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A STUDY OF THE EFFECTS OF LOCATION AREAS ON PAGING AND REGISTRATION IN A CELLULAR MOBILE TELEPHONE SYSTEM

par

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RAPPORT DE PROJET PRÉSENTÉ EN VUE DE L'OBTENTION
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Ce rapport de projet intitulé:

A STUDY OF THE EFFECTS OF LOCATION AREAS ON PAGING AND REGISTRATION IN A CELLULAR MOBILE TELEPHONE SYSTEM

présenté par: Michel DUBIEN
en vue de l'obtention du grade de: maître en ingénierie (M. Ing.)
a été dûment accepté par le jury d'examen constitué de:

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Mme SANSÒ Brunilde, Ph.D., membre
M. SAWYER François, M.Sc.A., membre

To Sylvie and Xavier, my loving wife and son,

Without your patience, love, and support, this never would have been possible.

SOMMAIRE

Les réseaux de téléphonie cellulaire se distinguent des réseaux téléphoniques traditionels par leur capacité d'acheminer des appels à des abonnés qui se déplacent. Leur plus important atout est leur capacité de gérer le déplacement d'abonnés cellulaires.

L'appel et l'inscription sont des concepts fondamentaux à la téléphonie cellulaire, puisqu'ils permettent au système cellulaire de chercher et de gérer la position des abonnés. L'appel comprend les étapes entreprises par le système pour trouver un abonné que l'on veut rejoindre. L'inscription comprend les étapes suivies par une station mobile pour enregistrer sa position.

Ces deux processus utilisent un système de coordonnées où l'élément de base est l'aire d'emplacement. L'aire d'emplacement est le moyen employé pour gérer la position des abonnés cellulaires. Il peut contenir une ou plusieurs cellules et représente la plus petite surface dans laquelle le système cherchera un abonné.

Identifier la configuration optimum des aires d'emplacement est présentement difficile, puisque le comportement du système cellulaire lorsque disposé selon une configuration quelconque est imprévisible. Aujourd'hui, les mesures de performance liées à cette question ne sont analysées selon aucune méthode systématique.

Pour essayer de répondre à ce manque, un modèle qui simule les processus d'appel et d'inscription a été développé. Ce modèle est basé sur la spécification nord-américaine IS-54B. Cette norme décrit la communication entre les stations radio et les stations mobiles. Le modèle tient compte aussi de l'environnement qui entoure le système cellulaire. Entre autres, l'environnement radio, les appels et le mouvement des véhicules font partie du modèle. Ce modèle de simulation constitue une architecture qui pourra nous servir à l'avenir pour poursuivre des analyses plus élaborées et pour développer d'autres outils qui ont attrait à l'appel et à l'inscription.

ABSTRACT

Mobile telephony distinguishes itself from traditional telephony in that a call can be routed to a subscriber regardless of his location. A cellular mobile telephone system or CMTS is what provides mobile telephony services. Its most important asset is its capability of managing subscriber mobility.

Paging and registration are fundamental to cellular telephony since they are the means by which a CMTS can find and keep track of the subscribers. Paging is the act of seeking a mobile station when an incoming call has been placed to it. Registration consists in the steps by which a mobile station identifies itself to a base station as being active in the system at the time the message is sent to the base station.

The paging and registration processes are executed using a positional reference system based on location areas. The location area is one of the configurable means that a cellular operator uses to manage the mobility of its subscribers. It can consists of one or more cells and represents the smallest area in which the system will track a mobile subscriber.

Determining the optimum location area configuration is a difficult exercise since the behaviour of a CMTS, given a particular location configuration, is currently very unpredictable. Paging and registration cost and success factors are not systematically compared in order to reach some type of optimal location area configuration which could increase the CMTS's mobility management capability.

A discrete-event simulation model dealing specifically with the paging and registration activities that go on in a CMTS has been developed. It is based on the call processing specification of the IS-54B North American interface standard for communications between mobile stations and base stations. The model also simulates the environment which surrounds the cellular system i.e. the movement of mobiles, radio propagation, and call behaviour. It sets the stage for the investigation of all types of mobility management issues and provides a framework for creating new simulation applications in this area.

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TABLE OF CONTENTS

CHAPTER 1 - INTRODUCTION

CHAPTER 2 - INTRODUCTION TO CELLULAR MOBILE TELEPHONE SYSTEMS

CHAPTER 3 - THE PAGING AND REGISTRATION SIMULATION MODEL

CHAPTER 4 - EXPERIMENTS AND RESULTS

CHAPTER 5 - CONCLUSION AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS & SYMBOLS

Acronyms

BS	Base Station (p.9)
CMTS	Cellular Mobile Telephone System (p. 1)
DCC	Digital Colour Code (p.40)
FOCC	Forward Control Channel (p. 1)
HLR	Home Location Register (p.9)
HPBW	Half Power Beamwidth (p.32)
LOCAID	Location Area Identification (p. 17)
MS	Mobile Station (p.9)
MSC	Mobile Switching Centre (p. 1)
OMT	Overhead Message Train (p.16)
REGID	Registration Identification (p. 15)
RECC	Reverse Control Channel (p. 15)
SPOM	System Parameter Overhead Message (p. 15)

Symbols

a	pointing azimuth of base station antenna (p.31)
d	distance from base station in km (p.31)
d_{sa}	service area depth (p.35)
$d_{i,j,k}$	distance between the centre of bin i,j and base station k (p.31)
dx	mobile displacement along x-axis (p.38)
$\overline{D}_c$	average call duration (p.27)
D_{pr}	page response delay (p.60)
$\overline{D}_{pr}$	average page response delay (p.60)
D_r	registration duration (p.61)
$\overline{D}_r$	average registration duration (p.61)

LIST OF ACRONYMS & SYMBOLS

$\overline{D}_s$	average control channel scan duration
f	carrier frequency in Mhz (p.31)
h	base station antenna height in meters (p.31)
L_a	antenna pattern loss in dB (p.30)
$L_{a\,k}$	antenna pattern loss of base station k (p.29)
L_p	propagation loss in dB (p.30)
$L_{p\ i,j,k}$	propagation loss between bin i,j and base station k (p.29)
n_a	number of first page attempts (p.58)
N_{ms}	number of mobile stations (p.61)
N_{bs}	number of base stations (p.76)
N_c	number of cells (p.35)
$\overline{n}_c$	average number of base station pages issued per terminating call (p.59)
n_{cr}	number of confirmed registrations (p.60)
n_f	number of forced registration attempts (p.60)
n_{fr}	number of failed registrations (p.60)
n_r	number of repeat page attempts (p.58)
n_{rg}	number of registration attempts (p.60)
n_{mb}	number of MAXBUSY failures (p.62)
n_o	number of originating calls (p.61)
n_p	number of base station pages per terminating call (p.58)
n_{sa}	number of system access attempts (p.62)
n_{se}	number of RECC (or access channel) seizure attempts (p.62)
n_{su}	number of successful RECC (or access channel) seizures (p.62)
n_{sr}	number of RECC (or access channel) seizure retries (p.62)
n_t	number of terminating calls (p.58)

LIST OF ACRONYMS & SYMBOLS

n_{to}	number of system access timeouts (p.62)
n_1	number of responses to first page attempts (p.58)
n_2	number of responses to second page attempts (p.58)
$\overline{p}_{ir}$	average percentage of time an MS is inaccessible due to it registering (p.61)
$P_{r\ i,j,k}$	the signal strength contribution of base station k received at bin i,j (p.29)
p_t	percentage of terminating calls successfully paged (p.59)
$P_{t\ k}$	effective radiated power of base station k (p.29)
p_1	response percentage for first page (p.58)
p_2	response percentage for repeated page (p.59)
phi	angle difference between the pointing azimuth of the base station antenna and the vector between the base station and the center of a bin (p.32)
s	mobile speed (p.38)
$\overline{s}$	mobile average speed (p.38)
r	cell radius (p.33)
theta	mobile direction (p.38)
T_d	displacement update period for mobiles (p.38)
T_o	time between originating calls (p.28)
$\overline{T}_o$	average time between originating calls (p.27)
T_{sim}	simulation duration (p.61)
T_t	time between terminating calls (p.28)
$\overline{T}_t$	average time between terminating calls (p.27)
$\overline{u}_{re}$	average RECC (or access channel) utilization (p.61)
$\overline{u}_{fo}$	average FOCC (or paging channel) utilization (p.61)

LIST OF ACRONYMS & SYMBOLS

x_k	x coordinate of base station k (p.31)
$x_{i,j}$	x coordinate of bin i,j (p.31)
$y_{i,j}$	y coordinate of bin i,j (p.31)
y_k	y coordinate of base station k (p.31)
w_{sa}	service area width (p.35)

CHAPTER 1
INTRODUCTION

1.1. Effects of Location Area Configurations on Paging and Registration

Mobile telephony distinguishes itself from traditional telephony in that a call can be routed to a subscriber regardless of his location. A cellular mobile telephone system or CMTS is what provides mobile telephony services. Its most important asset is its capability of managing subscriber mobility.

To be capable of routing a call to a subscriber, a cellular system must constantly be updated on his location. The cellular system tracks the position of the mobile subscribers by having them register their location. This is called registration. When a call is made to a subscriber, the CMTS pages the subscriber in all cells contained in the area from where the mobile station last registered. This is called paging. Once a mobile station responds to the page, the CMTS sets up the call.

Today the extent to which paging and registration cost and success factors are influenced by a location area configuration is difficult to predict given that there exists many intricate causal dependencies between them. We can nevertheless discuss in a very qualitative matter, the potential benefits and drawbacks of small location areas and large location areas.

1.1.1. Effects of Using Small Location Areas

The main reason for using small location areas is to minimize the number of pages that are broadcasted throughout the system. This has the advantage of limiting the usage of the paging channels (FOCCs) thereby increasing the overall paging capacity of the system.

One of the disadvantages of a configuration of small location areas is that it increases the registration rate since the number of forced registrations increases. In effect, it may shorten the period a mobile station can listen to pages since it cannot receive any page messages while it is registering. Furthermore, small location area configurations may increase the time a mobile station requires to access the system since more mobile stations may be attempting a registration access simultaneously. As a result, page responses may reach the MSC late thereby triggering a global page or simply causing a page failure.

Another disadvantage of small location area configurations is that location areas that are too small may lower the paging success rate. This is due primarily to the fact that mobiles in general may be travelling too fast with respect to the size of the location areas. As a result, the system may not be capable of accurately tracking the location of mobiles.

1.1.2. Effects of Using Large Location Areas

Using large location areas has essentially the opposite effects of using small location areas. The main reason for using large location areas is to increase the probability of paging success since it allows larger areas to be covered simultaneously with the same page. Mobile location data latency problems caused by fast moving mobiles and small location areas, are less likely with large location areas.

Large location areas lower the registration rate since the number of forced registrations is essentially decreased. It therefore is not subject to the consequences of high registration rate as in the case of small location areas.

The main drawback of configurations with large location areas is the high paging cost. Large location areas result in more pages being broadcasted by the system which in effect may decrease the overall paging capacity of the system. This may increase the probability of losing pages when the cellular system is subjected to peak traffic load conditions since the system might not be able to support the quantity of pages that need to be issued by each base station.

1.1.3. Summary of Effects

Table 1.1 summarizes the potential benefits and drawbacks of small and large location areas.

Table 1.1 Benefits and Drawbacks of Small and Large Location Areas

Location Area Sizes	Benefits	Drawbacks
Small	- Lower paging cost	- Higher registration cost - Lower paging success
Large	- Lower registration cost - Higher paging success	- Higher paging cost

1.1.4. Project Objective

The objective of this project is to build a simulation model to investigate the effects that location area configurations may have on the paging and registration aspects of a CMTS.

1.2. The Simulation Approach

To study the effects of location area configurations on paging and registration, a simulation approach was adopted.

Simulation is an effective way of pretesting proposed systems, plans, or policies before developing expensive prototypes, field tests, or actual implementations. Simulation is often used as an alternative to more traditional forms of analysis such as analytical solutions, numerical solutions, or even to scale-model building.

Within the discipline of computer-based simulations, there are two basic types: **continuous** simulation and **discrete-event** simulation. Continuous simulation describes systems by sets of equations to be solved numerically. These may be algebraic or differential equations, usually with time as an independent variable. Heat-flow and fluid-flow problems are typical examples. Discrete-event simulation deals specifically with modelling those systems in which the system state is deemed to change instantaneously at discrete points in time, rather than continuously. The aspects we wish to study in this project fall under the category of discrete-event simulation.

The process used to build the simulation model is based on the principles outlined by Russell [RUS83]. Figure 1.1. illustrates the simulation modelling paradigm which was actually used.

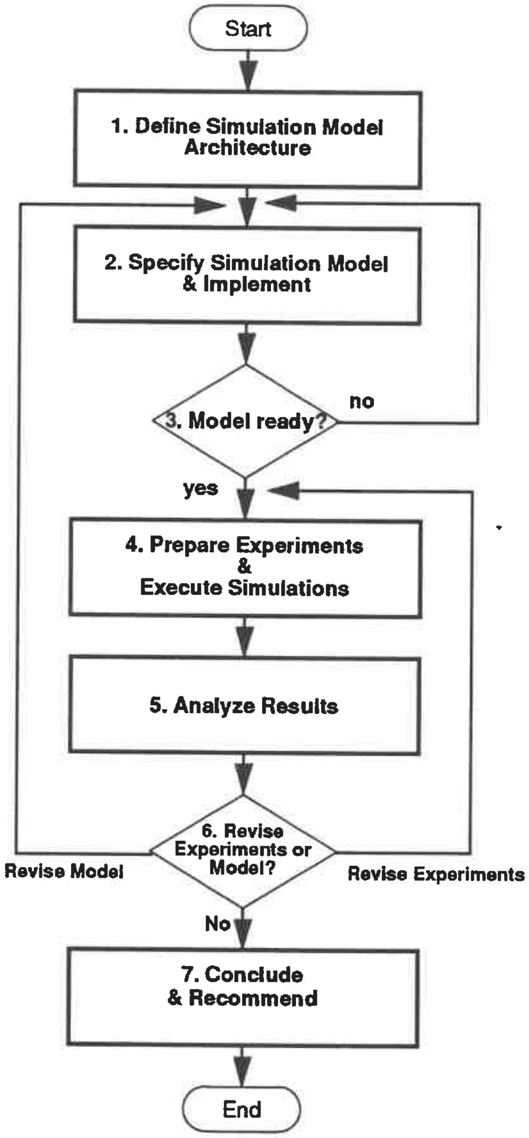


Figure 1.1. The Simulation Model Paradigm

The following describes the paradigm:

1) **Define Simulation Model Architecture** consists in defining a simulation model framework which includes describing the functional intent of each basic simulation model component. The architecture sets the stage for the subsequent specification and implementation work.

2) **Specify Simulation Model and Implement** consists in first describing the operation of the simulation model and then translating it into source code. Simulation model specification allows the simulation modeller and the other project participants to communicate more effectively through the use of graphical techniques such as state transition diagrams. The idea here is to make the actual implementation of the simulation model transparent to the project participants who may not be familiar with the simulation programming language which has been used. The implementation consists in translating the simulation model specification into code. In our case, the simulation language SIMSCRIPT II.5 was used for the implementation of the simulation model. Appendix A.1 provides an overview of the language.

3) **Model Ready?** Simulation Model Specification and Implementation are part of an iterative process. At any point in the process, certain observations may lead to returning to detailed model specification or implementation tasks to revise what was previously done.

4) **Preparate Experiments and Execute Simulations** consists in collecting data that is pertinent to the problem which is being studied and running a simulation for each experiment.

5) **Analyze Results** consists in studying the outcome of the experiments.

6) **Revise Experiments or Model?** Results Analysis may prompt the design of new experiments to investigate unexpected or misunderstood results or it may actually prompt modifications to be made to the specification of the simulation model and its implementation.

7) **Conclude and Recommend** consists in concluding on the experimental results which were obtained and recommending further work in related areas which may be of particular interest for the future.

1.3. The SIMSCRIPT II.5 Simulation Language

SIMSCRIPT II.5 was selected as the simulation language to implement the model. It was selected because it is an easily readable and understandable high-level language designed especially for simulation modelling.

The following provides a very brief introduction of the SIMSCRIPT II.5 language. The interested reader is encouraged to read [KIV84] for a more complete account of this language.

The Process Concept

A process represents an object and the sequence of actions it experiences throughout its life in the model. There may be many instances of a process during a simulation. There may also be many different processes in a simulation model.

A process object enters the model at an explicit simulated time. It becomes active immediately or at some later scheduled time. From then on, the description of the activity is contained in the process routine. It contains the sequence of interrelated events separated by lapses of time which are either predetermined or indefinite.

Predetermined lapses of time are used to model such phenomena as the service time (deterministic or stochastic), whereas indefinite delays arise because of processes competing for a limited amount of resources.

Processes interact explicitly through statements to “activate”, “interrupt”, or “resume” one another or implicitly through resource competition.

The Resource Concept

Resources are the passive elements of the simulation model. A resource is used to model the object required by the processes. If a resource is not available when requested, the process is queued until that resource becomes available again.

A resource becomes available once the process holding it relinquishes it. The next process in the queue is then given the resource and reactivated.

The simplest form of a resource consists of a single unit of a single type. For example, a one-teller bank or a single-runway airport could be modelled this way. To expand to multiple resources in the model, there are two options:

add more identical units of the resource. They are identical and serve processes from the same queue;

add more separate units of the resource. They are separated units that serve processes waiting in separate queues and allocated only to those processes that have specifically requested them.

Entities, Sets, and Attributes

An entity is a structured data that represents some element of a modelled system. It may represent more than one value: these values are called attributes of the entity. When assigned specific values, the attributes define a particular configuration or state of the entity. In this project, for instance, mobile stations have been considered entities.

Entities and attributes allow some structuring of related data. Sets provide a higher level of structuring of these data.

Sets are organized collection of entities. Sets are like arrays in that each of the entity elements of which they are composed may be identified and manipulated, but in contrast with the static structuring imposed on array elements, the organization of entities in sets may be dynamic and changeable. In this project, for instance, a location area has been considered a set which contains cells.

Modelling Statistical Phenomena

As simulation is essentially a tool for drawing statistical inferences from the operation of stochastic systems, it is crucial that a simulation language provide facilities for modelling statistical phenomena.

SIMSCRIPT II.5 offers a variety of functions for generating independent, pseudorandom samples from commonly encountered statistical distributions. SIMSCRIPT

II.5 offers such statistical distribution functions as Uniform, Poisson, Normal, and Exponential. It also allows the specification of customized sampling distributions through the definition of table look-up sampling variables.

CHAPTER 2
INTRODUCTION TO CELLULAR MOBILE TELEPHONE SYSTEMS

2.1. Basic Terms

Before discussing any potential trade-offs involving location areas, paging and registration, some basic principles of Cellular Mobile Telephony Systems (CMTS) need to be introduced. The information that follows is based on course material prepared by Ericsson Radio Systems, a division of Ericsson, a world renowned CMTS supplier, to train its staff in cellular systems and more specifically in one of its products used in North America, the CMS88 CMTS [MIS87]. Although prepared for the CMS88 product in particular, the concepts presented here are generic enough to apply to most types of cellular systems regardless of the actual product or manufacturer.

Figure 2.1. illustrates an automatic Cellular Mobile Telephone System (CMTS) controlled by a single telephone exchange. A CMTS generally comprises a network of Mobile Switching Centres (MSCs). This project deals with a CMTS having only one MSC.

A CMTS comprises the following basic components:

Mobile Switching Centre (MSC);

Radio Base Station (BS),

Mobile Station (MS);

There exists other CMTS components that are currently being introduced in the cellular industry. However, only those that had relevance to this project have been presented.

The **MSC** constitutes an interface between the Public Switched Telephone Network (PSTN) and the radio system. The MSC switches calls to and from mobile subscribers and provides all signalling functions needed to establish calls.

Radio base stations, also referred to as **base stations**, provide radio coverage in a given geographical area called a service area. The base station contains channel units each comprising a transmitter, a receiver, and a control unit. There are two types of channel units; voice channel units and control channel units. A voice channel unit is engaged in carrying a call while a control channel unit controls such aspects as paging and registration.

The **mobile station** is a transportable, car-mounted or pocket telephone used by a mobile subscriber. It consists of a radio transmitter and receiver, a logic unit for data signalling with the base station, and a telephone part.

At call set-up, speech is transmitted on the radio path between the mobile station and the selected voice channel unit of the base station situated closest to the mobile station. When the transmission quality deteriorates because the mobile station has moved away from the base station, an automatic change of base station occurs. This is known as handoff or handover.

Paging and registration are fundamental to cellular telephony since they are the means by which a CMTS manages the mobility of the subscribers. Paging is the act of seeking a mobile station when an incoming call has been placed to it. Registration consists in the steps by which a mobile station identifies itself to a base station as being active in the system at the time the message is sent to the base station. The MSC maintains the current location area of a mobile station through registration.

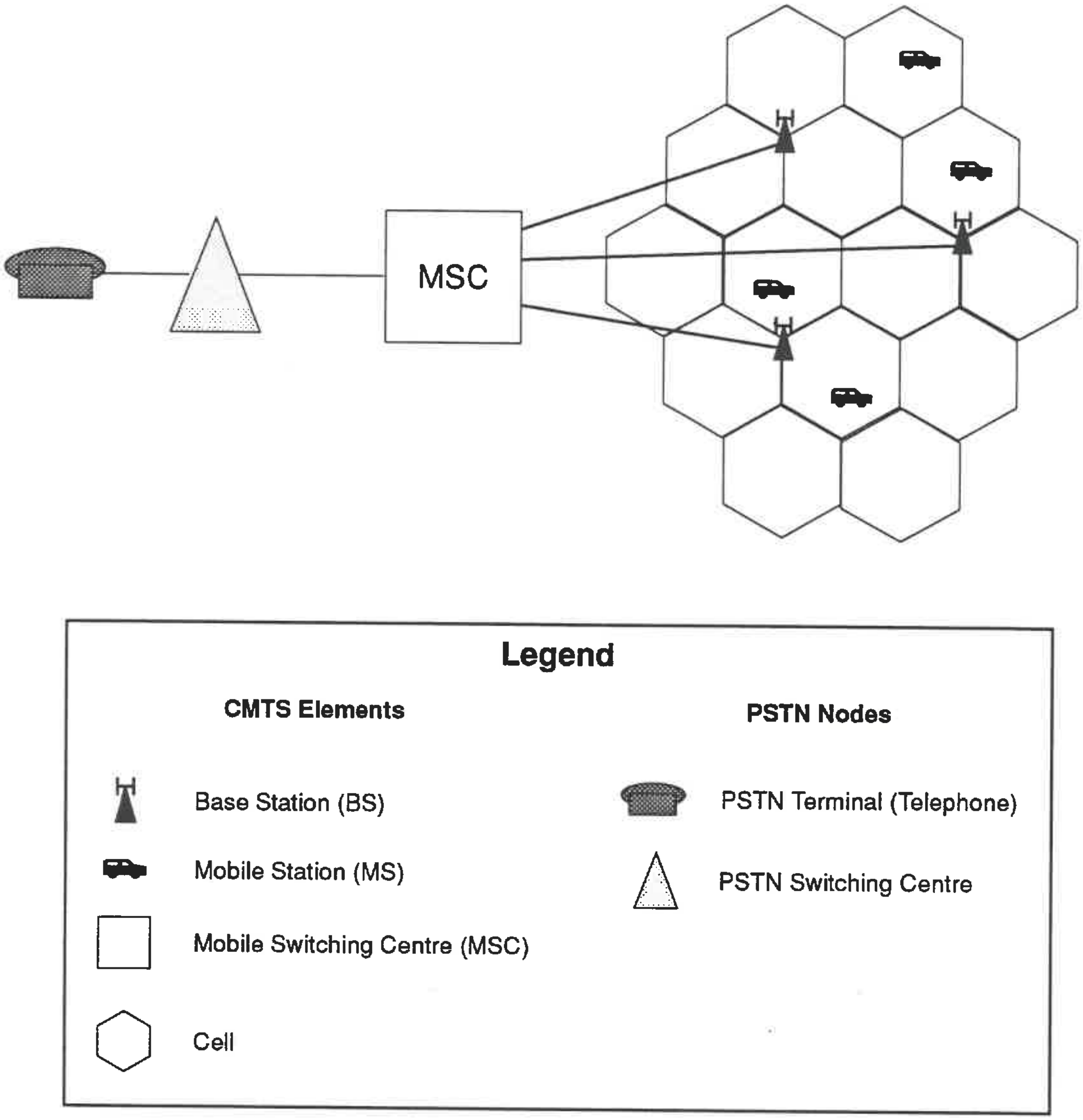
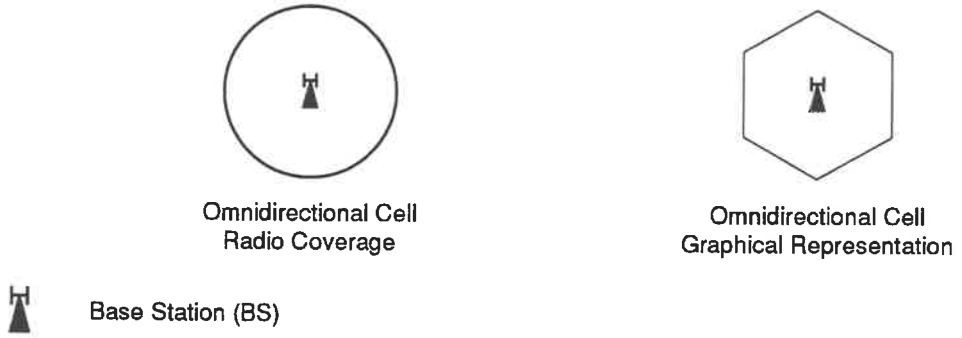


Figure 2.1. A Cellular Mobile Telephone System (CMTS)

2.2. Base Stations and Cells

The base station is able to communicate with any mobile station travelling at a sufficiently close proximity. The area covered by a BS is called a cell. The two most common types of cells are the omnidirectional cell and the sectorized cell.

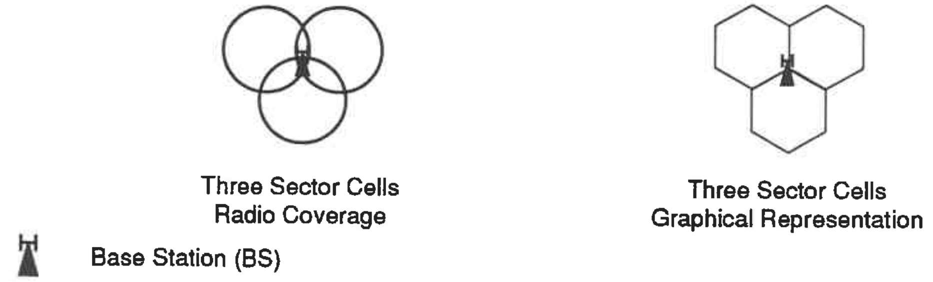
Omnidirectional cells are implemented by equipping a BS with an omnidirectional antenna transmitting equally in all directions. For cell planning purposes, omnidirectional cells are represented by hexagons. Figure 2.2. depicts these concepts.


Omnidirectional Cell
Radio Coverage

Omnidirectional Cell
Graphical Representation

Figure 2.2. Graphical Representation of an Omnidirectional Cell

Sectorized cells are implemented by equipping the BS with three directional antennas, each covering 120 degrees. In such an arrangement, some channel units are connected to one cell covering one sector cell, other channel units are connected to a second antenna, and the rest are connected to the third antenna. For cell planning purposes, sectorized cells are represented by three hexagons with the BS placed in the centre where all hexagons meet. This is shown in Figure 2.3.


Three Sector Cells
Radio Coverage

Three Sector Cells
Graphical Representation

Figure 2.3. Graphical Representation of Sectorized Cells

2.3. Location Areas

Some cellular systems allow mobile stations to move freely within an MSC service area without informing the exchange of their location. Consequently, the CMTS does not know the exact location of the mobile, and needs to page all cells in the service area when attempting to set up a call.

