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A Hierarchical Channel Selection Scheme

for Macro/Micro Cellular Networks

by

Ayesha Zaheer

B.S., Osmania University, 1994

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the School of Electrical Engineering & Computer Science
in the College of Engineering and Computer Science
at the University of Central Florida, Orlando, Florida

Fall Term

2000

Abstract

Hierarchical channel allocation schemes for cellular networks offer a promising approach to solve the pressing problem of increasing the cellular servicing capacity in spite of the limited radio spectrum available. We propose a hierarchical channel selection scheme for handling handoffs and new calls in micro/macro cellular systems. The scheme is intended to improve the performance and quality of service of these systems by increasing the cell channel utilization, reducing the handoff blocking probability and improving the responsiveness to new calls.

The proposed scheme is based on several design enhancements including an overflow buffer, which is used for handoff calls that cannot be immediately switched to a micro cell channel. The application of this overflow buffer is made feasible by the availability of the umbrella coverage of the macro cell. A modified Guard Channel policy is proposed in conjunction with the overflow buffer for the purpose of giving handoff requests higher priority without the aggressive blocking of new calls. Load balancing rules aimed at the careful selection of micro and macro cell channels are developed. Handoff and new call requests are classified into few categories and control techniques for handling each category are defined. Each allocation of a new channel requires a check on the load factor of the cell. A detailed simulation model was developed to evaluate the hierarchical

scheme, refine its design, and compare its performance with four of the schemes previously proposed in the literature. The simulation tests were performed under different teletraffic conditions and parameter values. The performance comparison results obtained by our extensive tests have shown that the proposed scheme consistently reduces the average handoff dropping rate, increases the new call acceptance rate and enhances the throughput of the cellular system.

This work is dedicated to my daughter, parents, and my sister whose love and support sustained me throughout this experience.

Acknowledgments

I would like to express my special thanks to my graduate advisor Dr. Mostafa A. Bassiouni for his extraordinary patient guidance and generous consideration especially throughout this research. I would also like thank Dr. Ali Orooji for teaching me important concepts about Object-Oriented Programming through his class, and I would like to thank Dr. Kien A. Hua for guiding me through how to develop research idea and express issues in research through his, Transaction Processing class.

Special thanks to my friend, Keith Birch, for his help and support.

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Chapter 1

Introduction

1.1 Thesis Organization

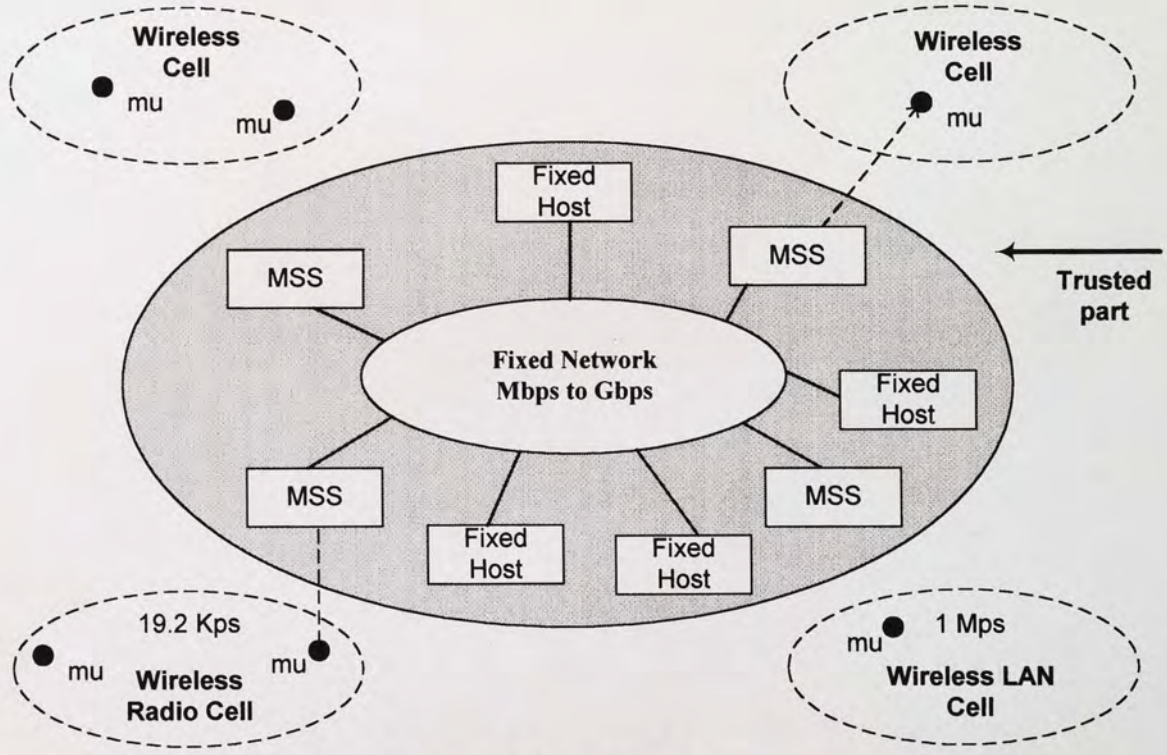
In this thesis, a new hierarchical channel allocation scheme for macro-micro cellular network is presented. A simulation model is used to test and evaluate the performance of the new scheme. The results are compared against the existing schemes.

This thesis is organized as follows: Chapter 1 provides brief information about the cellular network and the problems prevailing. Chapter 2 reviews the schemes proposed in the literature.

The new proposed channel allocation scheme is presented in Chapter 3. This chapter introduces the data structures, channel allocation algorithm, load balancing techniques and channel release algorithm. Chapter 4 describes the simulation model in detail. The performance model for the proposed scheme comparing it with the existing schemes is given in Chapter 5. Finally Chapter 6 concludes the thesis and gives some possible future extensions.

1.2 Background

PCS (Personal Communication Service) is a set of capabilities that allows some combination of terminal mobility, personal mobility, and service profile management. The mobile unit communicates with a network of base stations connected using local, metropolitan or Wide Area Network. All the communication to and from a mobile takes place via a base station in its geographic vicinity. The mobile user may move from the range of its current base station to a different base station while communication is still in progress. A typical architecture to support mobile wireless computing [ALAN94] is shown in the Figure 1 below.



mu : Mobile Unit (can be either dumb terminals or workstations)
MSS: Mobile Support Stations (has wireless interface)
Fixed Host: (no wireless interface)

Figure 1: PCS Wireless Network

The model consists of two distinct sets of entities: mobile hosts, fixed hosts and mobile support stations (MSSs). The MSSs are augmented with wireless interface to communicate with the mobile hosts. In addition to this, the MSS provides commonly used application software for the mobile user to download the software from the closest MSS and run it on the palmtop or execute it remotely on the MSS.

As the mobile user moves from one cell to another, the change in the location requires three steps to be taken care of: (1) termination of the communication with the current base station (2) establishment of communication with the new base station and (3) change in the network routing to reflect the new base station. This process is known as handover (or handoff) and it may result in loss, duplication and disordering of packets, which degrades the performance of the transport protocol.

As the load on digital cellular networks is increasing, the cell size in densely populated regions is becoming smaller and smaller (few hundred meters in diameter) to meet the growing bandwidth requirements. In a micro cell based environment, the user is likely to cross boundaries more frequently. Regions with light population, however, should still use macro cells, i.e., base stations with wider coverage in order to reduce the cost of hardware and the frequency of handoffs.

Chapter 2

Hierarchical Channel Selection Schemes

Below, we briefly review relevant recent proposals on handover protocols and channel allocation policies in cellular networks.

2.1 Non-Reversible Hierarchical Channel Selection Scheme [BERA96]

The increasing demand for mobile cellular services has encouraged the reuse of radio channels by employing cells with small radius, called the micro cells. The traditional larger macro cells are still needed in many applications requiring vast coverage areas. Some researchers believe that future cellular systems will employ a micro-macro cell overlay structure [BERA96, POLL96]. This cell overlay structure is also used in new proposed configurable cellular systems [BASS00]. The micro cell will be located in areas of dense population while the macro cell will serve the large sparse regions and will provide a set of overflow channels for the micro cells. Handover schemes for this structure have traditionally operated under the strict policy that a call served by the macro cell will not request handover to a cell that is lower in hierarchy, i.e., to one of its overlaid micro cells. For example: suppose that many users originate new calls in the macro cell only region and then move into a micro cell then the calls cannot request handover to the

micro cell, therefore the macro cell will soon be fully-loaded and several new calls will be blocked, even if the micro cell has many idle channels. Moreover, with this hierarchical model, the micro cells have lower channel utilization than the macro cell. Throughout the report this scheme is referred as NRHCS.

2.2 Reversible Hierarchical Channel Selection Scheme

The reversible hierarchical channel selection scheme (RHCS) proposed in [BERA96] employs an opposite policy: the system will try to switch the handoff call from the macro cell channel to a micro cell channel whenever the latter is available. In other words, the mobile involved in the handoff will continue to use the macro cell channel only if all the channels of the target micro cell are in use. In this scheme the micro cells have higher channel utilization and the whole system is more balanced in supporting the traffic load. The new calls and handover calls enter at both the micro cell and macro cell level. The macro cell accommodates the calls that the micro cells cannot. So the macro cell provides an overflow group of channels. A Fixed Channel Assignment (FCA) with cut-off priority scheme is used, so cell *i* is allocated a number of channels C_i of which Ch_i are used only by handover calls. It allows a new call to use an idle channel in a cell only if fewer than C_i-Ch_i are in use in that cell while a handover call can use any idle channel. So increasing Ch_i provides increasing priority for handovers at the expense of new call origination.

2.3 The Guard Channel Policy [RAMJ96]

Handover requests are traditionally given preference over new calls because of their sensitivity to call disconnects [CHIU00]. The Guard Channel policy does this by reserving a number of channels for the exclusive use of handoff calls. In a cellular network with C channels in a given cell the guard channel policy reserves a subset of these channels (C-T) for handoff calls. Whenever the channel occupancy exceeds a certain threshold (T), the guard channel policy rejects all the new calls. In this thesis, the Guard Channel Policy is referred to as RHCGS.

2.4 The Fractional Guard Channel Policy [RAMJ96]

The Fractional Guard Channel policy rejects certain fraction of the new calls in each state of the cell based on predetermined probabilities [RAMJ96]. Both the Guard Channel and the Fractional Guard Channel policies accept handoff calls as long as the channels are available. Reversible hierarchical channel selection scheme with Fractional Guard Channel policy is referred as RHGSFG in this report.

2.5 Fast Retransmission Procedure [ALAN94]

This procedure suggests a smooth handover scheme that is realizable in a real network only if overlap regions between cells are large enough and hosts move slowly enough for

handover operations to complete while a moving host is still in an overlapping region. This scheme also proposes modification in the transport protocol to overcome the performance degradation problem in the presence of loss of packets during handover. It uses a fast retransmission procedure when hosts become aware of the loss of packets due to handover.

2.6 Handoff Prioritization using Mobile Positioning [CHIU00]

In this scheme, reservations and cancellations based on the real time position measurement are used to significantly reduce handoff dropping without significantly harming the new call acceptance rate.

2.7 Distributed Handover Protocol [COHE96]

This protocol avoids loss of packets, preserves order of transmission and requires small time to complete. However, it does not eliminate the retransmission overhead encountered by the transport layer protocol. Figure 2 shows the typical signaling messages exchanged between the mobile m, the old base station b1, the new base station b2, and the gateway g. The diagram represents the case when the handoff request is accepted, i.e., the case when the new base station b2 gives a positive reply to the JOIN request.

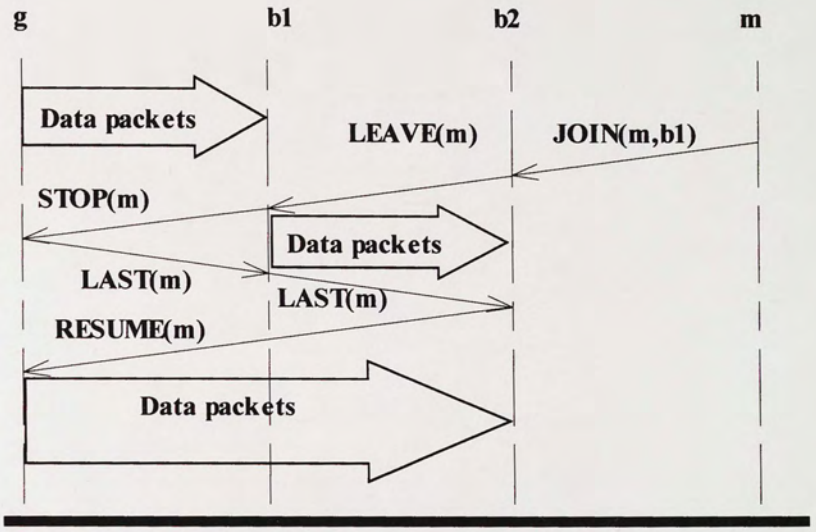


Figure 2: Distributed Handover Protocol

2.8 Subscriber Assisted Handover [JIAN97]

The authors in this paper divide customers into three classes based on their type of motions: i) stationary as in an office environment, ii) controllable motion as in the case of driving a car, and iii) forced or uncontrollable motion as in the case of riding a train. They advocate that the handover protocol should inform the user about any forthcoming call disconnect. Users with controllable motion can restrict their mobility in order to maintain access to the cellular service.

Chapter 3

Proposed Scheme

In this section, we outline our channel selection scheme for hierarchical micro/macro cellular networks. As in [BERA96, CHIU00, RAMJ96], we assumed a fixed channel allocation scheme with channel reuse policy. We first discuss the primary techniques that we proposed in our channel selection scheme then proceed to give a high-level description of the proposed hierarchical design.

3.1 Queuing of Handover Calls

Handover requests are more sensitive to delay in service (i.e., delay in establishing connection) than new calls. Some researchers argue that the delay sensitivity of handover calls makes it unfeasible to queue these calls in mobile cellular networks [TEKI91]. We used a queuing mechanism, called the micro cell overflow queue, for handover requests that occur when the mobile migrates from the macro cell area to one of its overlaid micro cells. The hierarchical nature of the macro/micro cellular architecture ensures that these handoffs don't get dropped; the application of a queuing mechanism in this case is therefore appropriate. The overflow queue at each micro cell has a limited capacity and operates according to the following rules:

- When the queue is full, a new handover request is added to the queue by deleting the oldest call in the queue.
- When a micro cell channel becomes available, the most recent handover request in the queue is dequeued and its macro cell channel is released.

3.2 Modified Guard Channel Policy

We used a modified Guard Channel (MGC) policy that employs the idea of fractional channel reservation [RAMJ96] while retaining the threshold T of the original Guard Channel Policy. The following is a high level description of MGC where C is the total number of channels assigned to the micro cell.

```
If (New Call) {
   if (#_used_channels <= T) admit call
   else {
        if  ( rand(0,1) > (#_used_channels -T)/(C-T) ) admit call
        else reject call
        }
             }
if (Handoff Call) {
      if (#_used_channels < C) admit call
      else reject or enqueue call
                  }
```

3.3 Load Balancing

Unlike the fixed policies used in the RHCS and NRHCS handover schemes [BERA96], our scheme pursues arbitration policy based on the load situation and the type of the two cells involved in the handoff. Our preliminary design uses a simple metric such as the load factor to implement load balancing (LB) between the macro cell and its overlaid micro cells. The load factor of a cell is defined as the ratio between the number of used channels in that cell and the total number of channels assigned to it. In many handover protocols, e.g. [COHE96], the load factor can be communicated between the two base stations by storing it in the handoff signaling messages without incurring any additional overhead. If this is not possible, periodic exchange between the macro cell and the micro cell would be needed to make each cell aware of the loading situation of the other. We used a macro cell initiated load balancing scheme when the mobile migrates from a macro cell to one of its micro cells and a micro cell-initiated scheme when it moves from one micro cell to an adjacent micro cell. In other words, the base station currently in contact with the mobile uses its load status information to decide about the appropriate protocol to be invoked. Using two thresholds in each cell, the load factor is used to classify the load status of the cell into light (L), medium (M) or high (H). The macro cell informs its micro cells whenever its status changes. Similarly, the micro cell informs the macro cell and its adjacent micro cells (if any) of the change in its load status. A hysteresis margin is used to prevent excessive message overhead when the cell status fluctuates around the threshold.

Based on the load status information and whenever load balancing is applicable to the handoff at hand, the base station currently in contact with the mobile executes a protocol leading to the allocation of either a micro cell channel or macro cell channel. The following are the load balancing rules we used.

- When both cells have L or M load status, the mobile is switched to a micro cell channel in conformance with RH policy.
- When one cell has an H load status and the load status of the other cell is L or M, the mobile is served by a channel from the latter cell.
- When both cells are heavily loaded, an attempt is made to assign a micro cell channel to the mobile. If this attempt fails, a macro cell channel is sought. Obviously the handoff call will be dropped if both cells are fully loaded; the overflow queue does not help in this case since the call will have to be disconnected for a period of unknown length.

3.4 The Hierarchical Scheme

The hierarchical channel selection scheme uses the techniques proposed in sections 3.1-3.3. Handover requests are divided into the following two main categories.

3.4.1 Intra-Macro Cell Handoffs

These are handoffs resulting from the movement of mobiles within the area of one macro cell. Table 1 illustrates the subcategories of this type of handoff and the techniques of sections 3.1-3.3 that are relevant to each subcategory.

Source Cell	Target Cell	Control Techniques
Macro Cell	Micro Cell	LB Overflow queue MGC
Micro Cell with overflow channel	Micro Cell	LB Overflow queue MGC
Micro Cell with local channel	Micro Cell	LB Overflow queue MGC
Micro Cell with overflow channel	Macro Cell	-
Micro Cell with local channel	Macro Cell	MGC

Table 1: Intra-Macro Cell Handoffs

3.4.2 Inter-Macro Cell Handoffs

These are handoffs resulting from the movement of mobiles from the area of one macro cell to the area of another macro cell. Table 2 illustrates the subcategories of this type of handoff and the techniques of sections 3.1-3.3 that are relevant to each subcategory.

