



ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

**New Bandwidth Allocation Scheme for Handover Voice Calls in
Mobile Cellular Networks**

By

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To My parent

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Glossary of Acronyms

3G	Third Generation
2G	Second Generation
ACO matrix	augmented channel occupancy matrix
BCCH	Broadcast Control Channel
BCO	Borrowing with Channel Ordering
BDCL	Borrowing with Directional Channel Locking
BSC	Base Station Controller
BTS	Base Transceiver Station
BU	Bandwidth Unit
CAC	Channel Allocation Scheme
CBR	Call Blocking Rate
CBP	Call Blocking Probability
CBWL	Channel Borrowing Without Locking
CDMA	Code Division Multiple Access
CDP	Call Dropping Probability

CDR	Call Dropping Rate
CS	Channel segregation
DCA	Dynamic Channel Allocation
EIR	Equipment Identity Register
FACCH	Fast Associated Control Channel
FDD	Frequency Duplex Division
FDMA	Frequency Division Multiple Access
FRC	First Reserved Channel
FSC	First Shared Channel
FSS	Fully Shared scheme
GCS	Guard Channel Scheme
GMSK	Gaussian Minimum Shift Keying
GoS	Grade of Service
GPS	Global Position System
GSM	Global System for Mobile communication
HCA	Hybrid Channel Allocation scheme
HC	Handover Control
HLR	Home Location registers
ISDN	Integrated Service Digital Network
LOS	Line of Sight
LTP	Long Term Prediction
MA	Maximum Packing
MAP	Mobile Application Part
MN	Mobile Node
MSC	Mobile service Switching Center
MS	Mobile Station
NLOS	Non Line Of Sight
PAGCH	Paging and Access Grant Channel
PCR	Predictive Channel reservation
PSTN	Public Switch Telephone Network
QoS	Quality of Service
RPE	Regular Pulse Excited
RC	Reserved Channel
RSS	Received Signal Strength
SACCH	Slow Associated Control Channel
SC	Shared Channel
SCB	Simple Channel borrowing scheme
SHCB	Simple Hybrid Channel Borrowing scheme
SIM	Subscriber Identity Module
TDMA	Time Division Multiple Access
TTBS	Time Threshold Based Scheme
UMTS	Universal Mobile Telecommunication System
VLR	Visitor Location Register
WLAN	Wireless Location Area Network

Abstract

The demand of mobile communication has grown remarkably in past years. Mobile communication network (system) should use limited resources in efficient and convenient manner. One way of achieving this is to use smaller cells in the expense of the corresponding handover management and system administration overhead. The limited radio frequency spectrum available cannot be longer support the increasing number of mobile user, and user demand, and the required quality of service (QoS) no longer are attainable if a best solution is not found.

The other simplest solution proposed to overcome this problem is to increase the network capacity, which is not economical and not really practical. The work in this thesis demonstrates the different types of channel allocation schemes and call admission control with handover management for voice call. This paper goes through the cellular capacity improvement: cell reuse, cell splitting cell tiering and cellular structure. Most of the proposed schemes in the literature give priority to ongoing (handover) calls on the expense of blocking the originating calls.

We deem to introduce a new bandwidth reservation scheme based on guard channel policy. Accordingly, new calls are blocked if the amount of occupied bandwidth is greater or equal to a bandwidth threshold; B_t . The novelty of the proposed Time Threshold Based Scheme (TTBS) is based on the elapsed real time of voice handover call and according to a time threshold, T_r parameter, handover calls could be either prioritized or treated as new calls.

The major contribution of this work is to exploit time threshold scheme to perform autonomous and intelligent negotiation to improve wireless resource allocation. We use simulation study to evaluate the performance of the proposed scheme. The TTBS scheme is simulated under different scenarios and the result show that, the proposed schemes provide good performance in terms of handover call dropping probability, new call blocking probability, and bandwidth utilization.

CHAPTER 1 INTRODUCTION

1.1 Introduction

Until recently the concept of wireless communications consisted of providing voice services over radio channels. However, an increasing number of wireless telecommunication providers are now offering both voice and data services to their users. As smaller (micro and pico) cells are developed to meet the demands for increased capacity, the number of cell boundary crossing increases. The cell structure implemented is hexagonal cells (approximated by a circle). A wireless cellular network consists of a large number of cells, mobile users with various movement patterns and a number of applications. A cell consists of a base station and mobile stations. The user mobility and network traffic causes ongoing call to be handed-over to the new base station. However, if the available bandwidth in the new cell is insufficient to accommodate handovers, forced termination of handover calls occur. Handover deals with the mobility of end user in a mobile network: it guarantees the continuity of the wireless services when the mobile user moves across the cellular boundaries. Handover between access points or base stations has long been an issue in the wireless telecommunication area. However, a higher level of handover complexity is introduced due to the difference between inter-networked heterogeneous wireless networks. This added complexity, causes additional delays to the handover process and utilizes more resources from the mobile node's (MN) and network's perspectives.

Since dropping a handover call is more annoying than blocking a new call from the user's perspective, handover calls are usually given higher priority than new calls. It has been shown that the method by which handover is achieved has a significant impact on the network's performance [1]. Due to the inherent bandwidth limitation in wireless cellular networks, micro/Pico cellular architectures are attractive for achieving higher system capacity [2]. In this case, a circular region that within a macrocell is a few hundred meters to a few kilometers in radius will define the coverage area of a cell. As a direct result, the rate of handovers increases dramatically even when MS's move at low speed. The

probability of an ongoing call being dropped due to a handover failure and the probability of a new call being blocked due to the temporary unavailability of an idle channel are major metrics that define the performance of cellular systems. The handover prioritization schemes implemented in the network have a significant impact on these two probabilities. All the handover prioritization schemes have a common characteristic: ensuring a lower handover dropping probability at the expense of an increased new call blocking probability. Efficient handover prioritizations schemes are those that allow a high utilization of the wireless bandwidth (by accommodating or allowing a higher number of new calls) while guaranteeing the prescribed QoS.

Much work has been done on handover prioritization in wireless cellular systems [3, 5, 6, 7]. Basically there are two strategies that are popular for prioritizing handover calls [2]: the guarded channel strategy and the handover queuing strategy. The guarded channel strategy decreases the handover dropping probability by reserving a fixed number of channels exclusively for handover calls. New calls will be blocked if the number of idle channels is equal to or less than the number of guarded channels, while handover calls can be served until all the channels are occupied. The handover queuing strategy is a way of delaying handover due to the temporary unavailability of channels. The mobile switching center (MSC) queues the handover requests instead of denying access if the candidate cell has no idle channel available. Queuing is possible due to the overlapping region between adjacent cells where it can communicate with both the old and the new base station (BS). The maximum queuing time is limited by the MS' dwell time in the overlapping area.

1.2. Problem Overview

It is expected that the number of deployed wireless cellular networks will increase in the observable future to accommodate the plans for extending 3G/UTMS networks with IEEE 802.11 cells, in the area of higher user density and relatively high mobility (e.g., airports, subways stations, campuses, city blocks, conventions, etc...).

In recent years there is a rapid growth in the population of mobile users and in order to support the drastic increase in demand for resources, wireless networks need an advanced resource allocation schemes. However, establishment and management of connections are crucial issues in quality of service sensitive cellular networks since users are expected to move around during communication sessions experiencing handovers between cells.

Wireless cellular network consists of a large number of cells, mobile users with various movement patterns and a number of applications. A cell consists of a base station (BS) and a number of mobile terminals (MTs). When an active MT moves from one cell to another, the call needs to be handed-over to the new base station. However, if the available bandwidth in the cell is insufficient to accommodate the handovers, forced termination of call occurs.

Efficient bandwidth allocation strategy with simultaneous fulfillment of quality of service (QoS) requirement of a user in mobile communication is still critical and important practical issue. Majority of earliest researches are in the area of resource allocation are purely based on call admission control with out keeping any reservation states. Most of the allocation schemes were based on predicting per user demand and employing it to provide quality of service through call admission control with or with out reservation states.

According to the previously used scheme, the fully shared scheme (FSS) [3, 4], all available channels in the cell is equally shared by handover calls and new calls. This minimizes the new call blocking rate (P_b) and increases system utilization, but increases the handover dropping rate (P_d). Obviously, the FSS scheme performs poorly when the offered traffic in the network is high i.e. the scheme results in higher ongoing call termination. Because this is critical problem from the user point of view, it has the network operators to develop new scheme called guard channel scheme.

In the literature, several approaches [1], [2], [4], and [5] have been proposed to provide priorities to handover requests and since it is practically impossible to eliminate handover drops, the proposed schemes are advocated providing probabilistic QoS guarantee at certain level. The most well known scheme is the guard channel scheme (GCS) that [2]

provides priority for handover calls by exclusively reserving channel for handover. GCS decreases handover dropping probability (P_d); it increases the new call blocking probability (P_b), which decreases the system efficiency.

Proponents of the guard channel scheme claim that forced termination of ongoing calls is more annoying than blocking of new calls. We believe that this is true up to certain extent, as we can see in our real life that some users are spending more than necessary time for their voice calls. This results more problems especially in high load areas. To overcome this problem the new proposed time threshold based scheme (TTBS) scheme implement the concept of time threshold in addition to the bandwidth threshold used in GCS scheme. In the TTBS scheme handover calls that have elapsed time less than the threshold time are prioritized and leaves room for the latest established calls. This is because mostly in voice communication users waste more time in connection for long time after they complete their message. For instance, one can observe this if he/she is waiting in a queue for making a normal call from public telephone box in a city. Challenging problem in cellular mobile network is to devise proper mechanisms for offering guaranteed upper bound on connection blocking probability, P_b and handover dropping probability, P_d .

The problem Described here is the result of the limitations of the conventional handover decision method, which lacks awareness of the user's need and the system utility. This Knowledge is very necessary to prevent system under utilization i.e. waiting long time to be connected and critical handover drop. Therefore, a different approach that combines the acceptable efficiency of the above two critical problems, the proposed scheme uses time threshold based scheme in addition to bandwidth threshold scheme (TTBS which reduces performance degradation.

1.3. Thesis objective.

The objective of the thesis work is to analyze the feasibility and benefits of augmenting the conventional bandwidth (channel) allocation scheme performance with the proposed time threshold based scheme for voice handover call in mobile cellular networks. The

underlying objective is to reduce the new call blocking probability, P_b to as minimum as possible and to minimize handover call dropping probability, P_d to provide best quality of service for network users with high system utilization. The specific objectives are:

1. Improve system utilization by reducing the new call blocking probability, P_b compared to the existing guard channel scheme.
2. To demonstrate that the TTBS scheme minimizes the system grade of service cost function compared with the GCS and FFS schemes, which maximize the performance metrics of the scheme.
3. To show that the TTBS scheme is to keep the handover call dropping probability, P_d as minimum as possible compared to the GCS and FFS schemes.
4. In addition to these, TTBS objective is to provide priority between handover calls based on time and bandwidth information of the cell conditions within the cell.

1.4. Motivation of the Study

Wireless cellular network consists of a large number of cells, mobile users with various movement patterns: (speed and directions), base stations and a number of mobile terminals (MTs). In [7], the observed history of mobility information is used to evaluate the amount of bandwidth to be reserved. Admission thresholds are controlled as in [8] in order to keep handover dropping probability below predefined level, which solves the intercell unfairness problem that result [7]. According to the fully shared scheme discussed in [9], available channels are equally shared by handover and new call and as a consequence the ongoing call termination rate increases, which provide poor quality of service for the network users. This is very critical problem and must be solved to satisfy customer need. The Guard channel scheme; in [9] prioritizes handover calls by extensively blocking the new call connection. This results in inefficient scarce wireless bandwidth utilization. These motivate to propose the TTBS scheme, which is essentially a compromise of the above two schemes through the use of guard channel policy with time threshold.

1.5 Methodology and scope

As discussed in the above subsections, the methodology and scope of this thesis work have a specific emphasis on the handover to keep QoS while increasing system utilization. It is essential to manage handover dropping probability and new call blocking probability using an effective bandwidth allocation scheme. The characteristic performance evaluation implemented in this work are: handover dropping probability (P_d), new call blocking probability (P_b), Grade of Service (GoS), performance metrics cost function, bandwidth utilization and network mobility management. To measure performance off these we implement simulation approach. Simulation model is always an approximation of a real system, expressing only a portion of the whole truth of the studied phenomenon. The performance of the proposed scheme is demonstrated and analyzed by comparing it to the performance of conventional bandwidth allocation scheme that result in best quality of service and high system utilization in cellular networks .Two primary scenarios are used to demonstrate the drawbacks of the conventional guard channel scheme (GCS) and the old Fully Shared Scheme (FSS), and demonstrate the capabilities of the proposed scheme, which was designed to tackle the source of such drawbacks. The limitations of the scheme are also addressed in the context of the worst-case scenario. Based on such evaluation and analysis of the proposed scheme's capabilities, limitations and specifications where established to point out the type of environments that would be most suitable for deploying the scheme.

The expected solution was based on the performance measurements obtained through the simulation results are the blocking probability of new voice calls (P_b), and the dropping probability of the handover calls (P_d). The Time Threshold based scheme (TTBS) results in high system utilization with out degrading the average quality of service expected by the user.

According to this evaluation method the real time service (voice) call handover having call duration time T_h less than threshold time become prioritized and the one having greater elapsed time than threshold time treated as new call. In addition to this, the TTBS scheme provides priority for critical calls, such as those based on application and customer requests.

1.6. Thesis outline

Chapter 2 provides further details regarding the technologies involved in the system under consideration. Chapter 3 provides further study on the related areas and further details of the problem addressed in this chapter. Chapter 3 includes a description of the different channel allocation schemes for handover decision scheme, and its associated requirements, assumption, and specifications. Chapter 3 discusses about frequency reuse and cell splitting mechanisms. Chapter 4 emphasizes on different types of call admission control and handover management Also in chapter 4 the first reserved channel allocation scheme for handover call is discussed and evaluated by simulating the call blocking probability and handover dropping probability with respect to reserved channel as a case study. End of chapter 4 and chapter 5 is the main part of this work and discusses the analysis and results of simulations. In this chapter we also discuss system model, simulation model, simulation results. Finally chapter 6 summarizes the conclusions reached at the end of this research effort and indicates potential future work. It will also briefly address some of the potential obstacles that may be associated with deploying the proposed scheme

CHAPTER 2 CELLULAR MOBILE NETWORK AND SYSTEMS

2.1 Global System for Mobile Communication (GSM) Overview

The successful development and deployment of GSM over the past two decades is most significant. 3G mobile technologies must, after all, in some way be the result of an evolution from pre-existing 2G systems. The two are in many ways inextricably linked, and therefore examining one necessarily implies looking at the successes/shortcomings of the other. Generally speaking, the story of the establishment of GSM is of interest to anybody studying the growth and trajectory of digital technology and its commercial applications. After all, as some have argued, the nature of digital economies implies that control over network evolution translates into control over the architecture of the digital marketplace.

After all, GSM was a network standard not merely a product standard and this had considerable significance in terms of the potential benefits to be derived from associated network externalities. Disharmony and the licensing of competing operators actually helped to make GSM a significant success in Europe: quality of service prior to GSM was low, and handsets were expensive. European markets happened to open up to competition right around the time that the GSM standard was developed, resulting in a massive surge in demand for cellular phones.

One of the most important conclusions from the early tests of the new GSM technology was that the new standard should employ Time Division Multiple Access (TDMA) technology [11]. This ensured the support of major corporate players like Nokia, Ericsson, and Siemens, and the flexibility of having access to a broad range of suppliers and the potential to get product faster into the marketplace. GSM fulfills in the best way the user

mobility requirement; at the same time its increasing worldwide presence provides high expectations for a future widely deployed application.

Since its inception, GSM was destined to employ digital rather than analog technology and operate in the 900 MHz and 1.8 GHz frequency bands, except in North America where they operate in the 1.9 GHz band. The Uplink and Downlink frequencies allocated for GSM are 890-915 MHz, and 935-960 MHz [10]. GSM divides up the radio spectrum bandwidth by using a combination of Time- and Frequency Division Multiple Access (TDMA/FDMA) schemes on its 25 MHz wide frequency spectrum, dividing it into 124 carrier frequencies (spaced 200 KHz apart). Each carrier frequency divided into eight time slots using TDMA, and different carrier frequencies are assigned to each base station network infrastructure.

The basic building blocks of a cellular network are the cell-sites also called BTS (Base Transceiver Station) or called just Base Stations. Each base station can be broken down into optional three sectors each covering an area of 120 degrees to provide maximum coverage. Next in the hierarchy is the Base Station Controller (BSC). Depending on the density of users and the topology, each BSC can control anywhere from 5-20 BTS.

Another of GSM's most attractive features is the extent to which its network is considered to be secure. All communications, both speech and data, are encrypted to prevent eavesdropping, and GSM subscribers are identified by their Subscriber Identity Module (SIM) card (which holds their identity number and authentication key and algorithm). This smartcard technology minimizes the necessity for owning terminals - as travelers can simply rent GSM phones at the airport and insert their SIM card. Since it's the card rather than the terminal that enables network access, feature access, and billing, the user is immediately on-line.

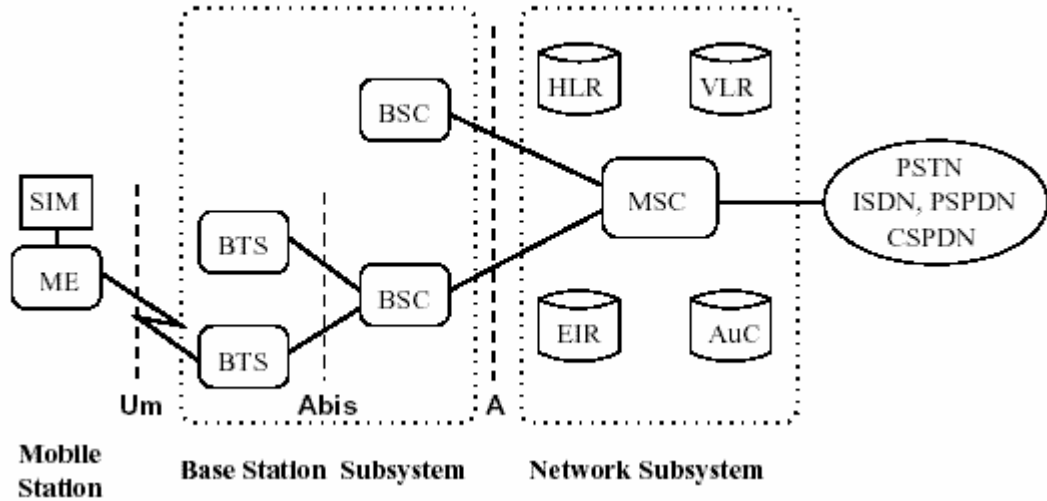
Basic GSM specification is given in table 2.1.

Table 2.1: Specifications of GSM

	GSM
Uplink frequency (MHz)	890-915
Downlink Frequency (MHz)	935-960
Multiple access techniques	FDMA/ TDMA
Duplex Mode	FDD
Carrier Spacing in (KHz)	200
Modulation	GSMK
Channels/ Frequency band	124
Speech Coding	RPE-LTP
Speech Rate (Kbps)	22.8/11.4
Data Rate (Kbps)	9.6 / 4.8 / 2.4
Traffic carrier	8

2.2 GSM Architecture

A GSM network is composed of several functional entities, whose functions and interfaces are specified as in figure 2.1 where a generic GSM network layout is shown. The GSM network can be divided into three broad parts. The Network Subsystem, the main part of which is the Mobile services Switching Center (MSC) that performs the switching of calls between the mobile and other fixed or mobile network users, as well as mobility management. The Mobile Station and the Base Station Subsystem communicate across the radio interface (Um interface), also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Center across the A interface. A more detailed description is presented in the following subsections.



- | | |
|--------------------------------------|---------------------------------|
| SIM Subscriber Identity Module | AuC Authentication Center |
| ME Mobile Equipment | BTS Base Transceiver Station |
| MSC Mobile services Switching Center | EIR Equipment Identity Register |
| BSC Base Station Controller | HLR Home Location Register |
| VLR Visitor Location Register | |

Figure2.1. General Architecture of a GSM network

2.2.1 Mobile Station

The mobile station (MS) consists of the mobile equipment, the terminal and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into any GSM terminal, the user is able to receive calls at that terminal, make calls from that terminal, and use other subscribed services.

2.2.2 Base Station Subsystem

All cellular networks overlay a geographical area with a grid of cells, where a single Base Transceiver Station (BTS) defines each cell. A BTS is assigned a set of frequencies in such a way that interference from other cells in the network reusing the same frequencies is kept

to a minimum, while maintaining enough radio channels in a cell to handle the required subscriber density. The BTS and BSC together comprise the base station subsystem, and handle almost all radio resource aspects of GSM. In order to keep infrastructure costs low and to provide sufficient coverage, the management of the radio resources for several BTSs is handled by a base station controller (BSC), including the setup and release of radio channels, frequency hopping and inter-BTS handovers.

2.2.3 Network Subsystem

The central component of the Network Subsystem is the Mobile services Switching Center (MSC). It acts like a normal switching node of the PSTN or ISDN, and additionally provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. The Home Location Register (HLR) and Visitor Location Register (VLR) together with the MSC, provide the call routing and roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network along with the current location of the mobile. The location of the mobile is typically in the form of the signaling address of the VLR associated with the mobile station. There is usually 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. Note that the MSC contains no information about particular mobile stations; this information is stored in the location registers.

2.3 GSM Standardization

Standards such as GSM are essential not just for the efficient working of the world's vast communications networks. They reduce technical barriers and promote compatibility between systems that, in turn, bring benefits to manufacturers, network operators and consumers. This results in a single infrastructure based on common industry standards,

which is equally accessible to all market participants. More importantly, it enabled operators to procure key network elements that give a high degree of flexibility, lower terminal and infrastructure costs and independence in their implementation, which eventually lead to lower costs for consumers.

2.4 GSM signaling

Each GSM cell has two signaling channels, a broadcast control channel (BCCH) that the mobile telephone is tuned to when it is not on a cell. The cell broadcast control channel (CBCH) is another signaling stream that sends 80-character short message and shares the same time slot as the BCCH. The other cell wide signaling channel is the paging and access grant channel (PAGCH). There are two signaling modes on the traffic channel (TCH), the slow associated control channel (SACCH) uses part of the TCH not associated to speech coding, and the fast associated control channel (FACCH) uses part of TCH normally used for speech. For this reason, the SACCH is called out of band signaling and FACCH is in-band.

2.5 Basic Mobile Cellular Operations

a) Call setup: The mobile will transmit an access request to the network on the mobile-land (M-L) signaling channel. If the network can process the call the base station will send a voice channel allocation message, which commands the mobile to switch to a designated voice channel. The mobile retunes to the channel indicated and the network proceeds to setup the call to the desired number. As part of the call setup procedure, the network will validate the mobile requesting the call to ensure that it is a legitimate customer. Paging calls to the mobile are transmitted on the land-mobile (L-M) signaling channels of all the base stations in the identified location and a response from the mobile awaited. If the mobile is turned on and receives the paging call it must acknowledge to its nearest base station on the M-L signaling channel. The base station sends a voice channel allocation

message to the mobile and informs the network so that the two halves of the call can be connected [72].

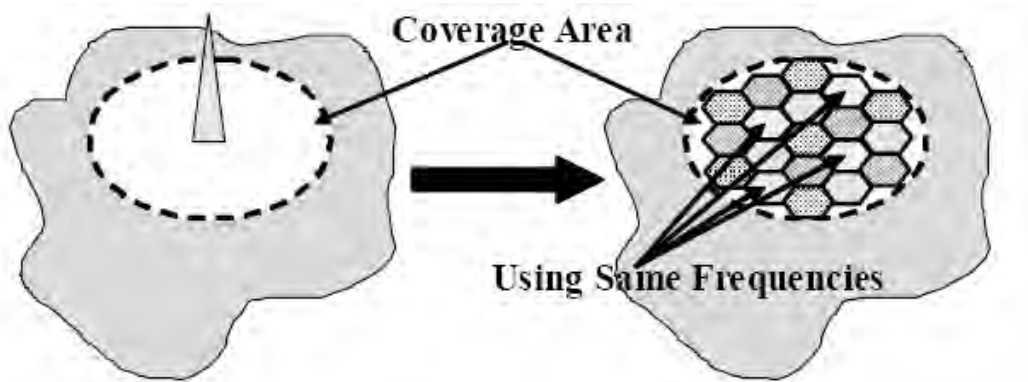
b) Monitoring on going conversation; Cellular system must have the ability to maintain ongoing conversation even while a mobile user (subscriber) moves throughout a cellular network service area [21]. This monitoring also serves to transfer the mobile terminal from the current serving base station or channel to another when the quality of signal from the current channel or base station is not satisfactory. This transferring of ongoing calls from one station or channel to other station or channel introduces the importance of call handover management development, in order to provide best QoS for customers. A detailed discussion about handover is given in the next sub sections.

c) Mobility Management: It is the technology, which supports roaming users with mobile terminals to enjoy their services through wireless networks when they are moving into a new service area. Mobility causes dynamic variations in link quality and interference levels in cellular systems, some times requiring that a particular user change its serving base station [71]. Mobile station is identifying them by reporting their locations to their HLRs through mobile application part (MAP) messages. Mobility management in 2G cellular network consists of two tasks; location management i.e. enabling in coming call delivery for idle mobile hosts, and the handover management including maintaining ongoing calls for active mobile hosts. In our study we emphasis on the second type of task, which will be discussed in detail in the next section on call handover.

2.6. Handover Overview

For first generation mobile radio systems, the concept of a cell consisted of a very large coverage area (150km radius) that was supported by a single transmitter. The infrastructure costs were consequently very low. However, due to the limited number of available frequency channels, the number of users per cell was also very limited. Due to the longer distance between the transmitter and the mobile stations, both had to transmit at higher powers in order to communicate. Therefore, mobile handsets were not a feasible solution; instead, a large terminal had to be installed into a user's vehicle [16].

