DESIGN AND ANALYSIS OF ENHANCED PERFORMANCE SIMULATOR FOR GSM NETWORK

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ABSTRACT

The rapid advances in mobile communication systems. especially in Global System for Mobile communications (GSM), have led to a wide range of developments in design, simulation, controlling mechanism, management protocols, and performance analyzing techniques of such systems.

Several software simulator systems are designed and implemented in this work. The designed systems have simulated the real GSM cellular network with all related topics concerning the control on calling mechanism, mobility managements, and others. In this concern, simulators for the GSM Cellular Network, Mobile Station, Base Transceiver Station, Base Station Controller, and Mobile Switching Center are all designed and implemented in this work.

Moreover, several Graphical User Interfaces (GUIs) are built to analyze and evaluate the performance of the designed cellular network systems at different operating conditions. This has been base on a comprehensive investigation to the mathematical analyzing approaches such as calculating the call blocking probability, the handoff dropping probability and network performance optimization after adopting the guard channel principle.

الخلاصة

إن التقدم المتسارع في تقنيات الاتصالات المتنقلة وخاصة في أنظمة GSM العالمية، أدى إلى تطورات واسعة في عمليات التصميم والمحاكاة والسيطرة وبروتوكالات إدارة الشبكة وتقنيات تحليل الأداء لمثل هذه الأنظمة.

في هذا العمل تم تصميم وتنفيذ مجموعة أنظمة محاكاة برمجية لمحاكاة شبكة الاتصالات الخلوية الحقيقية، وكل الموضوعات ذات العلاقة والخاصة بميكانيكية الاتصال وادارة التنقل وغيرها. وبهذا الخصوص فأن المحاكيات المنفذة كانت محاكي الشبكة الخلوية ومحاكي محطة التحكم ومحاكي الهاتف النقال ومحاكي بدالة النقال المركزية.

إضافة لذلك، عدد من واجهات الاتصال مع المستخدم تم بناءها لتحليل وتقييم أداء الأنظمة المصممة عند مختلف ظروف الاشتغال. وقد تم ذلك بالاعتماد على تحري شامل لتقنيات التحليل الرياضي مثل احتساب احتمالية عدم تحقيق الاتصال واحتمالية انقطاع المكالمة خلال عمليات المناولة وكذلك عملية تحسين كفاءة النظام بعد تبني مبدأ القنوات الحارسة.

KEY WORDS
Mobile communications, Cellular networks, GSM, Software Engineering, Simulator Design, GSM performance optimization, Handover, Call blocking, Call dropping.

INTRODUCTION
GSM is the telecommunication success story of the decade. GSM was first introduced into the European market in 1991 (Rappaport, 2002). The number of the GSM customers around the globe has already reached 400 million in more than 130 countries by year of 2002. It is expected to continue growing exponentially . There is only one way for a technology to reach that magnitude and become the technology of choice for so many businesses and consumers. GSM was designed from the ground up as an open platform, provides unmatched fraud prevention and privacy and has a clear evolution path to third-generation wireless solutions.
GSM was designed having interoperability with ISDN in mind, the services provided by GSM are the subset of the standard ISDN services (Scouries, 1995). The recent years have seen a rapid development of mobile communication technology. The cellular principle allows for efficient use of the scarce radio sources and helps to support large subscriber populations. Advances in microelectronics, on the other hand, have made cellular telephones a commodity. The growing number of mobile phone users suggests that the cellular communications will soon become the norm, rather than the exception, while state of the art cellular mobile systems are still optimized for voice communication, and the support of an increasing variety of data services. Recent initiatives to augment the Internet with mobility support indicate the increasing interest in mobile data services.
As the structure of any cellular system is managed by many switching centers, such as those in base stations, mobile stations, and central offices. The management of the whole system is completely dependent on the software systems that run by these switching centers. Hence, validity, efficiency, quality of service, and high performance of the developed software systems affect directly the performance of the cellular system and its management protocols. Accordingly, this work adopted the design and implementation of advanced software systems for planning, management, and evaluation of cellular networks.
In this work, several software system simulators are designed and implemented. These systems represent a special independent package built for the purposes of controlling calling mechanism and mobility management protocols in GSM cellular network. This included design and implementation of: GSM cellular network simulator, Mobile Station (MS) simulator, Base Transceiver Station (BTS) Simulator, Base Station Controller (BSC) Simulator, and Mobile Switching Center (MSC) Simulator. Furthermore, investigation of the various performance analyzing techniques used to assess, optimize and enhance the performance of cellular system, such that GUIs are designed to evaluate the implemented simulators at different operating conditions.