Source Cell	**Target Cell**	**Control Techniques**
Macro Cell	Macro Cell	MGC
Macro Cell	Micro Cell	LB Overflow queue MGC
Micro Cell	Macro Cell	MGC
Micro Cell	Micro Cell	LB Overflow queue MGC

Table 2: Inter-Macro Cell Handoffs

3.4.3 New Calls

Table 3 illustrates the two types of new calls and the techniques of sections 3.1-3.3 that are relevant to each type.

Originating Cell	**Control Techniques**
Micro Cell	LB MGC
Macro Cell	MGC

Table 3: New Calls

3.5 Performance Model

A performance simulation model has been developed and used to evaluate and refine the proposed scheme. The model is used to evaluate the effectiveness of the important design components (overflow queue, MGC, etc.) under different teletraffic conditions in the cellular system. The tests use parameter values and cell topologies similar to those used in previous work published in the literature. Appropriate performance metrics (handoff success rate, new call success rate, cell bandwidth utilization, cellular network throughput etc.) are collected and analyzed. Comparisons with previous literature results (e.g., RHCS, RHCSG, RHCSFG and NRHCS schemes) are made.

Chapter 4

Simulation Model

The simulation of the proposed hierarchical channel selection scheme in micro/macro cellular network has been implemented using the discrete simulation feature of Concurrent C. A Concurrent C program allows a set of processes to execute concurrently. Concurrent C provides mechanisms for the declaration and creation of processes, for process synchronization and interaction, and for process termination and abortion. In Concurrent C, process interaction uses synchronous message passing with data then by transferring information first by synchronizing, then by transferring information, and finally by continuing their individual activities. This synchronization is called a rendezvous [GEHA85]. In the following sections, we will discuss the process interaction model used in our discrete event simulation and simulation model for the hierarchical scheme using the three proposed techniques.

4.1 Process Interaction Model

4.1.1 Independent Entities

In order to use the process interaction model, we first have to determine the sequential, independent entities in the system being simulated. As an example, a queuing network contains entities such as sources, queues, and servers. Each entity performs a well-defined series of sequential operations. Some of these operations may involve interacting with another entity. Except these interactions, each entity performance its own independent operations regardless of the other entities. Each entity is modeled as a Concurrent C process [ROOM85].

4.1.2 Process Interactions

The next step is to identify interactions between entities, and map these interactions into transaction calls. There are two types of entities: active entity such as servers and passive entity such as queue. The passive entities provide service in response to the requests of active entities. Each type of service can be represented as a transaction in the passive entity.

4.1.3 A Simple Queuing System

The following is a brief description of the entities comparing the simple queuing system in Figure 3. The source process (active entity) generates a new item and places it on the queue. The queue (passive entity) accepts items from the source and gives them to the server in FIFO order. The server (active entity) takes items from the queue and processes them.

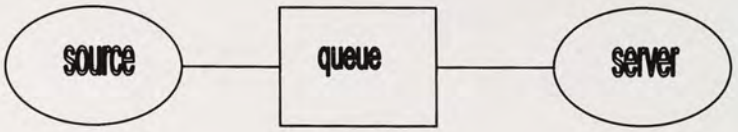


Figure 3: A Simple Queuing System Model

4.1.4 Scheduler Process

To obtain invariable simulation results, the simulation time should be independent of the load of the system. A user-level scheduler process has been used to handle the simulation clock and the delays in simulation time [ROOM85]. This process does not replace the internal scheduler of the Concurrent C run-time system. The virtual timer scheduler process maintains the simulation clock and advances it appropriately. For each delay request from a process, the scheduler determines the simulated time at which to re-activate that process, and saves this in an activation request list. When all processes are waiting, the scheduler chooses the next process to run, advances the simulation clock to that time, and re-activates that process. The system clock advances only when all processes are waiting. Any computation done by a process takes place in zero simulation time.

The scheduler can re-activate several waiting processes simultaneously at the same simulation time. At any given time the client process of the scheduler is in one of three states:

1. Waiting: Waiting for an explicit delay request from the scheduler.
2. Active: Computing in zero simulated time.

3. Passive: Waiting for an event other than delay request from the scheduler.

4.2 Structure of the Simulation

As shown in the figure 4, the simulation for the proposed hierarchical channel selection scheme in a macro/micro cellular network has three main entities. One is the mobile (active entity), second is the macro cell (passive entity) and the third is the micro cell (passive entity) with extended queue for the handoff calls. There are three auxiliary processes in the simulation: main process, scheduler process, and logger process.

The following is a description of each process:

1. Macro: A macro process receives a request from a mobile for its channels. It accepts the request based on the available channels of the total number of its channels and the status of its load at that instance of time. If all the channels are used then the request is rejected.
2. Micro: A micro process receives a request from a mobile for its channels. It accepts the request based on the available channels of the total number of its channels and the status of its load at that instance of time. If all the channels of micro cell are used then the mobile is put in an overflow queue until a channel in the micro cell becomes available.
3. Mobile: A mobile process moves from the source location to the destination with its specified speed. Whenever it moves from one cell to other it requests for the channels

of the host cell depending upon the load, the host cell either accepts or rejects its requests.

4. Scheduler: The scheduler process has the same functionality as mentioned earlier. After the scheduler accepts calls from all the processes, it increments the simulation time by one. This barrier synchronization guarantees that each mobile moves in one simulation time unit.
5. Main: The main process accepts the simulation parameters, creates the macro, micro, mobile processes and the other auxiliary processes during the initialization.
6. Logger: This process accepts logging requests from all the processes. The logging messages are stored into a log space file and are also displayed on the windows.

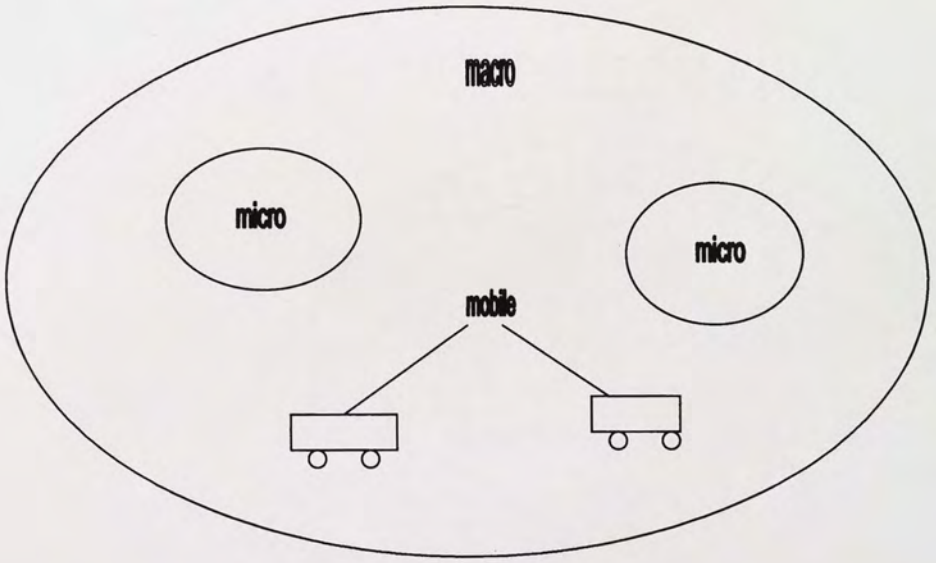


Figure 4:HCSS Structural Layout of Macro-Micro Cells

4.2.1 Data Structures and Initial Assignment

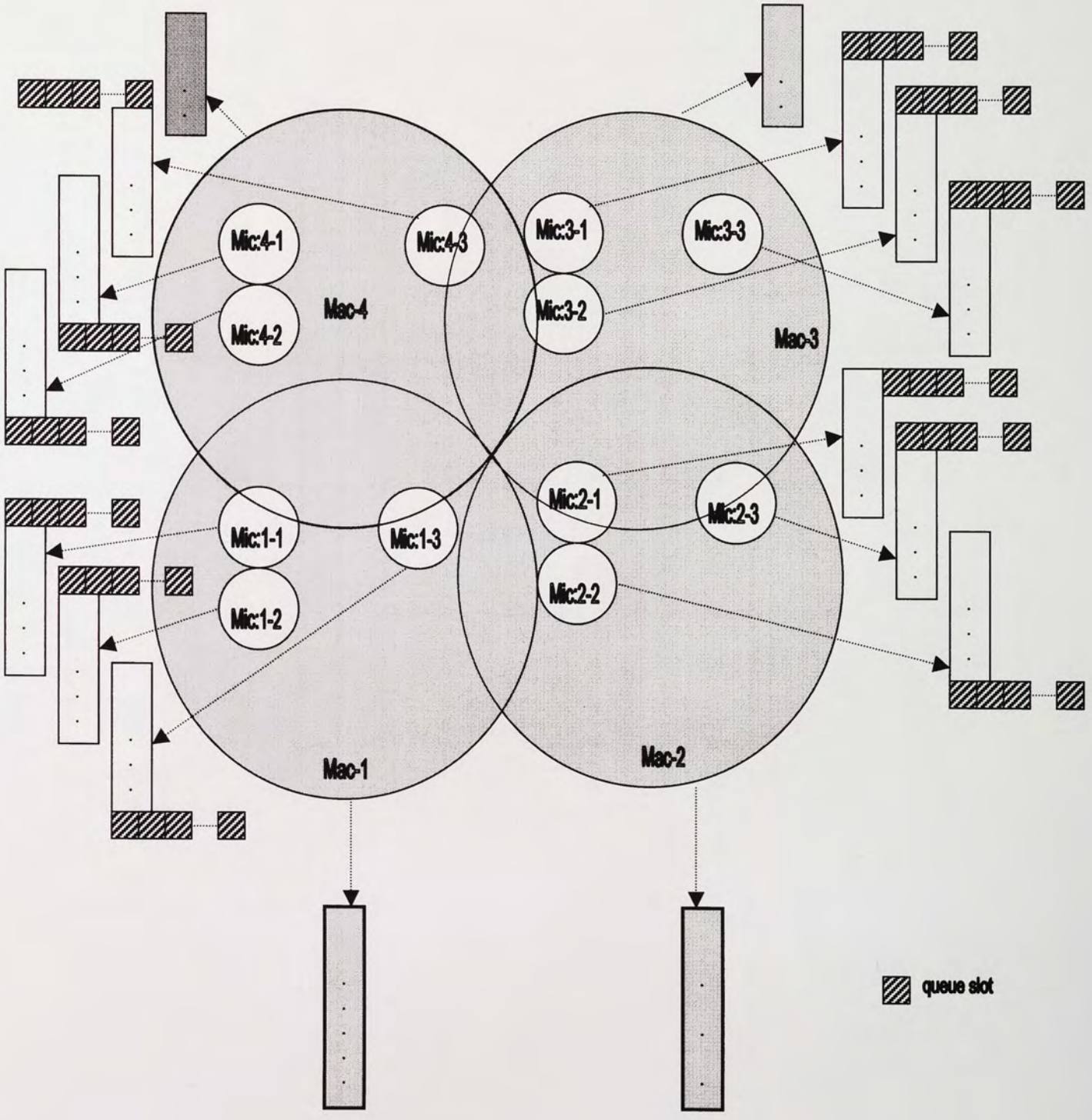


Figure 5: Cells Layout

Let 'C' be the total number of available channels in a Macro cell. Let 'T' be its threshold. Let 'c' be the total number of available channels in each Micro cell. Let 't' be its threshold and 'qSize' be the size of the overflow queue it has. It is assumed in the simulation model that all the macro cells have equal number of channels and all the micro cells have equal number of channel and same overflow queue size as well.

Each macro cell has memory equivalent to its 'C' value, allocated. And each micro cell has memory equivalent to its 'c' value, allocated. Each micro cell also has an overflow queue to hold the mobile on the fly. The queue is of size 'qSize' and of type mobile. Each macro cell has a radius 'R' and each micro cell has a radius 'r', which is used to calculate the area of the cell and its location in a two dimensional space.

During the simulation each mobile keeps track of which cell it's in. And also each cell keeps track of the number of mobiles using its channels and also its type.

4.2.2 Channel Assignment

Channel assignment in Macro cell is as follows:

To assign a channel to a new call or handoff call in a cell, the base station in the cell checks to the number of free channels available. If a free channel is available then it compares the number of channels being used with its threshold and also compares it with the cell load factor. If the number of channels being used at that instant is less than the threshold and if the cell load factor is equal to MEDIUM, then it assigns the channel to

the requesting mobile. If the number of channels being used is equivalent or greater than the threshold and also if the cell load factor is equal to HIGH, then it assigns the fee channel to the requesting call if it's a handoff call, otherwise if it's a new call it assigns the free channel based on probability. If the number of channels being used has reached its limit, which is 'C', then it blocks all the calls. A high level description of the channel assignment procedure is given below:

```
Procedure Macro_Assign()
{
if (number_of_channels_used < T)
            Assign the channel to the call.
Else if (number_of_channels_used >= T AND number_of_channels_used < C)
     {
       if (the call type is handoff)
            Assign the channel to handoff call.
       Else if (the call type is new)
            Assign the channel to the new call based on probability.
     }
Else if (number_of_channels_used == C )
      Block all the calls.
}

Procedure macro_i_macro_j_move()
{
      macro_j.Macro_Assign()
}

Procedure macro_i_micro_j_move()
{

if (macro_i.number_of_channels_used = LOW or
    macro_i.number_of_channels_used = MEDIUM)
{
```

```
   if (micro_j.number_of_channels_used = LOW or
       micro_j.number_of_channels_used = MEDIUM)

            micro_j.Micro_Assign()
}
   else if (macro_i.number_of_channels_used = HIGH)
        {
          if (micro_j.number_of_channels_used = LOW or
              micro_j.number_of_channels_used = MEDIUM)

                    micro_j.Micro_Assign()

          else if (micro_j.number_of_channels_used = HIGH)
               {
                if (overflow channels available in micro_j)
                        assign the overflow channel
                else
                   drop the call
               }
        }
}
```

Channel assignment in micro cell is as follows:

Channel assignment in micro cell is pretty much the same as that of the macro cell until the number of channels being used at any instant becomes equal to its 'c' value. Once the number of channels being becomes equal to 'c' then, the micro then puts the call in the overflow queue. Once a channel gets freed up, it assigns the channel to the handoff call waiting in the queue. A high level description of the channel assignment procedure is given below:

```
Procedure Micro_Assign()
{
  if (number_of_channels_used < t)
           Assign the channel to the call.
```

```
  Else if (number_of_channels_used >= t AND number_of_channels_used < c)
        {
          if (the call type is handoff)
             Assign the channel to handoff call.
          Else if (the call type is new)
             Assign the channel to the new call based on probability.
        }
  Else if (number_of_channels_used == c )
             Block all the calls.
}

Procedure micro_i_micro_j_move()
{
 if (micro_i.number_of_channels_used = LOW or
     micro_i.number_of_channels_used = MEDIUM)
 {
    if (micro_j.number_of_channels_used = LOW or
        micro_j.number_of_channels_used = MEDIUM)

                micro_j.Micro_Assign()
 }
 else if (micro_i.number_of_channels_used = HIGH)
       {
         if (micro_j.number_of_channels_used = LOW or
             micro_j.number_of_channels_used = MEDIUM)

                    micro_j.Micro_Assign()

         else if (micro_j.number_of_channels_used = HIGH)
               {
                if (overflow channels available in micro_j)
                       assign the overflow channel
                else
                       drop the call
               }
       }
}

Procedure micro_i_macro_j_move()
{
```

```
        macro_j.Macro_Assign()
}
```

4.2.3 Channel Release and Reassignment

When the mobile has terminated its call, the channel release procedure is initiated. The release procedure also involves channel reassignment and load balancing. When a call using a nominal channel has terminated in a cell, the base station then shuffles the channel being used and makes the channel available for the next call. It decrements its counter by one and removes the mobile information out of its memory and adjusts the load of the cell.

Chapter 5

Performance Model

The goal of the proposed scheme is to reduce the dropping probability of the handoffs without reducing the throughput of the system or the acceptance rate of the new calls.

The simulation model comprises of a highway macro/micro cellular mobile radio system with 4 concatenated macro cells each containing 3 micro cells as shown in Figure 5. Each macro cell has a coverage distance of 40 miles in diameter. Each micro cell has a coverage distance of 4 miles in diameter. The total number of channels available in the system is the sum of the channels of macro ('C') and micro ('c') cells, i.e. $4 * |C| + 4 * 3 * |c|$. In the simulation model the maximum number of channels available is 112 unless otherwise stated, i.e. $|C| = 7$, $|c| = 7$, so each macro cell contains a maximum of 28 channels including the micro cell channels. All macro cells have a threshold 'T', which has a maximum value of 5 in the simulation model, unless otherwise stated, i.e. $|T| = 5$. And all micro cells have a threshold 't', which has a maximum value of 5 in the model, unless otherwise stated, i.e. $|t| = 5$. Free flowing highway traffic is assumed. The mobile can move in any direction from any point depending upon a random destination. The vehicular speeds have a mean value of 35 miles/h, a maximum speed of 40 miles/h and a minimum speed of 25 miles/h. The simulations in this thesis have symmetrical cell

parameters i.e. all the macro cells have same number of channels, and all the micro cells have same number of channels, and the size of the queue is same in all the micro cells, unless otherwise stated. The simulation model is written in Concurrent C.