The concept of frequency reuse was developed in order to accommodate a greater number of subscribers in a given coverage area. Its basic idea consisted of reducing the size of cell's coverage area by transmitting power of the cell's base station. Furthermore, the same frequencies could be reused within relatively small distances of each other without a significant amount of interference (Figure 2-2).



- Single Large Cell
- In-efficient Frequency Utilization
- Few Users Supported
- Significantly More Users Supported
- Multiple Small Cells
- Frequency Reuse in Same Area

Fig. 2-2. A comparison between First Generation coverage concepts and the cellular concept allowing for Frequency Reuse.

The number of allocated channels per cell would vary according to the number of cells in the cluster and the load within each cell. Today, the term “cell” is used in the wireless domain to refer to oval shaped, square shaped, circular, and hexagonal shaped coverage areas, all employing frequency reuse [16].

Frequency Reuse and small cellular coverage areas created a need for a mechanism to quickly switch a subscriber's connection from one cell to a neighbouring cell, as the subscriber moves from one location to another. The handover mechanism introduced a new level of complexity to the system. The intention has been to avoid involving the user in the handover process and to conduct it without the user's awareness (i.e., seamless handover). Section 2.6.3 addresses some common types of handover, with respect to different classes of systems.

2.6.1 Handover Initiation

In current systems handover decision can be conducted by a superior network as central coordinator, mobile assisted or the mobile device itself optimizes its connection to the network. In GSM handover is mobile assisted handover (MAHO) [17], which is an improvement on the network-controlled handover (NCHO). This approach gives autonomy to the mobile device, which can evaluate the received signal strength (RSS) of all surrounding base stations transceivers. The need for fast handover in future mobile networks introduces the third, mobile controlled handover (MCHO). This type of handover is generally triggered by the poor link quality measured by the mobile. Another reason for applying MCHO is that handovers in future mobile networks are not only carried out in order to maintain a connection, but also to provide users better service and to meet individual requirements. A mobile station should make a handover decision based on user preferences automatically.

The over all objectives of handover can be summarized as follows:

- a) Guaranteeing the capacity of wireless service when the mobile user moves across the cellular boundaries.
- b) Keep required QoS
- c) Minimizing interference level of the whole system by keeping the mobile linked to the strongest BSs.
- d) Roaming different networks
- e) Distributing load form hot spot areas (or load balancing).

2.6.2 Handover stages

Handover is performed in three stages; Decision stage, planning stage, and Execution stage [10]. In the decision stage, the handover decision is made in the network at the mobile station (MS), according to some, metrics like received signal strength (RSS), signal to noise ratio (SNR) and cell traffic. A handover decision algorithm likes RSS, RSS with

threshold, RSS with hysteresis, RSS with threshold and hysteresis, velocity adaptive handover algorithm, multi-criteria handover algorithm, or pattern recognition based handover algorithm is employed in this stage [73, 74]. These algorithms are beyond the scope of this work and no attempt will be made to discuss them. Once the handover is decided, then the next stage is the planning stage where the appropriate channel, which is free and has least interference, from the candidate base station, is found and authentication protocols employed if necessary. Now handover can be executed in the execution stage where the mobile hosts dissociate itself from old serving base station and re-associates with the new candidate base station.

2.6.3 Handover Types

The categorization of handover types depends on a number of factors, which are further divided based on the type of technology and network architecture where the handover takes place. The handover process is no longer limited to the boundaries of a single technology. In fact, the emerging concept of “Always-Best-Connected” has blurred the line between different access networks. The following are the categorization factors along with the handover types that are based on them.

Factor A: Technologies Involved

A.1. Horizontal Handover: a term used to describe the handover process of a MN between base stations supporting the same technology, also referred to as intra-technology handover.

A-2. Vertical Handover: a term used to describe the handover process of a MN between base stations supporting different technologies, also referred to as inter-technology handover. Examples of such handover include but are not limited to a handover between 2G and 3G base stations, a handover between 3G and WLAN base stations, or a handover between base stations supporting different 3G standards. There are two types of vertical handovers:

Downward Handover: A handover from a large network cell with low data rates to a smaller network cell with higher data rates, which is implemented in UTRAN and WLAN.

Upward Handover: A handover from a small network cell with high data rates to a larger network cell with lower data rates. Since the user experiences better performance with the higher data rates, it is typically desirable to remain connected to such a network for as long as possible. However, a handover to a network with less data rates becomes necessary when the user is exiting the current small coverage area. Therefore, discovering the upper network is delay sensitive in the context of an upward handover.

Factor B: Administrative Domains Involved

The term “Administrative Domain” is defined as “A collection of End Systems, Intermediate Systems, and Sub networks, operated by a single organization with administrative authority. The components which make up the domain are assumed to interoperate with a significant degree of mutual trust among themselves, but interoperate with other Administrative Domains in a mutually suspicious manner.” Based on this definition of Administrative Domains, handovers can be categorized as:

B-1 Intra-Administrative Domain Handover: a handover process where the MN switches between base stations supporting the same or different technologies, managed by the same administrative domain.

B.2 Inter-Administrative Domain Handover: a handover process where the MN switches between base stations supporting the same or different technologies, managed by different administrative domains.

Factor C: Number of Connections Involved

This category mainly applies to the handover process within cellular networks [18]:

C-1 Hard Handover: A term used to describe a handover that involves the MN maintaining a connection with only one base station at any given time. This process is sometimes referred to as “Break before you make.” Hard handovers may be seamless or non-seamless depending on their severity of and whether they are noticed by the user in the form of an interruption in service (i.e., dropped call, terminated session, or significant delays).

C-2 Soft Handover: A term used to describe a handover that involves the MN always being connected to at least one base station when moving between cells. This process is sometimes referred to as “Make before you break.” Soft handovers are possible in

situations where the MN is moving between cells that operate on the same frequency. It has been realized as an option in 3G systems.

C-3 Softer Handover: A term used to describe a type of Soft Handover that involves the MN switching connections over radio links that belong to the same base station. This type of handover is possible in such networks where a base station serves several individual sectors of a cell (i.e., Node-B in UMTS systems).

Factor D: Frequencies Involved

D-1 Intra-Frequency Handover: a term used to describe the handover process of a MN switching between stations that operate on the same frequency. This type of handover may occur in 3G systems that use CDMA with Frequency Division Duplex (FDD1) allowing for a Soft or Softer handover.

D-2 Inter-Frequency Handover: a term used to describe the handover process of a MN switching between stations that operate on different frequencies. This type of handover is the only one supported in 2G systems (i.e., GSM) due to their reliance on TDMA2 and FDMA3 multiple access schemes, which require the change in carrier frequency. Another example is 3G systems that use CDMA with Time Division Duplex (TDD4). All inter-frequency handovers are “Hard Handovers.”

2.7 Handover in GSM

In any cellular network, the radio links are not permanently allocated to a user for the duration of a call. Handover is a process of switching an on going call from the coverage of one cell to another cell or sectors as described above.

Depending on the network load and mobility of the user, GSM can perform four different procedures or types of handovers.

- a) Handover from one channel (time slots) to another or from one sector of the cell to another in the same cell also called intracell handover.
- b) Handover from one BTS (Base Transceiver Stations) to another, when both are under the control of the same Base Station Controller (BSC), this is called intercell handover.

- c) Handover between BTSs that are from different BSCs but belonging to the same mobile services Switching Center (MSC). This is called Inter BSC handover.
- d) Handover between two BTSs that are under the control of different MSCs. This type of handover is called Inter MSC handover; the MS continuously checks the received signal strength of its BTS as well as its surrounding BTSs, which is in the range of -110dBm and -48dBm.

Whenever the received signal from any surrounding BTS is greater for a particular interval of time, handover is initiated. The first two types of handover, called internal handovers, involve only one Base Station Controller (BSC). To save signaling bandwidth, they are managed by the BSC without involving the Mobile services Switching Center (MSC), except to notify it at the completion of the handover. The last two-handover types are called external handovers, there is handled by the MSC.

All these handover types and procedures, which are implemented in order to provide, best QoS for the network user. As discussed above terminating ongoing call is highly unwanted from the user point of view. To realize the above-discussed concept, we need sufficient channels, which support the handover request by user in the target cell. The detailed discussion of, bandwidth (channel) allocation scheme, is given in chapter 3, which discusses different types of channel allocation. The chapter provides bandwidth allocation integrated with handover in order to minimize the probability of on going call termination.

CHAPTER 3

BANDWIDTH ALLOCATION AND HANDOVER MANAGEMENT SCHEME

3.1 Introduction

Reserving some bandwidth solely for handover calls can reduce the connection-dropping rate (CDR). However, the connection blocking rate (CBR) of new connections may increase due to such bandwidth allocation. Two supplementary techniques have been used for controlling the CDR and CBR or call dropping probability (CDP) and call blocking probability (CBP) respectively in the cellular networks: These are bandwidth allocation and admission control. Bandwidth allocation helps in minimizing CDP of on going connections; it cannot, however, effectively guarantee a certain level of QoS with out admission control scheme when the traffic load is high. The difficulty in admission control in a mobile cellular environment is that it is not sufficient to admit a new call only on the basis of the status of the current cell, within which the call originated. This may be due to the fact that when the MS (mobile station) an attempt to move from the current cell to the next cell, there may not be sufficient bandwidth in the destination cell to guarantee the handover. This may result in dropping the call and increase the CDP.

Most of the previously studied bandwidth allocation schemes [22], were based on handover prioritization, where each cell reserves a fixed bandwidth or dynamically adjustable amount of bandwidth exclusively for handovers. Other priority schemes [21, 23] either allow the handover or new call connections to be queued until enough bandwidth is available in a cell. In addition to these, several distributed channel allocation algorithms have been proposed to increase channel reuse to meet the increasing demand for wireless cellular communication [25]. Currently, dynamic channel allocation is integrated with an adaptive handover mechanism [19] to improve the bandwidth utilization and guarantee a certain acceptable level of QoS. However, these schemes incur high information complexity especially when traffic load is high.

In this work, the fixed channel allocation scheme is implemented with time threshold admission control. The time threshold based scheme works on the basis of the guard policy or based on guard channel admission control with time threshold control, which will be discussed in detail in chapter 5. Moreover, in most prior studies, bandwidth allocation and admission controls have been treated separately. But, it is essential to combine both of these techniques to provide improvement and predictable performance in mobile cellular networks.

3.2 Cellular concept

The cellular concept was a major breakthrough in solving the problem of spectral congestion and user capacity. The advent of the cellular concept was a crucial contribution in the development of mobile communication. A cell is viewed as the (approximate) coverage area of a particular land site. Each cell within a cluster is allocated a distinct set of frequencies (channels) and cells labeled with in a given number i.e. co-channels reuse the same channel set obeying channel reuse conditions. In addition to this, when an active user reaches the boundary of the cells, there is a need to change its current frequency channel for another belonging to the neighbouring cell. The critical features of the cellular system that made possible the achievement of cellular network objectives were frequency reuse and cell splitting, which discussed in detail as follow.

3.2.1 Frequency Reuse

Frequency reuse refers to the use of the same carrier frequency in different areas that are distant enough from each other such that the interference caused by the use of the same carrier is not a problem. Frequency reuse has two applications: to reduce the cost of the land transmitter receiver base station by placing several moderate power land stations to cover sub-areas (cells) of the designated area. Secondly, to increase the number of simultaneous calls that can be achieved by the same number of allocated channel frequencies as shown in figure 3.1 below for a cluster size of 7. The distribution of the

frequency channels in a cellular network is dependent on several parameters, such as cellular geometry, signal propagation characteristics and signal interference.

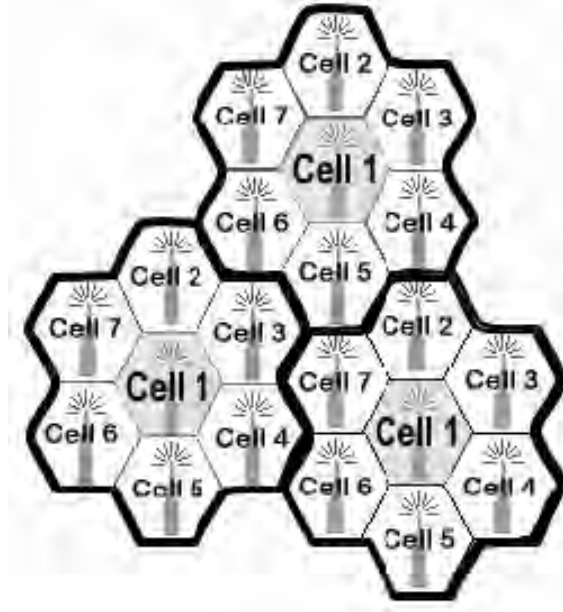


Figure 3.1 Diagram showing cellular frequency reuse. Cell with the same letter use the same set of frequencies. The reuse shown here is for a cluster size of $N = 7$.

The assignment of frequency channels in the cellular concept is fixed, i.e. a set of frequency channels is statistically allocated to a cell. This same set is reused in another cell distant enough to allow the use of the frequency channels with acceptable level of signal interference. Cells that use the same set of frequency channels are called co-channel cells and the distance between them is called co-channel reuse distance. The total number of frequency carriers allocated to a network operator is divided into sets and each set is assigned to a cell inside a cluster of cells. The cluster of cells forms a pattern. The pattern is reused according to the co-channel reuse distance. The choice of the number of cells per cluster is mainly governed by co-channel interference considerations. A better understanding about signal propagation and cellular geometry is needed in order to understand how frequency assignment is performed in mobile cellular system.

The propagation Path loss of a signal is a function of several factors, such as environment, antenna type, antenna height, location, etc. Considering omnidirectional antennas, the propagation path loss in a mobile environment is normally taken as 40dB per decade, i.e. the signal will suffer a 40dB loss over a distance of 10km [22]. The ratio of received power at two different distance d_1 and d_2 from a transmitter are related as [36]:

$$C_2 / C_1 = (d_2 / d_1)^{-4} \quad (3.1)$$

Where C_1 is the received carrier power at receiver 1, C_2 is the received carrier power at receiver 2, d_1 is the distance measured from the transmitter to receiver 1, and d_2 is the distance measured from the transmitter to receiver 2.

Therefore, the signal strength is inversely proportional to the distance to the power of 4. Or in decibel this can be expressed as:

$$\Delta C = 10 \log [C_2 / C_1] = 40 \log [d_1 / d_2] \quad (3.2)$$

In the same condition, but in free space, the propagation path loss would be of 20dB/10km. In a real mobile radio environment the propagation path loss varies [36]:

$$\Delta C = \alpha (d)^{-\gamma} \quad (3.3)$$

Or in decibel:

$$\Delta C = 10 \log \alpha - 10\gamma \log d \quad (3.4)$$

Where, γ is the propagation path loss factor, α is constant, d is the distance from the transmitter to the receiver. γ usually lies between 2 and 5; as it cannot be lower than, the free space condition and this concept is discussed in detail under section 4.7 of this paper. Interference is the limiting factors in the performance of cellular networks [82]. Source of interference are: another mobile in the same cell, a call in progress in adjacent cell, other base stations operating in the same frequency band and same non-cellular system emitting energy. Co-channel interference occurs as a result of multiple uses of the same frequency carrier. The carrier to interference ratio (C/I) is used to measure the amount of interference over a specified carrier.

$$C/I = C / \sum_{k=1}^{K_I} I_k \quad (3.5)$$

Where K_I is the number of co-channel cells interfering in the first tier (the interference of the second tier of co-channel cells can be neglected) [22]. Assuming the local noise is much less than the interference level and can be neglected, the C/I can be expressed by the following equation:

$$C/I = (R^{-\gamma}) / \sum_{k=1}^{K_I} D^{-\gamma_k} \quad (3.6)$$

Where; D is the frequency reuse distance, R is the radius of the cell, defined as the distance from the center of the cell to any of its vertices. Assuming for simplicity, that $D_k = D$ for all K_I , the C/I of a cell site radiating in all directions (omni directional antenna) can be represented (dB) by [36]:

$$C/I = 10 \log [(1/K_I) * (D/R)] \quad (3.7)$$

If evaluation of the effect of co-channel interference on received quality of service indicates service degradation, it is necessary to obtain a good transmission quality for a channel. Assuming the ideal case of hexagonal cells, the frequency reuse distance normalized to R (D/R) can be related to finite set of cells N in a hexagonal cellular network. In [37] a convenient set of co-ordinates for hexagonal geometry has been introduced as shown in figure 3.2 below. The positive halves of the two axes intersect at 60-degree angle, and the unit distance along either axis is root 3 times the radius of the cell (R), that corresponds to the distance between the centers of two hexagonal cells (or in cell radii) as illustrated in figure 3.2. The distance between the origins to any cell center is given by:

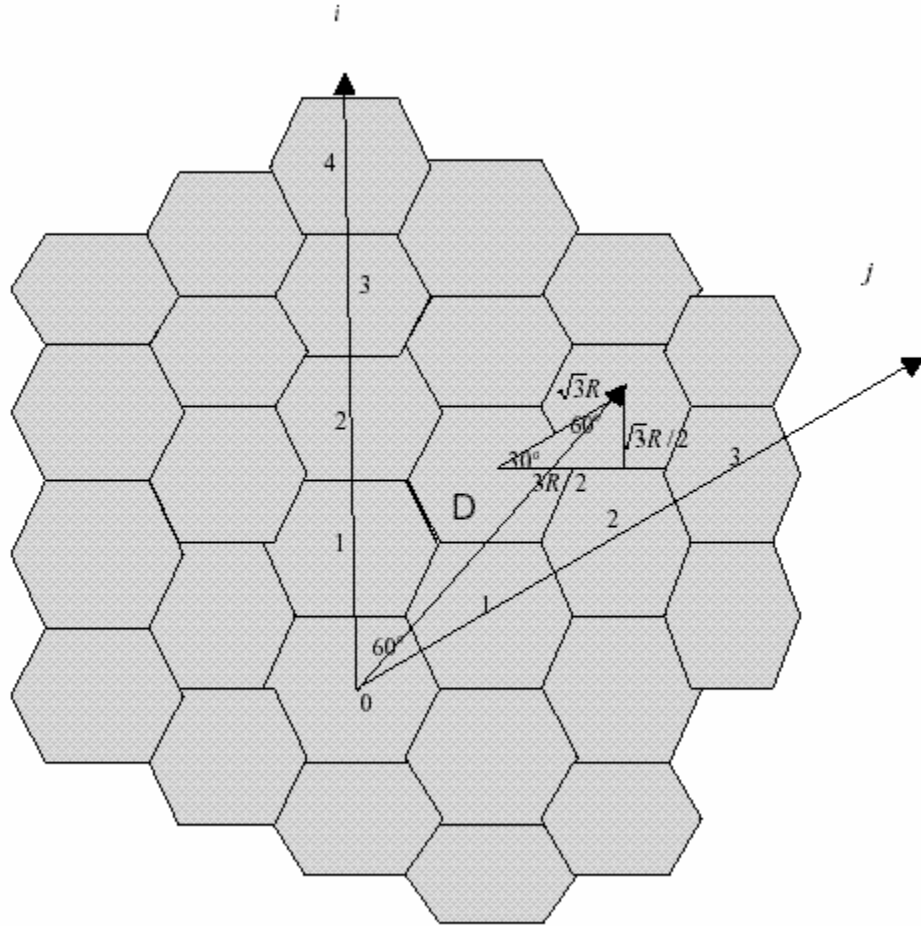


Fig3 .2 Co-ordinate for Hexagonal geometry of cellular network

$$D = \sqrt{i^2 + ij + j^2} \quad (3.8)$$

The vectors from the center of any arbitrary cell and the six adjacent cells are separated from each other by 60 degrees; this same observation is valid for the vectors from a cell to its co-channel cells. Therefore, a cluster of contiguous cells can be visualized as a large hexagon. As the normalized distance between centers of adjacent cell is unity, the distance between centers of the large hexagon is $\sqrt{i^2 + ij + j^2}$. The pattern of large hexagons can be visualized as enlarged replica of the original cellular pattern with a scale factor of $\sqrt{i^2 + ij + j^2}$. Therefore, the number of cell areas contained in the area of the large hexagon is:

$$N = i^2 + ij + j^2 \quad (3.9)$$

From equation 3.9 above valid number of cells in a cluster are 3, 4, 7, 9, 12, 13, 19 and so on as can be obtained from equation 3.9 and figure 3.3. In our case the defined schemes is (or three sectors) a 4-cell reuse plan and normally would use 120-degree directional antenna. Finally, the relation between the co-channel reuse distance (D/R) and the number of cells per cluster can be found by combining the equations 3.8 and 3.9 and replacing the unity by $\sqrt{3} R$:

$$D/R = \sqrt{3 * N} \tag{3.10}$$

Now, the minimum number of cells per cluster that is needed to meet the system performance requirements can be determined. When considering omnidirectional cell sites and a flat terrain, a cluster with 7 cells gives a 4.58 frequency reuse distance, enough to comply with the performance requirements.

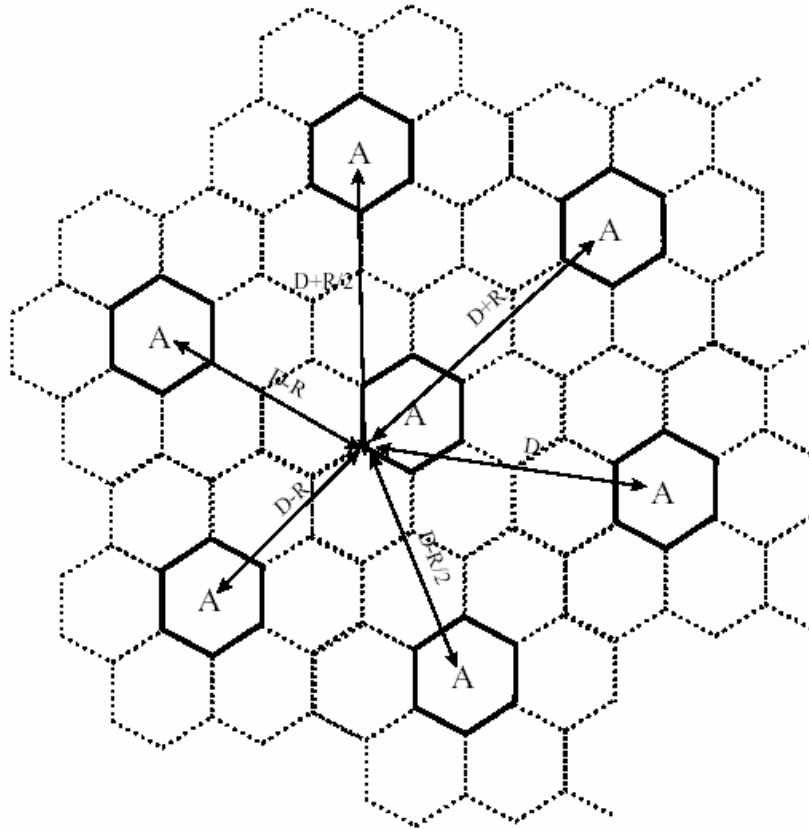


Figure 3.3 shows the first tier of cells for a cluster size of $N=7$. Also shown are the distances from a mobile at the edge of a cell to the base stations in co-channel cells.

However, in practical system when omni directional antennas are used a cell cluster of 9 or 12 cells is implemented to guarantee the system performance requirements and the reason for that is explained as follows.

A 7-cell cluster does not provide a sufficient frequency reuse separation distance even when an ideal condition of flat terrain is assumed. This happens in the worst-case scenario for the mobile station that is analyzed. In the worst case, the mobile station is at the boundary R , where it would receive the weakest signal from its own base station. The distance from all six co-channel cells are: $D - R$ from the two nearest co-channel interfering cell and approximately $D + R/2$, D , $D-R/2$ and $D + R$ from the other interfering cells in the 1st tier for $N=7$ cell cluster as shown in figure 3.2 above. Cell tiering is dividing the cell into two tiers and reusing frequencies intelligently such that the frequencies used in the serving cell are used in the co-channel cells increases C/I ratio.

Following the mobile radio propagation rule of 40dB/10km,

$$C \propto R^{-4} \quad \text{and} \quad I \propto D^{-4} \quad (3.11)$$

Then

$$C/I = R^{-4} / (2(D-R)^{-4} + D^{-4} + (D+R)^{-4} + (D-R/2)^{-4} + (D+R/2)^{-4}) \quad (3.12)$$

For a D/R of 4.6, the value of C/I is 55 or 17dB, which is lower than 18dB (or which is a minimum requirement). In real systems, as the site locations are imperfect and the terrain is not flat, the C/I received is always worse than 17dB and could be lower than 14dB. Therefore, in an omni-directional-cell system, a cell cluster of 9 or 12 would be a better choice, because, even considering the shortest distance of $R-D$ for all six interferes as worst case, the value of C/I would be greater than 18dB. The use of directional antenna can improve the C/I with out the need to increase the number of cells in the cluster.

3.2.2 Cell Splitting

Cell splitting is the reconfiguration of a cell into smaller cells. This feature makes it possible for the same network to service different densities of demand for channels. Large

cell can serve low demand areas and smaller cells serve high demand areas, as shown in figure 3.4 below. Cell splitting is a long-term configuration planning that allows the system to adjust to a growth traffic demand in certain areas, or in the whole network, without any increase in the spectrum allocation. It allows the system to grow gradually in response to a growing demand of traffic. It takes place by reducing the radius of a cell by half and splitting the old cell into four new small cells. The reuse frequency can be used more often allowing the traffic to grow four times in the same area where an old cell was placed. The ideal location for new cells is the midway points between neighboring existing cells. Considering cell splitting in a 7-cell cluster system, the new cluster will present a relation of 120-degree counter-clockwise in relation to the larger cluster [37], as shown in figure 3.4. The channel set assigned to a new cell is the one that makes the new cell lie at a midway point between two of its nearest co-channel cells in the larger cluster, each one situated approximately a large cell diameter away from the new cell.