NETWORK STRUCTURE AND MANAGEMENT:

GSM Architecture:
Fig. (1) depicts a typical block diagram for the GSM system architecture. MS(s) communicate with the BSS over the radio air interface. The BSS consists of many BSCs, which connect to a single Mobile Switching Center, and each BSC typically controls up to several BTSs (Valko, 1999). Some of the BTSs may be co-located at the BSC, and others may be remotely distributed and physically connected to the BSC by microwave link or dedicated/leased lines. The BSCs are physically connected via microwave link or dedicated/leased lines.
The Public Land Mobile Network (PLMN) is the geographical service area of the GSM system. It may be a certain country. The PLMN can be determined by single MSC or more, depending on the size of the geographical service area and several other parameters which must be determined at GSM planning step (Brusic, 2000).

On the other hand, the MS consists of the physical equipment used by the subscriber to access the PLMN for offered telecommunication services. Basically, an MS may be divided into two parts. The first part contains the hardware and software that support radio and human interface functions. The second part contains terminal/user-specific data in the form of a smart card, which can be effectively considered a sort of logical terminal. This card is called the Subscribe Identity Module (SIM). It contains all subscriber-related information stored on the user's side of the radio interface, these are (Scouries, 1995 and Valko, 1999):

* International Mobile Subscriber Identity (IMSI); it is assigned to an MS at subscription time. It uniquely identifies a given MS in the GSM network.
* Temporary Mobile Subscriber Identity (TMSI); it is assigned to an MS by the MSC. The TMSI uniquely identifies an MS within the area controlled by a given MSC.
* International Mobile Equipment Identity (IMEI); the IMEI uniquely identifies the MS equipment. It is assigned by the equipment manufacturer.
* Cell Global Identity (CGI); the CGI is the broadcasting data spread from the BTS to all the MSs covered by it. The CGI uniquely identifies the location of a given MS in the GSM network.
* Authentication Key (K_i) and Cipher Key (K_c); they are used for security purposes.

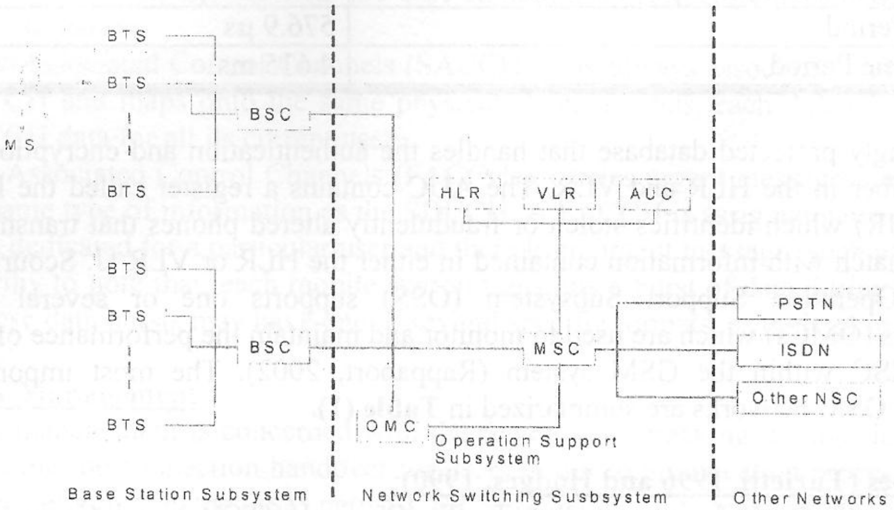

Fig. (1) GSM network structure

Moreover, the Base Station Subsystems (BSS) is the physical equipment that provides radio coverage to the cells. It contains all equipments required to communicate with the MS. Functionally, a BSS consists of a control function carried out by the BSC and a transmitting function performed by the BTS. The BTS is the radio transmission equipment that covers each cell (Rahnema, 2000). Whilst, the Network Switching Subsystem (NSS) includes the main switching functions of GSM, databases required for the subscribers, and mobility management. Software systems have the main role to manage and handle the NSS functions. It responsible for the switching of GSM calls between external networks and the BSC(s) in the radio subsystem. It is also responsible for managing and providing external access to several customer databases.