The simulation tests have been performed under three teletraffic scenarios. The simulation was done by varying the cell parameters such as: Total available channels ('C', 'c'), threshold of each cell ('T', 't') and the micro cell queue size ('q'). The three teletraffic scenarios can be briefly described as follows: Teletraffic scenario 1 corresponds to the case when the parameters 'C', 'c', 'T', 't' and 'q' are given relatively high values. Teletraffic scenario 2 is obtained by keeping the values of 'C', 'c', 'q' high and reducing the values of 'T' and 't'. Teletraffic scenario 3 is obtained by keeping the values of 'C', 'c', 'T', 't' and 'q' low. The parameters 'T', 't' are applicable to HCSS, RHCSG and RHCSFG schemes only, the parameters 'C' and 'c' are applicable to all the five schemes and 'q' is applicable only to HCSS scheme only.

5.1 Performance of the Cellular System

The performance results for the cellular systems under different schemes, and different teletraffic conditions are compared in this section.

5.1.1 Successful New Calls

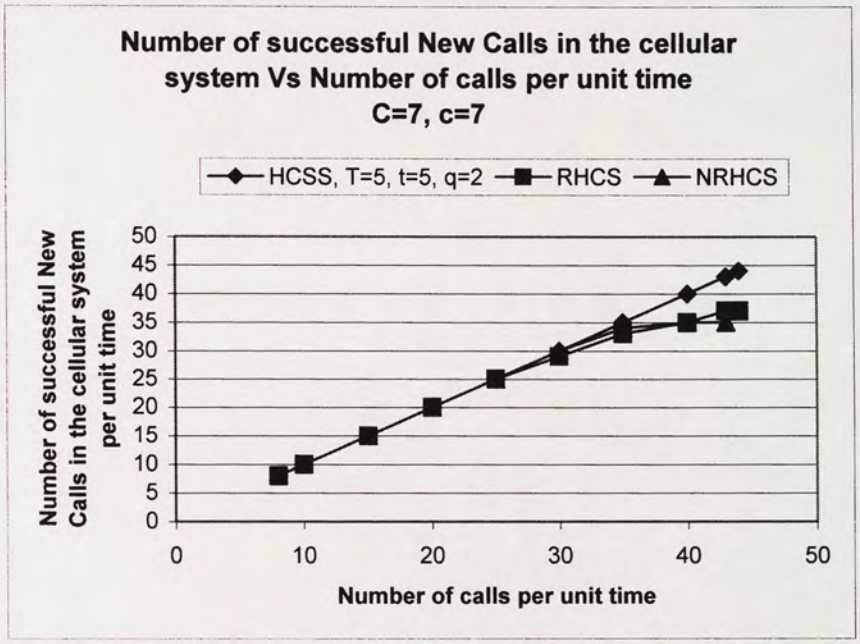


Figure 6: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 1

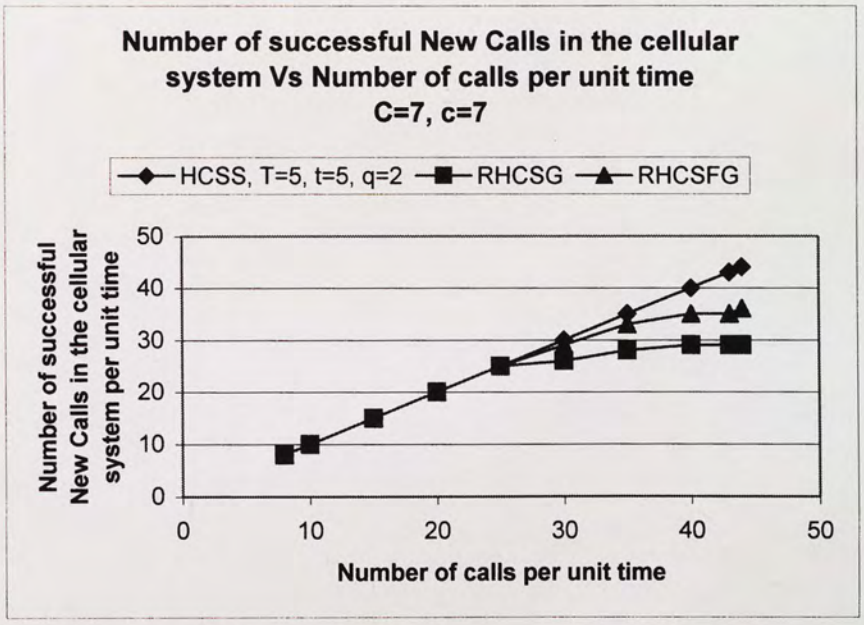


Figure 7: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 1

Figures 6 and 7 show that the proposed scheme, HCSS performs better than the existing schemes under teletraffic scenario 1.

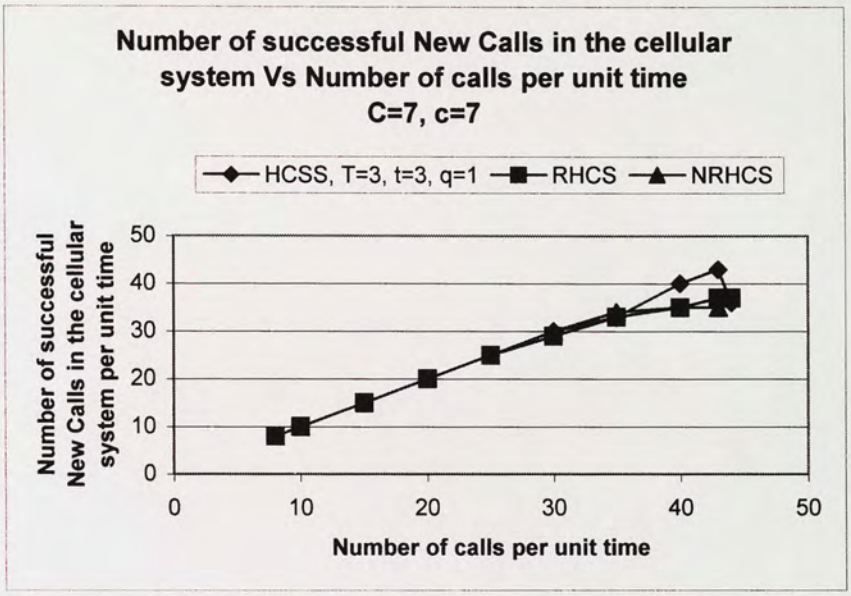


Figure 8: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 2

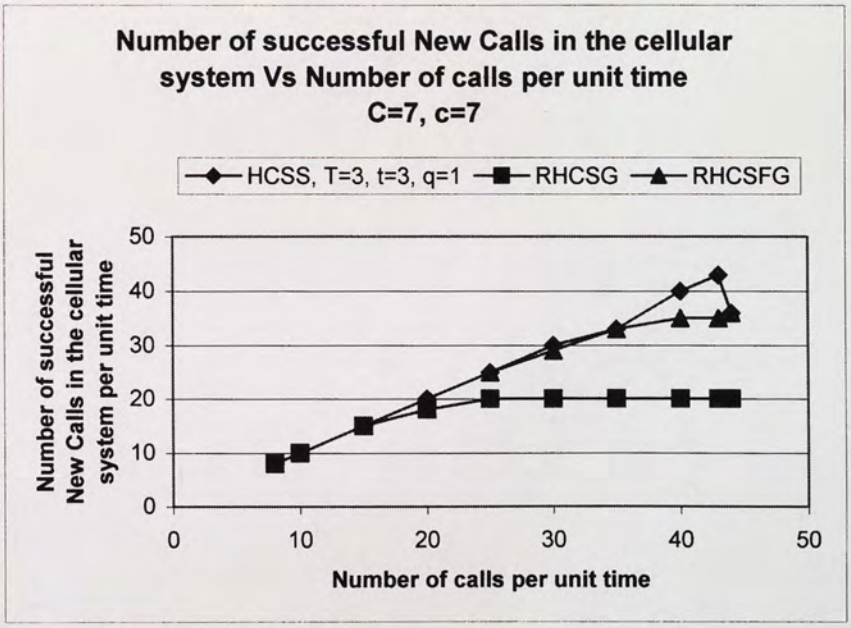


Figure 9: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 2

Figure 8 and Figure 9 show that proposed scheme, HCSS performs better than the existing schemes under teletraffic scenario 2.

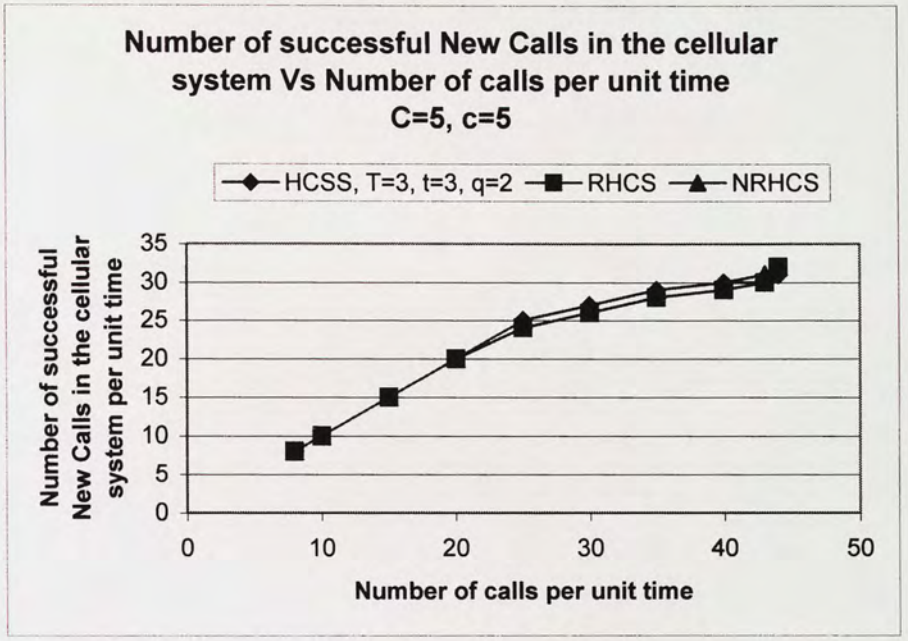


Figure 10: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 3

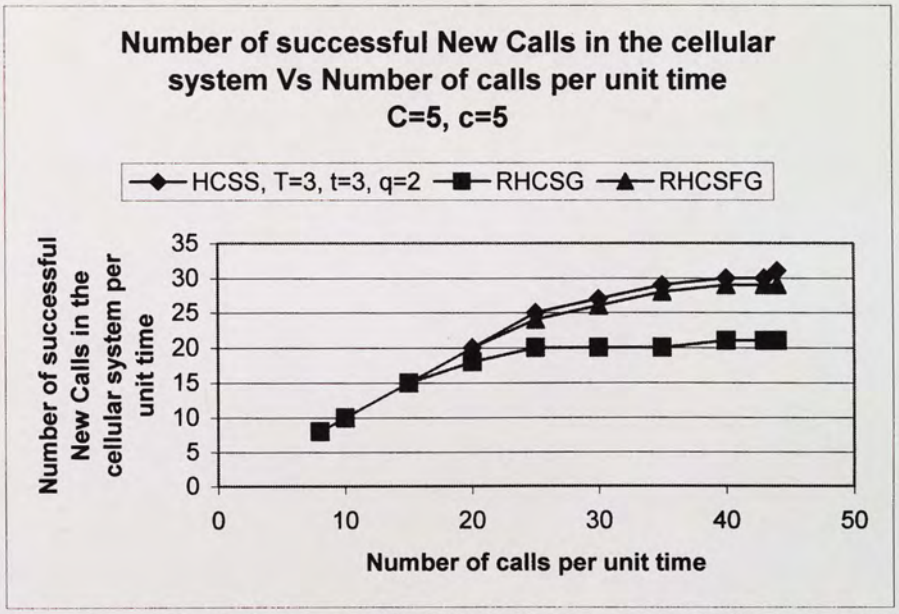


Figure 11: Comparison of the Performance of the Cellular System on New Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 3

Figure 10 and Figure 11 show that the proposed scheme, HCSS performance better than the existing schemes under teletraffic scenario 3. It is clear from the graphs that the HCSS scheme performs better in all the traffic conditions, especially when the call volume increases.

5.1.2 Successful Handoff Calls

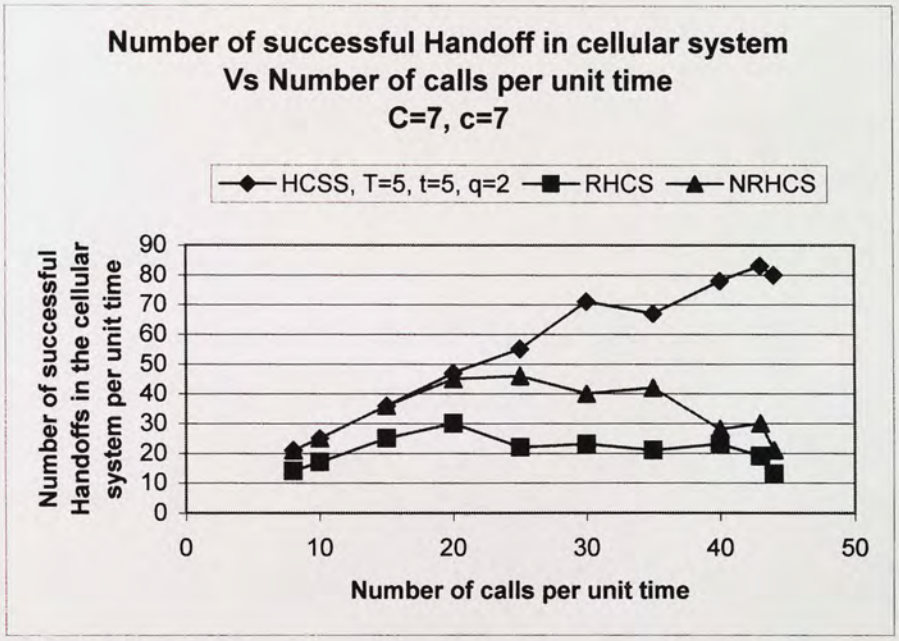


Figure 12: Comparison of the Performance of the Cellular System on Handoff Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 1

Figure 12 and Figure 13 show the performance of the cellular system for the successful number of handoffs per unit time, for teletraffic scenario 1 (C=7, T=5, c=7, t=5, q=2) for HCSS, RHCS, NRHCS, RHCSG and RHCSFG schemes. It is clear from the graphs that the proposed scheme, performs roughly the same as the existing schemes initially, but as the call volume increases, the HCSS scheme outperforms the existing schemes.

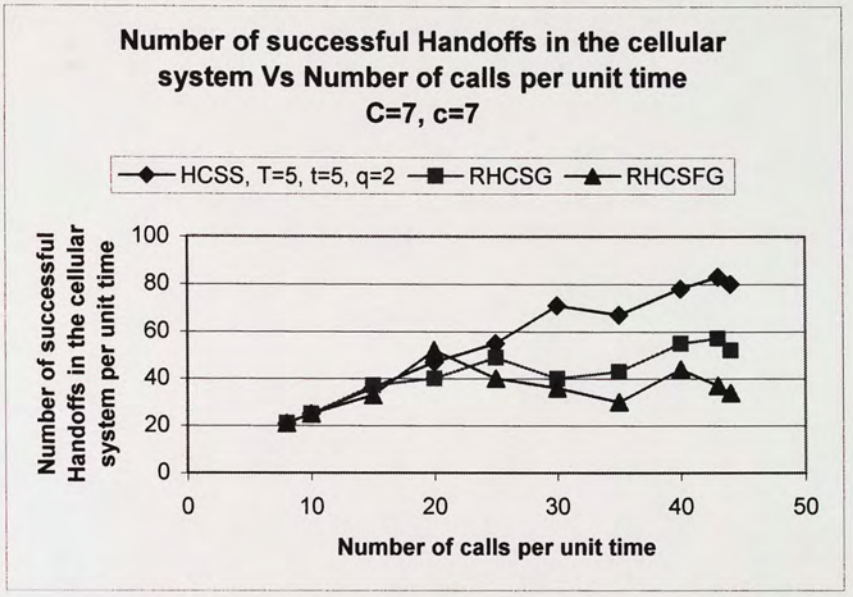


Figure 13: Comparison of the Performance of the Cellular System on Handoff Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 1

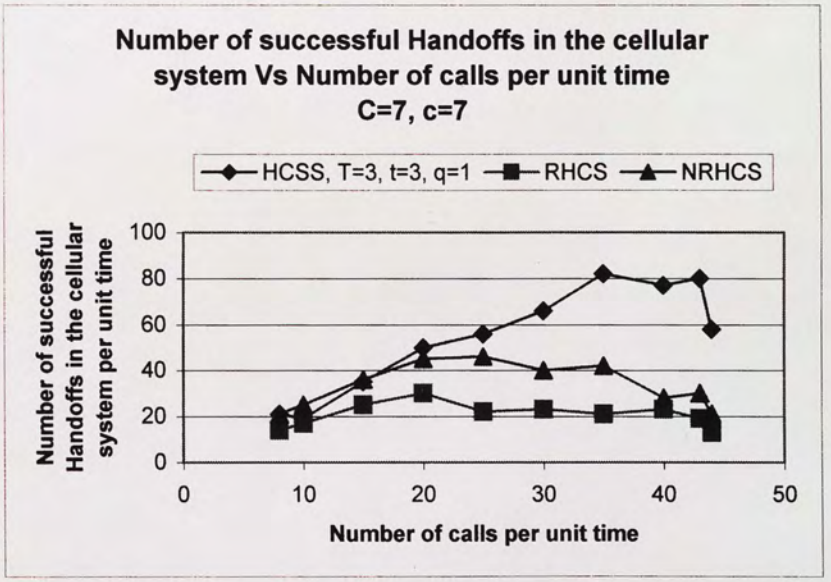


Figure 14: Comparison of the Performance of the Cellular System Handoff Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 2

Figure 14 through Figure 15 shows the performance of the cellular system for the successful number handoff calls per unit time, for teletraffic scenario 2 (C=7, c=7, T=3, t=3, q=1) for the HCSS, RHCS, NRHCS, RHCSG and RHCSFG schemes.

