Modelling and Analysis of Resource Management Schemes in Wireless Networks

Zaid Ahmed Said Zabanoot

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Analytical Models and Performance Evaluation of Handoff Schemes and Resource Re-Allocation in Homogeneous and Heterogeneous Wireless Cellular Networks

Zaid Ahmed Said Zabanoot

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Abstract

Over recent years, wireless communication systems have been experiencing a dramatic and continuous growth in the number of subscribers, thus placing extra demands on system capacity. At the same time, keeping Quality of Service (QoS) at an acceptable level is a critical concern and a challenge to the wireless network designer. In this sense, performance analysis must be the first step in designing or improving a network. Thus, powerful mathematical tools for analysing most of the performance metrics in the network are required. A good modelling and analysis of the wireless cellular networks will lead to a high level of QoS.

In this thesis, different analytical models of various handoff schemes and resource re-allocation in homogeneous and heterogeneous wireless cellular networks are developed and investigated. The sustained increase in users and the request for advanced services are some of the key motivations for considering the designing of Hierarchical Cellular Networks (HCN). In this type of system, calls can be blocked in a microcell flow over to an overlay macrocell. Microcells in the HCN can be replaced by WLANs as this can provide high bandwidth and its users have limited mobility features. Efficient sharing of resources between wireless cellular networks and WLANs will improve the capacity as well as QoS metrics.

This thesis first presents an analytical model for priority handoff mechanisms, where new calls and handoff calls are captured by two different traffic arrival processes, respectively. Using this analytical model, the optimised number of channels assigned to handover calls, with the aim of minimising the drop probability under given network scenarios, has been investigated. Also, an analytical model of a network containing two cells has been developed to measure the different performance parameters for each of the cells in the network, as well as altogether as one network system. Secondly, a new solution is proposed to manage the bandwidth and re-allocate it in a proper way to maintain the QoS for all types of calls. Thirdly, performance models for microcells and macrocells in hierarchical cellular networks have been developed by using a combination of different handoff schemes. Finally, the microcell in HCN is replaced by WLANs and a prioritised vertical handoff scheme in an integrated UMTS/WLAN network has been developed. Simulation experiments have been conducted to validate the accuracy of these analytical models. The models have then been used to investigate the performance of the networks under different scenarios.

Keywords: Analytical Models, Handoff Schemes, Resource Re-Allocation, Performance Evaluation, Hierarchical Cellular Networks, Integrated Wireless Networks.

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List of Abbreviations

1G	First Generation (Mobile Network)
2G	Second Generation (Mobile Network)
3G	Third Generation (Mobile Network)
4G	Fourth Generation (Mobile Network)
AMPS	Advanced Mobile Phone System
AUC	Authentication Center
BS	Base Station
CAC	Call Admission Control
CAS	Channel Allocation Schemes
CBHS	Channel Borrowing Handoff Schemes
CBS	Call Bounding Scheme
CCHS	Channel Carrying Handoff Schemes
CDMA	Code Division Multiple Access
CRS	Channel Reservation Schemes
CRT	Cell Residence Time
CTHS	Channel Transferred Handoff Schemes
D-AMPS	Digital-Advanced Mobile Phone System
DCA	Dynamic Channel Allocation
DCRS	Dynamic Channel Reservation Schemes
DHQS	Dynamic Handoff Queuing Schemes

DVH	Downward Vertical Handoff
EDGE	Enhanced Data Rates for Global Evolution
EIR	Equipment Identification Register
FCA	Fixed Channel Allocation
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Support Node
GHS	Genetic Handoff Scheme
GMM	GPRS Mobility Management
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HCA	Hybrid Channel Allocation
HCN	Hierarchical Cellular Network
HCS	Hierarchical Cellular Structure
HH	Horizontal Handoff
HHS	Hybrid Handoff Schemes
HLR	Home Location Register
HQS	Handoff Queuing Schemes
HSCSD	High Speed Circuit Switched Data
IP	Internet Protocol
MSC	Mobile Switching Service Center
MT	Mobile Terminal
MTSO	Mobile Telephone Switching Office
NAMPS	Narrow band AMPS

NMT	Nordic Mobile Telephone
NPS	Non-Prioritized Scheme
PCS	Personal Communication Systems
PLMN	Public Land Mobile Network
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RAN	Radio Access Network
SCRS	Static Channel Reservation Schemes
SGSN	Serving GPRS Support Node
SHQS	Static Handoff Queuing Schemes
SHT	Session Holding Time
SRS	Sub-Rating Schemes
TACS	Total Access Communication System
TACS	Total Access Communication System
TDMA	Time Division Multiple Access
UHF	Ultra-High-Frequency
UMTS	Universal Mobile Telecommunication System
UVH	Upward Vertical Handoff
VH	Vertical Handoff
VLR	Visitor Location Register
WLAN	Wireless Local Area Network

List of Symbols

g	Number of Guard Channel for Handoff Calls
λ_n	New Call Arrival Rate
λ_h	Handoff Call Arrival Rate
μ_c	Service Rate for Ongoing Call (New or Handoff)
μ_h	Service Rate of Handoff Calls
$P_b(N,g)$	Blocking Probability of New Calls
$P_d(N,g)$	Dropping Probability of Handoff Calls
$E[N]$	Mean Number of Active Calls in the Network (2 cells)
P_{loss}	Blocking (loss) Probability of the network (2 cells)
Th	Total Network Throughput (2 cells)
$E[T]$	Mean Response Time (Mean Total Delay) of the Network (2 Cells)
BW_T	Total Bandwidth Allocated to Calls
BW_{UT}	Total Bandwidth Utilized by Calls
BW_{NUT}	Total Bandwidth not Utilized
C_{ALN}	Total Number of Active Lower Priority Calls
BWC_{AL}	Bandwidth for Active Lower Priority Call
BWC_{UTAL}	Total Bandwidth Utilized by Active Lower Priority Calls
BW_{reqH}	Bandwidth Requested by Higher Priority Handoff Call
BW_{UTAL}	Total Bandwidth Utilized by Active Lower Priority Call

BW_{ALTM}	Total Bandwidth of Active Lower Priority Calls Calculated after Minimum
BW_{Borrow}	Bandwidth Borrowed from Neighboring Cell
BW_{reqL}	Bandwidth Requested by Lower Priority Handoff Call
λ_{sn}^{m}	Slow New Call Arrival Rate to Microcell
λ_{fn}^{M}	Fast New Calls Arrival Rate to Macrocell
λ_{sh}^{m}	Slow Handoff Call Arrival Rate to Microcell
λ_{fh}^{M}	Fats Handoff Calls Arrival Rate to Macrocell
λ_{sno}^{m}	Mean Arrival Rate of Overflowed Slow New Call from Microcell
λ_{sho}^{m}	Mean Arrival Rate of Overflowed Slow Handoff Call from Microcell
$(\mu_{sc}^{m})^{-1}$	Mean Channel Holding Time in the Microcell
$(\mu_{sdc}^{m})^{-1}$	Mean Dwell Time in the Microcell
P_{bsn}^{m}	Blocking Probability of Slow New Calls in the Microcell
P_{bsh}^{m}	Blocking Probability of Slow Handoff Calls in the Microcell
P_{bfn}^{M}	Blocking Probabilities of Fast New Calls in the Macrocell
P_{dfh}^{M}	Dropping Probability of Fast Handoff Call in the Macrocell
P_{bsno}^{M}	Blocking Probabilities of Overflowed Slow New Calls in the Macrocell
P_{dsho}^{M}	Dropping Probability of Overflowed Slow Handoff Call in the Macrocell
P_{bsn}	Total Slow New Call Blocking Probability Including Microcell and Macrocell
P_{dsh}	Total Slow Handoff Call Dropping Probability Including Microcell and Macrocell
$E[H_{busy}]$	Expected Number of Busy Channels in the Microcell
$E[H_{sub}]$	Expected Number of Sub-Rated Channels in the Microcell

$E[DR_n^m]$	Mean Degradation Ratio of Voice Quality for Microcell Slow New Calls
$E[DR_h^m]$	Mean Degradation Ratio of Voice Quality for Microcell Slow Handoff Calls
λ_n^u	Arrival Rate of New Calls in the UMTS
λ_{hh}^u	Arrival Rate of Horizontal Handoff Calls in the UMTS
λ_{vh}^u	Arrival Rate of Vertical Handoff Calls in the UMTS
λ_n^u	Arrival Rate of New Calls in the WLANs
λ_{vh}^w	Arrival Rate of Vertical Handoff Calls to the WLANs
$E[T_{ns}^u]$	Mean Channel Holding Time for New Calls of UMTS Users
$E[T_{vhs}^u]$	Mean Channel Holding Time for Back Vertical Handoff Calls of UMTS Users
$E[T_{hhs}^u]$	Mean Channel Holding Time for Horizontal Handoff Calls of UMTS Users
$E[T_{ns}^w]$	Channel Occupancy Time for WLANs Users
$E[T_{vhs}^w]$	Channel Occupancy Time for Vertical Handoff UMTS Users in WLANs
$P^u(i,j,k)$	Steady State Probability of New, Horizontal Handoff and Back Vertical Handoff Calls from the UMTS Users in the UMTS Cell
$P^w(i,j)$	Steady State Probability of Calls of WLANs Users and the Number of Vertical Handoff Calls of UMTS Users in the WLANs
P_{dn}	Dropping Probability of New Calls in UMTS and WLANs for UMTS users
P_{dh}	Dropping Probability of Horizontal Handoff Calls in UMTS and WLANs for UMTS users

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Working on PhD research is both a painful and enjoyable experience. It is like climbing a high mountain that you would not be able to reach the top of without having the help and experience of others, and people who believe in you that you can get there. I have now found myself at the top enjoying the feeling of relief, and I would like to give many, many thanks to all the people who have helped me during my research.

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List of Publications

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Z. Zabanoot, G. Min, Mike Woodward, A Fair Solution for Bandwidth Re-Allocation Management in 3G Wireless Cellular Networks, *Proc. Int. Conference on Information and Communication Technology and Systems (ICTS '09)*, Indonesia, August 4-6, pp. 1-8, 2009.

Z. Zabanoot, G. Min, Performance Design and Analysis of Handoff in Hierarchical Wireless Networks, Accepted at: *The Second International Workshop on Wireless Networks and Multimedia (WNM-2011)*, 16-18 November 2011, Changsha, China.

Z. Zabanoot, G. Min, Modeling of Prioritised Vertical Handoff Scheme in Integrated UMTS-WLANs, ready to submit to: *Wireless Communications and Networking Conference (WCNC 2012)*.

Chapter 1

Introduction

1.1 Background and Motivation

Cellular network technology is one of the fastest growing forms of mobile communications today. The bounds of an existing communication network infrastructure have been extended by cellular technology via connecting mobile units to public networks operated by the local exchange or long distance carriers, in order to make special features and functions specific to both cellular and public networks available to all users. Global standards have been developed to provide voice and data services anytime and anywhere regardless of user mobility, while satisfying their diverse Quality of Service (QoS) requirements. The frequency spectrum allocated for cellular communications is very limited. The success of today's cellular network is mainly due to the frequency reuse concept. This is why the coverage area is divided into cells, each of which is served by a base station (BS). Each BS (or cell) is assigned a group of radio channels according to the transmission power constraints and availability of spectrum. A channel can be a frequency, a time slot or code sequence. To avoid radio co-channel interference, the group of channels assigned to one cell must be different from the group of channels assigned to its neighboring cells. However, the same group of channels can be assigned to the two cells that are far enough apart such that the radio co-channel interference between them is within a tolerable limit.

As it is very important to satisfy the QoS requirements of the user, an efficient resource management is required during handoff when the mobile terminal (MT) moves from one cell to another. The problem of maintaining service continuity for users' applications during handoffs has been intensified with the use of better handoff schemes, or increasing the number of microcells and integration with other technologies in cellular networks. Call admission control (CAC) schemes have been developed to manage scarce radio resources to maximise network utilisation by selectively limiting the number of admitted calls. Two important QoS measures used when evaluating performance of call admission control schemes are the probabilities of call blocking and call dropping. Call blocking occurs when a cellular network is unable to assign network resources to enable a call initiated in a cell, whereas call dropping occurs when a cellular network is unable to assign network resources to enable a call handed off from a neighbouring cell. A higher priority is normally assigned to handoff calls over the new ones to minimise the probability of call dropping, since dropping an on-going call is generally more objectionable to a user than blocking a new call request. However, reducing dropping probabilities for handoff calls, as they have higher priority, increases the probability of blocking for calls with relatively lower priorities resulting in a tradeoff between both types of calls. Therefore, the goal is to sustain a balance between calls of different priorities while satisfying the respective QoS requirements.

Call admission control has been intensively studied in the past [1] and many priority-based CAC schemes have been proposed [2-17]. Call admission control schemes are analysed using Markov chain models. Markov chain models have been developed to evaluate performance analytically in cellular networks. Calls arriving to a particular cell are grouped into QoS classes or call types, such as new and handoff, based on their first appearance in the corresponding cell. Channel occupancy times for each group are measured from the call starting time, until the occupied channel in the respective cell is discarded due to call termination or handoff. However, call holding times are measured from the call starting time until call termination, regardless of occupying a channel in the same cell or not. The characteristics of various types of channel occupancy times need to be analysed to provide sufficiently representative channel occupancy time statistics, not only when developing analytical models, but also for feeding simulations with realistic traffic statistics to obtain network performance metrics.

As the number of subscribers to wireless networks is increasing dramatically, there has been much research work carried out to improve the capacity of these networks by using hierarchical cellular networks (HCN) [88, 89]. In these networks, the cells are grouped into two different layers depending on their sizes; microcell in one layer and macrocell in another layer. Depending on the CAC schemes used to assign channels for new and handoff calls, each layer can receive a type of call class, and calls which are blocked at one layer can overflow to the other layer. The microcell can be replaced by WLANs and it can be integrated with the overlay macrocell.

Most of current research on the integration of wireless cellular networking and WLAN focuses on relatively high-level issues such as the integration architecture [111]. The system is often studied from the perspectives of access control, mobility management, security and billing and so on. Another research focus of cellular/WLAN integration is the issue of Radio Access Network (RAN) selection and handover decision [112]. Here, the objective is to use the handoff schemes in a way that improves the network performance and decreases the dropping probabilities of new and horizontal handoff calls of the UMTS users by allowing them to vertically handoff to the WLANs. Handover makes mobility possible, but also makes the mobile-level topology of cellular/WLAN integrated systems challenging due to user mobility in the study of such systems.

1.2 Aims and Objectives

The research work in this thesis is mainly aimed towards studying different mechanisms of handoff under different network scenarios with the aim of decreasing the dropping probability of handoff calls, whilst at the same time keeping the blocking probability of new calls to a minimum. The main objectives of the research are outlined as follows:

- To develop an analytical model for priority handover mechanisms and optimise the number of channels assigned to handover calls, with the aim of minimising the drop probability under given network scenarios.
- To develop and provide a performance model for a two-cell model as one network system, and measure the different performance parameters for each of the cells in the network altogether as one network system.
- To develop a solution for re-allocation of the unutilised bandwidth to be used fairly by all nodes who request a bandwidth.
- To develop a new performance model for Macro/ Micro cells network which supports fast and slow mobility users.

- To propose a performance model for prioritising a vertical handoff scheme in integrated UMTS/WLAN network.

1.3 Contributions

The original contributions of this thesis are outlined below:

- An analytical model for priority handover mechanisms whereby new calls and handover calls are captured by two different traffic arrival processes respectively will be developed. The analytical performance model has been validated by simulation experiments. Using the blocking probability of the new calls and the drop probability for handover calls derived from the analytical model, the optimised number of channels assigned to handover calls was calculated with the aim of minimising the drop probability under given network scenarios. Also, a performance model for a two-cell network has been developed and the different performance parameters have been measured for each of the cells in the network and all together as one network system.

- A new solution model is proposed to manage the bandwidth. A bandwidth, which is not utilised by fewer mobile nodes, will be re-allocated to the needy ones. In order to maintain the QoS for the higher priority handover call (multimedia call), the focus here is to allocate the required bandwidth to this call and maintain constancy during its connection life time. For the lower priority handover call (data call) at least the minimum bandwidth will be allocated in the worst-case scenario. The unutilised bandwidth will be distributed fairly among active lower priority nodes, and will be utilised later by either handover calls or incoming local calls. With this method, maximum bandwidth in the cell will be reached, and it will remain available whenever a new call, either handover or locally generated, comes in; thus, the wastage of network resources can be avoided. The dropping probability of handover calls will be reduced to a minimum and the blocking probability of newly generated calls will be maintained at a minimum through this method.

- Performance models for a two layer microcells/ macrocell Hierarchical Cellular Network will be developed by using 1-D and 2-D markov process for microcell and macrocell, respectively. In this proposed CAC, the HCN system supports both fast and slow mobility users. The macrocells handle the fast-mobility users while the microcells serve the slow-mobility users. In the microcells, a combination of sub-rating, call bounding and handoff queuing schemes is used, while in the macrocell the call bounding scheme is used. The effect of sub-rating in the microcell on the voice quality is also studied.

- A new performance model will be developed to prioritise the vertical handoff scheme in integrated UMTS/WLAN networks. In this model, the call residence times are modelled by general distribution to adapt the flexible mobility environments. The new originated and horizontal handoff call of UMTS users that are blocked in the UMTS-only coverage, can attempt a vertical handoff to the underlying WLANs. In the WLANs these call are given more priority than the WLANs users' call by reserving some channels for them, plus they can share the rest of the channels with the WLANs users. The channel occupancy times and the blocking and dropping probabilities have been derived and calculated.

1.4 Thesis Outline

The rest of the thesis is organised as follows:

Chapter 2 presents the background to the research and related work for handoff mechanisms in single and two layer networks. It discusses the different types of handoff and channel allocation schemes. Also, it presents an overview of the integration between cellular networks and wireless local area networks.

Chapter 3 presents a performance model to optimise the number of channels assigned to handoff calls with the aim of minimising the drop probability under given network scenarios, and to keep the new call blocking probability at a minimum. Also, this chapter includes developing a performance model for a two-cell network and studies its performance parameters.

Chapter 4 proposes a new solution to manage the bandwidth in 3G network and re-allocate the unutilised bandwidth in better way to be used by all types of calls and not be wasted. The multimedia calls are given higher priority and they are assigned more bandwidth to keep it constant during their lifetime. The data calls are lower priority and are given at least the minimum bandwidth in the worst case scenario.

Chapter 5 develops a performance model for a two layer microcells/ macrocell Hierarchical Cellular Network to enhance the performance of the network. The dropping and blocking probability of slow and fast mobility user calls is calculated. The blocked slow calls in the microcell are allowed to overflow to the overlay macrocell to minimise the dropping and blocking probabilities. The number of microcells has been increased to see the effect on the network performance. The voice degradation because of using sub-rating in the microcell has also studied.

Chapter 6 develops a performance model for an integrated UMTS/ WLAN network. The newly originated and horizontal handoff call of UMTS users that are blocked in the UMTS-only coverage, can attempt a vertical handoff to the underlying WLANs, and they are given more priority in the WLANs than the WLANs users. The size of the WLANs has been varied to see the effect on the network performance.

Chapter 7 concludes the thesis and points out future directions of interest.

Chapter 2

Background Research

This chapter provides an overview of some background knowledge related to the work in this thesis. In Section 2.1, an introduction to wireless cellular networks will be given and the basics will be explained, including how it works and the importance of mobility. In Section 2.2, an overview will be presented of multiple access, briefly explaining the basic three multiple access methods. The horizontal and vertical handoff will be explained in Section 2.3. Also, another classification of handoff- hard and soft- will be explained in the same Section. In Section 2.4, the different channel allocation schemes that have been used in wireless cellular networks will be explained. Section 2.5 will highlight the importance of hierarchical wireless cellular networks to improve performance, and the integration of UMTS with WLANs will be briefly discussed in Section 2.6. Finally, the wireless networks mobility management methods in the different generations will be discuss in Section 2.7.

2.1 Wireless Cellular Networks

Telephone service subscribers are a demanding group of customers. Ubiquitous access, reliability, availability, scalability and ease of use are expected attributes of telephone networks. The continuous evolution of the telephone network satisfies these requirements by varying degrees. Network technology, cost of service and infrastructure establishment, are the major impediments to complete customer satisfaction.

Wireless mobile telephone networks or public land mobile networks (PLMNs) leverage the services provided by the public switched telephone network (PSTN). PLMNs use the PSTN as a backbone. PLMNs consist of network elements that provide the infrastructure for wireless access, mobility management and external network gateways [113, 114].

A simple PLMN consists of base stations, mobile switching service centers (MSC), Home Location Register (HLR), Visitor Location Registers (VLR), Authentication Center (AUC) and an Equipment Identification Register (EIR), as shown in Figure 2.1.

The base stations provide network access via a radio interface for mobile subscribers. The MSC manages base stations; consults PLMN databases to establish subscriber access rights; routes mobile traffic, and serves as a gateway to external networks. The HLR, VLR, AUC and EIR are PLMN databases, which contain subscriber profiles, location, encryption codes and equipment data.

Call establishment and connection maintenance are fundamental services required by all telephone networks. A PSTN call process for two authorised fixed location subscribers consists of call initiation signalling, connection path establishment, alerting the called party, call acceptance and preservation of connection until the end of session signalling is detected. The PSTN uses the fixed location of the subscriber to simplify network functions. A fixed subscriber location simplifies authentication, call establishment and call preservation. Although a PLMN call process must perform the same functions as a PSTN, subscriber mobility significantly complicates network operations.

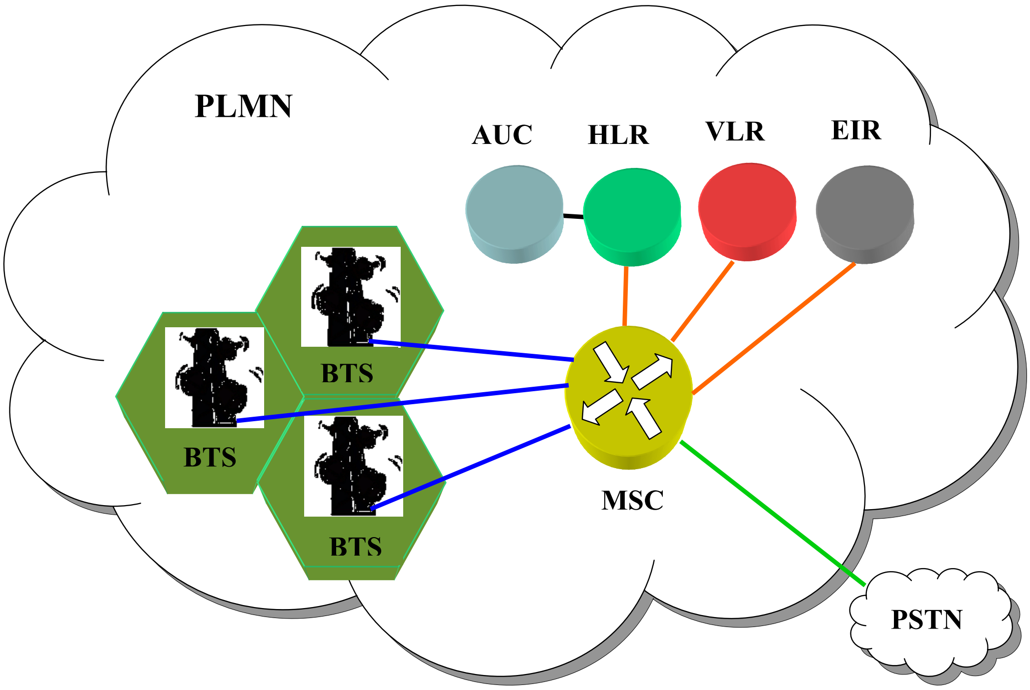


Figure 2.1: Simple PLMN

In order to provide PSTN services, PLMNs must implement mobility management technologies. These technologies enable PLMNs to establish and maintain calls to authorised mobile subscribers. Mobility management uses the HLR, VLRs, MSCs and Base Stations [115]. The AUC and EIR servers verify subscribers and their equipment. Mobility management technologies strongly influence call quality, reliability and availability.

Mobility management is the fundamental technology for the support of seamless accessing to wireless networks and mobile services. Two main aspects need to be considered in mobility management; these are location management (for example addressing, location registration and update, tracking and paging, and so on) and handoff (Handover) management (for example handoff initialisation, resource relocation, connection re-establishing, and so on) [21, 116].

Handoff management is one of the most critical issues that mobility management protocols are concerned with. There are usually two classes of calls: new calls and handoff calls. The new calls are the ones which are just starting within the cell and the handoff calls are calls which are already ongoing, but have moved onto a new cell and need to connect to a new base station. When a new call is originated and attempted in a cell, one of the channels assigned to the base station of the cell is used for communication between the mobile user and the base station if any channel is available for the new call. If all the channels assigned to the base station are in use, the new call attempt is blocked and cleared from the system. When a new call gets a channel, it keeps the channel until it is completed in the cell or the mobile moves out of the cell. When the call is completed in the cell, the channel is released and becomes available to serve another call. When the mobile crosses a cell boundary into an adjacent cell while the call is in progress, the call requires a new base station and channel frequency in order to continue. The procedure of changing channels is called handoff (Handover). If no channel is available in the new cell into which the mobile moves, the handoff call is forced to terminate before completion. Incomplete calls are considered less desirable from the user's viewpoint than the occurrence of blocking of a new call, and they should be kept at a minimum. Since a customer's satisfaction is determined by the rate of call completions and how low the connection delays are, it is in the interest of the service provider to meet these satisfaction measures as much as possible.

2.2 Multiple Access Methods

Within a cell covered by a BS, there are multiple MTs that need to communicate with the BS. Those mobile terminals must share the air interface in an orderly manner so that MTs within the cell do not interfere with each other. This sharing of the air interface in an orderly manner is referred to as multiple access. Popular multiple access methods include Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) [23].

- Frequency Division Multiple Access (FDMA): With FDMA, different signals are assigned frequency channels, and a channel is a frequency. FDMA is a basic technology in the analog Advanced Mobile Phone System (AMPS). With FDMA, each channel can be assigned to only one user at a time. FDMA is also used in the Total Access Communication System (TACS).

- Time Division Multiple Access (TDMA): In TDMA, it makes use of the same frequency spectrum but allows more users on the same band of frequencies by dividing the time into "slots", and it shares the channel between users by assigning them different time slots. TDMA is utilised by Digital-Advanced Mobile Phone System (D-AMPS) and Global System for Mobile communications (GSM). However, each of these systems implements TDMA in a somewhat different and incompatible way.

- Code Division Multiple Access (CDMA): In CDMA, each user is assigned a different pseudorandom binary sequence that modulates the carrier, spreading the spectrum of the waveform and giving each user a unique code pattern. This technology is used in ultra-high-frequency (UHF) cellular telephone systems in the 800 MHz and 1.9 GHz bands.

2.3 Handoff

As mentioned earlier, the process of transferring a call from the current cell to a neighbouring cell is called handoff. Handoffs may be classified based on several factors, like the type of network, the involved network elements or the number of active connections and the type of traffic that the network supports. There are two types of handoff: a horizontal handoff which takes place between points of attachment supporting the same network technology, such as between two neighbouring base stations of a UMTS, or between two Access points of a WLAN. On the other hand, a vertical handoff occurs between points of attachment supporting different network technologies, such as, between a WLAN access point and a UMTS base station. Handoffs can also be classified into hard and soft handoffs [20, 21] depending on which BS is serving the MT in the crucial period during handoff execution when there is a communication between the user in question with more than one BSs.

Table 2-1: Handoff Types Classification

Types	**Classification**	
Horizontal	Intracell	Intercell
	Soft	Hard
Vertical	Downward	Upward
	Soft	Hard

2.3.1 Horizontal Handoff

Horizontal handoffs in a cellular network can be broadly classified into intra-cell and inter-cell handoffs. Intra-cell handoffs occur when a user, moving within a cell, changes radio channels in order to minimise inter-channel interference under the same BS [18]. On the other hand, inter-cell handoffs occur when an MT moves into an adjacent cell and, therefore, all the MTs connections should be transferred to the new BS [18].

Horizontal handoff can be classified into four phases [122]: Measurement, Initiation, Decision and Execution. In the measurement phase, different measurements will be carried out by the BS and the MT [122, 123] such as Received Single Strength (RSS), Signal to Interference Ratio (SIR), Bit Error Rate (BER), and distance measure. The initiation phase is in order to decide whether a handoff is needed or not, and if it is needed, to initiate the process. In this phase, the handoff process should be accomplished according to the received signal quality inside a cell, or when the MT is moving along the common boundary of two cells, or between two adjacent cells [24]. The objective of the Decision phase is the selection of a new channel in the cell while taking into account the network load and the available resources. In the Execution phase, the network allows the MT which is communicating with BS to transfer its communication to another channel or transfer to another cell. Authentication, database lookup and network reconfiguration all are done during this phase.