Other cellular systems, such as the one that we will study, offer the possibility of dividing the service area into location areas. As a mobile travels from one location area to another, it must inform the MSC of its new location. This is known as **location area registration** or **forced registration.** Location areas provide a means of controlling the outflow of page messages since a mobile would first be paged in all cells contained in the location area that it last registered rather than be paged in the entire service area.

Figure 2.4. provides an example of a location area configuration.

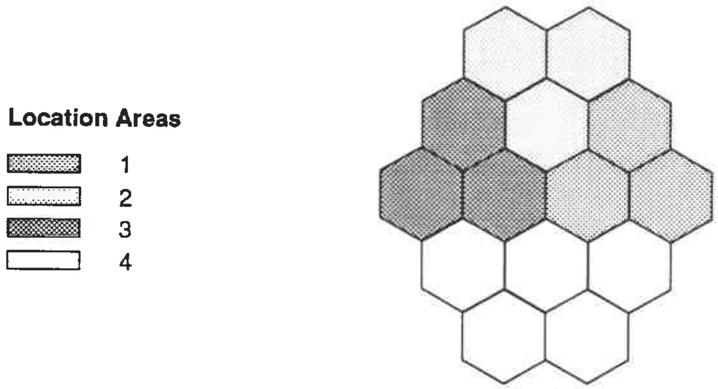


Figure 2.4. Example of a Location Area Configuration with 4 Location Areas

2.4. Radio Channels

The radio channel is a bidirectional radio transmission path between the mobile station and the base station. A channel uses separate radio frequencies, one for transmission from the mobile station and one for transmission from the base station.

Each radio channel has its channel unit in the base station. The mobile station has only one transceiver which is tuned to one radio channel at a time. However, it can automatically change channel and tune to any radio frequencies specified by the system.

All radio channels in the same cell use different frequencies. Neighbouring cells use other frequencies. This is done to prevent co-channel interference which can occur since neighbouring cells overlap each other. The same radio channels can nevertheless be re-used if the cells in which they are used are spaced far enough from each other.

A voice channel is selected and seized by the MSC during a call set-up procedure. The selected voice channel carries the conversation until the call is released or handed off to another cell in which case the channel is made available for the next call.

There is normally one control channel per cell. A base station serving an omnidirectional cell will have one control channel unit while a base station serving three sector cells will be equipped with three control channel units. The control channel is used only for data. A mobile station in a cell and not in conversation state is always tuned to the control channel of that cell, supervising the continuous data stream. The mobile station while travelling in an "idle" state from one cell to another eventually loses its radio connection on the control channel to which it is tuned and tunes to the control channel of the cell towards which it is travelling. The change of the control channel is done by automatically scanning all the control channels provided by the CMTS. When a control channel providing good reception quality is found, the mobile station tunes to this channel and remains tuned until the quality deteriorates once again. In this way, a mobile station is more or less continuously in touch with the CMTS.

2.4.1. Forward Analog Control Channel (FOCC)

The control channel in the direction from the base station is called the **Forward Analog Control Channel (FOCC)**. Pages are sent on this channel which is why it is often called the **paging** channel.

Two types of messages are issued on the FOCC; **mobile station control** messages and **overhead** messages. The content and format of these messages are detailed in [EIA92].

Mobile station control messages contain orders that are specific to a single MS. Mobile station control messages include:

the **Page** message which is a call to a mobile station;

the **Initial Voice Channel Designation** which is an order to a mobile station to switch over from the control channel to the voice channel selected for the conversation;

the **Registration Confirmation** which is sent by a base station indicating that the mobile has registered successfully.

It is important to note that only the mobile station control messages relevant to this project have been addressed here.

Overhead messages contain information and orders that allow all mobile stations to gain access and remain in touch with the CMTS. The overhead messages are:

the **System Parameter Overhead message (SPOM)** which contains system identification information required by mobile stations to properly access the CMTS;

the **Registration Identification Overhead message (REGID)** is a Global Action Overhead message which contains registration information vital to the registration process;

the **Control Filler Overhead message (CF)** which is sent whenever there is no other message to be sent on the FOCC.

Other Global Action Overhead messages are also overhead messages called out in [EIA92]. However, these were not considered in this project since 1) they are of rare occurrence and therefore do not represent a significant load when compared to the other overhead message and 2) the are not relevant to paging and registration.

2.4.2. Reverse Control Channel (RECC)

The control channel in the direction from the mobile station is called the **Reverse Analog Control Channel (RECC)**, and used by mobile stations tuned to the control channel to transmit signalling messages. This is the case, for example, when a mobile subscriber dials a number to make a call. The mobile station sends access information to the MSC via the RECC and base station which is why the RECC is often called the **access** channel.

The RECC messages relevant to this project are:

the **Page Response** message which is an answer to a call;

the **Call Origination** message which is used by a mobile station when a mobile subscriber originates a call;

the **Registration** message which is used by a mobile station to register with the CMTS.

The content and format of these messages are detailed in [EIA92].

2.5. Traffic Cases

A traffic case is a sequence of interactions carried out between the CMTS nodes (MSC, HLR, BS, and MS) during the execution of a CMTS function. A CMTS can execute a large number of traffic cases. Only those that are fundamental to the operation of a CMTS and to mobility management in particular have been addressed in this project. The traffic case that are part of this project are:

periodic overhead broadcast;

registration;

call termination (to a mobile subscriber);

call origination (from a mobile subscriber).

Figure 2.5. illustrates the concept.

2.5.1. Periodic Overhead Broadcast

Overhead messages are broadcasted periodically to allow mobile stations to gain access and remain in touch with the CMTS. The broadcast takes the form of an **Overhead Message Train (OMT)** which consists of a SPOM broadcasted approximately every second and a REGID appended to the SPOM typically every 5 seconds.

2.5.2. Registration

Registration, or location registration, is the means by which a mobile station identifies itself to a base station as being active in the system at the time the message is sent to the base station. There are two types of registrations; **periodic** and **forced.**

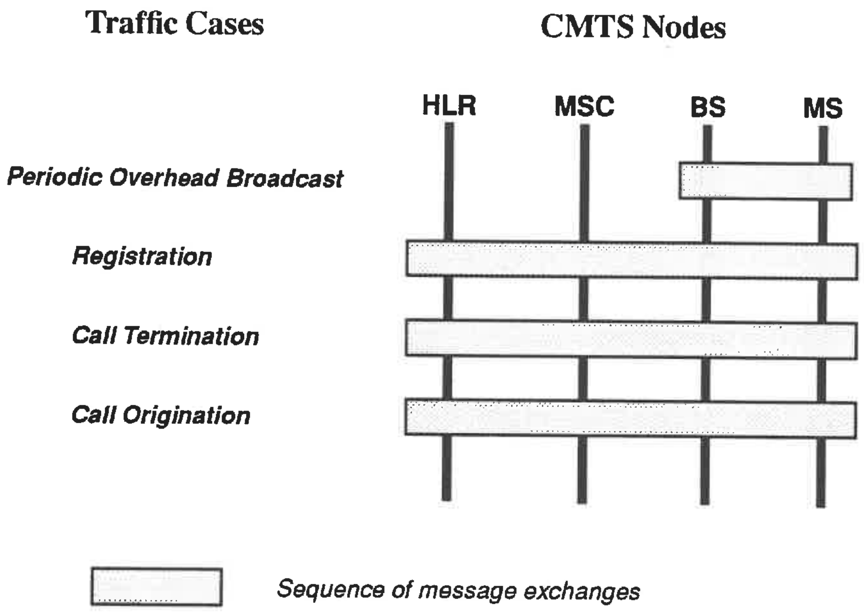


Figure 2.5. Traffic Case Concept

Periodic registration consists of mobile stations accessing the cellular system periodically to report their activity. Registration intervals are typically in the order of 10 to 20 minutes.

Forced registration requires mobile stations to report their locations whenever they cross a location area border. Smaller location areas cause a mobile station to register more often while larger location areas have the opposite effect.

Forced registration can be implemented in a number of ways. One way is to periodically issue as part of the OMT, a Location Area Global Action message. This message contains a location area identification field (LOCAID) which indicates the location area to which the transmitting base station belongs. With this approach, mobiles detect that they have crossed a location area boundary once they process the Location Area Global Action message and detect the change in the LOCAID field.

Another method is called **shifted-REGID**. It uses the same “time-to-register” algorithm as for periodic registration and requires no extra messages. The idea is to create “time zones” particular to each location area. All base stations belonging to a particular location area broadcast a REGID shifted by some time value assigned to that location area. With this approach, mobile stations that move to another location area eventually lock on to a control channel belonging to a different base station. Since that base station is transmitting REGID messages that contain a REGID value that is shifted, the mobile stations register with the CMTS. The mobile stations never know in which location area they are in. The MSC deduces the location area of a mobile station by associating the location area to which the base station belongs, to the registering mobile station.

The registration process is shown in Figure 2.6.

2.5.3. Call Termination

A call to a mobile subscriber or call termination is divided into the following phases:

first page attempt which consists in attempting to notify a mobile subscriber of an incoming call by broadcasting pages in the location area from which the called mobile last registered;

second page attempt which consists in attempting to reach the called subscriber when the MSC fails to receive a page response within the time-out period. It is carried out by broadcasting pages in all location areas. If the second page attempt fails, the call is never set up;

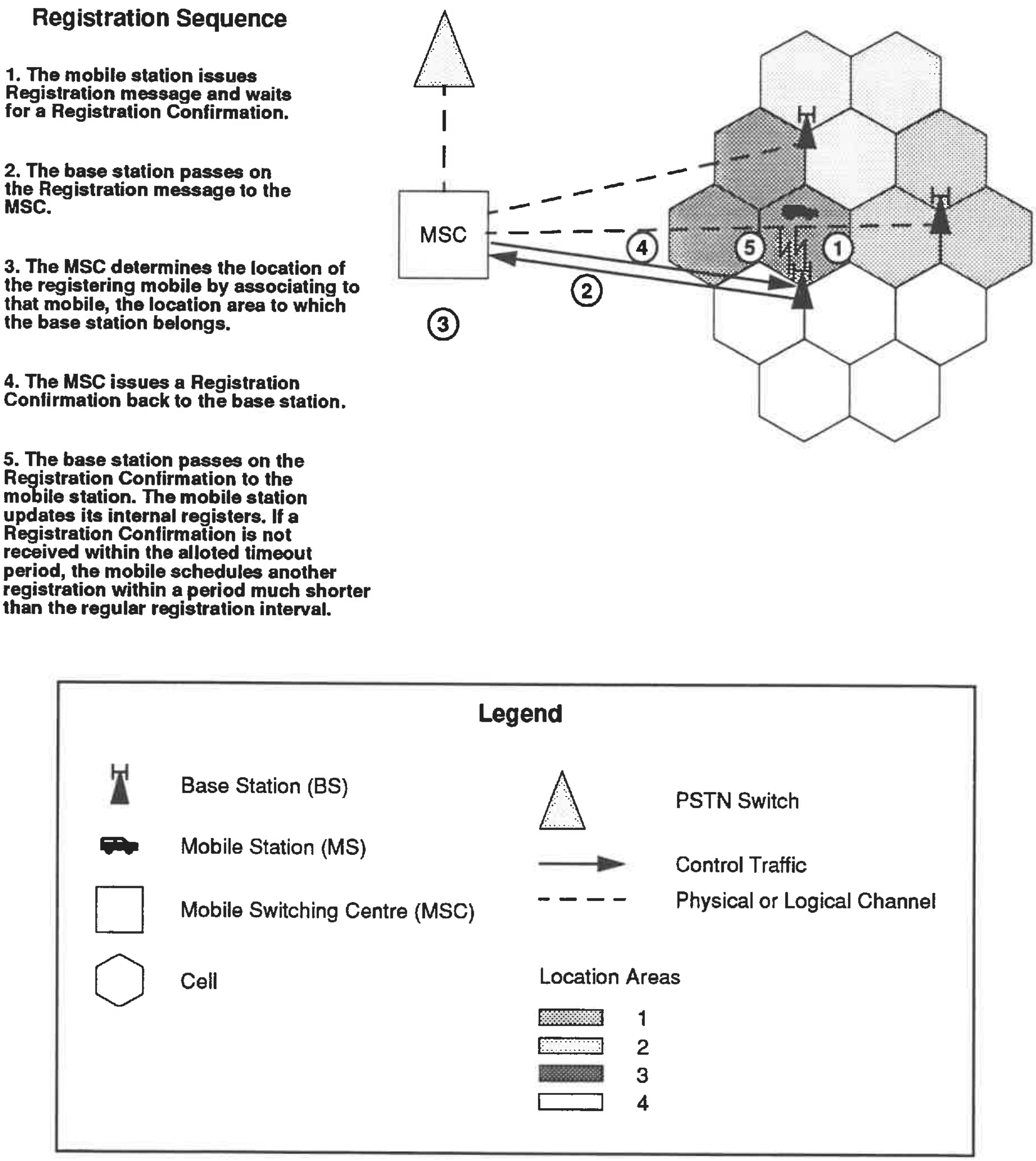
page response which consist in the mobile station acknowledging the reception of the page;

initial voice channel designation which consists in directing the called mobile station to the voice channel on which the ensuing conversation will be carried out.

Figures 2.7 to 2.10 illustrate respectively the sequences for first page attempt, second page attempt, page response, and initial voice channel designation.

2.5.4. Call Origination

Call origination is the case where a mobile subscriber attempts to initiate a call from his mobile station. The call from a mobile subscriber traffic case is illustrated in Figure 2.11.



Registration Sequence

1. The mobile station issues Registration message and waits for a Registration Confirmation.

2. The base station passes on the Registration message to the MSC.

3. The MSC determines the location of the registering mobile by associating to that mobile, the location area to which the base station belongs.

4. The MSC issues a Registration Confirmation back to the base station.

5. The base station passes on the Registration Confirmation to the mobile station. The mobile station updates its internal registers. If a Registration Confirmation is not received within the alloted timeout period, the mobile schedules another registration within a period much shorter than the regular registration interval.

Figure 2.6. Registration

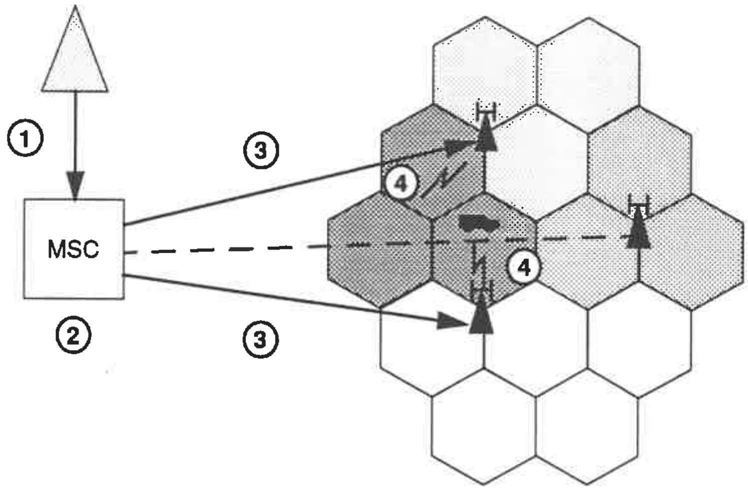
First Page Attempt Sequence

1. The MSC receives an incoming call for a mobile subscriber from the PSTN.

2. The MSC retrieve the location area of the mobile station.

3. The MSC orders the base stations associated to the location area provided by the HLR to page in their respective cell and waits for a response.

4. The base stations broadcast a Page message in their respective cell.



Legend

▲	Base Station (BS)	△	PSTN Switch
🚐	Mobile Station (MS)	→	Control Traffic
□	Mobile Switching Centre (MSC)	– – – –	Physical or Logical Channel
⬡	Cell		

Location Areas

▨	1
░	2
▓	3
□	4

Figure 2.7. First Page Attempt

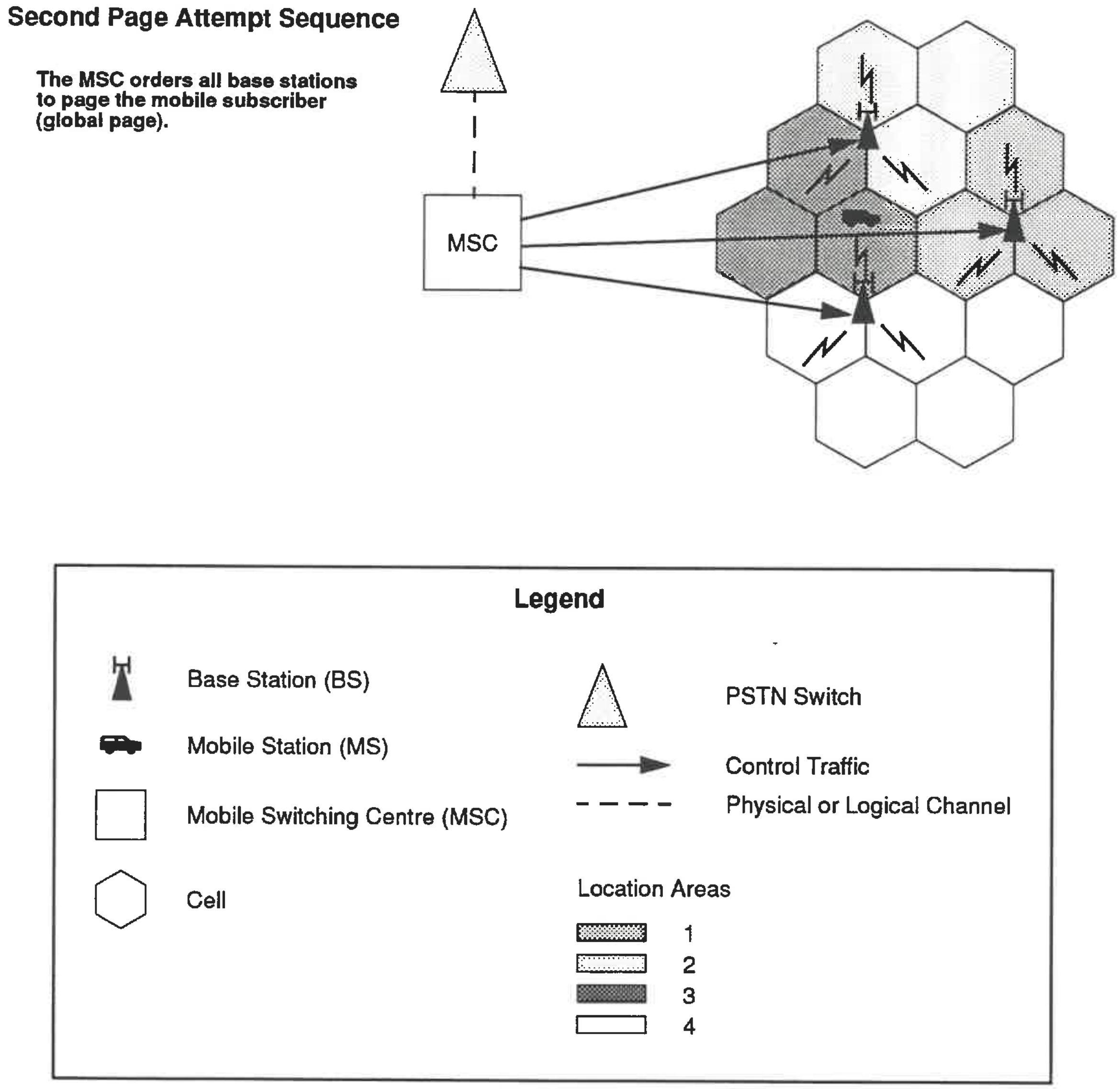


Figure 2.8. Second Page Attempt

Page Response Sequence

5. The mobile station replies to the Page message with a Page Response.

6. The base station transfers the Page Response to the MSC.

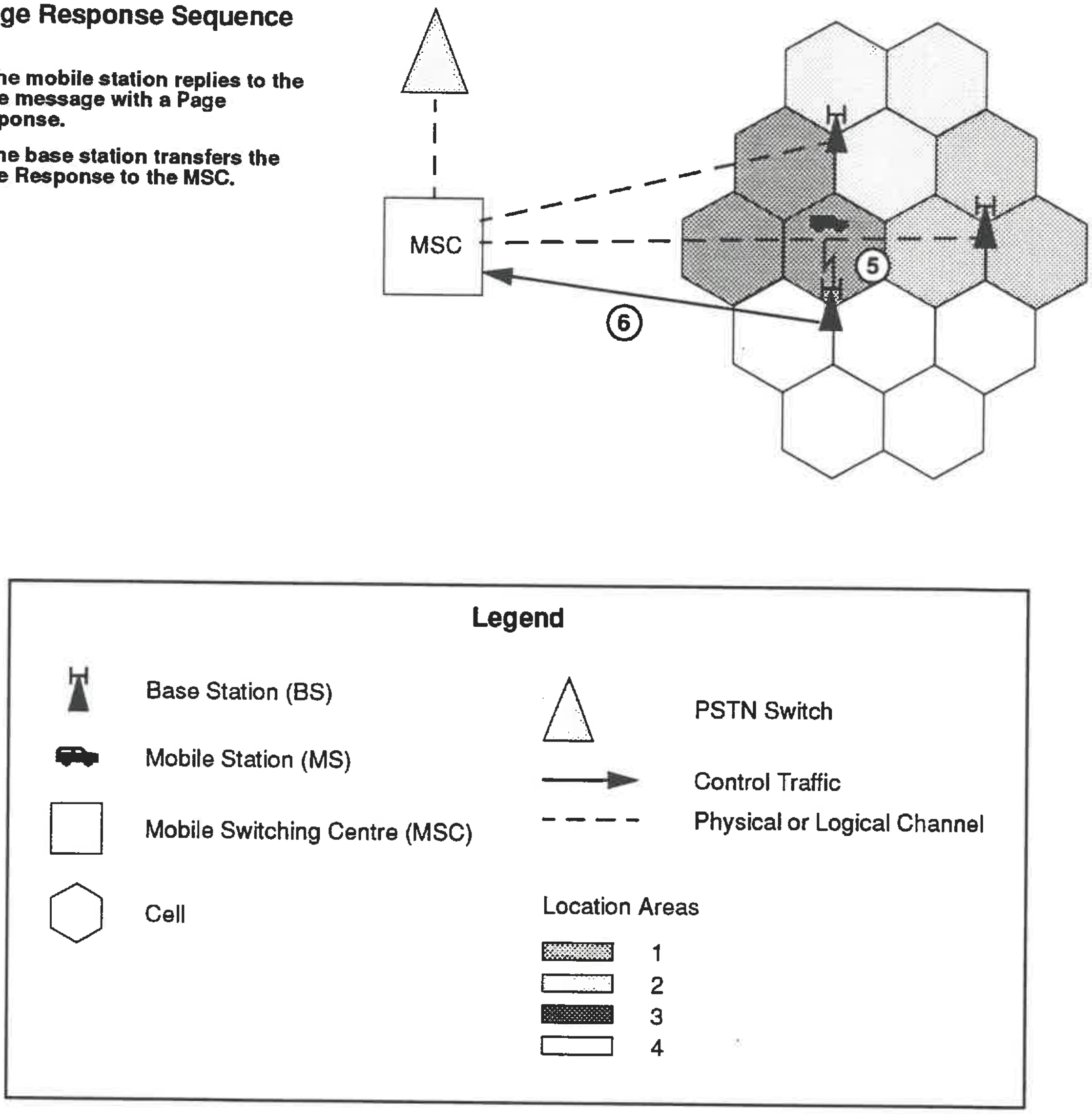
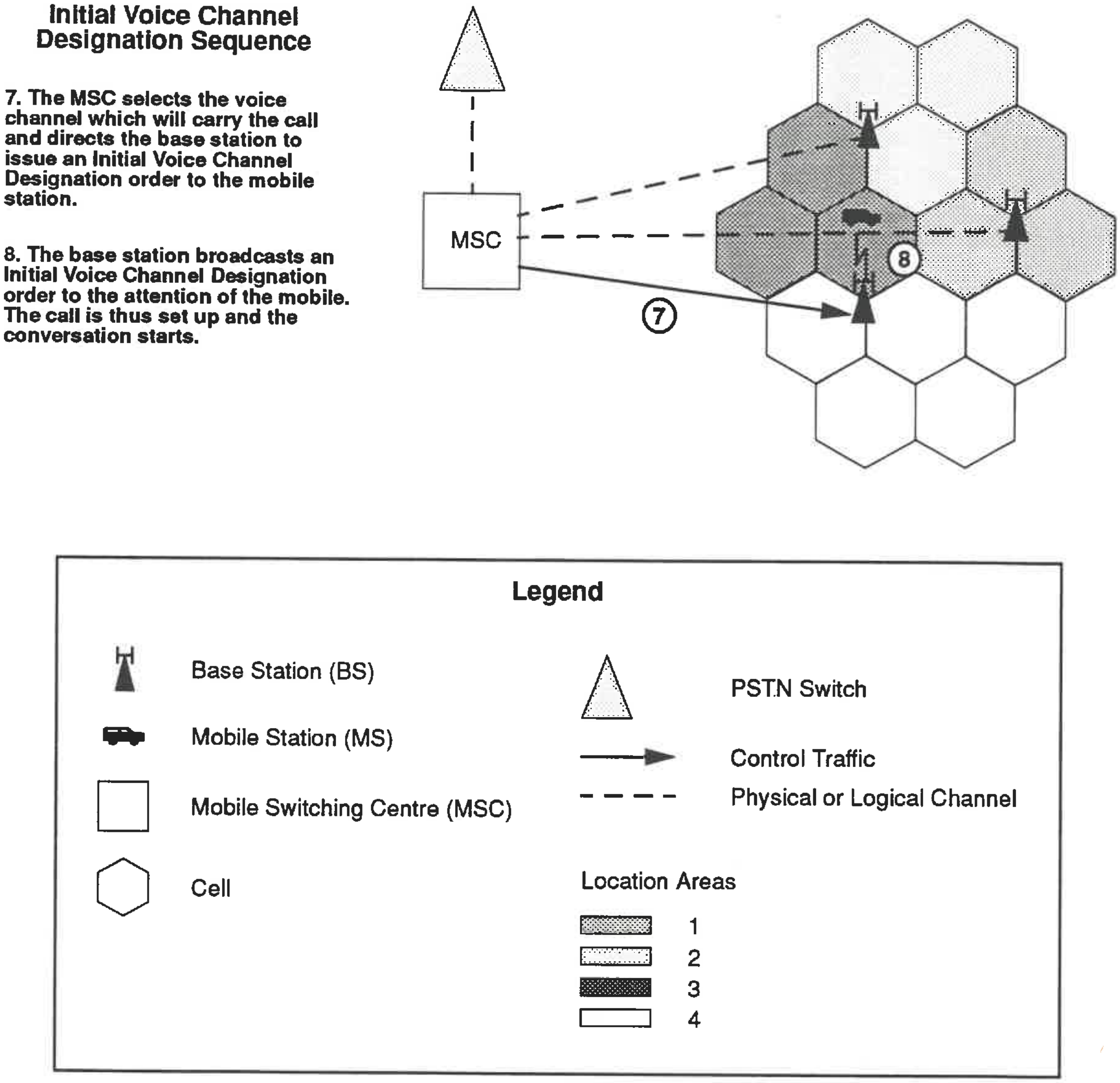


Figure 2.9. Page Response

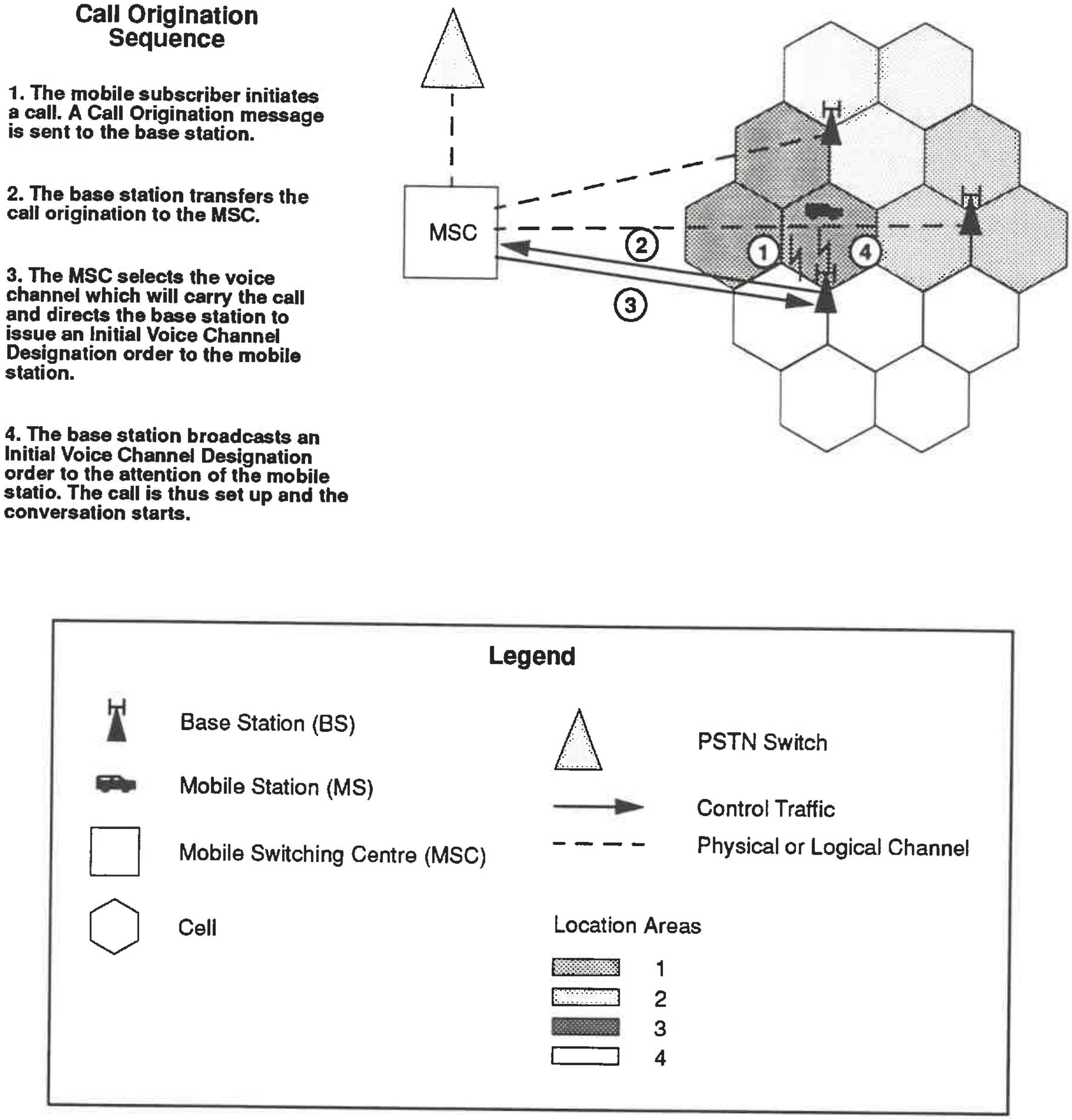


Initial Voice Channel Designation Sequence

7. The MSC selects the voice channel which will carry the call and directs the base station to issue an Initial Voice Channel Designation order to the mobile station.