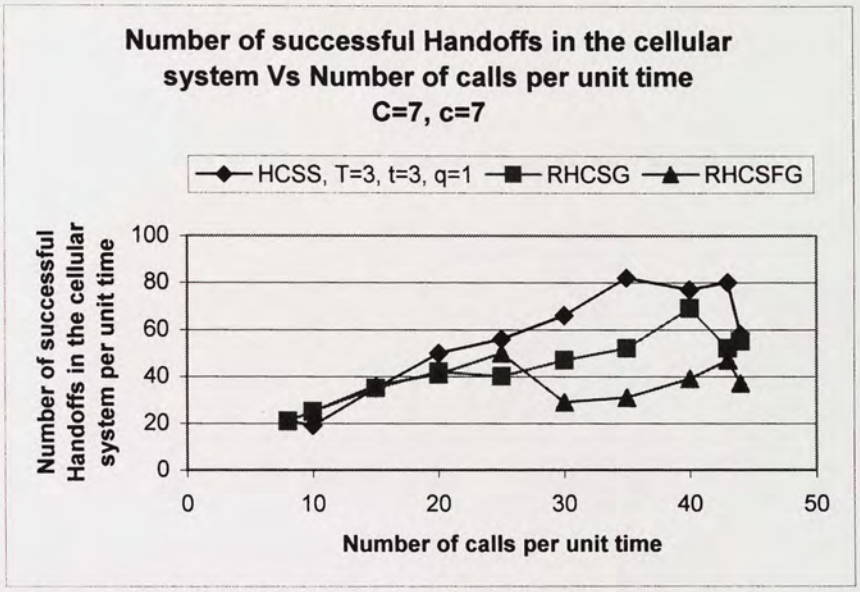


Figure 15: Comparison of the Performance of the Cellular System on Handoff Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 2

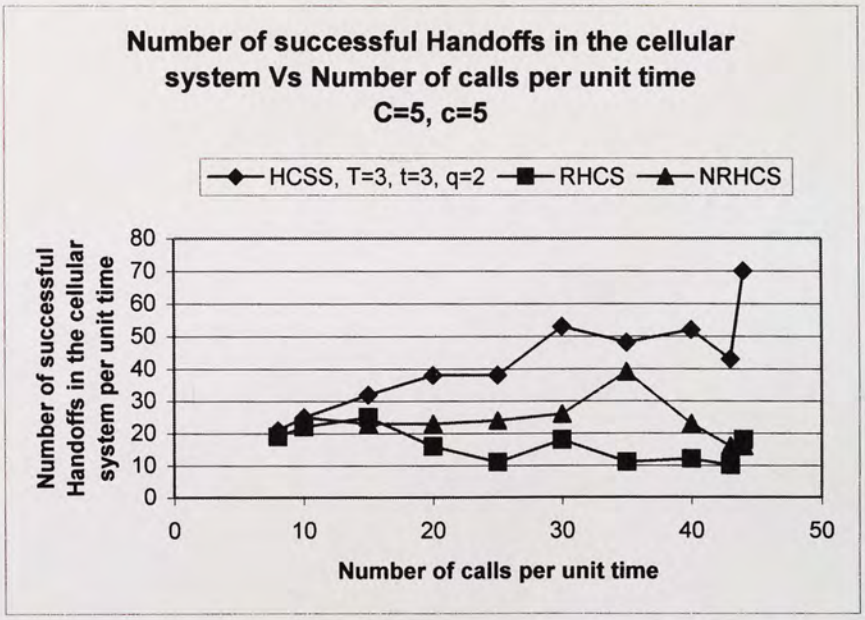


Figure 16: Comparison of the Performance of the Cellular System on Handoff Calls for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 3

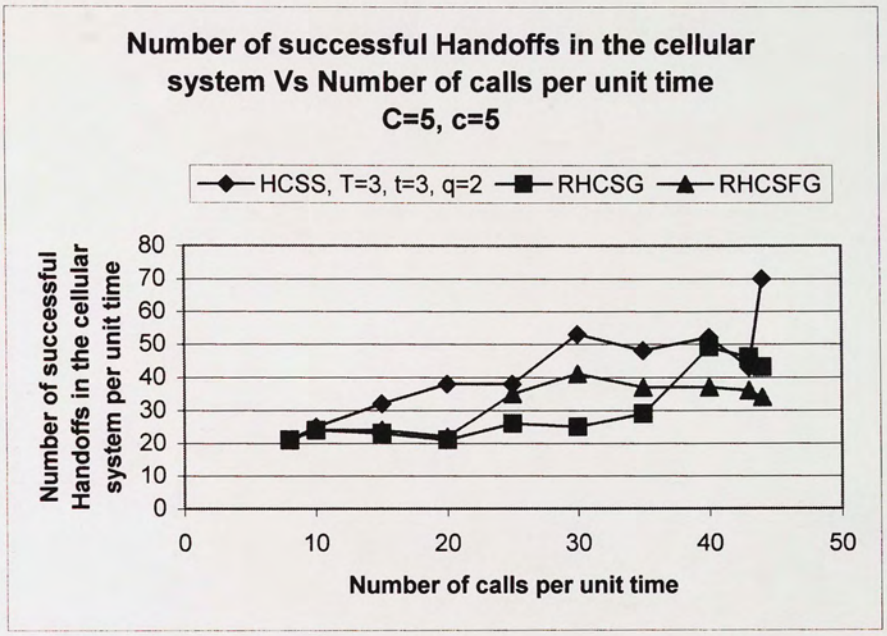


Figure 17: Comparison of the Performance of the Cellular System on Handoff Calls for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 3

Figure 16 and Figure 17 show the performance of the cellular system under different schemes under teletraffic scenario 3. The proposed HCSS schemes performs better in all the traffic conditions, especially when the call volume increases.

5.1.3 Handoff Blocking

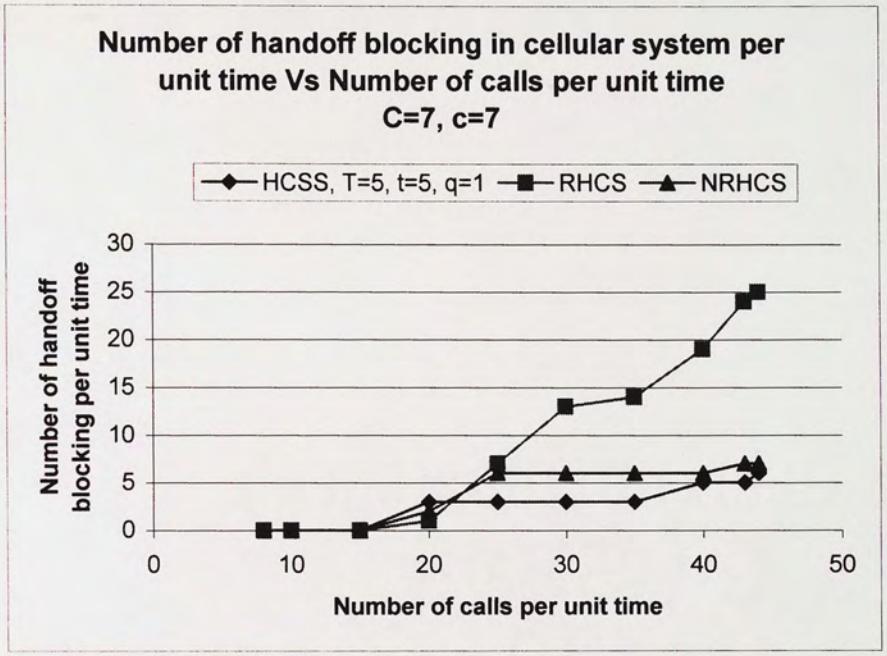


Figure 18: Comparison of the Performance of the Cellular System on Handoff Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 1

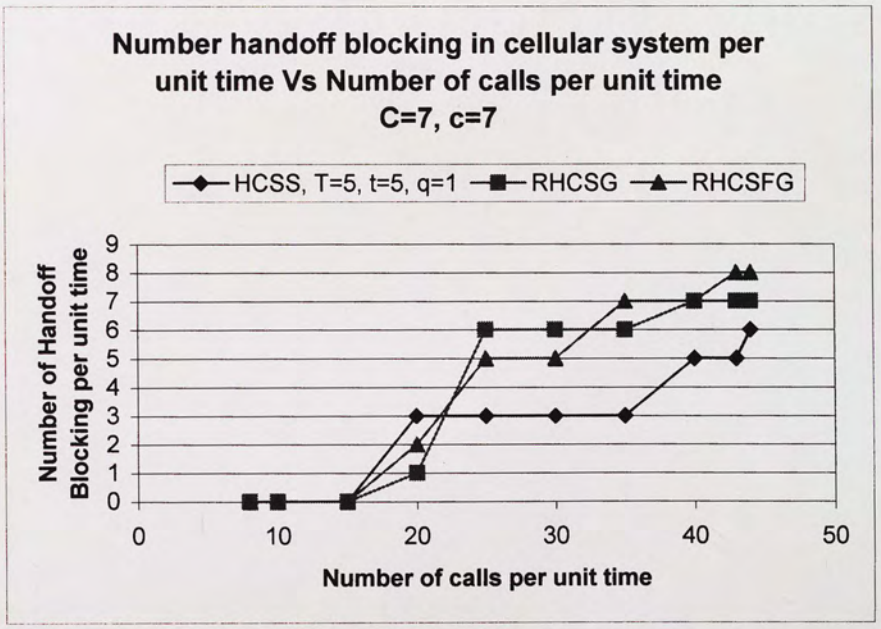


Figure 19: Comparison of the Performance of the Cellular System on Handoff Call Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 1

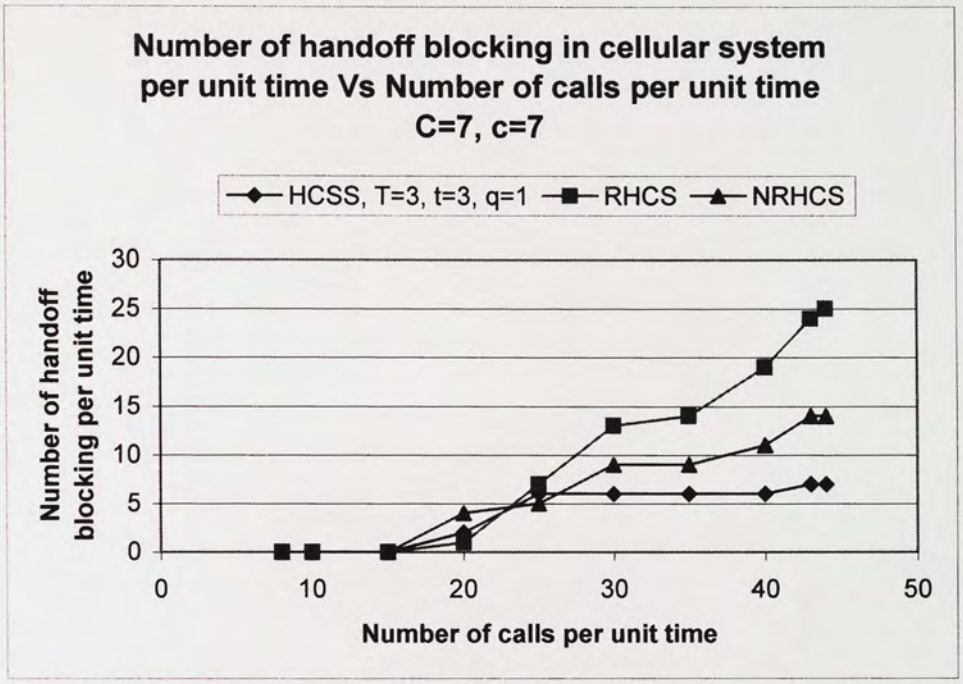


Figure 20: Comparison of the Performance of the Cellular System on Handoff Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 2

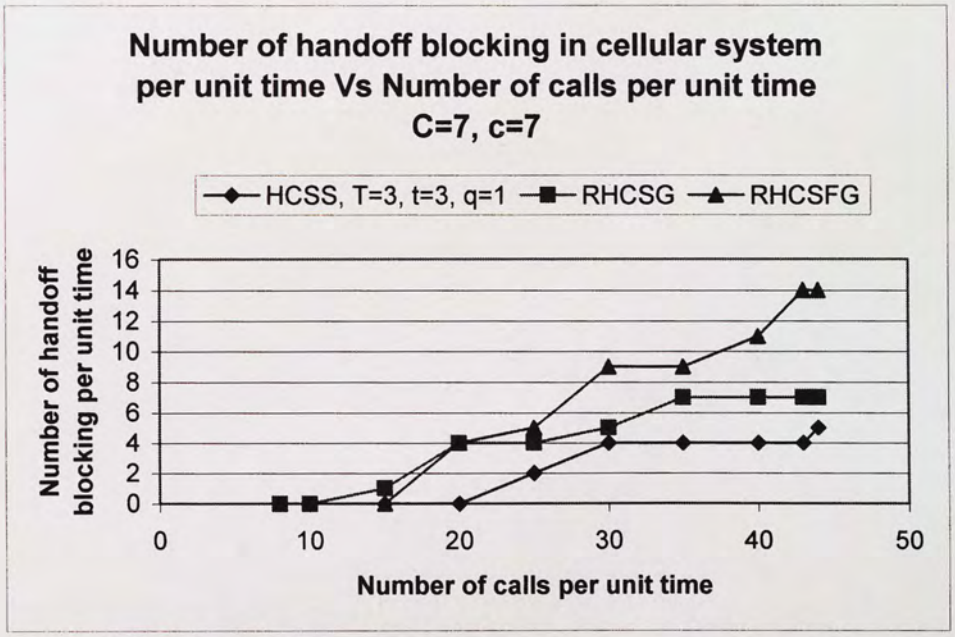


Figure 21: Comparison of the Performance of the Cellular System on Handoff Calls Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 2

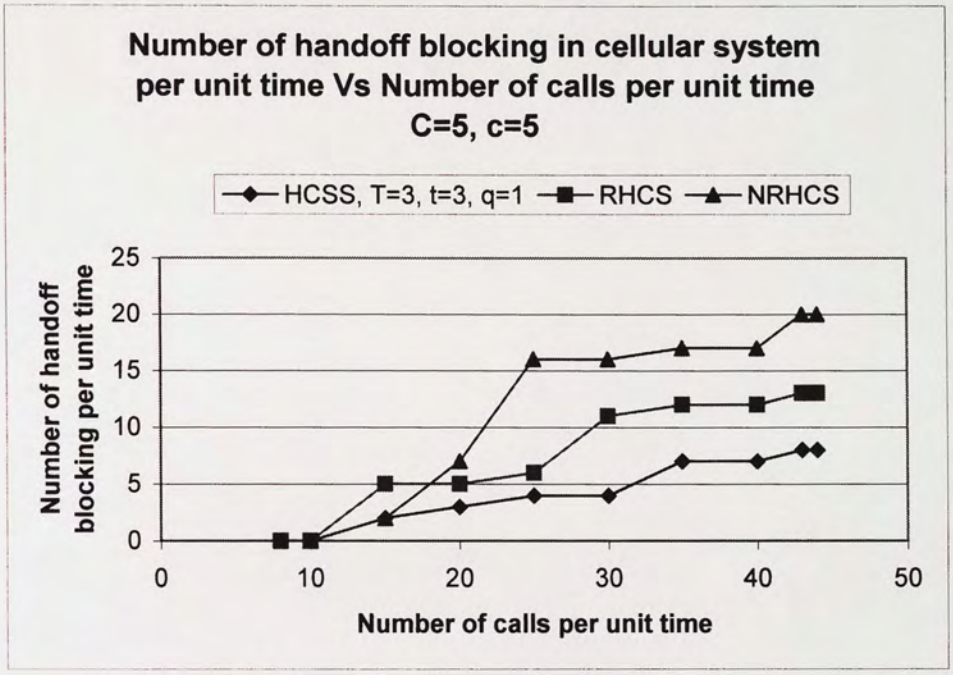


Figure 22: Comparison of the Performance of the Cellular System on Handoff Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 3

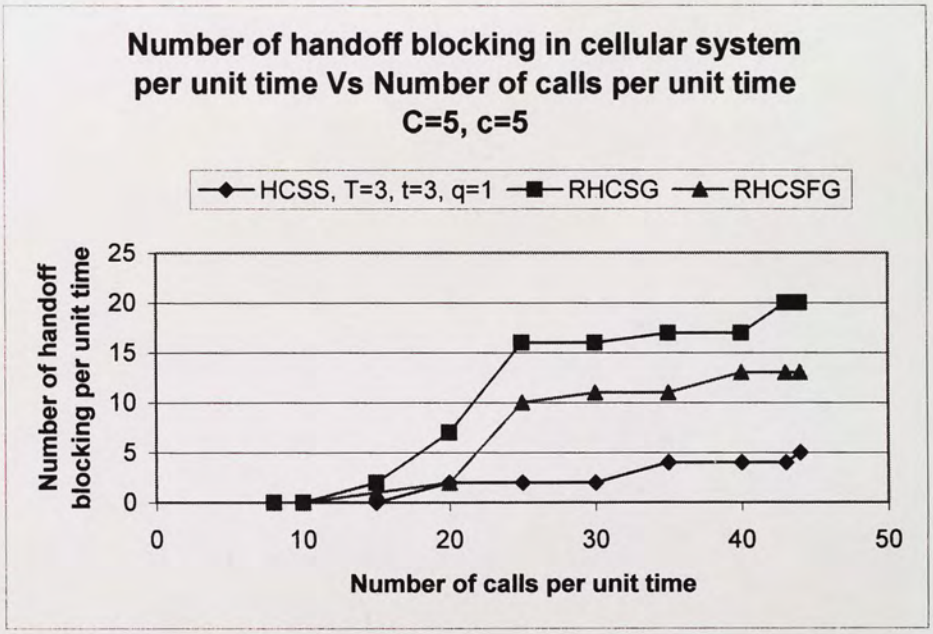


Figure 23: Comparison of the Performance of the Cellular System on Handoff Call Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 3

Figure 18 through Figure 23 show that the proposed scheme, HCSS scheme has lesser number of handoffs blocked than the existing schemes, especially when the call volume increases.