When two or more sizes of cells co-exist in a mobile network, special attention needs to be taken in order to guarantee that the minimum frequency reuse distance is being respected. The use of channels in the new cell site will not cause interference problems in the large system because the strength of the signal is smaller and designed to comply with the constant D/R , but taking the radius of small cell. The problem comes with the channels of the co-channel cell in the large system, because the small cell is within the frequency reuse distance of the large cell. One way to deal with this problem is to use the overlaid-cell concept. In the overlaid –cell concept the cellular network is seen as a superposition of the smaller cell pattern on top of the complete large cell pattern, and not only where the smaller pattern is in reality deployed. Each cell face will divide its channels between a large-cell group and a smaller-cell group. The selected channels in the larger cell group will be used in all coverage area of a large cell. The selected channels installed in the smaller cell will compose the smaller-cell group of its larger co-channel cells. The formation and use of the channel groups is then governed by the presence, or not, of real smaller cell neighbours. For example the use of any channel installed in a small cell must be restricted to the smaller cell overlay area in the nearest larger co-channels. If a mobile user using a smaller cell channel goes out of the perimeter of the small cell overlay on the larger cell, it needs to

handover to a channel of the larger group or to a neighboring cell. Therefore, the presence of two sizes of cells in a network reduces the capacity of some of the larger cells and can force their cell to split even if they would not be split if only the growth of traffic in their areas would be considered. In addition to this the estimated handover rate due to cell splitting is shown in the figure3.5

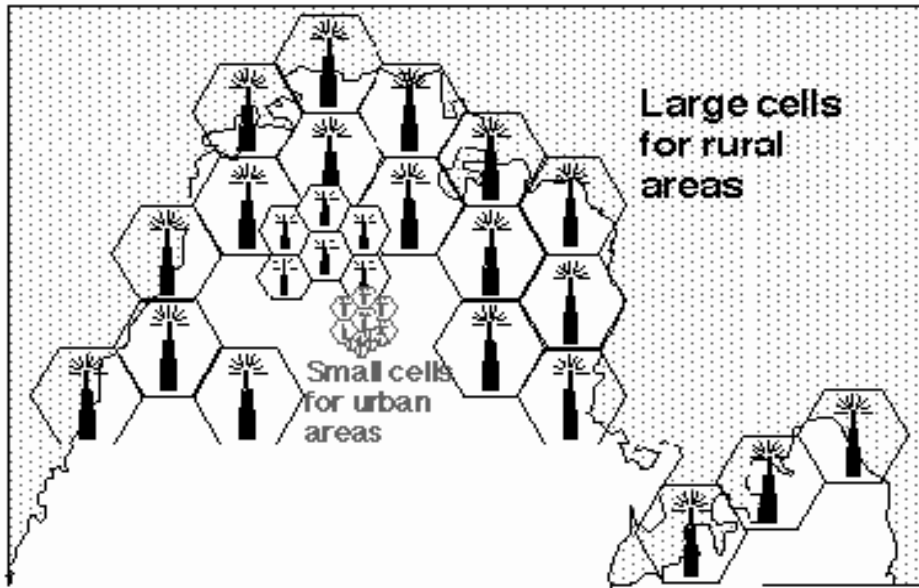


Fig. 3.4 Cell Splitting

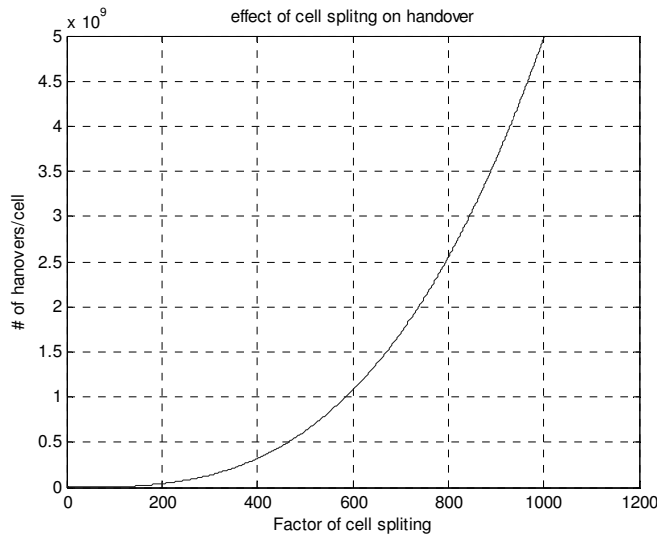


Fig. 3.5 Effect of cell splitting on handover

3.3 Traffic Engineering in Mobile Cellular network

This section gives a basic understanding of traffic engineering and engineering aspects of cell site provisioning in cellular communication systems. Telecommunication network resources are limited and they need to be shared by all the network users. The problems that arise from the necessity of sharing resources are addressed by traffic engineering, which tries to bring a balance between customer satisfaction and revenue for network operators, i.e. to serve the greatest number of customers with a specified system quality. Traffic engineering should have a good understanding of traffic distribution, traffic growth and customer requirements. In mobile cellular networks, the result of such calculations will show how many customers will be served in a busy hour, how many subscribers can be taken by the cellular system, how many cells are needed and how many channels per cell are needed.

3.3.1 Traffic Characteristics

The intensity of two kinds of traffic can be measured: The offered traffic (The traffic the network receives under the condition that there are unlimited servers) and the carried traffic (the traffic the network successfully carries). The offered traffic varies during the day. It is normally low during the night, rises in the business opening hours, goes down during lunchtime and rises again in the afternoon. The two peaks in traffic, measured over an hour, represent the busiest periods and are called busy-hour traffic. The daily variation in the offered traffic intensity is known as hourly variations. The intensity of the busy-hour traffic varies also depending on the day of the week and month of the year and these variations are known as daily variations. The network operator needs to meet the demands of the average busy-hour traffic if it is to be credible to its customers. Traffic intensity can be measured using the dimensionless units: Erlang.

The Erlang is a unit named in memory of Anders K.Erlang, the founder of traffic theory. One Erlang is equivalent to one circuit (or trunk) in continuous use, and it can be translated as the number of calls (made in one hour) multiplied by the duration of these calls (in hours). Each call has a different duration or a different call holding time; for traffic intensity measurements the average call holding time is taken into account. This has different values for business or private subscribers, but the typical values for average call holding time vary between 120 and 180 seconds. Therefore, The traffic intensity in Erlangs can be defined as:

$$T(\text{in Erlangs}) = \frac{(\text{No of calls in hour})(\text{average call holding time(s)})}{3600} \quad (3.13)$$

3.4 Channel allocation algorithms

A given radio spectrum is to be divided into a set of disjointed channels that can be used simultaneously while minimizing interference in adjacent channel by allocating channels appropriately (especially for traffic channels). In [22], a detailed survey of the different channel allocation strategies is presented. The channel allocation can be fixed, dynamic or hybrid, depending on how the resources are shared among the different cells in the network. However, whatever scheme is used, there is a rule which needs to be observed, due to the nature of mobile communications. To avoid interference between calls, the same frequency cannot be reused in another cell within a “normalized co-channel reuse distance” σ , which has been discussed earlier in section 3.2 above.

3.4.1 Fixed Channel Allocation (FCA) scheme

In the basic FCA scheme, the number of channels allocated to each cell is the same. And, the set of channels are permanently allocated to each cell based on pre-estimated traffic intensity. It is of course possible to adapt the number of channels allocated to the traffic conditions encountered by the cells. This can be done using historical data. The performance can be greatly improved if the allocation is done efficiently, but there is also an associated risk; if the traffic conditions change over time, it is possible that the

allocation becomes non-suitable, resulting in extremely poor performance. The frequency channel assignment in the cellular concept is static, i.e. after careful frequency planning. Channels are assigned to cell sites and these cells will not change except for a new long-term reconfiguration. Cell sites will only make use of the assigned channel per sector.

Two FCA variant schemes have been proposed: load sharing and channel borrowing (with or without channel locking). It is assumed in the load-sharing scheme [38, 39] that there is an overlapping coverage area between cells where mobiles can obtain a quality of transmission from the neighbouring cell almost as good as that in their own cell. When there is a call attempt and there is no more available bandwidths [38], or when the bandwidth occupancy reaches a predefined threshold [39], the MSC may advise some mobile users of the cell to check the transmission quality of channels in the neighbouring cells. When they find acceptable transmission quality from the neighbouring cell, a handover request will be made to that cell, provided the cell has enough available channels to allocate one to the requesting mobile user. In this way, the congested cell can have some of its nominal channels freed and use them in the new call request.

Schemes using channel-borrowing strategy differ from the pure FCA concept by allowing a cell to use some of the channels of other channel sets in addition to its own. Channel borrowing is performed when there are no more nominal channels to serve call request (new call, or handovers) or when channel occupancy reaches a predefined threshold. Channel borrowing with channel locking scheme [40, 41] borrows a channel from an adjacent cell, but prevents totally or partially the reuse of the borrowed channel in the co-channel cells of the lender cells that are near to the borrower, taking into account the co-channel interference constraints.

Channel locking scheme reduces the channel traffic capability of the network. To overcome such penalty, the scheme has also adopted channel reassignment strategies. Channel reassignment is an intracellular handover, i.e. a mobile user asked to its current frequency channel for another one under the control of some base station. This scheme reduces the call blocking probability and maximizes the channel reuse. Channel borrowing with out locking (CBWL) [42, 43] strategy proposes the use of a channel of a neighbouring cell.

This strategy allows the use of borrowed channels within co-channel cells, which uses reduced transmission power to avoid interference within the co-channel cells.

Some channel allocation schemes, using different channel assignment strategies, have special features. There are schemes that have special policies to prioritize handover requests over new call requests. Handover has direct impact on the perceived quality of service. One of the important factors to improve quality of cellular service is to make handovers nearly invisible to the service user and successful. Other channel assignment schemes are specially designed for hierarchical cellular network. Hierarchical cellular network is an overlaid cellular system where clusters of micro-cells are covered by macro-cells as shown in figure 3.6. In micro-cells, handovers occur very often. If there is no available channel in the micro-cells to perform a handover, then a channel from the macro-cell can be used. The channel reassignment drawback is an even higher increase in intracellular handovers.

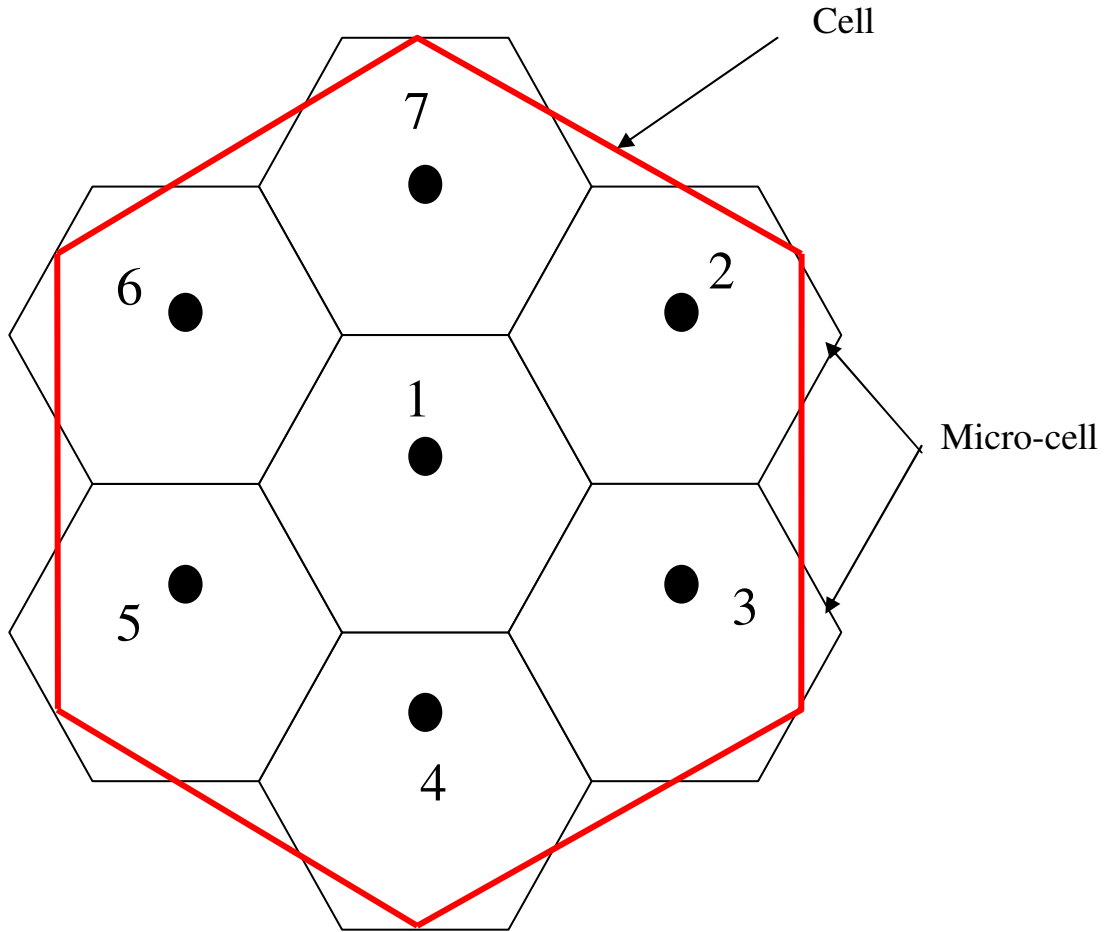


Fig.3.6 Overlapped Cells-based Allocation

In addition to this, there is channel allocation scheme based on the reuse –partitioning concept. In this concept, each cell in the cellular network is divided in two or more concentric sub-cells called zones as shown in figure 3.7. The inner zone being closer to BS would require lesser power to attain a desired channel. In this case the channel reuse distance for the inner zone is smaller than outer zones, resulting in higher spectrum efficiency. Here, the two design issues are how the actual channel assignment is performed and how many channels to allocate to each zone. Based on these issues, fixed and adaptive reuse-partitioning scheme have been proposed [44]. Fixed reuse partitioning scheme supports up to three times more traffic as FCA [45, 80]. However, they suffer the same kind of problem as FCA when handling time-variant traffic conditions, so that adaptive schemes have been proposed to overcome this drawback.

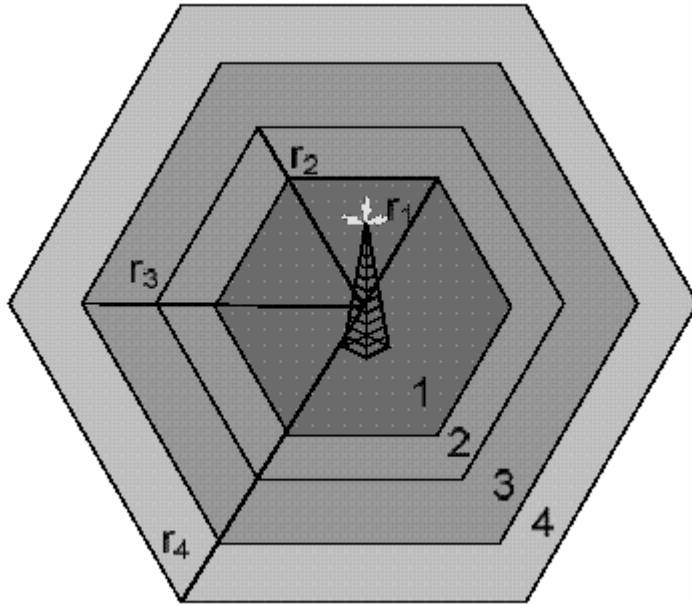


Fig.3.7 Reuse Partitioning based Channel Allocation

Channel borrowing does one improvement to the FCA scheme. When a heavily loaded cell can no longer serve incoming calls (handover or new calls), it can try to borrow a channel from a neighboring cell, always respecting the normalized minimal distances σ . This results in what is called channel locking: when a channel is borrowed, several other cells are prohibited from borrowing it. The blocking probabilities get using channel borrowing is lower than the ones with FCA. As with other parts of channel allocation, a lot of research has been conducted into channel borrowing. For example, the channel can be borrowed from a non-adjacent cell [24, 25], it can be done from the richest cell (the cell with the most number of available channels), or it can simply be the first channel found. It is also possible to make only a portion of the channels available for borrowing; this is called Hybrid Channel Borrowing [26, 27].

3.4.1.1 Fixed Channel allocation (FCA) based handover schemes:

In FCA based on handover schemes, a set of channels is permanently assigned to each cell, according to frequency reuse distance [28, 29]. Handover can only be given a channel if

any channel belonging to the set of the call is available; the call is blocked, or in the worst cases dropped if there is no channel available for the call. Fixed channel allocation schemes have a very simple implementation due to fixed predefined channel distribution [29]. However, in a non-uniform traffic condition, the implementation becomes complex as sophisticated network planning is required to assign more capacity to access when high traffic rate is expected [28]. An interesting variation of FCA based handover scheme is channel-sharing handover [30]. Channel sharing handover uses a channel-sharing scheme, where channels can be shared between adjacent cells. A pair of adjacent cells called a meta-cell, and the two adjacent cells that form a meta-cell are called component cells [30]. This scheme assumes the movement of a user is towards higher number of cells, that is, user moves from cell 1 to cell 2, and so on. When there is a new call in cell j it is given a channel if there is any idle channel in the meta-cell $(j, j+1)$, otherwise, the call is blocked. Handover calls arriving at cell j are assigned a channel from a meta-cell $(j, j+1)$ if channel is idle. If a call has already a channel from the meta-cell $(j-1, j)$, it is allowed to carry the same channel in j , and is queued in the FIFO queue for a requiring channels belonging to meta-cell $(j, j+1)$ [30]. During handover, the call can be dropped if it is using a channel from the meta-cell $(j-2, j-1)$. Any time a channel becomes free in the meta-cell $(j, j+1)$, the channel is assigned to the first call waiting in the queue of those meta-cells. This scheme offers a significantly lower call blocking probability (P_b) for the same handover call dropping probability (P_d) compared with the pure FCA schemes [30], which increases a system utilization keeping the same QoS.

The total number of available channels in the system S is divided into sets, the minimum number of channel sets N required to serve the entire coverage area is related to the normalized frequency reuse distance δ which, discussed in section 3.4 above as follows [76]:

$$N = D^2 / 3R^2 = (\delta^2) / 3 \quad (3.15)$$

3.4.1.2 Performance of Different Fixed Channel reservation Schemes

The performance of a channel allocation scheme, using a given channel assignment strategy, is measured by the following network characteristics: blocking probability of new call request, number of handover requests, dropping probability of handover requests, delay in channel assignment and total carried traffic. “In selecting a channel assignment strategy, the objective is to achieve a high degree of spectrum utilization for a given quality of service with the least possible number of database lookups and simplest possible algorithms employed at the base station and (or MSC)” [45].

3.4.1.2.1 Simple Channel Borrowing (SCB) Schemes

In SCB schemes, when an incoming call request arrives in the cell and there are no more available nominal channels, the base station can borrow a channel from a neighbouring cell to accommodate the call request, provided this frequency channel does not interfere with the existing cells. In the SCB schemes, cell (acceptor cell) that has used all its nominal channels can borrow free channels from its neighboring cell (donor cell) to accommodate new calls. Borrowing can be done from an adjacent cell, which has largest number of free channels (borrowing from the richest). Select the first free channel found for borrowing using a search algorithm (borrow first available scheme). Return the borrowed channel when channel becomes free in the cell (basic algorithm with reassignment). To be available for borrowing, the channel must not interfere with existing calls.

3.4.1.2.2 Hybrid Channel Borrowing Strategies

The main Drawback in the SCB scheme is the absence of control in the number of channels that can be lent by a cell; this is taken in to account in the hybrid channel borrowing schemes. There are three different techniques that are used in hybrid channel borrowing schemes:

In the simple hybrid channel-borrowing scheme (SHCB) [46] the set of channels assigned to a cell is divided into two classes, I and II. Class I channels are local serve channels only used to serve call requests within to the cell. Where as class II channels can be borrowed by neighbouring cells and referred to as, borrowable channels. The ratio I: II is determined a priori; optimized ratio depends on the percentage increase in the traffic density.

The borrowing with channel ordering (BCO) scheme also divides assigned nominal channels into two groups, but the local to borrow able ratio varies dynamically according to the current traffic conditions. In this scheme the first channel has highest priority to be assigned to the next local call, and the last channel has the highest priority to be assigned be borrowed by neighbouring cells. Here, the MSC uses an adaptive algorithm to calculate and update each channel probability to being borrowed, according to traffic conditions.

Borrowing with direction channel locking (BDCL) [40] is similar to BCO with channel reassignment. Channel borrowing with channel locking scheme [40, 41] borrows a channel from an adjacent cell as discussed above. However, BDCL uses an efficient way to lock channels. When a channel is locked it is only locked in the directions that would cause co-channel interference. Cells located toward the free direction can borrow or lock the channel. It means channels are locked in the direction of interference and can be reused in the direction with no interference.

The FCA variant schemes with the best results (BCO and BDCL) use centralized control inside the MSC. The MSC has to keep a record of free, serving, borrowed, and locked channels and to label them with updated priority. The need for a continuous up-to-date global knowledge of the entire mobile network can lead to a slow response and a heavy signaling load. To alleviate this problem, several authors have proposed modifications to make the scheme more distributed [80,81].

3.4.2 Dynamic Channel Allocation (DCA)

The core idea of DCA scheme is to allocate a channel to a call request with minimum cost, with respecting the signal interference constraints. The dynamic channel allocation scheme

is based on the prevailing traffic condition and demand of the resource in the cell. The DCA scheme has the potential to achieve significantly improve bandwidth utilization when there are temporal and spatial traffic variations. The other main concept of DCA technique is that to provide the advantage of increase channel utilization and reduced call-dropping probability by prioritizing the handover request [42]

Most DCA schemes work on a call- by- call basis, searching the minimum cost channel for the current call request, based on the existing traffic conditions. Some DCA schemes are adaptive, and take in to account the past traffic history. Due to the short-term temporal and spatial variations of traffic in cellular systems, FCA schemes are not able to attain high channel efficiency. To overcome this, Dynamic Channel Allocation (DCA) schemes have been studied. In contrast to FCA, there is no fixed relationship between channels and cells in DCA. All channels are kept in a central pool and are assigned dynamically to radio cells as new calls arrive in the system [33, 34]. After a call is terminated, the channel is returned to the common pool.

In DCA, a channel is eligible for use in any cell provided that signal interference constraints are satisfied. Since, in general, more than one channel might be available in the central pool to be assigned to a cell that requires a channel; some strategy must be applied to select the assigned channel [32]. The main differences between the strategies are related to how this choice is made. It is often associated with a cost function. Channel assignment takes place through minimization of a cost function such as the allocated bandwidth under the constraint that channel reuse takes place above specified interference levels. In [31] it is assumed that the mean traffic in each cell is Gaussian distributed to demonstrate that DCA is more resilient to traffic volatility than FCA.

3.4.2.1 Dynamic channel allocation scheme Based on Handover Schemes

Dynamic channel allocation scheme, based on handover scheme, uses dynamic channel allocation, where channels are grouped together in central pool. Any cell requiring channel can use a channel from the pool subject to satisfying the channel reuse distance [28, 29].

During call time the allocated channel are removed from the common channel pool. Channel is returned to the central pool for the future reuse up on the termination of calls. The DCA based schemes provide important advantage of coping up with traffic variation in different cells. Under low and moderate traffic conditions the DCA scheme provides a reduction of new call blocking probability (P_b) and handover dropping probability (P_d) compared to FCA schemes.

It is fairly straightforward to select the most appropriate channel for any call based simply on current allocation and current traffic, with the aim of minimizing the interference. DCA scheme can overcome the problem of FCA scheme. However, variations in DCA schemes center on the different cost functions used for selecting one of the candidate channels for assignment. Thus the DCA schemes can be centralized or distributed. The centralized DCA scheme involves a single controller selecting a channel for each cell; the distributed DCA scheme involves a number of controllers scattered across the network (MSCs).

3.4.2.2 Centralized DCA

For a new call, a free channel from the central pool is selected that would maximize the number of members in its co-channel set. Several DCA schemes formulate a cost function that maximizes the channel efficiency by optimizing the reuse channel distance packing. The scheme performs well in light and moderate traffic conditions, but in heavy traffic condition they are not able to maximize the channel reuse because the best candidates most probability is already serving call request. In [22] proposed that, an ideal DCA scheme: Maximum Packing (MP). In this proposed scheme new call request will be blocked only if there is no possible reallocation of channels to allow the call to be carried. The MP scheme is impractical for implementation and the complexity of searching all possible reallocations is computationally hard.

3.4.2.3 Distributed DCA Schemes

The distributed DCA schemes are normally a cell-based schemes or signal strength measurement based scheme. The base station (not the MSC as in the centralized scheme) is responsible for keeping information about current available channel in the vicinity. The ACO (augmented channel occupancy) matrix [81] contains the entire local and vicinity information needed for selection of a channel and channel information is up dated by base station.

The signal strength measurement based schemes, known as interference adaptation schemes, use the location of the mobile users to maximize the packing of channels. The reason behind this is because depending on the location of the mobile user; the frequency reuse channel distance used for the selection of the channel may be greater than the actually needed. The users are able to measure the amount of co-channel interference to determine the reusability of channel. When the mobile user and BS strength measurement offer this functionality maximum channel packing could be achieved. The other signal based scheme is the channel segregation (CS) scheme [41], which is a self, organized DCA.

3.4.2.4 Comparison FCA versus DCA

A detail comparison between, the FCA and DCA schemes are given in table 3.1 below.