8. The base station broadcasts an Initial Voice Channel Designation order to the attention of the mobile. The call is thus set up and the conversation starts.

Figure 2.10. Initial Voice Channel Designation



Call Origination Sequence

1. The mobile subscriber initiates a call. A Call Origination message is sent to the base station.

2. The base station transfers the call origination to the MSC.

3. The MSC selects the voice channel which will carry the call and directs the base station to issue an Initial Voice Channel Designation order to the mobile station.

4. The base station broadcasts an Initial Voice Channel Designation order to the attention of the mobile statio. The call is thus set up and the conversation starts.

Figure 2.11. Call Origination

CHAPTER 3

THE PAGING AND REGISTRATION SIMULATION MODEL

3.1. Simulation Model Architecture

Figure 3.1. depicts the architecture of the simulation model that was developed for this project.

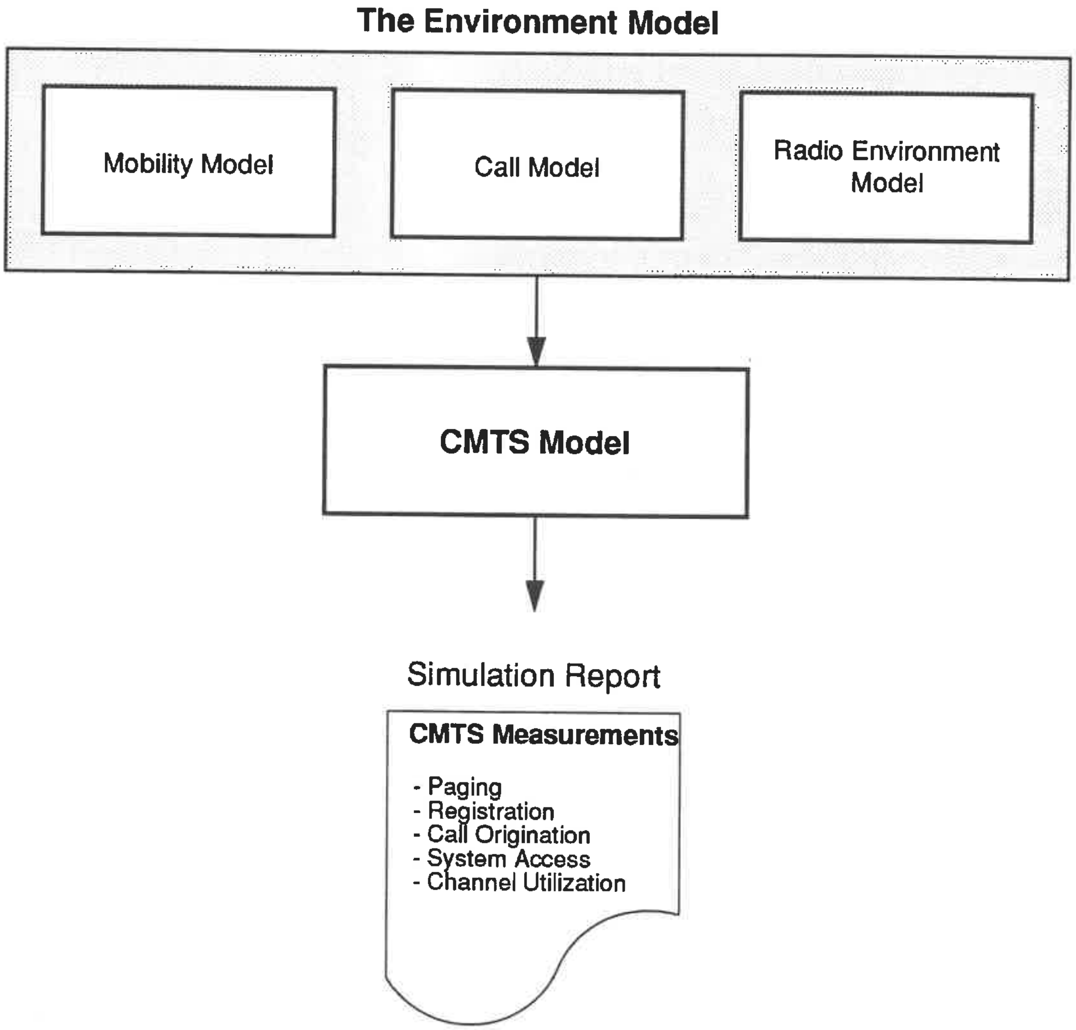


Figure 3.1. Simulation Model Architecture

The simulation model is made up of four basic components:

a **Call Model** which simulates calls to and from mobile subscribers;

a **Mobility Model** which simulates the movement of the mobile subscribers by periodically displacing them according to a set of mobility rules;

a **Radio Environment Model** which simulates propagation loss incurred during radio transmissions between base stations and mobile stations;

a **CMTS Model** which simulates periodic overhead broadcast, registration, call termination, and call origination. The CMTS model is based on the call processing specification described in the EIA/TIA Interim Standard, Cellular System Dual-Mode Mobile Station-Base Station Compatibility Standard, IS-54-B, April 1992 [EIA92].

The Call Model, Radio Environment Model, and Mobility Model are external to the CMTS Model and essentially comprise the environment within which the CMTS is required to operate.

A simulation report is generated after every simulation. It contains a series of measurements that will provide insight into the behaviour of a CMTS configured in a certain manner and operating under various external conditions. These measurements are defined later when the CMTS Model is described.

3.2. The Call Model

The Call Model consists of two call generators which simulate calls to and from mobile subscribers. Both call generators are based on the M/M/1 queuing model with an infinite waiting room [HAY86]. In this case, calls arrive according to a Poisson distribution. The exponential function is related to the Poisson function in that, if the number of arrivals in a given unit of time are Poisson distributed, the interarrival times are exponentially distributed.

$\overline{T}_t$ represents the mean time between calls to mobile subscribers and $\overline{T}_o$ represent the mean time between calls from mobile subscribers. Call duration, $\overline{D}_C$, is the same for calls from or to mobile subscribers and is also specified in the input file.

The operation of the Call model is as follows:

For call origination, mobile stations are selected according to a uniform distribution. The state of the selected mobile station is then checked to ensure that it is not already being paged or in conversation. If the selected mobile station meets these conditions, the Call Model injects the call into the CMTS Model. If the mobile station is not in the desired state, another selection is made immediately. This goes on until a mobile station with the desired state is found.

For call termination, mobile stations are also selected according to the same uniform distribution as for call origination. Once selected, the state of the mobile station is checked to ensure that the mobile station idle and is thus capable, from the MSC's perspective, to receive a call. This also goes on, as in the case of call origination, until a mobile station that meets the desired criteria is found.

Figure 3.2. illustrates the Call Model and its relationship with the CMTS Model.

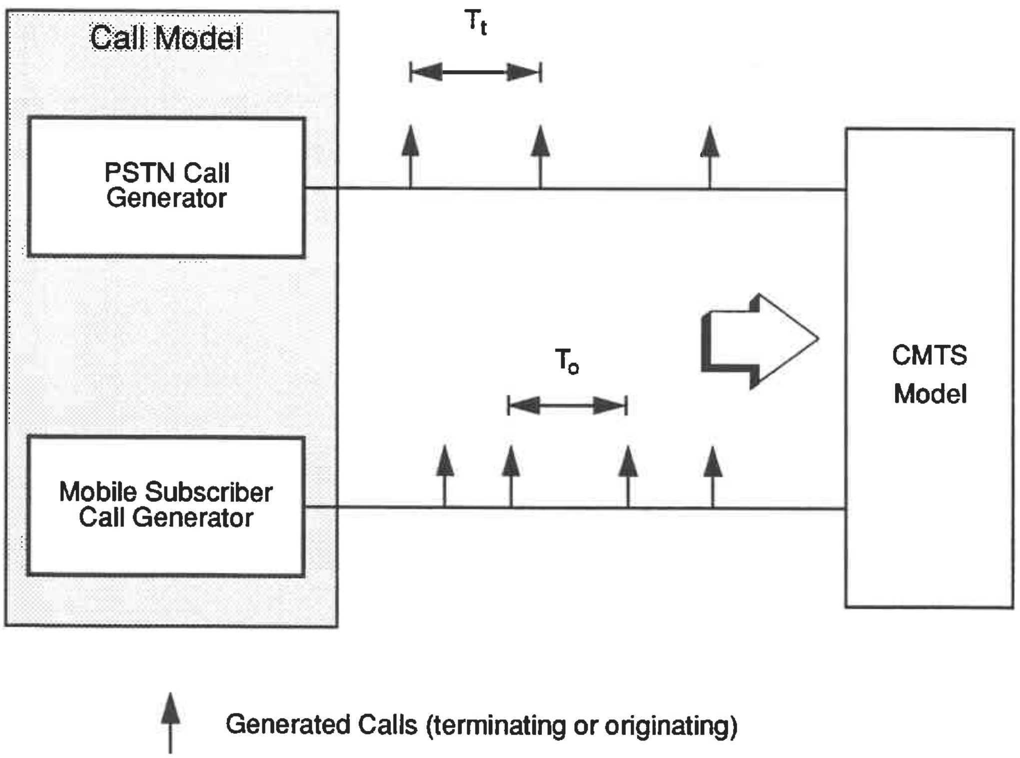


Figure 3.2. The Call Model

3.3. The Radio Environment Model

The Radio Environment Model that has been developed focuses mainly on radio propagation. It does not address such radio related phenomena as interference and Rayleigh fading. Modelling such phenomena was seen as being outside the scope of this project.

The Radio Environment Model consists essentially in generating a series of signal strength vectors mapped onto a spatial reference system used specifically for the radio environment. The radio environment spatial reference system consists of signal strength bins whose size can be altered in the input file. For each bin, a signal strength vector containing the signal strength contribution of all base stations is computed prior to the start of the simulation. As mobiles move across the service area, the bin position of the mobile is recalculated after each movement. The signal strength vector at a bin is read whenever the mobile station executes a control channel scan. This means that the mobile will not notice that there is a stronger signal that it can lock on to until it actually performs a rescan. Control channel scanning is discussed in further detail later on when the CMTS Model is described.

Figure 3.3. illustrates the concept of signal strength vectors which are calculated as follows:

$$P_{r\,i,j,k} = P_{t\,k} - (L_{p\,i,j,k} + L_{a\,k}) \tag{3.1}$$

where

i = *bin x coordinate*

j = *bin y coordinate*

k = *base station number*

$P_{t\,k}$ = *the effective radiated power of base station k*

$L_{p\,i,j,k}$ = *propagation loss between bin i,j and base station k*

$L_{a\,k}$ = *antenna pattern loss of base station k*

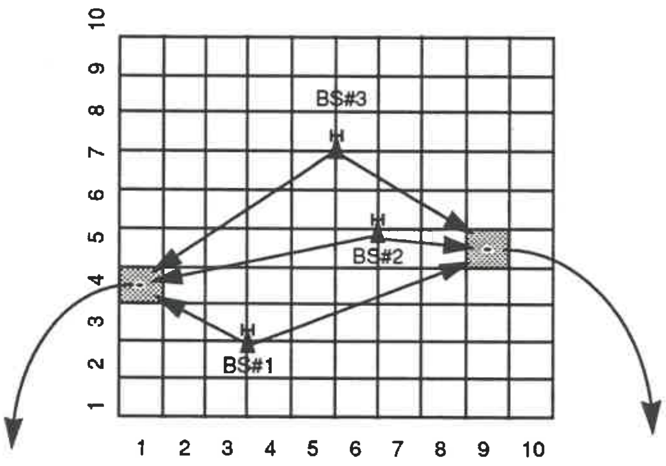
$P_{r\,i,j,k}$ = *the signal strength contributed by base station k at bin i,j*

The mathematical models used for to compute L_p and L_a are described in the following sections.

3.3.1. Radio Propagation Loss Predictions

Predicting transmission loss in a cellular system involves serious difficulties, mainly because of the movement of the mobile station and the low antenna position at the mobile. This leads to a constantly changing terrain profile of the transmission path and the mobile station will in most positions receive several reflected signals.

A fairly basic propagation model based on the works of two Japanese engineers, Okumura and Hata (summarized in [GUS91]), was used to create a basic radio environment. Hata developed in 1980, a number of empirical formulas based on Okumura's earlier research in 1968, which consisted in assembling empirical data from a series of comprehensive radio wave measurements and mapping them onto a series of diagrams.



P_r Vector for Bin 1, 4

$P_r^{(1)}$	k
-50 dBm	1
-75 dBm	2
-75 dBm	3

P_r Vector for Bin 9, 5

$P_r^{(1)}$	k
-100 dBm	1
-50 dBm	2
-75 dBm	3

(1) Note: The P_r values shown are meant as examples only. They are not the result of any calculation.

Figure 3.3. Example of Signal Strength Vectors

The basic formula presented by Hata and used in this project is as follows:

$$L_p = 69.55 + 26.16\log f - 13.82\log h + (44.9 - 6.55\log h)\log d \qquad (3.2)$$

where

L_p = *propagation loss in dB*

f = *carrier frequency in Mhz*

h = *base station antenna height in meters*

d = *distance from base station in km*

Applying the bin structure to the Okumura-Hata formula gives:

$$L_{p\ i,j,k} = 69.55 + 26.16\log f - 13.82\log h + (44.9 - 6.55\log h)\log d_{i,j,k} \qquad (3.3)$$

where

$d_{i,j,k}$ = *distance between the centre of bin i,j and base station k*

$d_{i,j,k}$ is expressed as follows:

$$d_{i,j,k} = ((x_k - x_{i,j})^2 + (y_k - y_{i,j})^2)^{1/2} \qquad (3.4)$$

where

x_k = *x coordinate of base station k*

y_k = *y coordinate of base station k*

$x_{i,j}$ = *x coordinate of bin i,j*

$y_{i,j}$ = *y coordinate of bin i,j*

Figure 3.4. illustrates these distances.

3.3.2. Antenna Pattern Loss Predictions

The antenna pattern loss L_a varies with ***phi*** which is the angle difference between the pointing azimuth, a, of the base station antenna and the vector traced between the base station position to the center of the bin for which P_r is to be calculated. This is shown in Figure 3.5. The modelled antenna pattern was based on a typical sectorized antenna specification. The antenna pattern losses in this reference were averaged out to show only four discrete losses. The half power beamwidth (***HPBW***) was considered to be 120 degrees.

The antenna pattern that was used is defined in Table 3.1 and illustrated in Figure 3.6. A single antenna pattern was used for all base stations.

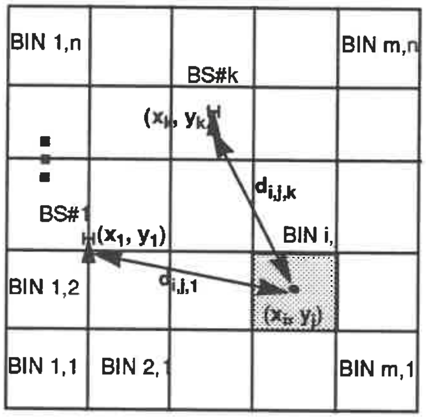


Figure 3.4. Distance Calculations

Table 3.1 Antenna Pattern Losses

L_a (dBm)	**Phi**
0	$300^\circ < phi < 60^\circ$
-7.5	$270^\circ < phi < 300^\circ$ and $60^\circ < phi < 90^\circ$
-15	$225^\circ < phi < 270^\circ$ and $90^\circ < phi < 135^\circ$
-30	$225^\circ < phi < 135^\circ$

3.3.3. Balance Formula

Coverage in a two-way radio communication system is decided by the weakest transmission direction. Up-link and down-link signify communication from a mobile station to a base station and from a base station to a mobile station respectively. The two transmission directions should be balanced to each other in order to avoid interference, reduced system access or extra costs.

It has been assumed that the two transmission directions are balanced. In essence this means that if the strength of the down-link signal transmitted by a base station is strong enough for a mobile station to decode the message it is carrying, the strength of the up-link signal transmitted by the same mobile station will be strong enough for the base station to decode the message it is carrying. This is the typical way a cellular operator sets up its cellular system.

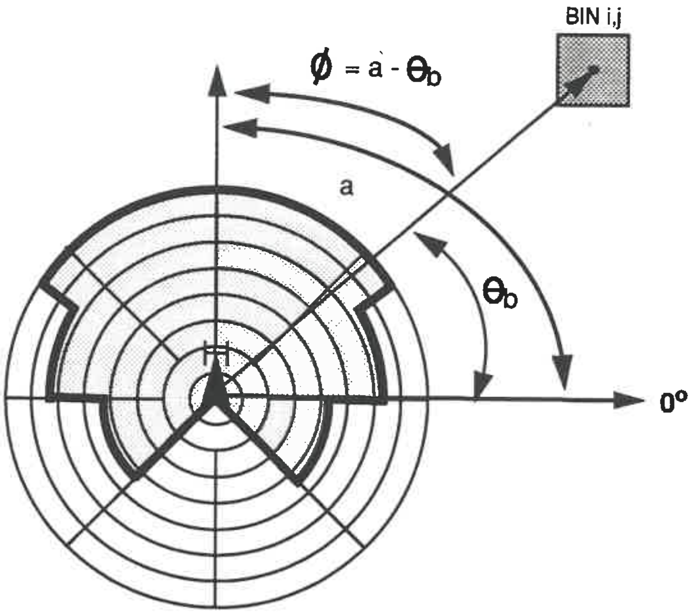


Figure 3.5. Antenna Pattern Loss as a Function of ***phi***

3.3.4. Cell Plan

To complete the radio environment, it was necessary to design a cell plan which would be used as a basis for all experiments. Since we wanted to study the sensitivity of movements on the CMTS given a location area configuration, we selected a cell radius ***r*** of 500 meters which is relatively small given today's reality. The area that was studied comprised 60 sectorized cells all of which having r = 500 meters.

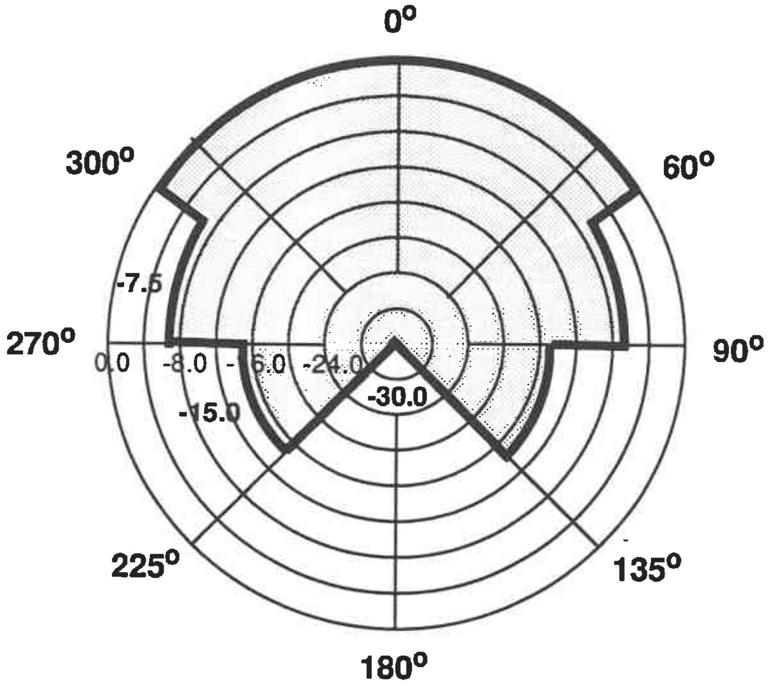


Figure 3.6. Antenna Pattern for a Sectorized Cell

The service area dimensions and the position of the base stations were calculated from r and then entered in the input file. Figure 3.7. shows the service area dimensions and the base station positions as a function of r. These relationships were determined through simple geometric construction. In order to create an environment where all cells had equal radius, the base stations were placed at equal distances from each other. The distance used was $3r$ which is the theoretical separation distance required between base stations according to cell planning principles [GUS91].

Since the radio environment model does not support an hexagonal view of a cell, it was necessary to determine a P_t which would be consistent with the cell radius r and the calculated base station positions. A common P_t of 40 dBm was used to support this 60-cell configuration. It was noted that a P_t of 40 dBm is high for a cell radius of 500m. However, all values that have been selected for the model were calculated using the Okumura-Hata empirical model and are therefore consistent with each other. It was not the intent of this project to study in any great detail radio propagation as this is a very specialized field of its own. It was sufficient to create an environment which would cause the mobile stations to rescan based on the strength of the radio signal received. By deriving our values from the Okumura-Hata model, it did not matter how the signal strength received by a mobile station was calculated, whether it was with a high antenna height and low power transmitted or with a low antenna height and high power trasmitted. The resulting cell plan was all that mattered.

It is important to note that every base station that is shown actually represents three base stations. Thus, there is one base station per cell. The pointing azimuth for each base station was either 90°, 210°, or 330°. Table 3.2 shows the base station data that was used for all experiments. The actual cell plan data that was used is provided in the Experiments and Results chapter.

The following sequence outlines the steps that were executed to design our cell plan configuration:

1) Assume that $r = 500$m since mobility would potentially have greater impact on CMTS performance with smaller cells.

2) Since the radio environment is not hexagonal by nature, the radio model parameters must be set in a way which is consistent to some extent with the hexagonal view of the cell plan. Assume that at $2r = 1$km, $P_r = -110$ dBm and assume that $P_t = 40$ dBm.

3) Calculate h using Okumura-Hata for the conditions above. ($h = 4$m as a result)

4) Position the base stations apart by a distance of $3r$ as shown in Figure 3.7.

5) Calculate P_r at $d = 3r/2$. $P_r = -93$ dBm as a result. This would correspond approximately to the signal strength received by a mobile station at the boundary of two cells.

6) Construct a cell plan using hexagons with $r = 500$m and $N_c = N_{bs} = 60$. The decision to use 60 was based on the need to have a great enough quantity so some trends may be observed. The need for a symmetric layout was also an important criterion since the movement of mobiles followed a random pattern.

7) Calculate service area width w_{sa} and depth d_{sa} using geometrical construction. (w_{sa} = 6062 m and d_{sa} = 6250 m as a result.) This is shown in Figure 3.7.

8) All values specified in the above sequence are then entered in the input file under the approriate header.

Table 3.2 Common Base Station Data

P_t	40 dBm
f	850 Mhz
HPBW	120°
h	4 meters

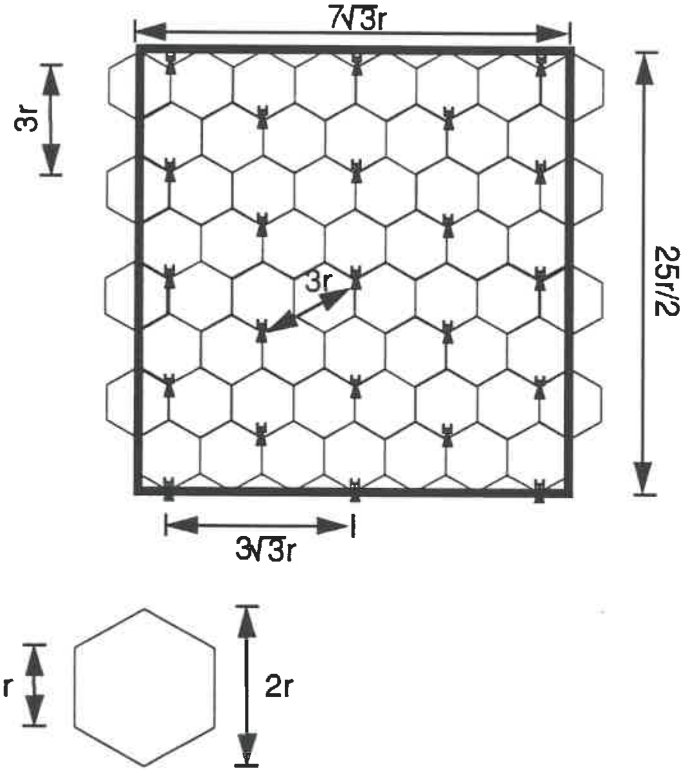


Figure 3.7. Cell Plan

3.4. The Mobility Model

The Mobility Model simulates the displacement of mobiles throughout the simulation. It periodically displaces all mobiles according to a pre-defined displacement rate and manages their physical location as opposed to their location as viewed by the CMTS i.e. location areas.

The displacement algorithm that was implemented is as follows:

1) At initialization, an initial position, in cartesian coordinates, is randomly selected within the service area for each mobile.
2) An initial speed ***s*** is selected according to a normal distribution with mean $\bar{s}$ and a standard deviation ***sigma***.
3) An initial direction ***theta*** is selected randomly between 0^o and 359^o.
4) At the end of each displacement period, each mobile position is updated using the previous x-y position, speed ***s***, and direction ***theta***. The formulas that were used follows immediately after this sequence.
5) The new x-y position of each mobile is then converted to radio environment spatial coordinates i.e. they are converted to bins. This conversion provides the tie-in between the radio environment, the physical location of a mobile, and the control channel scanning process executed by the mobile.
6) A new speed is selected according to the same rules specified earlier in the sequence.
7) A direction variation is selected according to the uniform distribution shown in Figure 3.8. A new direction is calculated using the old direction and the selected direction variation.
8) Steps 4 through 7 are repeated until the expiration of the simulation period.