5.1.4 New Call Blocking

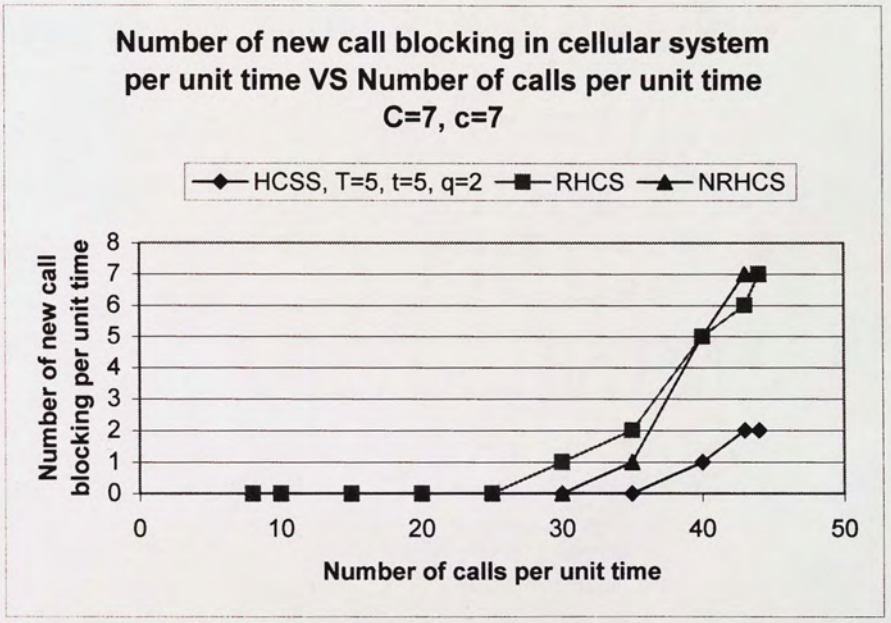


Figure 24: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 1

Figure 24 through Figure 29 show that the proposed scheme, HCSS has lesser number of new calls blocked than the existing schemes.

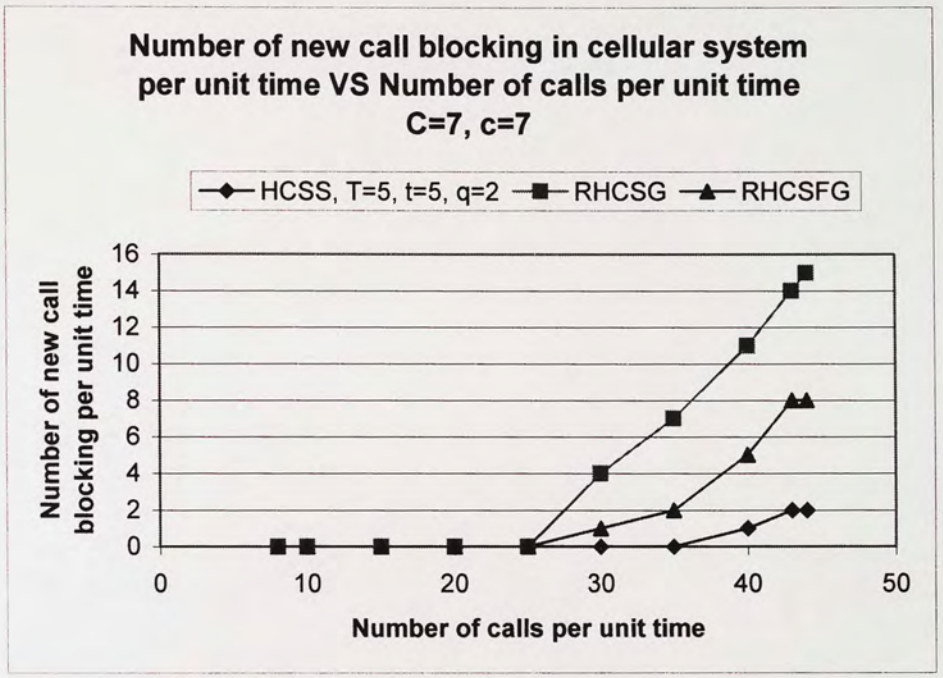


Figure 25: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 1

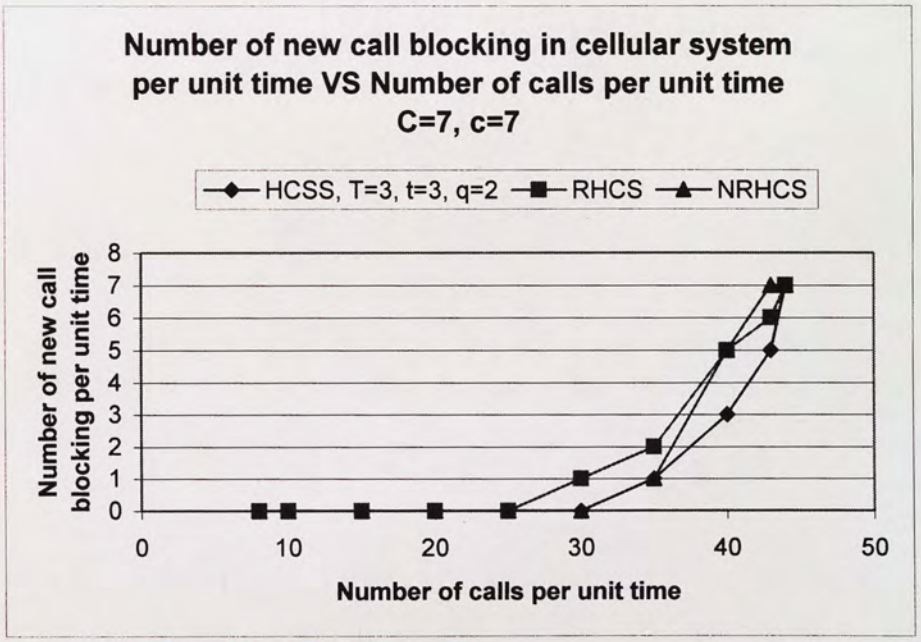


Figure 26: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 2

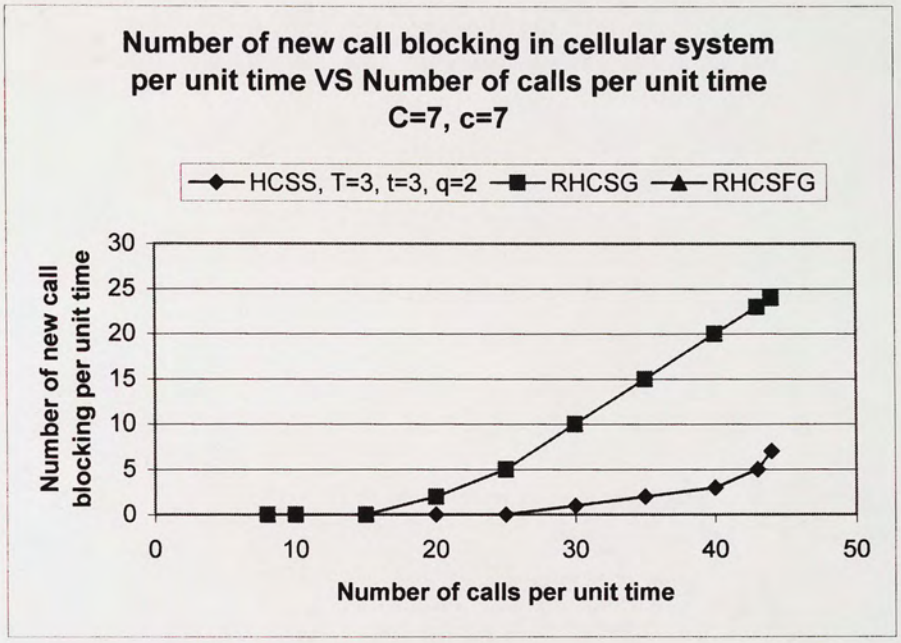


Figure 27: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 2

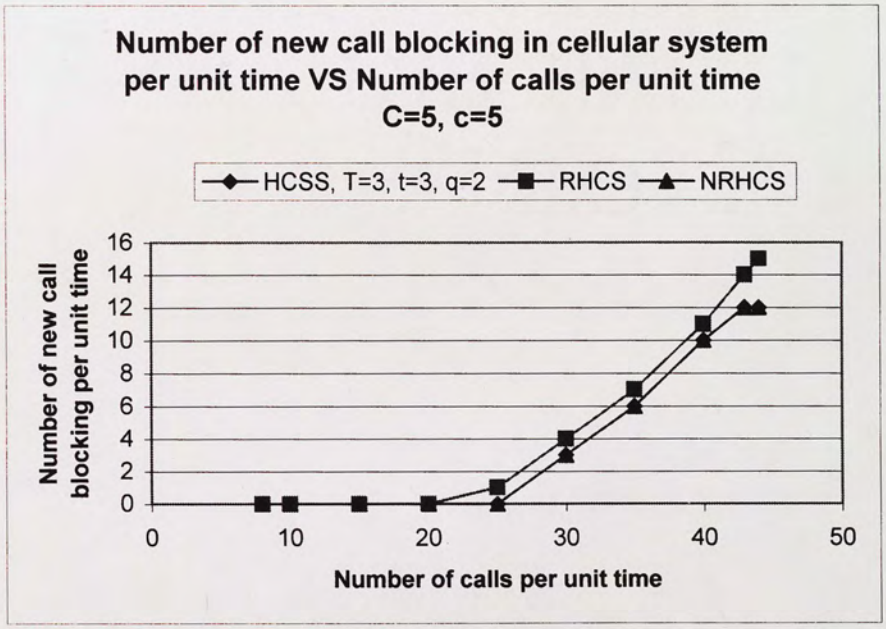


Figure 28: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCS, and NRHCS Schemes under Teletraffic Scenario 3

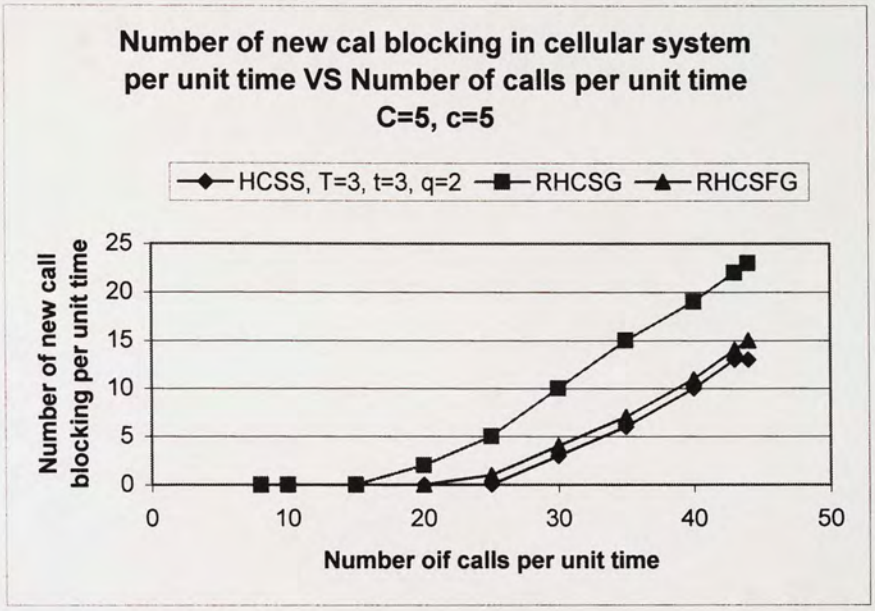


Figure 29: Comparison of the Performance of the Cellular System on New Call Blocking for the HCSS, RHCSG, and RHCSFG Schemes under Teletraffic Scenario 3

5.2 Network Traffic and Channel Distribution in Cellular System

This section compares the probabilities of successful handoffs, probabilities of successful new calls, handoff dropping probabilities and new call blocking probabilities. The probability of success if define as:

$$probability\ of\ successful\ new\ calls = \frac{total\ number\ of\ successful\ new\ calls}{total\ number\ of\ new\ call\ attempts}$$

$$probability\ of\ successful\ handoffs = \frac{total\ number\ of\ successful\ handoff\ calls}{total\ number\ of\ handoff\ attempts}$$

The probability of handoff dropping and new call blocking is defined as:

$$handoff\ dropping\ probability = \frac{total\ number\ of\ dropped\ handoffs}{total\ number\ of\ handoff\ attempts}$$

$$new\ call\ blocking\ probability = \frac{total\ number\ of\ blocked\ new\ calls}{total\ number\ of\ new\ call\ attempts}$$

Figure 30 through Figure 37 compare the probability of successful handoffs, successful new calls, handoff dropping and new call blocking.

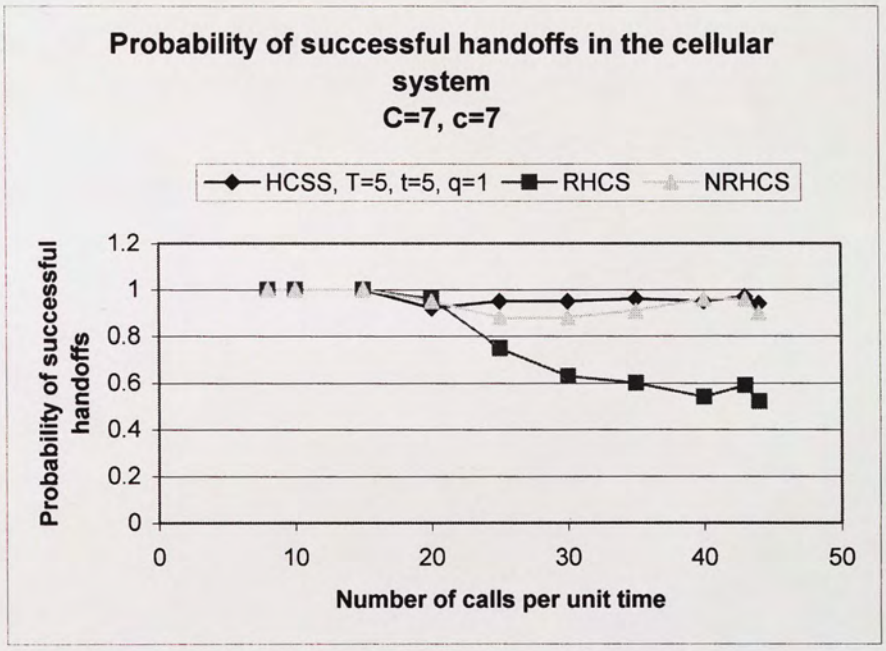


Figure 30: Comparison of the Probability of Successful Handoffs in the Cellular System for HCSS. RHCS, and NRHCS Schemes in Teletraffic Scenario 1

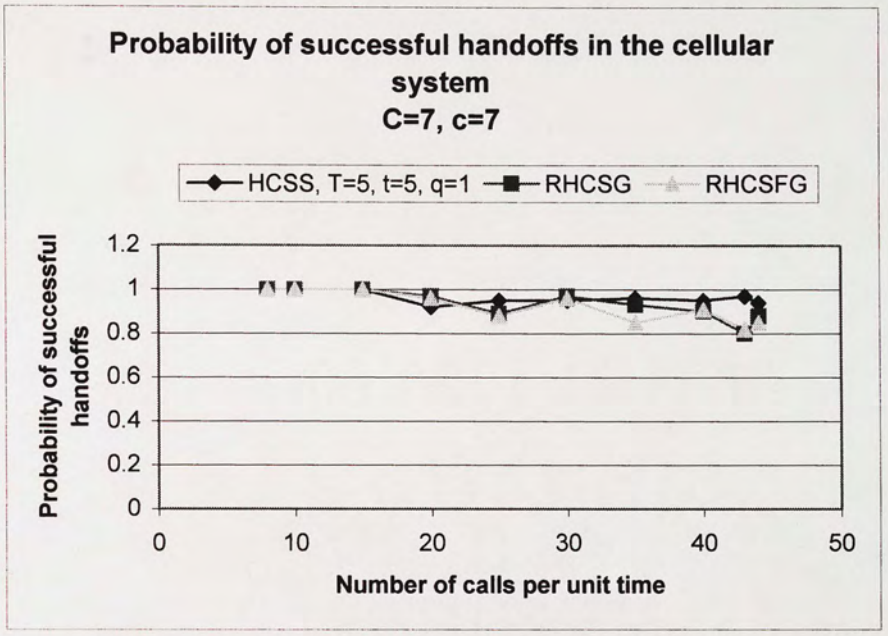


Figure 31: Comparison of the Probability of Successful Handoffs in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 1