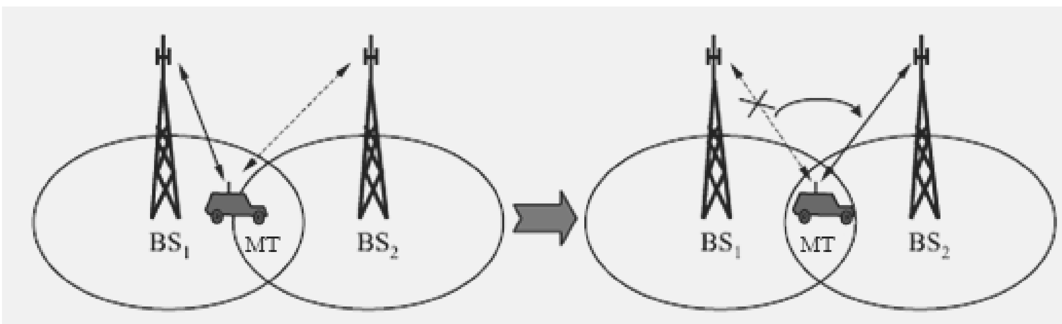
2.3.2 Vertical Handoff

Vertical handoffs can be further distinguished into Downward Vertical Handoffs (DVH) and Upward Vertical Handoffs (UVH). In DVH, the mobile user handoffs to the network that has the higher bandwidth and limited coverage, while in UVH the mobile user transfers its connection to the network with a lower bandwidth and wider coverage [19].

The Vertical Handoff process can be classified into three main phases [124, 125]: System Discovery, Handoff Decision and Handoff Execution. In the system discovery phase, the MTs determine the service available in each network and which network can be used. The networks also show the data rate it can support for each service and the QoS parameters. In the handoff decision phase, based on several parameters, the MT determines the network that it should be connected to. During the handoff execution phase, the connection will be re-routed from the current network to the new network in a seamless manner. Authentication, authorisation, and user's context information transfer is included in this phase.

2.3.3 Hard Handoff

In hard handoffs, an MT is served by only one BS (or by only one access network in the case of vertical handoff) at a time, as in Figure 2.2. It contacts with the new BS or the new network only after having broken its connection with the serving BS. This is referred to as "break before make" connection.



a. Before Handoff b. After Handoff

Figure 2.2: Hard Handoff between MT and BSs

Hard handoff is used by systems such as the Global System for Mobile Communications (GSM) and General Packet Radio Service (GPRS), where Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are applied [22].

2.3.4 Soft Handoff

In soft handoff, the MT may be served by more than one BS (or by more than one access network). Soft handoff can be used to extend the time needed to make a handoff decision without any loss of QoS. It refers to a "Make before Break" switching action with no disruption of service. The cellular Code Division Multiple Access (CDMA) systems use soft handoff techniques, due to the fact that in these systems a mobile node may communicate with more than one coded channel, which enables it to communicate with more than one BS [22]. In soft handoff, a conditional decision is made on whether to handoff. Making the handoff and deciding to communicate with only one BS depends on the change in the pilot signal strength from the two or more BSs involved. This happens after it is clear that the signal from one BS is considerably stronger than those from the others. It is normally consists of one BS, but other BSs are added when the signal strength between them and the MT exceeds the predefined add threshold.

2.4 Channel Allocation Schemes

As the handoff process is managed by channel allocation schemes (CAS), the main interest is focused on them. CAS deals with how to assign available channels to the newly generated calls within the cell as well as the handoff calls, because the efficient utilisation of the scarce spectrum for cellular communications is certainly one of the major challenges in cellular system design. The most restraining factor on the overall system capacity in wireless networks is the co-channel interference caused by frequency reuse.

As the demand for mobile wireless service increases, the numbers of channels allocated to a cell and the allocation scheme may become insufficient to support the desirable QoS. The CAS can be broadly classified into Non-Prioritized and Prioritization Schemes [24-26], [28-46]. The Non-Prioritized Scheme (NPS) [26] has been employed by the typical radio technologies proposed for Personal Communication Systems (PCS) which operates on a band of 2 GHz. There is no difference between handoff and newly requested calls in this scheme. As long as there is a channel available in the cell, a new or handoff call request will be served, but the request will be blocked if there are no free channels. The main disadvantage of this scheme is that the forced termination probability is relatively higher than is normally anticipated [26, 27].

As the termination of an ongoing call is more annoying than the blocking of a new call [28, 29], [45, 46], several handoff prioritising schemes have been proposed. The basic concept of all handoff prioritisation approaches is to give handoff requests precedence over new session requests in some way. Handoff prioritisation schemes provide an improvement in performance according to the way that each scheme gives priority to handoff calls. Prioritisation handoff channel allocation schemes can be classified into Channel Reservation, Handoff Queuing, Channel Transferred, Sub-Rating, Genetic and Hybrid.

2.4.1 Channel Reservation Schemes (CRS)

In these schemes, a number of channels will be reserved exclusively for handoff requests. Depending on whether the set of reserved channels is fixed or varies, these schemes can be further divided into static and dynamic reservation schemes.

- Static Channel Reservation Schemes (SCRS): These schemes set a fixed threshold to guarantee that a proper bandwidth is allocated for handoff calls. There are two ways to do that: either by using Guard Channel Scheme or Threshold Priority Scheme (also called New Call Bounding Scheme) [32]. In Guard Channel Scheme, a number of channels will be reserved to be used by handoff calls only [31] and the remaining channels are shared between new calls and handoff calls. In the Threshold Priority Scheme, the number of admitted new calls will be limited by a predefined threshold [30].
- Dynamic Channel Reservation Schemes (DCRS): based on the variation in the system parameters, each BS will dynamically change the number of reserved channels for handoff. In these schemes, more new connection requests will be accepted compared to the fixed schemes [17, 33]. Depending on the way that these schemes obtain the required information for the variation in the system parameters, they can be classified into Local and Collaborative [29]. The Local Scheme uses the locally available information in the BS, whereas the Collaborative Scheme uses the information obtained from neighbouring BSs.

2.4.2 Handoff Queuing Schemes (HQS)

If the MT is in the handoff area and the destination cell has no free channels, then the MT maintains its connection with the source cell and the handoff request will be placed in a queue. The handoff request will be sent to the BS of the destination cell and if a channel is available before the MT crosses the handoff area, then the channel will be assigned to the MT, or it will be forced to terminate the call. HQS gives more priority to handoff calls being queued [34], but it also allows both new calls and handoff calls to be queued [35]. These schemes can be further classified into static and dynamic schemes.

- Static Handoff Queuing Schemes (SHQS): in these schemes there are two general policies: preemptive and non-preemptive. In Preemptive, when a call arrives at a queue and finds a lower priority call in service, the arriving call preempts the lower priority call from the queue and begins its service [36]. The preempted lower priority call will resume its service at the point at which its service was suspended as soon as there are no higher priority calls remaining in the queue. The Non-Preemptive policy requires a call that begins service to complete its service without interruption.
- Dynamic Handoff Queuing Schemes (DHQS): in these schemes the handoff requests in the queue will be dynamically reordered to reduce the probability of forced termination. This dynamic reorder reflects the dynamics of the user motion such as changes in the user moving speed.

2.4.3 Channel Transferred Handoff Schemes (CTHS)

In these schemes, if a handoff call request arrives and there are no available channels, a channel from a neighbouring cell will be transferred. There are two categories to be followed by the handoff call request on selecting the transferred channel; they are Channel Carrying Approach and Channel Borrowing Approach.

- Channel Carrying Handoff Schemes (CCHS): in these schemes the MT is allowed to carry its channel to the destination cell. Here the BS of the new cell will maintain the communication using the old channel [37].
- Channel Borrowing Handoff Schemes (CBHS): in these schemes, the cell that has used all its channels is allowed to borrow free channels from the neighbouring cells to be able to accommodate new calls [38]. The channel can be borrowed by the cell if the borrowed channel does not interfere with existing calls.

2.4.4 Sub-Rating Schemes (SRS)

The main concept of Sub-Rating is that an occupied full-rate channel can be temporarily divided into two channels at half of the original rate; one to serve the existing call and the other to serve the handoff request [39]. The channel Sub-Rating mechanism is only activated when all the channels are occupied on handoff request arrival. When a sub-rated channel is released, it is transformed to its original full-rated channel. The SRS scheme reduces the blocking probabilities and the forced termination probabilities of handoff calls but it introduces degradation into the system [40]. A Wideband class has been considered [41] as it accepts channel sub-rating and narrow band classes which does not accept QoS degradation.

2.4.5 Genetic Handoff Scheme (GHS)

These schemes use genetic algorithms to assign the channels using local state-based call admission double-threshold policies [42]. Here, the BS only keeps track of the state of information of a small number of cells and makes decisions based on that. This scheme shows better results than some other schemes, but its main drawback is the time needed to assign channels. The genetic algorithms are adaptive procedures that find solutions to problems by an evolutionary process based on natural selection. It is found that these schemes finds better admission policies compared with other well-known methods of handoff reservation for both one-dimensional and two-dimensional cellular networks. However, the time needed to assign channels for the genetic algorithms scheme is the main drawback of it. It mostly applied for hard optimisation problem with larger search spaces.

2.4.6 Hybrid Handoff Schemes (HHS)

HHS are a combination of channel reservation, handoff queuing, channel transfer, genetic and sub-rating schemes [43 – 46]. The main idea of these schemes is to combine the different prioritisation schemes to further decrease the dropping probabilities or to improve channel utilisation. Either two or more prioritisation schemes have been combined in different studies to enhance the performance. For example, some schemes combined Channel Borrowing, Genetic algorithm and channel Degradation schemes to increase the network efficiency. Also, some other hybrid schemes combined sub-rating with handoff queueing and/or with guard channel scheme. Combination of different schemes leads to decreasing of dropping probability of handoff calls and blocking probability of new call.

2.5 Hierarchical Wireless Cellular Network

In recent years, wireless communication systems are experiencing a dramatic and continuous growth in the number of subscribers, thus placing extra demands on system capacity. At the same time, keeping QoS at an acceptable level is a critical concern and a challenge to the wireless network designer. One trend in cellular networks is to shrink cell size in order to accommodate more mobile users and traffic in a given area. The small-cell system has the advantages of greater spectral reuse and larger capacity than those of large-cell systems. However, such a policy results in the increased number of handoff calls and a corresponding increase in signalling load. With inadequate resources in the network, increased handoff rates can lead to high forced call termination probability.

In order to achieve and maintain high network performance, one network design approach is to use a hierarchical cellular structure (HCS). In this structure, cells of different sizes are organised into different layers to provide high coverage and capacity over a given service area. This structure can effectively reduce the number of handoffs in the wireless system, thus significantly improving the overall system capacity.

There are a number of different approaches proposed for handling calls in HCS. [48, 49] present an approach where a new call or a handover call will be directed to the appropriate layer based on its previous speed. In [49], only handoff overflow from the lower layer to the higher layer is allowed. In [50] mobile subscribers travelling in the lower layer may borrow channels from a pool of channels reserved for handoff calls at the higher layer. [51] has presented a mobility-dependent connection admission control scheme, which was analysed assuming the interrupted Poisson process (IPP), under stationary and non-stationary conditions.

2.6 Hierarchical Cellular/WLAN Overlay Architecture

To utilise many useful methods developed in hierarchical cellular network (HCN) research, micro-cells in HCN are replaced with WLANs. The cellular networks have a widely entrenched infrastructure, which provides almost ubiquitous connectivity and supports user mobility levels, from fast trains and highway vehicles to stationary users in an indoor environment. In contrast, WLANs are usually deployed in hotspot local areas. Thus, the cellular/WLAN interworking results in an overlay structure similar in some ways to hierarchical cellular structure. Both cellular access and WLAN access are available to mobile users within WLAN-coverage areas. The incoming traffic load should be properly shared between the overlay macro-cell and WLAN for QoS enhancement, congestion relief, cost reduction and so on.

2.7 Wireless Network Mobility Management Methods

The generation of numbers to describe categories of wireless networks; each generation resolves the issues encountered by its predecessor and introduces new technologies. The ultimate objective of this evolutionary process is to elevate the performance of a wireless network to that of its wireline counterpart. Ideally, subscriber mobility should not affect quality of service.

2.7.1 Mobility Management for 1G Wireless Networks

The first generation technologies were limited capacity analog wireless networks with Frequency Modulation (FM) and Frequency Division Multiple Access (FDMA). First Generation networks provided voice delivery services with in-band signaling. Advanced Mobile Phone Service (AMPS), Narrow band AMPS (NAMPS), Nordic Mobile Telephone (NMT), Total Access Communication System (TACS), C-450 and R-2000 were implementations of First Generation networks.

First Generation networks supported mobile subscriber registration, authentication, paging, conditional roaming and RRM. The Mobile Telephone Switching Office (MTSO) provided all mobility management operations. Radio resource management depended on signal strength measurements from base stations. Networks used hard handoffs and supported voice delivery services only.

2.7.2 Mobility Management for 2G Networks

Second Generation wireless networks introduced digital technologies, which significantly improved performance, capacity and services. Voice delivery services continued to be the focus.

A great debate over architecture hampered the introduction of digital technology in 2G wireless networks. The technology chosen to implement a 2G wireless network affects mobility.

Roaming is extremely limited between networks with different technologies. When a mobile terminal changes BS, it may roam to a cell that corresponds to a new serving VLR. In that case it has to update the information stored in the HLR. Therefore, the terminal initiates an update message (1), which, via the BS and MSC, is forwarded to the current associated VLR. The VLR checks its local records. If the terminal's Mobile Identification Number (MIN) is already stored there, no further action takes place, since the terminal has not changed location area. Otherwise, the terminal's MIN is stored locally and a new update message is forwarded to the HLR (2). The HLR in turn authenticates the terminal and replies with a positive registration acknowledgment to the new VLR (3). Additionally, the HLR may send a registration cancellation message to the old VLR, or a periodical mechanism may automatically update the VLR database and remove out-of-date entries [52] (refer to Figure 2.3 below) [52].

In this generation, Radio resource management introduced soft handoffs and defined more handoff scenarios.

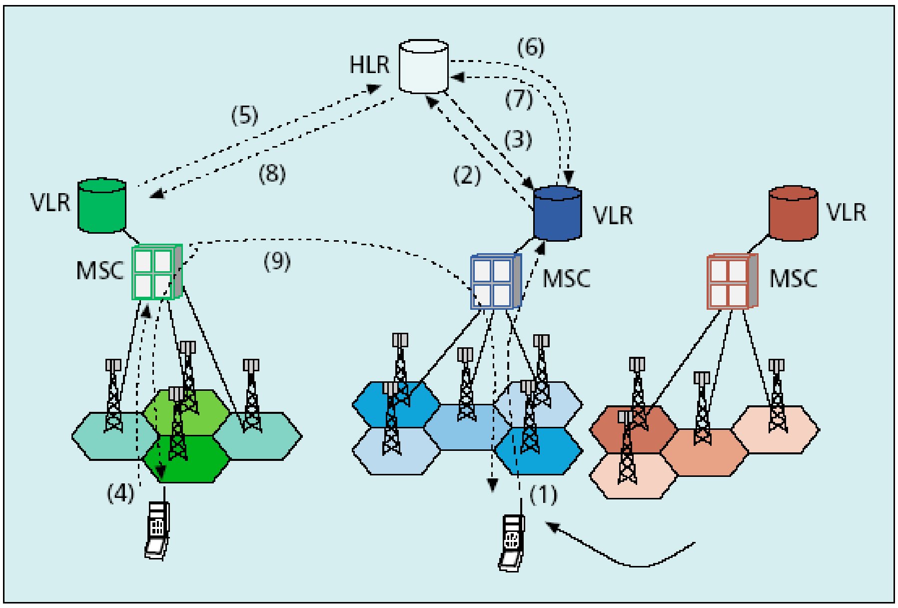


Figure 2.3: Reference Architecture of a 2G Network

2.7.3 Mobility Management for 2.5G Networks

Second Generation wireless networks continued to focus primarily on voice delivery services. The demand for data delivery services grew rapidly, and as a result, an interim generation of wireless networks was developed. These new network standards were referred to as 2.5 G and they are High Speed Circuit Switched Data (HSCSD), General Packet Radio Service (GPRS) and IS-95B.

The Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) are new network elements [53]. The SGSN routes all mobile station packet traffic, performs logical link management, supports the mobile station attach /detach process and authenticates mobile stations. Subscriber profiles and location information is stored in the SGSN's location register. SGSNs serve a group of cells, a Routing Area, within a location area. The GGSN is a protocol converter and it interfaces the GPRS network to external packet data networks. It transforms GPRS traffic to the packet data format of the external network, and readdresses and routes external packets terminating in the GPRS network to the appropriate SGSN. GPRS Mobility Management (GMM) and Session Management (SM) perform security processes, GPRS Attach / Detach procedures, routing area updates and protocol data packet context activation.

GPRS implements mobility management with Idle, Ready and Standby states. The Idle state indicates that the GPRS network is not aware of the mobile terminal. The Standby state indicates that the GPRS network knows the subscriber and its routing area [117]. The Ready state indicates that the GPRS network knows the subscriber, its cell location and is exchanging packets at will.

In this generation, subscriber equipment classification determined service access such as concurrent use of voice and data, switched use of voice and data, and exclusive use of one service. The goal was to minimise handoff disruption for voice services and zero packet loss for data services.

2.7.4 Mobility Management for 3G Networks

Enhanced Data rates for Global Evolution (EDGE) are a convergence technology providing GSM and TDMA operators with a migration path to 3G, Universal Mobile Telephone System (UMTS).

UMTS networks leverage GSM and EDGE networks. The result is a network that delivers high bit rates, circuit & packet switched services, Quality of Service (QOS) and compatibility with previous 2G and 2.5G technologies.

Initial implementations contain discrete circuit switched networks within the UMTS' core network. The packet switching elements share the same names as their 2.5G predecessors.

Registration, authentication and paging activities are determined by mobility management states. Two different three state models are used for circuit and packet switched mobility management [118-121]. Circuit switched mobility management uses MM-Idle, MM-Connected and MM-Detached states as shown in Figure 2.4. Packet switched mobility management uses PMM-Idle, PMM-Connected and PMM-Detached states as shown in Figure 2.5. The mobility management states are indicators of mobile station location resolution.

In 3G, Roaming benefits from all the architectural compatibilities and becomes global. Radio resource management implements a broad range of handoffs and supports most mobility issues.

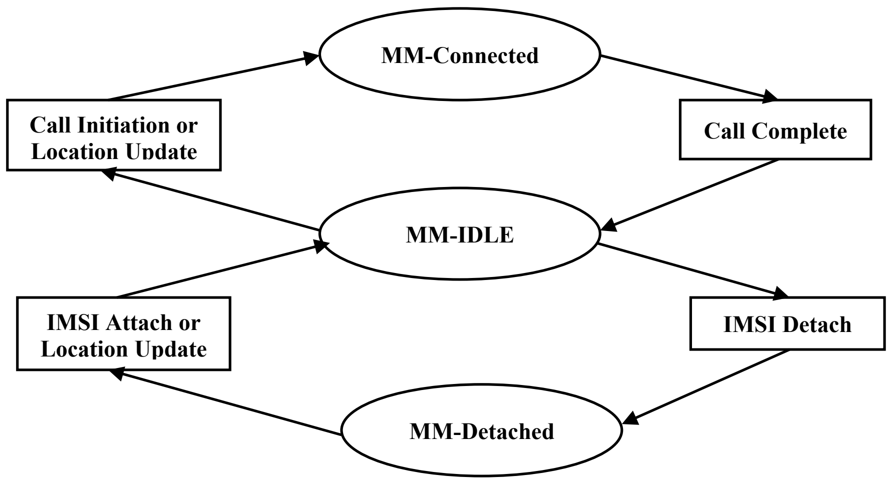


Figure 2.4: UMTS Circuit Switched Mobility Management States

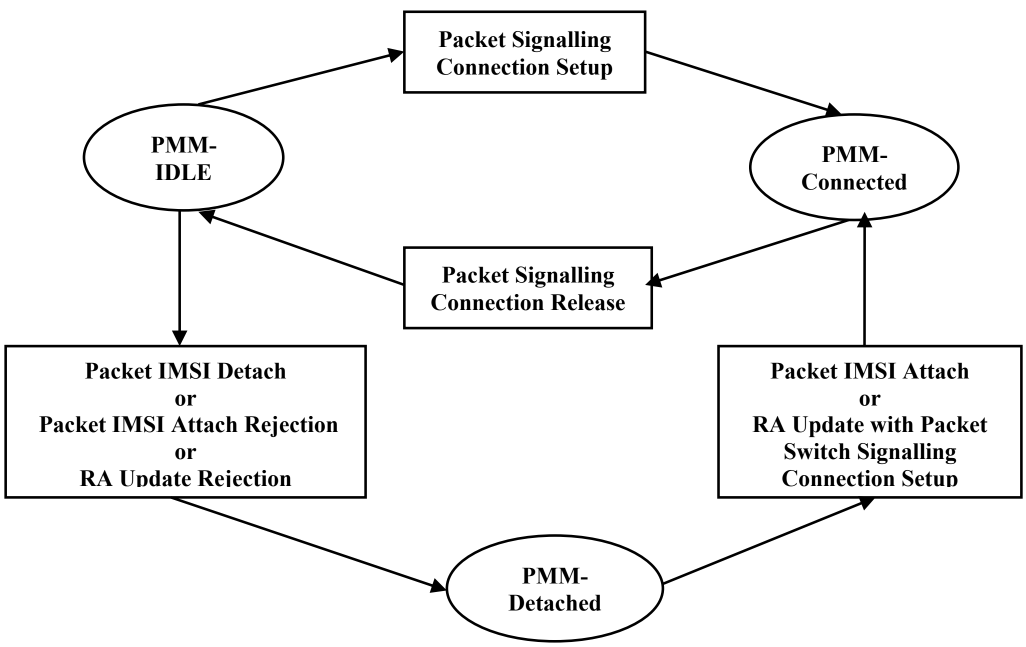


Figure 2.5: UMTS Packet Switched Mobility Management States

2.7.5 Mobility Management Scheme Comparison

Table 2-2: Mobility Management Scheme Comparisons

Network Type		Mobility Management			Radio Resource Management
		Registration & Paging Areas	AUC	Roaming	Handoff Types
1G	AMPS	Single Cell & Proprietary Cell Groups	MS Only Simple MIN & ESN	Conditional Difficult	Network Controlled, Hard, Intra-MSC, Inter-MSC IS41
2G	GSM	Global Single Cell & Location Areas (LA)	MS Only 3 keys A3 Algor.	Good between GSM Operators	Network Controlled, MAHO, Hard, Intra- BSC, Intra-MSC & Inter-MSC
2G	NA-TDMA	Single Cell & Location Areas (LA)	IS54, CAVE	Conditional	Network Controlled, MAHO, Hard, Intra-MSC & Inter-MSC IS41
2G 2.5G	CDMA One IS95 A & B	Single Cell & zone	MS Only Based on Long Code Masks, CAVE	Conditional ANSI 41	Mobile Initiated, Network Controlled, Soft, Hard & HO to Analog ANSI 41 compliant
2.5G	GPRS	Global Single Cell, Location Areas (LA), Routing Areas (RA)	MS Only 3 keys A3 Algor.	Good between GSM Operators, SIM	Network Controlled, MAHO, Hard, Intra- BSC, Intra-MSC & Inter-MSC
3G	UMTS	Global Single Cell, Location Areas (LA), Routing Areas (RA) & UTRAN Routing Area	MS & Network Private Master Key algor.	Almost Everywhere SIM	NEHO, MEHO, Hard, Soft, and Softer Intra- BS, Inter-BS, Intra-MSC, Inter-RNC, Inter-SGSN & Inter-Sys. Inter-MSC

2.7.6 Mobility Management in 4G Networks

In 4G Networks, mobility is a critical aspect. There are three main issues that should be dealt with independently to accommodate an easy work split. Interactions between these aspects should, however, not be overlooked.

The first issue deals with optimal choice of access technology, or how to be best connected. Given that a user may be offered connectivity from more than one technology at any one time, one has to consider how the terminal and the network choose the technology suitable for the services the user is accessing.

The second issue regards the design of a mobility enabled IP networking architecture, which contains the functionality to deal with mobility between access technologies. This includes fast, seamless handoffs (IP micro-mobility), quality of service (QoS), security and accounting.

The third issue concerns the adaptation of multimedia transmission across 4G networks. Indeed, multimedia will be a main service feature of 4G networks, and changing radio access networks may, in particular, result in drastic changes in the network condition. Thus the framework for multimedia transmission must be adaptive.

Chapter 3

Performance Modelling of Handoff Mechanisms in Single and Two Cells Wireless Cellular Networks

3.1 Introduction

For a mobile cellular system, it is important to establish a traffic model before analysing the performance of the system. The Erlang-B formula is normally used to compute the loss probability in wired networks. This formula cannot be used in cellular wireless networks due to the phenomenon of handover. When a mobile station moves across a cell boundary, the channel in the earlier cell is released and an idle channel is required in the target cell. If an idle channel is available in the target cell, the handoff call is resumed almost transparently to the user. Otherwise, the handoff call is dropped. The dropping of a handoff call is generally considered more serious than the blocking of a new call.

3.2 Performance Model of Handoff Mechanisms in a Single Cell

In this section, an analytical model was developed for priority handover mechanisms in a single cell, where new calls and handover calls are captured by two different traffic arrival processes respectively. The analytical performance model is validated by simulation experiments. Using the blocking probability of the new calls and the drop probability for handoff calls derived from the analytical model, the optimised number of channels assigned to handoff calls has been investigated, with the aim of minimising the drop probability under given network scenarios while at same time keeping the blocking probability of new calls to its lowest possible minimum.

The dropping of a handoff call is generally considered more serious than the blocking of a new call. One way of reducing the dropping probability of a handover call is to reserve a fixed number (say g) of channels exclusively for the handover calls. As a result, separate formulas for the dropping probability of handover calls, and the blocking probability of new calls, are required. Furthermore, as the number of channels increases, the dropping probability will be reduced whilst the blocking probability will increase. Thus, it is possible to derive an optimal number of g channels subject to given constraints on the dropping and blocking probabilities. Recently, many analytical and simulation models that characterise the handover problems have been presented [54-62]. In this section, an analytical model will be developed for priority handover mechanisms where new calls and handover calls are captured by two different traffic arrival processes respectively. In this model, the number of g channels will be optimized with aim to minimize the handoff dropping probability and keep the new calls blocking probability at its minimum.

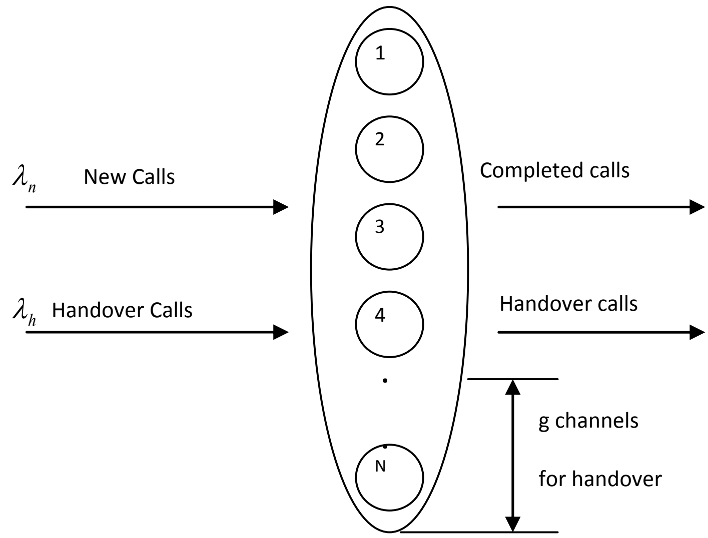


Figure 3.1: Two Classes System Model

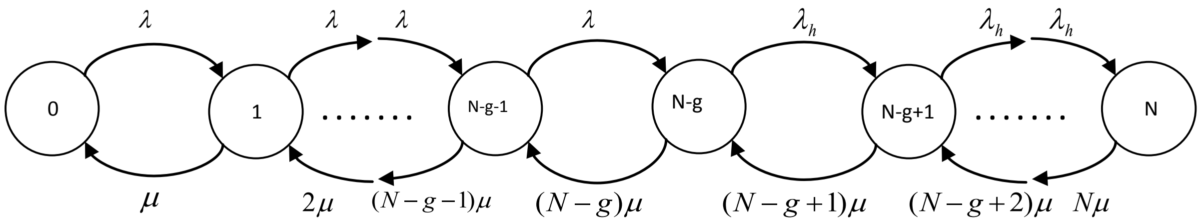


Figure 3.2: State Transition Diagram

3.2.1 Analytical Model

Let λ_n be the rate of Poisson arrival stream of new calls and λ_h be the rate of Poisson stream of handover arrivals. Let μ_c be the rate at which an ongoing call (new or handoff) completes service and μ_h the rate at which the mobile engaged in the call departs the cell. Assume that there are a limited number of channels, N in the cell. When an idle channel is available and a handover call arrives, the call is accepted and a channel is assigned to it. Otherwise, the handover call is dropped. When a new call arrives, it is accepted if there are $g + 1$ idle channels available; otherwise, the new call is blocked. Here, g is the number of guard channels and is less than N in order not to exclude new calls altogether. The system model is illustrated in Figure 3.1, where:

$$\lambda = \lambda_n + \lambda_h \tag{3.1}$$

λ_n : The arrival rate of the new calls.

λ_h : The arrival rate of the handover calls.

$$\mu = \mu_c + \mu_h \tag{3.2}$$

μ_c : The rate at which an ongoing call (new or handover) completes service.