Table 3.1

FCA	DCA
<ul style="list-style-type: none"> ■ Radio equipment covers all channels assigned to the cell ■ Independent channel control ■ Low computational effort ■ Low call set up delay ■ Low implementation complexity ■ Complex, labor intensive frequency planning ■ Low signaling load ■ Centralized control ■ Performs better under heavy traffic ■ Low flexibility in channel assignment ■ Maximum channel reusability ■ Sensitive to time and spatial changes ■ Not stable grade of service per cell in an interference cell group ■ High forced call termination probability ■ Suitable for large cell environment ■ Low flexibility 	<ul style="list-style-type: none"> ■ Radio equipment covers the temporary channel assigned to the cell ■ Fully centralized to fully distributed control dependent on the scheme ■ High computational effort ■ Moderate to high call set up delay ■ Moderate to high implementation complexity ■ No frequency planning ■ Moderate to high signaling load ■ Centralized, distributed control depending on the scheme ■ Performs better under light/moderate traffic ■ Flexible channel allocation ■ Not always maximum channel reusability ■ Insensitive to time and spatial changes ■ Stable grade of service per cell in an interference cell group ■ Low to moderate forced call termination probability ■ Suitable in microcellular environment ■ High flexibility

3.4.3 Hybrid Channel Allocation (HCA)

To combine the advantages of both FCA and DCA, hybrid channel allocation has been proposed [35, 26]. In Hybrid Channel Allocation schemes, the set of available channels are split into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and in all cases are to be preferred for use in their respective cells. All users share the second set of channels in the system to increase

flexibility. When a call requires service from a cell where all of the associated nominal channels are busy, then a channel from the dynamic set is assigned to the call. The dynamic set is managed by a DCA scheme. Some other possible combination of DCA and FCA strategies are to use a DCA for light and moderate traffic loads and FCA in heavy traffic conditions. The proposed TTBS scheme uses the FCA strategies, because the scheme works effectively at heavy traffic condition.

3.5. Performance Summary of Channel Allocation Scheme

DCA scheme perform better under low traffic intensity; modified FCA schemes have superior performance in high traffic load. DCA schemes use channels more efficiently (better trunking efficiency) and for the same blocking rate have a lower forced call termination than FCA based schemes. However, the optimum channel allocation is at the expense of high overheads through its use of centralized allocation schemes, which make the scheme not practicable for large networks. The distributed DCA schemes suffer less overhead, but lead to sub-optimum allocations. Such schemes are used in microcellular system as this cell structure allows intercell information sharing by interference measurements [84]. For macrocellular systems, where explicit communication is needed, FCA with channel borrowing offers good results and less computational complexity than DCA. Although the FCA schemes are less complex than DCA schemes, there is a need to maintain an up-to-date global knowledge of the entire mobile network, leading to a heavy signaling load and a slow response.

In addition to effective channel allocation schemes the mobile cellular communication must look for call admission control integrated with handover management schemes as pointout at the beginning of this chapter, in order to provide good QoS for network user and good system utilization for network provider need. Thus, the detail discussion of call admission control and handover management is given in chapter 4.

CHAPTER 4

CALL ADMISSION CONTROL AND HANDOVER MANAGEMENT

4.1 INTRODUCTION

All the allocation schemes discussed above did not take in to account the effect of handover calls in the performance of the system. In general, call handover is caused by degradation of the radio link, either because there is some change in the environment, or because the user is moving and needs to change base station to keep sufficient transmission power. Handover is the process of changing the Channel (frequency, time slot, Spreading code, or combination of them) associated with the current connection while a call is in progress. It is often initiated either by crossing a cell boundary or deterioration in quality of the signal in the current channel. To get some insight into this process we will review some handover schemes in the following sub-sections.

4.2 GUARD CHANNELS

Among call admission control schemes, the guard channel scheme is the nearest to standard. The guard channel approach offers a generic means of increasing the chance of success for handover requests, simply by allocating a number of channels exclusively for them. Although it is possible to decide statically which channels will be guard channels and which will not, the general meaning of guard channel call admission control does not refer to the static case.

What it means is that, if there are N channels of communication in the cell among which G are guard channels ($G < N$), a new call will be accepted only if the number of available channels is greater than or equal to G , where as handover calls will be accepted as long as at least one channel is available. The number of the guard channels for a given network is extremely important. This mean, if all channels are guard channels, it is impossible to start a new call, but handover dropping probability is very low. In contrast if no channel is allocated exclusively for handover requests new call-blocking probability reduced in the expense of handover dropping. A more general scheme, namely, the fractional guard

channel scheme is introduced in [47]. In this case, an incoming call is accepted with certain probability, which depends on the number of busy channels. Under this scheme there are four different arrangements as discussed below:

- a) **New Call Bounding Scheme:** The scheme works as follow: if the number of new calls in a cell exceeds a threshold value when a new call will be blocked; otherwise it will be admitted. On other hand the scheme limit the admission of new calls and only reject the handover call when all channels in the cell are occupied [79].
- b) **Cutoff Priority Scheme:** The scheme proposes, instead of putting limitation on the number of new calls, the decision whether a new arriving call is accepted or is not based on the number of total ongoing calls in the cell. Let k denote threshold, upon a new call arrival. If the total number of busy channels is less than k , the new call is accepted; otherwise the new call is blocked [79].
- c) **New Call Thinning (Fractional Guard Channel) scheme.** These schemes are schemes in which, a new call is admitted with certain probability. This mean when the network is approaching the congestion, the admitted new call stream becomes thinner. The flexibility of the scheme made it very general (more practical) [79].
- d) **Rigid Division Schemes:** The scheme divide all channels allocated to a cell into two classes: one for common use to all call and the other for handover call only [79].

4.3 Queuing Schemes

Queuing is way of delaying handover, the MSC queues the handover requests instead of denying access if the current BS is busy. In [48], the probability of a successful handover could be improved by queuing handover request at the cost of increased new call blocking probability and a decrease in the ratio of carrier- to-admitted traffic. This is due to the fact that new calls are not assigned a channel until all the handover requests in the queue are served. Queuing is very beneficial in macro-cells, since the mobile station can wait for handover before signal quality drops to an unacceptable level. The effectiveness of queuing decreases for micro-cells.

Queuing is mostly used in order to give better service to subscribers. New call attempts and handovers both can be queued and they are in the same queue. During queuing different prioritizations can be used for both new call and handovers (non-critical handovers and critical handovers) using parameter queuing calls. Along with guard channels, the queuing of calls is the second major scheme for handover prioritization. There are different types queuing schemes:

4.3.1 Queuing of Handover Calls

Here the handover calls are queued and no new calls are handled before the handover calls in the queue are served. Hence this scheme is stricter than the guard channel schemes. The handover calls can be queued because of the overlapping zone where two or more base stations in neighbouring cells can work at the same time [63].

4.3.2 Queuing New Calls

It seems more natural to queue new calls given the fact that they are almost insensitive to delay. Queuing of new calls reduces the probability of new call blocking. However, queuing of new calls, results in increased dropping probability of handover calls. Queuing of handover call is more important than queuing of new call, since dropping ongoing calls upsets the customer than blocking of new calls.

The above-presented schemes are basic in the sense that they do not consider the mobility of the user. One of the major advantages provided by mobility information over traditional call admission control (CAC) schemes is channel reservation. In the next sub-section we consider some schemes, which works based on this concept.

4.4 Predictive Channel Reservation (PCR)

The position of the mobile station in the network is also employed in [3], where the notion of threshold distance is used to define the size of channel reservation area. The PCR scheme makes predictive channel reservations for each mobile station (MS) based on its

current position location (calculated using GPS data) and orientation. The threshold distance (D_{th}) is the radius of a circle, which is co-centered with a cell of smaller size than the cell's coverage area (figure 4.1 below). The area between these two circles is called the channel reservation area. When a mobile station enters the reservation area of a cell from the inner part of that cell, and at the same time, is heading to a new cell, a reservation request will be sent to that new cell's base station.

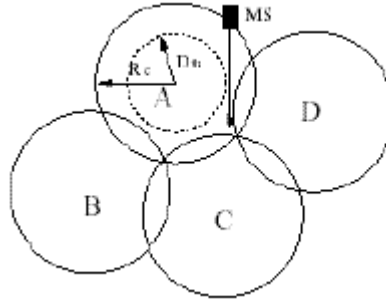


Figure 4.1 notion of threshold distance (Predictive channel reservation)

4.5 Adaptive Channel Reservation

It is argued that the predictive channel reservation scheme has some problems, including the following: the threshold distance is the same for all users, regardless of their speed. Thus, the time the base station will have to make the reservations can vary a lot between two different incoming calls. Even if, some users request reservation, there is a lot of time before the mobile enters into the target cell, which causes the resource to be idle for a long time. This results in an under utilization of system.

This can be overcome by using the adaptive channel reservation schemes, which is based on time threshold T_{th} . According to each mobile station's current speed, orientation and location information, base stations can predict the time within which the mobile station will reach the boundary of the next target cell as shown in figure 4.2 below.

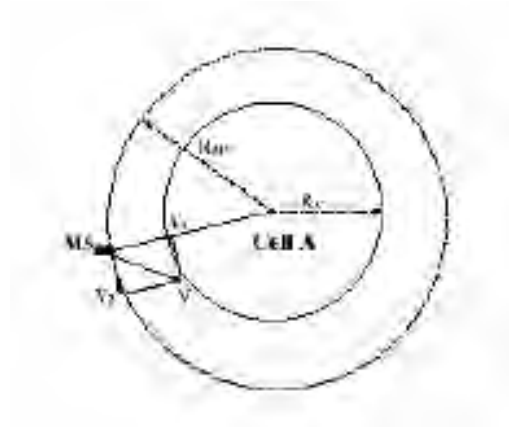


Figure 4.2 Adaptive channel reservations

4.6 Hybrid Predictive Handover

Because of the rapid growth of mobile cellular users, especially in the urban areas, hierarchical networks are dominant. Here when the mobile is approaching the handover area in a microcell its signal strength is compared with a predefined handover threshold set by the handover control (HC), providing the required parameters for the handover decision-making. This is different from the conventional signal strength based handover approaches, in which the signal strength of the target cell is compared with that of the present cell and if the former is superior to the later then a handover event is triggered. The predefined threshold is based on minimum signal level required to provide the minimum quality of service (QoS) attribute of an ongoing connection.

4.7. Propagation Model for Mobile Cellular Networks.

In wireless communication systems, signals travel through air to reach their destination. The mobile hosts may use the air interface to access a wired communication infrastructure. Likewise the communication network must use the air interface to access the mobile host. For every case, the air interface is the vital component of wireless communication system. In wireless communication environments, radio waves propagate through various mechanisms such as; reflection, diffraction and scattering. A propagation model can be used to predict the strength of the radio signal and its variability at a given distance from the transmitter. The radio signals traveling in the air are affected by three main factors:

These factors are the distance between the transmitter and receiver, shadowing and multipath propagation, and motion of the mobile station.

Received signal strength is inversely proportional to the square of the distance, d . In free space, path loss formula is given by:

$$L_p = 10 \log \left[\frac{(4\pi d)^2}{\lambda} \right] \quad (4.1)$$

Where, d is the distance from the transmitter to the mobile station, λ is the wavelength of the transmitted signal. This loss in dB exhibits a straight-line variation respect to distance with a constant slope for a given traffic and medium. This path loss slope is assumed '2' in free space and increases in dense urban environments or in high traffic areas. The path loss slope may decrease indoors due to the wave-guide effect of the walls, wide area median, and long-term median path loss attenuation [51].

The second factor is attributed to shadowing and multi-path propagation caused by structures and terrain variations and is log-normally distributed with zero mean value of the long-term median of the received signal and with the standard deviation of $4\text{dB} \leq \sigma \leq 10\text{dB}$ [79]. The value of σ depends on the environment. It has low values in rural areas and high values in dense urban areas. This component is known as shadow fading, large scale fading, lognormal shadowing, and narrow area median [51].

The third factor is caused by the traveling of a mobile through a standing wave pattern that is produced by the summing of the multi-path waves and is Rayleigh distributed around the narrow area median [50], Rayleigh probability density function is given by [52].

$$f(r_k) = (r_k / p_k) \exp \left(\frac{-(r_k)^2}{2p_k} \right) \quad (4.2)$$

Where, p_k is the parameter of the density function, and $r_k \geq 0$. This third component of radio wave propagation examines the fine details of the received signal and is called in the literature as Rayleigh fading, fast fading, small scale fading, short term fading, Rician fading (if the parameter, rice factor, of the Rayleigh distribution is non zero), and instantaneous variation. The envelope process of this fast fading phenomenon is Rayleigh distributed if there is no strong direct component. Otherwise it is Rician [78].

Rayleigh fading is usually handled in mobile system designs by diversity techniques such as frequency hopping, multiple receivers, or correlators with variable delay lines and antenna diversity, and signal processing techniques such as bit interleaving, convolutional coding, and equalizers [50]. Shadow fading is handled by increasing transmitter power and co-channel reuse distance [50]. The fading due to distance, path loss exponent, is handled by handing-over to the new base station whenever the signal from the old base station becomes unusable.

Finally, we should examine the effect of fresnel zone. In multi-path environments, diffraction of radio waves occurs when the wave fronts encounter an obstacle. The electromagnetic wave front is divided into zones of concentric circles, separated by $\lambda/2$. It can be assumed that the place where the radio waves hit the ground is the Fresnel zone break point. Within this point and the transmitter, radio wave propagates according to the free space path loss slope, since diffraction and multi-path phenomena generally occur beyond this region. Fresnel zone breakpoint is related to the transmitter and receiver antenna heights and the frequency of the transmitted signal [83].

$$d_0 = d = \left(\frac{4h_1h_2}{\lambda} \right) \quad (4.3)$$

Where, h_1 is transmitter antenna height, h_2 is the receiver antenna height, λ is the carrier wavelength, d_0 is the Fresnel zone breakpoint. Moreover, Variation due to path-loss and shadowing occur over large distances of the order of cell size and they are also frequency dependent. Variations due to multi-path fading occur over very short distances of the order of signal wavelength and frequency dependent.

4.8 CELLULAR SYSTEM DEVELOPMENT SCENARIOS

The radio propagation environment and related handover challenges are different in different cellular structures. A handover algorithm with fixed parameter cannot perform in the same way in different system environments. Specific characteristics of the communication system should be taken into account while designing handover algorithms.

Several basic cellular structures: macrocells, microcells, picocells, and overlay systems and special architectures include underlay, multichannel bandwidth systems, and evolutionary architectures.

4.8.1 Macrocells

The base station transceiver in macrocell transmits high output power with the antenna mounted several meters high on a tower to cover a large area. Macrocell radii are several kilometers. Due to the low cell-crossing rate, centralized handover is possible despite the large number of MSs the MSC has to manage. The quality of the transmission in the uplink and downlink is approximately the same. The transition region between the BS's is large; handover schemes should allow some delay to avoid flip-flopping. To preserve the signal quality, the delay must be short enough because the signal interference increases as the mobile station penetrates to the new cell, which is called cell dragging. Macrocells are characterized by relatively high path-loss [53]. To overcome this problem, the time period used to average the signal strength variations should be long enough to get rid of fading fluctuations.

4.8.2 Microcell

In mobile cellular networks, some capacity improvement techniques such as; implementing larger bandwidth, advanced speech coding, channel coding, and modulation will not be sufficient to satisfy the required service by customers. Under these circumstances using micro-cell is believed to be the single most effective means of increasing the capacity of cellular systems. The use of microcell improves the capacity of cellular network, but the radio resource management is more difficult. Microcells can be one, two, or three-dimensional depending on their implementation. The BTS of the microcells are characterized by lower out-put transmit power with small antenna mounted at lamppost level approximately 4 to 5 meter from ground [54]. Here the mobile station is also transmitting using low power output, which leads to a longer battery life. The RF signal from the BTS propagates along streets. The coverage of microcell BTS antenna may be 100

to 200m in each direction of the street, serving a few city blocks. Microcells are highly sensitive to traffic and signal interference than macrocells, which is due mainly to their short-term variation. The number of handover per cell can be high and the time taken to make handover is very fast [55].

Microcell face a propagation phenomenon called corner effect, which is a sudden drop in signal strength by as much as 20-30dB, while a mobile turns around a corner at 10-20m distance when a mobile turn around. This is due to loss of the line of sight (LOS) between mobile station and serving base stations. It degrades the quality of service rapidly and hard to predict. In the microcellular network (system) there are basically two types of handover scenarios: line of sight (LOS) and non-line of sight (NLOS) handovers. Handovers from one LOS BS to another LOS BS is called LOS handover, where as the NLOS handover is the handover from NLOS base station to LOS base station, which is due to users turns a corner and handover must be done as fast as possible.

4.8.3 Macrocell and Microcells overlays

High speed of some users, lack of service of microcells in some areas, and congestion of certain microcells are some reasons for signaling load and higher handover rates. To reduce this drawback, a mixed cell architecture called overlay/underlay system, consisting of larger macrocells called umbrella (overlay cells) and small- size microcells, which is underlay cells can be used as shown in figure 3.6 above. This architecture provides a balance between maximizing the number of users per unit area and reducing the network control load associated with handover. Macrocell insure intercell handover and microcell improve capacity due to its greater frequency reuse and implemented in high traffic areas: an airport, a railway station, campus etc... In this case macrocells are expected to cover high-speed mobile stations and areas, which are not covered by the microcells due to shortage of channels or the microcell coverage limit. The implementation of the overlay/underlay system has several advantages over a pure microcell system: The base stations are required only in high traffic density areas. Since it is not necessary to cover the whole service area with microcells, infrastructure costs are saved. The requested number of

handovers in an overlay system is much less than in a pure microcell system because fast moving vehicles can be connected to the overlay macrocell. Both calling from MS and location registrations can easily be done through the micro-cell system.

The Global system for mobile communication (GSM) technology based system can use the macrocell/microcell overlay system [12]. There are several special cellular architectures that try to improve the scarce cellular spectral efficiency without a significant increase of infrastructure costs. As an example, the underlay/overlay system, which is different from the overlay/underlay system discussed above. In underlay/overlay system a tighter frequency reuse factor is implemented within an overlay, where as, frequency spectrum is divided between macro-cells and micro-cells, which implies macro-cells uses some channels throughout the cellular system.

4.9 Handover Prioritization (Rigid division scheme)

When no priority is set between handover calls and new call dropping and blocking probabilities are the same. A handover prioritization scheme can improve quality of service by minimizing handover failures with spectrum utilization degradation. In many previous proposed approaches the handover calls are generally given a high priority than new calls [2, 3, 5]. The existing channels are categorized in to shared channel (SC) and reserved channel (RC) [56]. The shared channels are shared between the handover and new calls and the reserved channels are only used by the handover calls. The different number of RCs will make the base station runs in different performance. Based on this concept there are two channel allocation strategies, i.e. first shared channel (FSC) scheme and first reserved channel (FRC) scheme were considered based on the arrival of handover call. In FSC, the handover calls are first allocated resource from shared channel then allocated with the reserved channel and this scheme uses one dimensional markov model [56]. FRC strategy discussed in detail in section 4.5.1 and those who are interested with the FSC can referee [56]

4.9.1 FRC Allocation Scheme

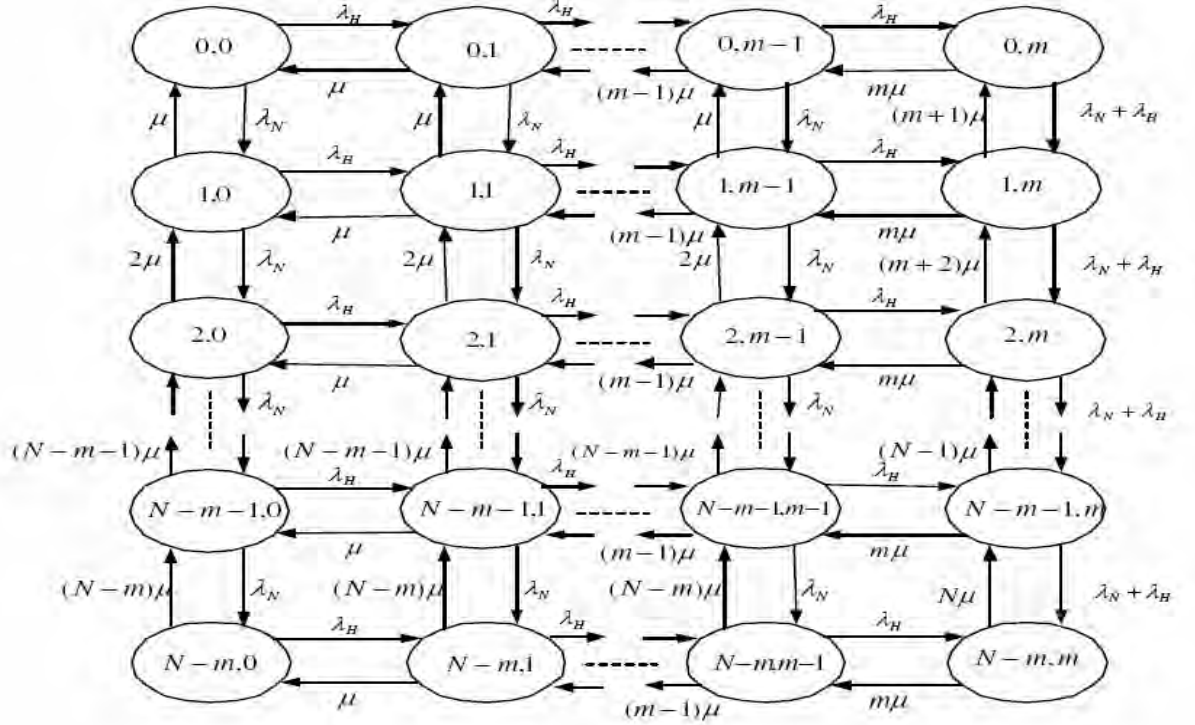
The handover calls are first reserved from RC and if unsuccessful from SC. In this study the work implements a two-dimensional markov model to analyze the new-call blocking probability and handover call dropping probability as shown in figure 4.3 When the

reserved channels are fully occupied, the handover calls share the shared channels with the new calls. Assuming that the total number of channels in each cell is N , number of reserved channels is m and $N-m$ shared channels we have two cases:

I) When $k < m$ at time t , then the call arriving rate $\lambda_{k,2}$ and the leaving rate μ_k on queue of RC are shown as follow: $\lambda_{k,2} = \lambda_h$, $k = 0, 1, 2, \dots, m-1$ and $\mu_k = (\mu_E + \mu_H)$, and the call arriving rate λ_k and the leaving rate μ_k on queue of SC are as follow [57]: $\lambda_k = \lambda_N$, $k = 0, 1, 2, \dots, N-m$ and $\mu_k = k(\mu_E + \mu_H)$. Where μ_E is rate of the call end in each channel, which follows an exponential distribution and μ_H is the rate of the call that will be handed over to the neighbor cells in each channel, follow an exponential distribution. Handover and new call arrival rate is Poisson distributions with rates λ_H and λ_N respectively.

II) When $k > m$, then the RC is saturated, consider the number of calls in the SC is k , k element of $[0, N-m]$ at time t . Then the call arriving rate $\lambda_{k,1}$ and the leaving rate μ_k as follows and for more understanding reader can referee [56]. $\lambda_{k,1} = \lambda_n + \lambda_h$, $k = (0, 1, 2, \dots, N-m)$ and $\mu_k = (k + m)(\mu_E + \mu_H)$. According to this assumption the two-dimensional transition diagram of the FRC shown as in figure 4.3.

Figure 4.3 Transition diagram of FRC



Based on this transition state diagram for $k \leq m$, the stationary distribution of RC is derived [56]. The deep mathematical derivations of this new call blocking probability and handover call dropping probability given in [56]. Based on this derivation using some approximation the dropping probability, Pd and blocking probability, Pb for the FRC Scheme given as follow [56, 79]: For $j \leq m$.

$$P_b = \frac{1}{(N-m)!} \left[\frac{\lambda_n}{\mu_E + \mu_H} \right]^{N-m} \left[1 + \sum_{j=1}^{N-m} \frac{1}{j!} \left(\frac{\lambda_n}{\mu_E + \mu_H} \right)^j \right]^{-1} \quad (4.4)$$

and

$$P_d = \frac{1}{m!} \left[\frac{\lambda_h}{\mu_E + \mu_H} \right]^{N-m} \left[1 + \sum_{k=1}^m \frac{1}{k!} \left(\frac{\lambda_h}{\mu_E + \mu_H} \right)^k \right]^{-1} \quad (4.5)$$

The FRC scheme handover dropping probability, Pd and new call blocking probability, Pb versus reserved channel shown in figure 4.4. For simulation result given by figure 4.4, the

simulation parameters are: $\mu_H = 1.7/\text{sec.}$, $\mu_E = 2.2/\text{sec.}$, $\lambda_h = 4/\text{sec.}$, $\lambda_n = 3/\text{sec.}$ which are calculated (obtained) from ETC mobile network data indicated under the annex part using the above relation given for them. And total channel implemented are 11, and reserved channel varies from 1 to 11. Where each single channel divided in to eight time slot (bandwidth unit) for GSM system working on the basis of TDMA access method as discussed in section 2.2 above. As one can observe from the figure 4.4, the handover call dropping probability decreases as the numbers of reserved channels increases. The simulation result given, under figure 4.4 using the above values and equation 4.4 and 4.5 given above. In contrast to this the new call blocking probability increase as the number of reserved channel increases.