The MSC is the central unit in the NSS; it controls traffic among all of the BSCs. In the NSS, there are three different databases called the Home Location Register (HLR), Visitor Location Register (VLR), and the AUthentication Center (AUC). The HLR is the database that contains subscriber information and location information for each user who resides in the GSM network. Each subscriber in a particular GSM market is assigned a unique IMSI, and this number is used to identify each home user. The VLR is the database which temporarily stores the IMSI and customer information for each roaming subscriber who is visiting the coverage area of the particular MSC. Once the roaming mobile is logged in the VLR, the MSC sends the necessary information to the

HLR so that the calls belong to the roaming mobile can be appropriately routed to it. All the MSCs in the GSM network shared the same HLR, but each one has a single VLR.

Table (1) GSM Air Interface Specifications

Parameter	Specifications
Uplink/Reverse Channel Frequency Band	890-915 MHz
Downlink/Forward Channel Frequency Band	935-960 MHz
ARFCN Number	0-124
Carrier Separation	200 kHz
Duplex Distance	45 MHz
Access Method	TDMA
Subscriber per TDMA Frame	8 (Number of Time Slots)
Modulation Technique	GMSK
8 Subscriber Data Rate	270.833 kbps
Signaling Bit Period	3.692 μs
Channel Transmission Rate per Subscriber	33.854 kbps
Time Slot Period	576.9 μs
TDMA Frame Period	4.615 ms

The AUC is a strongly protected database that handles the authentication and encryption keys for every single subscriber in the HLR and VLR. The AUC contains a register called the Equipment Identity Register (EIR) which identifies stolen or fraudulently altered phones that transmit identity data that does not match with information contained in either the HLR or VLR [J. Scouries, 1995]. Furthermore, the Operation Support Subsystem (OSS) supports one or several Operation Maintenance Centers (OMCs) which are used to monitor and maintain the performance of each MS, BTS, BSC, and MSC within the GSM system (Rappaport, 2002). The most important radio specifications of the GSM networks are summarized in **Table (1).**

GSM Channel Types (Turletti, 1996 and Hodges, 1990):

There are two types of GSM channels, called Traffic Channels (TCHs) and Control Channels (CCHs). TCHs carry digitally encoded user speech or user data and have identical functions and formats on both the uplink and downlink. CCHs carry signaling and synchronization commands between the base station and the mobile station. Certain types of CCHs are defined for just the uplink and downlink.

TCHs may be either full-rate or half-rate and may carry either digitized speech or user data. When transmitted as full-rate, user data is contained within one time slot per frame. While when transmitted as half-rate, user data is mapped onto the same time slot, but is sent in alternate frames. That is, two half-rate channel users would share the same time slot, but would alternately transmit during every other frame.

Frames of TCH data are broken up every thirteenth frame by either Slow Associated Control Channel (SACCH) or idle frames. Each group of twenty-six consecutive TDMA frames is called a multiframe (or speech multiframe, to distinguish it from the control channel multiframe). For every twenty-six frames, the thirteenth and twenty-sixth frames consist of SACCH data, or the idle frame, respectively. The twenty-sixth frame contains idle bit for the case when full-rate TCHs are used, and contains SACCH data when half-rate TCHs are used.