μ_h : The rate at which the mobile engaged in the call departs the cell.

Following the principle of the incoming flow rate equal to the outgoing flow rate, it is possible to write the following equations by using the state transition diagram shown in Figure 3.2:

Flow Rate In = Flow Rate Out Principle

$$\lambda P_0 = \mu P_1 \Rightarrow P_1 = \frac{\lambda}{\mu} P_0 \Rightarrow P_1 = u P_0 \quad , where \quad u = \frac{\lambda}{\mu}$$

$$\lambda P_1 = 2\mu P_2 \Rightarrow P_2 = \frac{\lambda}{2\mu} P_1 = \frac{u}{2} P_1 \Rightarrow P_2 = \frac{u^2}{2!} P_0$$

$$\lambda P_{N-g-1} = (N-g)\mu P_{N-g} \Rightarrow P_{N-g} = \frac{\lambda}{(N-g)\mu} P_{N-g-1} = \frac{u}{(N-g)} P_{N-g-1} \Rightarrow$$

$$P_{N-g} = \frac{u^{N-g}}{(N-g)!} P_0$$

$$\lambda_h P_{N-g+1} = (N-g+2)\mu P_{N-g+2} \Rightarrow$$

$$P_{N-g+2} = \frac{\lambda_h}{(N-g+2)\mu} P_{N-g+1} = \frac{u_1^{\ 2}}{(N-g+2)(N-g+1)} P_{N-g} \Rightarrow$$

$$P_{N-g+2} = \frac{u_1^{\ 2}}{(N-g+2)} \cdot \frac{u^{N-g}}{(N-g+1)!} P_0 \Rightarrow \ P_{N-g+2} = \frac{u_1^{\ 2}.u^{N-g}}{(N-g+2)!} P_0$$

$$P_N = \frac{u_1^{\ n-(N-g)}.u^{N-g}}{N!} P_0$$

$$P_0 + P_1 + P_2 + P_3 + ... + P_{N-g-1} + P_{N-g} + P_{N-g+1} + ... + P_N = 1$$

$$P_0 + uP_0 + \frac{u^2}{2!} P_0 + \frac{u^3}{3!} P_0 + ... + \frac{u^{N-g}}{(N-g)!} P_0 + \frac{u_1.u^{N-g}}{(N-g+1)!} P_0 + \frac{u_1^{\ 2}.u^{N-g}}{(N-g+2)!} P_0 + ...$$
$$..... + \frac{u_1^{\ n-(N-g)}.u^{N-g}}{N!} P_0 = 1$$

$$P_0 [\sum_{n=0}^{N-g-1} \frac{u^n}{n!} \ + u^{N-g} \sum_{n=N-g}^{N} \frac{u_1^{\ n-(N-g)}}{n!}] = 1$$

$$P_0 = \left[\sum_{n=0}^{N-g-1} \frac{U^n}{n!} + U^{N-g} \sum_{n=N-g}^{N} \frac{U_1^{\ n-(N-g)}}{n!} \right]^{-1} \qquad (3.3)$$

where $U_1 = u_1 \ \ and \ U = u$

Then it is possible to obtain the expression of P_n

$$P_n = \begin{cases} \dfrac{U^n}{n!} P_0 & n < N-g \\ \dfrac{U^{N-g}}{(N-g)!} P_0 & n = N-g \\ \dfrac{U_1^{\ n-(N-g)}.U^{N-g}}{n!} P_0 & N > n > N-g \end{cases} \qquad (3.4)$$

The blocking probability for the new calls becomes

$$P_b(N,g) = \sum_{n=N-g}^{N} P_n = \frac{\sum_{n=N-g}^{N} \frac{U^{N-g}.{U_1}^{n-(N-g)}}{n!}}{\sum_{n=0}^{N-g-1} \frac{U^n}{n!} + U^{N-g} \sum_{n=N-g}^{N} \frac{{U_1}^{n-(N-g)}}{n!}} \quad (3.5)$$

The dropping probability for Handoff calls is

$$P_d(N,g) = P_N = \frac{\frac{U^{N-g}.{U_1}^{g}}{N!}}{\sum_{n=0}^{N-g-1} \frac{U^n}{n!} + U^{N-g} \sum_{n=N-g}^{N} \frac{{U_1}^{n-(N-g)}}{n!}} \quad (3.6)$$

3.2.2 Validation of the Model

A discrete-event simulator has been developed in order to validate the above analytical model. An M1+M2/M/C/C Loss Queuing System has been simulated where M1 and M2 represent the Poisson processes of the New Call (M1) and handover Arrivals (M2), respectively, in the cellular Mobile Wireless System shown in Figure 3.1. Because the Handover failure is more serious than blocking new calls, Handover has been assigned a higher priority than New Calls.

There are N channels in this system, of which C are free. Handover (M2) is treated with higher priority. So the system works as follows:

- For Handover Arrivals (M2)

  If $C > 0$ then accept Handover, else Block

- For New Call Arrivals (M1)

  If $C > n > g$ then accept a New Call, else Block, where n is the threshold

So, in this simulation, there are g free channels specifically for Handover Arrivals (M2).

Table 3-1: Simulation Parameters for Single Cell

	Symbol	Assumed Value
New Call Arrival Rate	λ_n	0.01
Handoff Call Arrival Rate	λ_h	Varied from 0.0125 to 0.2
Service Rate	μ	0.01
Total Number of Channels in the Cell	N	16
Number of Guard Channels	g	2

In the simulation experiments, the number of channels N is set to 16 and g to 2. The interarrival time of new calls follows an exponential distribution, with a mean of 100, and the service time is equal to 100. The interarrival time of the handover call varies from 5 to 80. As can be seen in Figures 3.3 and 3.4, the results of blocking probability and drop probability obtained from simulation experiments and analytical models are the same. The results obtained from both the analytical and the simulation models are show in table 3.1 below.

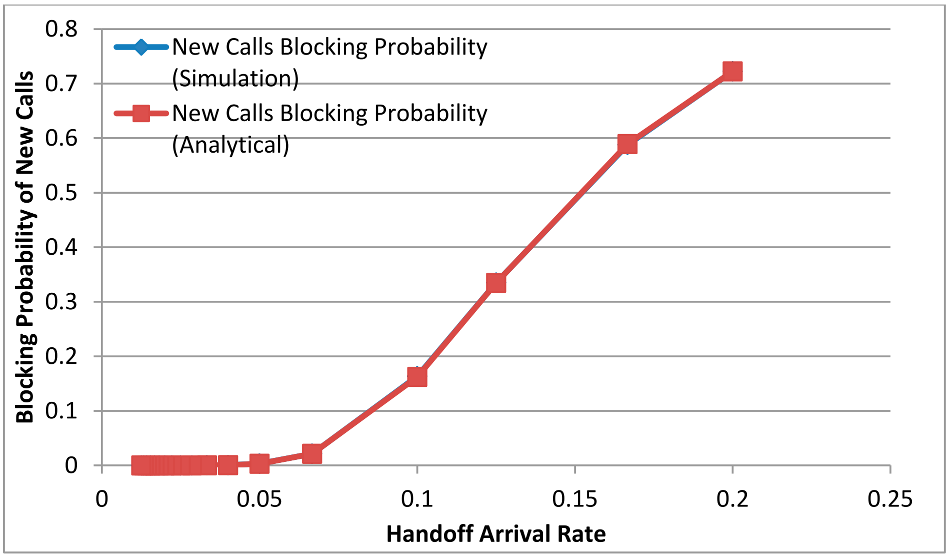


Figure 3.3: Validation of the Analytical Performance Model of New Calls Blocking Probability by a Simulation.

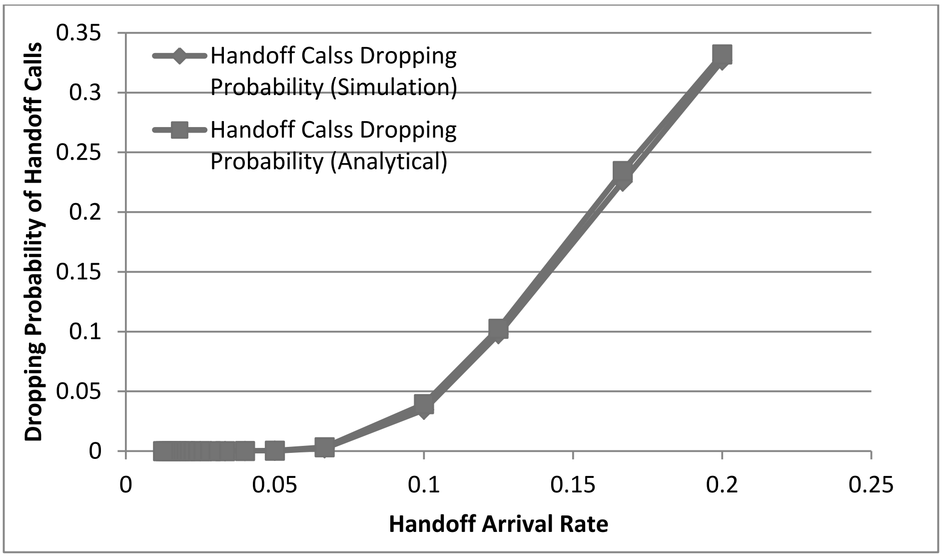


Figure 3.4: Validation of the Analytical Performance Model of Handoff Dropping Probability by a Simulation

Table 3-2: Results of the Analytical Performance Model and the Simulation of Handoff Dropping Probability and New calls Blocking Probability

Handoff Arrival Rate	New Calls Blocking Probability (Simulation)	Handoff Dropping Probability (Simulation)	New Calls Blocking Probability (Analytical)	Handoff Dropping Probability (Analytical)
0.2	0.722431795	0.326853337	0.7224	0.3319
0.166666667	0.587853513	0.225468462	0.5891	0.2344
0.125	0.335167335	0.097892998	0.3349	0.1024
0.1	0.163429276	0.034630744	0.1625	0.0393
0.066666667	0.021338111	0.002428576	0.0213	0.0032
0.05	0.003294998	2.37E-04	0.0032	3.34E-04
0.04	6.36E-04	3.25E-05	6.29E-04	4.91E-05
0.033333333	1.53E-04	4.68E-06	1.57E-04	9.70E-06
0.028571429	4.90E-05	2.29E-06	4.79E-05	2.42E-06
0.025	1.85E-05	8.40E-07	1.71E-05	7.32E-07
0.022222222	6.13E-06	0	6.95E-06	2.57E-07
0.02	3.30E-06	0	3.14E-06	1.02E-07
0.018181818	1.41E-06	0	1.55E-06	4.52E-08
0.016666667	1.07E-06	0	8.23E-07	2.17E-08
0.015384615	5.08E-07	0	4.64E-07	1.12E-08
0.014285714	7.28E-07	0	2.76E-07	6.15E-09
0.013333333	0	0	1.73E-07	3.58E-09
0.0125	0	0	1.12E-07	2.17E-09

3.2.3 Performance Analysis

From the performance analytical model, it is possible to obtain the optimised number of channels assigned to handover calls g with the aim of minimsing the drop probability of Handover Calls P_d while keeping the blocking probability of new calls P_b as minimum as possible. It is known that increasing g will decrease the drop probability of handover calls, but it will increase the blocking probability of new calls. Using Matlab software P_d and P_b were calculated from equations 3.5 and 3.6, and it was found that the best g for minimising the drop probability and also minimising the blocking probability of new calls is $g = 1$ when there are 16 channels in the cell; this is illustrated in Figure 3.5 below.

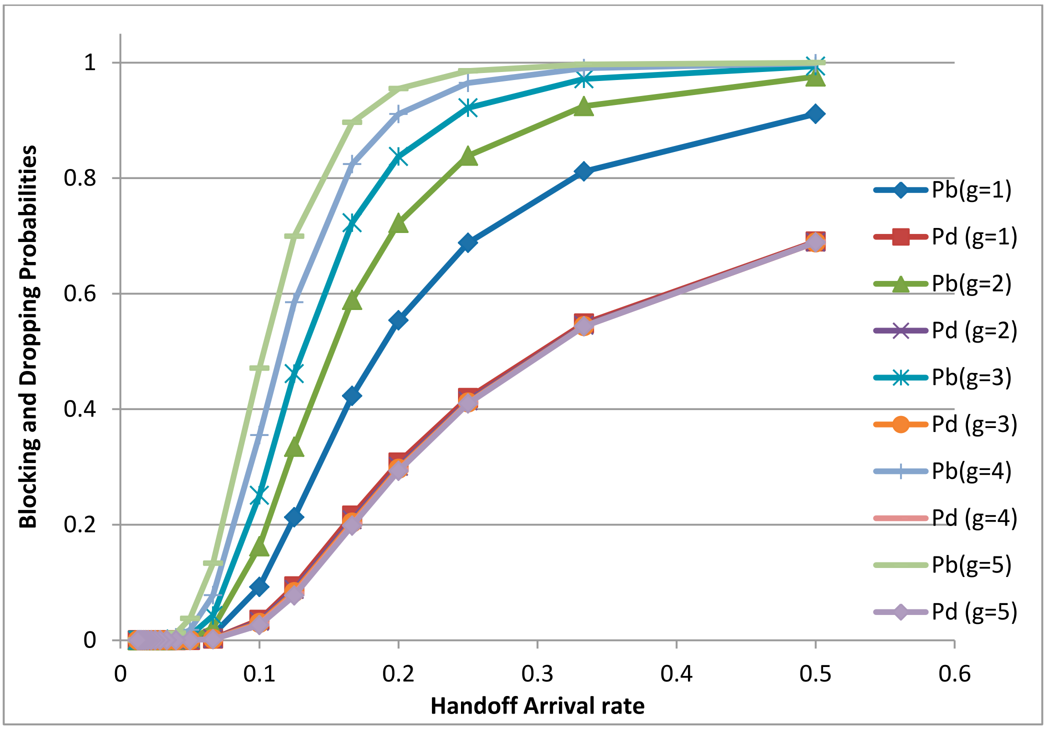


Figure 3.5: Optimisation of Handover Guard Channels (g)

3.3 Performance Model of Handoff Mechanisms in Two-Cells

In this Section, a two-cell model is considered, where each cell is represented by a single server queue with finite capacity, as shown in Figure 3.6. In this model, the basic performance parameters of a queuing network are derived, such as mean number of active calls in each one of the queues (cells); the loss probability of each queue (blocking probability for each cell); mean response time or the delay in each queue (cell), and the throughput of each queue (cell). Also, some analysis will be carried out to decrease the blocking probability of the network while at the same time increasing the number of users in the network.

3.3.1 Network System Model

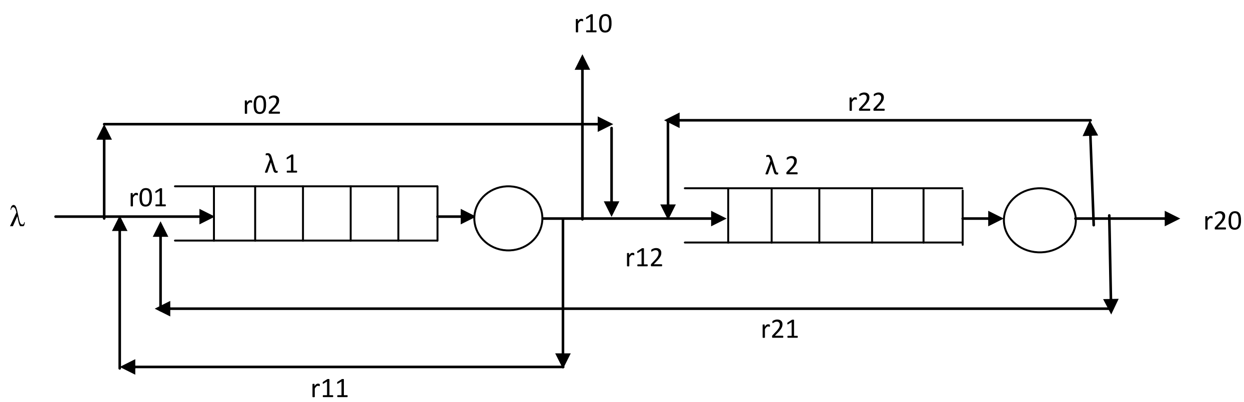


Figure 3.6: Two cells queuing system model

Here, a cellular network containing two cells is modelled. Each queue in the above Figure 3.6 represents a cell, and each queue has a finite capacity, where Q_1, and Q_2

correspond to the capacities for queue 1 and 2 respectively; including calls that are currently in service. The arrival process in this model is based on the identical independent distribution (Poisson arrival). In this queuing network system, each queue node will be analysed separately in order to come up with the traffic equations for each one of them. It is assumed that λ is the arrival rate probability of the external calls (calls arriving from outside the system). λ_1 and λ_2 are the probabilities of calls that arrive at cell1 and cell 2 respectively. It is also assumed that the queuing network is in equilibrium, and the process of each queue is Markov chain with finite state space. The state spaces of queue cell 1 are {0, 1, 2, 3, …., Q_{1-1}, Q_1} and the state spaces for queue cell 2 are {0, 1, 2, 3, …., Q_{2-1}, Q_2}.

Since each queue node in the queuing network system is analysed separately, the arrival rate for each queue node requires an independent evaluation. The equations below represent the arrival rate of calls for queue node 1 and 2, respectively,

$$\lambda_1 = r_{01}\lambda + r_{11}\lambda_1 + r_{21}\lambda_2 \quad (3.7)$$

$$\lambda_2 = r_{02}\lambda + r_{12}\lambda_1 + r_{22}\lambda_2 \quad (3.8)$$

Where,

$$\lambda = r_{01}\lambda_1 + r_{02}\lambda_2 \quad (3.9)$$

After solving the above equations recursively, the final form is obtained for λ_1 and λ_2 as follows:

$$\lambda_1 = \frac{\lambda r_{01}(1 - r_{22}) + \lambda r_{02} r_{21}}{(1 - r_{11})(1 - r_{22}) - r_{12} r_{21}} \quad (3.10)$$

$$\lambda_2 = \frac{\lambda r_{02}(1 - r_{11}) + \lambda r_{01} r_{12}}{(1 - r_{11})(1 - r_{22}) - r_{12} r_{21}} \quad (3.11)$$

From the above equations, r_{12} and r_{21} represent the routing probabilities of calls between the two queue nodes in the queuing network, and (r_{10}, r_{20}) represent the probabilities of calls leaving the queuing network from queue node 1 and 2 respectively. Also r_{01} and r_{02} represent the routing probabilities of calls that arrive from outside the network to queue nodes 1 and 2 respectively. In the analysis of the analytical model and the simulation, it has been assumed that the probability of external calls arriving to node 1 is 60%, whereas it is 40% for node 2. Thus, queue node 1 has higher priority than queue node 2 in serving calls which arrive from outside the network. By using the state transition diagram for each queue node and by deriving the balance equation for both the queue nodes, the blocking or loss probability of queue node 1 has been obtained:

$$P_{1loss} = \frac{(1 - u_1){u_1}^{k_1}}{1 - {u_1}^{k_1+1}} \quad (3.12)$$

And for queue node 2:

$$P_{2loss} = \frac{(1 - u_2){u_2}^{k_2}}{1 - {u_2}^{k_2+1}} \quad (3.13)$$

Also, the mean number of active calls in the queue cell 1 or mean queue length for queue node 1 is:

$$E[N]_1 = \frac{u_1}{1 - u_1} - \frac{(k_1 + 1){u_1}^{k_1+1}}{1 - {u_1}^{k_1+1}} \quad (3.14)$$

and for queue cell 2 is:

$$E[N]_2 = \frac{u}{1 - u_2} - \frac{(k_2 + 1){u_2}^{k_2+1}}{1 - {u_2}^{k_2+1}} \quad (3.15)$$

The mean response time (or mean total delay) for queue cell 1 is:

$$E[T]_1 = \frac{E[N]_1}{\lambda_1(1 - P_{1loss})} \quad (3.16)$$

And for queue cell 2 is:

$$E[T]_2 = \frac{E[N]_2}{\lambda_2(1 - P_{2loss})} \quad (3.17)$$

Also, the Throughput of queue cell 1 is:

$$Th_1 = \lambda_1(1 - P_{1loss}) \quad (3.18)$$

And for queue cell 2 is:

$$Th_2 = \lambda_2(1 - P_{2loss}) \quad (3.19)$$

Where, $u = \frac{\lambda}{\mu}$ and $u_1 = \frac{\lambda_1}{\mu_1}$ and $u_2 = \frac{\lambda_2}{\mu_2}$.

The joint equilibrium probability for the queuing network is expressed as:

$$P(Q_1, Q_2) = P(Q_1)P(Q_2) \quad (3.20)$$

where, K_1 calls at queue node 1 and K_2 calls at queue node 2, then the blocking (loss) probability for the network:

$$P_{loss} = P_{1loss} * P_{2loss} \quad (3.21)$$

And the mean number of active calls in the system:

$$E[N] = \sum_{m=1}^{m} E[N_m] = E[N]_1 + E[N]_2 \quad (3.22)$$

The total network throughput is:

$$Th = \sum_{m=1}^{m} Th_m = Th_1 + Th_2 \tag{3.23}$$

From this the mean response time (or mean total delay) can be found for the network:

$$E[T] = E[N]/Th \tag{3.24}$$

3.3.2 Validation of the Model

A simulation has been developed to validate the above analytical model. In this simulation, the capacity of each queue of two cells is considered to be 16 channels, and the arrival rate to the system follows an exponential distribution with the mean varying from 0.01 to 0.75. It is considered that 60% of this arrival rate will enter to cell one and 40% will enter to cell two. The service rate for each queue of the two cells is equal to 0.6. As each queue of the two cells have arrivals coming from three different sources (from outside plus; queue one of cell one, arrivals come from itself r_{11} and from cell two r_{21}.for queue two of cell 2, arrivals come from itself r_{22} and from cell one r_{12}) it is assumed that the mean arrival rate of all these are equal to 0.3.

Table 3-3: Simualtion Parameters for Two Cells

	Symbol	Assumed Value
Arrival Rate to the System	λ	Varied from 0.01 to 0.75
Arrival Rate to Queue 1	λ_1	0.6
Arrival Rate to Queue 2	λ_2	0.4
Service Rate of both Queues	μ_1=μ_2	0.6
Arrival Probabilities to Queue 1	$r_{11} = r_{21} = r_{01}$	0.3
Arrival Probabilities to Queue 2	$r_{22} = r_{12} = r_{02}$	0.3
Queue 1 Capacity	Q_1	16

Queue 2 Capacity	Q_2	16

As can be seen in Figures 3.7, 3.8, 3.9 and 3.10, the results of Loss Probability, Mean total Delay, Mean number of active calls and throughput obtained from simulation experiments and analytical models shows a very close agreement.

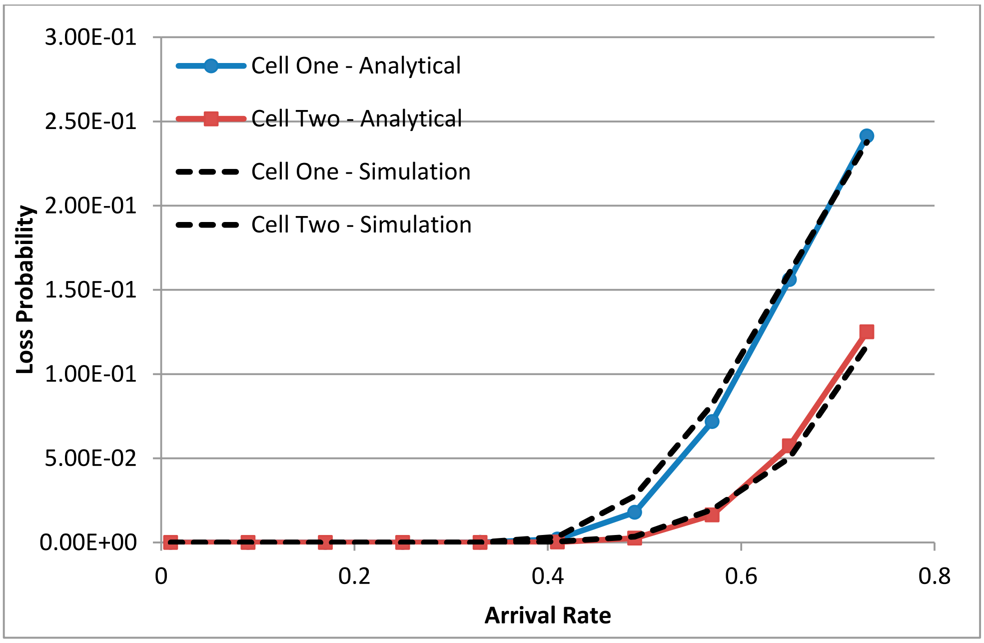


Figure 3.7: Loss Probability for each Queue

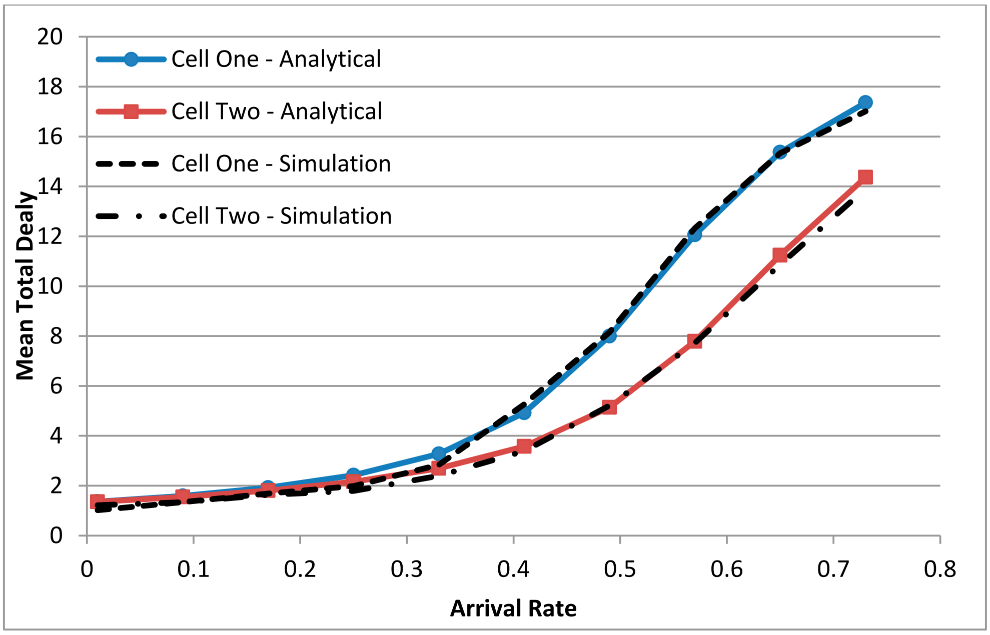


Figure 3.8: Mean Total Delay or Mean Response Time for each Queue

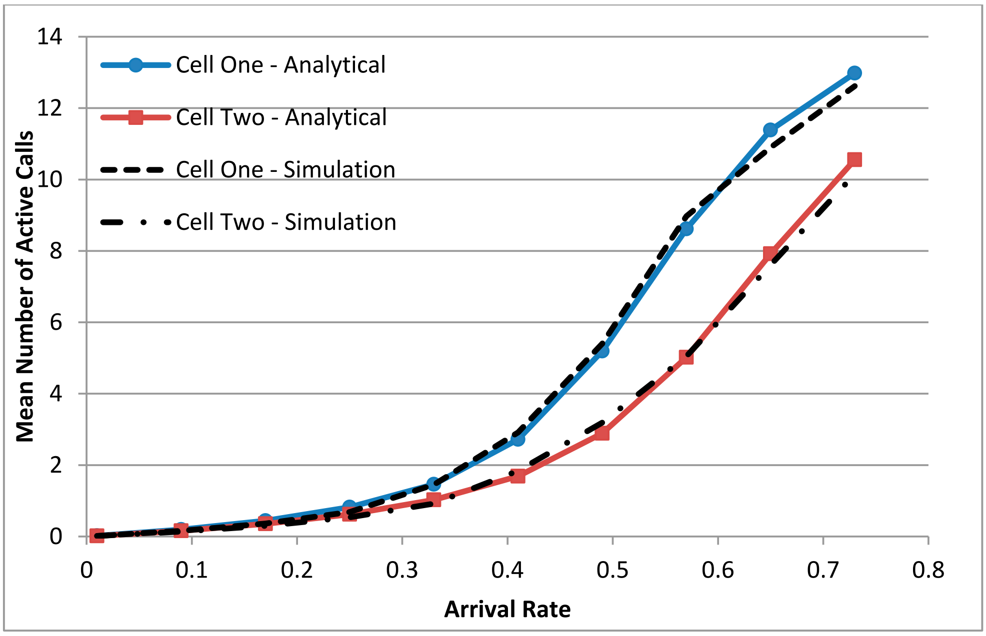


Figure 3.9: Mean Number of Active Calls or Mean Queue Length for each Queue

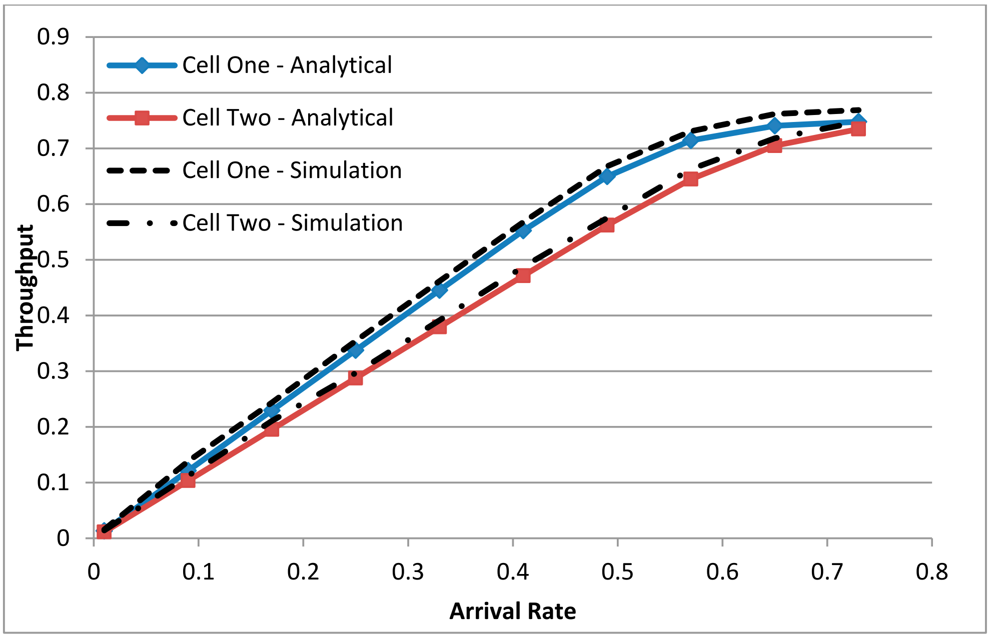


Figure 3.10: Throughput for each Queue

3.3.3 Performance Analysis

Here, the network is being tested as one system to see how the blocking probability of the network decreases when the cell capacity is increased by increasing the number of channels in the cells of the network, as shown in Figure 3.11 below. Also, in Figure 3.12, it can be seen that by increasing the capacity of the cells in the network, the mean number of active calls in the network increases.