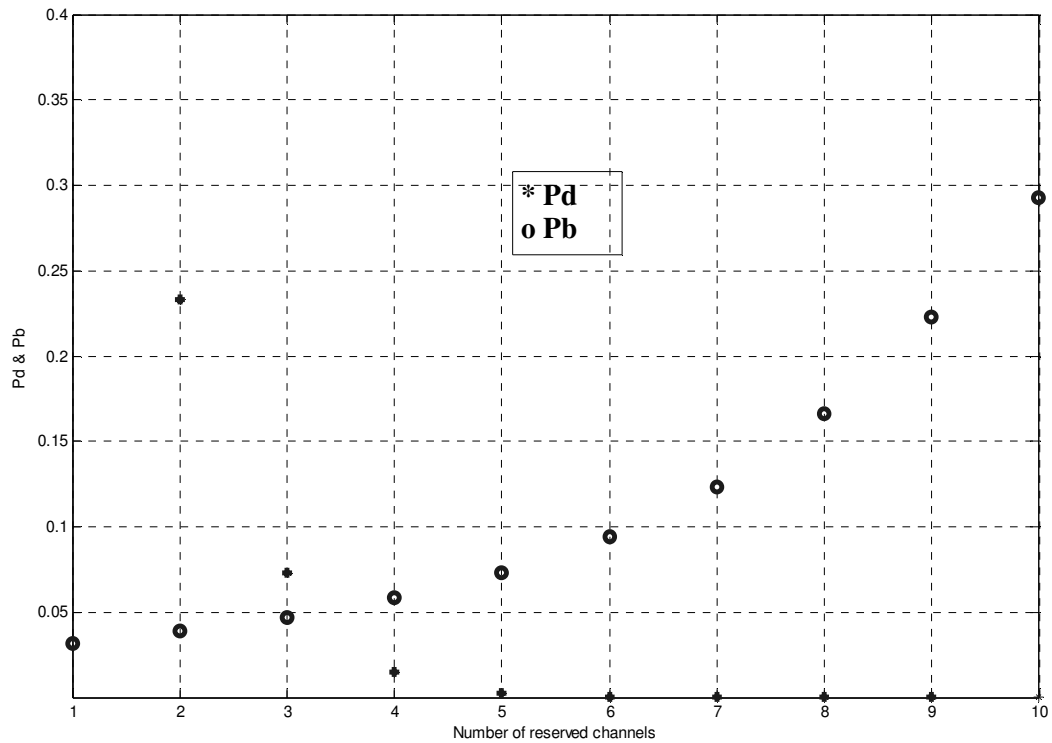


Fig. 4.4 new call blocking and Handover call dropping probabilities versus reserved channels for FRC schemes (based on the above equation).

However, this scheme provides good system utilization than that of FSC by minimizing new call blocking probability [56]. In the FSC the new call blocking probability increase faster than the new call blocking probability of FRC scheme and there is no as such change in handover dropping probability with the increase of reserved channels [77]. In this proposed scheme for simulation study implement the reserved channel where each channel contains eight bandwidth units as discussed in the previous section. In this case study the work implements a two-dimensional markov model chain to analyze the new call blocking probability and handover call dropping probability. The data used in the simulation of this case study taken from ETC (Ethiopia telecommunication corporation) mobile communication department, to test the result use an actively operating network under moderate traffic condition.

Figure 4.5 below show the result obtained from simulating the grade of service (GoS) cost function versus number of reserved channel. GoS is a measure of the ability of a user to accesses a trunked system during the busiest hour of call traffic. The number of channels required is determined based the number of subscribers, desired GoS, average call holding time and traffic distribution with time. GoS decreases as the reserved channel increases and attains its minimum value between 5 and 6 as shown from the plot and become slowly increase after the reserved channel number reach 6. This is because; the GoS increases in the 1st time and in the 2nd half the system utilization decreases as more channels are reserved for handover call, which increases the new-call blocking probability. As a result the system channel utilization is reduced, which leads to rising of GoS as shown from figure 4.5.

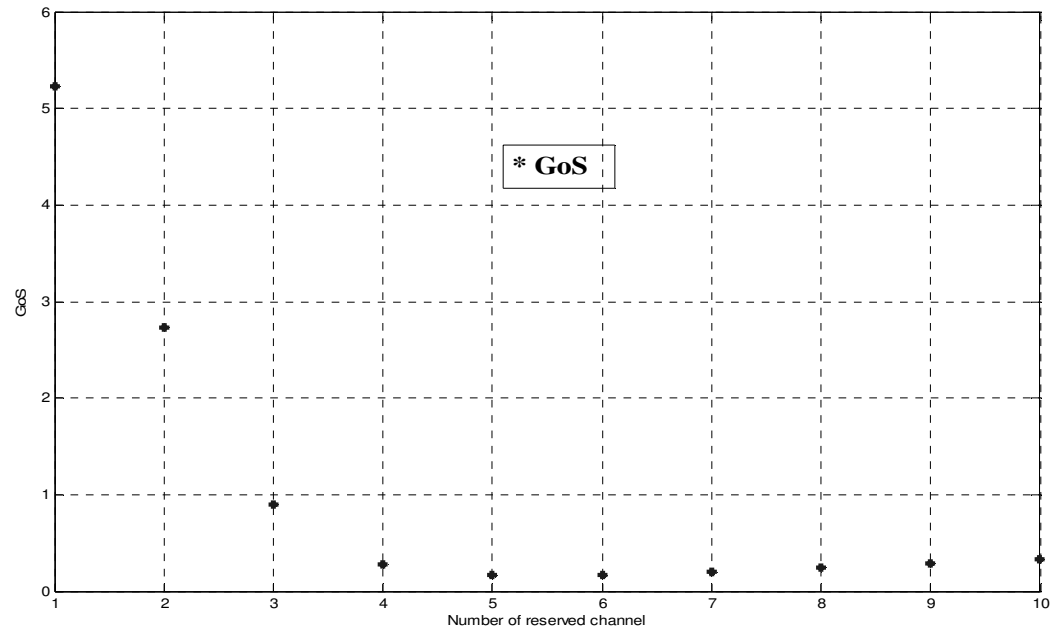


Fig. 4.5 GoS versus reserved channel for Handover calls in FRC

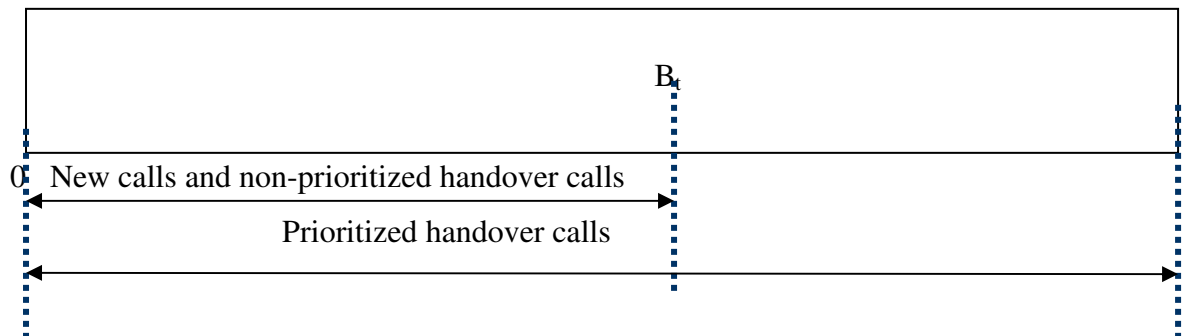
The main drawback with this scheme is due to not considering time threshold based approach in addition to channel (bandwidth) threshold based approach. Our proposed scheme TTBS (Time threshold based scheme) consider this problem, which is discussed in detail in the next chapter.

CHAPTER 5 ANALYSIS AND SIMULATION

5.1. Time Threshold Based Scheme (TTBS)

In the TTBS Scheme, this work focuses on a single cell as a reference cell in cellular wireless network, assuming every cell has identical statistical behavior and have uniform channel allocation. The estimated arrival traffic at the base station (BS) of the reference cell is of voice type and we assume that cell has a total capacity of B of say 80 bandwidth units (BUs) in the case of ETC mobile network. About 16-bandwidth unit (two channels) are used for signaling, and each voice call requires one bandwidth unit (single time slot). The proposed Scheme is also based on observing the elapsed real time voice handover calls and it uses some threshold parameters. The scheme works on the principle of the guard channel policy, although, the scheme “Time Threshold Based (TTBS) Scheme” relies on completely, new idea for some handover calls from traditional well-known GCS. Figure 5.1 shows the bandwidth allocation of our TTBS Scheme for new and handover calls. An originating voice call and non-prioritized hand-over voice call are served if they find occupied bandwidth less than the threshold Bandwidth (B_t) Units.

Fig.5.1. Bandwidth Allocation for Prioritized, non-prioritized handover and new calls.



A successful handover with out interruption is very important to real time service i.e. for voice call [60]. Based on the TTBS scheme, a new call is blocked if the occupied bandwidth is greater than or equal to the threshold bandwidth ‘ B_t ’ Where B_t takes a value between zero and B . Otherwise, the new call is accepted and one unit of bandwidth is reserved. Similarly the same threshold B_t , is used for non-prioritized handover calls

(handover calls that have elapsed real-time greater than time threshold T_h). In other words, the handover calls that have elapsed real time greater than time threshold T_h are dropped if the amount of occupied bandwidth is greater than or equal to B_t excluding critical handover calls. Otherwise, it is accepted and one BW unit is allocated. The proposed TTBS scheme treats the non-prioritized handover calls the same as a new call. However, we do not consider a bandwidth threshold for handover calls that have elapsed real time smaller than T_h , such that those handover calls are accepted as long as the occupied bandwidth in the cell is smaller than the total cell bandwidth capacity B . The proposed TTBS scheme or system can be expressed in the block diagram form as shown in the figure 5.2 below, which is known as the voice call preprocessing flow chart (algorithm).

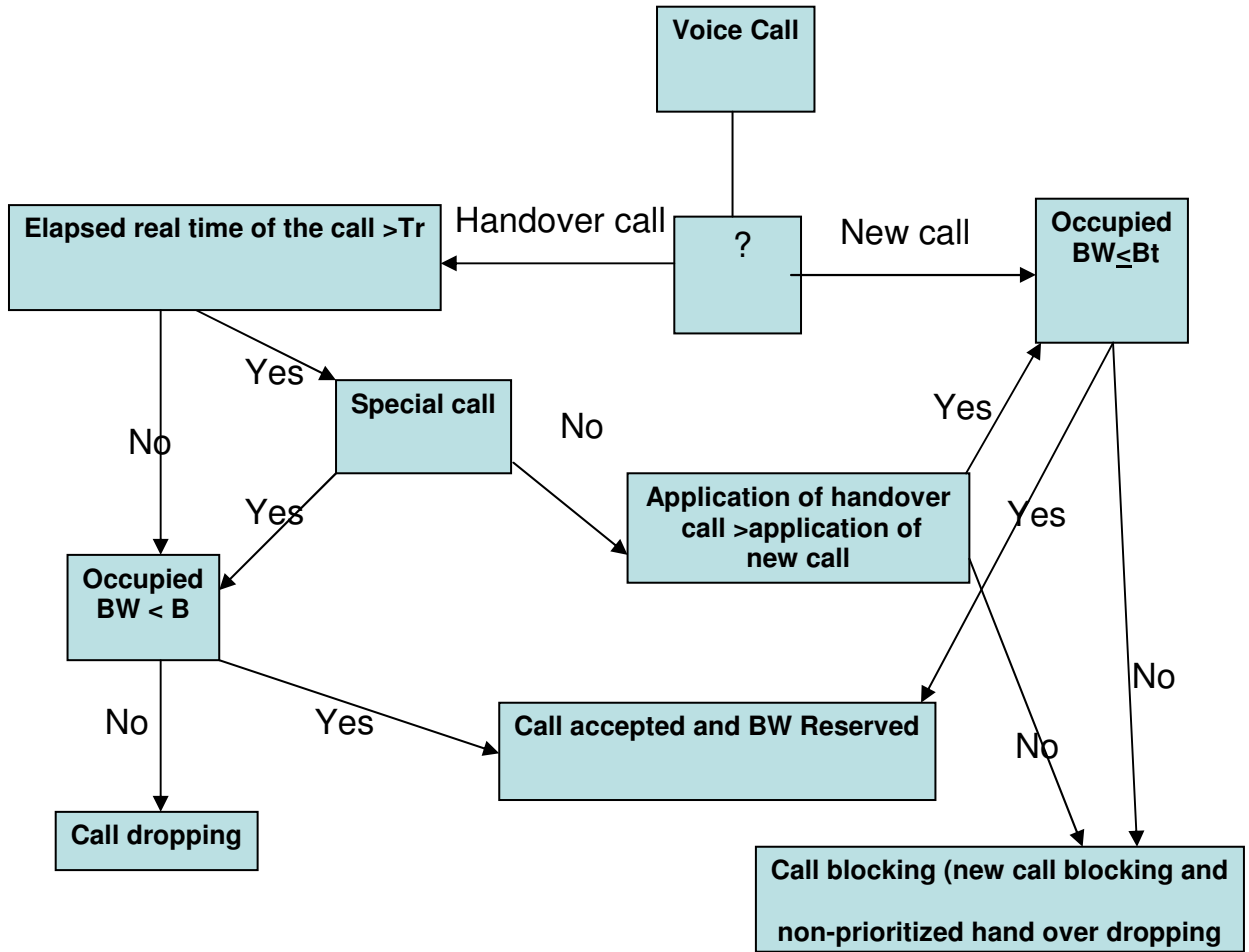


Figure 5.2 Voice call processing flow chart (algorithm)

5.2 System Model

We consider a general model of voice calls with mobility characteristics, which is frequently used [61, 62]. The proposed approach is based on decomposing the wireless cellular network into individual subsystems, each comprising a single cell. Under this formulation, each cell can be modeled and analyzed individually. The same model is used for all cells in the network, but the model parameters may be different, reflecting the mobility and traffic conditions in the individual cell. Thus each model can support homogeneous and heterogeneous traffic. However, in this study, for easy of description and to simplify the analysis, we consider the homogeneous traffic where all cells have the same mobility and traffic condition. The work assumes the system uses the fixed channel allocation (FCA) scheme, which means the cell has a fixed amount of capacity. Note that no matter which multiple accesses technology (frequency division multiple access FDMA, Time division multiple access TDMA, and Code division multiple access CDMA) is used, the system capacity can be interpreted in terms of its effective or equivalent bandwidth [62]. By bandwidth of a call, we mean the number of bandwidth units (BUs) that is adequate for guaranteeing a desired QoS for the call with certain traffic characteristics.

5.2.1 Simulation Model and System Parameter

The Simulation has been performed using matlab codes. As mentioned before, the simulation focused on a single reference cell. The simulating code have loop for time checking, the time checker loop determines if the elapsed time of voice handover call is greater than the time threshold T_h or not. That is, to say, if the elapsed real time of the call is 80 seconds, then it has 100 seconds left since it is assumed that the average voice call duration is 180 seconds as given in table 5.1 below under section 5.3 for new call and uniformly varies for handover call between 90 seconds to 150 seconds, and we use average value for the simulation study i.e. 120sec.

For originating calls, and handover calls that have elapsed real time greater than the time threshold T_h , the bandwidth unit checks if the amount of bandwidth is greater than the Bandwidth threshold B_t or not. On the other hand, for handover calls that have elapsed real time less than time threshold T_h , the bandwidth unit check to find out if the capacity which is with in the assumed to be 80 unit of Bandwidth) or not.

The new call and handover call request to a given cell are Poisson processes with an average service rates λ_n and λ_h respectively. Assuming call arrival as Poisson process is more general one can work for new call with out extra assumption. But the arrival rate for handover call is non-Poisson; handover traffic is non-Poisson due to the blocking phenomenon in the neighboring cells. However, previous studies have shown that the Poisson approximation for handover traffic is reasonable when cells are identical, and have the same statistical behavior, and then the new call generation in the cell is a Poisson process [64, 65]. The cell call holding time also follows exponential distribution with an average service rate μ_n for new calls and exponential distribution with an average service rate μ_h for handover calls. Considering the conditions discussed under section 5.1, the simulation model and system parameter can be treated separately for the three (FSS, GCS, and TTBS) scheme involved in the simulation study. Mainly the simulation model for these three schemes looks for specific system model and analysis model as discussed in the next sub sections.

5.2.2 Fully Shared (Non-Prioritized) Scheme

In this scheme all of N channels are shared by both originating call and handover call request. The base station (BS) handles a handover request exactly in the same way as a new call.

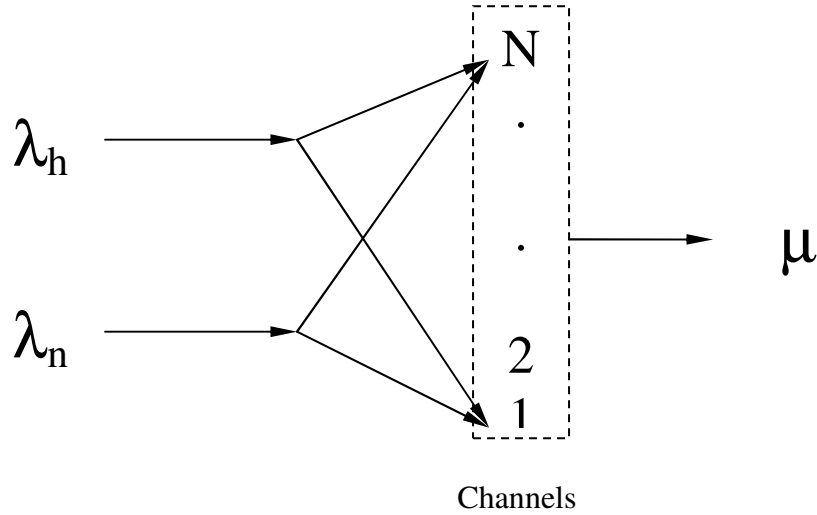


Fig 5.3 - A generic System mode for FSS scheme

Analysis model: The states of a cell can be represented by (N+1) states markov model as shown below in figure 5.4 below.

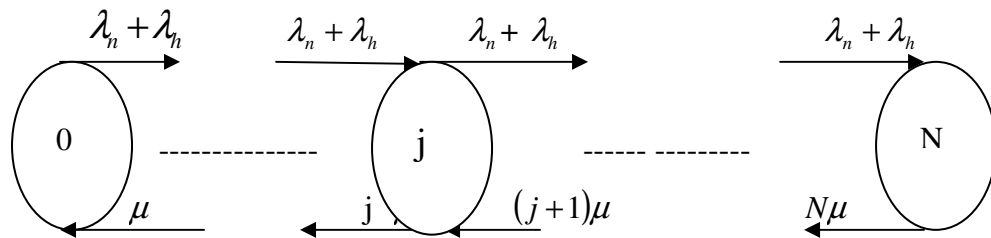


Fig. 5.4 State transition diagram for FSS of the figure above,

Let P (j) be the probability that the system in state j, the probabilities P (j) can be determined in the usual way for birth-death processes [63].

$$P(j) = ((\lambda_n + \lambda_h) / j\mu)P(j-1) \quad \text{for } 1 \leq j \leq N \tag{5.1}$$

Where from normalization conditions

$$\sum_{j=0}^N P(j) = 1 \quad (5.2)$$

The steady-State probability P (j) is found as follows:

$$P(j) = \frac{(\lambda_n + \lambda_h)^j}{j! \mu^j} P(0); \quad 0 \leq j < N \quad (5.3)$$

$$\text{Where } P(0) = \frac{1}{\sum_{j=0}^N \frac{(\lambda_n + \lambda_h)^j}{j! \mu^j}} \quad (5.4)$$

The new call blocking probability P_b is

$$P_b = P(N) = \frac{(\lambda_n + \lambda_h)^N}{j! \mu^N} / \left(\sum_{j=0}^N \frac{(\lambda_n + \lambda_h)^j}{j! \mu^j} \right) \quad (5.5)$$

The handover call dropping probability P_d is:

$P_d = P_b = P(N)$ and the above equation is known as the Erlang-B formula. In this schemes a dropped handover call request still maintain the communication via current BS until the received signal strength goes below the receiver threshold or the conversation is completed before the received signal strength goes below the receiver threshold, this works well in the Guard channel policy.

5.2.3 Guard Channel Policy

5.2.3.1 Guard channel scheme (GCS)

In this scheme (policy) all of (N-m) channels are reserved only for the handover calls and the remaining m channels are shared by both new call and handover call request. The base station (BS) handles a handover request by providing priority than a new call. The normalized offered load in GCS (in Erlang) given as

$$\rho = (\lambda_n + \lambda_h) / ((Bt + B)\mu) \quad (5.6)$$

The mobility (γ) of calls is a measure of terminal mobility and is defined as the ratio of handover call arrival rate (λ_h) to new call arrival rate (λ_n), i.e.

$\gamma = \lambda_h / \lambda_n$. The system model is shown below in figure 5.5. It is proposed in [70] the state j , ($j = 0, 1, \dots, N$) of a cell as the number of calls in progress from the BS of that cell. It proposes the steady-state probability that the BS is in state j is $P(j)$. The normalization condition results:

$$\sum_{j=0}^N P(j) = 1 \tag{5.7}$$

The steady-state probability $P(j)$ is easily given as follows [64]:

$$P(j) = \begin{cases} \frac{(\lambda_n + \lambda_h)^j P(0)}{j! \mu^j}, & 0 \leq j \leq m \\ \frac{(\lambda_n + \lambda_h)^m P(0)}{j! \mu^j}, & m \leq j \leq N \end{cases} \tag{5.8}$$

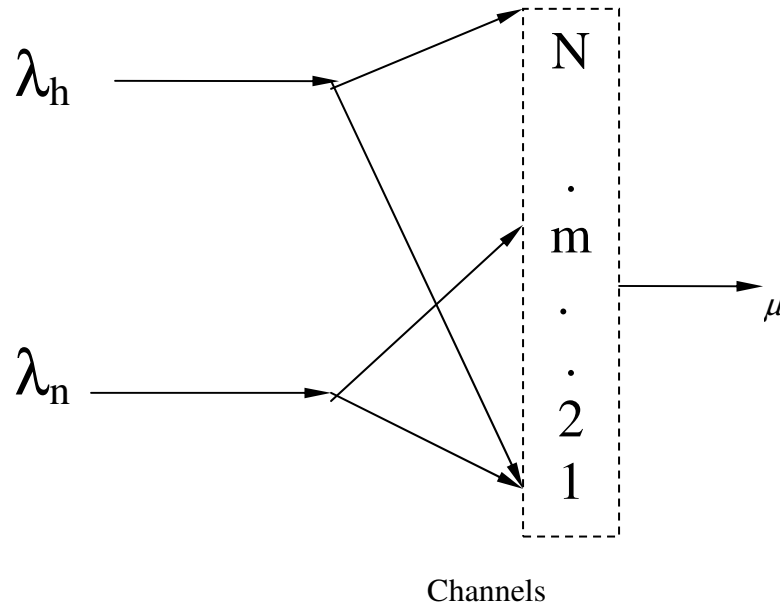


Fig. 5.5 System model with priority hard over call (GCS) Scheme

System model with reserved channels for handover (No new call blocking until greater or equal to m channels is busy)

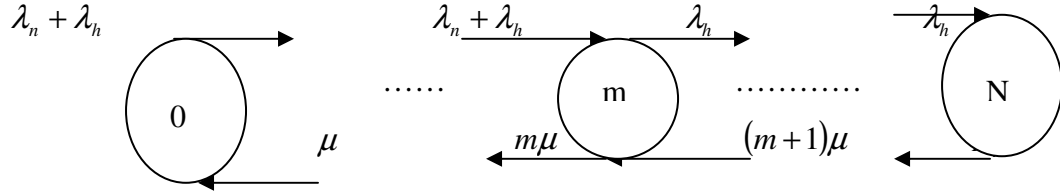


Fig. 5.6 State transition diagram for fig 5.5 above (GCS)

Where

$$P_0 = \left[\sum_{k=0}^m \frac{(\lambda_n + \lambda_h)^k}{k! \mu^k} + \sum_{k=m+1}^N \frac{(\lambda_n + \lambda_h)^m \lambda^{k-m}}{k! \mu^k} \right]^{-1} \quad (5.9)$$

The originating call blocking probability defined as below, where $P(k)$ is given by equation 5.11 above:

$$P_b = \sum_{k=m}^N P(k) \quad (5.10)$$

$$P_b = \sum_{k=m}^N \frac{(\lambda_n + \lambda_h)^m \lambda^{k-m}}{k! \mu^k} \left[\sum_{k=0}^m \frac{(\lambda_n + \lambda_h)^k}{k! \mu^k} + \sum_{k=m+1}^N \frac{(\lambda_n + \lambda_h)^m \lambda^{k-m}}{k! \mu^k} \right]^{-1} \quad (5.11)$$

And the handover dropping probability is

$$P_d = \frac{(\lambda_n + \lambda_h)^m \lambda^{n-m}}{N! \mu^N} \left[\sum_{k=0}^m \frac{(\lambda_n + \lambda_h)^k}{k! \mu^k} + \sum_{k=m+1}^N \frac{(\lambda_n + \lambda_h)^m \lambda^{k-m}}{k! \mu^k} \right]^{-1} \quad (5.12)$$

5.2.3.2 Guard Channel Policy for TTBS

The guard channel discussed in section 5.2.3.1 above implements the one-dimensional markov chain model for new call blocking and handover call dropping probabilities. In our scheme using the one-dimensional markov chain model lead us to in accurate result [79], which implies that we cannot use the traditional approach if the channel holding times for new and handover calls are distinct with different average service times. Or implementing one dimensional markov chain model in such condition results an over estimate at one condition and under estimate at another condition the blocking and dropping probabilities. Thus, we use two-dimensional Markov chain to model the TTBS system.

However, solving the global balance equations for multi-dimensional state is computationally intensive [79]. To overcome such problem, it will be useful to find some approximation for the call blocking probabilities [79]. The approximation is based on the following idea: reduce the two dimensional Markov chain model to a one dimensional Markov chain model by normalizing the average service time for each stream so that the average service time becomes identical for both streams. In this way we can use the one-dimensional Markov chain theory to find the new call blocking and handover call dropping probabilities [79]. Normalizing service time mean making the average service time to unity. The assumptions are; normalization does not change network traffic intensity.