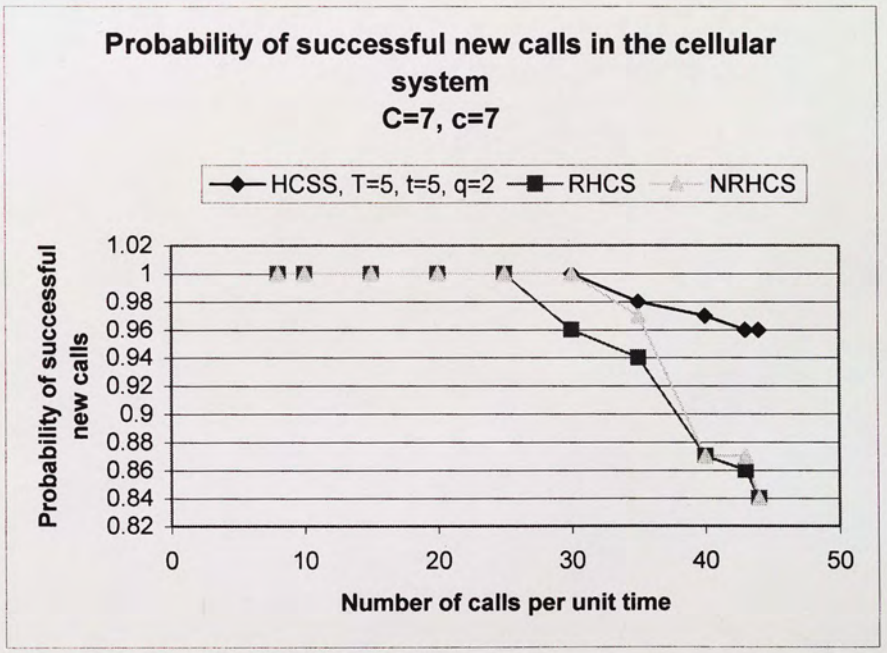


Figure 32: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 1

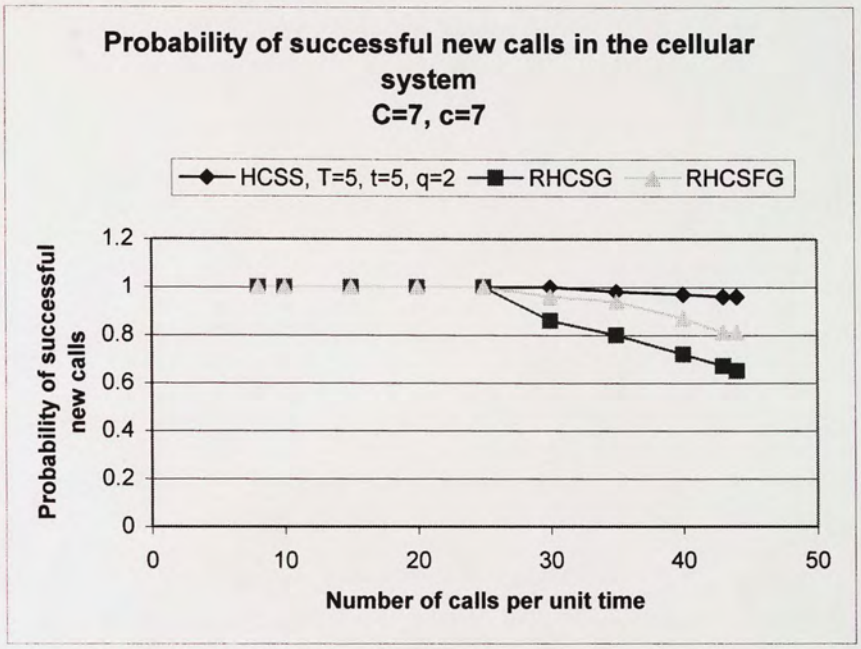


Figure 33: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 1

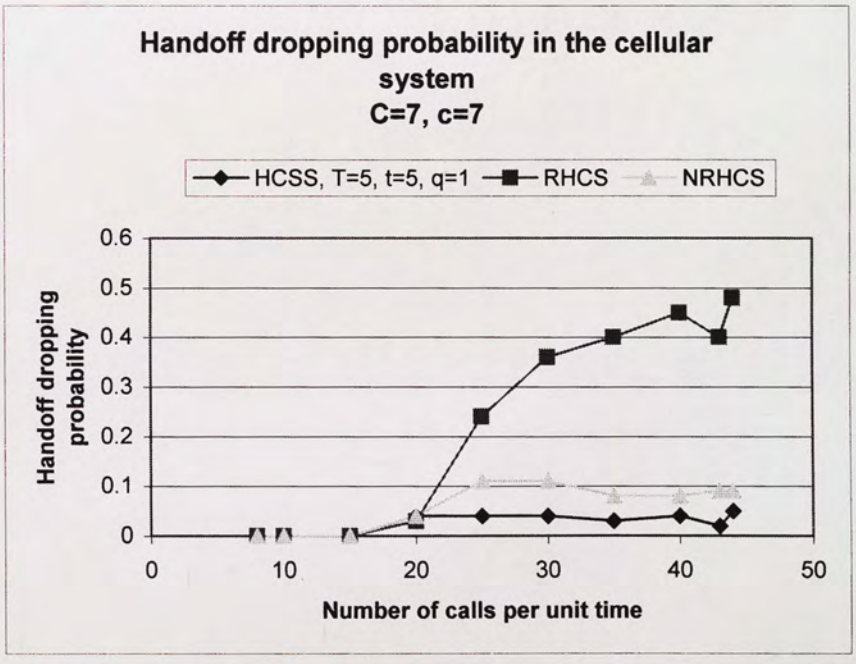


Figure 34: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 1

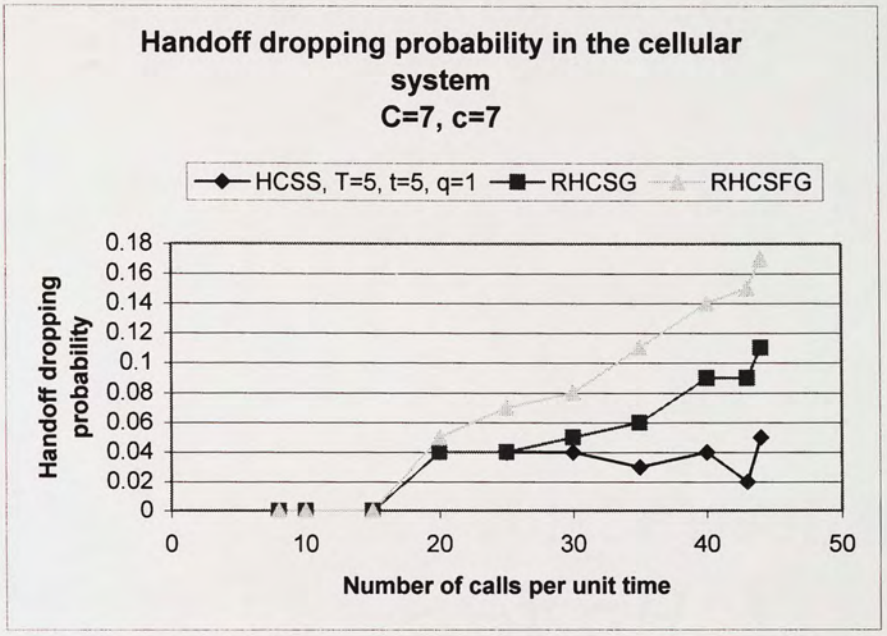


Figure 35: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 1

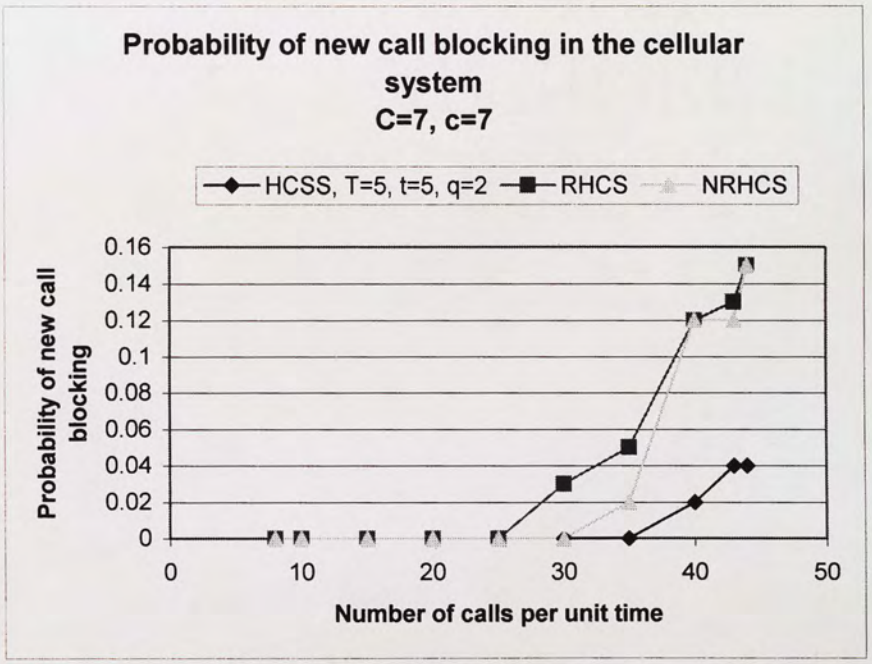


Figure 36: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 1

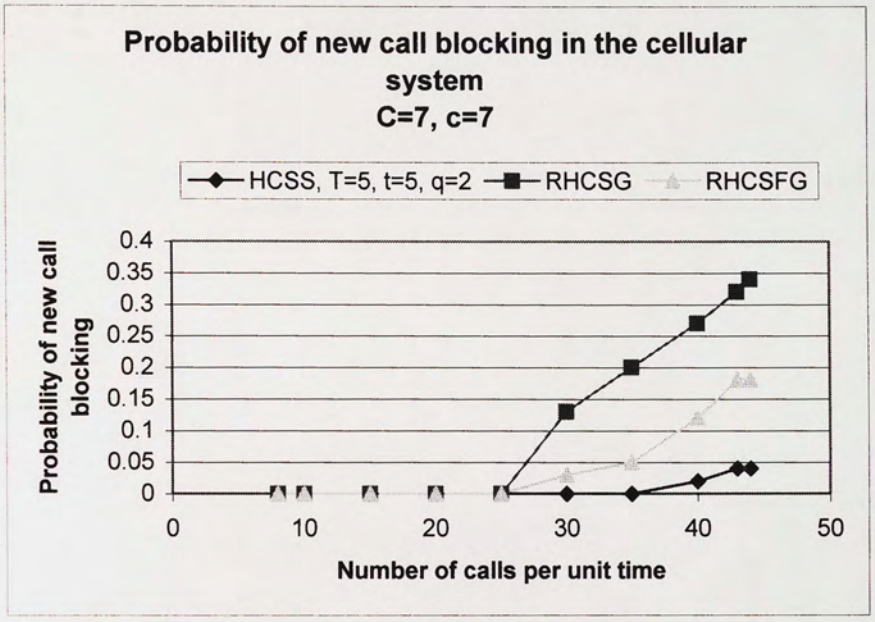


Figure 37: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 1

The above graphs show that the proposed scheme has higher probability of success both for the handoffs and new calls and lower probability of handoff dropping and new call blocking, when compared to the existing schemes, in teletraffic scenario 1.

Figure 38 through Figure 45 compare the probabilities of successful handoffs, successful new calls, handoff dropping and new call blocking respectively for the different schemes.

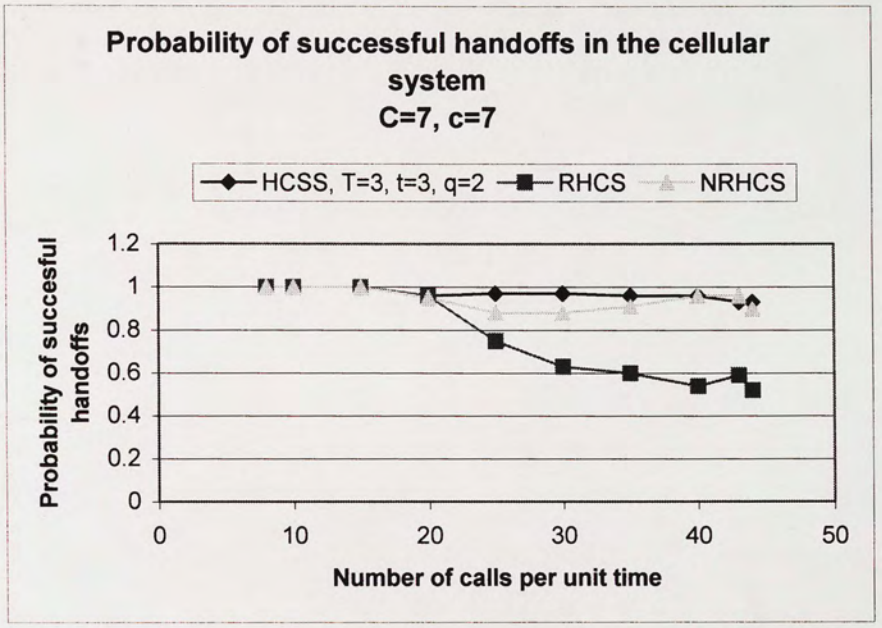


Figure 38: Comparison of the Probability of Successful Handoffs in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 2

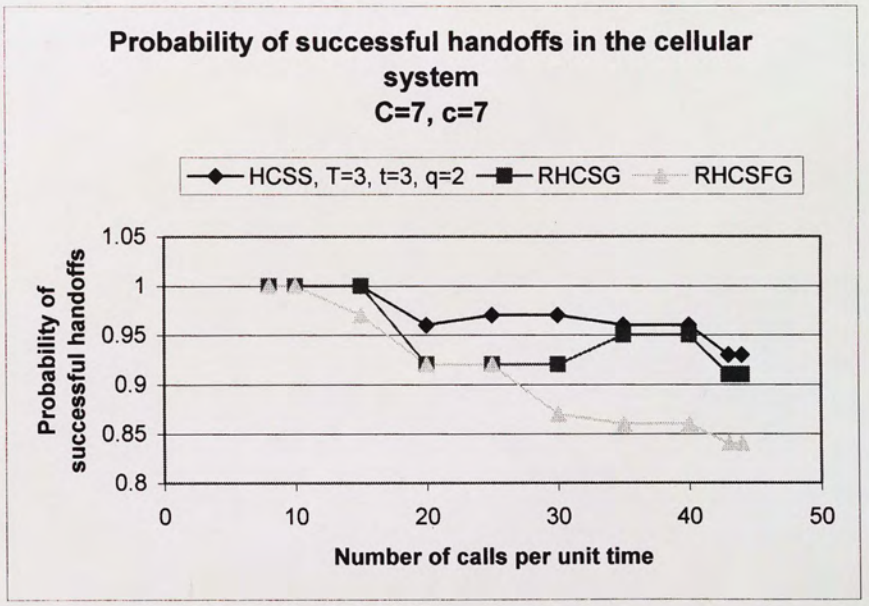


Figure 39: Comparison of the Probability of Successful Handoffs in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 2