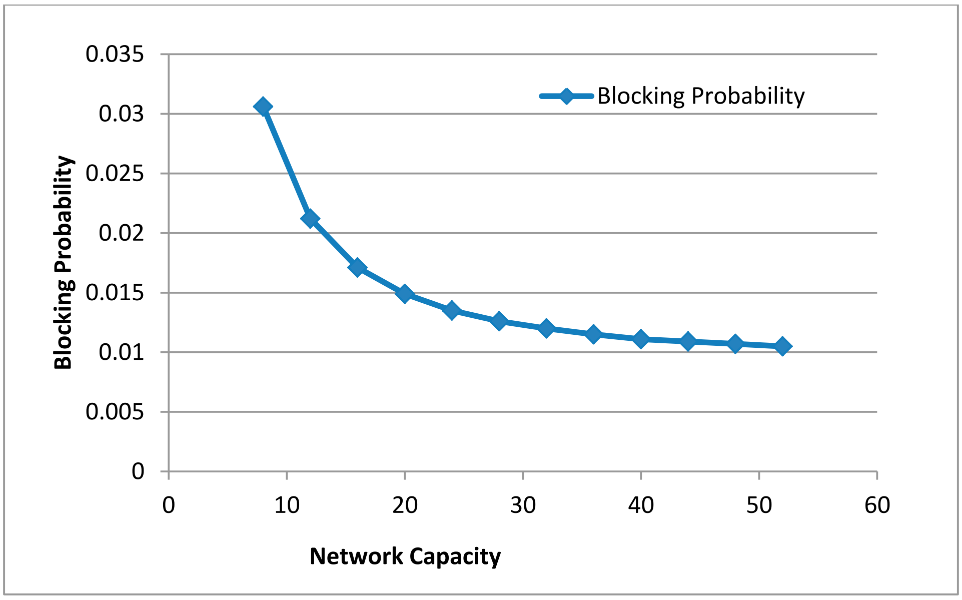


Figure 3.11: Blocking Probability of a Two-Cells Network

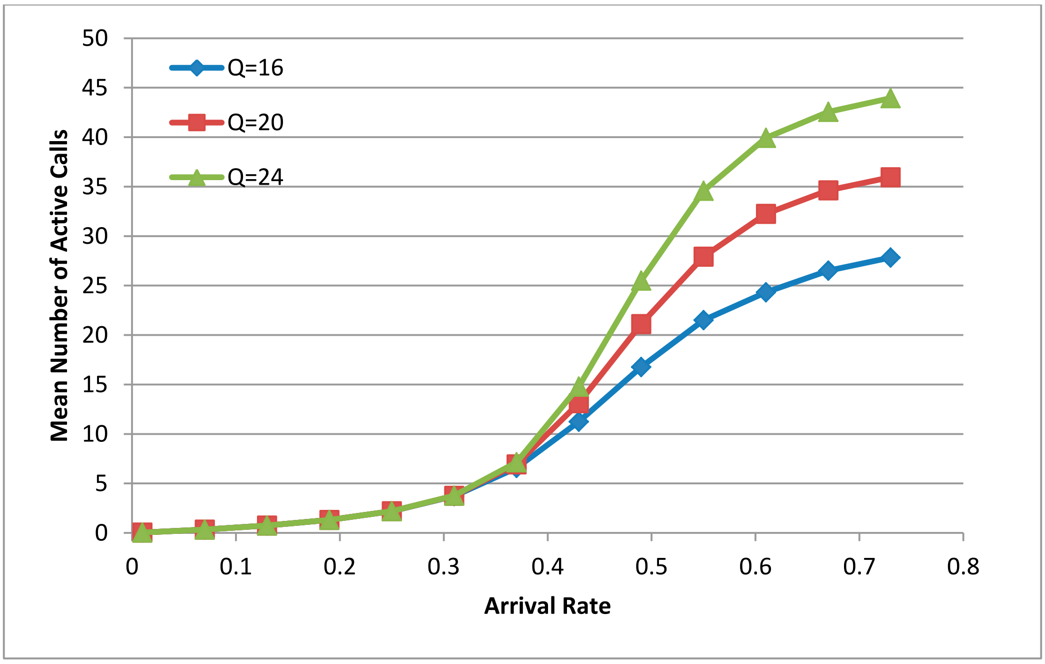


Figure 3.12: Mean Number of Active Calls in a Two-cells Network

In Figure 3.13 below, the loss probability in the network is shown when the handoff rate between the two cells increases. Here, the rate of r_{12} is changed from 0.3 to 0.6, increasing by 0.1 each time. r_{12} is the handoff rate of calls moving from cell 1 to cell 2. Here, it is considered that cell 2 is in an area that has more traffic coming to it from cell 1. It can be seen from the graph that the loss probability of cell 2 increases more than the loss probability of cell 1. The same thing will happen to cell 1 by increasing r_{21}; which is the handoff rate from cell 2 to cell 1.

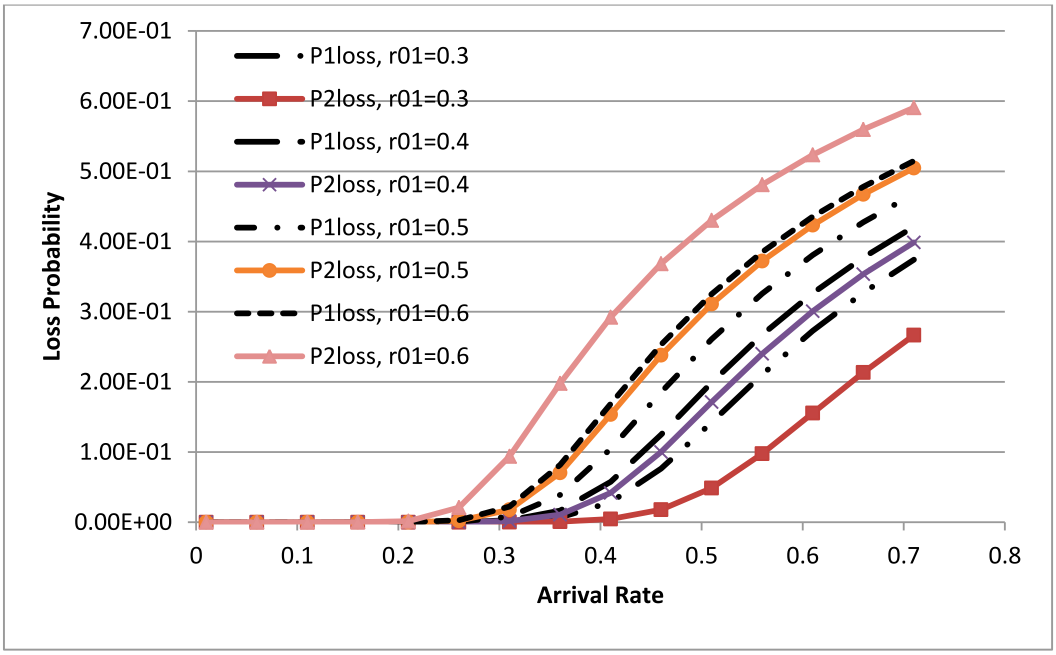


Figure 3.13 : Loss Probability in the network by increasing the handoff rate between the cells

3.4 Summary

In this chapter, the analytical model for priority handoff mechanisms has been derived and validated, with new calls and handoff calls captured by two different traffic arrival processes. Also, the model has been used to optimise the number of channels assigned to handoff calls, which minimises the dropping probability of handoff and the blocking probability of new calls under given network scenarios.

Also in this chapter, a performance model has been derived for two-cell and the different QoS parameters for the network found. The analytical model has been validated through a simulation. Each cell in the network is represented by a single queue with finite capacity. This queuing model can be developed in the future to represent each cell in a multiple server queuing system. Also, this work can be extended and study can be done on more cells. Work in the future will focus on a cluster of 7 cells.

Chapter 4

Bandwidth Re-Allocation Management in 3G Wireless Cellular Networks

4.1 Introduction

Bandwidth Management in wireless cellular networks is a critical issue, especially if the mobile node is a multimedia one and wants to transmit video information or video and data together. In wireless mobile cellular networks, if bandwidth is not managed properly, either it gets wasted or does not reach to the needy sources that want to connect to the network. Also, the dropping probability of handoff calls and blocking probability of locally generated calls will be increased. With proper bandwidth management, the service provider can gain benefits from generating more revenue and the network could accommodate a greater number of users.

Solutions available for wire line networks cannot be applied to wireless mobile cellular networks, due to the unpredictable movement of the mobile node, changing of signaling power and frequent migration of calls from one cell to another. Certain mechanisms are needed in allocation of bandwidth and managing the bandwidth in the cell, which can tackle the above problems so that network resources can be utilised properly.

Many solutions have been proposed regarding bandwidth allocation and management. Scalable QoS architecture for mobile Ad Hoc networks is proposed in [63], and increasing the utilisation of resources through accurate prediction by using mobile tracking methods is mentioned in [64]. An online load balancing solution for multimedia cellular network is proposed in [65] and [66]. Adaptive bandwidth allocation to increase system utilisation with degradation of QoS is shown in [67]. In [68], a distributed adaptive bandwidth allocation and admission control scheme is proposed, where the authors attempt to limit the dropping probability for handoff calls based upon the number of successes and failures of handoff calls. In [69], a novel QoS management scheme based on per class degradation is proposed. In [70], an admission control and Daynamic Bandwidth Management scheme that provides fairness in the absence of distributed link level weighted fair scheduling is proposed. A dynamic and adaptive bandwidth management scheme is proposed to provide a satisfactoty QoS guarantee as possible for wireless multimedia services under variable traffic conditions is suggested in [71]. An Adaptive Bandwidth Management and Reservation Scheme in Heterogeneous Wireless Networks is proposed in [72]. A resource Management strategy for heterogeneous adaptive-rate traffic which is a combination of CAC management strategy and bandwidth management is propsed in [73].

In this chapter, a new solution is proposed to manage the bandwidth. In this solution, bandwidth, which is not utilised by fewer mobile nodes, will be re-allocated to the needy ones. In order to maintain the Quality of Service (QoS) for the higher priority handoff call (multimedia call), the focus here is on allocating the required bandwidth to this call and maintaining constancy during its connection life time. For the lower priority handoff call (data call) at least minimum bandwidth will be allocated in the worst-case scenario. The unutilised bandwidth will be distributed fairly among active lower priority nodes, which will be utilised later on by either handoff calls or incoming local calls. With this method, maximum bandwidth in the cell will be reached; it will remain available whenever there is a new call, either handoff or locally generated, and the wastage of network resources could be avoided. The dropping probability of handoff calls will be reduced to a minimum and blocking probability of newly generated calls will be maintained at a minimum through this method. In this scheme, QoS could be maintained for multimedia calls, and flexibility in changing the bandwidth for data calls will keep the network always at maximum utilisation of network resources.

4.2 Channel Allocation Schemes

Bandwidth is allocated in the form of channels. Channels are allocated to cells and these channels are used to communicate within the cell by mobile nodes. Three major categories are used for assigning the channels. They are: 1. Fixed channel allocation (FCA); 2. Dynamic channel allocation (DCA), and 3. Hybrid channel allocation (HCA).

Fixed channel allocation (FCA) is a widely used channel allocation method. In fixed channel allocation (FCA), fixed numbers of channels are assigned to each cell in a network. It is a static channel allocation method and cannot be changed. In this method, if calls arrive in excess of the allocated number of channels, the assignment of channels to these calls become difficult, and the dropping and blocking probability of handoff and local calls will be increased. Also, if a large enough number of calls is not available in the queue, then some channels will not be used and it is a waste of resources. This is not an appropriate method for non-uniform traffic in the cell. In dynamic channel allocation (DCA) method, the channels are allocated whenever needed by the cell, following the channel reuse distance rules, which should not be violated. The bandwidth in the network will be utilised in a more efficient manner and this can avoid the wastage of resources. Whenever bandwidth is needed, channels can be assigned from a pool cell if enough channels are not available in the cell. Many schemes have been proposed in dynamic allocation of channels [74 – 78]. In the hybrid channel allocation (HCA) method, both techniques, static and dynamic, are used in assigning the channels [79, 80]. Many sub schemes have been proposed in this hybrid method. One of them is channel borrowing from neighbouring cells [46, 81]. If the fixed allocated channels are exhausted, then channels will be borrowed from a neighbouring cell following the non-violation of frequency reuse.

4.3 Proposed Architecture and Bandwidth Management Scheme

4.3.1 Architecture

In this proposed architecture, all base stations (BS) in cells are connected together wirily and communicate to one another regarding their status of bandwidth information as shown in Figure 4.1. There is no centralised managed system used in this architecture. The main drawback to the centrally controlled system is that if any problem occurs in the central system or central controller, the whole network will be affected. To overcome this problem, each base station in a cell should be given the responsibility to manage its own bandwidth with the knowledge of bandwidth available at other base stations in the network. To do this, all base stations in network should be connected together and should be capable of communicating with one another. With this method, if any problem occurs in network, only a part of the network will be affected and the number of users in other parts of the network can utilise the resources without being interrupted.

Every base station maintains its bandwidth table, as shown in Table 4.1 below, and updates at every averaging interval according to the changing conditions of the network. The bandwidth table in each cell contains information about the bandwidth negotiation, allocation and utilisation of each multimedia node (higher priority node), minimum guaranteed bandwidth for each data node (lower priority node) and unutilised bandwidth of both types of nodes, as well as if there is any freely available bandwidth in the cell.

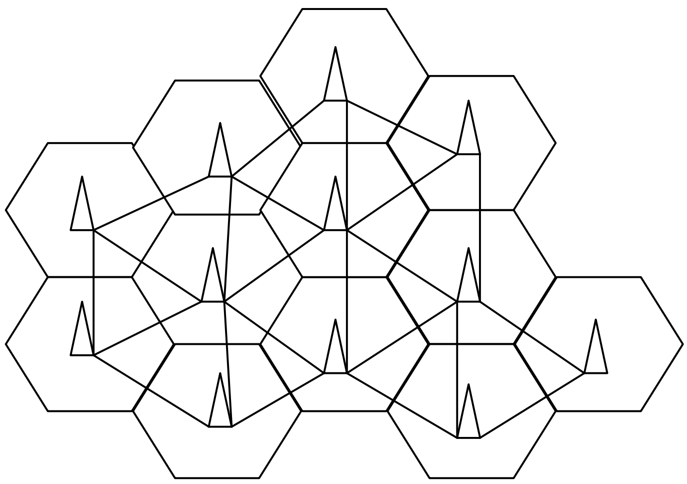


Figure 4.1: Cellular Network Architecture

Table 4-1: Bandwidth Table

Bandwidth Table				
Node	Negotiated & Allocated B. W	Utilised B. W	Minimum Guaranteed B. W	Un Utilised B. W
$Node_{1H}$	2	2		0
$Node_{2H}$	2	1		1
$Node_{1L}$	0.75	0.75	0.5	0
$Node_{2L}$	0.75	0.75	0.5	0
$Node_{3L}$	0.75	0.5	0.5	0.2
$Node_{4L}$	0.75	0.5	0.5	0.2
$Node_{5L}$	0.75	0.75	0.5	0
$Node_{6L}$	0.75	0.75	0.5	0
$Node_{7L}$	0.75	0.75	0.5	0
$Node_{8L}$	0.75	0.5	0.5	0.2

$Node_H$: Multimedia node (Higher Priority Node)

$Node_L$: Data node (Lower Priority Node)

4.3.2 Proposed Bandwidth Management Scheme in Three Scenarios

Bandwidth Management for different services in wire line ATM networks is proposed by the Raj Jain group. In this paper, the basic idea was adapted from ERICA algorithm [82 – 87] and modified to suit handoff calls in mobile wireless cellular networks. A bandwidth management scheme is proposed here in three scenarios:

- Bandwidth managed for existing calls.
- Bandwidth managed when higher priority handoff calls arrive.
- Bandwidth managed when lower priority handoff calls arrive.

In this proposal, two types of calls are used, one is higher priority calls and the other one is the lower priority call. Higher priority calls are multimedia calls and are delay sensitive, and negotiated bandwidth has to be allocated and maintained during connection lifetime. Lower priority call is a data call whose bandwidth is flexible and changes according to the changing network conditions; it is delay tolerant and minimum bandwidth has to be maintained for this call. Lower priority calls will utilise the maximum freely available bandwidth if the network is not having many higher priority calls. As the number of higher priority calls increases, the lower priority calls are asked to reduce their transmission rates.

Each higher and lower priority call can be in any one of three forms. The first one is an active form (active call), which will fully utilize the 100% allocated bandwidth. The second one is a semi active form (semi active call), which will utilise a portion of allocated bandwidth, and the third and final one is the passive form (passive call), which will never utilise the allocated resource.

4.3.2.1 Bandwidth Management for existing calls

All the calls in a cell may not use fully allocated bandwidth (semi active) during their connection period due to various reasons, such as due to bottleneck problems for some calls, and other calls they may not need part of the allocated resources. Also, some calls may not use any allocated bandwidth (passive calls) at all due to line of sight problems or large variation in their signalling power. It is assumed that no calls are waiting in the queue and no request for channels has been received from neighbouring cells as shown in Figure 4.2. In this situation, part of the bandwidth will get wasted. In order to avoid the wastage, this portion of unutilised bandwidth will be distributed fairly among active lower priority calls. If any part of allocation is not being used after this distribution, it will be left in the unutilised Section. With this method, the network condition changes from under load to normal load.

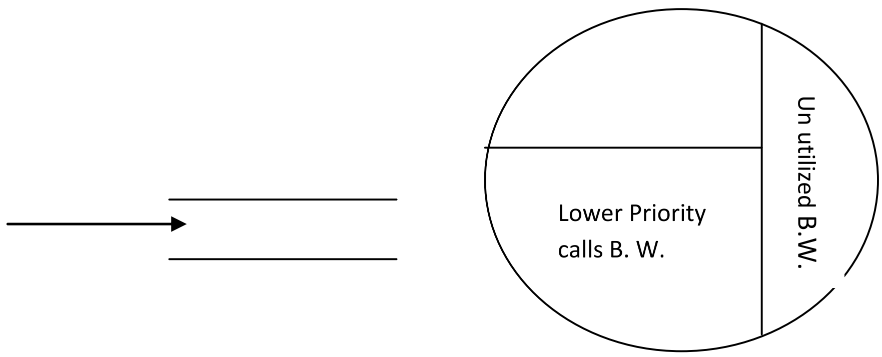


Figure 4.2: Bandwidth in Cell with no Handoff Calls in Queue

4.3.2.2 Bandwidth Management when Higher Priority Handoff Calls Arrive

If the higher priority call wants to travel from one cell to another neighbouring cell, the base station in the existing cell will inform the base station in neighbouring cell, where this mobile node is expected to migrate to, about the bandwidth requirement. The neighbouring cell will reserve bandwidth following the procedure specified below.

For higher priority handoff calls, initially the base station will check if enough bandwidth is available in the unutilised section. If it is available, then that will be reserved for this call; otherwise, a portion of bandwidth from lower priority calls will be added to this unutilised bandwidth in order to fulfill the request. If at this stage the requirement is still not fulfilled, then it will borrow part of the bandwidth from a neighbouring cell and this will be added to the above sum. This bandwidth will be reserved and allocated for this call.

Since it is a higher priority call, this bandwidth will be allocated and maintained constantly during its connection lifetime. Priority will be given to this call against lower priority handoff calls and locally generated calls.

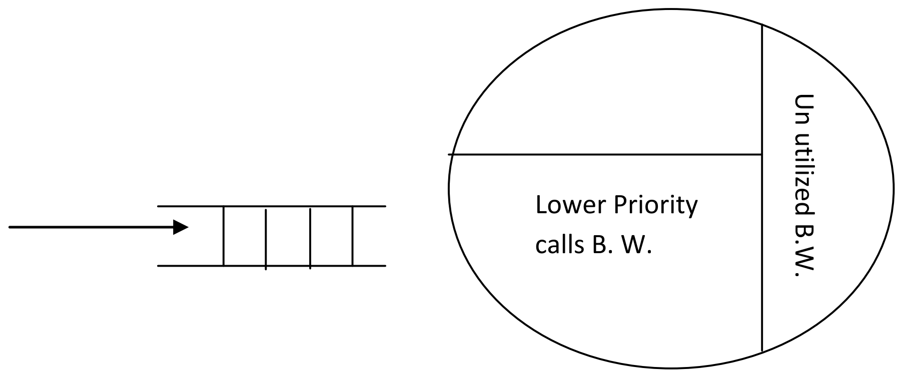


Figure 4.3: Bandwidth in Cell with Handoff Calls in Queue

4.3.2.3 Bandwidth Management when Lower Priority Handoff Calls Arrive

If the migrated call is a lower priority one, the base station in the cell will first check, as above, in the unutilised section for enough availability of bandwidth, or at the least minimum amount. If available, that will be allocated to this call. If this bandwidth is not enough or not even minimal, then part of the bandwidth from active lower priority calls will be added to the unutilised part as above and will be reserved. If at this stage, it is still not obtaining the minimum then part of the bandwidth from a neighbouring cell will be borrowed and added. This bandwidth will be reserved and allocated to this call. If it has not obtained the minimum, this call has to negotiate the minimum bandwidth or wait in the queue as shown in Figure 4.3. Preference will be given to this handoff call against locally generated calls.

4.4 Proposed Algorithm

The following is the proposed algorithm for the mentioned three scenarios of the bandwidth management scheme.

$Begin$

IF $(no\ calls\ in\ queue\ \&\ no\ bandwidth\ requests\ from\ neighbour)$ $Then$

$add\ bandwidth\ leftover\ by\ semi\ active\ calls\ with\ total\ unutilized$

$bandwidthfrom\ passive\ calls\ and\ distribute\ among\ active\ calls$

$Else\ IF$ $(the\ call\ in\ queue\ is\ higher\ priority)$ $Then$

$Reserve\ \&\ allocate\ enough\ badnwidth\ either\ from\ unutilized$

$portion\ or\ from\ part\ of\ active\ lower\ priority\ calls\ or\ borrow$

$from\ neighbour\ or\ combination\ of\ all$

$Else\ IF$ $(the\ call\ is\ lower\ priority\ call)$ $Then$

$Allocate\ at\ least\ the\ minimum\ either\ from\ unutilized\ portion\ or$

$from\ active\ lower\ priority\ calls\ or\ borrow\ from\ neighbour$

$Else$

$Negotiate\ Bandwidth\ or\ wait\ in\ queue$

End

4.5 Analytical Evaluation

Analytical evaluation has been done for three Scenarios: for existing calls; when a higher priority handoff call arrives, and when a lower priority handoff call arrives.

4.5.1 Bandwidth Management for Existing Calls

In this scenario, it is assumed that no calls are waiting in queue and no bandwidth is requested from neighbours.

Let Total Bandwidth allocated to calls = BW_T

Total Bandwidth utilised by calls = BW_{UT}

Total Bandwidth not utilised $BW_{NUT} = BW_T - BW_{UT}$

Total number of Active Lower Priority calls $C_{ALN} = [C_{AL1}C_{AL2}C_{AL3} \dots \dots \dots \; C_{ALN}]$

Bandwidth for Active Lower Priority call = BWC_{AL}

Total Bandwidth utilised by Active Lower Priority calls = BWC_{UTAL}

Bandwidth Distribution among Active Lower Priority calls = BW_{NUT}/C_{ALN}

New Total Bandwidth for Active Lower Priority calls = $BWC_{UTAL} + BW_{NUT}$

Added Bandwidth for each Lower Priority Call = $(BW_T - BW_{UT})/C_{ALN} = BW_{NUT}/C_{ALN}$

New Total Bandwidth for Active Lower Priority calls

$= (BW_{NUT}/C_{ALN}) + [BWC_{AL1}BWC_{AL2}BWC_{AL3} \dots \dots \dots BWC_{ALN}]$

New Total Bandwidth for Active Lower Priority calls:

$$BW_{ALT} = \left(\frac{BW_{NUT}}{C_{ALN}}\right) + \sum_{C_{AL1}}^{C_{ALN}} BWC_{ALN} \qquad (4.1)$$

Bandwidth Management when Local call generated within the cell

Bandwidth reduction from each Active Lower Priority Call =

$$= \frac{Total\ Bandwidth\ of\ Active\ Lower\ Priority\ Calls\ after\ Minimum}{Total\ Number\ of\ Active\ Lower\ Priority\ Calls} = \frac{BW_{ALT}}{C_{ALN}}$$

New Bandwidth for each Active Lower Priority Call

$= (C_{ALN}) - [BWC_{AL1}BWC_{AL2}BWC_{AL3} \dots \dots\ BWC_{ALN}]$

$BW_{ALT}(Old) \rightarrow BW_{ALT}(New)$

In this scenario, every averaging interval base station in the cell will evaluate, as shown above, and try to keep its unutilised section to a minimum.

4.5.2 Bandwidth Management when Higher Priority Handoff Call Arrive

Bandwidth Requested by Higher Priority Handoff Call = BW_{reqH}

Total Bandwidth utilised by Active Lower Priority Call = BW_{UTAL}

Total Bandwidth of Active Lower Priority Calls calculated after minimum = BW_{ALTM}

Bandwidth Borrowed from Neighbouring Cell = BW_{Borrow}

$IF\ BW_{reqH} < BW_{ALTM}$

$\quad BW_{reqH} \leftarrow (obatin\ from\ BW_{ALTM})$

$IF\ BW_{reqH} = BW_{ALTM}$

$\quad BW_{reqH} \leftarrow BW_{ALTM}$

$IF\ BW_{reqH} > BW_{ALTM}$

$\quad BW_{reqH} \leftarrow (BW_{ALTM} + BW_{borrow})$

4.5.3 Bandwidth Management when Lower Priority Handoff Call Arrive

Bandwidth Requested by Lower Priority Handoff Call $= BW_{reqL}$

$IF\ BW_{reqL} < BW_{ALTM}$

$BW_{reqL} \leftarrow (obatin\ from\ BW_{ALTM})$

$IF\ BW_{reqL} = BW_{ALTM}$

$BW_{reqL} \leftarrow BW_{ALTM}$

$IF\ BW_{reqL} > BW_{ALTM}$

$BW_{reqL} \leftarrow (BW_{ALTM} + BW_{borrow}\ OR\ BW_{ALTM})$

$BW_{reqL} \leftarrow BW_{min} \leftarrow BW_{ALTM}$

4.6 Performance Evaluation, Simulation & Results

4.6.1 Performance Evaluation for Bandwidth Management for Existing Calls

Performance has been evaluated at different intervals of time t. CH refers to Higher Priority calls and CL refers to Lower priority call. Bandwidth utilised by different calls at different time intervals is shown in the following table.

Total Bandwidth in the cell is fixed as 10Mbps. CH_1 and CH_2 are allocated data rate as 2Mbps and rest of lower priority calls are allocated 1Mbps. At Time $t = 1.1$ the data rate for CH_2, has dropped to 1.6Mbps and data rate for CL_1 and CL_2 has dropped to 0.8Mbps and Call CL_6 has not at all used its rate from $t = 1.1$ onwards. Cell utilisation becomes under load. At time $t = 1.2$ Base station in cell distributes the unutilised bandwidth fairly among active Lower priority calls CL_1, CL_4 and CL_5. Their bandwidth changes from 1Mbps to 1.6Mbps. It can be seen from the evaluation as shown in Figure 4.4 that the network has been brought back from under load to normal load condition. The base station in the cell always tries to ensure 100% utilisation of the bandwidth in the cell. Figure 4.5 shows the total bandwidth for all the calls from $t = 0$ to $t = 2$.