On the other hand, there are three main control channels in the GSM system. These are the Broadcast Channel (BCH), the Common Control Channel (CCCH), and the Dedicated Control Channel (DCCH). Each control channel consists of several logical channels that are distributed in time to provide the necessary GSM control functions. The BCH and CCCH forward control channels are implemented only on certain Absolute Radio Frequency Channel Numbers (ARFCN) channels and are allocated time slots in very specific manner. The GSM specification defines thirty-four ARFCNs a standard broadcast channels. For each broadcast channel, frame 51 does not contain any BCG/CCCH forward channel data and is considered to be an idle frame.

The other important channels associated with this type are:

a- Paging Channel (PCH): The PCH provides paging signals from the base station to all mobiles in the cell, and notifies a specific mobile of an incoming call. The PCH transmits the IMSI of the target subscriber, along with a request of acknowledgment from the mobile unit on the RACH.

b- Random Access Channel (RACH): The RACH is a reverse link channel used by the subscriber unit to acknowledge a page from the PCH, and is also used by mobiles to originate a cell.

c- Access Grant Channel (AGCH): The AGCH is used by the base station to provide forward link communication to the mobile, and carries data which instructs the mobile to operate in a particular physical channel. The AGCH is used by the base station to respond to a RACH sent by a mobile station in a previous CCCH frame.

Moreover, there are three types of DCCHs, these are:

a- Stand-alone Dedicated Control Channels (SDCCHs), carries signaling data following the connection of the mobile with the base station, and just before a TCH assignment is issued by the base station.

b- Slow-Associated Control Channels (SACCHs), are always associated with a traffic channel or a SDCCH and maps onto the same physical channel. Thus, each ARFCN systematically carries SACCH data for all its current users.

c- Fast-Associated Control Channels (FACCHs), carries urgent messages, and contains essentially the same type of information as the SDCCH. A FACCH is assigned whenever a SDCCH has not been dedicated for a particular user and there is an urgent message (such as handoff request).

It is worthy to note that, each mobile station transmits a burst of data during the time slot assigned to it. These data bursts may have one of several specific formats, as defined in GSM standardss.

Mobility Management

Mobility management is concerned with the functions of tracking the location of roaming mobiles and handling the connection handover for users in the communication process. There are two main functions supported by the GSM network for handling mobility management, these are:

Location Updating:

Throughout movement of the mobile user, the cell on a broadcast channel sends the CGI of a cell that belongs to it, thus enabling mobile stations to be informed about the location they are in. The latter action is referred to as location updated. It can be described as follows; each BTS on the network send the CGI belongs to it (for each cell/BTS there is a unique CGI that identify it) on the BCCH over the air interface. Then, all MSs in the certain BTS area will receive the CGI and store it in their SIM cards. When MS is moving from one cell/BTS to another, the CGI received over the BCCH is changed. That is, the old CGI stored in the MS SIM card is not matching the new one and the MS has to perform a location updating. Crossing the cell/BTS border is not the only way for initiating a location update. Switching on an MS in a new cell area will initiate the location update process also.

Functionally, the location update procedure is achieved using two types of registers that are supported by the GSM network. These registers are:

- Visitor Location Register (VLR): where all relevant data concerning an MS are stored as long as the MS were within the area controlled by the VLR.
- Home Location Register (HLR): here all subscriber information (profiles) of the MSs is permanently stored, also the current address (CGI) is temporary stored.

HANDOVER PROCESS

When two subscribers are connected (making a call), and someone or both of them passes the coverage of the cell that he/her or they were in, the network should manage this problem and handle the connection without any sense from the two connected users. This is called a handover operation (Rahnema, 1993).

There are two types of handover processes; these are the soft handover and hard handover. However, in GSM systems hard handover is usually employed (Lin, 2000). Hard handover must be performed successfully and as infrequently as possible, and be imperceptible to the users. In order to meet these requirements, system designers must specify an optimal signal level at which handover should be initiated. Actually, in Mobile Assisted Handover (MAHO), every mobile station measures the received power from surrounding base stations and continually reports the results of these measurements to the serving base station. A handover is initiated when the power received from the base station of neighboring cell begins to exceed the power received from the current base station by a certain level (signal power threshold) or for a certain period of time (time threshold).