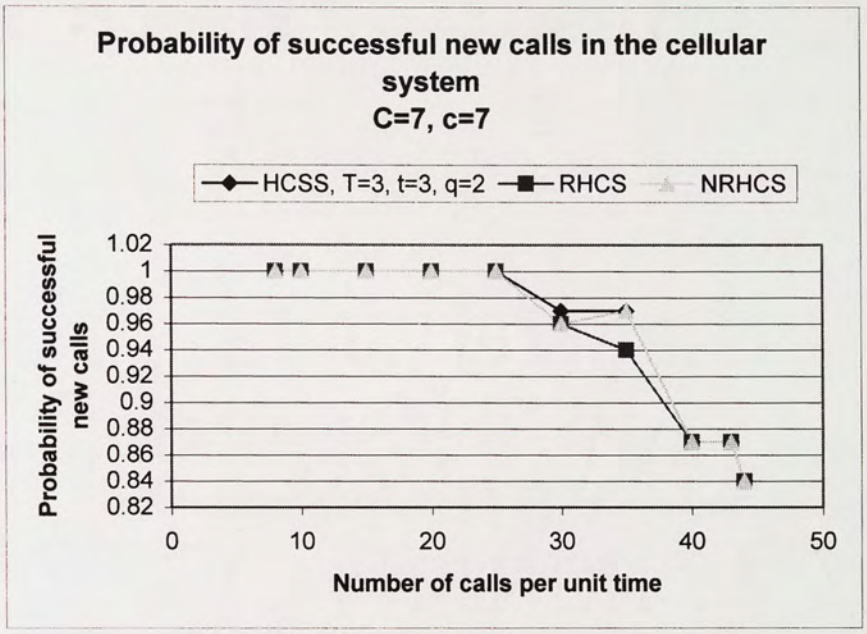


Figure 40: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 2

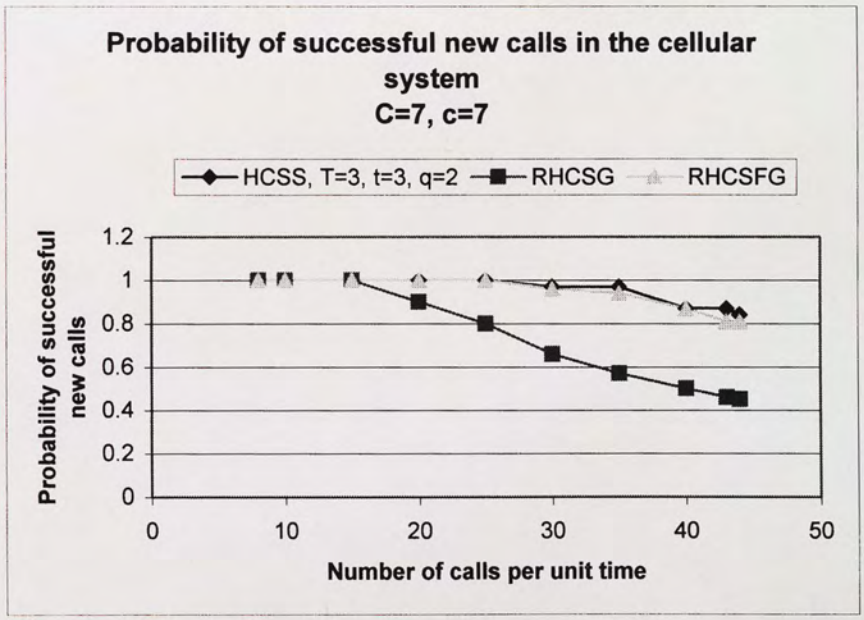


Figure 41: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 2

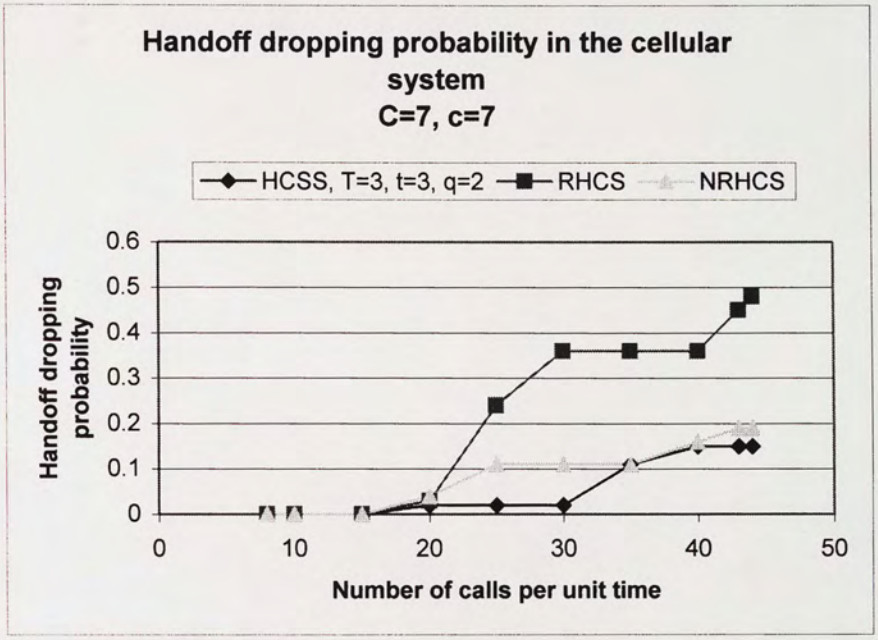


Figure 42: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 2

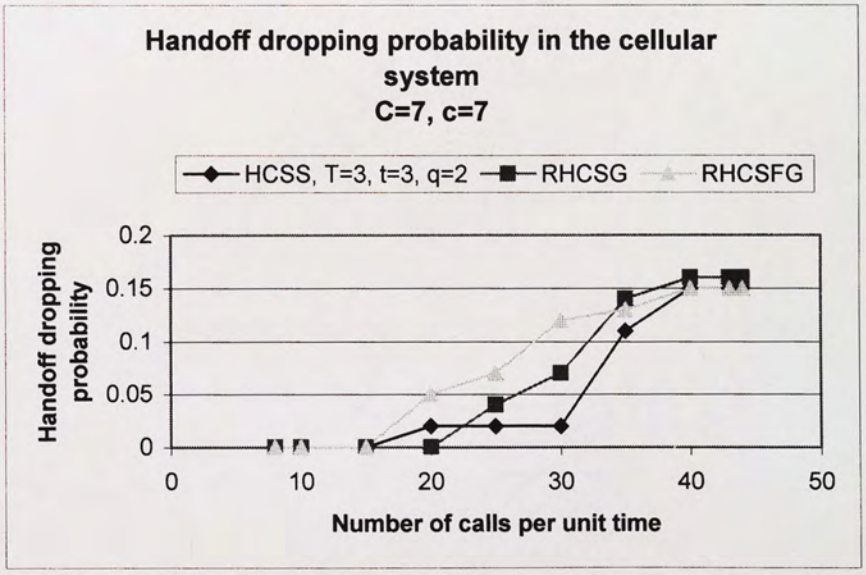


Figure 43: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 2

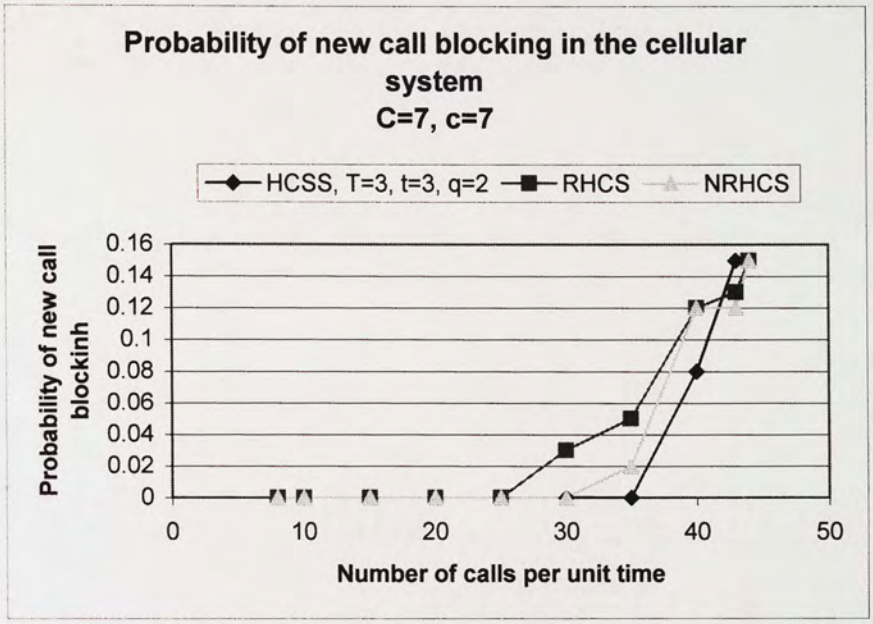


Figure 44: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 2

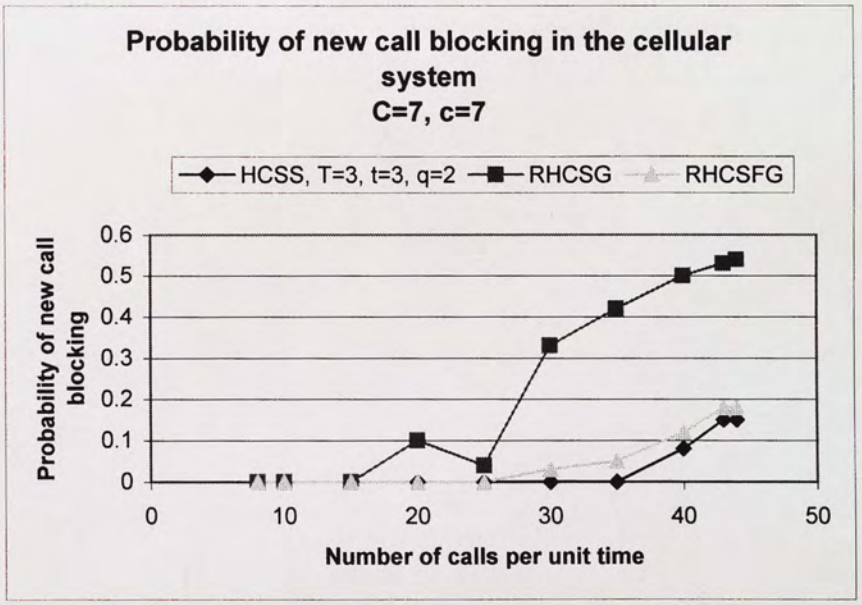


Figure 45: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 2

The above Figures show that the HCSS scheme performs better than the existing schemes.

Figure 46 through Figure 53 compare the probabilities of successful handoffs, new calls, handoff dropping and new call blocking respectively for the different schemes in teletraffic scenario 3.

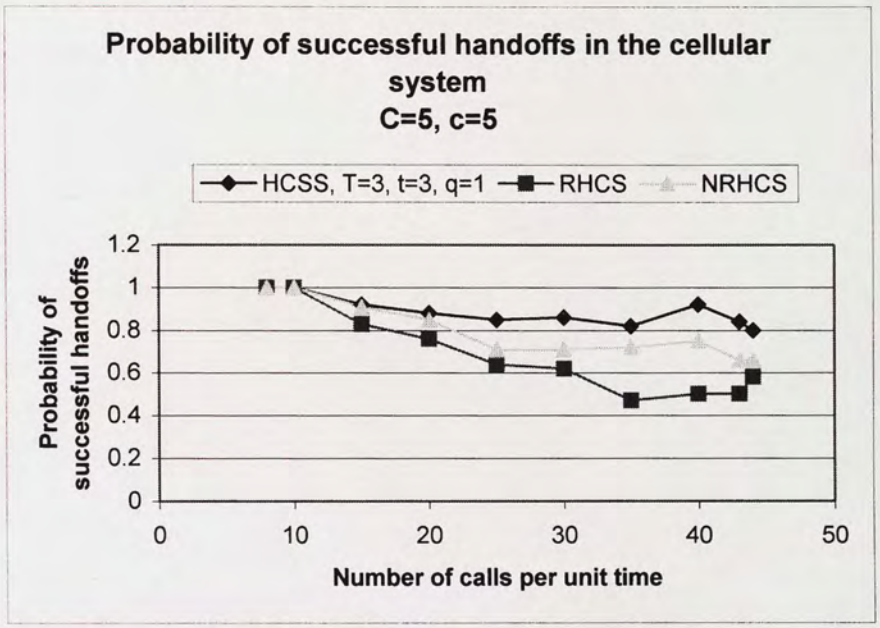


Figure 46: Comparison of the Probability of Successful Handoffs in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 3

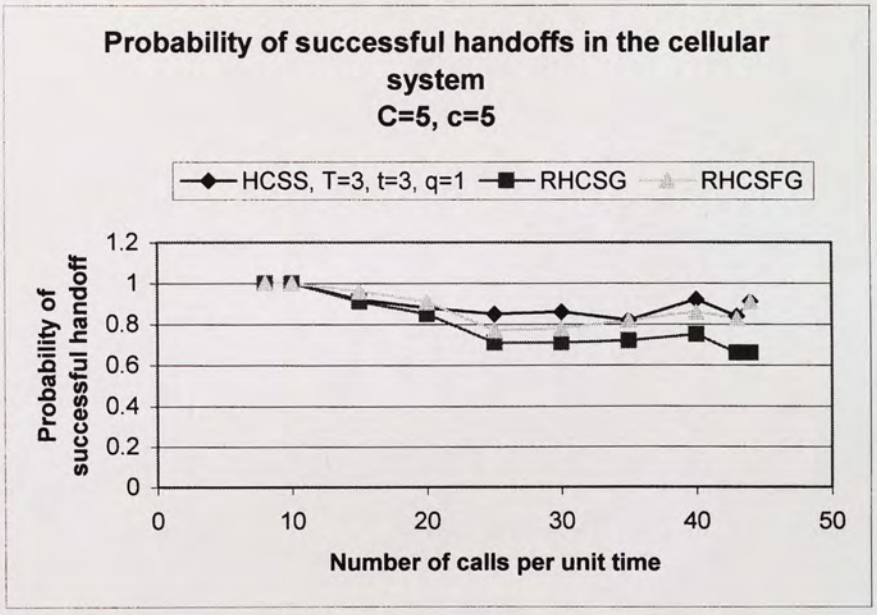


Figure 47: Comparison of the Probability of Successful Handoffs in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 3

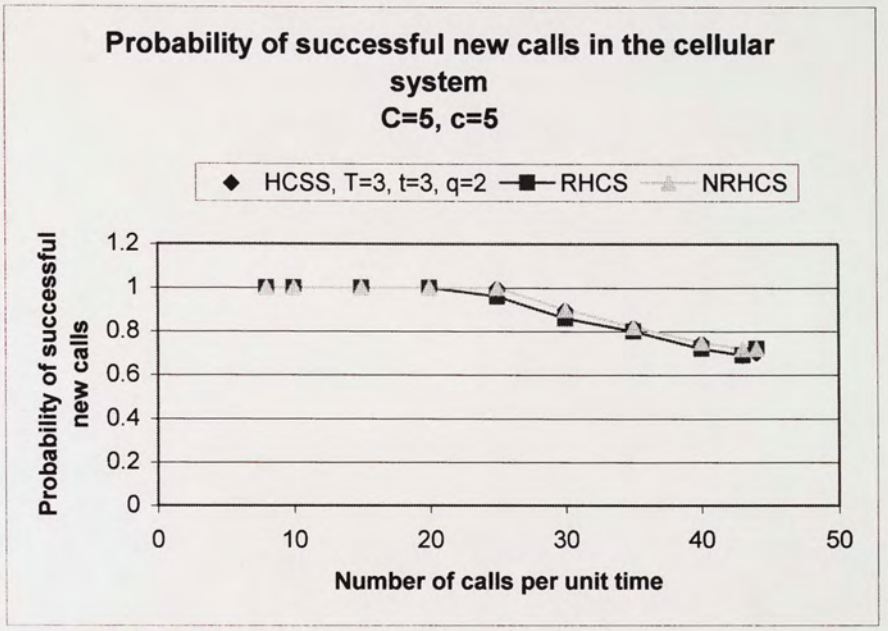


Figure 48: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 3

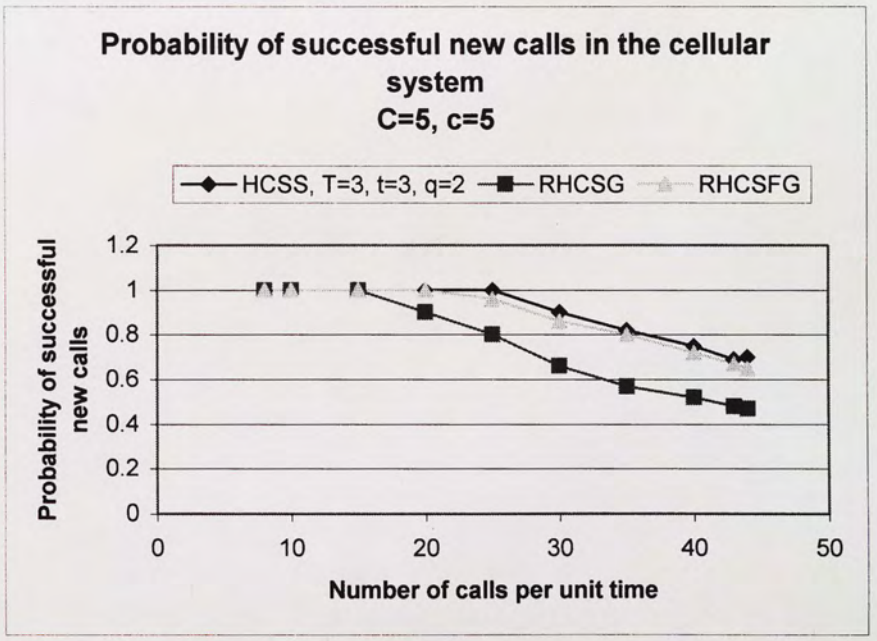


Figure 49: Comparison of the Probability of Successful New Calls in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 3

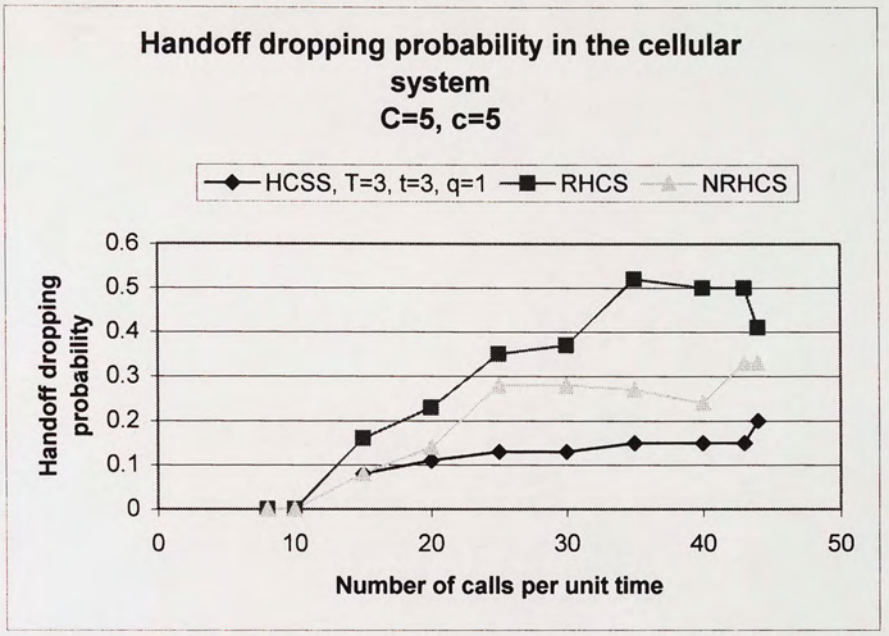


Figure 50: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 3

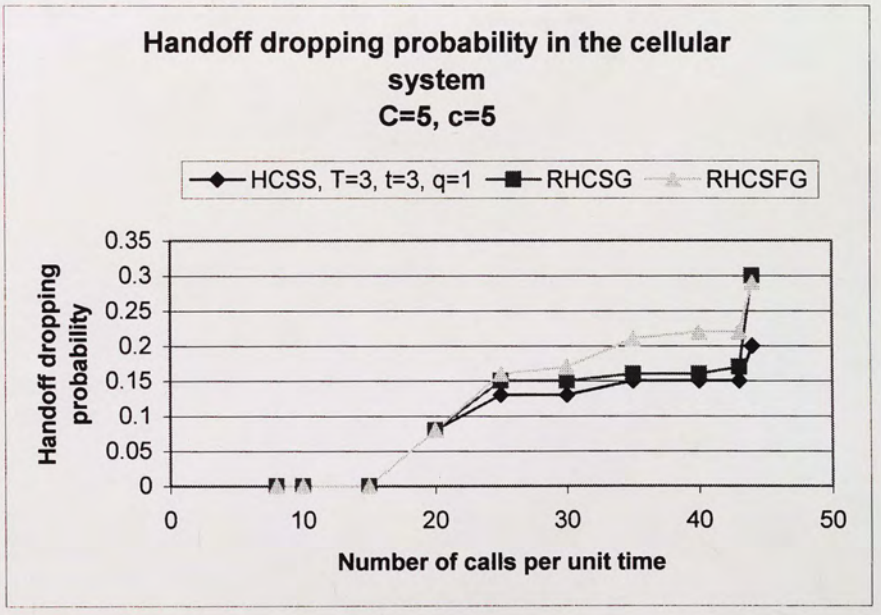


Figure 51: Comparison of the Handoff Dropping Probability in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 3