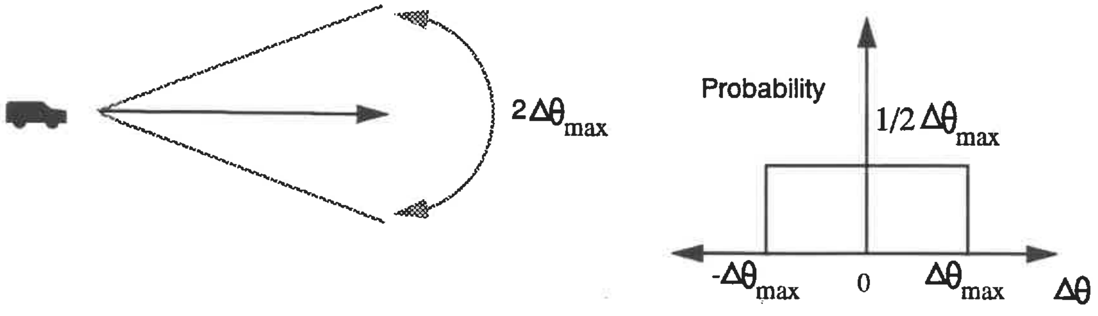


Figure 3.8. Direction Variation of Mobiles

Displacement Formulas

$$dx = sT_d / (1+tan^2(theta)^{1/2} \tag{3.5}$$

$$x_{new} = x_{old} - dx \qquad \text{for } pi/2<theta<3pi/2 \tag{3.6}$$

$$x_{new} = x_{old} + dx \qquad \text{for } 3pi/2<theta<pi/2 \tag{3.7}$$

$$y_{new} = y_{old} + tan(theta)(x_{new} - x_{old}) \tag{3.8}$$

where

dx = *displacement along x-axis*

s = *speed of mobile*

T_d = *displacement period*

$theta$ = *direction of mobile*

x_{new} = *new x-position*

x_{old} = *old x-position*

y_{new} = *new y-position*

y_{old} = *old y-position*

During the simulation, mobiles may move outside the area under study. To deal with this, the mobility algorithm has been designed to change a mobile's direction by 180 degrees when it detects that a mobile has reached the outer boundaries of the area. In effect, this assumes that for each mobile subscriber leaving the area there is another one that enters it.

3.5. The CMTS Model

The purpose of the CMTS model is to simulate the previously described traffic cases namely periodic overhead broadcast, call termination, call origination, and registration. The CMTS model focused mainly on the communication that goes on between the mobile station and the base station during these traffic cases. It was modelled according to the call processing and signalling specification of the IS-54B standard [EIA92]. This compatibility standard contains the technical requirements for cellular mobile telecommunications systems in North America. Its purpose is to ensure that a mobile station can obtain service in any cellular system manufactured according to this standard. Communication between the MSC and the base stations was not modelled according to any standard.

The CMTS model focuses mainly on the transmission of messages between an MSC and mobile stations (via the base stations) during paging and registration and their behaviour during these processes. The vital aspects of the IS-54B specification have been translated into state transition diagrams. This was done to help ensure that all those involved in the project had a common understanding of the operation of the mobile station thereby ensuring a more thorough validation of the CMTS Model.

Two operational views have been provided. One depicts the operation of a mobile station while the other shows the operation of the MSC as it monitors the state of a mobile station during the registration and paging process. These views along with the assumptions that have been made are described in the following sections. Provided also in the next sections are the types of measurements that have been modelled and a description of the simulation model's implementation.

3.5.1. Call Processing Assumptions

IS-54 is a compatibility standard which specifies the interface between dual-mode mobile stations and base stations. It contains a great amount of detail since manufacturers use it as a basis for their mobile station and base station designs. However, not all the information in this standard is relevant to this study. Since this project focuses on the paging and registration processes, only the parts dealing with call processing and signalling have been considered. Aspects such as signal processing are beyond the scope of this project. Additionally, within call processing it was necessary to assume various conditions to further narrow the scope of the project. The following call processing assumptions with respect to the IS-54B specification have been made in this study:

1) mobile stations are all in the idle state at the start of the simulation;
2) voice channel activity during a call is not considered, more specifically handoffs have not been modelled;
3) forced registration is based on the shifted-REGID method;
4) the serving-system is always the preferred system;
5) autonomous registration is enabled;
6) the number of paging channels is identical to the number of dedicated control channels in the primary set;
7) the access and paging functions are combined on the same set of analog control channels;
8) the number of access channels is equal to the number of paging channels;
9) all location areas are within the same system area;
10) there are no roamers;
11) extended addressing is used;
12) the authentication procedure is not supported;
13) mobile stations will not power up nor power down during the simulation;
14) mobile stations will read a Control-Filler message before accessing the system on the RECC;
15) the DCC field or the control-filler message is always received within the time allowed;
16) mobile stations will wait for an Overhead Message Train before accessing the system on a reverse analog control channel;
17) mobile stations will not check for an idle-to-busy transition on a reverse analog control channel when accessing the system;
18) voice channel activity has not been modelled;
19) Page, Page Response, Registration, Registration Confirmation, Origination, Initial Voice Channel Designation, SPOM, and REGID are the only IS-54B messages that have been modelled.

3.5.2. Mobile Station Registers

The state of a mobile station during its operation is maintained in a series of internal registers. The registers that pertain to the paging and registration process have been defined here.

NXTREG$_{sp}$: Identifies when a mobile station must make its next registration to a system.

REGID$_s$: The stored value of the last registration number (REGID$_r$) received on a forward analog control channel.

REGINCR$_s$: Identifies increments between registrations by a mobile station.

MAXSZTR$_s$: The maximum number of seizure attempts allowed on a reverse analog control channel.

MAXBUSY$_{sl}$: The maximum number of busy occurrences allowed on a reverse analog control channel.

NBUSY$_{sv}$: The number of times a mobile station attempts to seize a reverse analog control channel and finds the reverse control channel busy.

NSZTR$_{sv}$: The number of times a mobile station attempts to seize a reverse analog control channel and fails.

RCF$_s$: Identifies whether the mobile must read a Control-Filler Message before accessing a system on a reverse analog control channel. The number of times a mobile station attempts to seize a reverse analog control channel and finds the reverse control channel busy.

WFOM$_s$: Identifies whether a mobile station must wait for an Overhead Message Train before accessing a system on a reverse analog control channel.

BIS$_s$: Identifies whether a mobile station must check for an idle-to-busy transition on a reverse analog control channel when accessing a system.

3.5.3. Mobile Station Operation

Figure 3.9. depicts the operation of a mobile station. The diagram is described in the following paragraphs. The ***Attempting System Access*** and ***Initializing*** states are further detailed later in this section.

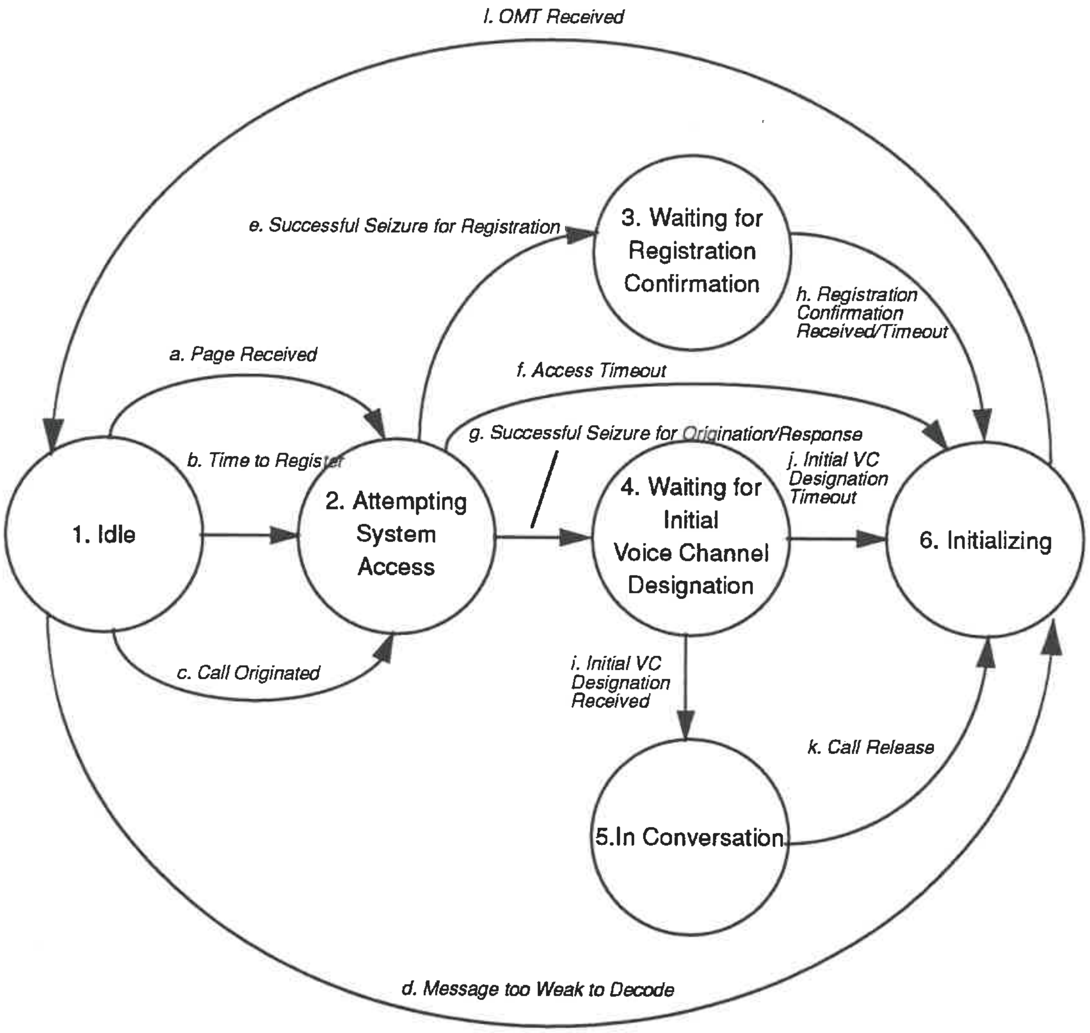


Figure 3.9. Mobile Station State Transition Diagram

State 1 - Idle

During its ***Idle*** period, the mobile station continuously processes OMT messages broadcasted periodically by the base stations.

The mobile station leaves the ***Idle*** state and enters the ***Attempting System Access*** state in the following circumstances:

when it receives a page message (***event a-Page Received***);

when it detects that it is time to register (***event b-Time to Register***);

when the mobile subscriber originates a call (***event c-Call Originated***);

The mobile station leaves the ***Idle*** state and enters the ***Initializing*** state in the when the broadcasted OMT cannot be decoded successfully (***event d-Message too Weak to Decode***).

State 2 - Attempting System Access

In the ***Attempting System Access*** state, the mobile station attempts to seize the access channel. If the mobile station successfully seizes the access channel, it has the following options:

it enters the ***Waiting for Registration Confirmation*** state if a Registration message was issued (***event e-Successful Seizure for Registration***);

it enters the ***Waiting for Initial Voice Channel Designation*** state if either a Call Origination or a Page Response was issued (***event g-Successful Seizure for Origination/ Response***); or

it enters the ***Initializing*** state if the mobile station fails to seize the access channel after a predetermined maximum number of attempts (***event f-Access Timeout***).

State 3 - Waiting for Registration Confirmation

During this state, the mobile station waits for a Registration Confirmation message from the base station. The mobile station leaves the ***Waiting for Registration***

Confirmation state to enter the ***Initializing*** state (***event h-Registration Confirmation Received/Timeout***) under the following conditions:

the Registration Confirmation message is received before the expiration of the timeout period upon which the mobile sets its internal register NXTREG_{sp} equal to $\mathrm{REGID}_s + \mathrm{REGINCR}_s$;

the Registration Confirmation message is not received before the expiration of the timeout period.

In both of these cases, the mobile determines whether the serving-system is the preferred-system. The only difference is that if the mobile station fails to receive a Registration Confirmation message before the timeout period expires, it will not wait the usual registration interval before attempting to register again. Instead, it will attempt to register again within a few seconds following initialization.

State 4 - Waiting for Initial Voice Channel Designation

During this state, the mobile station waits for an Initial Voice Channel Designation message from the base station. The mobile station leaves the ***Waiting for Initial Voice Channel Designation*** state and enters:

the ***In Conversation*** state if it receives the Initial Voice Channel Designation message before the timeout period expires (***event i-Initial VC Designation Received***); or

the ***Initializing*** state if it fails to receive the Initial Voice Channel Designation message before the timeout period expires (***event j-Initial VC Designation Timeout***).

State 5 - In Conversation

During this state, the mobile subscriber carries on a conversation. The mobile station leaves the ***In Conversation*** state and enters the ***Initializing*** state when the call is ended (***event k-Call Release***).

State 6 - Initializing

The mobile station performs an initializing sequence during this state. It enters the ***Idle*** state upon the receipt of an OMT message which completes the sequence (***event l-OMT Received***).

3.5.3.1. Attempting System Access

The state transitions experienced by a mobile station during system access is shown in Figure 3.9.

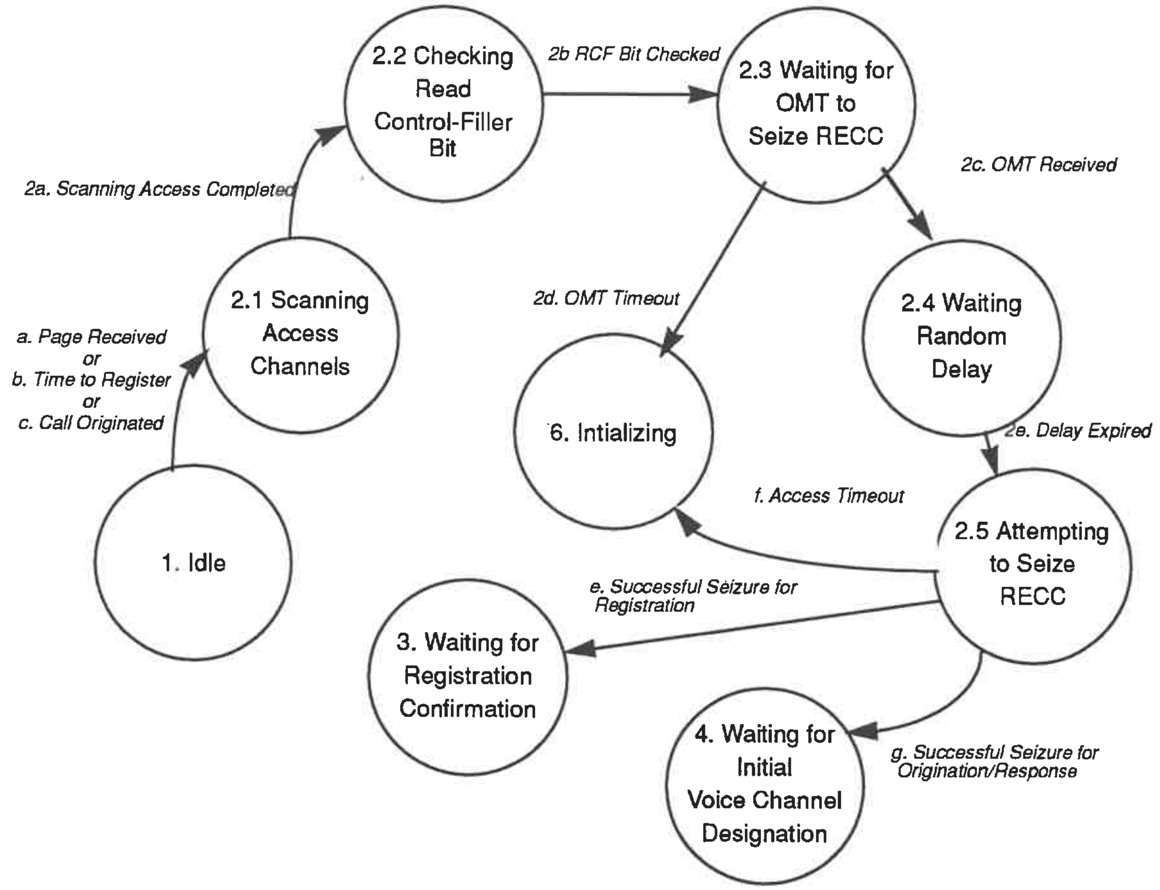


Figure 3.10. Mobile Station State Transition during Attempting System Access

A mobile station can only access the system from the ***Idle*** state. As described previously, it will attempt to access the system in the following circumstances:

when it has received a page (***event a-Page Received***); or

when it has detected that it is time to register (***event b-Time to Register***); or

when it is originating a call (***event c-Call Originated***).

State 2.1 - Scanning Access Channel

At the beginning of the system access, the mobile station sets an access timer as follows:

- to 12 seconds for an originating call;
- to 6 seconds for a page response;
- to 6 seconds for a registration.

The mobile station then enters the ***Scanning Access Channels*** state where it scans the access channels and chooses the two channels with the strongest signals. The time required to scan the access channels, D_s, has been modelled as a normal distribution. The model for scanning access channels is identical to the one for scanning paging channels. i.e. a normal distribution having the same mean and same standard deviation. Upon completing the scan (***event 2a-Scanning Access Completed***), the mobile station enters the ***Checking Read Control-Filler Bit*** state.

State 2.2 - Checking Read Control-Filler Bit

During this state, the mobile station tunes to the strongest access channel and proceeds to retrieve the access attempt parameters. The mobile station then sets the maximum-number-of-seizure-attempts allowed ($\mathrm{MAXSZTR}_s$) to a maximum of 10, and the maximum-number-of-busy-occurrences ($\mathrm{MAXBUSY}_{sl}$) to a maximum of 10. It then initializes to zero the number-of-busy-occurrences (NBUSY_{sv}) and number-of-unsuccessful-seizure-attempts (NSZTR_{sv}). The mobile station examines the read control-filler bit (RCF_s). For the purpose of this study, RCF_s is assumed to be 1. This means that the mobile must within 1000 milliseconds, read a control-filler message and update a number of internal register values. These parameters have not been considered in this study. The process of examining the read control-filler bit is only important in the sense that the time spent doing so will affect the delay in responding to a page and the time a mobile is inaccessible to pages in the case of a registration. IS-54B specifies that if a read control-filler bit is not received within the time allowed, the mobile station examines the access timer to determine whether it has expired. The simulation model assumes that the RCF will always be received within the time allowed. The mobile station then sets the BIS_S to “1” and examines the $WFOM_S$ bit. This bit is assumed to be set to 1 since this is generally how cellular systems are set up to operate. This means that the mobile waits a delay uniformly distributed between 0 and 92 milliseconds and before entering the ***Waiting for OMT to Seize RECC*** state (***event 2b-RCF Bit Checked***).

State 2.3 - Waiting for OMT to Seize RECC

During this state, the mobile station waits to receive an OMT. It leaves this state and enters:

the ***Waiting Random Delay*** state if an OMT is received and processed correctly within 1.5 seconds (***event 2c-OMT Received***);

the ***Initializing*** state if an OMT is not received within 1.5 seconds thereby re-starting the entire initialization process (***event 2d-OMT Timeout***).

State 2.4 - Waiting for Random Delay

During this state, the mobile station waits a delay uniformly distributed between 0 and 750 milliseconds and then enters the ***Attempting to Seize RECC*** state (***event 2e-Delay Expired***).

State 2.5 - Attempting to Seize RECC

During this state, the mobile station reads the busy-idle bits of the access channel. If the channel is idle, the mobile sets NBUSY_{sv} to 0, turns on the transmitter, waits the proper delay until the transmitter is within 3dB of the required power level, and then starts to send the message, be it a Registration, a Page Response, or a Call Origination. Once the transmission is completed, the mobile enters the ***Waiting for Registration Confirmation*** state if a Registration message was sent (***event e-Successful Seizure for Registration***) or the ***Waiting for Initial Voice Channel Designation*** message if either a Call Origination or a Page Response message was sent (***event g-Successful Seizure for Origination/ Response***).

If the channel is busy, the mobile increments NBUSY_{sv} by 1. If NBUSY_{sv} exceeds $\mathrm{MAXBUSY}_{sl}$, the mobile enters the ***Initializing*** state (***event f-Access Timeout***).

If NBUSY_{sv} does not exceed $\mathrm{MAXBUSY}_{sl}$, the mobile examines the access timer. If the access timer has expired, the mobile enters the ***Initializing*** state (***event f-Access Timeout***).

If the timer has not yet expired, the mobile waits a delay uniformly distributed between 0 and 200 milliseconds and then attempts to seize the reverse control channel once again.

3.5.3.2. Initializing

The state transitions experienced by a mobile station during intialization is shown in Figure 3.11.

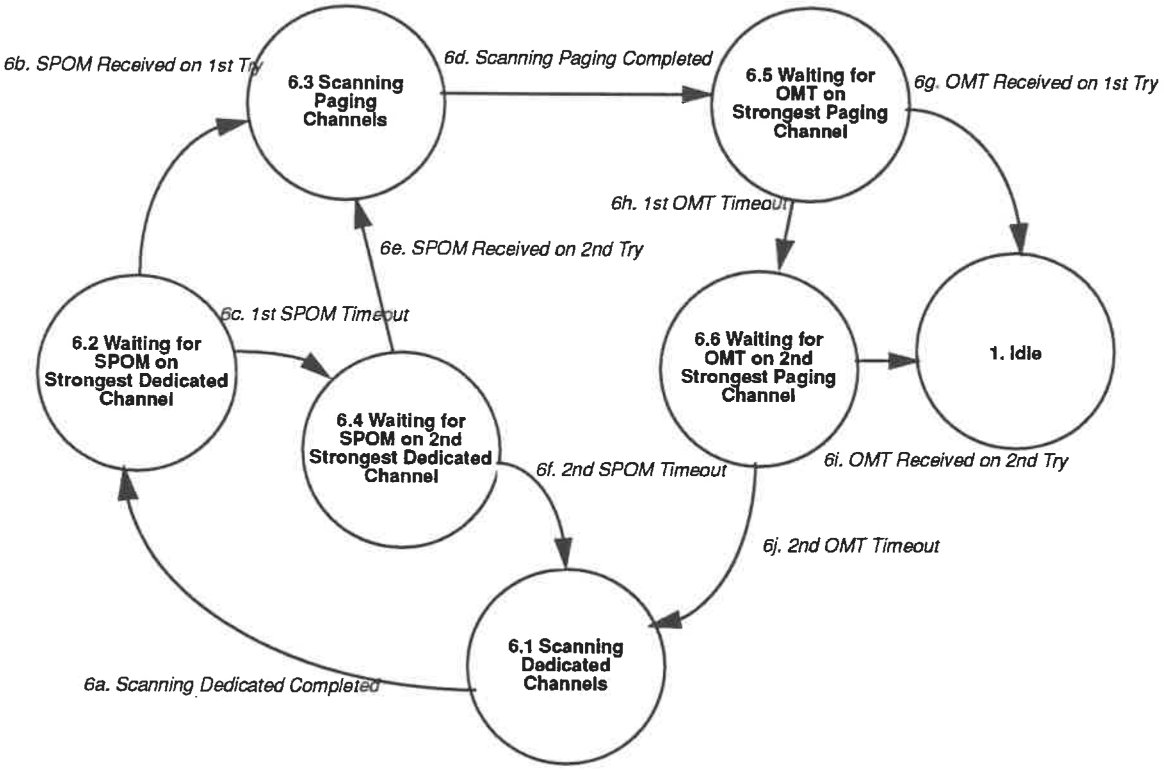


Figure 3.11. Mobile Station Initialization State Transition Diagram

A mobile station is required to initialize under the following conditions:

- when it powers up (it has been assumed that all mobile stations are powered up at the start of the simulation and none power down during the simulation);
- when it receives a registration confirmation (***event h-Registration Confirmation Received/Timeout***);
- when it releases a call (***event k-Call Release***);
- when it is unable to access the system after a predetermined number of access attempts (***event f-Access Timeout***);

- when it fails to receive an expected response, i.e. an Initial Voice Channel Designation or a Registration Confirmation, within a predetermined timeout period (***event h-Registration Confirmation Received/Timeout*** and ***event j-Initial VC Designation Timeout***); and
- when it is unable to decode the Overhead Message Train e.g. when it moves too far from the base station it is currently listening to (***event d-Message too Weak to Decode***).

State 6.1 - Scanning Dedicated Channels

The first ***Initializing*** sub-state to be entered is the ***Scanning Dedicated Channels*** state where the mobile station scans the dedicated control channels and selects the strongest and second strongest channels. The time required to scan the dedicated control channels has been modelled as a normal distribution. The standard deviation and mean are specified in the simulation program. Once the scanning completed (***event 6a-Scanning Dedicated Completed***), it tunes to the strongest dedicated control channel and enters the ***Waiting for SPOM on Strongest Dedicated Channel.***

State 6.2 - Waiting for SPOM on Strongest Dedicated Channel

During this state, the mobile station waits to receive a SPOM. The mobile station leaves this state and enters:

the ***Scanning Paging Channels*** state if it is able to decode the SPOM properly within 3 seconds (***event 6b-SPOM Received on 1st Try***);

the ***Waiting for SPOM on 2nd Strongest Dedicated Channel*** state if it does not receive the SPOM or cannot decode it properly within the 3 seconds (***event 6c-1st SPOM Timeout***).

State 6.3 - Scanning Paging Channels

During this state, the mobile station scans the paging channels specified in the SPOM. The time required to scan the paging channels has been modelled identically to the case of scanning dedicated control channels i.e. same mean and same standard deviation.

Once the scanning of the paging channels is completed (***event 6d-Scanning Paging Completed***), the mobile station enters the ***Waiting for OMT on Strongest Paging Channel.***

State 6.4 - Waiting for SPOM on 2nd Strongest Dedicated Channel

During this state, the mobile station waits for the SPOM on the second strongest dedicated control channel. It leaves this state and enters:

the ***Scanning Paging Channels*** state if it finally succeeds at decoding a SPOM (***event 6e-SPOM Received on 2nd Try***);

the ***Scanning Dedicated Channels*** state if it still cannot successfully process an SPOM hence re-initiating the entire initialization process (***event 6f-2nd SPOM Timeout***).

State 6.5 - Waiting for OMT on Strongest Paging Channel

During this state, the mobile station waits for an OMT on the strongest paging channel that was selected. It leaves this state and enters:

the ***Idle*** state if it is able to decode an OMT properly within 3 seconds hence completing the initialization process (***event 6g-OMT Received on 1st Try***);

the ***Waiting for OMT on 2nd Strongest Paging Channel*** state if it does not receive an OMT or cannot decode it properly within 3 seconds (***event 6h-1st OMT Timeout***)

State 6.6 - Waiting for OMT on 2nd Strongest Paging Channel

During this state, the mobile station waits for an OMT on the second strongest paging channel that was selected. It leaves this state and enters:

the ***Idle*** state if it is able to decode an OMT properly within 3 seconds hence completing the initialization process (***event 6i-OMT Received on 2nd Try***)

the ***Scanning Dedicated Channels*** state if it still cannot successfully process the OMT thereby re-starting the entire initialization process (***event 6j-2nd OMT Timeout***)

3.5.4. MSC Operation

The MSC state view shown in figure 3.12 is not based on any standard or formal specification. The MSC operation described reflects nevertheless the typical behaviour of an MSC during the paging and registration process.

One important note is that the MSC state transition diagram shown here provides the state view of the MSC as it manages one mobile station. This means that there are multiple instances of the states depicted here, one for each mobile station. For example, the MSC may be in the ***Attempting First Page*** state for one mobile and ***MS Idle*** state for another. Figure 3.12. illustrates the state transitions experienced by the MSC during its operation.