The choice of the handover threshold varies in different GSM networks. It depends on the size of the cell and the probability of handover event. However, this threshold cannot be too large or too small. If it is too small, unnecessary handovers that burden the MSC may occur. Whilst if it is too large, there may be insufficient time to complete a handover before a call is lost due to weak signal conditions.

In GSM, each BTS transmits its signal threshold (for handover decisions) to all MSs in its covering area through the broadcast channel, and with a value appropriate with its cell size (Rahnema, 1993). Also, it is should be noted that for each execution of a handover procedure the location updating function should be performed too.

SIMULATORS DESIGN AND IMPLEMENTATION

The main simulator controlling the GSM cellular network consists of four main parts executed repeatedly and in parallel. These are; Ms part, BTS part, BSC part and MSC part. Each part is implemented independently of the others and related to them with a special protocol mechanism. All data are assumed to be transferred ideally and with no errors, in order not to treat the data transmission topics, as they are out of the scope of this work. Also, all mobiles in the network are assumed to be authenticated, in order not to concern with security techniques. Moreover, the whole cellular network is assumed to be managed by a single MSC for simplicity.

There are many MSs, BTSs, and BSCs operating in the network and controlled by a single MSC. Therefore, each part of the main program will expand to a local loop serving all the entities of its corresponding element, see **Fig. (A-2).**

Knowing that the whole software system is implemented in a single computer within a single microprocessor unit; the important question here is how collections of independent statements be run in parallel? By using an advanced programming language, like "Visual Basic", it is possible to make multiple timer objects. These timer objects could use the property of multitasking that supported by earlier operating systems, like Windows Operating System, making their collections of statements appear to run in parallel. So, any block of operations in the software system could be coded in a particular timer object, allowing it to run simultaneously with the others.

Each part-block of the main simulator scans and analyzes the input data received then submit and transfer the proper output data for the desired destination. Actually, the data travel among the elements of the network using the various channel types used by the GSM system; each channel type carries the appropriate output data for it. Therefore, there should be an advanced protocol mechanism that controls and manages the transferred information among the network elements. Table (2) illustrates the structure of the transferred information. Note that the contents of the table represent implementation examples for the use of the transferred information.

The Information to be sent should be attached with the sender source equipment identity and with the purposed serving destination equipment identity. For example, in this table, the second content row means that the 2^{nd} BTS sent its output data and should be received by only the 1^{st} BSC.

Table (2) Transferred Information Structure

Transferred Information					
Source Item	**Source Index**	**Request**	**Data**	**Destination Item**	**Destination Index**
MS	40	XXXXX	XXXXX	BTS	2
BTS	2	XXXXX	XXXXX	BSC	1
BSC	1	XXXXX	XXXXX	MSC	1
MSC	1	XXXXX	XXXXX	BSC	2

In order this information to be understood by the desired receiver, it should be annexed with data request field (Request column). Therefore, the action made by the receiver element in the network depends on the information request field from the transmitter one. **Table (3)** illustrates the MS requests from the MSC server, while **Table (4)** illustrates the MSC requests from its MS clients.

Table (3) MS Requests

MS Requests	
Request	**Description**
Make a call	The MS wants to make a conversation call with another one.
Call acceptance	The MS wants to inform the MSC that it accepts the coming call.
End call	The MS wants to end its current conversation call
Location update	The MS wants to update its location to a new cell coverage area.
Handover	The MS wants to perform the handover function to keep its current conversation call.
Remove location	The MS wants to inform the MSC server that it is not available (either turned off or out of the coverage area of the system).
Speech	The MS wants to transfer speech data.

Table (4) MSC Requests

MSC Requests	
Request	**Description**
Make a call	The MSC wants to inform an MS for an incoming call.
Undefined MS	The MSC wants to inform an MS that the dialed number is undefined.
Not available	The MSC wants to inform an MS that the dialed MS is either turned off or is out of the coverage area of the whole network.
User network busy	The MSC wants to inform an MS that the network of the dialed MS is busy (there is no free channels in the dialed MS BTS server).
User connected (busy)	The MSC wants to inform an MS that the dialed MS is busy (already have a call).
OK to make a call	The MSC wants to inform an MS that the dialed MS is currently ringing (no problems occur during the connecting method).
Call acceptance	The MSC wants to inform an MS that the dialed MS accepts the call.
End call	The MSC enforces an MS to end the call.
Network failure	The MSC ends a call of an MS due to network problem.
Speech	The MSC transfers speech data.