Table 4-2: Bandwidth Management for Existing Calls

	CH1	**CH2**	**CL1**	**CL2**	**CL3**	**CL4**	**CL5**	**CL6**
t=0	2	2	1	1	1	1	1	1
t=0.1	2	2	1	1	1	1	1	1
t=0.2	2	2	1	1	1	1	1	1
t=0.3	2	2	1	1	1	1	1	1
t=0.4	2	2	1	1	1	1	1	1
t=0.5	2	2	1	1	1	1	1	1
t=0.6	2	2	1	1	1	1	1	1
t=0.7	2	2	1	1	1	1	1	1
t=0.8	2	2	1	1	1	1	1	1
t=0.9	2	2	1	1	1	1	1	1
t=1	2	2	1	1	1	1	1	1
t=1.1	2	1.6	1	0.8	0.8	1	1	0
t=1.2	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.3	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.4	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.5	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.6	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.7	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.8	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=1.9	2	1.6	1.6	0.8	0.8	1.6	1.6	0
t=2	2	1.6	1.6	0.8	0.8	1.6	1.6	0

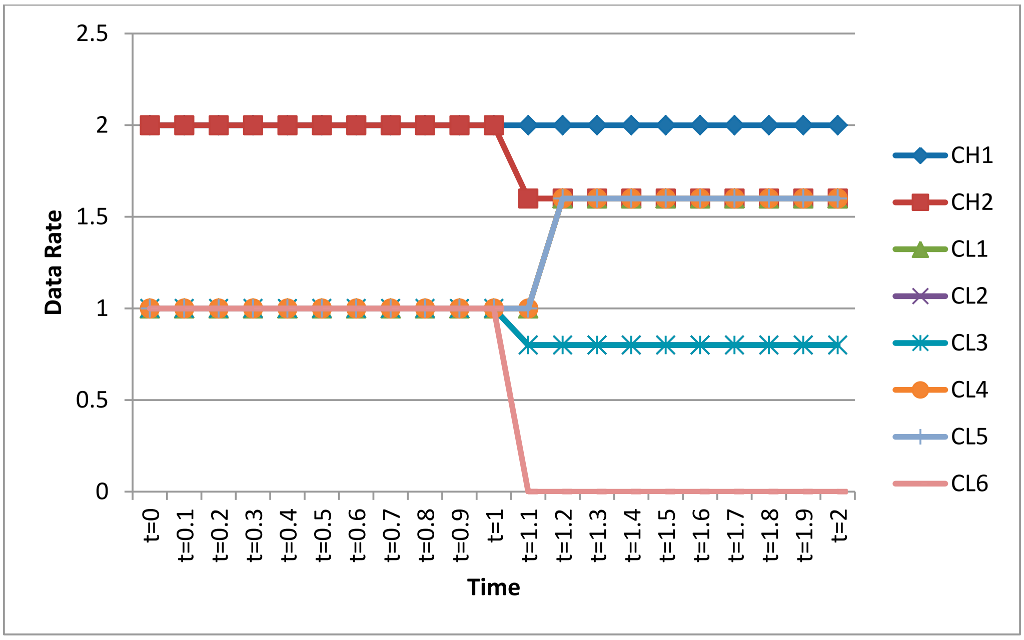


Figure 4.4: Bandwidth for Existing Calls

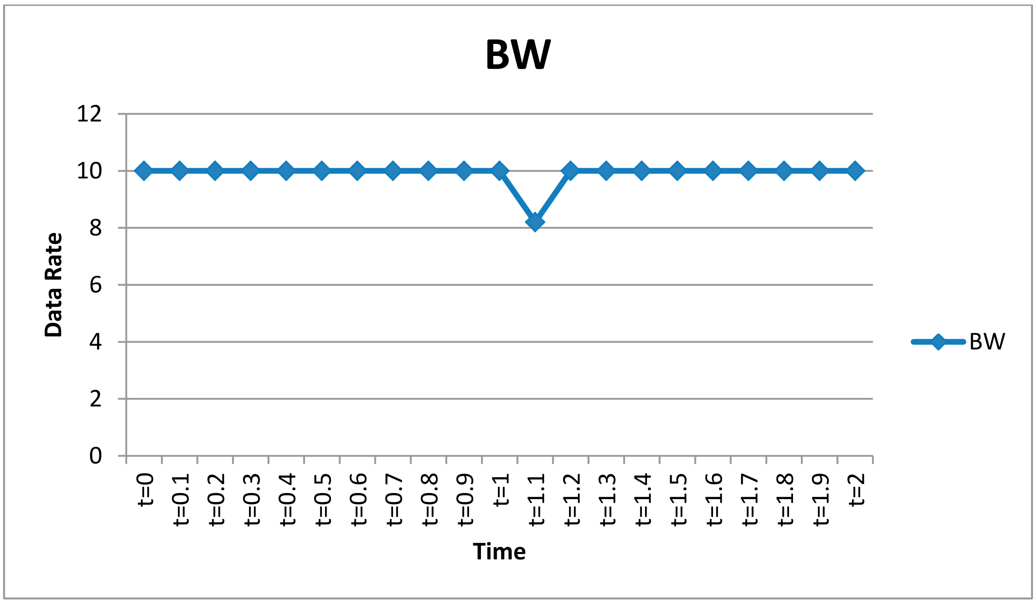


Figure 4.5: Total Bandwidth for all Calls

4.6.2 Performance Evaluation for Bandwidth Management when Higher Priority Handoff Calls Arrive

Performance has been evaluated under the following five conditions:

1. When Higher priority call arrived & $B.W$ allocated at $t = t_1$, $B.W$ allocated from local cell.
2. When Higher priority call arrived & $B.W$ allocated at $t = t_2$, $B.W$ allocated from local cell.
3. When Higher priority call arrived & $B.W$ allocated at $t = t_3$, $B.W$ allocated from neighbouring cell.
4. When Higher priority call left the cell & $B.W$ managed at $t = t_4$, $B.W$ distributed equally among active lower priority calls.
5. Bandwidth management when channel requested from neighbouring cell.

Table 4-3: Bandwidth table for High Priority calls

	CH1	**CH2**	**CL1**	**CL2**	**CL3**	**CL4**	**CL5**	**CL6**	**CH3**	**CH4**	**CH5**
t=0	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.1	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.2	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.3	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.4	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.5	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.6	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.7	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.8	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=0.9	2	1.8	0.87	0.87	0.8	0.8	0.87	0			
t=1	2	1.8	1.53	1.53	0.8	0.8	1.53	0			

t=1.1	2	1.8	0.87	0.87	0.8	0.8	0.87	0	1.98		
t=1.2	2	1.8	0.87	0.87	0.8	0.8	0.87	0	1.98		
t=1.3	2	1.8	0.87	0.87	0.8	0.8	0.87	0	1.98		
t=1.4	2	1.8	0.87	0.87	0.8	0.8	0.87	0	1.98		
t=1.5	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=1.6	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=1.7	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=1.8	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=1.9	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=2	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	
t=2.1	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.2	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.3	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.4	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.5	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.6	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.7	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.8	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=2.9	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=3	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=3.1	2	1.8	0.57	0.57	0.5	0.5	0.57	0	1.98	1.5	1.5
t=3.2	2	0	1.17	1.17	0.5	0.5	1.17	0	1.98	1.5	1.5
t=3.3	2	0	1.17	1.17	0.5	0.5	1.17	0	1.98	1.5	1.5
t=3.4	2	0	1.17	1.17	0.5	0.5	1.17	0	1.98	1.5	1.5
t=3.5	2	0	1.17	1.17	0.5	0.5	1.17	0	1.98	1.5	1.5
t=3.6	2	0	0.67	0.67	0.5	0.5	0.67	0	1.98	1.5	1.5
t=3.7	2	0	0.67	0.67	0.5	0.5	0.67	0	1.98	1.5	1.5
t=3.8	2	0	0.67	0.67	0.5	0.5	0.67	0	1.98	1.5	1.5

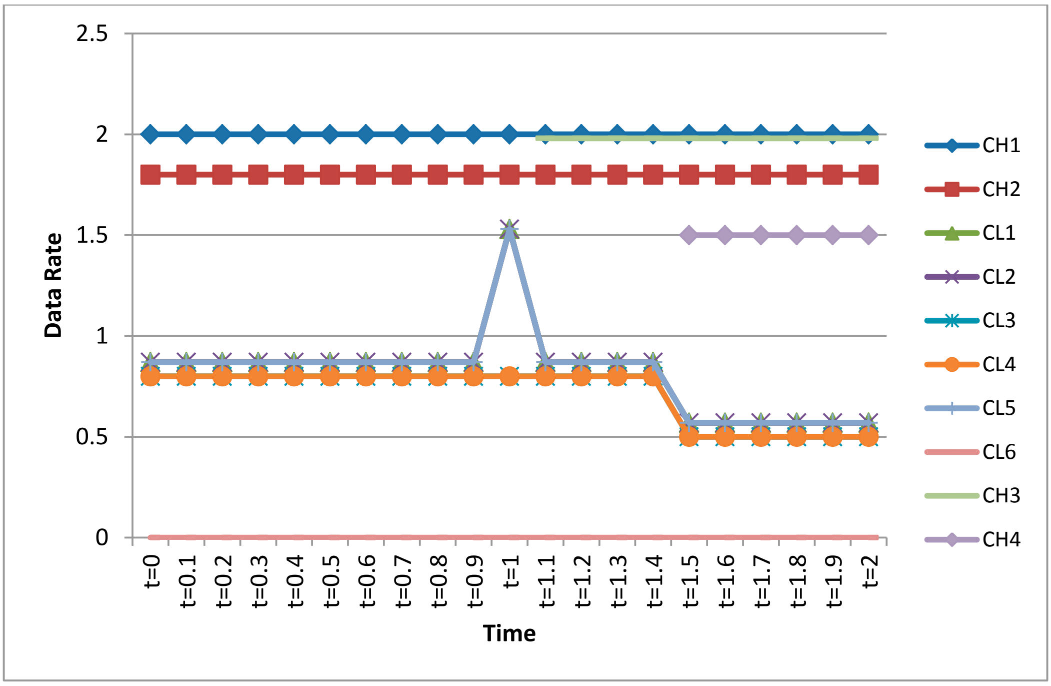


Figure 4.6: Allocation within the Cell when Higher Priority Handoff Call Arrived

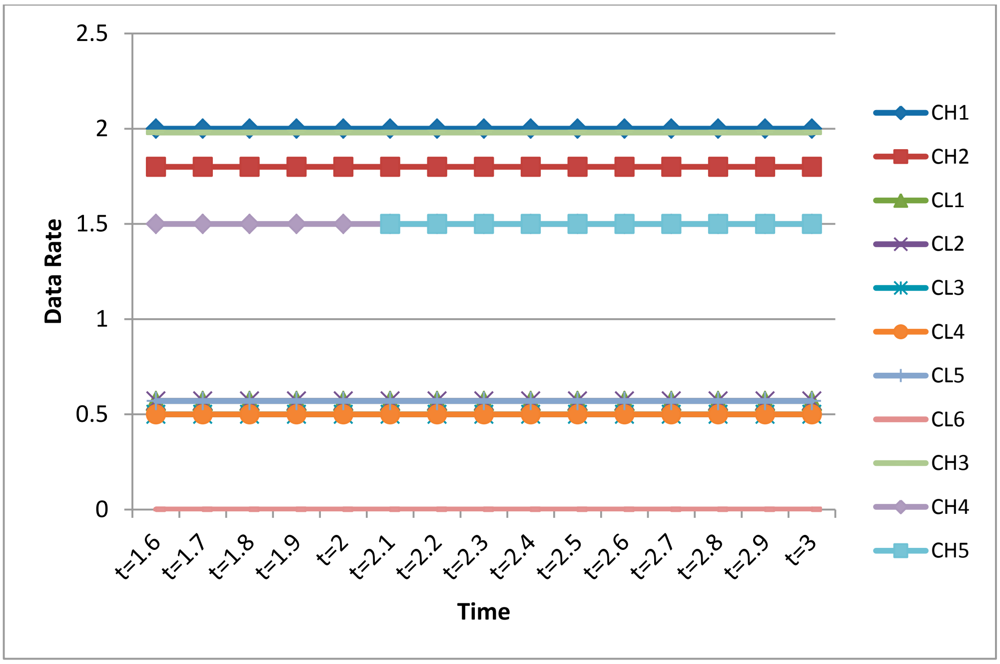


Figure 4.7: Allocation from Neighbouring Cell

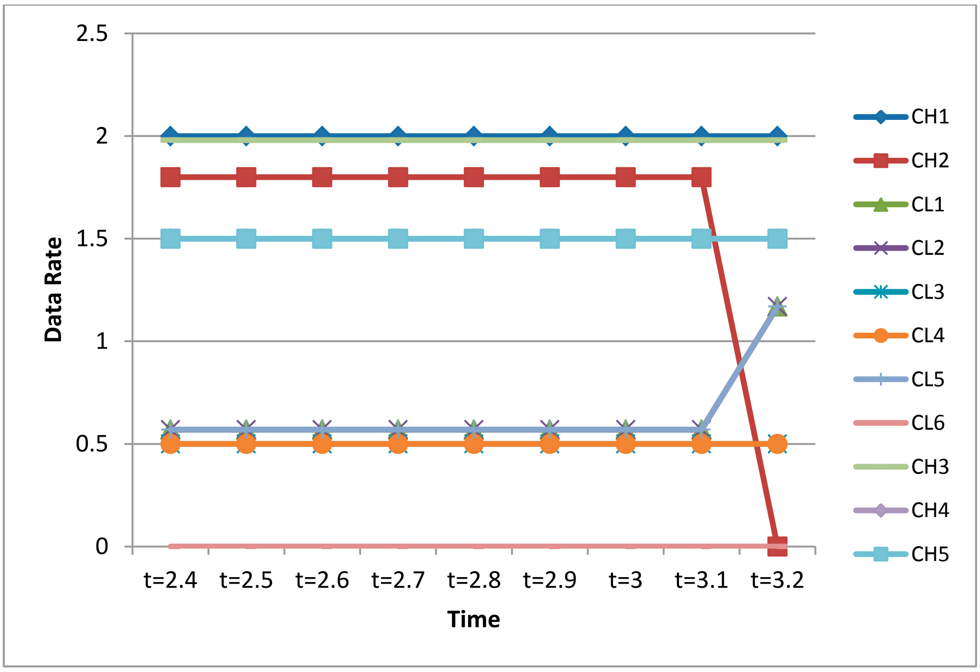


Figure 4.8: Bandwidth Management after Node left

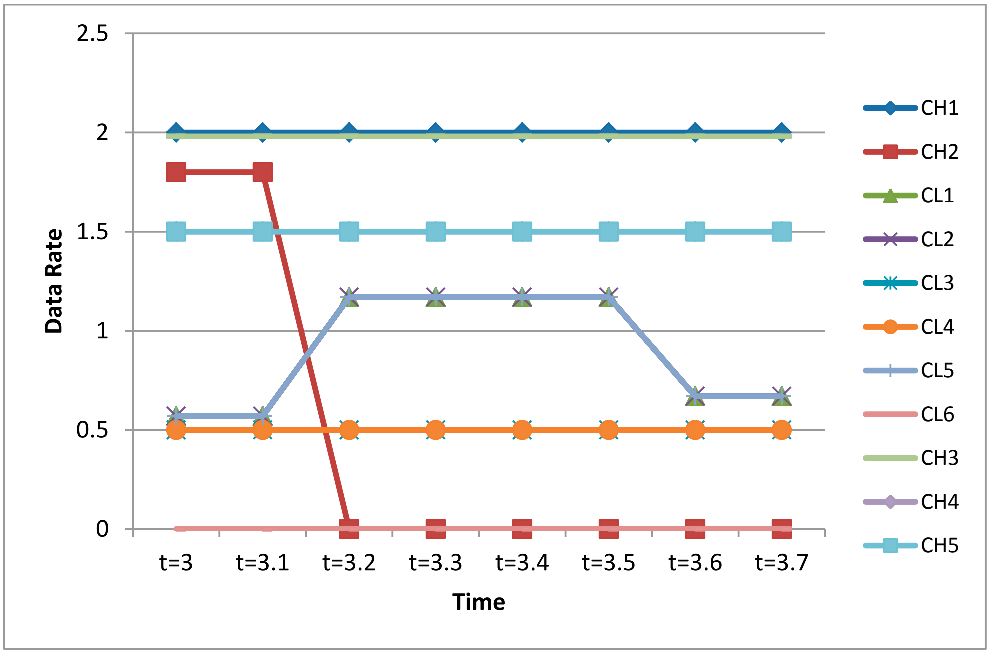


Figure 4.9: Bandwidth Management when Channels are requested from Neighbour

Two higher priority calls $(CH_1\ and\ CH_2)$ are allocated the bandwidth of 2Mbps each, and CH_2 uses 1.8Mbps and 0.2Mbps left in the unutilised section. As can be seen from Figure 4.6, Bandwidth allocated to lower priority calls $(CL_1\ to\ CL_6)$ is less than 1Mbps. $(CL_1, CL_2\ and\ CL_5)$ are utilising their allocation fully, and two calls $(CL_3\ and\ CL_4)$ are utilising part of allocation, and one call CL_6 is not utilising its allocation at all. This part of the bandwidth is fairly distributed among active lower priority calls. At $t = 1$, the unutilised part has been distributed fairly among $CL_1, CL_2\ and\ CL_5$. CH_3 arrived at $t = 1.1$ and bandwidth allocated to this call is from lower priority calls. CH_4 entered at $t = 1.5$, again bandwidth allocated as above but the minimum bandwidth is maintained for these active lower priority calls. For call CH_5 in Figure 4.7, the bandwidth is borrowed from a neighbour as a minimum is maintained for lower priority calls. At every averaging interval, the base station calculates the bandwidth and brings back the cell from under load to normal load condition. At $t = 3.2$ as shown in Figure 4.8, CH_2 has completed the call and bandwidth is again distributed among lower priority calls. When bandwidth is requested from a neighbour at time $t = 3.6$, a portion of lower priority calls have been transferred to the requested neighbouring cell as shown in results in Figure 4.9. If a higher priority call is going to enter, the lower priority calls are asked to reduce their rates, and in absence of higher priority calls, they are asked to increase their rates.

4.6.3 Performance Evaluation when Lower Priority Handoff Calls Arrive

1. When lower priority handoff call arrived & $B.W$ allocated from local cell.

2. When Lower priority handoff call arrived Bandwidth allocated minimum (worst case).
3. When lower priority handoff call arrived & $B.W$ allocated from neighbouring cell.
4. When higher priority handoff call arrived Bandwidth allocated from lower priority calls.

Table 4-4: Banwidth table for Lower Priority calls

	CH1	**CH2**	**CL1**	**CL2**	**CL3**	**CL4**	**CL5**	**CL6**	**CL7**	**CL8**	**CL9**	**CL10**	**CH3**	**CL11**
t=0	2	2	1	1	1	1	1	1						
t=0.1	2	2	1	1	1	1	1	1						
t=0.2	2	2	1	1	1	1	1	1						
t=0.3	2	2	1	1	1	1	1	1						
t=0.4	2	2	0.83	0.83	0.83	0.83	0.83	0.83	1					
t=0.5	2	2	0.857	0.857	0.857	0.857	0.857	0.857	0.857					
t=0.6	2	2	0.712	0.712	0.712	0.712	0.712	0.712	0.712	1				
t=0.7	2	2	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75				
t=0.8	2	2	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	1			
t=0.9	2	2	0.666	0.666	0.666	0.666	0.666	0.666	0.666	0.666	0.666			
t=1	2	2	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	1.5		
t=1.1	2	2	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655		
t=1.2	2	2	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	1	
t=1.3	2	2	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555	1	1
t=1.4	2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
t=1.5	2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
t=1.6	2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
t=1.7	2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
t=1.8	2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5

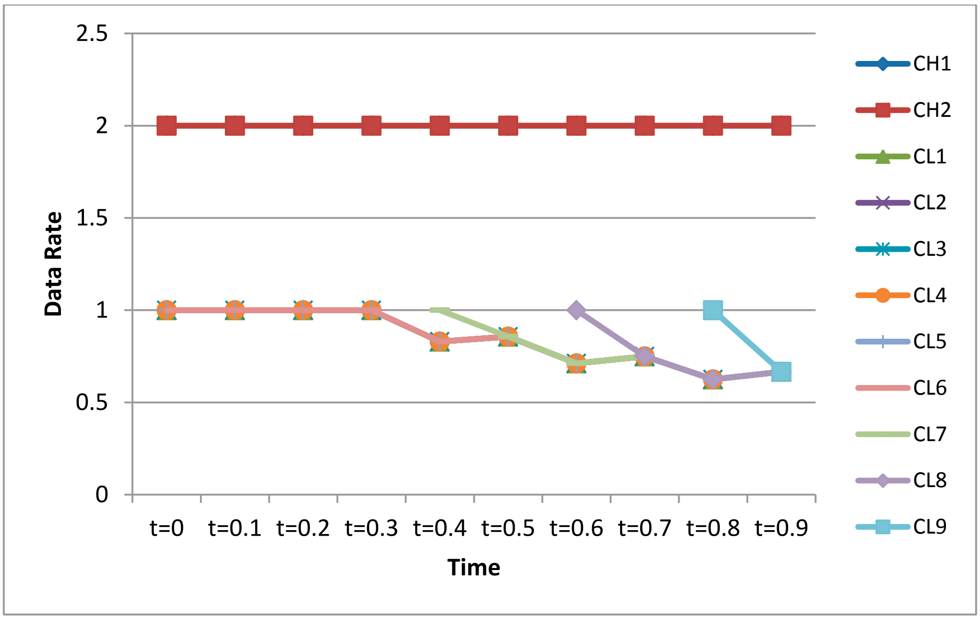


Figure 4.10: Lower Priority Handoff Calls Arrived

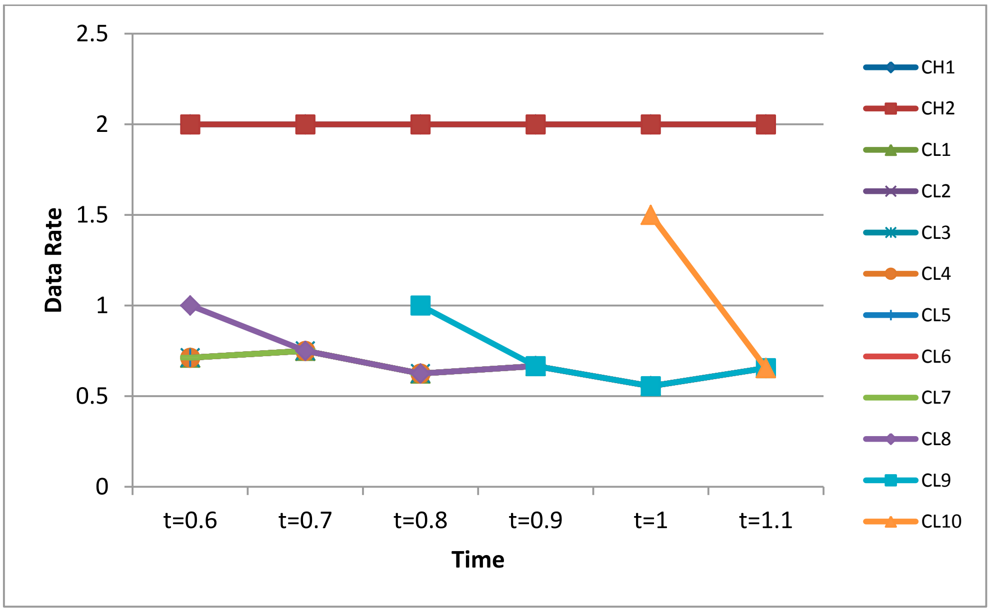


Figure 4.11: Bandwidth Borrowed from Neighbour

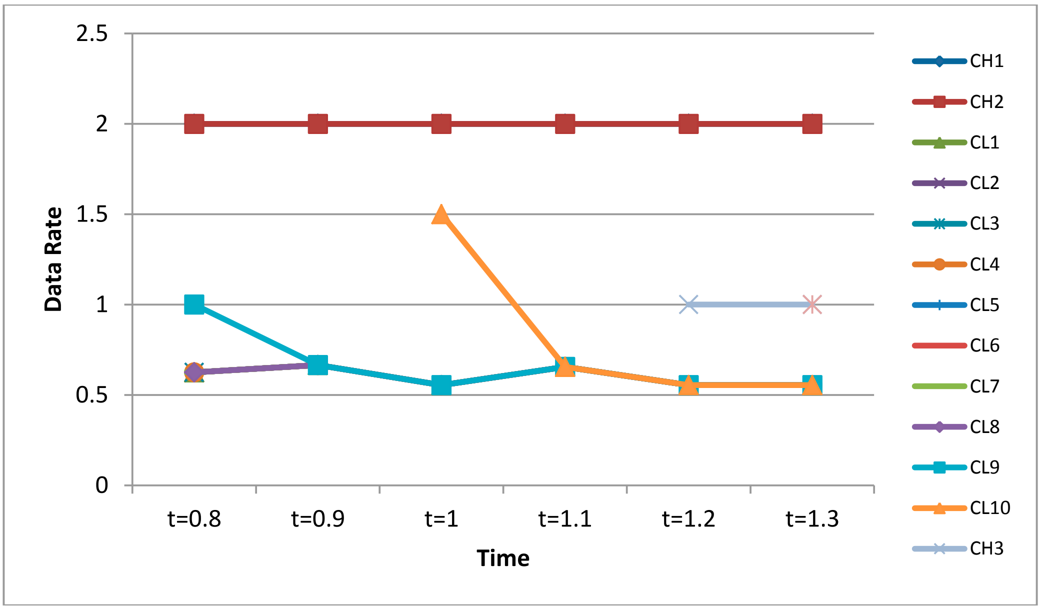


Figure 4.12: When Higher Priority Handoff Call Arrived

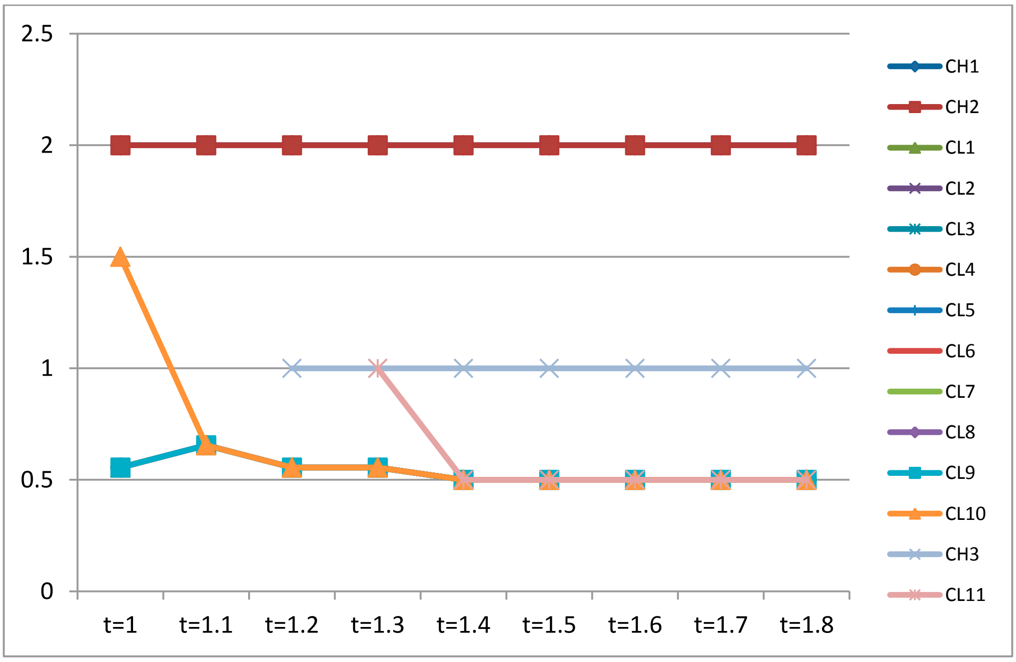


Figure 4.13: Minimum Bandwidth Allocation for Lower Priority Handoff Call (Worst Case Scenario)

In this scenario, CH_1 and CH_2 are allocated 2Mbps and $CL_1 to\ CL_6$ are allocated 1Mbps. CL_7 entered at $t = 0.4$ and bandwidth has been allocated from a portion of $CL_1 to\ CL_6$ and adjusted as shown in Figure 4.10. In the same manner, bandwidth was allocated to CL_8 and CL_9. CL_{10} entered at $t = 1$, and requested for 1.5Mbps. Bandwidth allocated to this call is equal to the portion of bandwidth of lower priority calls plus bandwidth borrowed from the neighbor as shown in Figure 4.11. When CH_3 entered at $t = 1.2$ as shown in Figure 4.12, the allocation is done from lower priority calls, but maintained the minimum (0.5Mbps) for all lower priority calls. For CL_{11} at $t = 1.3$, bandwidth 1Mbps was borrowed from a neighbour which was later adjusted. At $t = 1.4$, bandwidth is requested and transferred to neighbouring cell and is adjusted for all lower priority calls so that all lower priority calls can maintain the same amount of bandwidth as shown in Figure 4.13. The same procedure could be applied to locally generated calls.