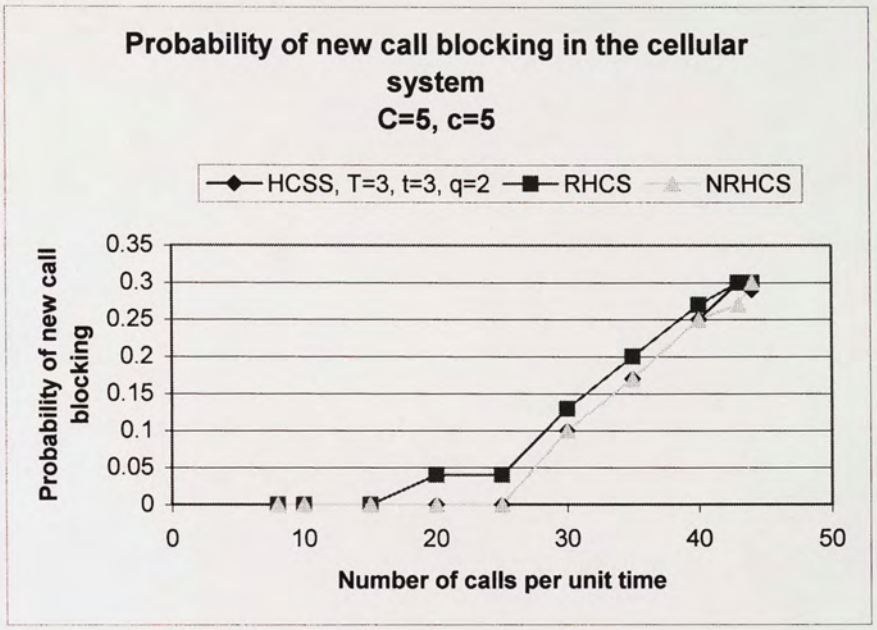


Figure 52: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 3

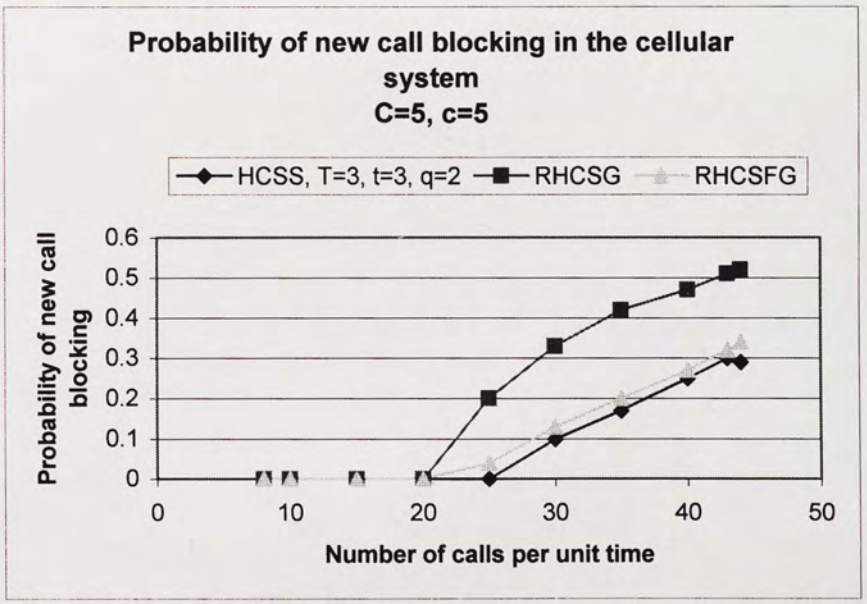


Figure 53: Comparison of the Probability of New Call Blocking in the Cellular System for the HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 3

It is clear from the figures above that the proposed scheme, HCSS, has better performance than the existing scheme, which is desirable to improve the QoS.

5.3 Throughput of the Cellular System

The throughput of the cellular system under different schemes, under different teletraffic conditions are compared in this section.

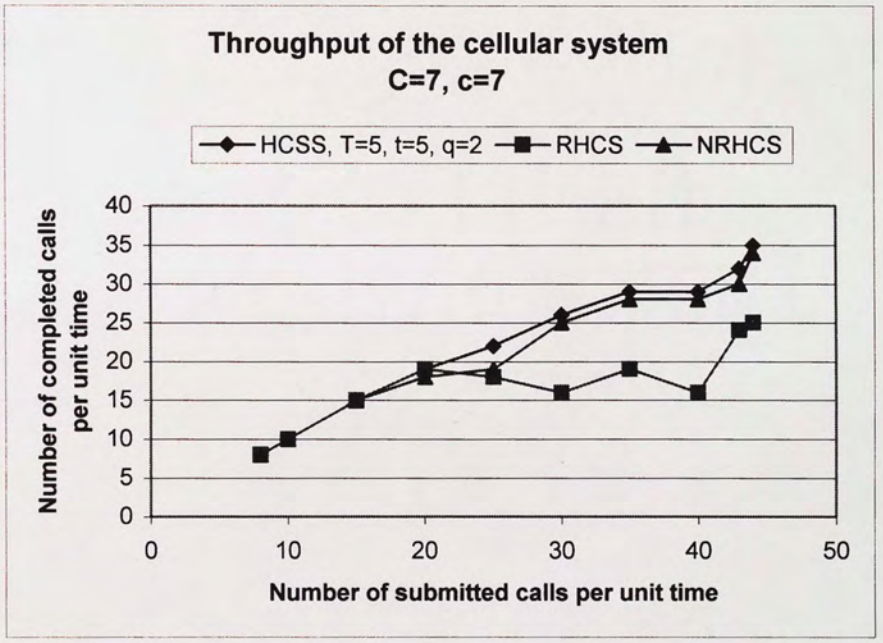


Figure 54: Comparison of the Throughput of the Cellular System Under HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 1

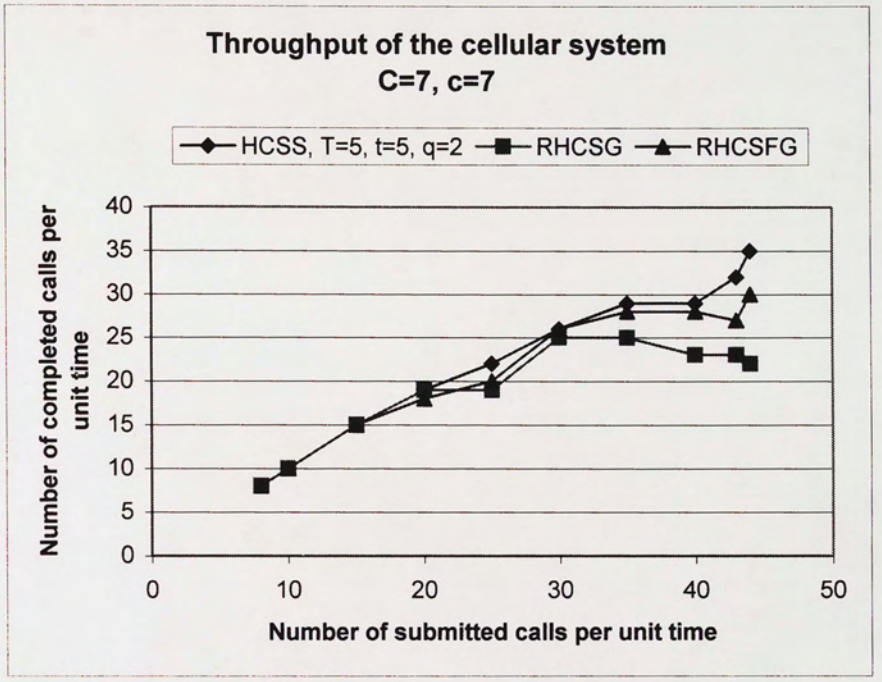


Figure 55: Comparison of the Throughput of the Cellular System under HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 1

The above graphs show that the proposed scheme has higher throughput compared to the existing schemes in teletraffic scenario 1.

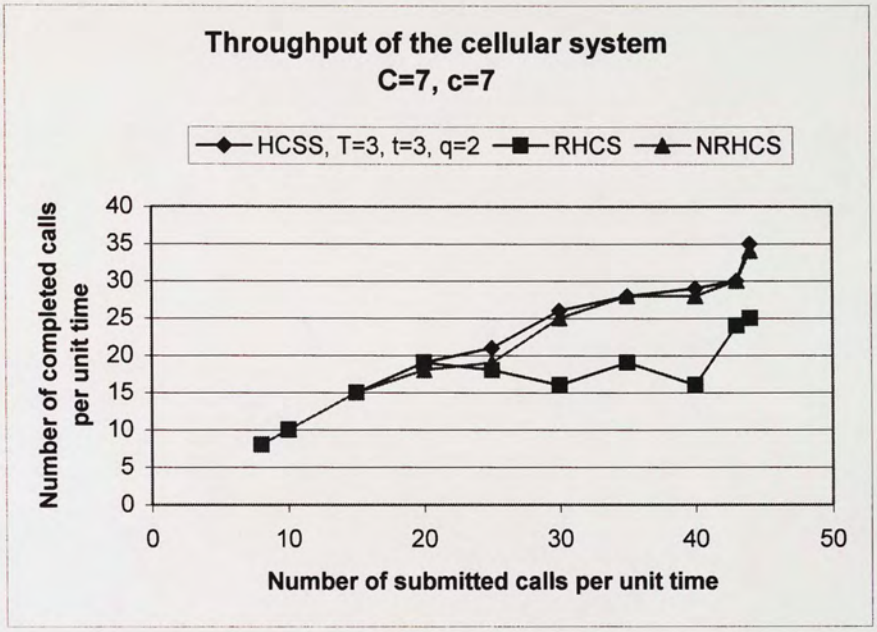


Figure 56: Comparison of the Throughput of the Cellular System Under HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 2.

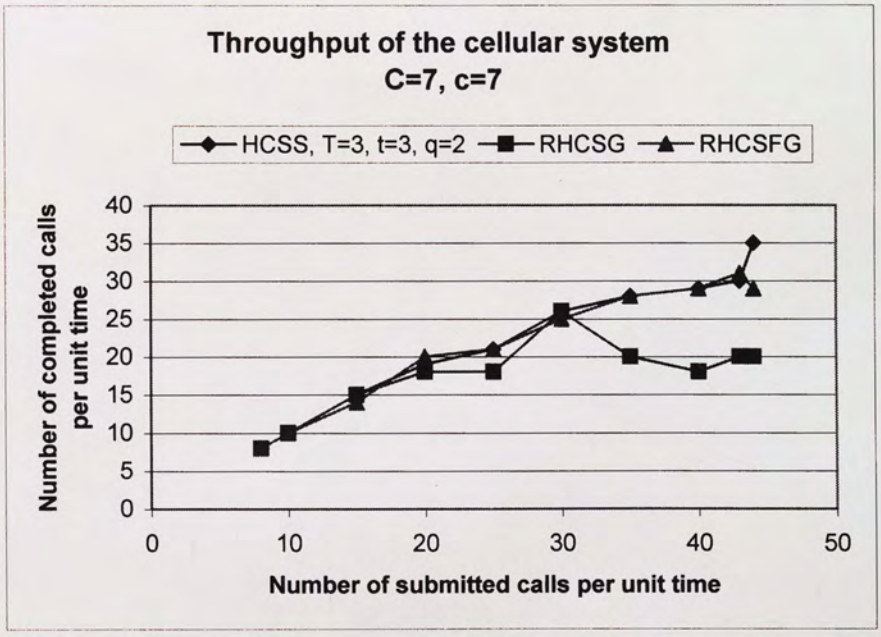


Figure 57: Comparison of the Throughput of the Cellular System Under HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 2

Figure 56 and Figure 57 show that the proposed scheme has similar throughput as the existing schemes initially but as the call volume becomes higher it has higher throughput than the existing ones in teletraffic scenario 2.

Figure 58 and Figure 59 show that the proposed scheme has higher throughput than the existing schemes under higher call volumes in teletraffic scenario 3.

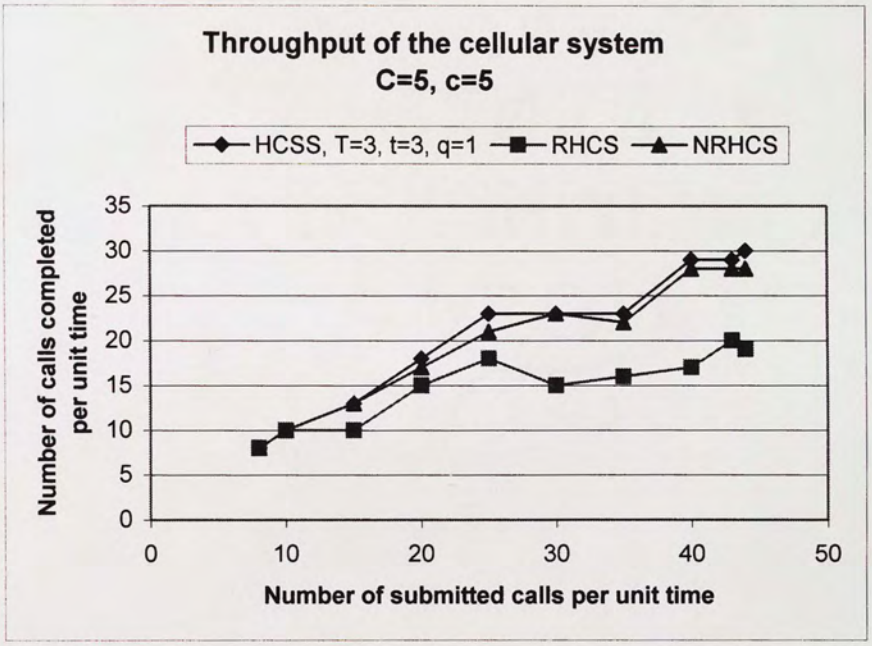


Figure 58: Comparison of the Throughput of the Cellular System Under HCSS, RHCS, and NRHCS Schemes in Teletraffic Scenario 3

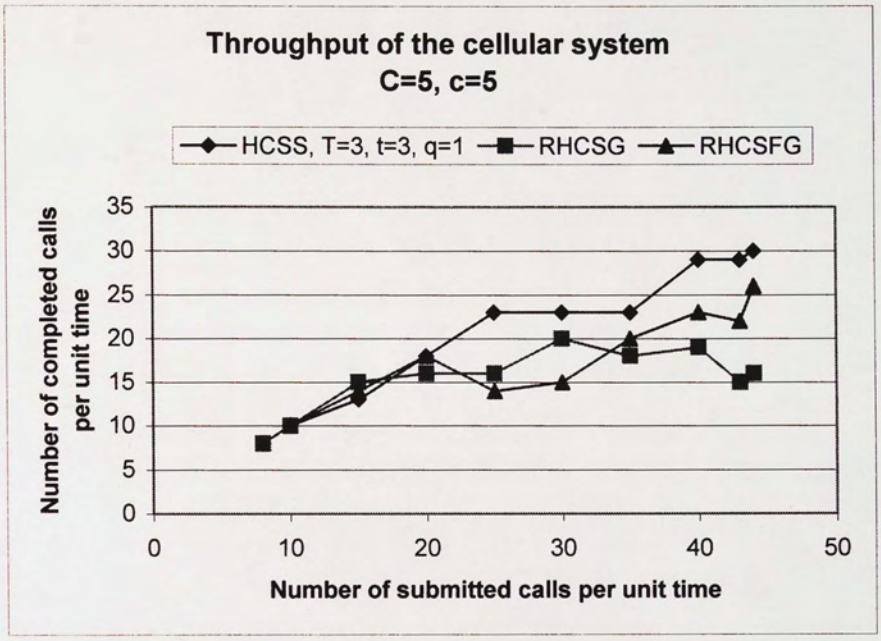


Figure 59: Comparison of the Throughput of the Cellular System under HCSS, RHCSG, and RHCSFG Schemes in Teletraffic Scenario 3

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In this thesis, a new hierarchical channel selection for macro-micro cellular network, called 'A Hierarchical Channel Selection Scheme for Macro/Micro Cellular Network (HCSS)', was proposed. This new scheme employs load balancing techniques and guard channel policy in channel assignment and re-assignment. The HCSS uses the proposed load balancing technique to minimize handoff call blocks over the new call blocks. To compare the performance of the HCSS with the other methods, a detailed simulation model was developed using Concurrent C.

The performance of HCSS is compared with NHCS, RHCS, RHCSG, RHCSFG schemes (defined in Chapter 2). The HCSS scheme shows a significant improvement towards reducing the reducing the dropping rate of the handoffs and reducing the new call blocks. The HCSS scheme gives better performance than the NHCS, RHCS, RHCSG and the RHCSFG scheme in teletraffic scenario 1 and teletraffic scenario 2 conditions, and it outperforms all the other four schemes significantly under teletraffic scenario 3. It has lowered the probability of handoff call block over the new call blocks significantly. However the existing schemes have roughly equal probabilities of handoff call blocks and

new call blocks and handle the channel selection and allocation inefficiently which makes them impractical.

The HCSS scheme uses a combination of both channel availability and cell load factor as a hybrid approach for the channel selection. To further reduce the overhead of handoff call blocks over the new calls, the thresholds are used. The threshold specifies when the cell should allocate available channels to calls based on the selection criteria.

6.2 Future Work

The basic design of the HCSS scheme can be extended by using large number of concatenated micro cells in each macro cell. Each micro cell can have smaller number of channels and with more efficient queues which will enable the mobile to use channels from immediate neighboring micro cells as soon as they become available, if the channels are full in the micro cell in whose queue the call is waiting. This may increase the performance even more and reduce the handoff call blocks and the new call blocks significantly.

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