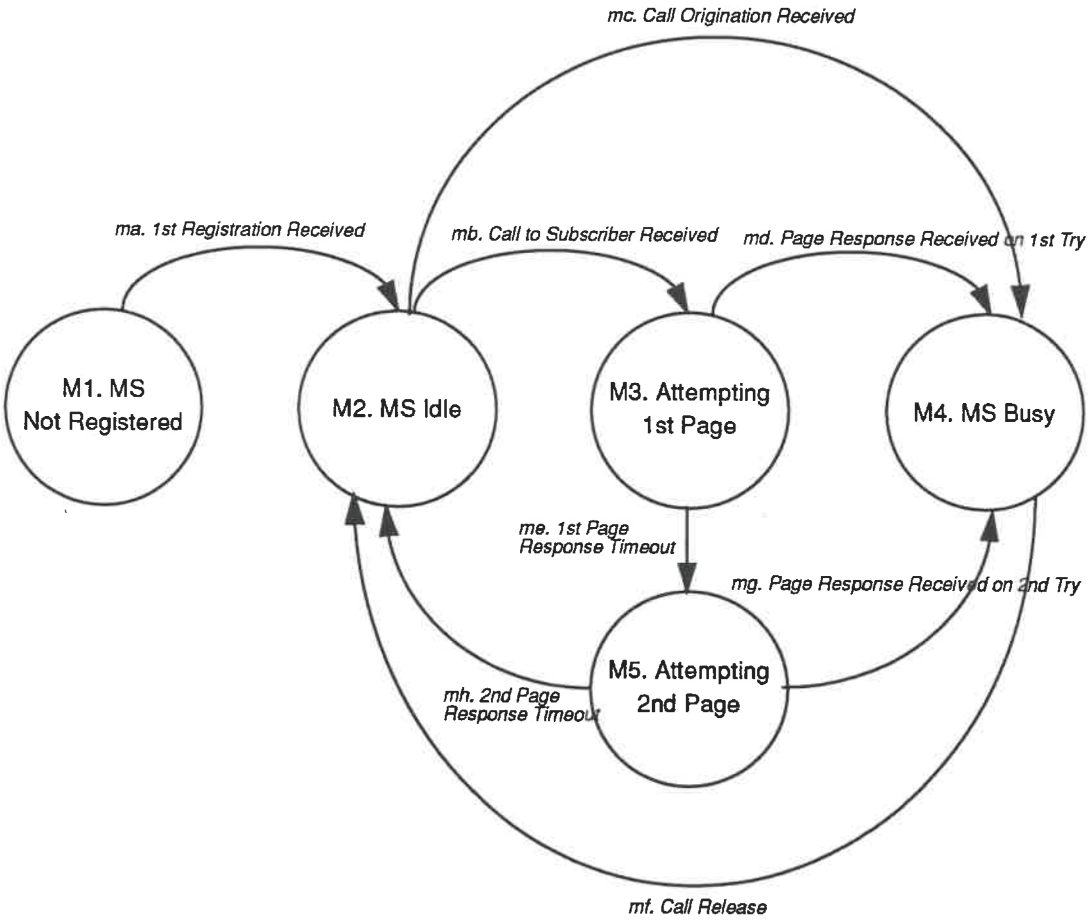


Figure 3.12. MSC State Transition Diagram

State M1 - MS Not Registered

This state exists mainly to account for mobiles that may be outside the service area at the start of the simulation. With the model used here, the probability of any mobile station being in this state is extremely low. The ***MS Not Registered*** state means that the mobile station has not yet registered with the MSC. It therefore will not be issued calls until its first registration. The MSC enters the ***MS Idle*** state when it receives a registration from the mobile station in question (***event ma-1st Registration Received***).

State M2 - MS Idle

At the start of the simulation run, the majority of mobile stations will be in this state. The ***MS Idle*** state means that the mobile station has registered and is ready to receive calls.

The MSC leaves this state and enters:

the ***Attempting First Page*** state when a terminating call is placed to a mobile subscriber (***event mb-Call to Subscriber Received***);

the ***MS Busy*** state when a call is originated by a mobile subscriber (***event mc-Call Origination Received***).

State M3 - Attempting 1st Page

During this state, the MSC issues an order to all base stations that are part of the location area under which the mobile station is registered, to broadcast a page message. The MSC leaves this state and enters:

the ***MS Busy*** state when it receives a page response from the mobile station which has been paged (***event md-Page Response Received on 1st Try***);

the ***Attempting 2nd Page*** state when the paged mobile station fails to respond before the expiration of the first page response time-out period (***event me-1st Page Response Timeout***).

State M4 - MS Busy

During this state, the MSC monitors the call until its release upon which the MSC returns to the ***MS Idle*** state for that particular mobile (***event mf-Call Release***).

State M5 - Attempting 2nd Page

During this state, the MSC issues a second order to broadcast a page to all base stations. The MSC leaves this state and enters:

the ***MS Busy*** state when it receives a page response from the mobile station which has been paged (***event mg-Page Response Received on 2nd Try***);

the ***MS Idle*** state when the paged mobile station fails to respond before the expiration of the second page response time-out period (***event mh-2nd Page Response Timeout***). In this case, the call is never set up.

3.5.5. Signalling Message Lengths

The format of the signalling messages that have been modelled were taken directly from [EIA92]. The message streams on both the RECC and FOCC are provided in tables 3.3 and 3.4. Table 3.5 shows the message lengths that were used in the model. The lengths of the messages take into consideration control elements required for synchronization and error detection. Messages transmitted on the FOCC also include busy-idle bits required as part of the access protocol.

Table 3.3RECC Message Stream (mobile-to-base)

Information Elements	Lengths (bits)
SEIZURE PRECURSOR	
DOTTING = 1010...010	30
WORD SYNC = 11100010010	11
CODED DCC	7
1st Word Repeated 5 times	240
2nd Word Repeated 5 times	240
...	

Table 3.4FOCC Message Stream (base-to-mobile)

Information Elements	Lengths (bits)
DOTTING = 1010...010 WORD SYNC = 11100010010	10 11
Repeat 1 of Word A	40
Repeat 1 of Word B	40
...	
Repeat 4 of Word B	40
Repeat 5 of Word A	40
Repeat 5 of Word B	40

With regards to the FOCC message stream, a given mobile will only read one of the two interleaved messages (A or B) and busy-idle bits are inserted approximately every 10 bits. Each FOCC consists of three discrete information streams, called stream A, stream B, and busy-idle stream that are time-multiplexed together. Messages to mobile stations with the least significant bit of their mobile identification number equal to '0' are sent on stream A and those with the least significant bit of their mobile identification number equal to '1' are sent on stream B. The busy-idle stream contains busy-idle bits, which are used to indicate the current status of the reverse control channel.

It was realized during the preparation of this report that the simulation model did not model the FOCC message stream correctly. The simulation model does not consider the interleaving of messages of streams A and B. As a result, the time it takes to broadcast a message to a mobile station should be twice as long as what was modelled. The CMTS model would need to be revised to take into account the interleaving of messages on streams A and B.

Table 3.5 Signalling Message Lengths

Control Channels	Designations	Breakdowns	Lengths (bits)
RECC - seizure precursor length = 48 bits - word length = 48 bits - busy-idle bits = 10%	Page Response	Seizure Precursor + 5(Word A-Abbreviated Address Word + Word B-Extended Address Word + Word C-Serial Number Word)	768
	Origination	Seizure Precursor + 5(Word A-Abbreviated Address Word + Word B -Extended Address Word + Word C-Serial Number Word + Word D-First Word of the Called-Address + Word E-Second Word of the Called-Address)	1008
	Registration	Seizure Precursor + 5(Word A-Abbreviated Address Word + Word B-Extended Address Word + Word C-Serial Number Word)	768
FOCC - dotting length = 10 bits - word sync length = 11 bits - word length = 40 bits - busy-idle bits = 10%	SPOM	Dotting + Word Sync + 5(SPOM Word 1 + SPOM Word 2) + 10%	463
	SPOM + REGID	Dotting + Word Sync + 5(SPOM Word 1 + SPOM Word 2 + REGID) + 10%	683
	Page	Dotting + Word Sync + 5(Mobile Station Control Word 1 + Mobile Station Control Word 2) + 10%	463
	Initial Voice Channel Designation	Dotting + Word Sync + 5(Mobile Station Control Word 1 + Mobile Station Control Word 2) + 10%	463
	Registration Confirmation	Dotting + Word Sync + 5(Mobile Station Control Word 1 + Mobile Station Control Word 2) + 10%	463

3.5.6. Delays

Radio transmission, transmission, MSC processing, and voice line check delays have been incorporated in the CMTS model.

Radio transmission delay is the time it takes to transfer data between mobile stations and base stations. It depends on the length of the message being transmitted and the data rate of the control channel (10 kbps).

Transmission delay is the time it takes to transfer data between a base station and an MSC. Transmission delays were assumed to be 50 ms.

MSC processing delay is the time required by the MSC to process Page Responses, Call Originations, and Registrations. This means that whenever the MSC receives any one of these messages, it waits for a fixed amount of time before sending back its response. The MSC processing delay was assumed to be 60 ms.

Voice line check delay is the time it takes the MSC to verify whether the voice line to be used is functioning correctly. This check is performed prior to sending an Initial Voice Channel Designation message to a mobile station to set up a call. The voice line check delay was assumed to be 200 ms.

3.5.7. CMTS Measurements

The following section describes the measurements that were seen of interest for this project. The measurements have been categorized as paging, registration, call origination, channel utilization, and system access. All measurements described here are contained in the simulation report.

3.5.7.1. Paging Measurements

The following measurements are taken during the paging process.

Paging Counters

n_1 = *number of responses to first page attempts*

n_a = *number of first page attempts*

n_2 = *number of responses to second page attempts*

n_r = *number of repeat page attempts*

n_p = *number of base station pages*

n_t = *number of terminating calls*

Response Percentage for First Page

$$p_1 = (n_1 / n_a) \times 100\% \tag{3.9}$$

where

p_1 = *response percentage for first page;*

n_1 = *number of responses to first page attempts;*

n_a = *number of first page attempts.*

Response Percentage for Repeated Page

$$p_2 = (n_2 / n_r) \times 100\% \tag{3.10}$$

where

p_2 = *response percentage for repeated page;*

n_2 = *number of responses to second page attempts;*

n_r = *number of repeat page attempts.*

Percentage of Terminating Calls Successfully Paged

$$p_t = ((n_1 + n_2) / n_a) \times 100\% \tag{3.11}$$

where

p_t = *percentage of terminating calls successfully paged;*

n_1 = *number of responses to first page attempts;*

n_2 = *number of responses to second page attempts;*

n_a = *number of first page attempts.*

Average Number of Base Station Pages per Terminating Call

$$\bar{n}_c = n_p / n_t \tag{3.12}$$

where

$\bar{n}_c$ = *average number of base station pages issued per terminating call;*

n_p = *number of base station pages;*

n_t = *number of terminating calls.*

Average Page Response Delay

Page response delay is illustrated in Figure 3.13.

$\overline{D}_{pr}$: *average page response delay*

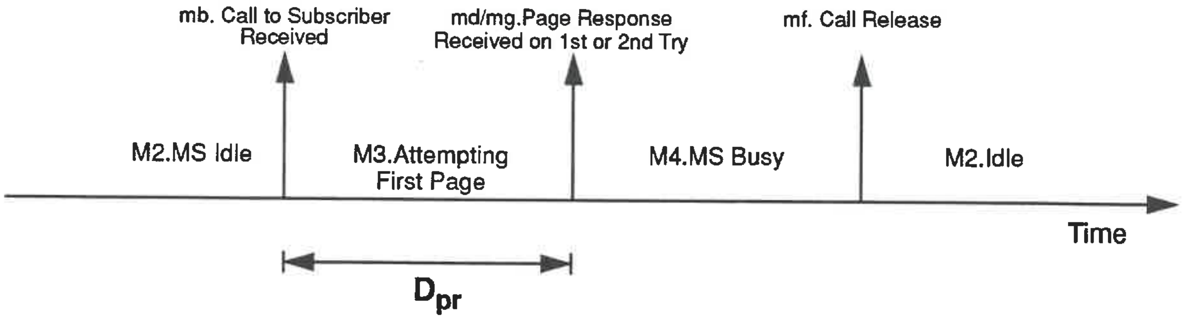


Figure 3.13. Page Response Delay

3.5.7.2. Registration Measurements

The following measurements are taken during the registration process.

Registration Counters

n_f: *number of forced registration attempts*

n_{rg}: *number of registration attempts*

n_{cr}: *number of confirmed registrations*

n_{fr}: *number of failed registrations*

Average Registration Duration

Registration duration is the time expended from the time a mobile station starts the registration until it completes the initialization process that follows the receipt of the Registration Confirmation. Registration duration is illustrated in Figure 3.14.

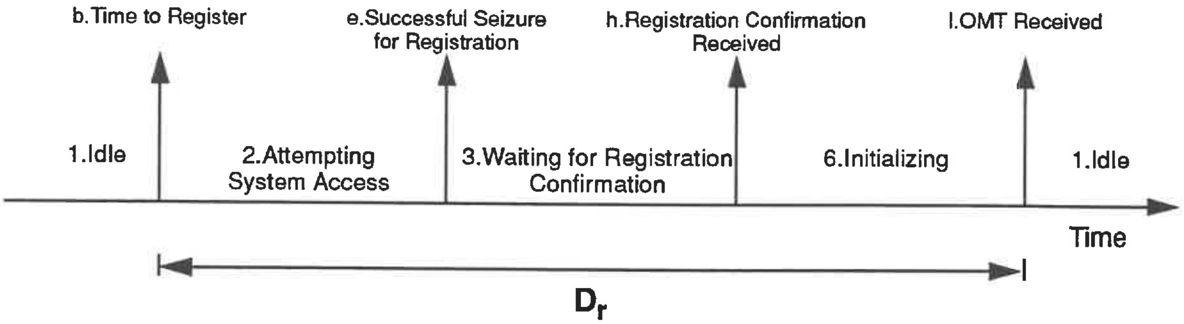


Figure 3.14. Registration Duration

Average Percentage of Time Mobile Station Inaccessible Due To It Registering

This measurement provides an indication of how long a mobile station is inaccessible to calls because of it carrying out the registration process.

$$\overline{p}_{ir} = (((n_{rg} / N_{ms}) \text{ x } \overline{D}_r) / T_{sim}) \text{ x } 100\% \tag{3.13}$$

where:

N_{ms}: *number of mobile stations*

T_{sim} : *simulation duration*

3.5.7.3. Call Origination Counter

The following measurement is particular to call origination.

n_o: *number of originating calls*

3.5.7.4. Channel Utilization

The following measurements pertain to the utilization of the access (RECC) and paging (FOCC) channels.

$\overline{u}_{re}$: *average RECC (or access channel) utilization*

$\overline{u}_{fo}$: *average FOCC (or paging channel) utilization*

3.5.7.5. System Access Counters

The following measurements provide indications on the overall system behaviour with regards to mobile stations accessing the CMTS.

n_{sa}: *number of system access attempts*

n_{se}: *number of RECC (or access channel) seizure attempts*

n_{su}: *number of successful RECC (or access channel) seizures*

n_{sr}: *number of RECC (or access channel) seizure retries*

n_{mb}: *number of MAXBUSY failures*

n_{to}: *number of system access timeouts*

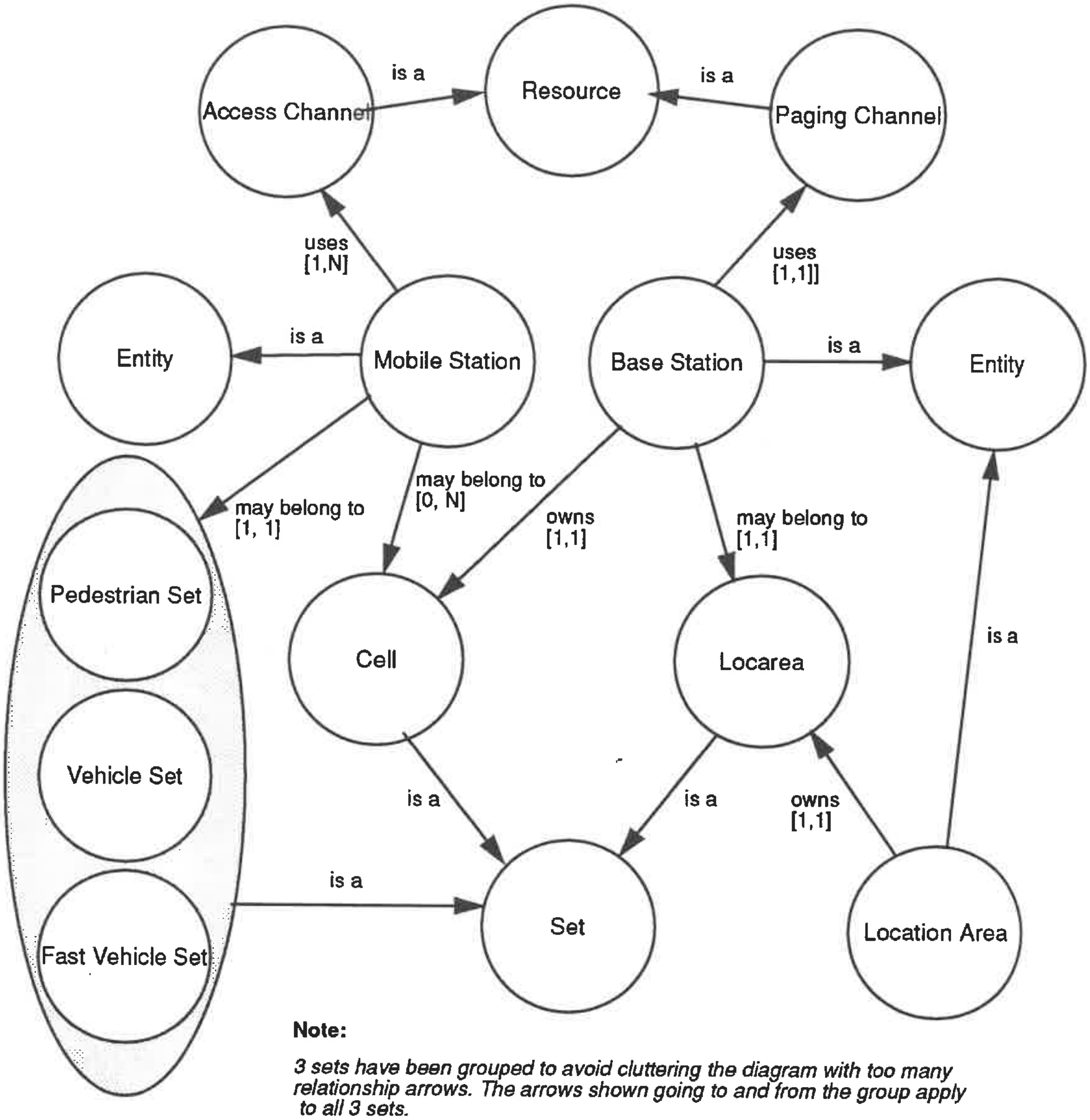
3.5.8. CMTS Model Implementation

The following sections describe how the simulation model was implemented. The implementation is described using an object model and a series of process interaction diagrams depicting a few selected simulation cases.

3.5.8.1. Object Model

An object model provides a formal representation of the static relationships between the objects that are part of the domain of interest. In our case, it has been used to represent how the SIMSCRIPT II.5 concepts of sets, entities, and resources have been applied in this project. It represents a graphical summary of the **permanent entities** and the **resources** declarations made in the **preamble** part of the simulation program.

Figure A.1.depicts the object model.



Note:

3 sets have been grouped to avoid cluttering the diagram with too many relationship arrows. The arrows shown going to and from the group apply to all 3 sets.

Figure A.1. Object Model

The following relationships that may exist between objects:

is a;

uses;

owns;

may belong to.

The "is a" relationship was used to depict the relationship between our domain objects and SIMSCRIPT II.5 objects such as **set**, **entity**, and **resource**.

The "owns" relationship was used to depict the ownership of a domain object towards another domain object of type **set**.

The "uses" relationship was used to depict the relationship between domain object of type **entity** and a domain object of type **resource**. This is not semantically correct according to SIMSCRIPT II.5 as it is the processes that compete for the resources and not the entities. However, this method of representation depicts more acurately the intent of the simulation model.

The "may belong to" relationship was used to depict the membership of a domain object of type **entity** to a domain object of type **set**.

Figure A.1.illustrates the object model used for this simulation model.

Mobile stations, **base stations**, and **location areas** are **entities**.

Access channels and **paging channels** are **resources** for which the processes compete. If they are busy, all subsequent processes requesting their use are queued.

Each **mobile station** uses an **access channel** to communicate with the CMTS. It can use one or more since the **mobile station** moves and is therefore not permanently tied to any **access channel**. Each **base station** uses a **paging channel** to communicate with the **mobile stations**. There is only one **paging channel** per **base station**. A **paging channel** is permanently tied to the **base station** for the entire simulation.

Each **base station** owns a **cell**. A **cell** is a **set** which contains one or many **mobile stations**. As **mobile stations** travel, they get removed and added to the **cell sets**.

Each **location area** owns a **locarea**. A **locarea** is a **set** which contains one or more **base stations**. The number of **base stations** contained in a **locarea set** is determined at the start of the simulation and depends on the location area configuration data.

3.5.8.2. Initialization Sequence

The following summarizes the intialization sequence executed at the start of the simulation. It is basically a description of the **main** portion of the simulation program.

1) The simulation data is read from the input file by the **READ.DATA** routine.
2) The radio environment is created by the **GENERATE.RADIO.ENVIRONMENT** routine.
3) All mobile stations are intialized by the **INITIALIZE.MOBILE.STATIONS** routine. This includes initializing their positions, speeds, directions, and internal register values.
4) All paging and access channels are created by the **CREATE.RESOURCES** routine.
5) The first executions of the displacement processes **FAST.VEHICLE.DISPLACEMENT**, **VEHICLE.DISPLACEMENT**, and **PEDESTRIAN.DISPLACEMENT** which will periodically move the mobile stations are scheduled.
6) The **OVERHEAD.MSG.GENERATOR** process which will constantly generate periodic overhead message trains is activated
7) The **PSTN.CALL.GENERATOR** process which constantly generates calls originating from the PSTN is activated.
8) The **MS.CALL.GENERATOR** process which constantly generates calls from the mobile subscribers is activated.
9) The **STOP.SIMULATION** event which stops all simulated activities once the simulation period has expired is scheduled.

3.5.8.3. Process Interaction Diagrams

Despite SIMSCRIPT II.5's readability and understandibility, there is still a fair amount of familiarization required for one to properly understand a simulation model simply by reading the source code. To facilitate understanding, Process Interaction diagrams were used to graphically represent the implementation of parts of the CMTS Model.

The Process Interaction Diagram shows the sequence of interaction between processes according to the semantics of the SIMSCRIPT II.5 language. Process Interaction Diagrams were found to be a natural extension of the SIMSCRIPT II.5 language since SIMSCRIPT II.5 is based largely on intercommunicating processes. Not all implementation details have been shown in these diagrams. For example, the arguments being passed via the process notice are not shown. The purpose of the Process Interaction diagram was to provide a quick overview of the way the call termination and registration traffic cases of the CMTS were modelled and implemented using SIMSCRIPT II.5.

The following relationships between processes and events are shown on the Process Interaction Diagram:

activate;

schedule;

cancel.

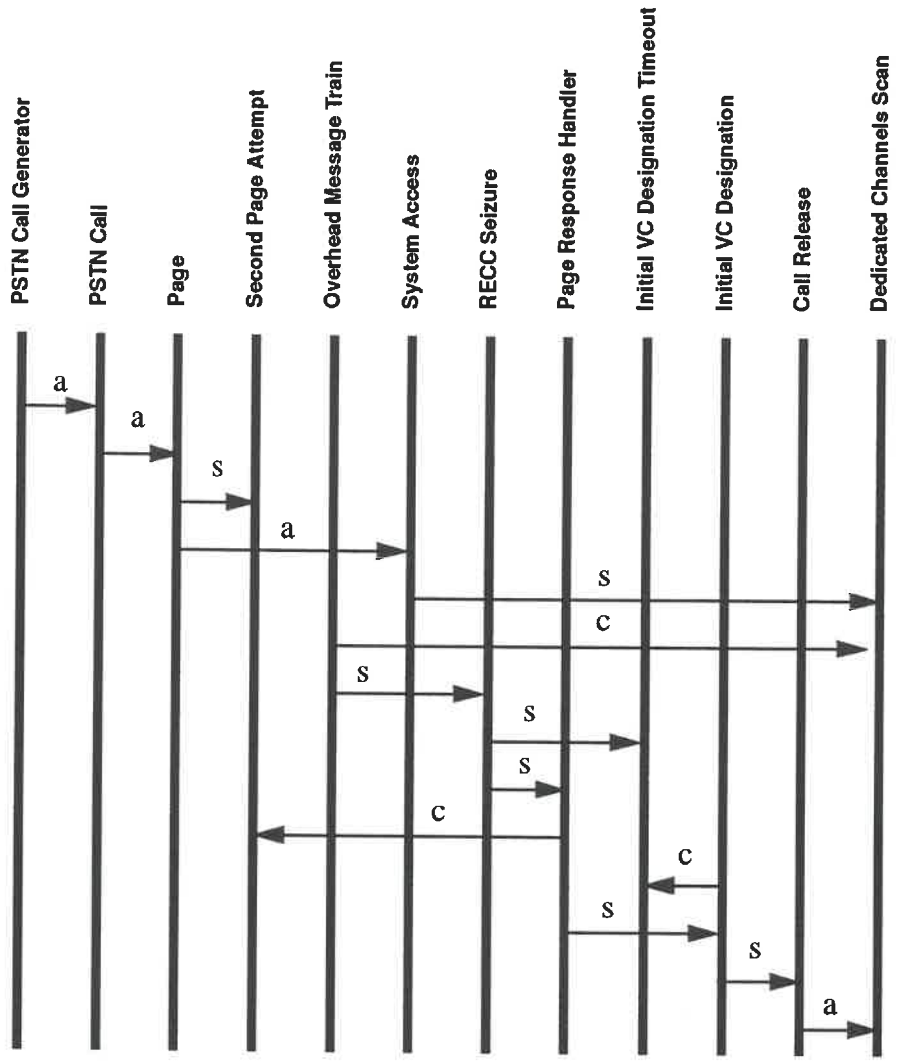
The "activate" relationship represents the initiation of a process by another process. Activation can be made now or at some later time.

The "schedule" relationship represents the initiation of an event by another event or process. Scheduling can be made for now or later.

The "cancel" relationship represents the cancellation of a process or event that has been scheduled to be activated later by another process or event.

3.5.8.4. Call Termination

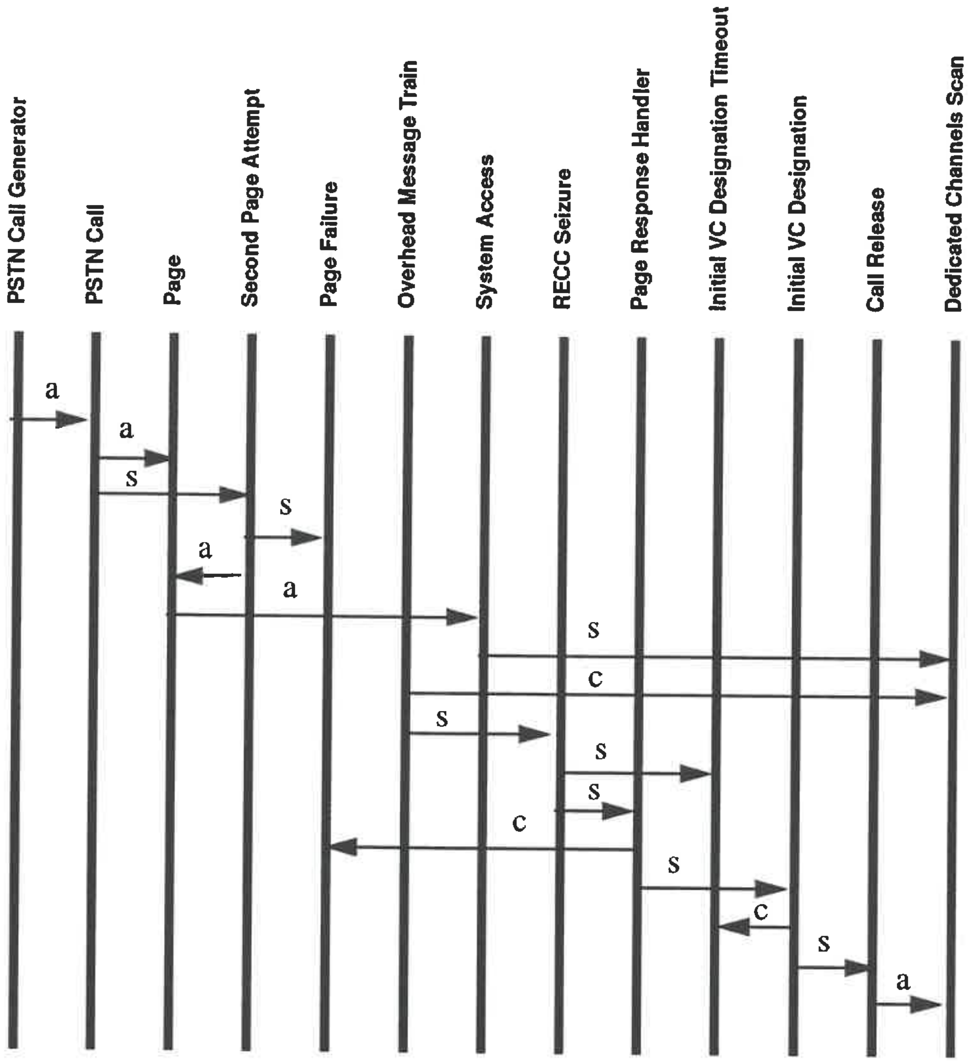
Figure A2., Figure A3. and Figure A4. illustrate how the call termination traffic case has been modelled. The description that follows uses the actual names of variables, processes, entities, etc., that were employed in the simulation program. These have been highlighted throughout the text.