4.7 Summary

In this chapter, a new solution for bandwidth management is proposed. In this proposed solution, the unutilised bandwidth will be allocated among active lower priority calls. Higher priority calls will obtain the bandwidth without any difficulty and be maintained constant during their connection lifetime. If there are not many higher priority calls in the cell, lower priority calls will utilise the maximum bandwidth, and during network overload condition, the lower priority calls will be asked to reduce their rates. Also, bandwidth will be borrowed from a neighbouring cell if enough bandwidth is not available in the cell. In the worst-case scenario, minimum bandwidth will be allocated and maintained for lower priority calls. At every averaging interval, the base station will check its table and bring back the network to normal condition. In this method, bandwidth in the cell will be utilised to its maximum (100%) and wastage of resources can be avoided. With this scheme, the dropping probability of handoff calls will be minimised, and the blocking probability of locally generated calls will be decreased. QOS can also be maintained.

Chapter 5

Performance Design and Analysis of Handoff in Hierarchical Wireless Networks

5.1 Introduction

A hierarchical cellular network (HCN) approach was considered as a solution to increase the system capacity [88, 89]. In HCN, cells of different sizes are organised into separate layers. For example, in the two-layer (micro/ macro) hierarchical structure [91, 95], several small cells called microcells, with a radius of a few hundred meters are organised as a microcell layer, which is overlaid by a large macrocell whose radius is a few kilometers. The macrocell/ microcell overlay architecture provides a balance between maximising the number of users per unit area and minimising the network control load associated with handoff. Macrocell provides wide-area coverage beyond microcell service areas, and ensure better intercell handoff. Microcells provide high capacity and cover areas with high traffic density.

Furthermore, handoff call handling is an important topic in cellular networks. In wireless cellular networks there are many ways to prioritise handoff calls for reducing the dropping probability: reserved guard channel, queuing, channel transferred, genetic and sub-rating schemes. Many variations or combinations of the aforementioned schemes have been proposed. The key idea is to combine the different prioritisation policies in order to further decrease the blocking and dropping probabilities, or to improve the channel utilisation. Then they can effectively reduce the dropping probability of handoff calls, but it is at the cost of increasing the blocking probability of new calls.

In HCN, upon entering the system, the mobile terminals can select the service layer based on their mobility or traffic patterns. In the speed-sensitive strategy, the mobile terminals travelling at high speeds (fast-mobility subscribers) are normally serviced by the macrocell, whereas low-mobility subscribers are handled by the microcells [51, 90, 91, 92, 93]. Under the speed-sensitive layer selection strategy, the overflow operation can be used to transfer calls to the other layer if there is not sufficient resource in the current service layer [94, 95].

For call admission control (CAC) in HCN, handoff call handling is particularly important because, generally, the dropping of an ongoing call is considered less desirable than the blocking of a new call. Thus, handoff calls have higher priority than new calls during the call admission control process. Several approaches have been proposed for handling handoff calls in HCN. Guard channels [91, 96] are reserved for serving the handoff calls in both microcells and macrocells. [91] propose a mobility-dependent call admission control scheme whereby new calls are accepted according to some mobility-based acceptance probability, while handoff calls are admitted when there are free channels available. [93] Considered hierarchical cellular CDMA networks support users with different mobility, soft handoff, and handoff queuing strategy, where slow users are assigned to the associated microcell, and fast users are assigned to the associated macrocell. The analytical method is derived in order to compute the performance measures of interest, such as new call blocking probability, handoff failure probability, and forced termination probability for the studied system. [96] allows the queuing of both overflow slow-mobility calls (from the lower layer microcells) and macrocell handover fast-mobility calls that are blocked due to lack of free resources at the macrocell. [90, 97] propose using sub-rating for handoff calls in the microcell and macrocell to reduce the dropping probability of handoff calls. Sub-Rating means that an occupied full-rate channel can be temporarily divided into two channels at half of the original rate: one to serve the existing call and the other to serve the handoff request. The dropping probability of handoff calls is eliminated by using of SRS under the penalty of a slight increase in the blocking probability of new calls. The channel sub-rating scheme has been used in [98] to improve the performance of handoff packets for the cellular radio network. The proposed scheme, which combines fixed channel assignment, sub-rating, and directed retry, gives a significant improvement in the QoS of the cellular radio network. In [99], the author has applied channel sub-rating for handoff calls in CDMA cellular networks. However, apart from the few studies mentioned above, the channel sub-rating is only used in a single-tier system.

In this chapter, a two-layer macrocell/ microcell HCN system model is considered. Performance models for macrocell and microcell are developed respectively. In our proposed CAC, the HCN system supports both fast and slow mobility users. The macrocells handle the fast-mobility users, while the microcells serve the slow-mobility users.

In the microcells:

- Slow newly originated or handoff calls will be served with a full-rate channel on their arrival.
- When all channels in the microcell are full, the slow new and handoff calls are handled by using a sub-rating that is for an occupied full-rate channel, and will be divided into two channels at half of the original rate; one to serve the existing call and the other to serve the slow new call request or slow handoff call request.
- When the number of sub-rated channels reaches a certain threshold, the base station will block all kinds of slow new calls originating in the microcell and will reserve the rest of the channels that can be sub rated for slow handoff calls.
- When all the channels are already sub rated in the cell, a slow handoff call will wait in queue until a channel or a half of a channel is free. The queue size should be kept small and the time spent in the queue should be below a certain threshold, since handoff attempts and waiting should not last forever.
- Blocked slow new and slow handoff calls are allowed to overflow to the overlaying macrocell.

In a macrocell:

- The fast new calls and overflowed slow new calls will be served until the number of busy channels reaches a certain threshold, and then they will be blocked.

- The rest of the channels in the macrocell will be used by the fast handoff calls and the slow handoff overflow calls.
- The overflow of fast calls from macrocell to microcell is not allowed to prevent the incurring of frequent handoff of the fast calls in the microcell layer, due to the small size of a microcell.

The rest of this chapter is organised as follows. The proposed system model and the performance analysis of microcell and macrocell are presented in Section 5.2, and the degradation ratio in the microcell resulting from using sub-rating the channels is presented in the same Section. In Section 5.3, numerical results, validation and discussions are presented. Finally, Section 5.4 summarises the chapter.

5.2 System Model and Performance Analysis

5.2.1 System Model

In the proposed system model, a macrocell in the macrocell layer is overlaid completely by N microcells in the microcell layer and there is no macrocell-only or microcell-only area. All the microcells under the macrocell have the same shape and size. The slow-mobility calls are first directed to a microcell, and fast-mobility calls are directed to a macrocell. The following assumptions are considered in the proposed CAC:

- Each macrocell contains C_M channels and each microcell contains C_m channels.
- It is assumed that the velocity of mobile terminals (MT) will not change during its call lifetime.

- The total new call arrivals to the macrocell and its associated N microcell follow a Poisson process with mean λ_n.
- The slow/fast new call arrival to a given cell at each layer is assumed to be an independent Poisson process with mean arrival rate $\lambda_{sn}^m/\lambda_{fn}^M$, respectively.
- The portion of slow new calls to the overall new calls is α.
- Slow new calls, which cannot be served at the microcell, will overflow to the overlaying macrocell layer with a Poisson process and mean arrival rate λ_{sno}^m; the slow handoff call, which cannot be served in the microcell layer, will overflow to the macrocell with a Poisson process and mean arrival rate λ_{sho}^m.
- The call holding time in a microcell or macrocell is exponentially distributed with mean rate $1/\mu$.

As there are N number of microcells and it covers α from the total coverage of the cluster, therefore, the slow and fast newly originated call arrival rates can be obtained as:

$$\lambda_{sn}^m = \frac{1}{N}\alpha\lambda_n\,;\;\; \lambda_{fn}^M = (1-\alpha)\lambda_n \qquad (5.1)$$

Based on the system model, it is possible to carry out the performance analysis of the proposed call admission control (CAC) in the two-layer. The analysis is performed for the microcell and the macrocell layers separately.

5.2.2 Performance Analysis of the Microcell

Table 5-1: Proposed Scheme for the Microcell

State Variables			Events/ Action	
No. of Calls (i)	No. of Calls with split channels	No. of Calls in the queue	New Call Arrival	Handoff Call Arrival
$0 \leq i < C_m$	0	0	Accepted (full rate)	Accepted (full rate)
$C_m \leq i < C_m + g$	$C_m + g$	0	Accepted (split rate)	Accepted (split rate)
$C_m + g \leq i < 2\,C_m$	$2\,C_m$	0	Blocked	Accepted (split rate)
$2\,C_m \leq i < 2\,C_m + Q$	$2\,C_m$	Q	Blocked	Accepted (split rate)
$i = 2N+k$	2N	Q	Blocked	Blocked

The proposed scheme combines the idea of Sub-Rating (SR), Call Bounding (CB), and Queuing (Q), which is described as follows:

- Each cell consists of C_m channels that can be used by slow newly originated calls and slow handoff calls.
- When a slow newly originated call arrives and all C_m channels are busy, a used channel in the cell will be sub rated and half of it will be used by the new arrived call. When the number of sub rated channels is equal to threshold g, the slow newly originated calls will be blocked.
- When a slow handoff call arrives and all C_m Channels are busy, a used channel in the cell will be sub rated and half of it will be used by the new slow handoff call. When all the channels in the cell are sub rated, the slow handoff calls will be placed in a queue with size Q until a time at which either it gains a channel for service or it disconnects from the system because of the user's impatience, or the mobile moves out of the current cell. If a handoff call finds the handoff queue full when it arrives, it will be forced to terminate and is cleared from the system.

A description for the proposed scheme is given in table 5.1 above.

It is assumed that the channel holding time T_c and the mean dwell time T_{dc} in the whole covering area of a microcell follow exponential distributions with means $(\mu_{sc}^m)^{-1}$ and $(\mu_{sdc}^m)^{-1}$, respectively. The channel holding time is the time duration between the instant that a channel is occupied by a call and the instant it is released by either completion of the call or cell boundary crossing by a portable- whichever is less.

The purpose of the proposed scheme in the microcell layer is to incorporate the commonly used schemes SR, CB and Queuing in a way which decreases the handoff dropping probability but at the same time keeps the new calls blocking probability as minimum as possible.

The state diagram of the birth-death Markov chain is shown in figure 5.1 below. The slow newly originated calls will be blocked if the number of busy channels is equal to $C_m + g$, then the rest of the channels that can be sub rated will be used by slow handoff calls until all the C_m channels are sub rated, which is at state $2C_m$. After that, the arriving slow handoff calls will wait in the queue. A handoff attempt that joins the queue will be successful, if both of the following events occur before the mobile moves out of the handoff area: All of the attempts which joined the queue earlier than the given attempt have been disposed, and a channel or a half of it becomes available when the given attempt is at the first position in the queue.

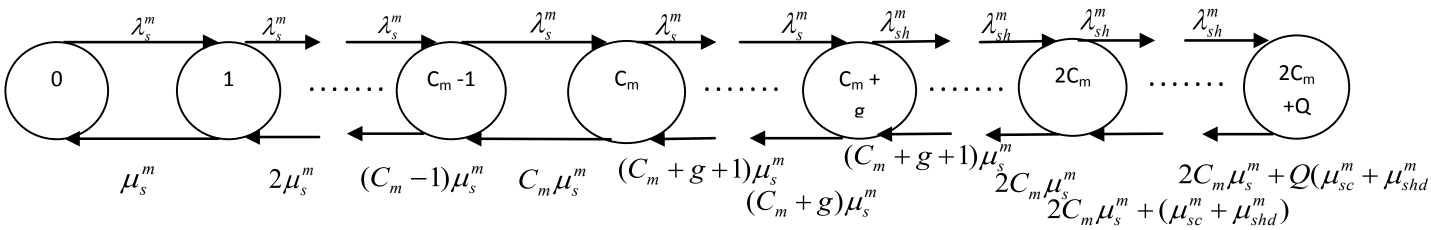


Figure 5.1: State Transition Diagram of the Microcell

By solving the birth-death Markov chain in the state transition diagram in Figure 5.1 above and because $\sum_{n=0}^{2C_m+Q} P_n^m = 1$ obtained:

$$P_0^m = \left[\sum_{n=0}^{C_m+g-1} \frac{u^n}{n!} + u^{C_m+g} \sum_{n=C_m+g}^{2C_m} \frac{u_1^{n-(C_m+g)}}{n!} + \right.$$

$$\left. + \frac{u^{C_m+g}.u_1^{C_m-g}}{2C_m!} \sum_{n=2C_m+1}^{2C_m+k} \frac{(\lambda_{sh}^m)^{n-2N}}{\prod_{i=1}^{n-2N} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{sdc}^m)} \right]^{-1} \tag{5.2}$$

Where: $\lambda_s^m = \lambda_{sn}^m + \lambda_{sh}^m,\ u = \frac{\lambda_s^m}{\mu_s^m}, u_1 = \frac{\lambda_{sh}^m}{\mu_s^m}$. Then we can obtain the expression of P_n^m

$$P_n^m = \begin{cases} \frac{u^n}{n!} P_0 & n < C_m + g \\ \frac{u_1^{n-(C_m+g)}.u^{C_m+g}}{n!} P_0 & C_m + g \le n \le 2C_m \\ \frac{u^{C_m+g}.u_1^{C_m-g}}{2C_m!}. \sum_{n=2C_m+1}^{2C_m+Q} \frac{(\lambda_{sh}^m)^{n-2N}}{\prod_{i=1}^{n-2N} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{sdc}^m)} P_0; & 2C_m + 1 \le n \le 2C_m + Q \end{cases} \tag{5.3}$$

The slow new originated calls will be blocked after $C_m + g$ channels are busy. Then the Blocking probability of slow new calls (P_{bsn}^m):

$$P_{bsn}^{m} = \sum_{n=C_m+g}^{2C_m+Q} P_n^m \qquad (5.4)$$

$$P_{bsn}^{m} = \frac{u^{N+g} \cdot \sum_{n=C_m+g}^{2C_m} \frac{u_1^{\,n-(C_m+g)}}{n!} + \frac{u^{C_m+g} . u_1^{\,C_m-g}}{2C_m!} \cdot \sum_{n=2N+1}^{2C_m+Q} \frac{(\lambda_{sh}^m)^{n-2C_m}}{\prod_{i=1}^{n-2C_m} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{shd}^m)}}{\sum_{n=0}^{C_m+g-1} \frac{u^n}{n!} + u^{C_m+g} \cdot \sum_{n=C_m+g}^{2C_m} \frac{u_1^{\,n-(C_m+g)}}{n!} + \frac{u^{C_m+g} . u_1^{\,C_m-g}}{2C_m!} \cdot \sum_{n=2C_m+1}^{2C_m+Q} \frac{(\lambda_{sh}^m)^{n-2C_m}}{\prod_{i=1}^{n-2C_m} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{shd}^m)}}$$

The slow handoff calls will be blocked in the microcell when all the C_m channels already sub rated which is at state $2C_m$ and there are Q calls waiting in the queue at state $2C_m + Q$. The expression of the Blocking probability of slow handoff calls (P_{bsh}^m) is:

$$P_{bsh}^{m} = P_{2C_m+Q}^{m} \qquad (5.5)$$

$$P_{bsh} = \frac{\frac{u^{C_m+g} . u_1^{C_m-g}}{2C_m!} \cdot \frac{\lambda_h^Q}{\prod_{i=1}^{Q} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{shd}^m)}}{\sum_{n=0}^{C_m+g-1} \frac{u^n}{n!} + u^{C_m+g} \cdot \sum_{n=C_m+g}^{2C_m} \frac{u_1^{n-(C_m+g)}}{n!} + \frac{u^{C_m+g} . u_1^{C_m-g}}{2C_m!} \cdot \sum_{n=2C_m+1}^{2C_m+k} \frac{\lambda_h^{n-2C_m}}{\prod_{i=1}^{n-2C_m} 2C_m\mu_s^m + i(\mu_{sc}^m + \mu_{shd}^m)}}$$

According to the system model CAC scheme, the slow new calls that are blocked at the microcell layer are not dropped but overflow to the overlaying macrocell. The aggregate mean arrival rate λ_{sno}^m of the overflowed slow new call from N microcells to the overlaying macrocell can be determined as $\lambda_{sno}^m = NP_{bsn}^m\lambda_{sn}^m$. The mean arrival rate λ_{sho}^m of the overflowed slow handoff call from N microcells to the overlaying macrocell can be determined as $\lambda_{sho}^m = NP_{bsh}^m\lambda_{sh}^m$.

5.2.3 Performance Analysis of Macrocell Layer

The macrocell will handle the fast new calls and fast handoff calls, plus the overflowed slow new and handoff calls from the microcell. In the macrocell, the call bounding scheme is used for new calls. Let K be the threshold for the new calls and C_M, the number of channels in the macrocell. The state space from the two – dimensional markov chain is shown in Figure 5.2 below:

$$S = \{(i, j); 0 \leq i \leq K, i + j \leq C_M\}$$

where i denotes the number of new calls initiated in the macrocell and j is the number of handoff calls in the macrocell. Let $q(i, j; i', j')$ denote the probability transition rate from state (i, j) to state (i', j').

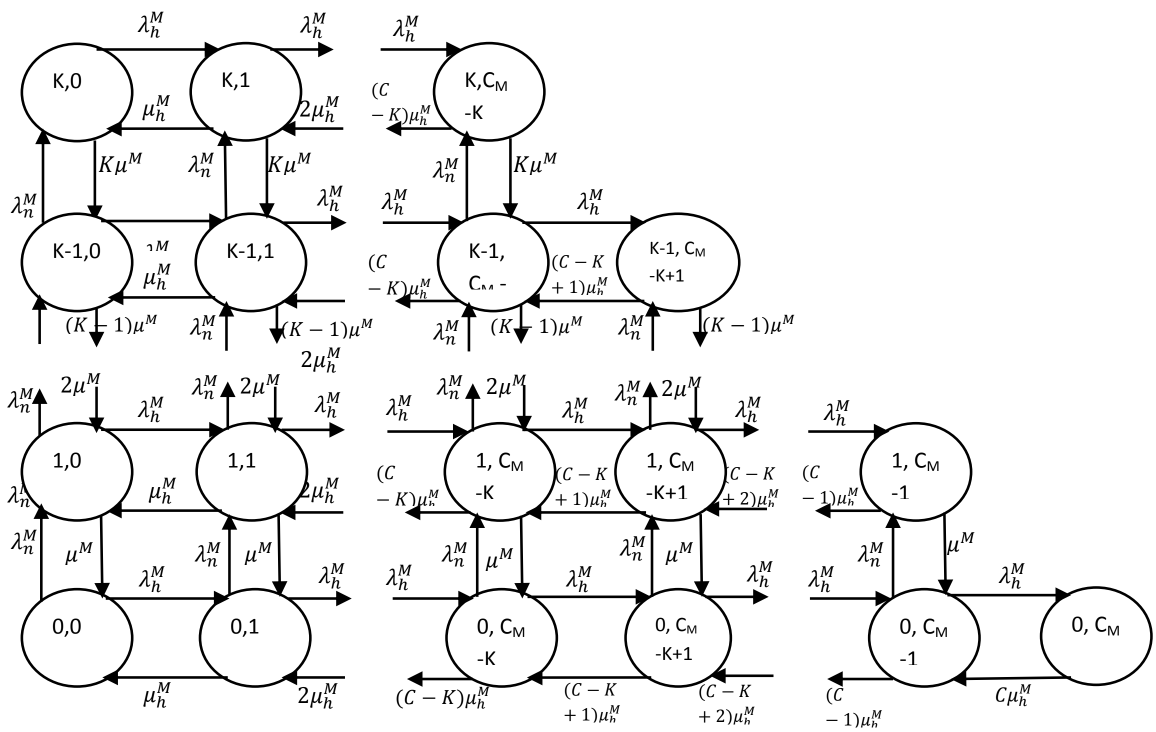


Figure 5.2: State Transition Diagram of the Macrocell

Then we have:

$q(i,j;i-1,j) = i\mu^M(0 \leq i < K, 0 \leq j \leq C_M)$

$q(i,j;i+1,j) = \lambda^M(0 \leq i < K, 0 \leq j \leq C_M)$

$q(i,j;i,j-1) = j\mu_h^M(0 \leq i \leq K, 0 < j \leq C_M)$

$q(i,j;i,j+1) = \lambda_h^M(0 \leq i \leq K, 0 \leq j < C_M)$

Where (i,j) is a feasible state in S. Let $P(i,j)$ denote the steady-state probability that there are i new calls and j handoff calls in the cell. Let $U_2 = \frac{\lambda^M}{\mu^M}$, $U_3 = \frac{\lambda_h^M}{\mu_h^M}$, where $\lambda^M = \lambda_n^M + \lambda_h^M$, $\lambda_n^M = \lambda_{sno}^m + \lambda_{fn}^M$, and $\lambda_h^M = \lambda_{sho}^m + \lambda_{fh}^M$. From the balance equation obtained from the state transition, we obtain

$$P(i,j)^M = \frac{{U_2}^i}{i!} \cdot \frac{{U_3}^j}{j!} \cdot P(0,0) \qquad (5.6)$$

Where, $0 \leq i \leq K,\ i+j \leq C_M, j \geq 0$

from the normalisation equation, we obtain

$$P(0,0)^M = \left[\sum_{0 \leq i \leq K, i+j \leq C} \frac{{U_2}^i}{i!} \cdot \frac{{U_3}^j}{j!} \right]^{-1} = \left[\sum_{i=0}^{K} \frac{{U_2}^i}{i!} \sum_{j=0}^{C-i} \frac{{U_3}^j}{j!} \right]^{-1} \qquad (5.7)$$

The blocking probabilities of fast new calls P_{bfn}^M and overflowed slow new calls P_{bsno}^M can be expressed as:

$$P_{bfn}^M = P_{bsno}^M = \left(\sum_{i=0}^{K-1} \frac{{U_2}^i}{i!} \cdot \frac{{U_3}^{C-i}}{(C-i)!} + \sum_{j=0}^{C-K} \frac{{U_2}^K}{K!} \cdot \frac{{U_3}^j}{j!} \right) \cdot P(0,0)^M \qquad (5.8)$$

The dropping probability of fast handoff call P_{dfh}^{M} and overflowed slow handoff calls P_{dsho}^{M} can be expressed as:

$$P_{dfh}^{M} = P_{dsho}^{M} = \left(\sum_{i=0}^{K} \frac{{U_2}^{i}}{i!} \cdot \frac{{U_3}^{C-i}}{(C-i)!}\right) . P(0,0)^{M} \qquad (5.9)$$

From equation (5.7) and (5.8) above, the total slow new call blocking probability including microcell and macrocell P_{bsn} can be obtained as:

$$P_{bsn} = P_{bsn}^{m} . P_{bsno}^{M} \qquad (5.10)$$

Also, the total slow handoff call dropping probability including microcell and macrocell P_{dsh} can be obtained as:

$$P_{dsh} = P_{bsh}^{m} . P_{dsho}^{M} \qquad (5.11)$$

5.2.4 The Degradation Ratio in the Microcell

As the sub-rating scheme in the microcell is being used, the voice quality degradation is calculated to see the effect when the number of sub-rated channels is increased. The sub-rating scheme is efficient under the limited channel resources because more new and handoff calls can be served. However, it is necessary to consider the degradation of the voice quality due to the employment of sub-rating. In the following, the degradation ratios of voice quality for the microcell are evaluated. The expected number $E[H_{busy}]$ of the busy channels in the microcell is expressed as:

$$E[H_{busy}] = \sum_{i=0}^{2C_m} i P_{n}^{m} \qquad (5.12)$$

The expected number $E[H_{sub}]$ of the sub-rated channels in the microcell is obtained as follows:

$$E[H_{sub}] = \sum_{i=C_m+1}^{2C_m} 2(i - C_m)P_n^m \tag{5.13}$$

The degradation ratio of the voice quality in the microcell, DR, is the portion of the call holding time that the mobile user experiences the degraded voice quality. The mean degradation ratio of the voice quality, $E[DR_n^m]$, for slow new originated calls in the microcell can be expressed as:

$$E[DR_n^m] = E\left[\frac{H_{busy}}{H_{sub}}\right] = \sum_{i=C_m+1}^{C_m+g} \frac{2(i - C_m)}{i} P_n^m \tag{5.14}$$

The mean degradation ratio of the voice quality, $E[DR_h^m]$, for slow handoff calls in the microcell can be expressed as:

$$E[DR_h^m] = E\left[\frac{H_{busy}}{H_{sub}}\right] = \sum_{i=C_m+1}^{2C_m} \frac{2(i - C_m)}{i} P_n^m \tag{5.15}$$

5.3 Numerical Results, Validation and Discussion

For evaluation of the proposed analytical models, a system with parameters has been considered, as shown in table 5.2 below. The analytical model is validated by a discrete event simulator using Java language.

Table 5-2: Modelling Parameters for the HCN

	Symbol	Assumed value
total new call arrivals	λ_n	Varied from 0 to 0.8
Modelling parameters for Microcell	N	Varied from 4 to 6
	α	0.8
	C_m	5
	g	3
	Q	2
	λ_{sh}^{m}	0.05
	μ_s^m	0.04
	μ_{sc}^m	0.01
	μ_{sdc}^m	0.03
Modelling parameters for Macrocell	C_M	10
	K	7
	λ_{fh}^{M}	0.03
	μ^M	0.04
	μ_h^M	0.02

First, the slow new call blocking probability was studied as well as slow handoff call dropping probability performance in the system. The study has been done by varying the total new call arrival rates to the system and by varying the number of microcells, in order to see the effect on the system's performance. It can be seen from Figure 5.3 and 5.4, that the blocking probability of slow new calls and dropping probability of slow handoff calls decreases when the number of microcells in the system is increased, as it will accommodate more slow calls, and at the same time it will decrease the number of overflowed calls to the macrocell. Note the good agreement between the analytical and simulation results in both figures.

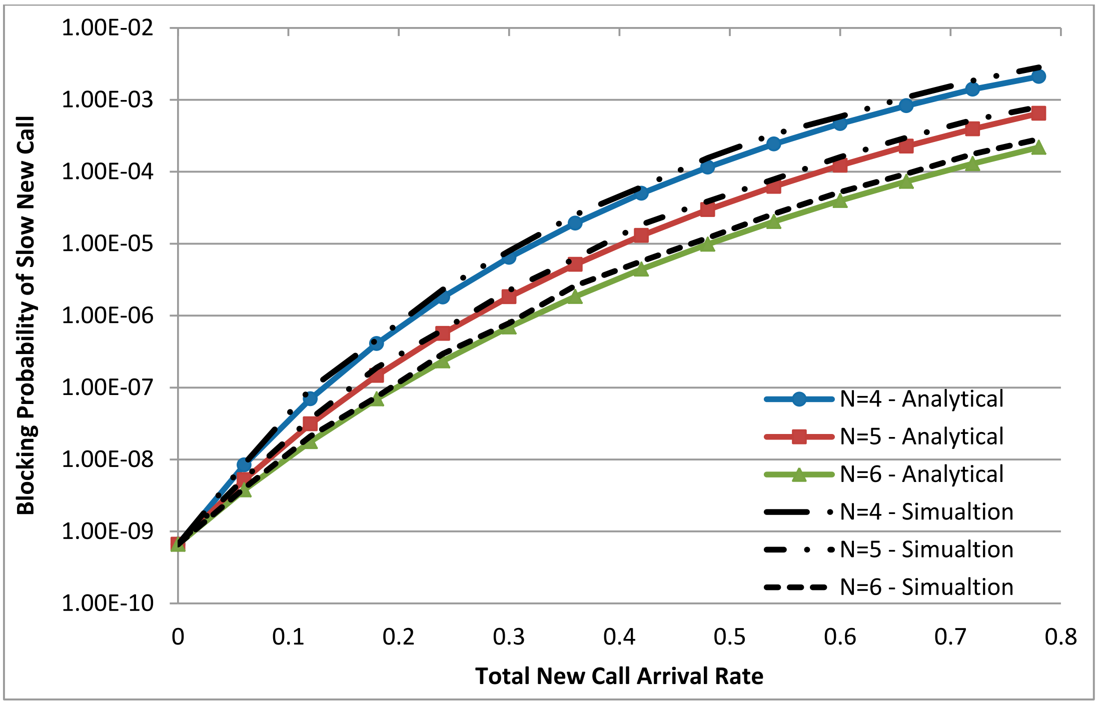


Figure 5.3: Blocking Probability of Slow New Call

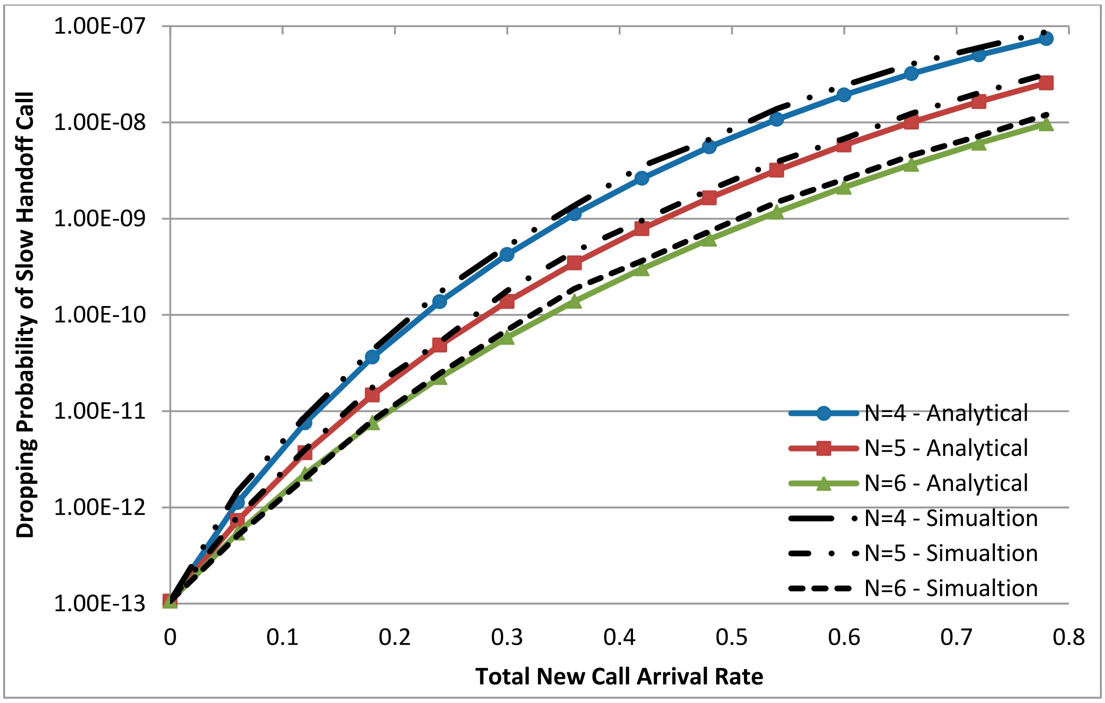


Figure 5.4: Dropping Probability of Slow Handoff Call

Figures 5.5 and 5.6 show the blocking probability of fast new calls and the dropping probability of fast handoff call respectively. It can be seen that increasing the number of microcells decreased the blocking probability of fast new calls in the macrocell, and also decreased the dropping probability of fast handoff calls in the macrocell. That is because the number of overflowed calls from microcell to the macrocell decreased. In these two figures, it is possible to also see the close agreement between the analytical and simulation results.