The approximations are as follow: Let $\phi_n = (\lambda_n) / \mu_n$ and $\phi_h = (\lambda_h) / \mu_h$. The approximation model used is the new call arrival stream is Poisson with arrival rate ϕ_n and with service rate (Channel holding time for new calls) 1. The handover call arrival stream is also Poisson with arrival rate ϕ_h and service rate 1. The scheme uses the same system model with the GCS scheme given above and the state transition is a two-dimensional markov chain model as shown by the next figure.

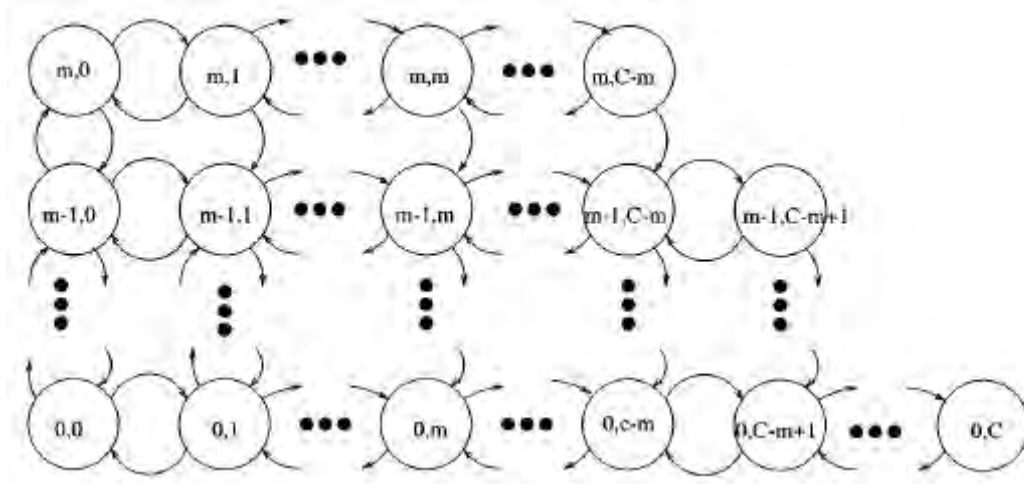


Fig.5.7 state transition diagram for the TTBS scheme (cutoff priority scheme.)

The stationary distribution for the model [79]:

$$P(j) = \begin{cases} \frac{(\phi_n + \phi_h)^j P(0)}{j!}, & j \leq m \\ \frac{((\phi_n + \phi_h)^m)(\phi_h)^{j-m} P(0)}{j!}, & m+1 \leq j \leq N \end{cases} \quad (5.13)$$

Where

$$P(0) = \left[\sum_{j=0}^m \frac{(\phi_n + \phi_h)^j}{j!} + \sum_{j=m+1}^N \frac{(\phi_n + \phi_h)^m (\phi_h)^{j-m}}{j!} \right]^{-1} \quad (5.14)$$

From the above stationary distribution, we obtained the new call blocking probability and handover call dropping probability as follows where P(0) is as defined above:

$$P_b = \sum_{j=m}^N \frac{(\phi_n + \phi_h)^m \phi_h^{j-m}}{j!} P(0) \quad (5.15)$$

$$P_d = \frac{(\phi_n + \phi_h)^m \phi_h^{N-m}}{N!} P(0) \quad (5.16)$$

We use these to approximate the new call blocking and handover call dropping probability for the TTBS Scheme. Table 5.1 below gives the simulation parameters.

The normalized offered load of the TTBS scheme (system) (in Erlang) is defined as [84]:

$$\rho = (\lambda_n + \lambda_h) / [(B_t * \mu_n) + ((\alpha)B_t + (1 - \alpha)B)\mu_h] \quad (5.17)$$

Where α is the expected percentage of handover calls that are entering to new call class (non-prioritized handover calls). It can be obtained by extending time threshold for the handover calls. The mean service time is defined in [10] as;

$$1/\mu = \lambda_n / (\lambda_n + \lambda_h) (1/\mu_n) + \lambda_h / (\lambda_n + \lambda_h) (1/\mu_h) \quad (5.18)$$

The design goal of the proposed TTBS Schemes should also include minimizing the Grade of service (GoS) Cost function. Even though, sophisticated cost functions have been proposed [67], in practice, a simple weighted average is useful for most design purposes. The weighted sum of the originating call blocking probability (P_b), prioritized call handover dropping probability (P_{d1}), and non-prioritized handover call dropping probability (P_{d2}) are introduced as a measure of Grade of service (GOS) and can be defined as

$$\text{GoS} = P_b + kP_{d1} + P_{d2} \quad (5.19)$$

Where, k is the penalty factor used to reflect the effect of the handover dropping over the new call blocking in the GOS cost function. A penalty of 5 to 20 times is commonly recommended [68]. In accordance with the proposed scheme, we the penalty factor is or prioritized handover calls, where as the non-prioritized handover calls have the same weight as the new calls. The simulation parameters are given in the table 5.1 below.

5.3 Bandwidth utilization

In the proposed scheme, the users are assumed to be homogeneous in terms of bandwidth requirements. Accordingly, we can factor out the bandwidth requirements and use the ratio of the number of users over maximum users as the bandwidth utilization. Assume that the call duration of a user in a given cell is $1/\mu$ or average call service time and the new call arrival rate is λ_n , and handover calls arrival rate λ_h . The over all number of users that arrived in the system during the $1/\mu$ time interval can be given by: where μ is given by equation 5.8 above for TTBS scheme.

$$N_{\text{arrivals}} = \lambda / \mu \text{ where } \lambda = \lambda_n + \lambda_h \quad (5.20)$$

In the practical implementation, it is clear that some of the users that arrive at the networks are lost by the new call blocking and handover call dropping, due to lack of sufficient bandwidth. Then, the number of users that exists in the system can now be expressed as [85]:

$$N_{\text{user}} = (1 - \lambda_l) \lambda / \mu \quad (5.21)$$

Where λ_l is lost rate, which is defined as the sum of new call, blocked and handover call dropped i.e.,

$$\lambda_l = \lambda_{hl} + \lambda_{nl} \quad (5.22)$$

Thus the ratio between the number of users that are being served by the system and the maximum number of users supported by the network (MaxUser equals to the total bandwidth units of a cell) is [85]:

$$N_{\text{user}}/\text{MaxUsers} = N_{\text{user}}/B = (1 - \lambda_l) \lambda / \mu B \quad (5.23)$$

In general case the system bandwidth utilization can be defined accordingly for the three different schemes as shown below [84, 85].

$$\text{Utilization for FSS is: } U = (1 - \lambda_t) \left(\frac{\lambda_n + \lambda_h}{\mu B} \right) \quad (5.24)$$

$$\text{For the GCS, } U = (1 - \lambda_t) \left(\frac{\lambda_h + \lambda_n}{(Bt + B)\mu} \right) \quad (5.25)$$

For the TTBS scheme utilization is,

$$U = (1 - \lambda_t) \left/ \left[(Bt * \mu_n) + ((\alpha)B_t + (1 - \alpha)B)\mu_h \right] \right. \quad (5.26)$$

Table 5. 1: Simulation Parameters

Time Threshold Values	110 to 165 Second
Time Threshold for handover call	90 to 150 second
New call average service time ($1/\mu_n$)	180 Sec exponential Dist
Mobility ($\gamma = \lambda_h / \lambda_n$)	0.5 to 1.5
Total Bandwidth Units (B)	80 unit (assumed) Uniform in all cell
Handover call average service time ($1/\mu_h$)	120-se expends. Dist.
Normalized Load (ρ)	1.05 to 1.55
Average new call arrival rate λ_n (Poisson)	$\lambda_n = 0.32$
Handover call arrival rate λ_h (Poisson)	$\lambda_h = 0.25$ to 0.475
% of handover call that are transformed to new call class (α)	$\alpha = 0.23$
Over all Mean call duration ($1/\mu$) = 180se	165 sec exp. Dist

However, from the mobile user's point of view, the objective is to minimize the GoS cost function in order to improve the performance of the system. Thus, the performance of a given system can be defined as

$$\text{Performance} = 1/ \text{GOS} \quad (5.27)$$

The other objective of the proposed scheme, from the service provider's perspective is to decrease the network cost function by increasing utilization of the system. Therefore, the cost of a system is proportional to the reciprocal of utilization ($\text{Cost} = 1/\text{utilization}$).

In order to make reasonable balance between both user satisfaction and service provider satisfaction, a certain crucial performance metric Y is introduced in order to measure the performance of different bandwidth allocation schemes and compare them. It is clear that, Y is a function of new call blocking probability; hand over call dropping probability and system utilization, which can be defined as

$$Y = \text{Performance} / \text{Cost} = \text{Utilization} / \text{GoS} \quad (5.28)$$

The proposed scheme design goals of handover scheme are increasing the performance and decreasing the cost, which means maximizing the crucial performance metric Y .

5.4 System Traffic Model

For mobile cellular communication system, it is important to establish a traffic model before analyzing the system performance. The system under consideration is wireless network with cellular infrastructure comprising a number of cells. There are various traffic models that have been developed based on different assumptions about user mobility. In the proposed scheme simulation model, we only consider homogeneous calls, and assume that each mobile station (MS) needs only one channel per call as discussed in the simulation model in the previous section. Number of channels in a cell is constant N or C . We introduce the Hong and Rappaport's traffic model (two-dimensional case), which provide the traffic characterizations used by this work. This model propose traffic model for hexagonal cell (which can be approximated by a circle) [63]. It assumes that the users are spread evenly over the coverage area, thus, the location of the user when the user

initiates a call is uniformly distributed in the cell. Also they assume that a user initiating a call moves from the current location in any direction with equal probability and that this direction does not change while the user remains in the cell.

Using these assumptions they showed that the handover call arrival rate is [63].

$$\lambda_h = \frac{P_H(1-P_b)\lambda_n}{1-P_{hh}(1-P_{hf})} \quad (5.29)$$

Where, P_H is the probability the new call that is not blocked would require at least one handover. P_{hh} is the probability a call that has already been handed-over successfully would require another handover. P_b is the new call blocking probability. P_{hf} is the probability of handover call failure. λ_n is the arrival rate of new calls in a cell. The probability density function (pdf) of the channel holding time T_c that is exponentially distributed in a cell is derived as:

$$f_{T_c} = \mu_c e^{-\mu_c t} + e^{-\mu_c t} \left[\frac{f_{T_n}(t) + \gamma_c f_{T_h}}{1 + \gamma_c} \right] - \mu_c e^{-\mu_c t} \left[\frac{F_{T_n}(t) + \gamma_c F_{T_h}(t)}{1 + \gamma_c} \right] \quad (5.30)$$

Where, $f_{T_n(t)}$ is the pdf of the random variable T_n as the dwell time in the cell for a new call.

$f_{(t)Th}$ is the pdf of the random variable T_h as the dwell time in the cell for the handover call. $F_{T_n}(t)$ is the cumulative distribution function (cdf) of the time T_n .

$F_{T_h}(t)$ is the cumulative distribution function (cdf) of the time T_h .

$1/\mu_c$ is the average call duration time.

$$\gamma_c = \frac{P_H(1-P_b)}{1-P_{hh}(1-P_{hf})} \quad (5.31)$$

5.5. Simulation Result and Discussions

The performance Parameters measured in this work is new call blocking probability, P_b , handover call dropping probability, P_d and bandwidth utilization (percentage utilization),

Grade of Service, Performance metrics, and call arrival rates. The result is collected using 95% confidence interval and the predicted values lie $\pm 5\%$ of the mean. Let us first, consider a self-performance evaluation of the TTBS schemes and then present a comparative evaluation of the proposed scheme with respect to the two prior schemes for different parameter measures. In this simulation study for the proposed scheme and its prior schemes, the real raw data is obtained from Ethiopia mobile network and the simulation parameters given in the above table 5.1 are calculated from these data. The type of collected data are number of handover request, handover accepted, handover rejected, new call request, new call accepted, new call rejected over different traffic time. These data are from different BSC and the duration for the data collection is 1 hour for each collection period. For more understanding sample raw data is given under the annex part.

5.5.1 Performance Evaluation

Figure 5.8 below shows the new call blocking probability P_b and handover call dropping probability P_d , versus time threshold T_r for two different network normalized load: $L_1=1.48$ and $L_2 =1.25$ Erlang and fixed bandwidth threshold $B_t = 40BW$ units. As expected, both handover call dropping and new call blocking probabilities increase as the system load increases. However, increasing system load has more effect on new call blocking probability, P_b than handover call dropping probability, P_d . This is the result of guard policy that means the TTBS (Time Threshold Based Scheme) works according to the guard policy as discussed in the previous sections. The other basic reason is that when time threshold T_r increases, the number of new calls arriving the cell become more and more. On the other hand, the increase in network traffic causes new call blocking probability, P_b and handover call dropping probability, P_d to be increase as time threshold, T_r increasing. The simulation emphasis on the region where the probability are low enough to meet GoS requirements commonly 2% GoS. For instance $P_b= 0.02$ when $T_r = 118$ second for L_1 and $T_r=130$ second for L_2 . Also, the handover dropping probabilities, $P_d = 0.02$ when $T_r = 137$ second for L_1 and $T_r = 147$ second for L_2 as one can observe from the graph.

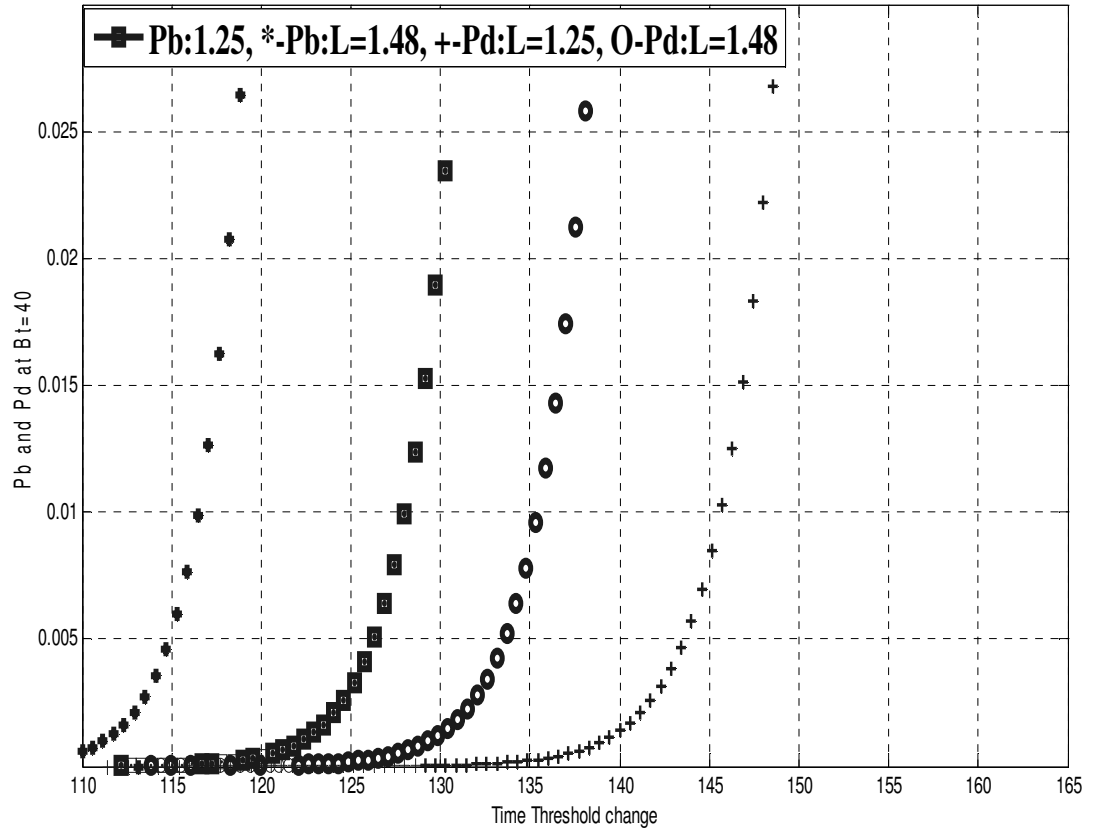


Fig.5.8. Handover dropping and new calls blocking probability versus Tr

Figure 5.9 below show that the new call-blocking and handover call dropping probabilities versus load for two different time thresholds $Tr_1=145$ second and $Tr_2=165$ second. It is obvious that as we increase the time threshold Tr , new call blocking probability increases and this is more obvious at high load. This is because increasing Tr gives more chance for the new calls to be arriving the network and unprioritized. Note that, when the network load is low, there is no serious deterioration of handover call dropping probability, P_d and new call blocking probability, P_b . The simulation result shows that at high load both the new and handover call failure rate are increasing. This can be expected result due to high traffic density of the network. For example, P_b for Tr_1 and Tr_2 attain the 2% GoS when normalized load get values 1.295 and 1.365 respectively. The dropping probability, P_d for Tr_1 and Tr_2 when $L=1.375$ and $l=1.45$ respectively as one can observe from the plot.

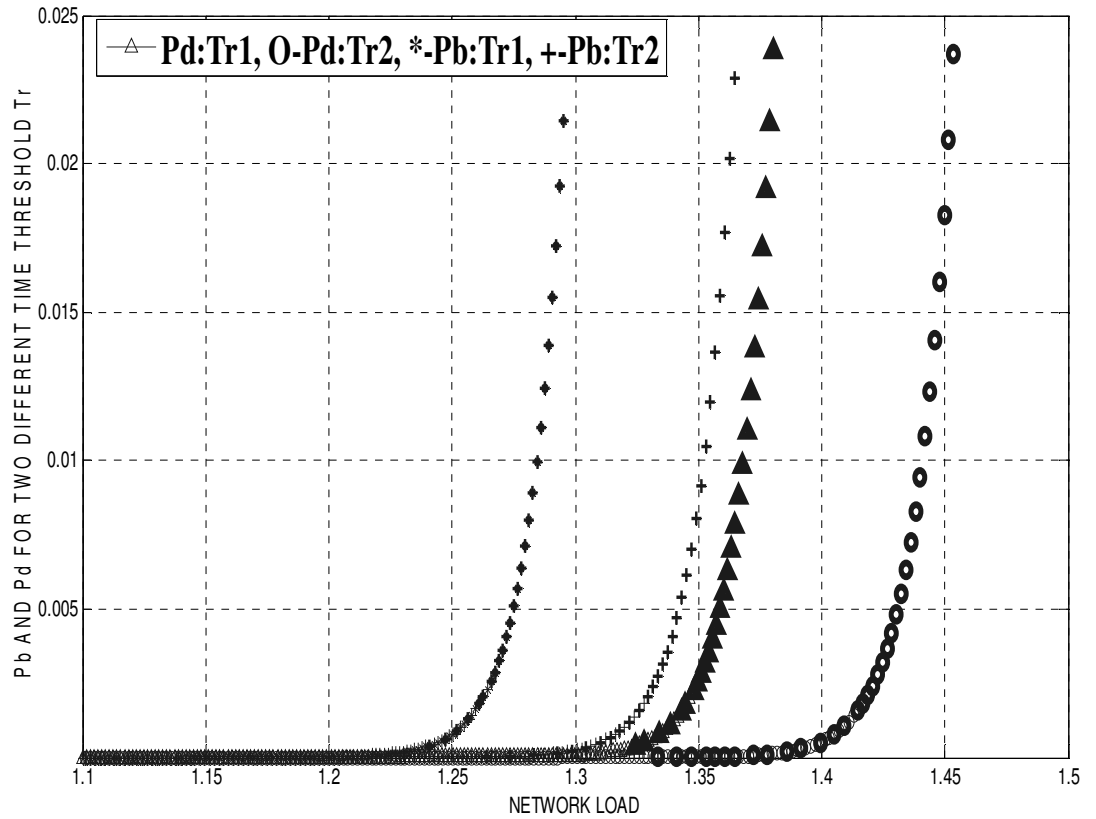


Fig. 5.9. Pd and Pb versus load in Erlang for different time threshold Tr

5.4.2 Performance Comparison

Figure 5.10 below shows that the utilization of the three different schemes. It is clear that the proposed scheme TTBS here also shows a good tradeoff between FSS and GCS schemes. Since, in FSS schemes, all bandwidth units are shared by a new and handover call as discussed above in the previous section, utilization of this scheme is the highest. However, it is clearly seen that Utilization of TTBS is much better than that of GCS scheme and close to that of FSS scheme, almost equal at low network mobility. This indicates that the TTBS strategy utilize system well as compared to GCS and provide high quality of service than both of the GCS and FSS schemes. Thus, TTBS scheme is compromise between the FSS and GCS schemes in terms of utilization, as one can see from the performance metrics given by figure 5.13 below.

Figure 5.11 below show the grade of Service (GoS) versus mobility for FSS, GCS, and TTBS schemes with $T_h = 120\text{sec}$. As discussed in the previous section, minimizing the GoS cost function improves the user satisfaction or it maximizes the system performance. As seen from the figure 5.11 (a), the proposed TTBS scheme achieves the minimum grade of service compared to GCS and FSS schemes. More than this result, the TTBS scheme does not show a serious deterioration in the GoS as mobility increases. As one can see from the figure 5.11 (a), the GoS for FSS is almost constant over the whole mobility considered for the simulation. It is clear that the GoS of FSS is high due to its poor quality of service, which provides poor system performance as one can observe from the simulation result obtained for the performance metrics below, even though, FSS result highest system utilization

The interesting result about GoS is figure 5.11(b), which has practical visibility. Figure 5.11(b) is the extension of figure 5.11(a). From this simulation result the proposed TTBS scheme provide best performance for network operator than GCS and FSS as seen from figure 5.11(a), and (b).

The other performance evaluation of the scheme is handover call dropping and new call blocking probabilities with the various bandwidth thresholds assuming constant network mobility as shown in figure 5.12 below. Increasing the bandwidth threshold allow more chance for new calls to be accommodated in the network and it increases the handover failure rate due to less prioritization. On the other hand, increasing the bandwidth threshold means, decreasing the reserved bandwidth unit for the handover calls. It is expected that the handover call dropping probability is decreasing as the reserved bandwidth units increasing and the new call blocking probability increases as the number of reserved bandwidth unit is increasing. Figure 5.12; show that the bandwidth threshold and reserved bandwidth unit are opposite to each other, i.e. as bandwidth threshold (the shared bandwidth unit) decreases, the reserved bandwidth unit increases, which results minimum handover call dropping probability and maximum new call blocking probability. The simulation result given by figure 5.12 for the proposed TTBS scheme is the result obtained using handover service time threshold $T_h = 120\text{second}$. One can observe reserving less than 40 Bu for handover call

results low QoS from user point of view and also reserving greater than 45 to 50 Bu results low system utilization from network point of view.