LEGEND

a	**activate**
s	**schedule**
c	**cancel**

Figure A2. Paging Success on First Attempt



LEGEND

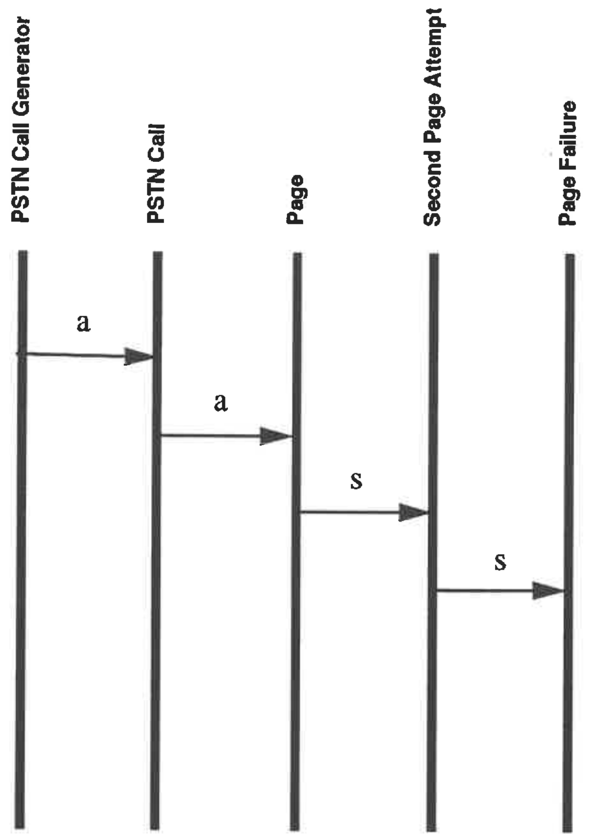
a	**activate**
s	**schedule**
c	**cancel**

Figure A3. Paging Success on Second Attempt

Once a **PSTN.CALL** process is activated by the **PSTN.CALL.GENERATOR** process, it sets, for the mobile to be paged, the **PAGE.START.TIME** to the current time, the **PAGE.ATTEMPT.COUNTER** to 1, and the **MONITORED.STATE** to **BUSY**. It then activates a **PAGE** process for each **CELL**, or **BASE.STATION**, that is contained in the location area last registered by the mobile station being called. The **PAGE** process is activated after a transmission delay which represents the time for the page message to arrive to the **BASE.STATION**s. After activating all **PAGE** processes, the **PSTN.CALL** process schedules a **SECOND.PAGE.ATTEMPT** event to be executed if a page response is not received within a pre-defined timeout period.

The **PAGE** process first requests the use of the paging channel of the base station which is to broadcast the page message. Once the paging channel becomes available, the page message is transmitted. During this transmission, no other message can be broadcasted on this channel. They are queued until the channel is released. If the state of the mobile being paged is idle and it is currently locked onto the same control channel over which the page message was issued, the mobile activates a **SYSTEM.ACCESS** process to respond to the page. If the state of the mobile does not correspond to the given states, the **PAGE** process simply exits. This means that the mobile is either not present in the cell that was paged or is busy executing other call processing activities and therefore not listening for page messages.

The **SECOND.PAGE.ATTEMPT** event is scheduled if a page response has not been received within a pre-defined timeout period. When it is activated, it increments the page attempt counter to indicate that a second page will be issued. It then activates a **PAGE** process for each cell contained in the entire service area and schedules a **PAGE.FAILURE** event to be executed if a page response is not received within a second pre-defined timeout period.



LEGEND

a	**activate**
s	**schedule**
c	**cancel**

Figure A4. Paging Failure

The **SYSTEM.ACCESS** process first increments the system access counter and sets the access start time to the current time. It then waits for a normally distributed access channel period. It then sets the **NBUSY.SV** register of the mobile station requiring access to 0 and sets its state to **CHECKING.RCF.BIT**. The **SYSTEM.ACCESS** process then waits for a normally distributed period which corresponds to the time required to check the RCF bit from the control-filler messages and changes the mobile state to **WAITING FOR.OMT.TO.SEIZE.RECC**. It then activates the **DEDICATED.CHANNELS.SCAN** process for the mobile requiring access 1.5 seconds. This would mean that the mobile was unable to access the system within the prescribed time limit and would be forced to initialize.

The **OVERHEAG.MSG.TRAIN** process is constantly driving the base stations to issue SPOMs and REGIDs. The reaction of the mobiles upon reception of these messages differs according to the state they are in. When a mobile is attempting to access the system and its state is **WAITING.FOR.OMT.TO.SEIZE.RECC**, it immediately activates the **RECC.SEIZURE** process.

The **RECC.SEIZURE** process first increments the RECC seizure count and sets the mobile's state to **ATTEMPTING.TO.SEIZE RECC**. It then checks if the **ACCESS. CHANNEL** resource is currently in use.

If the **ACCESS.CHANNEL** resource is busy, the **NBUSY.SV** register of the mobile station attempting system access is incremented. If the **NBUSY.SV** value exceeds the **MAXBUSY** value, the **DEDICATED.CHANNELS.SCAN** is activated which essentially initiates the whole initialization process. If the **NBUSY.SV** value does not exceed the **MAXBUSY** value, the time expired between the first attempt to access the channel and the current time is checked. If the expired time exceeds the specified access timeout value, the **DEDICATED.CHANNELS.SCAN** is activated to re-initialize the mobile station. If the expired time does not exceed the specified access timeout value, the **RECC.SEIZURE** process is activated again in a randomly distributed time between 0 and 200 milliseconds.

If the **ACCESS.CHANNEL** resource is not busy, the **NBUSY.SV** register is reset to 0 and the **ACCESS.CHANNEL** is requested for a period of time equal to the transmission time of the Page Response message. At the end of the transmission the **ACCESS.CHANNEL** resource is relinquished and made available to all other mobile stations that may need to access the system. The **PAGE.RESPONSE.HANDLER** process is then scheduled for activation after a period of time equal to a transmission delay from the base station to the MSC. An **INITIAL.VC.DESIGNATION.TIMEOUT** event is scheduled to be activated 5 seconds later. If the Initial Voice Channel Designation message is not received within 5 seconds, the **INITIAL.VC.DESIGNATION.TIMEOUT** immediately activates the

DEDICATED.CHANNELS.SCAN thereby initiating the mobile station initializing process.

The **PAGE.RESPONSE.HANDLER** process first checks whether the page response is to a first or second page attempt. If the response is to a first page attempt, the **SECOND.PAGE.ATTEMPT** event is cancelled and destroyed. If the response is to a second attempt, the **PAGE.FAILURE** event is cancelled and destroyed. In both cases, the **PAGE.RESPONSE.HANDLER** then waits for a period corresponding to the delays incurred by MSC processing and the voice line check. It then activates the **INITIAL.VC.DESIGNATION** after a period of time corresponding to the transmission delay from the MSC to the base station.

The **INITIAL.VC.DESIGNATION** process requests the **PAGING.CHANNEL** resource which belongs to the base station. The **PAGING.CHANNEL** is requested for a period of time equal to the transmission time of the Initial Voice Channel Designation message. At the end of the transmission, the **PAGING.CHANNEL** resource is relinquished. If the mobile station which is waiting for this message is in the cell which belongs to the base station that just issued the Initial Voice Channel Designation message and the mobile is in the **WAITING.FOR.INITIAL.VC.DESIGNATION** state, the **INITIAL.VC.DESIGNATION.TIMEOUT** event is cancelled and the **CALL.RELEASE** process is scheduled to be activated in a period equal to the duration of a call. The state of the mobile is then changed to **IN.CONVERSATION**.

Once activated, the **CALL.RELEASE** process immediately activates the **DEDICATED.CHANNELS.SCAN** thereby initiating the mobile station initialization process and waits for a period of time equal to 1.8 seconds plus the transmission delay back to the MSC. The monitored state of the mobile station is then set back to **IDLE** indicating that the mobile is ready to receive calls again.

3.5.8.5. Registration

The following information describes how the registration aspect of the simulation model was implemented. Figure A5.depicts the run-time sequence executed for a successful registration.

The **OVERHEAD.MSG.GENERATOR** is periodically activating an **OVERHEAD.MSG.TRAIN** process for each base station. The

OVERHEAD.MSG.TRAIN process then uses the **PAGING.CHANNEL** resource of a particular base station to broadcast the overhead message train (OMT). The state of every **MOBILE.STATION** contained in the **CELL** set owned by that particular **BASE.STATION** is then checked.

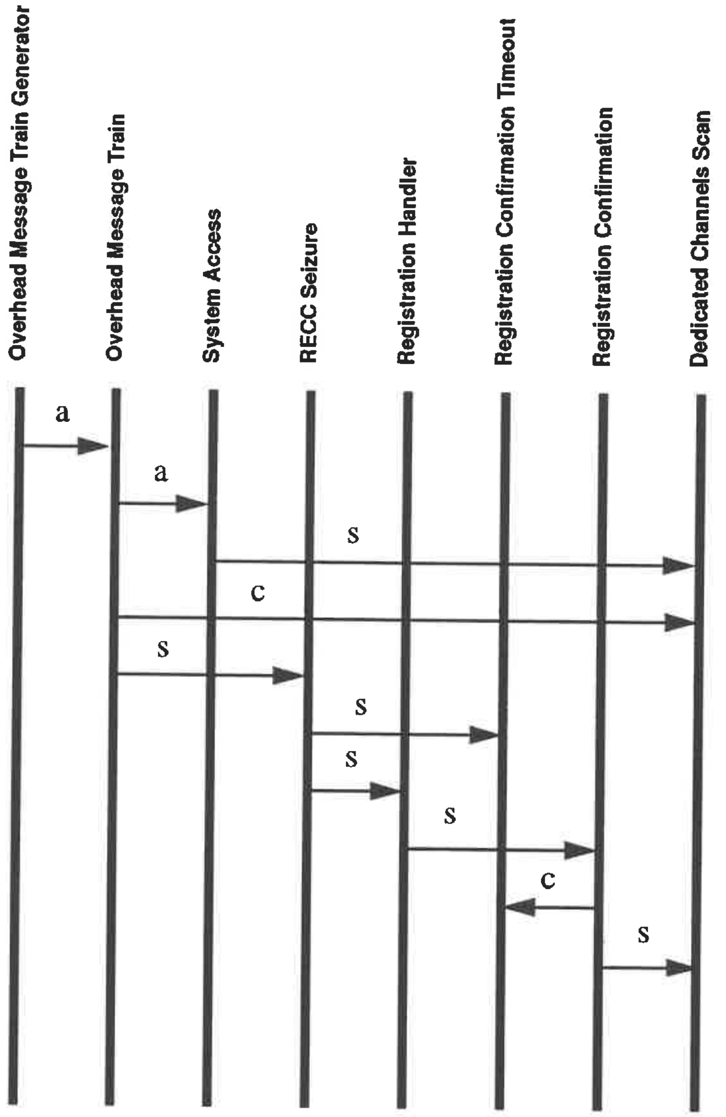
If the **MOBILE.STATION** is in the **IDLE** state and the following conditions are valid:

- the OMT contained a REGID,
- the strength of the radio signal carrying the OMT is strong enough to decode,
- the **REGID.S** value is larger than the **NXTREG.SP** (next time to register) value

then the state of the **MOBILE.STATION** is set to **SCANNING.ACCESS.CHANNELS** and a **SYSTEM.ACCESS** process is activated. The **SYSTEM.ACCESS** process is identical to the one described for the Call Termination traffic case.

The **REGISTRATION.CONFIRMATION.TIMEOUT** event is scheduled. It is cancelled once the Registration Confirmation message is received by the **MOBILE.STATION.** Upon the reception of this message, the **DEDICATED.CHANNEL.SCAN** is activated as part of the initialization sequence.

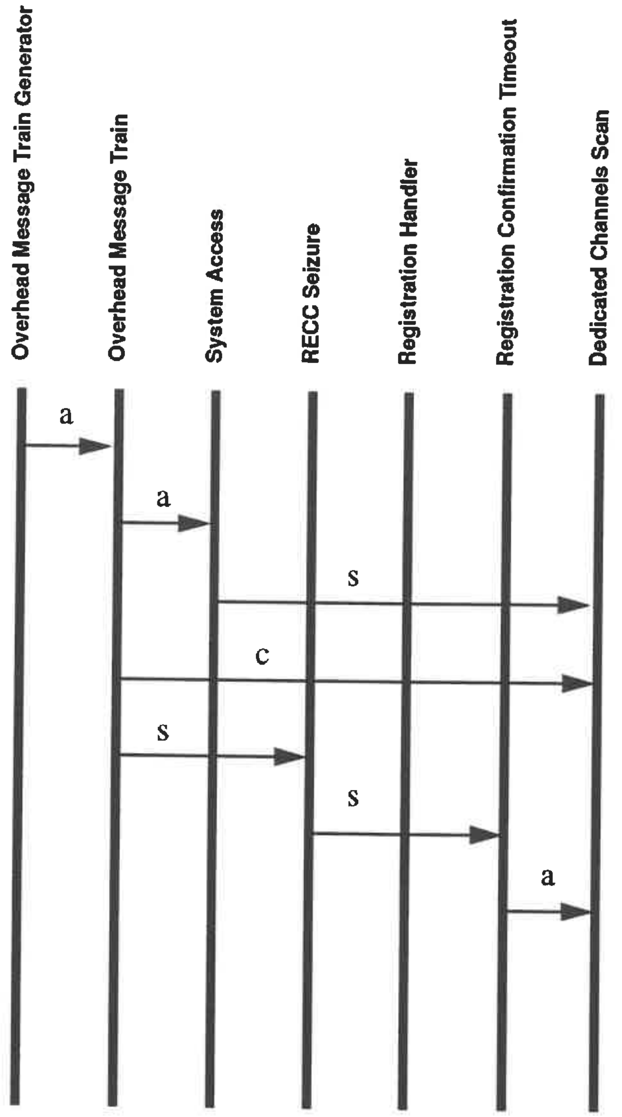
The case of failed registration is depicted in Figure A6. The only difference here is that the **REGISTRATION.CONFIRMATION.TIMEOUT** event is never cancelled and therefore the **DEDICATED.CHANNEL.SCAN** is activated as part of the initialization sequence but with the next registration scheduled way before the regular registration period.



LEGEND

a	**activate**
s	**schedule**
c	**cancel**

Figure A5. Successful Registration



LEGEND

a	**activate**
s	**schedule**
c	**cancel**

Figure A6. Failed Registration

CHAPTER 4

EXPERIMENTS AND RESULTS

The experiments were designed to take into consideration combinations of 6 different location area configurations (LAC1, 2, 4, 8, 20, 60), 3 different average control channel scanning durations $\overline{D}_s$, and 2 different average mobile speeds $\bar{s}$. A total of 36 simulations were executed.

The following sections provide a description of the data that was used, an explanation on how to run the simulation program, and a presentation and analysis of the results obtained.

4.1. Simulation Data

Simulation data was input to the simulation program through a data file. As a general rule, parameters which were to remain constant throughout all simulations were defined as constants in the simulation program while parameters that were called to vary from experiment to experiment were defined in an input data file.

A simulated duration of one hour was used in all simulations.

4.1.1. Radio Environment Data

The data shown in tables 4.1 and 4.2 are the result of the calculations made as per the sequence defined earlier during the description of the Radio Environment Model. This data was commonly used in all simulations.

Table 4.1Radio Environment Data

Parameters	Values
w_{sa}	6062 meters
d_{sa}	6250 meters
P_t	40 dBm
P_{rmin}	-110 dBm
N_{bs}	60

Table 4.2Cell Plan and Base Station Data

k	X (meters)	Y (meters)	a (degrees)	k	X (meters)	Y (meters)	a (degrees)
1	433	0	90	31	433	3000	90
2	1732	750	210	32	1732	3750	210
3	1732	750	330	33	1732	3750	330
4	3031	0	90	34	3031	3000	90
5	4330	750	210	35	4330	3750	210
6	4330	750	330	36	4330	3750	330
7	5629	0	90	37	5629	3000	90
8	433	1500	210	38	433	4500	210
9	433	1500	330	39	433	4500	330
10	1732	750	90	40	1732	3750	90
11	3031	1500	210	41	3031	4500	210
12	3031	1500	330	42	3031	4500	330
13	4330	750	90	43	4330	3750	90
14	5629	1500	210	44	5629	4500	210
15	5629	1500	330	45	5629	4500	330
16	433	1500	90	46	433	4500	90
17	1732	2250	210	47	1732	5250	210
18	1732	2250	330	48	1732	5250	330
19	3031	1500	90	49	3031	4500	90
20	4330	2250	210	50	4330	5250	210
21	4330	2250	330	51	4330	5250	330
22	5629	1500	90	52	5629	4500	90
23	433	3000	210	53	433	6000	210
24	433	3000	330	54	433	6000	330
25	1732	2250	90	55	1732	5250	90
26	3031	3000	210	56	3031	6000	210
27	3031	3000	330	57	3031	6000	330
28	4330	2250	90	58	4330	5250	90
29	5629	3000	210	59	5629	6000	210
30	5629	3000	330	60	5629	6000	330

4.1.2. Location Area Data

Each experiment group was executed using 6 different location area patterns. They are illustrated in the following 4 figures. The cases where there is one cell per location area (LAC1) and 60 cells per location area (LAC60) have not been illustrated since the location area patterns to be used in both these cases present no ambiguity.

Location area patterns were changed by altering the value of the Number of Location Areas and the LOCAID associated to each base station in the data file.

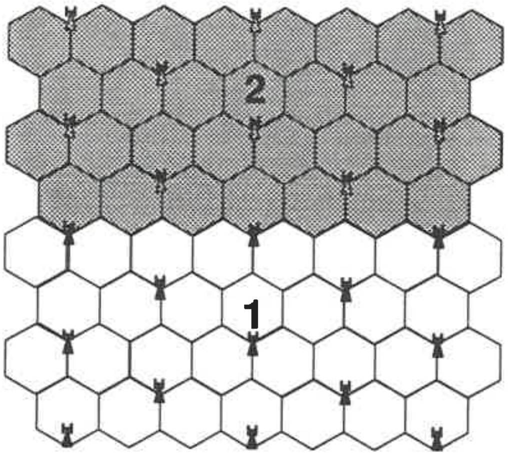


Figure 4.1. A 2-Location Area Configuration (LAC2)

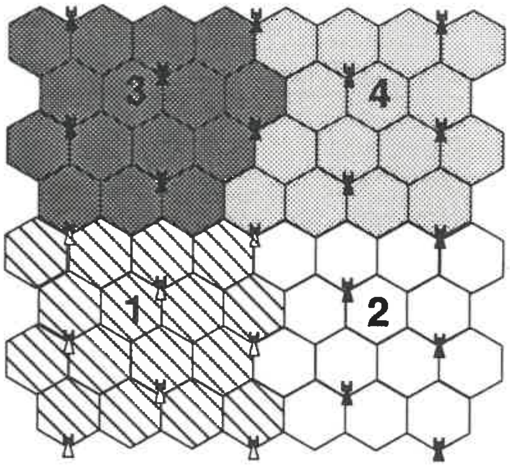


Figure 4.2. A 4-Location Area Configuration (LAC4)

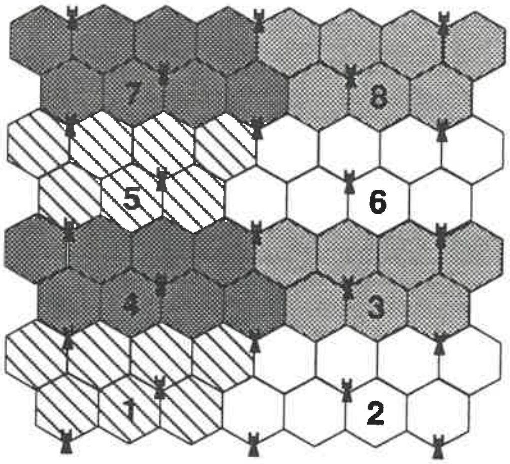


Figure 4.3. An 8-Location Area Configuration (LAC8)

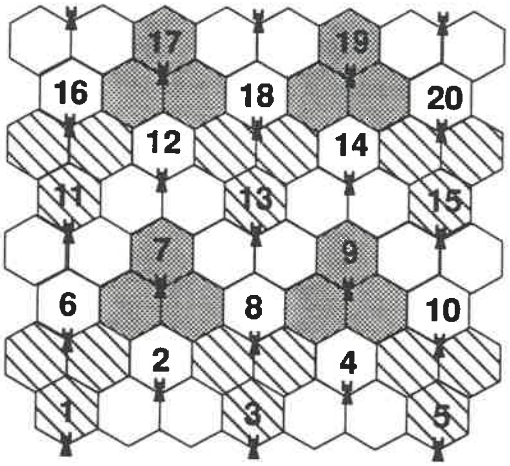


Figure 4.4. A 20-Location Area Configuration (LAC20)

4.1.3. Mobility Data

Two average speeds were selected: $\bar{s}$ = 10 kmph and $\bar{s}$ = 50 kmph. The standard deviation of the speed was assumed to be 25% of the average mobile speed.

These speeds were chosen since they were seen to reflect an urban environment where mobiles, on the whole, can be viewed as travelling in random patterns. In both cases, a maximum direction variation of 30^0 was used.

Two displacement rates were used during simulation execution. The displacement rates were dependant on the speed of the vehicles. Mobiles moving at an average speed of 50 kmph required a shorter displacement period than those moving at 10 kmph since within the same period of time, the faster moving mobiles travel further. A displacement period of 36 seconds was used for 10 kmph while a displacement period of 12 seconds was used for 50 kmph.

4.1.4. Call Data

The frequency of calls was based on the ratio 1 call/subscriber/hour. It was assumed that two-thirds of the calls were originating calls (from mobile subscribers and the other third were terminating calls (to mobile subscribers). Call duration was assumed to be 100 seconds for all calls regardless of whether they were originating or terminating. This value is commonly used throughout the cellular industry. A volume of 2000 mobile subscribers was used in all simulations. Table 4.3 shows the call data that was used.

Table 4.3 Call Data

Parameters	Values
D_c	100 seconds
T_t	5400 milliseconds
T_o	2700 milliseconds
N_{ms}	2000

4.1.5. CMTS Data

There are a number of parameters that were mentioned throughout the description of the CMTS Model. The values to which they were set are shown in Table 4.4

Table 4.4 CMTS Data

Parameters	Values
Periodic Registration Interval	10 minutes
First Page Timeout Period	3 seconds
Second Page Timeout Period	3 seconds
Registration Access Timeout Period	6 seconds
Call Origination Access Timeout Period	12 seconds
Page Response Access Timeout Period	6 seconds
Control Channel Data Rate	10 kbps
Mean SPOM Interval	926 milliseconds
REGID Rate	1/926 milliseconds x 5

4.2. Simulation Results

A total of 36 simulations were executed. Of all the measurements available from the simulation report, only p_1, p_t, $\overline{n}_c$, and n_f. measurements have been represented in bar graphs since they provide the most insight into the behaviour of the CMTS.

For each of these key measurements, two bar graphs have been produced. Each bar graph shows the value of the measurement for a particular $\overline{s}$, for all three variations of $\overline{D}_s$, and all six variations of location area configurations. Additionally, a combined view which shows the key measurements at both speeds have been provided to enhance later discussion of the results. A total of twelve graphs have been provided.

Four (4) simulations out of the thirty-six (36) did not complete. The cases where this occurred have been shaded in the tabular results contained in the following sections. This is of relatively minor consequence since the trends are apparent despite the absence of results in these four cases. The simulations simply need to be executed again using a batch execution class that has a longer maximum run-time. This what not done since time ran out.