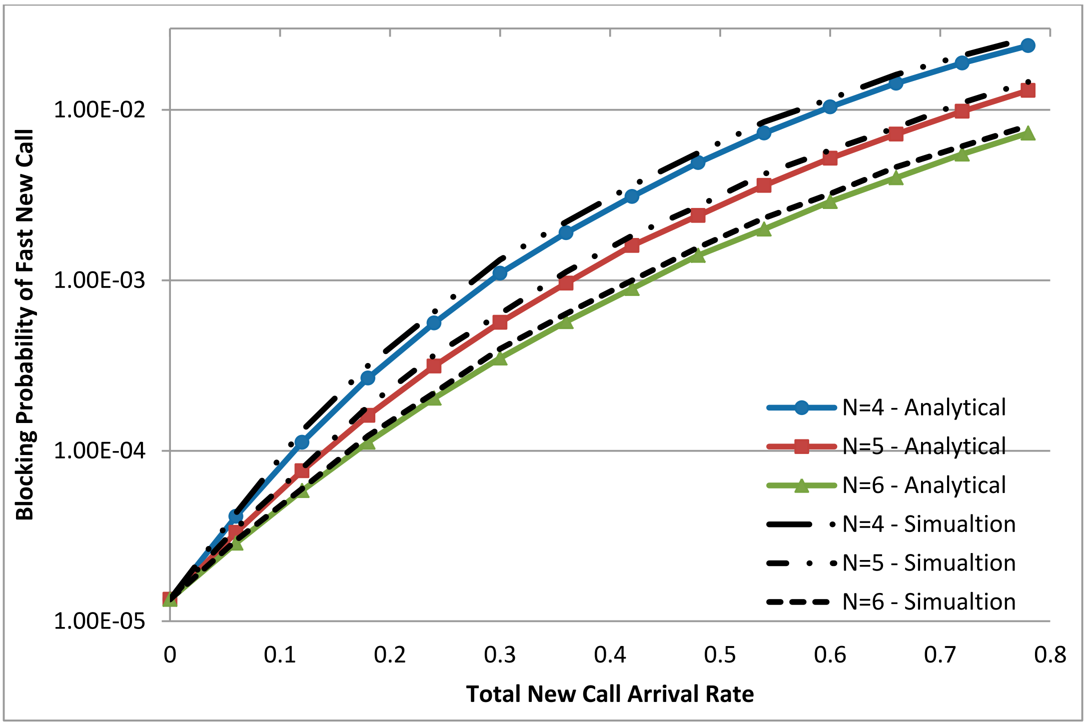


Figure 5.5: Blocking Probability of Fast New Call

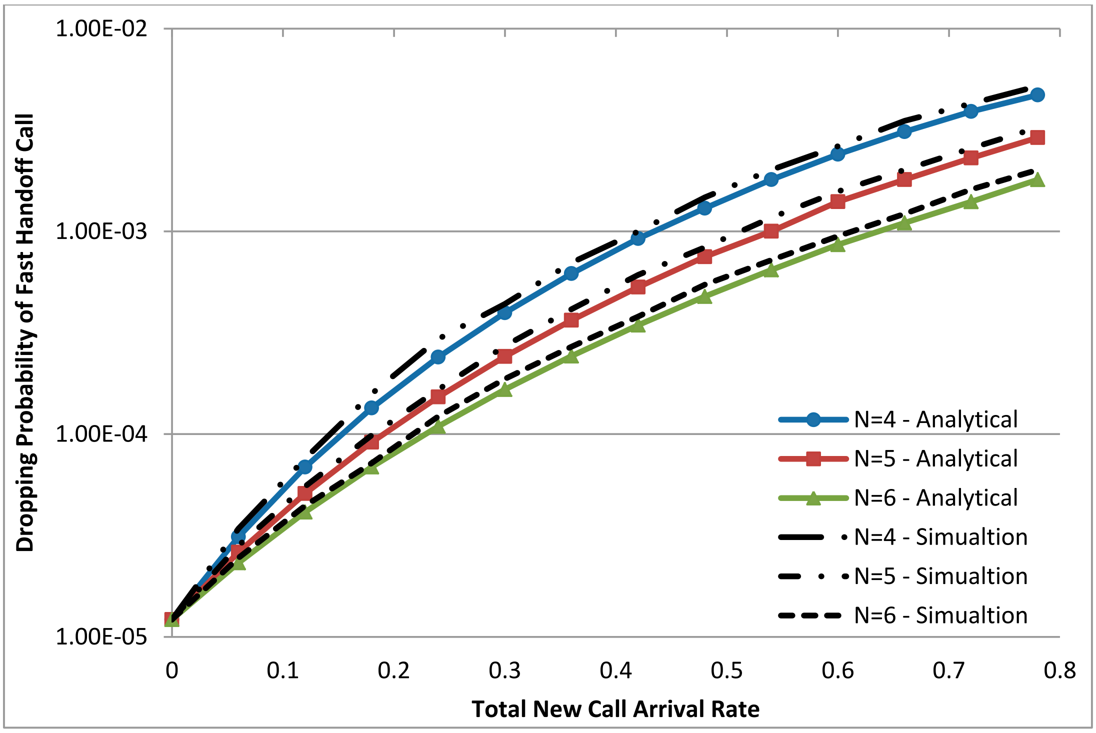


Figure 5.6: Dropping Probability of Fast Handoff Call

Figure 5.7 shows the degradation ratio of voice quality in the microcell as the sub-rating scheme in the microcell is being used. It can be seen that the slow new calls have a lower voice quality degradation ratio because the slow new calls use less numbers of sub-rated channels than the slow handoff calls. It can also be seen from the figure that when all the channels are sub-rated in the microcell, the low voice quality degradation ratio of slow handoff calls reaches the maximum. Increasing the number of microcells in the system makes the voice quality better as can be seen in the figure. Therefore, to meet the QoS requirements of the system on the blocking probabilities and dropping probabilities and Voice degradation ratio, the number of microcells should be increased, and sub-rated channels should be chosen carefully to achieve the best trade-off.

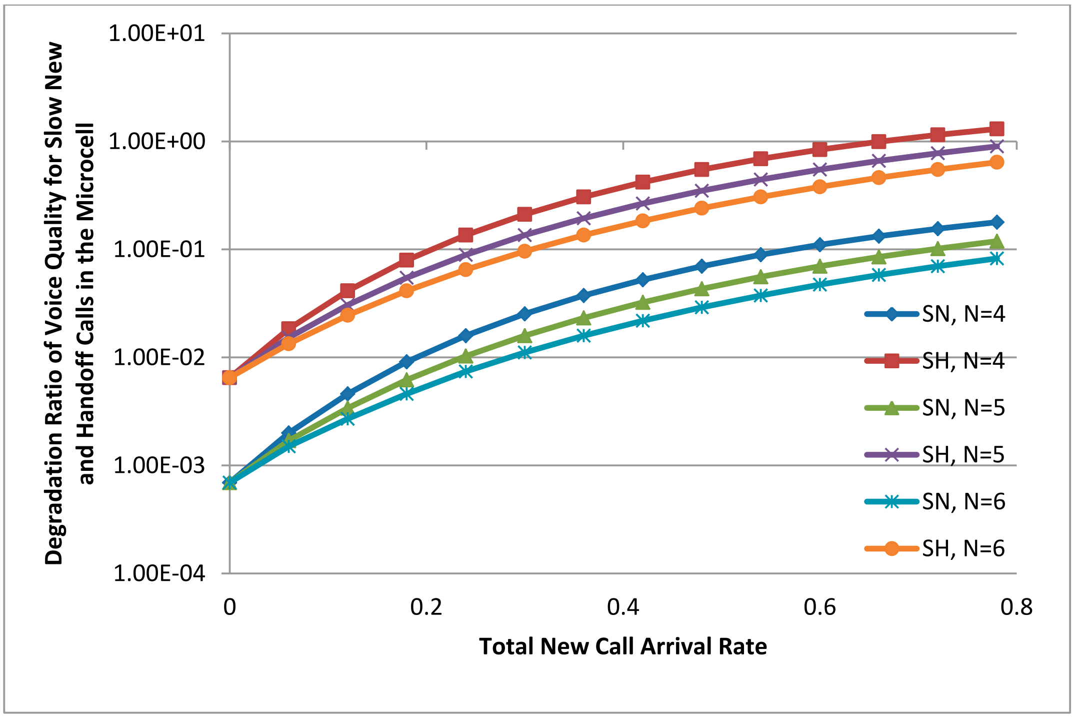


Figure 5.7: Degradation Ratio of Voice Quality for Slow New and Handoff Calls in the Microcell

5.4 Summary

In this chapter, a two-layer macrocell/ microcell HCN system has been studied. The 1-D markov process has been used to develop the Performance models for microcell and 2-D markov process to develop a performance model for the macrocell. In the proposed CAC, the HCN system supports both fast and slow mobility users. The macrocells handle the fast-mobility users, while the microcells serve the slow-mobility users. In the microcells, a combination of sub-rating, call bounding and handoff queuing schemes have been used, while in the macrocell the call bounding scheme has been used. The proposed analytical model was validated by a discrete event simulator, and the results of both show a very close agreement. The results show that the proposed scheme reduces both the dropping probability of slow and fast handoff calls and the blocking probability of slow and fast new calls, compared to the handoff calls sub-rating scheme and guard channel scheme for HCN. The effect of sub-rating in the microcell on voice quality has been studied, and the results show that the voice quality will degrade when the number of channels sub-rated is increased, and voice quality can be improved by increasing the number of microcells.

Chapter 6

Modelling of Prioritised Vertical Handoff Scheme in Integrated UMTS/WLANs

6.1 Introduction

In the evolution of 3G networks, one obstacle is that the data rates in these networks are limited. The complementary characteristics of UMTS networks (slow, wide coverage) and WLANs (fast, limited coverage) make it attractive to integrate the two technologies to provide ubiquitous wireless access. The UMTS networks provide global coverage, mobility and quality of service (QoS), while WLANs are designed to cover localised hot-spot areas, such as airports, shopping centers, hotels, and so on. Although the WLAN coverage is small and it has limited mobility, it can increase the capacity and the performance of the UMTS network it is located in.

In the integrated wireless networks, both UMTS and WLAN access are available to mobile terminals (MT) within the coverage of the WLANs that reside within the UMTS cells. In a network with limited capacity, the carrier uses handovers between the UMTS and the WLANs to enhance QoS, reduce cost, or balance traffic load [100] [101]. The handoff from the UMTS networks to a WLAN is called a vertical handoff (VH).

Similarly, a back- vertical handoff by UMTS users is defined as the handoff from a WLAN to the UMTS network.

There are two types of handoff in the integrated UMTS/WLANs network: a horizontal handoff which takes place between points of attachment supporting the same network technology, such as between two neighbouring base stations of a UMTS, or between two access points of a WLAN. On the other hand, a vertical handover occurs between points of attachment supporting different network technologies, such as between a WLAN access point and a UMTS base station.

There has been some work carried out in 3G/WLAN integrated networks [104, 108]. A simple admission strategy is to have an unconditional preference for WLANs, since WLANs are cheaper and have more bandwidth compared to the 3G (UMTS) networks [104]. In [108], the authors consider that users with high mobility tend to spend a short time in the double coverage area of 3G and WLANs, and they require a back vertical handoff to the UMTS network shortly after they have a vertical handoff from UMTS to WLAN. Guard channels are reserved for handoff and mobility [101] in the cellular network, and fixed amount of resources is allocated to the WLAN users; the remaining resources can be assigned to the cellular users who request connection to the WLAN [101, 102, 107]. In [102] and [107], channel occupancy times; horizontal and vertical handoff rates, as well as blocking probabilities of vertical handoff and new calls, have been derived and calculated. An analytical model for integration of UMTS and WLAN which uses queue capability to reduce the blocking probability of an originating data call and the dropping probability of a data call is presented in [105]. In [106], a scheme to allow selection of the most suitable network while preventing frequent handoffs in integrated UMTS/ WLAN is presented. This improves utilisation by using a combination of AHP and GRA to evaluate user preferences and service classes. To relieve traffic congestion in cellular networks, an optimal channel searching and replacement algorithm (oCSR) is further developed to balance total system traffics between WLAN and 3G cellular networks, as well as to reduce average system QoS costs. A novel joint call admission policy has been derived in [109]. [110] proposes multi-service load sharing for resource management in the Cellular/WLAN integrated network. It has investigated the load sharing problem for the cellular/WLAN integrated network so that the interworking is exploited to enhance multi-service provisioning.

In this chapter, a scheme is proposed for integrated UMTS/WLANs to decrease the blocking probabilities of new calls and horizontal handoff calls in the UMTS cell, by allowing them to have a vertical handoff to the WLANs. Consideration has been given to the type of user class, UMTS users with relative low bandwidth requirement and arbitrary mobility feature, while the WLAN users have a high bandwidth requirement and limited mobility feature. The work has been built by looking to the analytical model developed in [102] and [107]. In the UMTS-only coverage, the maximum numbers of channels that can be used by a newly originated call are m and the rest $M - m$ are reserved exclusively for the handoff calls. The strategies of the proposed CAC are as follows. In the UMTS-only coverage:

- A new call of UMTS users is rejected and attempts a vertical handoff (directly or indirectly) when there are m ongoing new calls of UMTS users or all the M channels are busy.

- A horizontal handoff call of UMTS users is rejected and attempts an indirectly vertical handoff when all the M channels are busy.
- A back vertical handoff call of UMTS users is rejected when all the M channels are busy.

In the WLANs coverage $K - C$ channels are shared by both WLAN users' calls and UMTS vertical handoff users' calls, where there are C channels reserved for the UMTS vertical handoff users' calls. The CAC strategies in the WLAN coverage are as follows:

- A new call from WLAN users is rejected when there are $K - C$ ongoing calls of WLAN users and UMTS vertical handoff users in the WLANs.
- A vertical handoff call of UMTS users is rejected when there are already K ongoing vertical handoff calls and WLANs calls in the WLANs.

The rest of the chapter is organised as follows: Section 6.2 describes the proposed model. In Section 6.3, the performance analysis is provided by estimating the handoff arrivals rates, deriving the steady state probability and channel holding time and it indicates the performance measures. Validation of the model is explained in Section 6.4. The numerical results and discussion are presented in Section 6.5. Section 6.6, gives a summary of this chapter.

6.2 Model Description

As can be seen in Figure 6.1 below, it is assumed that there are two user classes in the network. The UMTS users have a relative low bandwidth requirement and arbitrary mobility feature, while the WLAN users have a high bandwidth requirement and limited mobility feature.

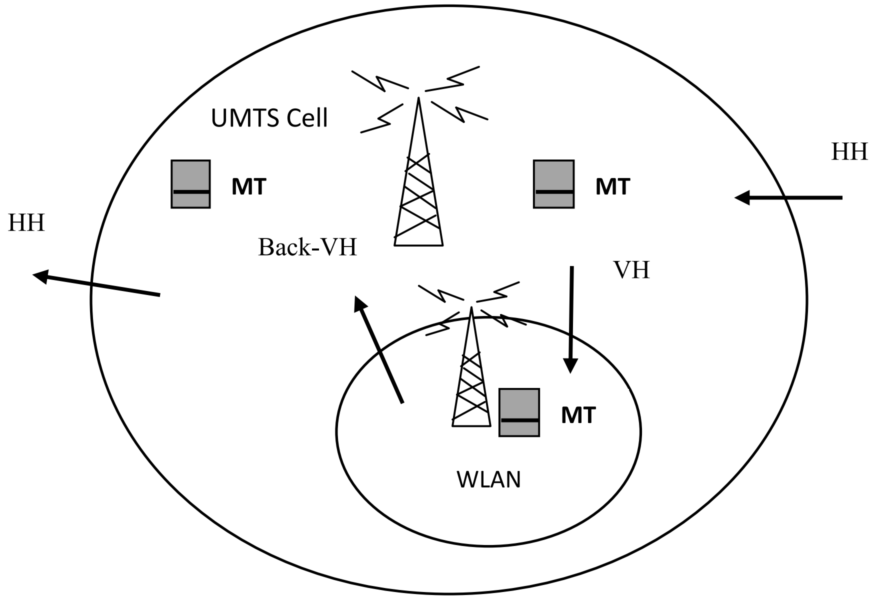


Figure 6.1: Integrated UMTS/WLANs Network Model

The UMTS users can always attempt a horizontal handoff to neighbour UMTS cells when they reach the boundary of a cell. In addition, if there is no channel available, the UMTS users can attempt a vertical handoff to one of the underlying WLANs. After successfully making a vertical handoff, the call may complete in the WLAN, or continue to attempt a back vertical handoff to the UMTS cell when the user moves out of the WLAN. However, the WLAN users are assumed to move only within the WLAN coverage, because there are no priorities for horizontal handoff between the WLANs, so here the entire underlying WLANs have been considered to be as one WLAN. For simplicity, here it is assumed that the WLAN users do not attempt vertical handoffs to the UMTS cell due to their limited movement range, and there is no channel exclusively reserved for WLAN users in the UMTS cell. However, if a WLAN user moves out of the

WLAN, they can request a call, in such a way he or she will become another class of user (that is, a UMTS user) and the request will become a new call request in the UMTS cell.

A handoff call is usually given higher priority over a new call, and here it can be assumed that there are M channels in the UMTS cell, of which m channels is the maximum number of channels that can be used by new calls, and $(M - m)$ are reserved for handoff calls. Assuming there are K channels in the WLANs, where C channels are reserved for vertical handoff call, all the other $K - C$ can be shared by both the vertical handoff calls of the UMTS user's and the WLAN user's calls. Thus, when rejection occurs under a call admission control (CAC) strategy, a new call from UMTS users may directly attempt a vertical handoff to the underlying WLAN if it happens to be in the WLAN's coverage.

6.3 Performance Analysis

The UMTS cell coverage without the underlying WLANs is called UMTS-only coverage. When a MT moves to neighbouring cell with an ongoing call session, it initiates horizontal handoff (HH). When a call is blocked in UMTS, it is transferred to WLANs, and this is called vertical handoff (VH) in WLANs. When a MT with ongoing call session moves from WLAN to UMTS-only coverage, it initiates VH in UMTS.

6.3.1 Flow diagram

Figure 6.2 below shows the flow diagram of the procedures for the logical coverage in a mixed cell of UMTS underlined by WLANs.

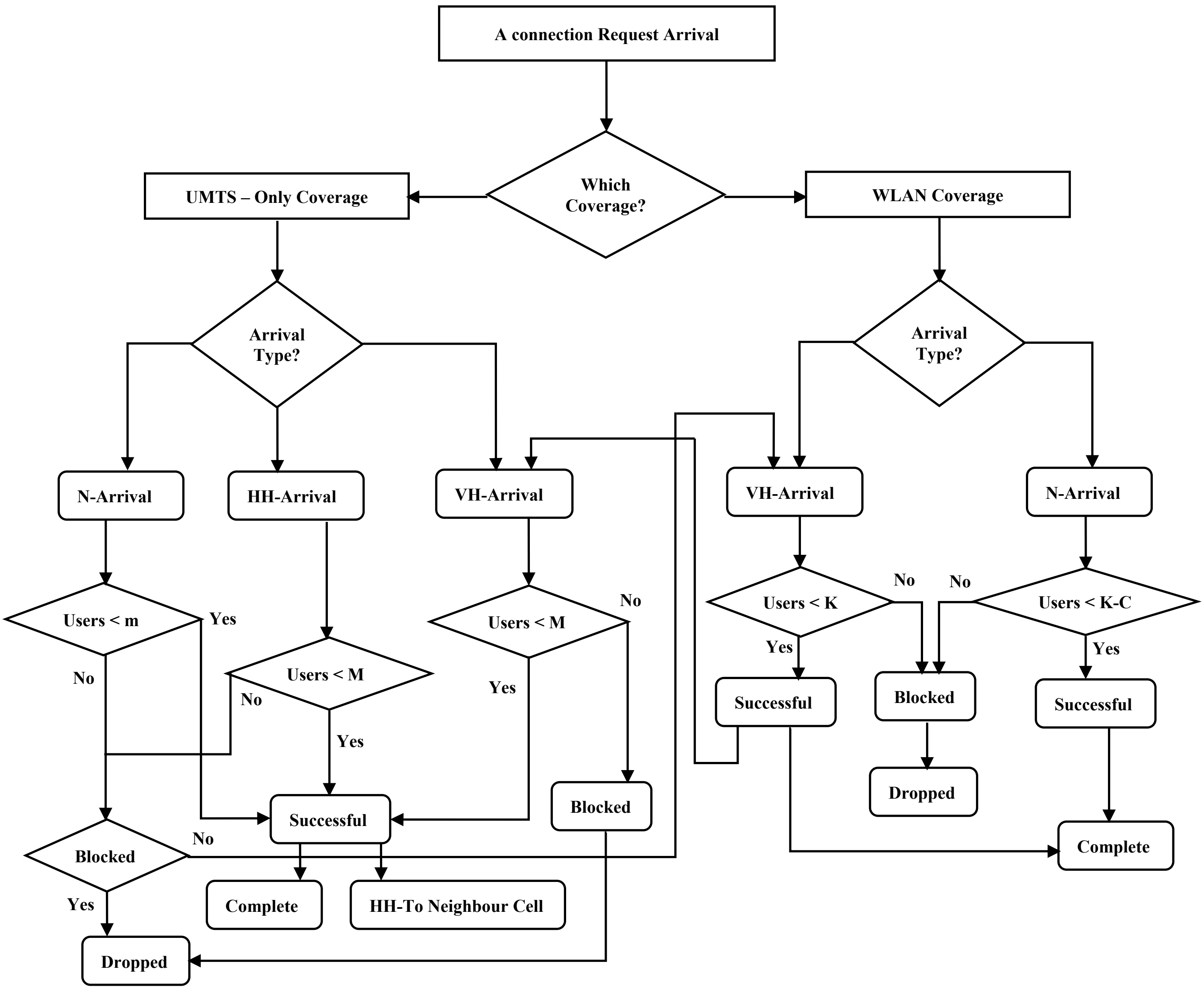


Figure 6.2: Flow Diagram of the Integrated UMTS/WLANs

UMTS-Only Coverage:

As can be seen in the flow diagram, N-Arrival, HH-Arrival, and VH-Arrival states represent the origins of new call requests (N), horizontal handoff call requests (HH), and vertical handoff call requests (VH) respectively. N-Arrival transits to Blocked if it is denied and transits to Successful if it obtains a channel. The N-Successful state may go to completion state when the session is completed or terminated, or it may move to HH-Arrival state when the MT has a HH to a neighbouring cell. Also HH-Arrival and VH-Arrival of UMTS will move to other states as shown in Figure 6.2.

WLANs Coverage:

The origins of new call requests (N), and vertical handoff call requests (VH) are represented by N-Arrival and VH-Arrival states respectively. The VH-Arrival moves to either blocked or Successful states. VH-Successful moves to either a completion state or VH-Arrivals state in UMTS.

It is assumed that the blocking probabilities of N and HH (or VH) in UMTS are b_1 and b_2, respectively. New call (N) blocking probability in WLAN is b. for simplicity; variable x' is represented as the complement of x given that $x' = (1 - x)$.

In UMTS-only coverage, N-Arrival moves to Block state and Successful state with probabilities b and b', respectively. HH-Arrival and VH-Arrival moves to Block state with probability b_2. Also, HH-Arrival and VH-Arrival moves to Successful states with probability b_2'. N-Successful, HH-Successful, and VH-Successful moves to HH-Arrival in the neighbour cells if the MT initiate a horizontal handoff to the neighbour cell with probabilities P_{ns}^{u}, P_{hhs}^{u}, and P_{vhs}^{u} respectively, and they move to completion states with probabilities $(P_{ns}^{u})'$, $(P_{hhs}^{u})'$, and $(P_{vhs}^{u})'$ respectively. A blocked N, HH, and VH can be dropped with probabilities $g'(P_{in})'$, $g'(P_{ih})'$ and 1, respectively. A blocked N and HH in the UMTS-only coverage can also initiate indirect vertical handoff to the WLANs with probabilities $g'P_{in}$ and $g'P_{ih}$, respectively. P_{in} and P_{ih} are the probabilities that blocked N and HH will initiate indirect VH in WLANs. g $(0 \leq g \leq 1)$ is the normalised WLAN coverage given by the ratio of the coverage of all WLAN hotspots to the coverage of a pure UMTS cell. When the probability that a MT is under the WLANs coverage is computed, it should be given a weight factor ω [102] to describe hot-spot features such as $\omega \geq 1$ and $0 \leq \omega g \leq 1$. p denotes the population coverage rate and $p = \omega g$. Here $p > g$ and when the traffic is uniform $\omega = 1$.

N-Blocked state occurs in UMTS with WLAN coverage with probability g and in UMTS-only coverage with probability $g^{'}$.

Here, if it happens that the N-blocked call is already within the WLAN coverage it will initiate a vertical handoff with probability g. The indirect VH for N calls and HH call can be written as:

$$P_{in} = 1 - (1 - g)^{m} \; and \; P_{ih} = 1 - (1 - g)^{M} \qquad (6.1)$$

Also, VH-Blocked will move to drop state with probability 1.

In the WLANs coverage, N-Arrival will move to blocked and successful states with probabilities b and $b^{'}$, respectively. The VH-Arrival will move to successful state with probability $b_3^{'}$ or to blocked state with probability b_3. Both the blocked VH-Arrival and N-Arrival will be dropped. The successful VH may move to completion states with probabilities $(P_{vhs}^{w})^{'}$ or initiate a vertical handoff to the UMTS coverage with probability P_{vhs}^{w}. The successful N can move only to completion states with probability 1.

By using the Laplace transform approach as in [102] and [103], these probabilities can be calculated and may directly be written as:

$$P_{ns}^{u} = \int_{0}^{\infty} \int_{t}^{\infty} f_{residual_{CRT}}(t) f_{SHT}(\tau) d\tau dt = \frac{r^{u}(1 - f_{CRT}^{*}(h))}{h} \qquad (6.2)$$

$$P^u_{hhs} = P^U_{vhs} = f^*_{CRT}(h) = 1 - \left(1/_{r^u}\right)(hP^u_{ns}) \tag{6.3}$$

$P^w_{vhs} = \frac{r^u(1-f^*_{CRT}(h))}{h}$ where $1/_{r^u}$ is the mean cell residence time (CRT) of a UMTS cell, $1/_h$ is the mean session holding time (SHT) in a mixed cell and $f^*_{CRT}(h)$ is the Laplace transform of probability density function of CRT at $s = h$.