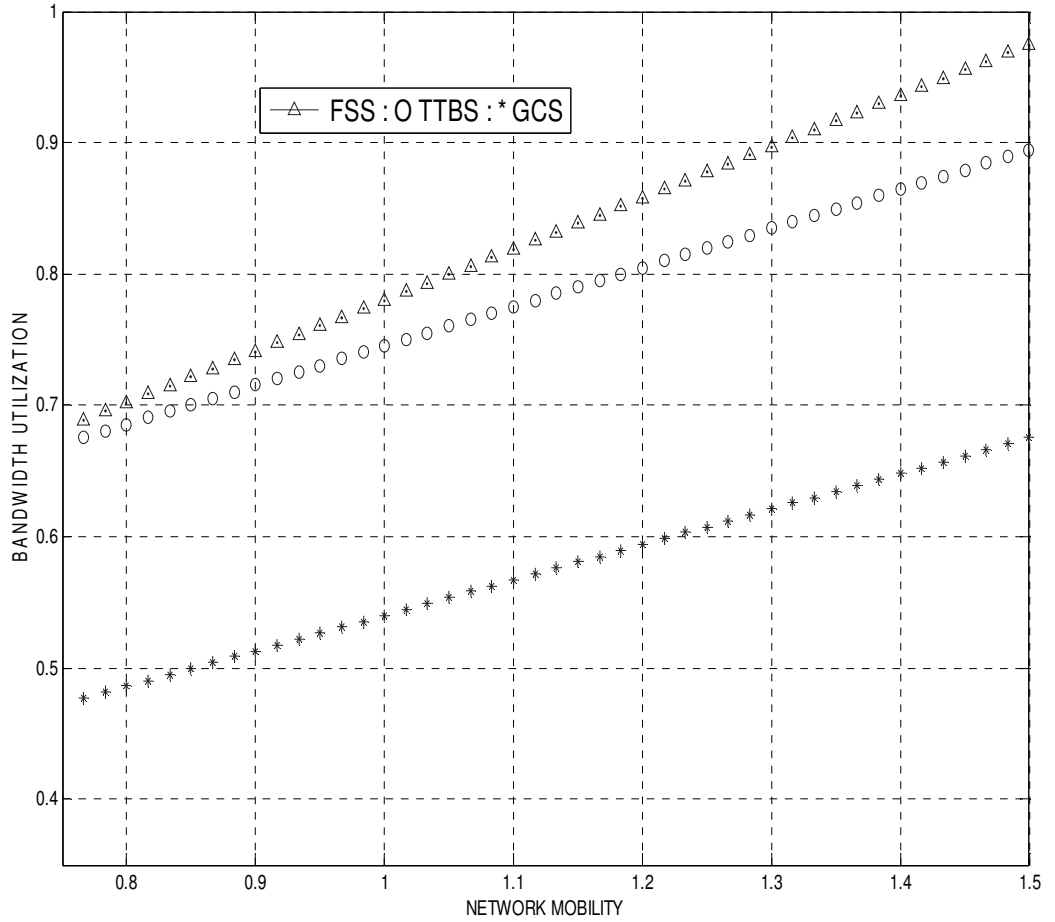
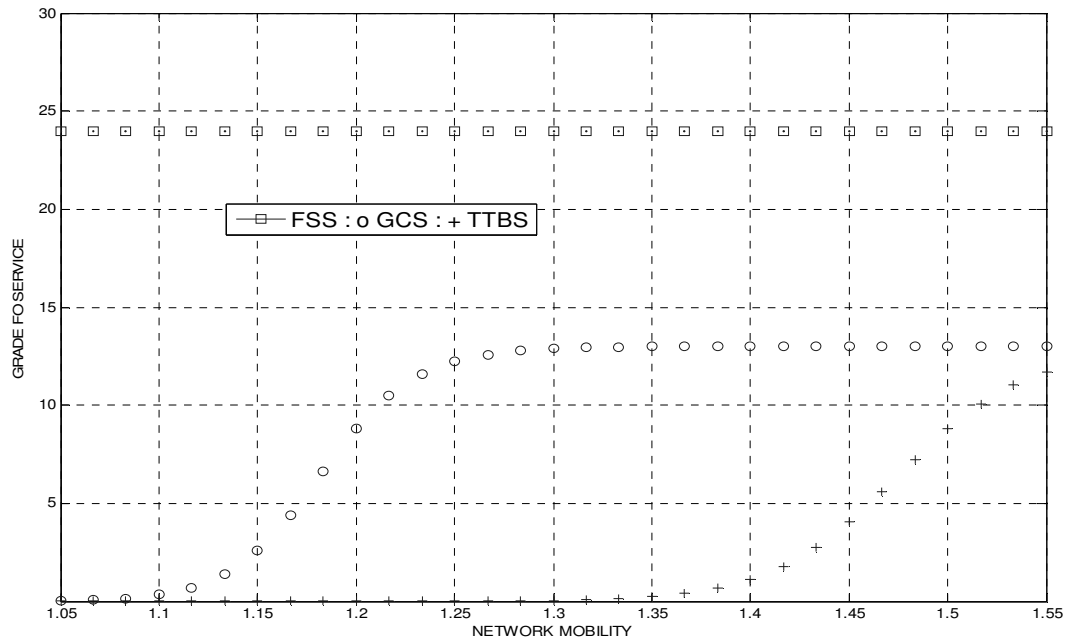


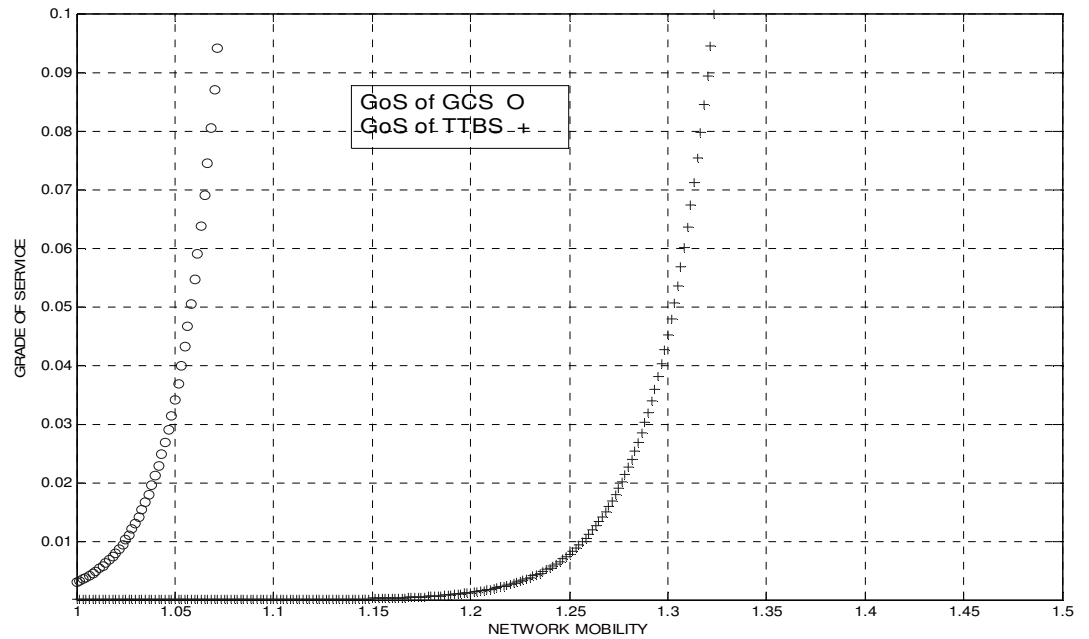
Fig.5.10. Utilization versus mobility of the three schemes.

Fig.5.11 (a) GoS versus mobility for three schemes and (b) for two schemes GCS and TTBS .

(a)



(b)



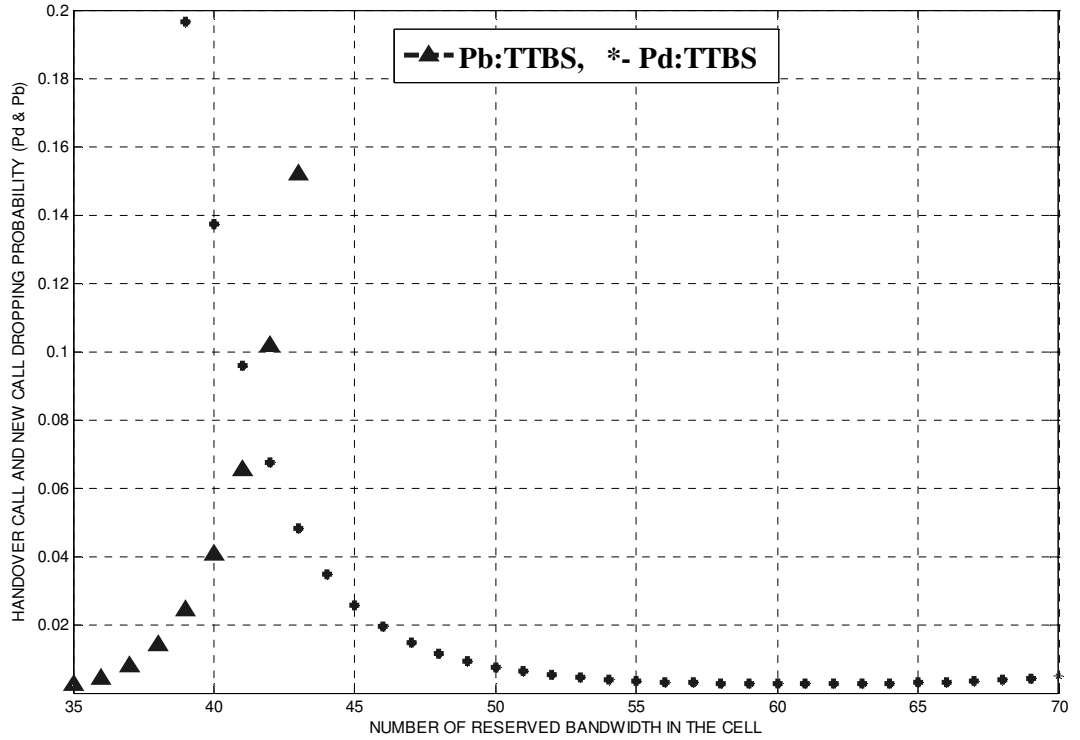


Fig. 5.12 Handover call dropping and new call blocking probability versus number of bandwidth reserved for handover calls or number of threshold bandwidth unit.

Figure 5.13 below shows that the general performance metric Y versus mobility functions for the FSS, GCS, and TTBS schemes (with $T_h = 120\text{sec}$). It is clear that the proposed TTBS scheme out performs the other schemes, since it has the highest Y for almost all mobility values. As expected the performance metric (Y) value of the fully shared scheme is almost constant with respect to mobility only varies from 0.075 to 0.09 as mobility runs from 1 to 1.5, because as discussed in the previous section, all channels are shared between new calls and handover calls. The Y value for the GCS decreases sharply with mobility, because of the increase in its GoS, and its low system utilization and after mobility = 1.2 Y for GCS become lower than Y for FSS scheme attain 0.05 as lower value. The slight decrease of the Y value of the Time Threshold based Scheme (TTBS) at high mobility is due to the increase in the percentage of the non-prioritized handover calls which may cause a marginal deterioration in the GoS of the TTBS scheme. The performance metric for the

TTBS scheme is highest among the other three schemes over all mobility values considered in the simulation, which is mainly due to its lower system grade of service cost function as discussed above.

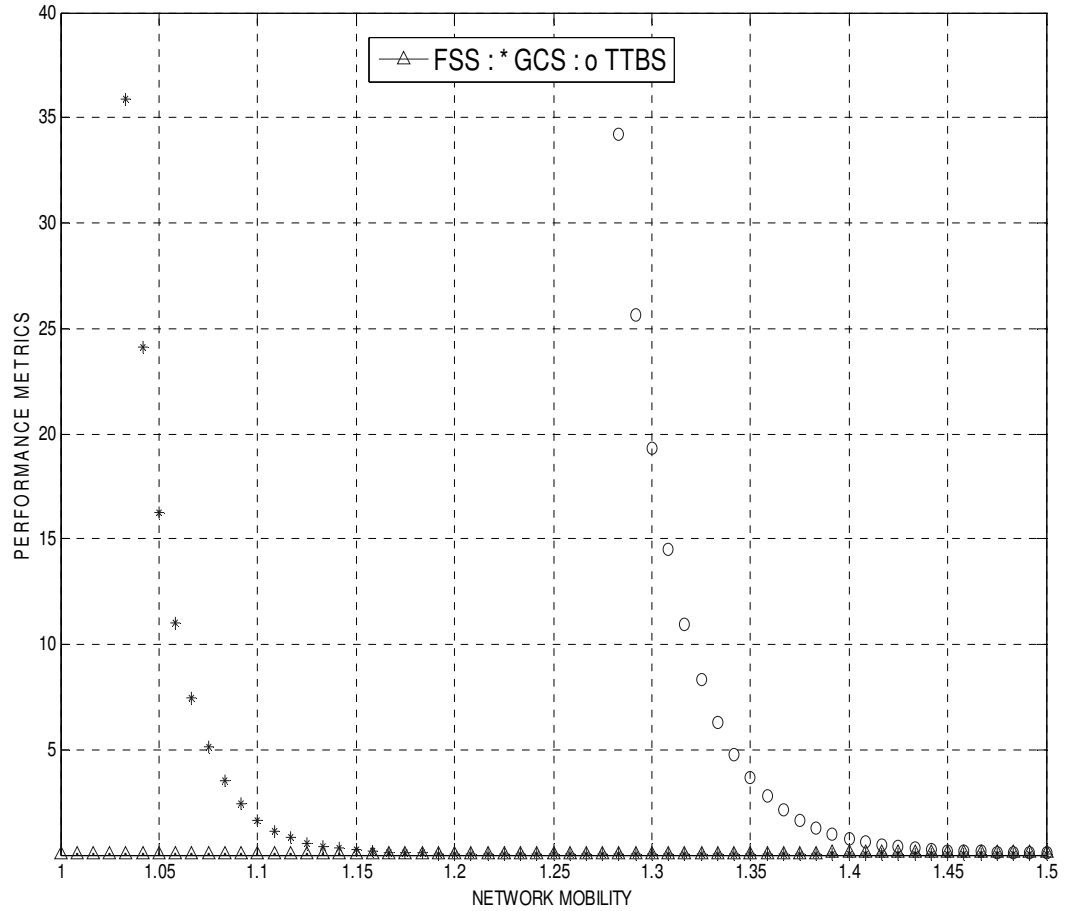


Fig.5.13 Performance metric, Y versus Mobility for TTBS and GCS schemes

Figure 5.14 below shows the relation between the cellular network channel utilization and the quality of service the network provides to the customers of the network. The simulation result obtained for the handover call dropping probability, which is the measure of quality of service versus the system utilization, is shown in figure 5.13 below. The proposed scheme (TTBS) shows much better performance in cellular network bandwidth utilization providing reasonable QoS (or lower ongoing call termination probability). The handover dropping probability for the TTBS scheme is very small until the system utilization

approaches to 85%, where as the handover call dropping probability for the GCS start rapid increment early at 65% system utilization. Thus the TTBS scheme is superior over the GCS scheme in system utilization keeping higher quality of service, which makes the scheme provide best application in mobile cellular communication. For example, to provide the same quality of service with handover calls dropping probability, $P_d = 0.02$, the system utilization for GCS is approximately 67% while for the TTBS scheme it is about 87% as one can see from the figure. This make our scheme is superior over the traditional GCS scheme in system utilization.

The Last simulation result, figure 5.15 shows that the variations of the new-call blocking probability and handover call dropping probability as a function of mobility for GCS scheme and at fixed time threshold $T_r = 145$ sec (or $T_h=120$ sec) for the TTBS scheme. It is clearly seen that the TTBS scheme shows a good performance than that of GCS Scheme, at the same mobility TTBS provide low new call blocking and handover call dropping probabilities (TTBS scheme results high utilization and best QoS). For all elapsed time threshold values T_r , the proposed TTBS scheme shows better performance than GCS scheme in terms of both handover call dropping probability and new call dropping probability. This is due to the consideration of the handover calls that elapsed more than time threshold, T_h as non-prioritized handover and considered as new call class to the cell. The plot can be explained at 2% GoS i.e. $P_b = 0.02$ at normalized load $L= 1.01$ and 1.24 for GCS and TTBS respectively. Also $P_d = 0.02$ at $L = 1.09$ and 1.35 for GCS and TTBS respectively as observed from figure 5.15 below.

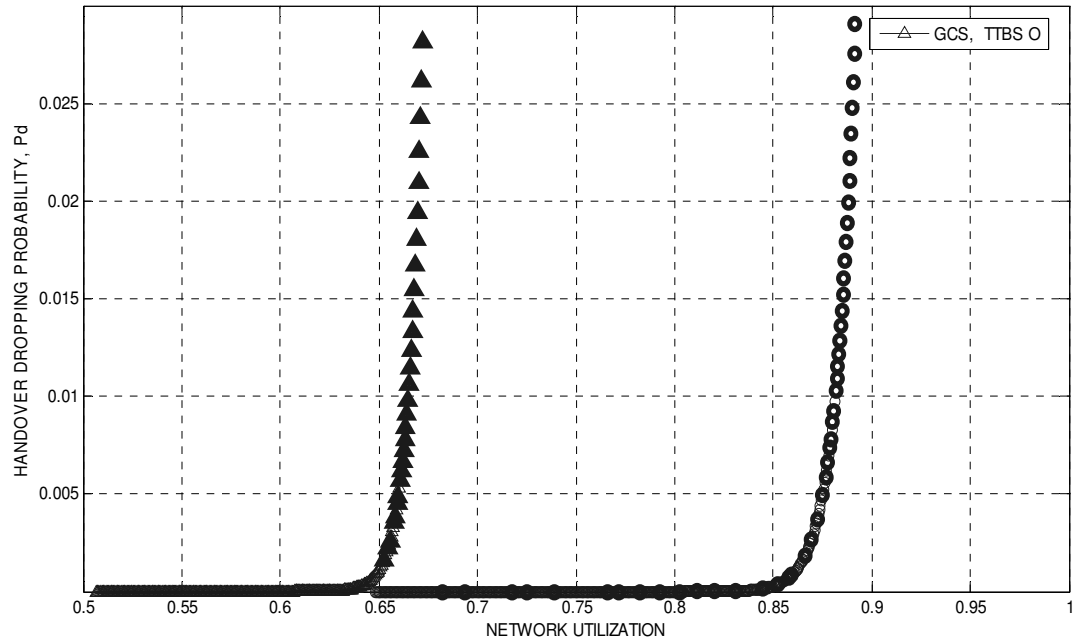


Fig. 5.13 Handover dropping probability versus Utilization for GCS and TTBS scheme

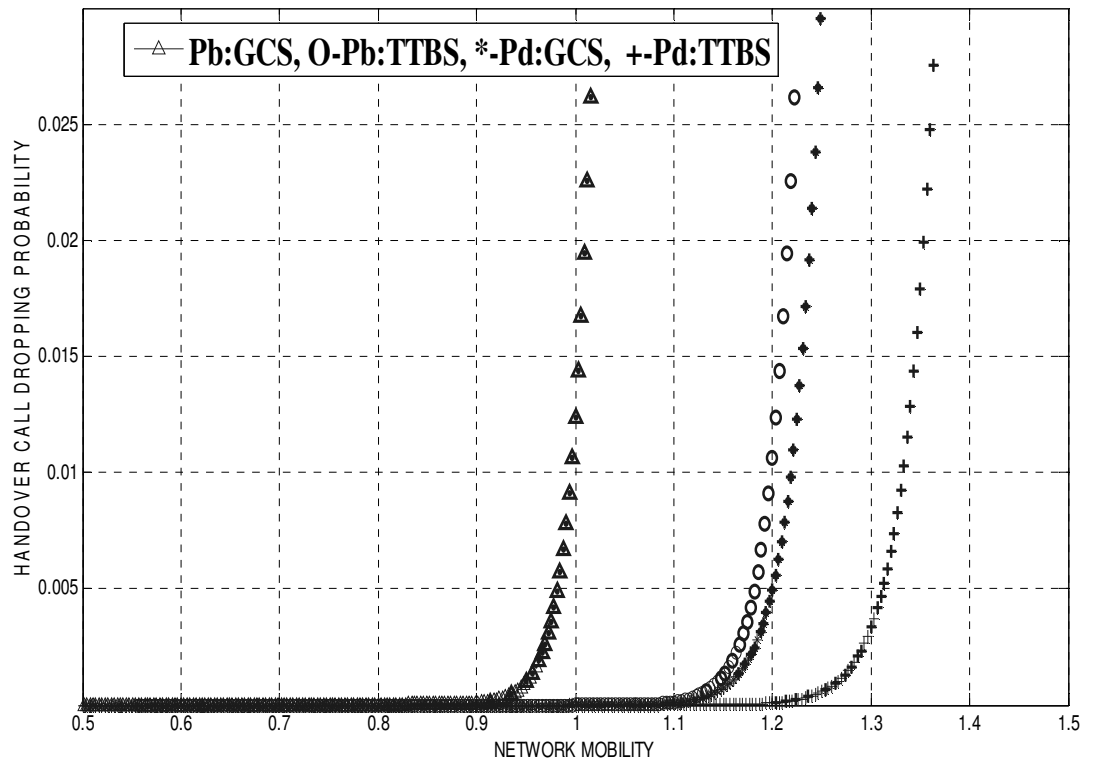


Fig.5.14. Pd & Pb versus mobility for two (GCS and TTBS) schemes

CHAPTER 6 CONCLUSION AND FUTURE WORKS

6.1 CONCLUSION

In this work, a new bandwidth allocation scheme is proposed. The scheme is based on monitoring the elapsed time of voice (real time) handover calls and according to time threshold parameter T_h and bandwidth threshold B_t . The handover calls can be either prioritized or treated as new calls. Resource flexibility is one of the most important requirements in the next generation mobile communications. Techniques for increasing flexibility of the network to deal with new services and traffic characteristics are the requirements and implementation challenges. The approach adopted has been to use time threshold scheme to provide more autonomy and flexibility to the system in order to improve the means of utilizing scarce radio spectrum and provide the best QoS for the network users.

The simulation results show that the new call blocking probability, P_b and the handover call dropping probability, P_d variation with threshold time, T_h . The handover calls having elapsed time greater than T_h become non-prioritized and considered as new calls. Our system model employes, two-dimensional Markov chain model. The results obtained from the analysis in this thesis are valuable for mobile cellular network planning and dimensioning. The proposed TTBS scheme can be used as network service improvement. Thus, a mobile cellular network operator can use TTBS scheme to provide better service for the network users.

In addition to this, the scheme results show as threshold bandwidth, B_t , increases or (the reserved bandwidth decreases) the handover dropping probability, P_d decreases due to reduction in priority and the new call blocking probability decrease as a result of sufficient bandwidth allocation with out priority. The TTBS works well in fixed channel reservation scheme to provide high system utilization and best quality of service, which satisfy both

mobile users and the service provider. Our scheme is not optimal in the sense that there might be better scheme resulting in a lower new call blocking probability while keeping the handover dropping probability below the target value. However, this scheme is neither highly complex nor based on any impractical assumptions and hence, it is readily implementable.

6.2 Future Work

There are several issues that will be addressed as a future work related to this research areas. This can be extended to the data communication and multimedia mobile cellular communication systems. A very interesting future work, which can be addressed is to implement this concept in multimedia wireless communication in order to provide service balance for the network user and service provider. In addition to this, one can evaluate the effectiveness of this concept for different mobile cellular standard QoS requested by customers and system utilization under heterogeneous network traffic condition and using several cells instead of using single cell for the study.

Appendix A

% Pseudocode for TTBS scheme;

```

IF new call THEN
If the amount of occupied BW  $\geq$  Bt
THEN Call blocking
ELSE
  Call acceptance and BW collocation
ELSE
  If elapsed real time of handover call  $>$  Tr
THEN
  Call dropping
ELSE
  Call acceptance & BW avocation
  If price of Handover call  $>$  price of new call
  THEN
  If the amount of occupied BW=B
  THEN Call dropping
  ELSE call acceptance & BW allocation.

```

% Pseudo code for Guard channel scheme

```

If new call THEN /*NEW call*/
If occupied BW  $\geq$  Bt
THEN Call blocking
ELSE
  Call acceptance & BW allocation
ELSE /*Handover call*/
  If occupied BW=B
  THEN Call dropping
  ELSE Call acceptance & Bandwidth allocation

```

% Pseudo code for FSS (fully shared scheme)

If New call THEN /*Originating call*/

If occupied BW=B

THEN

Call blocking

ELSE

Call acceptance and BW allocation

ELSE /*Handover calls*/

 If occupied BW=B

 THEN Call dropping

 ELSE Call acceptance and Bandwidth allocation

Annex 1

TCH Request of Addis Ababa Sites on MAY 26, from 10AM-11AM 26, from 9 to 10 PM and May 30.

BSC	SITE NAME	BTS NAME	2G Network	2G Network	tch_ho_s eiz	tch_norm seiz	tch_r eque st	tch_ho_ seiz +tch_ no_ seiz	Dro ppe d &bl ock ed call
BSC1	SARBET	AA122D2	LAC-10010 / CI-11222	LAC-10010 / CI-11222	2882	3027	6793	590 9	884
BSC1	TESHALE	AA128D3	LAC-10010 / CI-11283	LAC-10010 / CI-11283	2327	2670	5309	499 7	312
BSC1	GOTERA	AA015D1	LAC-10010 / CI-10151	LAC-10010 / CI-10151	2522	2478	5215	500 0	215
BSC1	URAEI	AA147D2	LAC-10010 / CI-11472	LAC-10010 / CI-11472	141	180	331	321	10
BSC1	BOLE	AA003D3	LAC-10010 / CI-10033	LAC-10010 / CI-10033	2355	2047	4506	440 2	104
BSC1	KIRKOS	AA001D2	LAC-10010 / CI-10012	LAC-10010 / CI-10012	2841	2540	5508	538 1	127

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

BSC1	KAZANCHI S	AA127D3	LAC-10010 / CI-11273	LAC-10010 / CI-11273	1796	2417	4310	421 3	97
BSC1	GOFA	AA008D1	LAC-10010 / CI-10081	LAC-10010 / CI-10081	3094	2663	5856	575 7	99
BSC1	FILWHA	AA072D3	LAC-10010 / CI-10723	LAC-10010 / CI-10723	4261	3468	7780	772 9	51
BSC1	BOLE	AA003D2	LAC-10010 / CI-10032	LAC-10010 / CI-10032	1347	1741	3104	308 8	16
BSC1	GOTERA	AA015D3	LAC-10010 / CI-10153	LAC-10010 / CI-10153	3827	2371	6213	619 8	15
BSC1	ABRICO	AA239D3	LAC-10010 / CI-12393	LAC-10010 / CI-12393	2059	1870	3936	392 9	7
BSC1	MINISTRY OF WATERW ORK	AA042D3	LAC-10010 / CI-10423	LAC-10010 / CI-10423	2739	1765	4511	450 4	7
BSC1	GOTERA	AA015D2	LAC-10010 / CI-10152	LAC-10010 / CI-10152	3056	3024	6087	608 0	7
BSC1	AIRPORT	AA102D1	LAC-10010 / CI-11021	LAC-10010 / CI-11021	2326	2438	4768	476 4	4
BSC1	KIRKOS	AA001D1	LAC-10010 / CI-10011	LAC-10010 / CI-10011	1351	1897	3250	324 8	2
BSC1	URAEI	AA147D1	LAC-10010 / CI-11471	LAC-10010 / CI-11471	2046	2525	4572	457 1	1
BSC1	KIRKOS	AA001D3	LAC-10010 / CI-10013	LAC-10010 / CI-10013	1629	962	2591	259 1	0
BSC1	BOLE	AA003D1	LAC-10010 / CI-10031	LAC-10010 / CI-10031	1199	677	1876	187 6	0
BSC1	GOFA	AA008D2	LAC-10010 / CI-10082	LAC-10010 / CI-10082	1981	1298	3279	327 9	0
BSC1	GOFA	AA008D3	LAC-10010 / CI-10083	LAC-10010 / CI-10083	1704	1094	2798	279 8	0
BSC1	ETC TRAINING	AA010D1	LAC-10010 / CI-10101	LAC-10010 / CI-10101	1642	989	2631	263 1	0
BSC1	ETC TRAINING	AA010D2	LAC-10010 / CI-10102	LAC-10010 / CI-10102	1378	1749	3127	312 7	0
BSC1	ETC TRAINING	AA010D3	LAC-10010 / CI-10103	LAC-10010 / CI-10103	1081	1131	2212	221 2	0
BSC1	BOLE MICHAEL	AA018D1	LAC-10010 / CI-10181	LAC-10010 / CI-10181	548	387	935	935	0
BSC1	BOLE MICHAEL	AA018D2	LAC-10010 / CI-10182	LAC-10010 / CI-10182	836	694	1530	153 0	0
BSC1	BOLE MICHAEL	AA018D3	LAC-10010 / CI-10183	LAC-10010 / CI-10183	591	957	1548	154 8	0
BSC1	MINISTRY OF WATERW ORK	AA042D1	LAC-10010 / CI-10421	LAC-10010 / CI-10421	435	448	883	883	0
BSC1	MINISTRY OF WATERW ORK	AA042D2	LAC-10010 / CI-10422	LAC-10010 / CI-10422	2123	1294	3417	341 7	0
BSC1	FILWHA	AA072D1	LAC-10010 / CI-10721	LAC-10010 / CI-10721	3857	2630	6487	648 7	0