Table 4.5 Simulation Results for $\overline{s}$ = 10 kmph, $\overline{D}_s$ = 500 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t	619	670	660	669	650	
n_a	619	670	660	669	650	
n_1	532	579	564	582	570	
p_1	85.95%	86.42%	85.45%	87.00%	87.69%	
n_r	87	90	95	87	80	
n_2	86	89	94	85	72	
p_2	98.85	98.89%	98.95%	97.70%	90.00%	
p_t	99.84%	99.70%	99.70%	99.70%	98.77%	
n_p	42360	25500	15600	10254	6750	
$\overline{n}_c$	68	38	24	15	10	
$\overline{D}_{pr}$	2602 ms	2580 ms	2577 ms	2567 ms	2562 ms	
Registration						
n_f	0	2010	3992	7130	10320	
n_{rg}	11926	13142	14286	16009	18272	
n_{fr}	0	0	0	0	0	
n_{cr}	11926	13142	14286	16009	18272	
$\overline{D}_r$	5420 ms	5363 ms	5404 ms	5438 ms	5353 ms	
$\overline{p}_{ir}$	0.90%	0.98%	1.07%	1.21%	1.36%	
Call Origination						
n_o	1350	1382	1376	1347	1335	
System Access						
n_{sa}	13896	15193	16321	18023	20250	
n_{to}	0	0	0	0	0	
n_{se}	14292	15819	17251	19409	22061	
n_{su}	13894	15192	16320	18023	20249	
n_{sr}	398	627	931	1386	1812	
n_{mb}	0	0	0	0	0	
Channel Utilization						
$\overline{u}_{fo}$	6.80%	6.57%	6.46%	6.32%	6.37%	
$\overline{u}_{re}$	0.72%	0.99%	1.11%	1.08%	1.25%	

Table 4.6 Simulation Results for $\overline{s}$ = 10 kmph, $\overline{D}_s$ = 750 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t		635	632	655	723	683
n_a		635	632	655	723	683
n_1		428	418	443	478	456
p_1		67.40%	66.14%	67.63%	66.11%	66.76%
n_r		207	214	212	244	227
n_2		205	213	210	238	216
p_2		99.03%	99.53%	99.06%	97.54%	95.15%
p_t		99.69%	99.84%	99.69%	99.03%	98.39%
n_p		31470	22320	17652	16809	14303
$\overline{n}_c$		50	35	27	23	21
$\overline{D}_{pr}$		2828 ms	2858 ms	2822 ms	2840 ms	2834 ms
Registration						
n_f		2049	4026	7151	10208	13355
n_{rg}		13162	14365	16094	18119	20037
n_{fr}		0	0	0	0	0
n_{cr}		13161	14360	16092	18117	20033
$\overline{D}_r$		6017 ms	6071 ms	6021 ms	6071 ms	6093 ms
$\overline{p}_{ir}$		1.10%	1.21%	1.35%	1.53%	1.70%
Call Origination						
n_o		1305	1243	1311	1304	1254
System Access						
n_{sa}		15100	16239	18060	20140	21966
n_{to}		0	0	0	0	0
n_{se}		15406	16695	18817	21080	23303
n_{su}		15100	16239	18057	20139	21961
n_{sr}		306	456	760	941	1342
n_{mb}		0	0	0	0	0
Channel Utilization						
$\overline{u}_{fo}$		6.77%	6.61%	6.46%	6.59%	6.60%
$\overline{u}_{re}$		1.03%	1.12%	1.01%	1.28%	1.36%

Table 4.7 Simulation Results for $\overline{s}$ = 10 kmph, $\overline{D}_s$ = 1000 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t	627	705	671	639	632	641
n_a	627	705	671	639	632	641
n_1	287	308	278	301	285	276
p_1	45.77%	43.69%	41.43%	47.10%	45.09%	43.06%
n_r	337	397	393	338	346	363
n_2	336	388	392	334	338	353
p_2	99.70%	97.73%	99.75%	98.82%	97.69%	97.25%
p_t	99.36%	98.72%	99.85%	99.37%	98.58%	98.13%
n_p	57840	44970	33645	25099	22656	22421
$\overline{n}_c$	92	64	50	39	36	35
$\overline{D}_{pr}$	3072 ms	3090 ms	3107 ms	3054 ms	3088 ms	3100 ms
Registration						
n_f	0	2004	3953	7050	10274	13420
n_{rg}	11903	13145	14239	16038	18221	20062
n_{fr}	0	0	0	0	0	0
n_{cr}	11895	13137	14231	16033	18217	20060
$\overline{D}_r$	7219 ms	7163 ms	7133 ms	7152 ms	7146 ms	7185 ms
$\overline{p}_{ir}$	1.19%	1.31%	1.41%	1.59%	1.81%	2.00%
Call Origination						
n_o	1369	1314	1354	1327	1361	1372
System Access						
n_{sa}	13898	15158	16264	18000	20207	22067
n_{to}	0	0	0	0	0	0
n_{se}	14174	15594	16806	18862	21269	23579
n_{su}	13891	15151	16261	17999	20204	22062
n_{sr}	283	443	545	863	1065	1517
n_{mb}	0	0	0	0	0	0
Channel Utilization						
$\overline{u}_{fo}$	7.12%	7.01%	6.79%	6.75%	6.69%	6.69%
$\overline{u}_{re}$	0.70%	0.97%	0.99%	1.26%	1.24%	1.25%

Table 4.8 Simulation Results for $\overline{s}$ = 50 kmph, $\overline{D}_s$ = 500 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t	665	674	679	601	641	595
n_a	665	674	679	601	641	595
n_1	574	564	577	519	534	500
p_1	86.32%	83.68%	84.98%	86.36%	83.31%	84.03%
n_r	91	107	102	81	107	95
n_2	90	104	97	71	92	75
p_2	98.90%	97.20%	95.10%	87.65%	85.98%	78.95%
p_t	99.85%	99.11%	99.26%	98.17%	97.66%	96.64%
n_p	45360	26640	16305	9406	8343	6295
$\overline{n}_c$	68	40	24	16	13	11
$\overline{D}_{pr}$	2594 ms	2658 ms	2632 ms	2585 ms	2638 ms	2677 ms
Registration						
n_f	0	8961	16917	31322	41232	49881
n_{rg}	11922	16753	21594	32903	42030	50476
n_{fr}	0	0	0	0	0	0
n_{cr}	11922	16753	21594	32903	42030	50475
$\overline{D}_r$	5416 ms	5400 ms	5393 ms	5420 ms	5416 ms	5407 ms
$\overline{p}_{ir}$	0.90%	1.26%	1.62%	2.48%	3.16%	3.79%
Call Origination						
n_o	1291	1297	1312	1334	1329	1398
System Access						
n_{sa}	13878	18724	23582	34830	43985	52450
n_{to}	0	0	0	0	0	0
n_{se}	14285	20432	27009	42059	56173	70762
n_{su}	13877	18719	23581	34827	43985	52448
n_{sr}	408	1713	3428	7232	12188	18313
n_{mb}	0	0	0	0	0	1
Channel Utilization						
$\overline{u}_{fo}$	6.77%	6.45%	6.20%	6.05%	6.26%	6.35%
$\overline{u}_{re}$	0.55%	0.71%	0.64%	0.66%	1.01%	1.25%

Table 4.9 Simulation Results for $\overline{s}$ = 50 kmph, $\overline{D}_s$ = 750 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t	675	695		679	622	639
n_a	675	695		679	622	639
n_1	425	480		421	380	381
p_1	62.96%	69.06%		62.00%	61.09%	59.62%
n_r	250	215		257	242	258
n_2	244	211		246	227	228
p_2	97.60%	98.14%		95.72%	93.80%	88.37%
p_t	99.11%	99.42%		98.23%	97.59%	95.31%
n_p	55500	33750		20513	16385	16119
$\overline{n}_c$	82	49		30	26	25
$\overline{D}_{pr}$	2893 ms	2829 ms		2900 ms	2915 ms	2918 ms
Registration						
n_f	0	8805		31449	41216	49893
n_{rg}	11920	16626		32939	42008	50487
n_{fr}	0	0		0	0	0
n_{cr}	11917	16621		32935	42000	50474
$\overline{D}_r$	5969 ms	5990 ms		6006 ms	5993 ms	6010 ms
$\overline{p}_{ir}$	0.99%	1.38%		2.75%	3.50%	4.21%
Call Origination						
n_o	1244	1325		1357	1334	1366
System Access						
n_{sa}	13833	18643		34967	43952	52463
n_{to}	0	0		0	0	0
n_{se}	14082	19558		38834	49891	61253
n_{su}	13833	18640		34962	43947	52459
n_{sr}	249	918		3871	5943	8794
n_{mb}	0	0		1	1	0
Channel Utilization						
$\overline{u}_{fo}$	6.96%	6.59%		6.26%	6.42%	6.56%
$\overline{u}_{re}$	0.50%	0.66%		0.59%	1.02%	1.24%

Table 4.10 Simulation Results for $\bar{s}$ = 50 kmph, $\bar{D}_s$ = 1000 ms

Measurements	LAC1	LAC2	LAC4	LAC8	LAC20	LAC60
Paging						
n_t	653	707	689	672		663
n_a	653	707	689	672		663
n_1	274	290	289	294		255
p_1	41.96%	41.02%	41.94%	43.75%		38.46%
n_r	378	417	399	377		407
n_2	375	410	384	359		373
p_2	99.21%	98.32%	96.24%	95.23%		91.65%
p_t	99.39%	99.01%	97.68%	97.17%		94.72%
n_p	61860	46230	34275	27662		25083
$\bar{n}_c$	95	65	50	41		38
$\bar{D}_{pr}$	3127 ms	3190 ms	3137 ms	3153 ms		3166 ms
Registration						
n_f	0	8957	17102	31573		51104
n_{rg}	11907	16740	21731	33117		51688
n_{fr}	0	0	0	0		0
n_{cr}	11902	16719	21709	33068		51628
$\bar{D}_r$	7132 ms	7127 ms	7147 ms	7138 ms		7146 ms
$\bar{p}_{ir}$	1.18%	1.66%	2.16%	3.28%		5.13%
Call Origination						
n_o	1361	1340	1317	1322		1316
System Access						
n_{sa}	13918	18781	23722	35093		53633
n_{to}	0	0	0	0		0
n_{se}	14217	19792	25736	39308		63928
n_{su}	13914	18775	23712	35074		53603
n_{sr}	303	1017	2024	4234		10324
n_{mb}	0	0	0	0		1
Channel Utilization						
$\bar{u}_{fo}$	7.10%	6.92%	6.58%	6.47%		6.92%
$\bar{u}_{re}$	0.51%	0.75%	0.66%	0.68%		1.52%

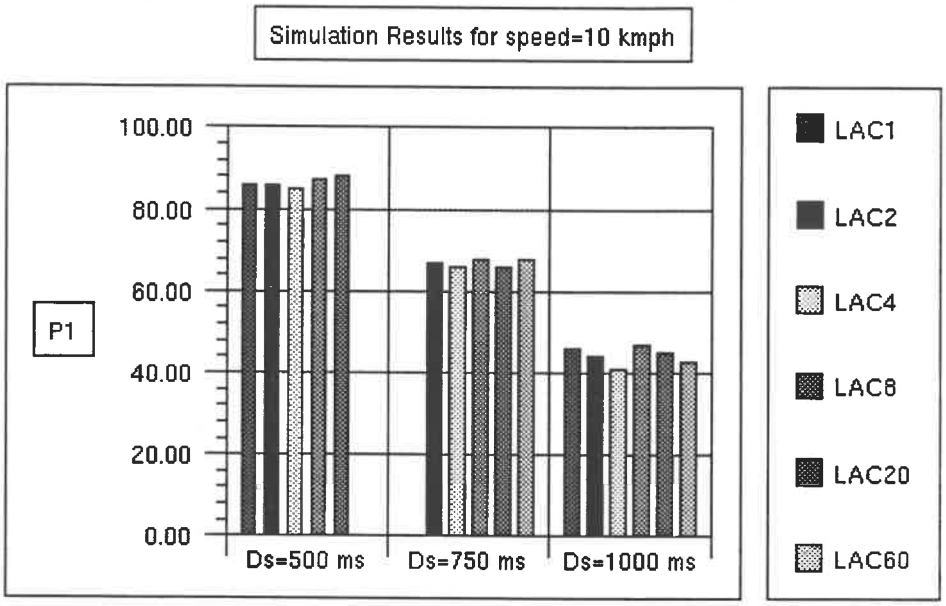


Figure 4.5. p_1 Results for $\bar{s}$ = 10 kmph

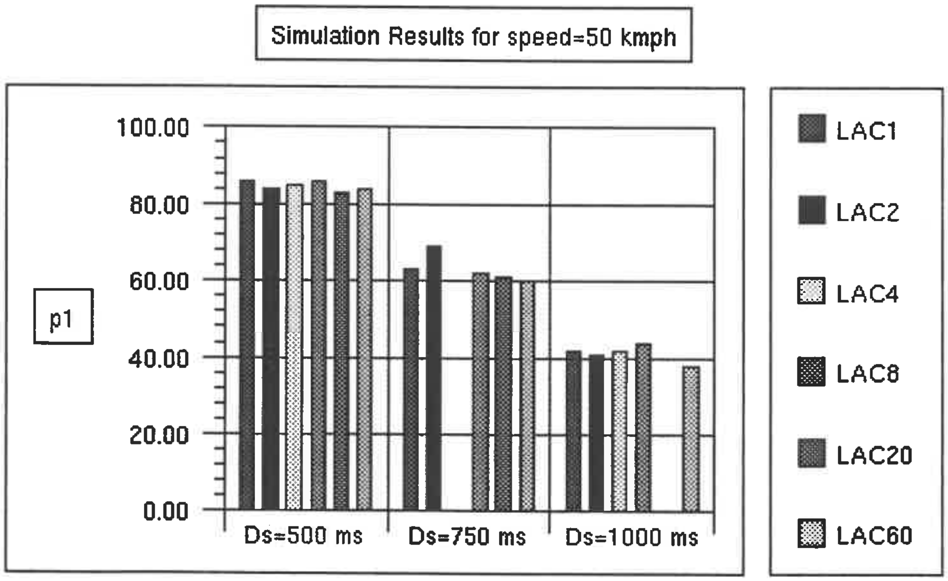


Figure 4.6. p_1 Results for $\bar{s}$ = 50 kmph

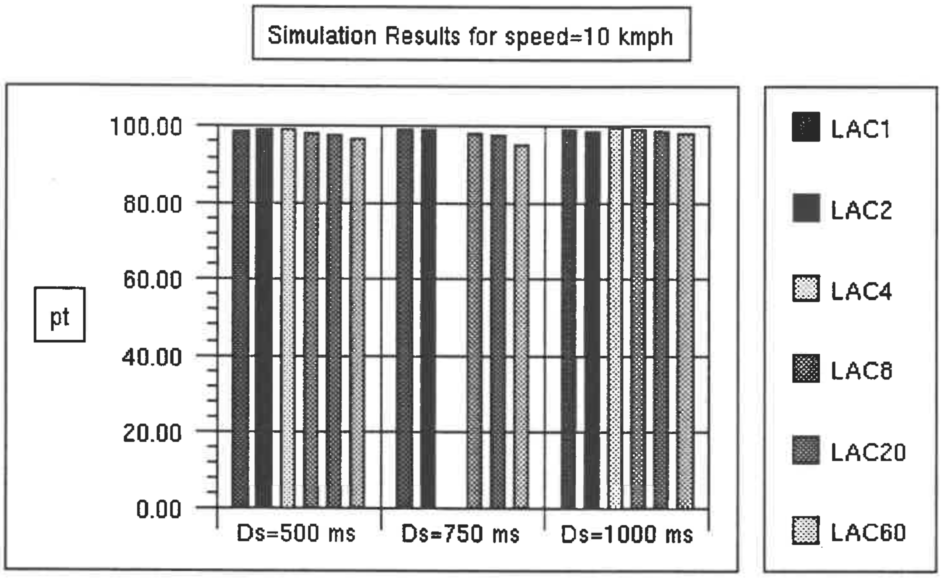


Figure 4.7. p_t Results for $\bar{s}$ = 10 kmph

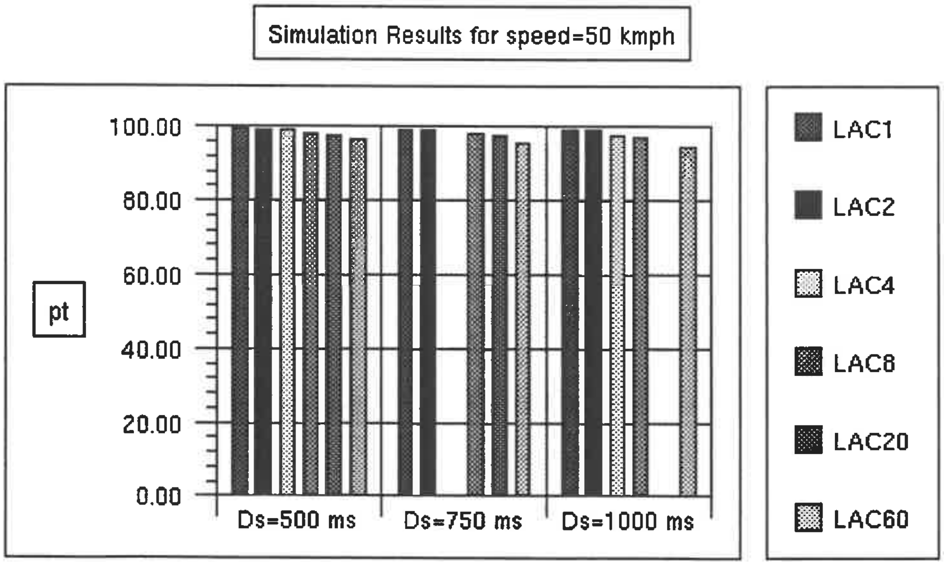


Figure 4.8. p_t Results for $\bar{s}$ = 50 kmph

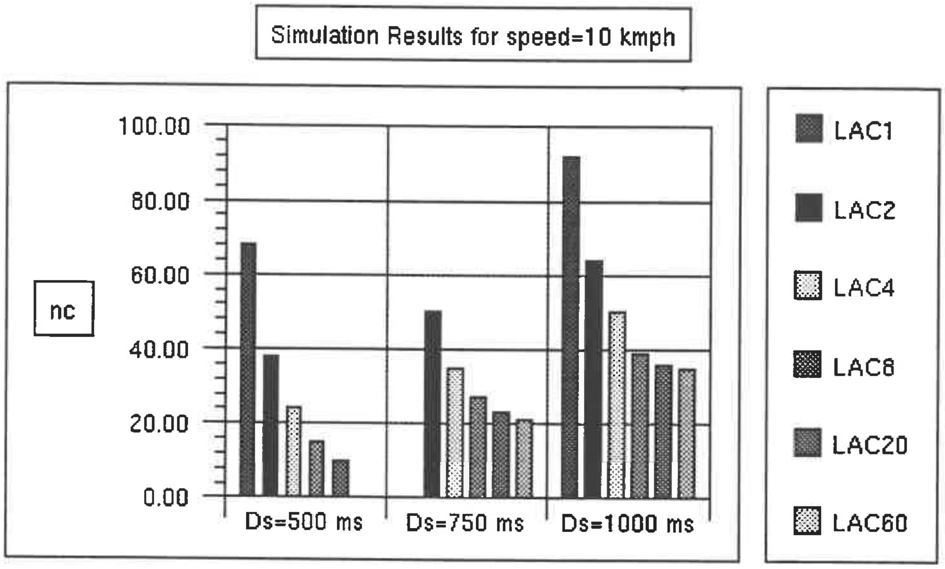


Figure 4.9. $\overline{n}_c$ Results for $\overline{s}$ = 10 kmph

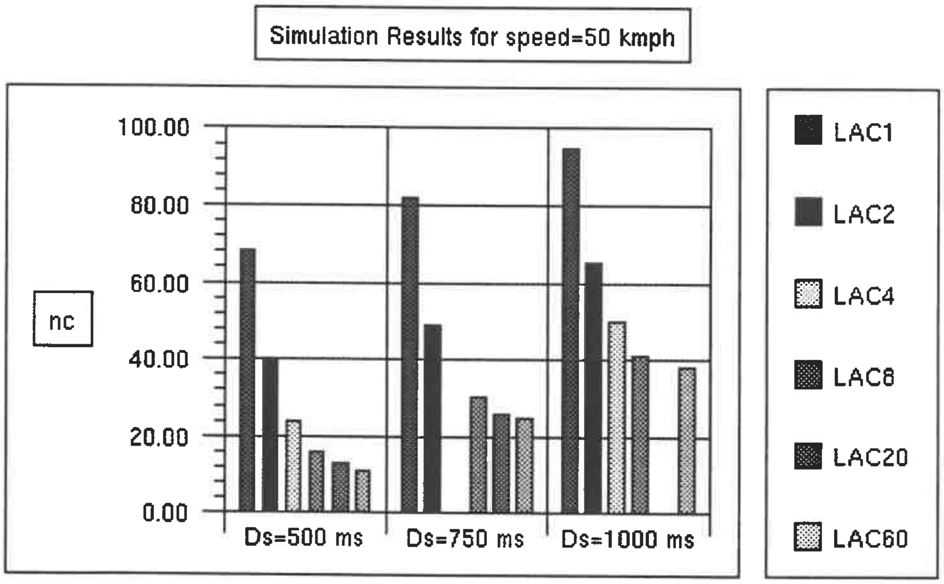


Figure 4.10. $\overline{n}_c$ Results for $\overline{s}$ = 50 kmph

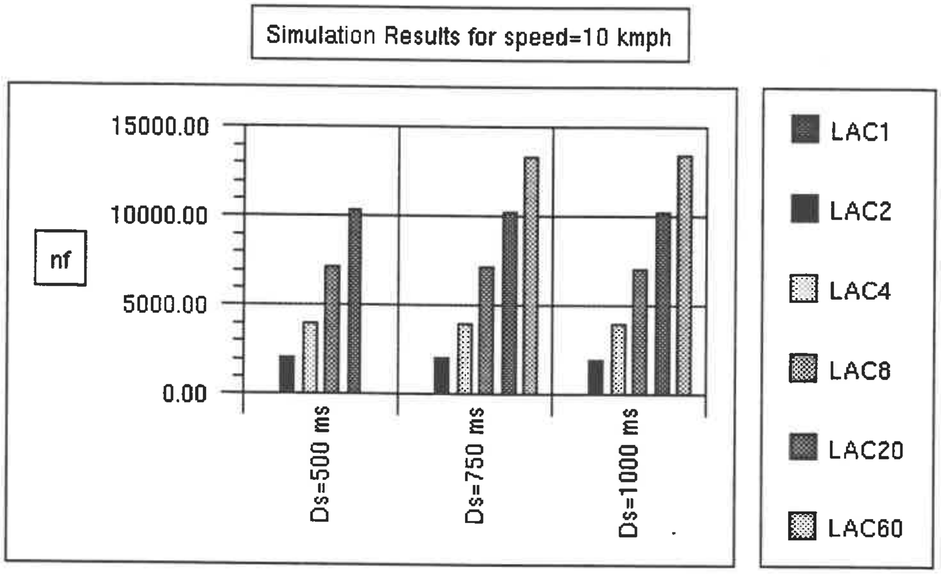


Figure 4.11. n_f Results for $\bar{s}$ = 10 kmph

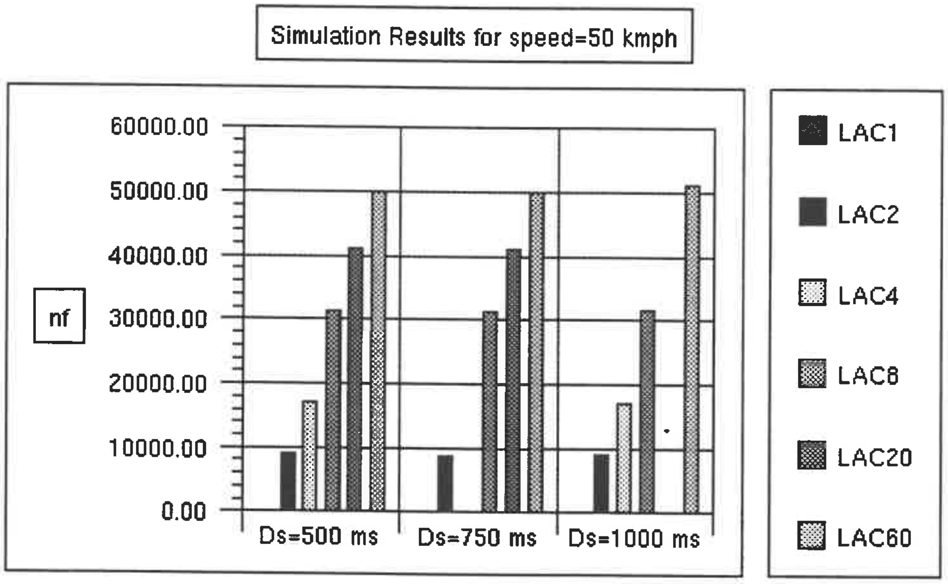


Figure 4.12. n_f Results for $\bar{s}$ = 50 kmph

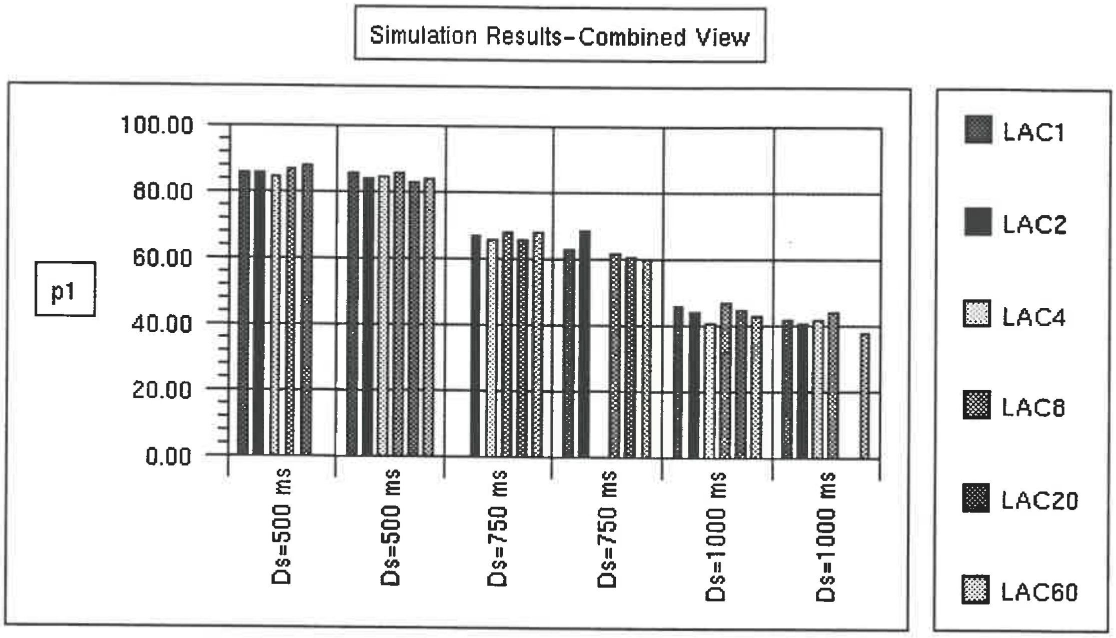


Figure 4.13. p_1 Results for $\bar{s}$ = 10 kmph, 50 kmph

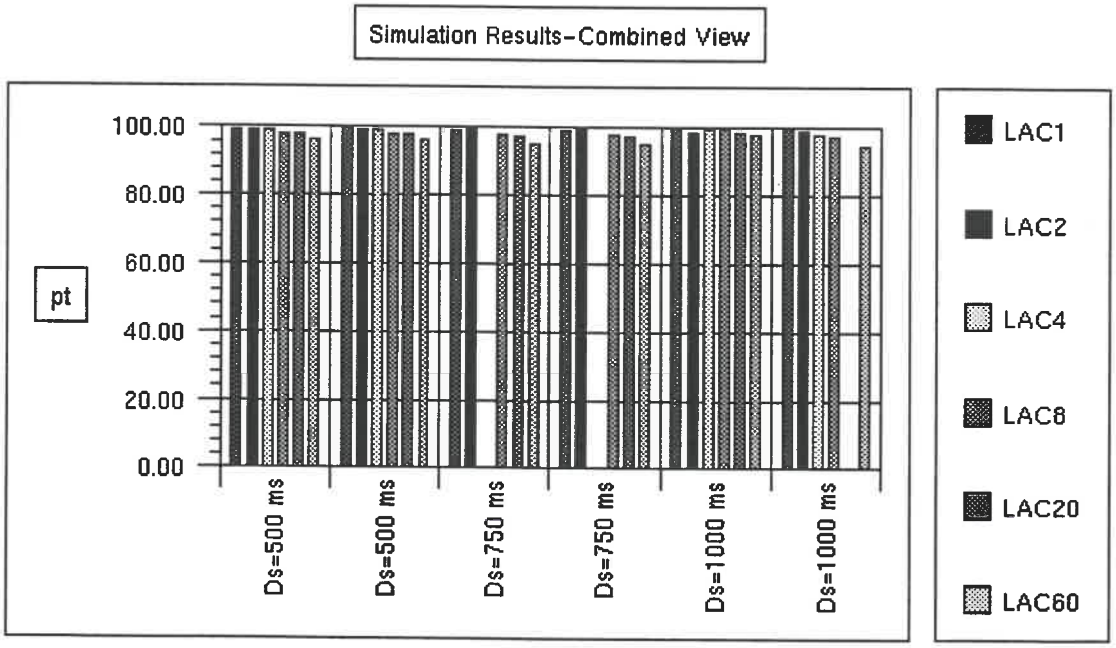


Figure 4.14. p_t Results for $\bar{s}$ = 10 kmph, 50 kmph

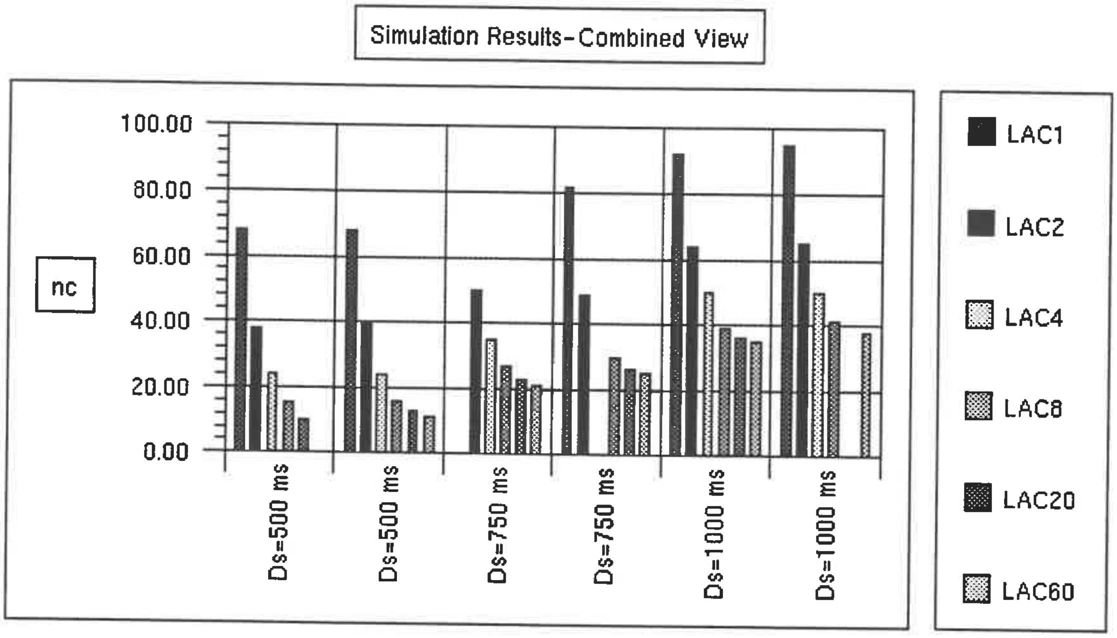


Figure 4.15. $\bar{n}_c$ Results for $\bar{s}$ = 10 kmph, 50 kmph

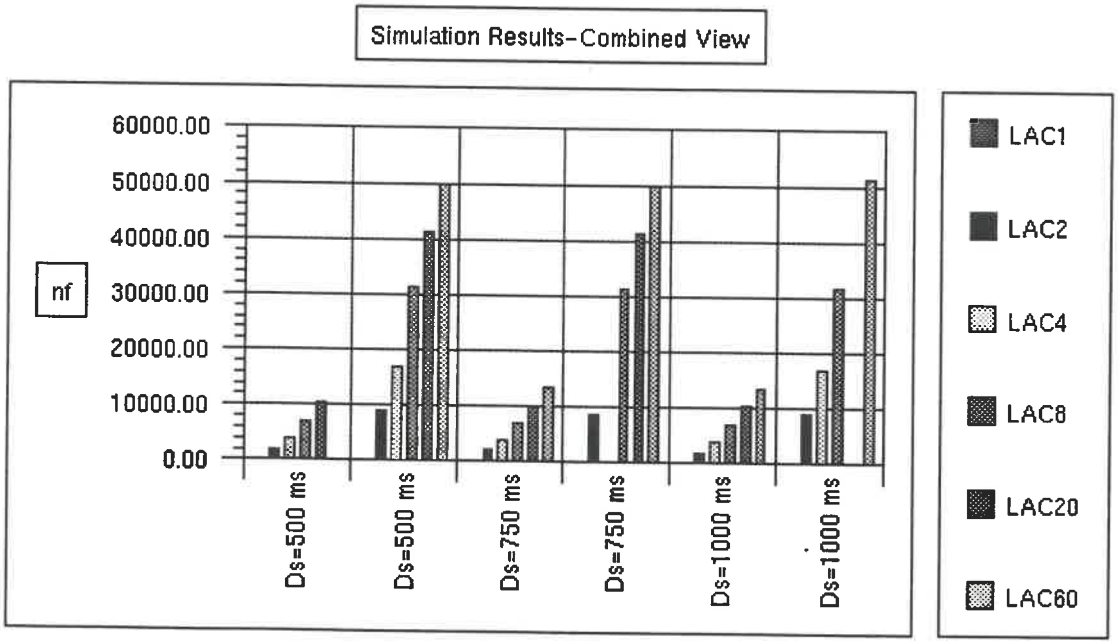


Figure 4.16. n_f Results for $\bar{s}$ = 10 kmph, 50 kmph

4.3. Analysis of Results

This analysis focuses more on how the results demonstrate the validity of the simulation model that has been developed. Because of certain performance and memory limitations exhibited during the execution of the simulations, it was not possible to analyze the behaviour of the CMTS operating under high subscriber volume conditions. This was unfortunate since many of the paging and registration assumptions that we wanted to investigate originally were related to this very issue. Despite this drawback, the results nevertheless demonstrate that the paging and registration mechanisms that have been modelled are executing correctly.