6.3.2 Handoff Arrival Rate Estimation

The arrival rate of N, HH, and VH is represented by λ^u_n, λ^u_{hh} and λ^u_{vh} respectively in the UMTS. λ^u_n and λ^w_{vh} are the N of WLANs users and VH of mixed users respectively. By following the flow balance equation at equilibrium state we can get:

$$\lambda^u_{hh} = \lambda^u_n b_1{}' P^u_{ns} + \lambda^u_{hh} b_2{}' P^u_{hhs} + \lambda^u_{vh} b_2{}' P^u_{vhs} \tag{6.4}$$

$$\lambda^u_{vh} = \lambda^w_{vh} b_3{}' P^w_{vhs} \tag{6.5}$$

$$\lambda^w_{vh} = \lambda^u_n b_1 (g + g' P_{in}) + \lambda^u_{hh} b_2 g' P_{ih} \tag{6.6}$$

We can derive these arrival rates if we know λ^u_n and other parameters.

6.3.3 Channel Holding Time

It is assumed that SHT has exponential distribution with mean $1/h$ sec in the entire cell. CRT has a hyper-Erlang distribution with mean $1/r^u$ sec in the UMTS-only coverage and $1/r^w$sec in the WLANs coverage.

$$F_{CHT}(t) = P(CHT \leq t) = 1 - P(SHT > t, residual_{CRT} > t) \tag{6.7}$$

$$f_{CHT}(t) = \frac{d}{dt}\left(1 - \int_{t}^{\infty} f_{SHT}(t)dt \int_{t}^{\infty} f_{residual-CRT}(t)dt\right) \tag{6.8}$$

Using the Laplace transform approach [102], [103], the mean value of X can be obtained as follows:

$E[X] = (-1)f_{CRT}^{*(1)}(0)$, where $f_{CRT}^{*(1)}(0)$ is the first derivative of $f_{CRT}^{*(1)}(s)$ at $s = 0$. From [102] and [103], the mean channel holding times are obtained for new calls (N), horizontal handoff (HH) and back vertical handoff (VH) calls of UMTS users are:

$$E[T_{ns}^{u}] = E[T_{vhs}^{u}] = \frac{1}{h} - \frac{r^{u}}{h^{2}}(1 - f_{CRT}^{*}(h)) \tag{6.9}$$

$$E[T_{hhs}^{u}] = \frac{1}{h}(1 - f_{CRT}^{*}(h)) \tag{6.10}$$

For WLAN users, the channel occupancy time is equal to its channel holding time that is $E[T_{ns}^{w}] = \frac{1}{h}$, because of limited mobility and is assumed to be active only in the WLANs. The channel occupancy time of a vertical handoff call of UMTS users in the WLANs is:

$$E[T_{vhs}^{w}] = \frac{1}{h} - \frac{r^{w}}{h^{2}}(1 - f_{CRT}^{*}(h)) \tag{6.11}$$

The Laplace transform of Hyper-Erlang distribution is:

$$f_{CRT}^{*}(s) = \sum_{i=1}^{N} \alpha_i \left(\frac{n_i\theta_i}{s + n_i\theta_i}\right)^{n_i} \tag{6.12}$$

where $\alpha_i \geq 0,\ \sum_{i=1}^{N} \alpha_i = 1$, and N, n_i and θ_i are positive numbers.

6.3.4 Steady State Probability for Call Sessions

Using the Erlang's loss-formula for a three dimensional steady state Markov Chain [103], the probability that there are N-Successful, HH-Successful and VH-Successful states in the UMTS system is:

$$P^u(i,j,k) = P^u(0,0,0)\left[\frac{(\lambda_n^u E[T_{ns}^u])^i\ (\lambda_{hh}^u E[T_{hhs}^u])^j\ (\lambda_{vh}^u E[T_{vhs}^u])^k}{i!\,j!\,k!}\right] \quad (6.13)$$

where $P^u(i,j,k)$ is the steady state probability that i, j and k are the number of new calls, horizontal handoff and back vertical handoff calls from the UMTS users in the UMTS cell. Then,

$$P^u(0,0,0) =$$

$$= \left[\left(\sum_{i=0}^{m}\frac{(\lambda_n^u E[T_{ns}^u])^i}{i!}\right)\left(\sum_{j=0}^{M-i}\frac{(\lambda_{hh}^u E[T_{hhs}^u])^j}{j!}\right)\left(\sum_{k=0}^{M-i-j}\frac{(\lambda_{vh}^u E[T_{vhs}^u])^k}{k!}\right)\right]^{-1} \quad (6.14)$$

$P^u(0,0,0)$ is the probability that there are no new calls or handoff calls requests in the UMTS cell. T_{ns}^u, T_{hhs}^u and T_{vhs}^u are channel holding times (CHTs) of successful new, successful horizontal handoff and successful vertical handoff session, respectively.

The probability of N-Successful and VH-Successful states in the WLANs is:

$$P^w(i,j) = P^w(0,0)\left[\frac{(\lambda_n^w E[T_{ns}^w])^i\ (\lambda_{vh}^w E[T_{vhs}^w])^j}{i!\,j!}\right] \quad (6.15)$$

where $P^w(i,j)$ is the steady state probability that i is the number of calls of WLANs users and j is the number of vertical handoff calls of UMTS users in the WLANs. Then,

$$P^w(0,0) = \left[\left(\sum_{i=0}^{K-C} \frac{(\lambda_n^w E[T_{ns}^w])^i}{i!}\right)\left(\sum_{j=0}^{K-i} \frac{(\lambda_{vh}^w E[T_{vhs}^w])^j}{j!}\right)\right]^{-1} \qquad (6.16)$$

and $P^w(0,0)$ it is the probability that there are no requests is being processed in WLANs. T_{ns}^w and T_{vhs}^w are the channel holding time of successful N and successful VH, respectively.

6.3.5 Performance measures

The blocking probability of new calls for UMTS users in the UMTS cell will occur when there is already m of N-Successful states in the UMTS or there are no available channels in the UMTS cell. Then, the blocking probability of new calls of UMTS users in the UMTS cell is:

$$b_1 = \sum_{j=0}^{M-m} \sum_{k=0}^{M-m-j} P^u(m,j,k) + \sum_{i=0}^{m-1} \sum_{j=0}^{M-i} P^u(i,j,M-i-j) \qquad (6.17)$$

The Blocking probability of horizontal handoff or vertical handoff in the UMTS cell will occur when there are already M successful states in the UMTS. In this situation $(j+k) \geq (M-m)$ and $(i+j+k) = M$. The blocking probability of handoff requests (HH or VH) in UMTS cell is:

$$b_2 = \sum_{i=0}^{m} \sum_{j=0}^{M-i} P^u(i,j,M-i-j) \qquad (6.18)$$

The Blocking probability of WLANs users will happen when there are $K-C$ successful states in the WLANs ($K-C$ busy channels):

$$b = \sum_{j=0}^{C} P^w(K - C, j) \qquad (6.19)$$

The Blocking probability of vertical handoff calls of UMTS users to the WLANs is the probability that all K channels are busy in the WLANs.

$$b_3 = \sum_{i=0}^{C} \sum_{J=0}^{K-i} P^w(i, j - i) \qquad (6.20)$$

When a new incoming call to the UMTS cell cannot be served in the cell it will be dropped and that is because of one of the following reasons:

- The user who is initiating this call is in the UMTS-only coverage area and there are no other ongoing calls by UMTS users in the WLAN coverage area.
- The user who is initiating this call is in UMTS-only coverage and there is at least one ongoing call by UMTS users under the WLAN coverage, but all the K channels of WLANs are occupied.
- The user initiating this call is under the WLAN coverage but all the K channels of WLANs are occupied.

Therefore, the dropping probability of a new call is:

$$P_{dn} = b_1 g'(P_{in})' + b_1(g + g' P_{in}) b_3 \qquad (6.21)$$

where b_1, and g are positive fractions.

Horizontal handoff arrival moves to dropped state in UMTS and in WLANs. Then the final dropping probability of HH is:

$$P_{dh} = b_2 g'(P_{ih})' + b_2 g'(P_{ih}) b_3 \qquad (6.22)$$

6.4 Validation of the Model

To validate the analytical results, a discrete event simulator has been created using java. Numerous validation experiments have been carried out with different values of K and C. Experiments have been carried out to obtain the results of the dropping probability of new UMTS calls and the dropping probability of UMTS horizontal handoff calls, when decreasing and increasing the number of channels in the WLAN and the number of channels which are exclusively used by vertical handoff calls from the UMTS to WLAN. It can be seen in Figure 6.3 and 6.4 below that the simulation results and the analytical results show a very good close agreement.

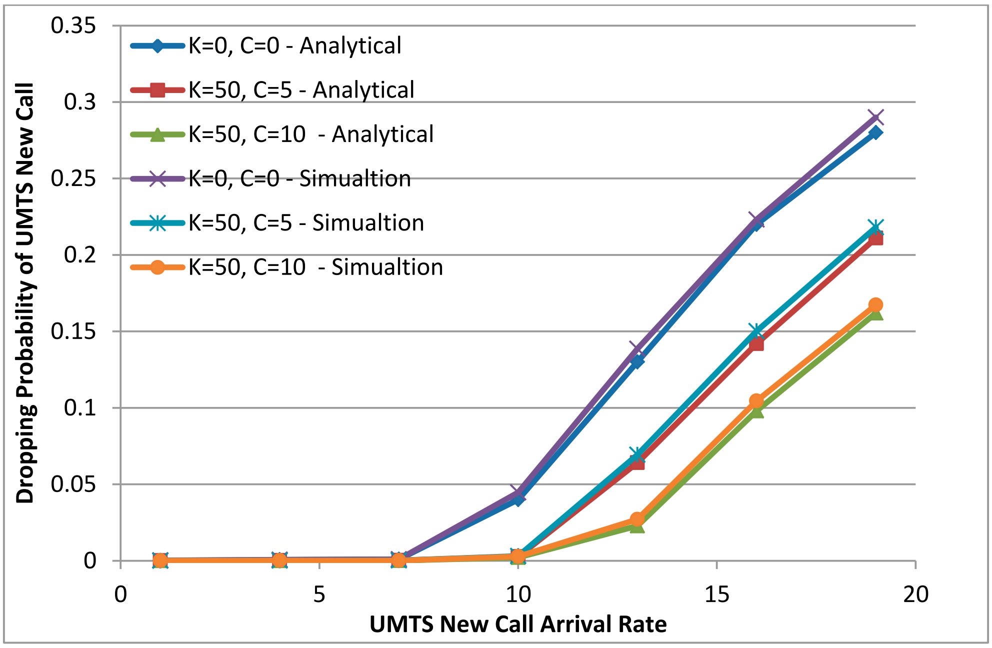


Figure 6.3 : Dropping Probability of UMTS New Call (Analytical and Simulation)

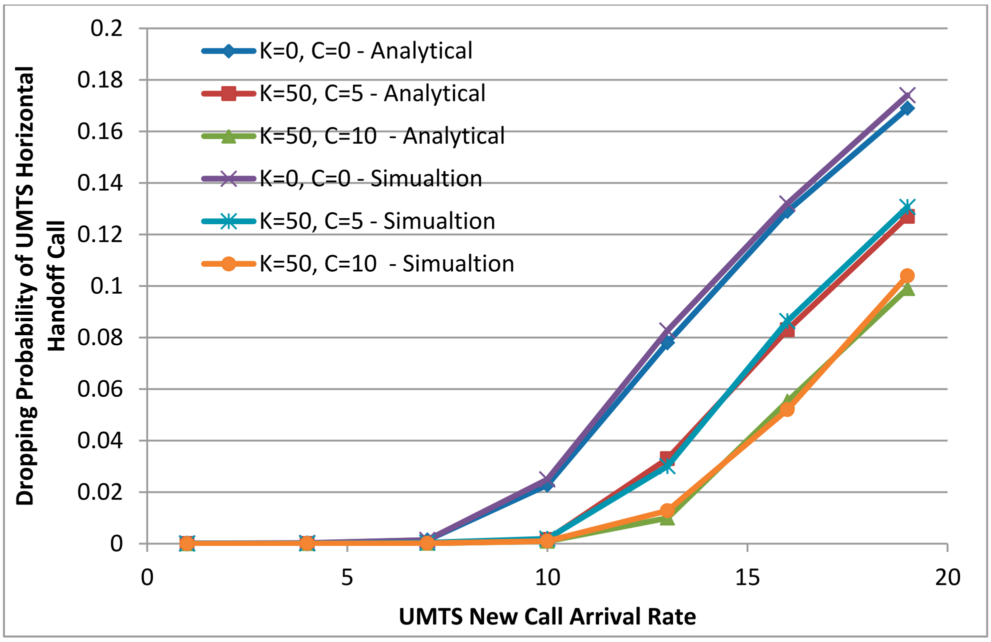


Figure 6.4: Dropping Probability of UMTS Horizontal Handoff Call (Analytical and Simulation)

6.5 Numerical Results and Discussion

Here, it is required to see the improvement of call blocking probabilities and call dropping probabilities of the UMTS users by having WLANs integrated in it. The effect of the C channels in the WLANs which will be used only by the vertical handoff calls of UMTS users (with $\lambda_n^u = 10$, p=0.4) will be seen. Also, the effect of increasing and decreasing the coverage rate (g) of the WLANs (with, $\lambda_n^w = 10$, C=10) will be discussed. The following parameters have been used: N=2, $\propto_1 = 0.4$, $\propto_2 = 0.6$, $n_1 = 3$, $n_2 = 2$, $\theta_1 = 0.45$, $\theta_2 = 0.35$, , $mean = 3.31\ min$ for the UMTS, and N=2, $\propto_1 = 0.2$, $\propto_2 = 0.8$, $n_1 = 2$, $n_2 = 2$, $\theta_1 = 0.25$, $\theta_2 = 0.35$, $mean = 2.73\ min$. For WLANs, the call holding time is exponentially distributed with mean 2.5 min for UMTS users and 2.5 min for WLANs users. $M = 30$, $m = 25$, $K = 50$, $C = 10$.

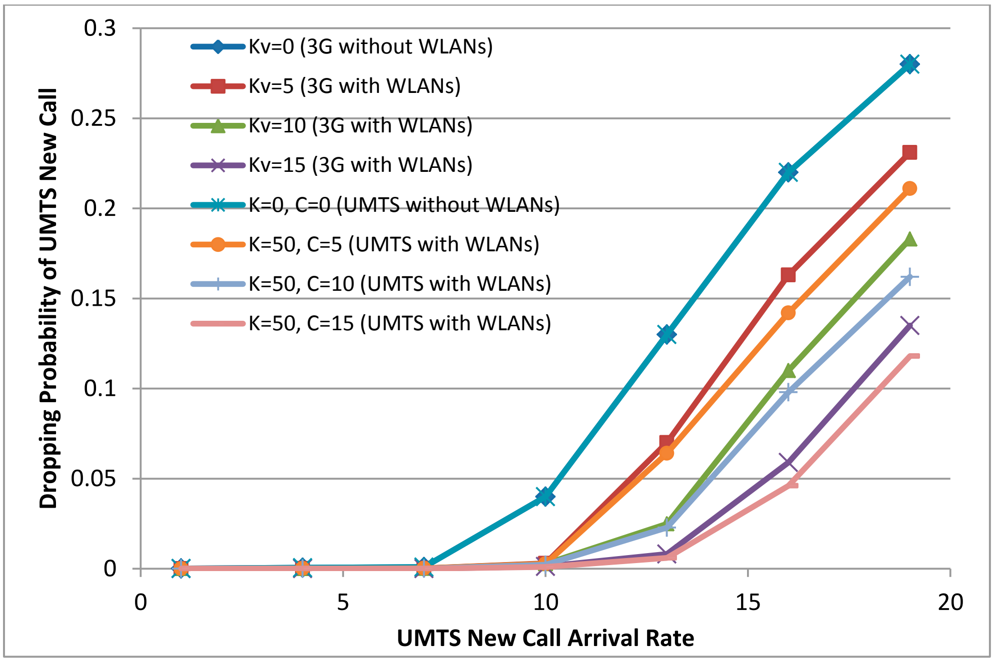


Figure 6.5: Dropping Probability of UMTS New Call with effect of K and C

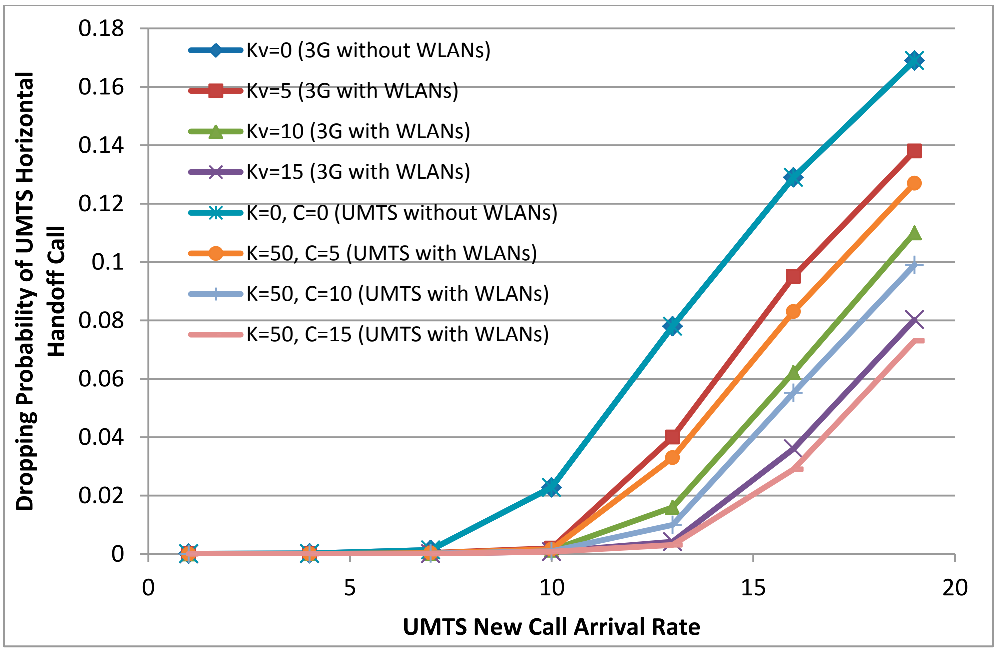


Figure 6.6: Dropping Probability of UMTS Horizontal Handoff Call with effect of K and C

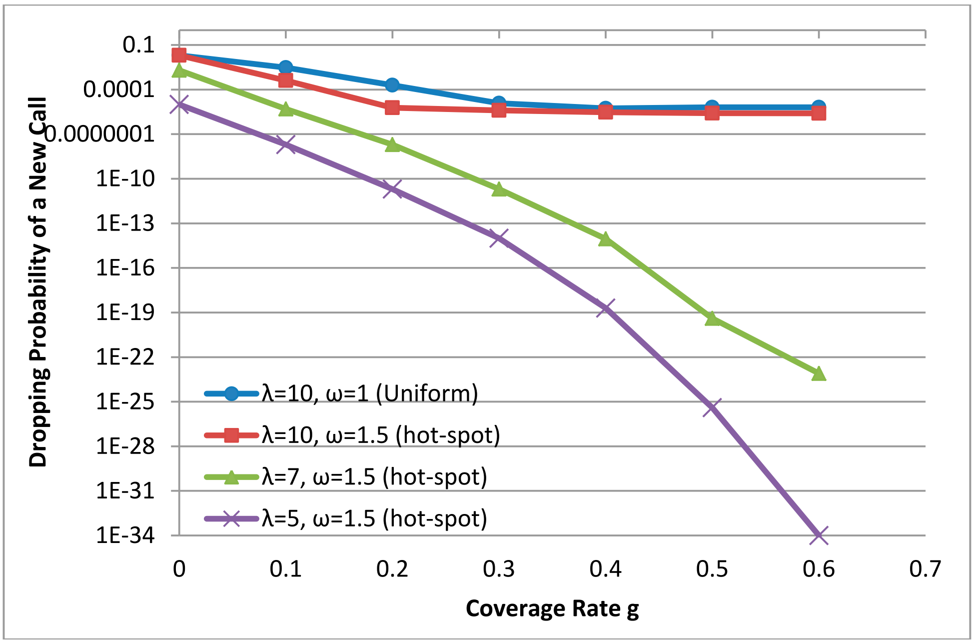


Figure 6.7: Dropping Probability of UMTS New Call with Effect of WLANs coverage Rate (g)

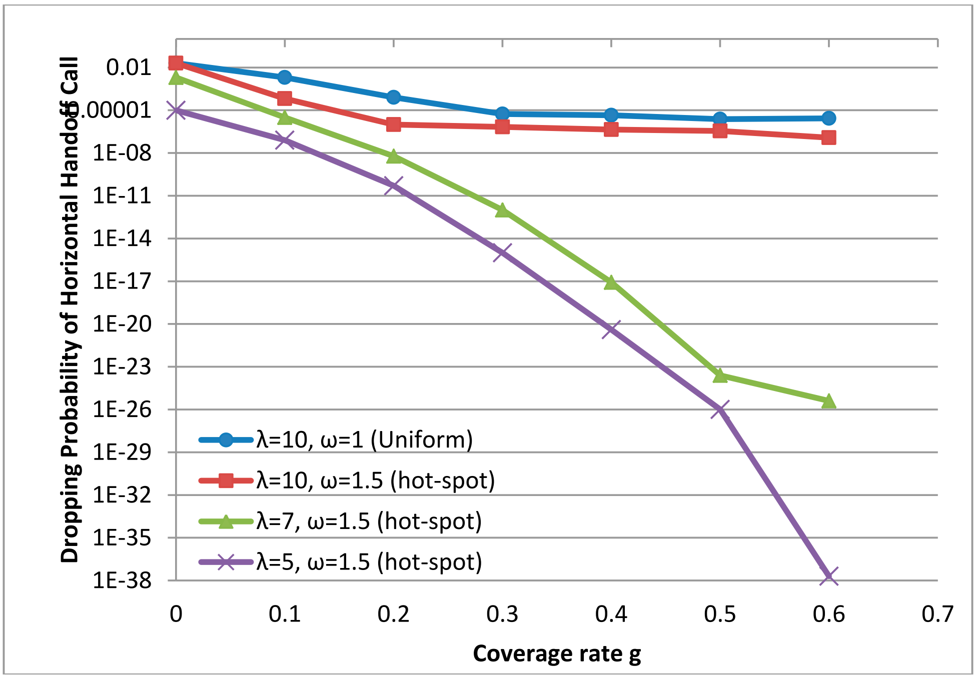


Figure 6.8: Dropping Probability of UMTS Horizontal Handoff Call with Effect of WLANs coverage Rate (g)

In Figure 6.5, it can be seen that the blocking probability of UMTS new calls decreases with the increase of C because by increasing $C,$ more new call users of UMTS can make a vertical handoff to the underlying WLAN instead of using shared channels $K - C$ only. To study the system performance of the UMTS system with and without the WLANs, we set $C = 0$ and $K = 0$ and saw that the integrated network has a much better performance than the conventional network from both the dropping probability of new calls and horizontal handoff calls. The same thing was noticed in Figure 6.6 as well. For these two figures, the results were compared with the results obtained in [102] and [107], and the proposed scheme shows better results in both the dropping probability of new calls and horizontal handoff because in [102] the 3G users use the reserved channels K_v in the WLANs only, but in this scheme they use the reserved channels C plus share the other $K - C$ channels with the WLANs users.

Figures 6.7 and 6.8 show the study of the effect of the WLAN coverage rate g with uniform traffic and hot-spot traffic on the system performance. It can be seen that the dropping probability of new calls decreases by increasing the coverage rate g. This is because increasing g gives more chances of vertical handoff, so that the calls that are blocked will not necessarily be dropped. It is also noticed that the performance improvement will be reduced when the coverage rate is increased to a certain value, as noted in [102] and [107] as well. Also, when the coverage area has a higher population density (hot-spot), the integrated network will gain better performance.

6.6 Summary

In the proposed modelling of a prioritised vertical handoff scheme in an integrated UMTS/WLANs network, the call residence times are modelled by general distribution to adapt to the flexible mobility environments. In this scheme, the horizontal handoff and new calls rates have been derived and calculated. The channel occupancy times and the blocking and dropping probabilities have been derived and calculated as well. From the numerical results, it is shown that the performance of the integrated UMTS/WLAN is improved, especially when the WLANs are in hot-spot areas. The analytical model has been validated by a discrete event simulator, and the results from both analytical and simulations show a close agreement. The results also show that this model provides better call-dropping performance than the model it was compared too. Integration of UMTS and WLANs can help in creating Mobile Hot-Spot that can provide high-speed wireless data solution to areas that require it.

Chapter 7

Conclusions and Future Directions

In this thesis, firstly, an analytical model has been developed for priority handoff mechanisms and optimised number of channels assigned to handoff calls, with the aim of minimising the dropping probability under given network scenarios. A performance model has also been developed and provided for a two-cell network system and the different performance parameters have been measured for each of the cells in the network and altogether as one network system. Secondly, a solution has been developed for re-allocation of the unutilised bandwidth to be used fairly by all nodes that request a bandwidth. Finally, a new performance model for a Macro/ Micro cells network has been developed, which supports fast and slow mobility users. The microcell has also been replaced by WLANs and a performance model proposed for prioritising a vertical handoff scheme in an integrated UMTS/WLAN network. In the following section, the results of this research are summarised, followed by a discussion of future research directions.

7.1 Summary of results

The main contributions of this thesis are summarised as follows:

- In Chapter 3, an analytical model has been developed for priority handover mechanisms, whereby new calls and handover calls are captured by two different traffic arrival processes respectively. The comparison between the results obtained from the analytical model and those obtained by the simulation has shown that the derived analytical model possesses a good degree of accuracy to predict the network performance under different network scenarios. Using the blocking probability of the new calls and the dropping probability for handoff calls derived from the analytical model, the optimised number of channels assigned to handoff calls has been calculated with the aim of minimising the dropping probability under given network scenarios. Also in this chapter, a performance model for a network with two-cells has been developed to measure the different performance parameters for each of the cells in the network, and altogether as one network system. The results obtained from the analytical model have been compared to results obtained by simulation experiments and they show the accuracy of the analytical model in predicting the network performance parameters.
- In Chapter 4, a new solution model has been proposed to manage the bandwidth in a 3G wireless cellular network. To manage the bandwidth in the network properly, a higher priority has been given to multimedia calls to keep them constant during their connection lifetime. A bandwidth, which is not utilised by fewer mobile nodes, has been re-allocated to the needy ones. For the lower priority handover call (data call) at least a minimum bandwidth has been allocated for the worst-case scenario. The unutilised bandwidth has been distributed fairly among active lower priority nodes, which will be utilised later on by either handoff calls or incoming local calls. With

this method, maximum bandwidth in the cell will be reached, it will remain available whenever a new call, either handoff or locally generated comes in, and therefore, the wastage of network resources can be avoided. The dropping probability of handoff calls has been reduced to a minimum and the blocking probability of newly generated calls has been maintained at a minimum by this method.

- In Chapter 5, analytical performance models for a two layer microcells/ macrocell Hierarchical Cellular Network has been developed by using a 1-D and 2-D markov process for microcell and macrocell, respectively. This analytical model's results have been compared to simulation experiment results, and they show a very good agreement. The macrocells handle the fast-mobility users, while the microcells serve the slow-mobility users. In the microcells, a combination of sub-rating, call bounding and handoff queuing schemes has been used, while in the macrocell, the call bounding scheme has been used. As sub-rating the channel effects the voice quality, the degradation ration of the voice quality has been studied in the microcell, and the results show that increasing the number of microcells will reduce this degradation ration and it will improve the performance of the network at same time.

- In Chapter 6, a new performance model has been developed to prioritise vertical handoff schemes in an integrated UMTS/WLAN network. In this model, the call residence times have been modelled by general distribution to adapt to the flexible mobility environments. The new originated and horizontal handoff call of UMTS users that are blocked in the UMTS-only coverage can attempt a vertical handoff to the underlying WLANs. In the WLANs, these calls were given more priority than the WLANs users call by reserving some channel for them, plus they shared the rest of the channels with the WLANs users. The channel occupancy times and the blocking and dropping probabilities have been derived and calculated. The results obtained from both the analytical model and the simulation experiments, show a very good agreement. The results also show that by increasing the coverage size of the WLANs, the network performance has been improved and the dropping probability of new calls and horizontal handoff calls of UMTS users have been reduced.

7.2 Direction of Future Work

In this Section, several interesting issues have been discussed and problems addressed that require further investigation. These are briefly outlined below:

- As mentioned at the end of chapter 3, where a performance model for two-cell in cellular network was developed, this work can be extended and a new performance model can be developed for a cluster of seven cells. This will allow the study of handoff and performance parameters between clusters of seven cells each, instead of studying the handoff and performance parameters of a single cell or between two cells. Further study can be carried out on the user movement between the cluster cells. Some intelligent tools can be used such as fuzzy logic, and genetic algorithms and this will help in predicting the motion of the MT in an accurate way.

- As future wireless networks will be integrated into different technologies, work on the study of integration between UMTS and WLANs should be extended to develop some analytical models for integration of LTE and WiMAX with the

Cellular networks. Different resource allocation schemes which support multiple traffic in an integrated wireless networks can be used. The different traffic flow from and to different wireless or mobile networks can be combined together to achieve a better QoS (that is, maximum throughput, minimum delay, minimum packet errors, and so on).

- The integration of WLANs and UMTS can also be extended to do a study on multiple class traffic where there will be data calls and voice calls.

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