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

BSC1	FILWHA	AA072D2	LAC-10010 / CI-10722	LAC-10010 / CI-10722	3118	2868	5986	5986	0
BSC1	MESKEL	AA075D1	LAC-10010 / CI-10751	LAC-10010 / CI-10751	359	478	837	837	0
BSC1	MESKEL	AA075D2	LAC-10010 / CI-10752	LAC-10010 / CI-10752	900	1257	2157	2157	0
BSC1	MESKEL	AA075D3	LAC-10010 / CI-10753	LAC-10010 / CI-10753	237	317	554	554	0
BSC1	BOLE COMMUNITY SCHOOL	AA098D1	LAC-10010 / CI-10981	LAC-10010 / CI-10981	1738	1405	3143	3143	0
BSC1	BOLE COMMUNITY SCHOOL	AA098D2	LAC-10010 / CI-10982	LAC-10010 / CI-10982	317	991	1308	1308	0
BSC1	BOLE COMMUNITY SCHOOL	AA098D3	LAC-10010 / CI-10983	LAC-10010 / CI-10983	2262	1543	3805	3805	0
BSC1	AIRPORT	AA102D2	LAC-10010 / CI-11022	LAC-10010 / CI-11022	158	144	302	302	0
BSC1	AIRPORT	AA102D3	LAC-10010 / CI-11023	LAC-10010 / CI-11023	348	682	1030	1030	0
BSC1	ST GABRAI GIBI	AA106D1	LAC-10010 / CI-11061	LAC-10010 / CI-11061	879	987	1866	1866	0
BSC1	ST GABRAI GIBI	AA106D2	LAC-10010 / CI-11062	LAC-10010 / CI-11062	852	654	1506	1506	0
BSC1	ST GABRAI GIBI	AA106D3	LAC-10010 / CI-11063	LAC-10010 / CI-11063	521	320	841	841	0
BSC1	BALDERAS	AA121D1	LAC-10010 / CI-11211	LAC-10010 / CI-11211	764	418	1182	1182	0
BSC1	BALDERAS	AA121D2	LAC-10010 / CI-11212	LAC-10010 / CI-11212	575	578	1153	1153	0
BSC1	BALDERAS	AA121D3	LAC-10010 / CI-11213	LAC-10010 / CI-11213	695	473	1168	1168	0
BSC1	SARBET	AA122D1	LAC-10010 / CI-11221	LAC-10010 / CI-11221	1323	598	1921	1921	0
BSC1	SARBET	AA122D3	LAC-10010 / CI-11223	LAC-10010 / CI-11223	1286	997	2283	2283	0
BSC1	RICHE	AA124D1	LAC-10010 / CI-11241	LAC-10010 / CI-11241	332	238	570	570	0
BSC1	RICHE	AA124D2	LAC-10010 / CI-11242	LAC-10010 / CI-11242	426	343	769	769	0
BSC1	RICHE	AA124D3	LAC-10010 / CI-11243	LAC-10010 / CI-11243	1151	1146	2297	2297	0
BSC1	OLIMPIA	AA126D1	LAC-10010 / CI-11261	LAC-10010 / CI-11261	1185	866	2051	2051	0
BSC1	OLIMPIA	AA126D2	LAC-10010 / CI-11262	LAC-10010 / CI-11262	1632	1525	3157	3157	0
BSC1	OLIMPIA	AA126D3	LAC-10010	LAC-10010 /	186	478	664	664	0

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

			/ CI-11263	CI-11263						
BSC1	KAZANCHI S	AA127D1	LAC-10010 / CI-11271	LAC-10010 / CI-11271	781	553	1334	133 4	0	
BSC1	KAZANCHI S	AA127D2	LAC-10010 / CI-11272	LAC-10010 / CI-11272	1692	1068	2760	276 0	0	
BSC1	TESHALE	AA128D1	LAC-10010 / CI-11281	LAC-10010 / CI-11281	1145	1352	2497	249 7	0	
BSC1	TESHALE	AA128D2	LAC-10010 / CI-11282	LAC-10010 / CI-11282	1022	1095	2117	211 7	0	
BSC1	CELLCOS T	AA132D1	LAC-10010 / CI-11321	LAC-10010 / CI-11321	493	401	894	894	0	
BSC1	CELLCOS T	AA132D2	LAC-10010 / CI-11322	LAC-10010 / CI-11322	579	622	1201	120 1	0	
BSC1	CELLCOS T	AA132D3	LAC-10010 / CI-11323	LAC-10010 / CI-11323	793	757	1550	155 0	0	
BSC1	URAEAL	AA147D3	LAC-10010 / CI-11473	LAC-10010 / CI-11473	1528	1567	3095	309 5	0	
BSC1	BEL AIR HOTEL	AA154D1	LAC-10010 / CI-11541	LAC-10010 / CI-11541	734	1119	1853	185 3	0	
BSC1	BEL AIR HOTEL	AA154D2	LAC-10010 / CI-11542	LAC-10010 / CI-11542	823	888	1711	171 1	0	
BSC1	BEL AIR HOTEL	AA154D3	LAC-10010 / CI-11543	LAC-10010 / CI-11543	716	879	1595	159 5	0	
BSC1	DEMBEL	AA157D1	LAC-10010 / CI-11571	LAC-10010 / CI-11571	1418	2025	3443	344 3	0	
BSC1	DEMBEL	AA157D2	LAC-10010 / CI-11572	LAC-10010 / CI-11572	747	910	1657	165 7	0	
BSC1	DEMBEL	AA157D3	LAC-10010 / CI-11573	LAC-10010 / CI-11573	1240	1332	2572	257 2	0	
BSC1	BOLE MICHAEL2	AA159D1	LAC-10010 / CI-11591	LAC-10010 / CI-11591	82	143	225	225	0	
BSC1	BOLE MICHAEL2	AA159D2	LAC-10010 / CI-11592	LAC-10010 / CI-11592	1460	1300	2760	276 0	0	
BSC1	BOLE MICHAEL2	AA159D3	LAC-10010 / CI-11593	LAC-10010 / CI-11593	305	640	945	945	0	
BSC1	KERA	AA186D1	LAC-10010 / CI-11861	LAC-10010 / CI-11861	1833	2912	4745	474 5	0	
BSC1	KERA	AA186D2	LAC-10010 / CI-11862	LAC-10010 / CI-11862	594	514	1108	110 8	0	
BSC1	KERA	AA186D3	LAC-10010 / CI-11863	LAC-10010 / CI-11863	2858	1331	4189	418 9	0	
BSC1	KIRKOS 2	AA195D1	LAC-10010 / CI-11951	LAC-10010 / CI-11951	1794	1835	3629	362 9	0	
BSC1	KIRKOS 2	AA195D2	LAC-10010 / CI-11952	LAC-10010 / CI-11952	2000	1334	3334	333 4	0	
BSC1	KIRKOS 2	AA195D3	LAC-10010 / CI-11953	LAC-10010 / CI-11953	2479	1297	3776	377 6	0	
BSC1	RAILWAY STATION	AA196D1	LAC-10010 / CI-11961	LAC-10010 / CI-11961	1238	2672	3910	391 0	0	
BSC1	RAILWAY STATION	AA196D2	LAC-10010 / CI-11962	LAC-10010 / CI-11962	889	1195	2084	208 4	0	
BSC1	RAILWAY STATION	AA196D3	LAC-10010 / CI-11963	LAC-10010 / CI-11963	335	532	867	867	0	
BSC1	RAS BIRU	AA207D1	LAC-10010	LAC-10010 /	1017	671	1688	168	0	

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

			/ CI-12071	CI-12071					8	
BSC1	RAS BIRU	AA207D2	LAC-10010 / CI-12072	LAC-10010 / CI-12072	644	707	1351	135	1	0
BSC1	RAS BIRU	AA207D3	LAC-10010 / CI-12073	LAC-10010 / CI-12073	479	899	1378	137	8	0
BSC1	MINISTRY OF FOREIGN AFFAIRS	AA208D1	LAC-10010 / CI-12081	LAC-10010 / CI-12081	397	400	797	797		0
BSC1	MINISTRY OF FOREIGN AFFAIRS	AA208D2	LAC-10010 / CI-12082	LAC-10010 / CI-12082	1470	1119	2589	258	9	0
BSC1	MINISTRY OF FOREIGN AFFAIRS	AA208D3	LAC-10010 / CI-12083	LAC-10010 / CI-12083	2380	1091	3471	347	1	0
BSC1	ABRICO	AA239D1	LAC-10010 / CI-12391	LAC-10010 / CI-12391	1321	623	1944	194	4	0
BSC1	ABRICO	AA239D2	LAC-10010 / CI-12392	LAC-10010 / CI-12392	1688	1399	3087	308	7	0
BSC2	AMANUEL	AA093D1	LAC-10011 / CI-10931	LAC-10011 / CI-10931	6015	3503	1366	951	8	414
BSC2	KETEMA	AA073D1	LAC-10011 / CI-10731	LAC-10011 / CI-10731	4914	2885	1002	779	9	222
BSC2	KETEMA	AA073D3	LAC-10011 / CI-10733	LAC-10011 / CI-10733	4217	2430	7899	664	7	125
BSC2	AMANUEL	AA093D2	LAC-10011 / CI-10932	LAC-10011 / CI-10932	3146	3679	7849	682	5	102
BSC2	EXCHANGE	AA062D2	LAC-10011 / CI-10622	LAC-10011 / CI-10622	7139	3546	1122	106	85	543
BSC2	MERCATO	AA113D1	LAC-10011 / CI-11131	LAC-10011 / CI-11131	4870	7120	1249	119	90	500
BSC2	KALIFA	AA130D1	LAC-10011 / CI-11301	LAC-10011 / CI-11301	3209	2245	5615	545	4	161
BSC2	COMMERCE	AA083D2	LAC-10011 / CI-10832	LAC-10011 / CI-10832	3389	3355	6800	674	4	56
BSC2	MERCATO	AA113D3	LAC-10011 / CI-11133	LAC-10011 / CI-11133	3832	5492	9399	932	4	75
BSC2	KETEMA	AA073D2	LAC-10011 / CI-10732	LAC-10011 / CI-10732	7681	4145	1191	118	26	89
BSC2	CHIDTERRA	AA120D3	LAC-10011 / CI-11203	LAC-10011 / CI-11203	2864	4342	7252	720	6	46
BSC2	CHEF AMEDA	AA136D3	LAC-10011 / CI-11363	LAC-10011 / CI-11363	2287	2127	4424	441	4	10
BSC2	MERCATO	AA113D2	LAC-10011 / CI-11132	LAC-10011 / CI-11132	2428	4707	7147	713	5	12
BSC2	ETC HQ	AA115D1	LAC-10011 / CI-11151	LAC-10011 / CI-11151	1542	1924	3467	346	6	1
BSC2	KALIFA	AA130D2	LAC-10011 / CI-11302	LAC-10011 / CI-11302	2545	1733	4279	427	8	1
BSC2	OAU	AA135D3	LAC-10011 / CI-11353	LAC-10011 / CI-11353	2840	2005	4846	484	5	1
BSC2	GARAD	AA112D2	LAC-10011	LAC-10011 /	2452	2880	5333	533		1

			/ CI-11122	CI-11122					2	
BSC2	OLD AIRPORT	AA002D1	LAC-10011 / CI-10021	LAC-10011 / CI-10021	529	160	689	689	0	
BSC2	OLD AIRPORT	AA002D2	LAC-10011 / CI-10022	LAC-10011 / CI-10022	1648	1727	3375	337	5	0
BSC2	OLD AIRPORT	AA002D3	LAC-10011 / CI-10023	LAC-10011 / CI-10023	1075	496	1571	157	1	0
BSC2	EXCHANG E	AA062D1	LAC-10011 / CI-10621	LAC-10011 / CI-10621	1607	1384	2991	299	1	0
BSC2	EXCHANG E	AA062D3	LAC-10011 / CI-10623	LAC-10011 / CI-10623	1704	1979	3683	368	3	0
BSC2	TEMAMA	AA082D1	LAC-10011 / CI-10821	LAC-10011 / CI-10821	1831	2025	3856	385	6	0
BSC2	TEMAMA	AA082D2	LAC-10011 / CI-10822	LAC-10011 / CI-10822	5123	3163	8286	828	6	0
BSC2	TEMAMA	AA082D3	LAC-10011 / CI-10823	LAC-10011 / CI-10823	734	871	1605	160	5	0
BSC2	COMMER CE	AA083D1	LAC-10011 / CI-10831	LAC-10011 / CI-10831	1302	3175	4477	447	7	0
BSC2	COMMER CE	AA083D3	LAC-10011 / CI-10833	LAC-10011 / CI-10833	2871	2324	5195	519	5	0
BSC2	MEKONIN OCH KIBUB	AA086D1	LAC-10011 / CI-10861	LAC-10011 / CI-10861	494	466	960	960	0	
BSC2	MEKONIN OCH KIBUB	AA086D2	LAC-10011 / CI-10862	LAC-10011 / CI-10862	1319	775	2094	209	4	0
BSC2	MEKONIN OCH KIBUB	AA086D3	LAC-10011 / CI-10863	LAC-10011 / CI-10863	504	934	1438	143	8	0
BSC2	JIMABER WORLD BANK	AA088D1	LAC-10011 / CI-10881	LAC-10011 / CI-10881	878	714	1592	159	2	0

Annex 2 incoming handover report

SCELL-INTCELL	HVERCNT	HVERSUC	KPIHOI	HOIToch
KBN1_EA-FRENE1B	59	35	59.3	24
KELIF1A-ARADA	21	21	100	0
ERIBE1B-ERIBE1C	31	31	100	0
ARADA-KELIF1A	41	41	100	0
KELIF1A-ARADB	1	1	100	0
RMEKO1A-ADMIN1C	22	22	100	0
ARADB-KELIF1A	0	0	0	
ARADB-ARADA	611	602	98.5	8
ARADA-ARADC	67	67	100	0
ARADC-ARADA	44	44	100	0
JAMA1A-ADMIN1A	72	72	100	0
JAMA1A-GOJAB1A	0	0	0	
ARADA-ARADB	153	137	89.5	16

KELIF1A-ARADC	59	58	98.3	1
ARADB-ARADC	76	62	81.6	14
ARADC-KELIF1A	162	162	100	0
GOJAB1B-MERCATA	297	296	99.7	1
KELIF1A-KELIF1B	38	37	97.4	1
KELIF1B-KELIF1A	12	12	100	0
KELIF1A-KELIF1C	6	5	83.3	1
KELIF1A-ENTOT1B	1	1	100	0
ARADC-ARADB	34	34	100	0
KELIF1C-KELIF1A	1	1	100	0
KELIF1A-KETE1A	105	105	100	0
ARADC-ATLIKTA	183	180	98.4	2
ATLIKTA-ARADC	195	194	99.5	1
KETE1A-KELIF1A	111	106	95.5	5
KELIF1A-KETE1B	157	123	78.3	33
KETE1B-KELIF1A	38	38	100	0
KELIF1A-GARAD1A	11	11	100	0
GARAD1A-KELIF1A	25	25	100	0
SHEGO1B-ADGB11A	19	18	94.7	1
ENTOT1A-KELIF1A	3	3	100	0
MENENSA-ARAT1C	4	3	75	1
ADMIN1B-KELIF1B	6	5	83.3	1
GARAD1A-GARAD1B	5	4	80	1
KELIF1A-GOJAB1A	35	34	97.1	1
MERCATA-KETE1B	65	55	84.6	10
KETE1B-MERCATA	58	58	100	0
GOJAB1A-KELIF1A	53	53	100	0
MERCATA-MERCATB	0	0	0	
KELIF1A-GOJAB1B	15	14	93.3	1
KETE1B-NMRK_EA	57	57	100	0
ARADC-GOJAB1B	36	35	97.2	1
ATLIKTC-ATLIKTA	17	14	82.4	3
ATLIKTA-ATLIKTC	14	14	100	0
GOJAB1B-KELIF1A	23	23	100	0
KELIF1A-GARAD1C	10	10	100	0
GOJAB1A-KETE1A	5	5	100	0
ATLIKTC-NMRK_EA	175	174	99.4	0
ENTOT1A-SIDI1A	0	0	0	
GARAD1C-KELIF1A	19	18	94.7	1
NMRK_EA-KETE1B	50	39	78	9
SABAR1A-GARAD1C	22	22	100	0
SABAR1A-GOJAB1B	54	52	96.3	2
SABAR1A-KELIF1A	104	101	97.1	3
NMRK_EB-GARAD1C	159	159	100	0
ADGB11A-SHEGO1A	39	36	92.3	3
JAMA1B-GOJAB1A	5	5	100	0
GOJAB1A-JAMA1A	0	0	0	
KELIF1B-KELIF1C	4	4	100	0

KELIF1C-KELIF1B	0	0	0	
FRENE2C-SIDI1A	39	39	100	0
SHIRM1B-SHIRM1A	69	69	100	0
GARAD1C-NMRK_EB	110	110	100	1
KELIF1B-ARADA	34	31	91.2	2
ARADA-KELIF1B	51	40	78.4	11
KELIF1B-ARADB	165	161	97.6	2
SIDI1A-FRENE2C	43	42	97.7	1
ARADB-KELIF1B	110	96	87.3	13
KELIF1B-ARADC	52	51	98.1	1
ARADC-KELIF1B	18	18	100	0
ARADA-ATLIKTB	4	3	75	1
GARAD1A-ATLIKTC	93	93	100	0
ATLIKTC-GARAD1A	110	109	99.1	1
ATLIKTB-ARADA	5	5	100	0
GOJAB1B-NMRK_EB	50	49	98	1
NMRK_EB-GOJAB1B	69	66	95.7	3
KBN1_EA-FRENE1A	79	70	88.6	9
KELIF1B-KETE1B	1	1	100	0
ARAT1C-RMEKO1C	29	27	93.1	2
ATLIKTA-ATLIKTB	59	57	96.6	1
ATLIKTB-ATLIKTA	81	75	92.6	6
KETE1B-KELIF1B	8	8	100	0
RMEKO1C-ARAT1C	8	8	100	0
KELIF1B-GARAD1A	16	15	93.8	1
GARAD1A-KELIF1B	10	10	100	0
FRENE1A-KBN1_EA	135	134	99.3	1
KELIF1B-GOJAB1A	0	0	0	
GOJAB1A-KELIF1B	0	0	0	
ARAT1C-RMEKO1A	26	26	100	0
KECHE1B-MENENSB	48	48	100	0
KELIF1B-GOJAB1B	2	2	100	0
GOJAB1B-KELIF1B	4	4	100	0
NMRK_EB-NMRK_EA	236	233	98.7	2
NMRK_EA-NMRK_EC	4	2	50	2
SHEGO1A-ADGB11A	60	59	98.3	1
KELIF1B-GARAD1B	3	3	100	0
GARAD1B-KELIF1B	1	1	100	0
GARAD1C-SABAR1A	39	36	92.3	3
RMEKO1A-ARAT1C	4	4	100	0
GOJAB1B-SABAR1A	68	67	98.5	1
ATLIKTA-GARAD1A	9	9	100	0
KECHE1A-MENENSA	0	0	0	
KELIF1A-SABAR1A	96	96	100	0
ADGB11A-SHIRM1C	3	1	33.3	2
GARAD1C-NMRK_EA	986	986	100	0
KETE1C-KETE1A	174	170	97.7	4
KECHE1B-SIDI1C	5	5	100	0

ARAT1C-ERIBE1A	7	5	71.4	1
ERIBE1A-ARAT1C	8	8	100	0
ADMIN1C-KELIF1A	736	726	98.6	7
ADMIN1A-KELIF1A	249	239	96	7
KELIF1A-ADMIN1C	225	216	96	9
KELIF1C-ARADB	56	50	89.3	5
ARADB-KELIF1C	40	39	97.5	1
KELIF1C-ARADC	115	113	98.3	2
ARADC-KELIF1C	144	141	97.9	2
ADGB11A-KETE1A	12	12	100	0
KELIF1C-KETE1A	0	0	0	
KETE1A-KELIF1C	0	0	0	
KELIF1C-KETE1B	18	15	83.3	3
KETE1B-KELIF1C	9	9	100	0

Annex 3 Going out handover report

SCELL- EXTCELL	HOCNT	HOSUC	KPIHOE	HOTTOCH
SABAR1C- AA137D1	52	51	98.1	0
NMRK_EA- AA165D2	0	0	0	
KELIF1A- AA137D1	114	113	99.1	0
KELIF1C- AA137D1	30	29	96.7	0
KETE1A- AA137D1	4	4	100	0
KETE1B- AA137D1	7	7	100	0
JAMA1B- AA137D1	10	9	90	0
GARAD1B- AA112D1	32	31	96.9	1
JAMA1C- AA137D1	0	0	0	
KELIF1A- AA137D2	4	4	100	0
KELIF1C- AA137D2	102	103	101	0

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

MERCATA- AA137D2	22	22	100	0
MERCATB- AA137D2	0	0	0	
GARAD1A- AA137D2	12	12	100	0
FRENE2A- AA129D2	2	2	100	0
KETE1B- AA137D2	144	143	99.3	0
MERCATC- AA113D3	540	522	96.7	14
KETE1A- AA073D2	4	4	100	0
GARAD1B- AA112D2	1054	1013	96.1	33
KETE1A- AA137D3	3	3	100	0
KETE1B- AA137D3	259	253	97.7	4
NMRK_EA- AA165D1	148	136	91.9	11
KETE1C- AA137D3	0	0	0	
MERCATA- AA137D3	0	0	0	
MERCATB- AA137D3	0	0	0	
MERCATC- AA137D3	14	14	100	0
ARADA- STGAB1C	0	0	0	
JAMA1B- AA137D3	10	10	100	0
JAMA1C- AA137D3	0	0	0	
KBN1_EB- BOL1_EA	2	2	100	0
NMRK_EA- AA137D2	131	131	100	0
NMRK_EC- AA113D2	140	140	100	0
NMRK_EC- AA113D1	0	0	0	
NMRK_EC- AA137D2	0	0	0	
NMRK_EC- CHF1_EA	16	16	100	0
NMRK_EC- AA137D3	0	0	0	
AMN1_EB- EMN1_EA	31	29	93.5	1
ARADC- EXCH1A	6	6	100	0

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

KETE1A-AA073D3	833	827	99.3	1
GARAD1B-AA112D3	88	85	96.6	1
ARAT1B-BLD1_EC	2	1	50	1
GARAD1C-AA112D1	119	115	96.6	0
KETE1B-KRA1_EB	0	0	0	
SHEGO1C-ASC1_EA	2	2	100	0
KETE1B-AA073D1	2974	2919	98.2	18
KETE1C-EMN1_EA	48	48	100	0
KETE1B-AA073D2	2073	2048	98.8	8
MERCATA-EXCH1A	7	6	85.7	1
KBN1_EB-YKA1_EB	7	7	100	0
ARADA-AA104D1	2778	2703	97.3	48
NMRK_EB-AA165D3	0	0	0	
GARAD1C-AA112D2	108	107	99.1	1
KBN1_EB-YKA1_EC	18	18	100	0
ERIBE1B-MSK2_EA	56	56	100	0
MDHN_EB-KOF1_EA	0	0	0	
KETE1C-AMAN_EA	59	59	100	0
MERCATC-AMAN_EA	0	0	0	
AMN1_EA-AMAN_EA	1	1	100	0
ATLIKTB-EXCH1A	45	44	97.8	1
GARAD1A-EXCH1A	11	11	100	0
AMN1_EB-AMAN_EA	24	24	100	0
ATLIKTB-ETCHQ2A	8	8	100	0
GARAD1C-AA112D3	1922	1889	98.3	12
AMN1_EC-AMAN_EA	0	0	0	
MDHN_EA-AA110D1	0	0	0	

NEW BANDWIDTH ALLOCATION SCHEME FOR HANDOVER VOICE CALLS IN MOBILE CELLULAR NETWORKS

MDHN_EA- AA110D2	0	0	0	
GOJAB1A- AA137D1	1733	1723	99.4	1
MDHN_EB- AA110D1	0	0	0	
MDHN_EB- AA110D2	0	0	0	
MDHN_EB- AA110D3	0	0	0	
GARAD1C- ETCHQ2A	0	0	0	
MDHN_EC- AA110D1	1	0	0	1
MDHN_EC- AA110D2	0	0	0	
MDHN_EC- AA110D3	0	0	0	
NMRK_EA- AA165D3	103	100	97.1	0
FRENE2A- AA129D1	33	31	93.9	2
ARADA- AA104D2	300	261	87	36
GOJAB1A- AA137D2	35	34	97.1	1
ERIBE1B- HLTN_EA	2	2	100	0
KETE1A- ASC1_EA	11	11	100	0
ERIBE1B- HLTN_EB	6	6	100	0
ARAT1B- HLTN_EB	0	0	0	
KBN1_EC- HLTN_EA	0	0	0	
ARAT1B- HLTN_EA	0	0	0	
KETE1B- AA073D3	19	19	100	0
GARAD1C- EXCH1C	19	18	94.7	1
ARADB- FILWHA	289	285	98.6	3
SHEGO1A- ASC1_EB	1	0	0	1
FRENE1A- STGAB1A	1	1	100	0

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I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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