The discussion of the results focuses mainly on the measurements of $\boldsymbol{p_1}$, $\boldsymbol{p_t}$, $\boldsymbol{\overline{n}_c}$, and $\boldsymbol{n_f}$, as $\boldsymbol{\overline{D}_s}$, $\overline{s}$, and **LACs** were varied. Of all the measurements, these four provide the most significant insight into the behaviour of the CMTS. Each measurement is first analyzed separately followed by a general summary and interpretation of the results.

4.3.1. Analysis of p_1 Measurements

From Figure 4.5., we observe that $\boldsymbol{p_1}$ remains virtually constant for all location area configurations for a given $\boldsymbol{\overline{D}_s}$. This was somewhat expected since at such a slow speed (10 kmph), one would not expect $\boldsymbol{p_1}$ to be affected. Figure 4.6, we observe the same phenomena for an average speed of 50 kmph. Therefore, it would seem like the paging performance of the CMTS is not affected by speed, at least for speeds less than 50 kmph, regardless of the location area configuration. Figure 4.13. provides a combined view of the $\boldsymbol{p_1}$ results obtained for speeds of 10 and 50 kmph. $\boldsymbol{p_1}$ results have been grouped by $\boldsymbol{\overline{D}_s}$ to more easily compare them at both speeds. At a glance, there does not seem to be any significant difference in $\boldsymbol{p_1}$ results at either speeds. This is a subjective assessment and would require further statistical analysis.

However, as mentioned earlier, these results were obtained using a low volume of subscribers (2000 subscribers spread over 60 cells). Thus, we cannot draw the conclusion that $\boldsymbol{p_1}$ remains constant for all location area configurations for a given $\boldsymbol{\overline{D}_s}$. To arrive to such a conclusion would require simulating with a subscriber volume which would stress the CMTS more substancially.

From Figure 4.5., we observe that p_1 decreases with increasing $\overline{D}_s$ for a speed of 10 kmph. This is justified by the fact that a longer $\overline{D}_s$ increases the page response delay, D_{pr}. Taking the average of D_{pr} for all location area configurations, we obtain 2578 ms for $\overline{D}_s$ = 500 ms, 2836 ms for $\overline{D}_s$ = 750 ms, and 3085 ms for $\overline{D}_s$ = 1000 ms. Since the page response time-out period is 3 s, the probability of responding late to a page naturally increases. This can also be observed for $\overline{s}$ = 50 kmph in Figure 4.6. Averaging D_{pr} for all location area configurations for $\overline{s}$ = 50 kmph gives 2630 ms, 2891 ms, and 3155 ms for $\overline{D}_s$ = 500 ms, 750 ms, and 1000 ms respectively. Thus, longer control channel scan durations have an effect on the page response delay and therefore affect p_1. The combined view of Figure 4.13. emphasizes this trend observed at both speeds. One important observation is that p_1 is quite sensitive to $\overline{D}_s$. This is due to the page response time-out period of 3 seconds being too short. This value is typically used in industry but has been known to cause problems in the past. From our results, we can conclude that a page response time-out period of 3 seconds is too low. Future simulation executions should include investigating the behaviour of the CMTS while using longer page response time-out values.

It is important to note that imulating with a high volume of subscribers may yield longer D_{pr} results since the resulting increase in the overall registration frequency could potentially increase the time it takes a mobile station to access the CMTS.

4.3.2. Analysis of p_t Measurements

From Figures 4.7 and 4.8, we observe that p_t remains high for all location area configurations, for all $\overline{D}_s$, and for both speeds. Figure 4.14. provides a combined view which further highlights the high p_t results. The p_t results range from 99.8% to 94.7% and are somewhat better than measurements taken from the field because the simulation model provides excellent radio coverage everywhere without consideration for Rayleigh fading or radio interference effects. Despite the variation in p_1, p_t results remain high as a consequence of the paging strategy applied by the CMTS which is to issue a second page whenever it does not receive a timely response to the first one. The results presented earlier showed that p_1 is affected by $\overline{D}_s$ and not by speed. This means that mobile stations do receive the first page regardless of their speed. Their late response is due mainly to the total delay incurred during the response process. Their late response is nevertheless processed as a response to the second page attempt. So, although p_1 is lower for longer $\overline{D}_s$, p_t remains high. Figure 4.14. further highlights the high p_t results.

Figures 4.7 and 4.8 also shows p_t to slightly decrease with increasing LAC. The rate of decrease is most noticeable for the simulation executed with a control channel scan duration of 1000 ms and a speed of 50 kmph. In this case, p_t went from 99.4% for LAC1 to 94.72% for LAC60. This behaviour supports our initial hypothesis that the overall paging success would decrease when the CMTS is configured with smaller location areas and subjected to mobiles travelling at higher speeds. This would require further experimentation and statistical analysis before any scientifically based conclusion can be reached.

As stated previously, a high volume of subscribers could decrease p_t results if it would cause the time for mobile stations to access the system to increase to a point where high volume page response delay would exceed by twice the page response timeout period.

4.3.3. Analysis of $\overline{n}_c$ Measurements

From Figure 4.9. and Figure 4.10, we observe that $\overline{n}_c$, at speeds of 10 kmph and 50 kmph, for all location area configurations, increases with increasing $\overline{D}_s$. This is expected since as described earlier, p_1 decreases with increasing $\overline{D}_s$. This means that more second page attempts will have to be made by the CMTS thereby increasing $\overline{n}_c$. From figures 4.9 and 4.10, we also observe that $\overline{n}_c$ decreases with increasing LAC. This is in line with our original expectations of larger location areas leading to a higher number of pages broadcasted throughout the system on the first attempt. As the number of cells per location area decreases, so does $\overline{n}_c$.

Figure 4.15 provides a combined view of the results obtained for $\overline{n}_c$. Comparing $\overline{n}_c$ results at both speeds indicates that speed is not a contributing factor.

$\overline{n}_c$ could actually be higher for high subscriber volume scenarios if we again consider that system access time could potentially increase. More first page attempts would time out causing an increased number of second page attempts leading to a higher $\overline{n}_c$ result.

4.3.4. Analysis of n_f Measurements

From Figure 4.11., we observe that for all $\overline{D}_s$ values, n_f increases as the number of cells per location area decreases (LAC1 has all 60 cells as part of one large location area while LAC60 has only one cell per location area). This is expected since the smaller the location area, the more often a mobile station will be required to perform a forced registration. n_f remains essentially constant for all $\overline{D}_s$ values.

From Figure 4.12., we observe the same trend for $s = 50$ kmph as just described for $s = 10$ kmph but with higher n_f values. This is also expected since the faster a mobile station is moving in a random pattern, the more often it will cross location area borders. Averaging n_f for all $\overline{D}_s$ values for both speeds and then averaging the ratio of n_f at both speeds, we obtain an average ratio of 4.2 between n_f at 50 kmph and n_f at 10 kmph. This ratio is essentially consistent with the five-fold increase in speed. It is a bit lower since periodic registrations eventually get replaced by forced registrations when their frequency reaches a certain level. Figure 4.16 highlights the difference in n_f at both speeds.

In all cases, we observe that $n_f = 0$ for LAC1 which is also expected since the LAC1 configuration contains a single location area and therefore has no location area borders. Other n_f results also verify the correct operation of the simulation model. For example, for a cell diameter of $2r = 1$ km, an average speed of 50 kmph, and a location area configuration of one cell per location area (LAC60), one would expect each mobile to cross location area borders an average of 25 times given that their movement pattern is completely random. Given that we simulated using 2000 mobile stations, one would expect n_f to be in the order of 50000. The results obtained for this case were in fact 52450, 49893, and 51104 for $\overline{D}_s = 500$ ms, 750 ms, and 1000 ms respectively.

4.3.5. General Analysis

The following summarizes the observations that can be made based on the results obtained:

- n_f is inversely proportional to the size of a location area;
- p_l remains virtually constant for all location area configurations and all speeds for a given $\overline{D}_s$;
- p_l decreases with increasing $\overline{D}_s$ with the page response time-out period of 3 seconds which is common but not ideal;
- p_t is high for all $\overline{D}_s$ and for all location area configurations for speeds up to 50 kmph;
- p_t decreases slightly with increasing speed and increasing control channel scan duration when using 2000 mobile subscribers;
- $\overline{n}_c$ is proportional to the size of a location area;
- $\overline{n}_c$ increases with increasing $\overline{D}_s$ for all location area configurations;
- $\overline{n}_c$ remains constant for speeds up to 50 kmph;
- $\overline{n}_c$ decreases with decreasing location area size;
- n_f increases as the number of cells per location area decreases for all $\overline{D}_s$ values;
- the normalized percentage of seizure retries n_{sr} per system access attempt n_{sa} increases with speed for all $\overline{D}_s$ values.

The results obtained are generally in line with our original expectations. We can see though, that more extensive work is required if we are to fully investigate all originally formulated hypotheses. It would seem like the simulation program that has been implemented is functioning correctly according to what was specified. There are areas, mainly simulating with high subscriber volume, that were not covered and would require attention in the future. If we refer back to the original hypotheses formulated in section 1.1 Effects of Location Area Size on Paging and Registration, some of our initial queries were not answered.

Of all the shortcomings identified in the present simulation model, the most critical is its inability to handle a large volume of subscribers. A number of hypotheses formulated originally could not be verified as a result. This was due to physical limitations imposed by the SIMSCRIPT II.5 environment. Further investigation is required to overcome these limitations as the effects of high subscriber volume on CMTS performance are of key interest to the study at hand.

For example, one hypothesis was that the increase in the number of forced registrations brought on by small location areas could increase the time a mobile station requires to access the system. This was somewhat verified by considering the percentage of number of seizure retries n_{sr} per system access attempt n_{sa}. From Figure 4.17., we observe that this ratio is higher at 50 kmph than at 10 kmph for all $\overline{D}_s$ values. The increasing trend is quite apparent. Given the low volume of mobile subscribers that was used for the simulations (2000), this effect did not cause any significant impact on the performance of the CMTS. This may not, however, be the case for large volumes in the order of 30000 mobile subscribers (which is closer to reality) where the CMTS would be operating closer to its maximum capacity.

Another hypothesis was related to potential paging congestion when using large location areas. It was initially thought that a high enough subscriber volume could cause the quantity of pages issued n_p to exceed the overall paging channel capacity of the CMTS As a result, pages could start being dropped. Again, this could not be verified with the low volume of subscribers that were used.

The impact of increased quantity of registrations may have on paging success was not verified either. The increase in n_f due to both speed and control channel duration did not affect p_1 or p_t. The percentage of time that a mobile station was unreachable by page varied between 0.9% and 5.13%. This may not be the case if the CMTS is subjected to higher subscriber volume.

The effect of speed on the performance of the CMTS was also of concern to this project. It is believed that mobiles travelling at high speeds within an area configured as small location areas, would cause the CMTS's perception of the position of a mobile to lag the actual position of a mobile leading to lower paging succes rates. CMTS performance thus becomes increasingly sensitive to speed if delays start occuring because of high subscriber volume. Furthermore, the mobility model that was developed assumed that mobiles were moving randomly within the service area. Speeds of 50 kmph were assumed to be reasonable for mobility behaviour within an urban environment. At 50 kmph, there was no evidence of the CMTS losing track of the position of the mobile. However, mobiles travelling on highways would reach much higher speeds. The effect that they would have on the CMTS has not been investigated. The current simulation program already supports highway movement patterns (Figure 4.18.) and it therefore may be of interest to pursue this investigation further in the future.

Another important note is that during the preparation of this report, it was realized that the simulation model did not model the FOCC message stream correctly. The simulation model does not consider the interleaving of messages on both streams A and B. As a result, the time it takes to broadcast a message to a mobile station is approximately half of what should be expected. This is relatively insignificant if we consider other factors that have more of an impact on delay. However, if any further use is to be made of this model, it is imperative that the interleaving of messages be incorporated to reflect reality.

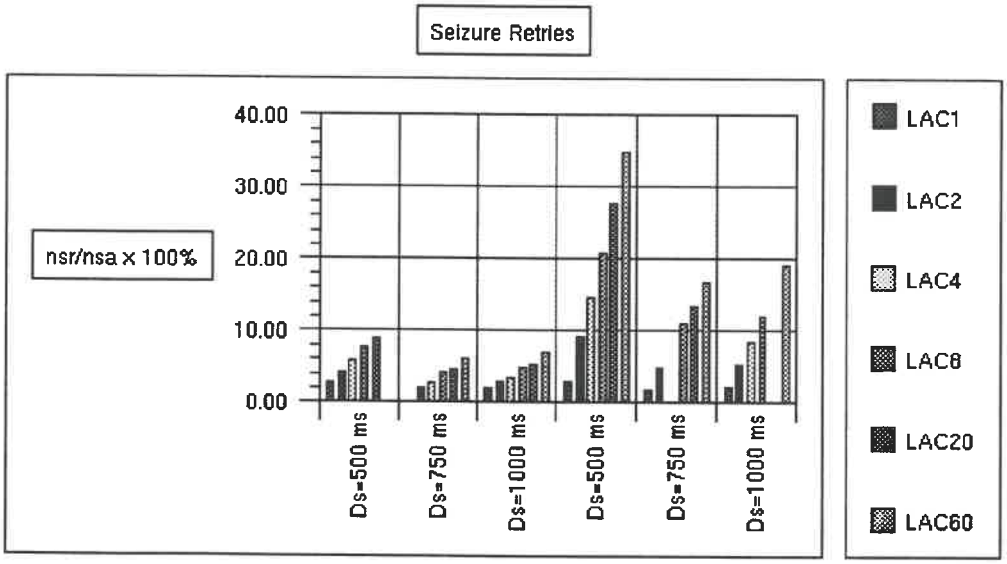


Figure 4.17. Normalized Percentage of Seizure Retries

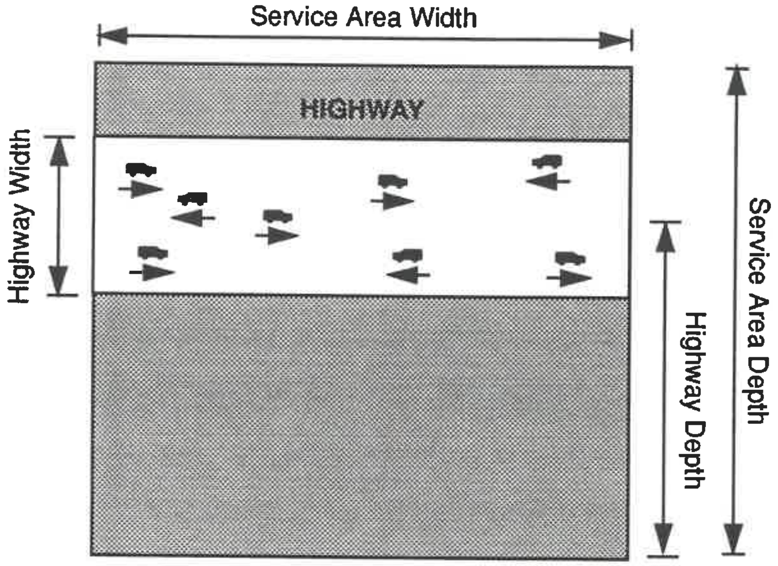


Figure 4.18. Highway Movement Pattern

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

One of the most important outcomes of this project is a proposed framework for continued work in CMTS mobility management. A simulation model which simulates the paging and registration processes of a CMTS and the external environment within which the CMTS operates was specified and implemented. The simulation of the CMTS operation was based on the call specification of the IS-54B compatibility standard. The CMTS "engine" was created by rigorously translating the IS-54B text into a state model. This is the cornerstone of the entire project.

There are shortcomings in the simulation model that has been developed and they have been identified throughout this report. As this study was diving much into the unknown (this seemed to be the case since it was difficult to locate any material that treated such a subject), what is most usable for the future is the approach taken and the actual framework which has been formulated. The work that has been done within the scope of this project is a step towards formalizing the study of mobility management and essentially sets the stage for future work in this area. The results that have been obtained, seem at first glance to be generally in line with our original expectations. However, they should not be the main focus here. More work is required to proper validate the model if we are to use the results for any real purpose. The results which were obtained seem to indicate for the most part that the model is functioning correctly but more extensive investigations using the model are required to properly validate it and thus be in a position to reach any scientifically based conclusion. Only then will the model be capable of serving any real purpose.

Based on the results obtained, we can nevertheless summarize our findings. All observations listed here were obtained using a low volume of mobile subscribers and thus are not conclusive. We have not attempted to extrapolate these findings for simulation scenarios involving a high volume of subscribers. Keeping with the simulation strategy, one would need to enhance the capability of the simulation model to allow simulation using high subscriber volume.

The findings are as follows:

- n_f is inversely proportional to the size of a location area;
- p_l remains virtually constant for all location area configurations and all speeds for a given $\overline{D}_s$;
- p_l decreases with increasing $\overline{D}_s$ with the page response time-out period of 3 seconds which is common but not ideal;
- p_t is high for all $\overline{D}_s$ and for all location area configurations for speeds up to 50 kmph;
- p_t decreases slightly with increasing speed and increasing control channel scan duration when using 2000 mobile subscribers;
- $\overline{n}_c$ is proportional to the size of a location area;
- $\overline{n}_c$ increases with increasing $\overline{D}_s$ for all location area configurations;
- $\overline{n}_c$ remains constant for speeds up to 50 kmph;
- $\overline{n}_c$ decreases with decreasing location area size;
- n_f increases as the number of cells per location area decreases for all $\overline{D}_s$ values;
- the normalized percentage of seizure retries n_{sr} per system access attempt n_{sa} increases with speed for all $\overline{D}_s$ values.

5.2. Recommendations

The following paragraphs highlight some of the shortcomings of the simulation model that need to be addressed before any further work is attempted with it. Also mentioned are areas of possible interest for future investigations.

FOCC Message Stream Model Correction

The simulation model does not consider the interleaving of messages on streams A and B. As a result, the time it takes to broadcast a message to a mobile station is approximately half of what it should be. If any further use is to be made of this model, the interleaving of messages must be incorporated to reflect the IS-54B standard.

Channel Utilization Investigation

There seems to be some inconsistencies in the FOCC and RECC channel utilization results that were obtained. There was a slight discrepancy between utilization results obtained through straightforward calculations using some of the other results that were reported and channel utilization results generated by the simulation program. This is of relatively low importance since the utilizations that have been reported are very low, in the order of 1%. However, it requires mention so that future users of the model investigate this aspect before pursuing any further work with it.

High Subscriber Volume

Large volumes of mobile subscribers were identified at the start as potential cause for poor paging performance but simulations using high mobile subscriber density scenarios were not executed. The subscriber density used in our simulation scenarios was in the order of 33 subscribers per cell of radius 500m. We should be simulating with subscriber densities that are more in the order 500 to 700 subscribers per cell. Attempts to run high subscriber volume simulations were unsuccessful because of physical limitations imposed by the SIMSCRIPT II.5 run-time environment. Future related projects should attempt to overcome this limitation since the capacity of a CMTS to process paging and registration transactions when subjected to high mobile subscriber volume is of critical interest to any CMTS operator.

MSC Registration Processing

Only the load created on the RECC and FOCC were considered by the simulation model. If we are to tackle the CMTS as a complete system, it may be beneficial to model the MSC processor which is handling paging and registration. A service area configured with small location areas may cause such a high volume of registrations that the MSC processor would not be capable of handling the load. A preliminary investigation could be made to determine the plausibility of such a scenario before initiating any modifications to the simulation model.

Parameter Sensitivity Analysis

Future analyses of results produced by the simulation model should include a parameter sensitivity analysis. This is required if we are to establish in a scientifically rigorous fashion the relationships that exist between the various parameters that are included in the simulation model. This could be done using some type of statistical analysis software package such as SAS. Prohibitive project time constraints made it impossible to perform such an analysis. In its current state, the simulation program offers the possibility of analyzing countless scenarios. It offers a fair amount of flexibility since parameters are easily changeable in the input file or the simulation program itself. It can be used to conduct other experiments related to mobility management or can be used as a starting point for modelling future CMTS mobility management functionality.

Multi-Exchange Paging Model

The study focused on paging within an MSC's service area. Multi-exchange paging is a new feature which allows paging to span multiple MSCs. Future development of the simulation model could include the concept of multi-exchange paging since the implementation of this new feature is sure to introduce a new class of problems and challenges.

Transmission Network Model

Rather than simulate using deterministic transmission delays, as was the case in this study, it may be of interest to introduce a more sophisticated transmission model which considers queuing of messages. This would be especially important if simulations with high mobile subscriber density are performed.

Cost Model and Optimization

A cost model for paging and registration would need to be developed using the parameters and the measurements defined within this project. This would lead to the capability of performing cost-benefit analyses in the area of mobility management and could eventually lead to optimization opportunities.

Simulation Model as a Commercial Tool

The modelling of the movement of mobile subscribers and radio propagation would require more work in the future if the simulation model is to become a CMTS operator's tool to dimension its cellular network. It may then become necessary to have the simulation program read data files gathered from transport and radio surveys rather than generate movement patterns according to statistical distributions and radio environments based on empirical formulas. Furthermore, if CMTS suppliers or operators had any interest in such a dimensioning tool, proper graphical user interface (including the entering of data and the reporting of results) and supporting user documentation could be developed to facilitate its use. It would be interesting to investigate whether CMTS operators or suppliers would have any interest in such a product.

Hierarchical Cell Structures

This study focused essentially on macro cell structures. The upcoming trend in the cellular industry is the use of micro and pico cell structures which are smaller than macro cells. The application of these new cell structures will be within the realm of Personal Communication Services (PCS). Numerous mobility management issues will arise as a result and will require investigation.

University and Industry Joint Research and Development

Since the mobile communication industry is evolving at an extremely rapid pace, Personal Communication Systems (PCS) being a current example of the future trend in mobile communication, analyzing and eventually optimizing mobility management will become even more crucial. To overcome the overall lack of knowledge support in the extremely challenging area of CMTS mobility management, a partnership involving CMTS operators, CMTS suppliers, and local universities should be formalized. Most CMTS operators and suppliers could benefit from being exposed to a more scientific approach applied to mobility management while universities could benefit from being directly exposed to the mobile telephony industry in general and to mobility management in particular. Joint research and development programs should be initiated and exploited to their fullest.

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APPENDIX A

A1 . SIMULATION FILES

The following is a brief description on how to run a simulation using the simulation model.

Running a simulation requires three components:

the **simulation program**;

the **data file**;

the **JCL (Job Control Language) file.**

There is one simulation program called **sim6.**

Thirty-six data files were created to account for for the six different location area configurations i.e. LAC1, LAC2, LAC4, LAC8, LAC20, and LAC60 and the two different vehicle speeds i.e. 10 kmph and 50 kmph. The control channel scan duration constant in the simulation program was modified to account for the three different control channel scan periods i.e. 500 ms, 750 ms, and 1000 ms. Simulation results have been stored in result files, one file per simulation. Table 0.1 lists the data files, JCL files, and result files that are stored on the medium.

To run a simulation simply requires the user to type the following:

exec jcl.<*x*>.<y>

where

<x> = the location area configuration number e.g. LAC1 is 1, LAC2 is 2, ...

<y> = the vehicle speed e.g. v10 is 10 kmph

APPENDIX A

Table 0.1 List of Simulation Files

Data Files	JCL Files	Result Files
lac1.v10	jcl.lac1.v10	lac1.v10.res
lac1.v50	jcl.lac1.v50	lac1.v50.res
lac2.v10	jcl.lac2.v10	lac2.v10.res
lac2.v50	jcl.lac2.v50	lac2.v50.res
lac4.v10	jcl.lac4.v10	lac4.v10.res
lac4.v50	jcl.lac4.v50	lac4.v50.res
lac8.v10	jcl.lac8.v10	lac8.v10.res
lac8.v50	jcl.lac8.v50	lac8.v50.res
lac20.v10	jcl.lac20.v10	lac20.v10.res
lac20.v50	jcl.lac20.v50	lac20.v50.res
lac60.v10	jcl.lac60.v10	lac60.v10.res
lac60.v50	jcl.lac60.v50	lac60.v50.res