There are no data requests from the BTS and the BSC elements, because they are only used for routing issues; they support a direct link between the MS and the serving MSC. In other words, the BTS and BSC hold the data and their requests for information which were sent by the MSC then transfer them to the routed MS or vice versa.
In order to perform the calling mechanism and the mobility management schemes, a strict deal must be established between the network and the MS. **Table (5)** summarizes the various statuses of the MS. Usually, the calling mechanism begins by a request from a subscriber. This request is taken by certain sequence of input commands, and these input commands can be activated by using the control panel of the MS. **Table (6)** illustrates the input data commands of it. On the other hand, **Fig. (A-3)** is a flowchart of the main structure of the MS mobility management software system.

Table (5) MS Statuses

MS Status	Description
Waiting for call (Idle)	MS is preparing to receive a call and make a speech conversation
Waiting for response	The calling MS is waiting for acceptance or rejection from the called one.
Ringing	MS is currently ringing due to an incoming call.
Connected (Busy)	MS is making a speech conversation.
Not available	The MS is either turned off or is out of the coverage area of the whole network.

Table (6) Basic Input Commands for the Control Panel of an MS

Command	Description
cmdDigits(10)	A one dimensional array of input data (from 0 to 9), they denote the pressure of any digit of the MS.
cmdOK	OK command, this denotes the action made by pressing the OK button of the MS.
cmdCancel	Cancel command, this denotes the action made by pressing the Cancel button.
Speaker/Microphone	Used for performing the speech conversation between two MSs.

The MS control panel management software system is performed by executing two parts in parallel. The first part manages the speech input data of the MS, while the second part manages the general input commands of the MS. The algorithm that performs these two parts is given in the appendix also. In addition the algorithm of the MS protocol management software system is given too.
The main function of the BTS is to forward the information sent by one of its MS client to the serving BSC and/or forward the information sent by its serving BSC to the routed MS.
Two main variables denoted to each BTS; these are:

1- CGI, the cell global identity of its covering area.
2- Free TCH(s) Count, the amount of free traffic channels available by it.

These data are sent frequently to all MSs clients of each BTS. **Fig. (A-4)** illustrates the general simulator structure of the BTS part.
The main function of the BSC is to forward the information sent by one of its BTS client to the serving MSC and/or forward the information sent by the serving MSC to the routed BTS. By completion of BTS and BSC functions, the MS could send its information to the serving MSC or vice versa. **Fig. (A-5)** illustrates the general simulator structure of the BSC part.

The main data structures of the MSC system are the HLR and VLR databases. HLR and VLR contain the most important information for calling mechanism and routing. HLR is listing all the MSs in the whole GSM network and each MS with its owner name, IMSI, and the current MSC/VLR area where it resides. More deeply, VLR is listing all the MSs in its covering area and each MS with its owner name, IMSI, and the current CGI where it resides. It is important to note the following remarks:

- IMSI field is an input in the registers. This means that any equipment in the network, even the databases themselves, could take any information of a specified MS by sending its IMSI. Then, a matching scheme is performed. So, the corresponding values of this MS could be taken or changed.
- In calling mechanism, the called MS could be routed to perform a speech conversation with the calling ones by using the MSC/VLR and CGI fields in the two registers.
- IMSI could also be used as an output value for caller identification issue (Caller ID). This means that in the calling scheme, the database could send the IMSI of a calling MS to the called MS for notification.
- In mobility management techniques, the MS could be tracked by frequently changing the values in the MSC/VLR and CGI fields in the two registers as the MS is roaming. The general flow charts of all simulators are shown in the appendix.

A simulation model for a basic cellular network has been designed in this work, to study the various succession and failure scenarios occur in calling mechanism and mobility management schemes of a mobile cellular network. A schematic diagram for this model is shown in **Fig. (3).** There is a single MSC controlling two BSCs, each BSC covers two BTSs, each BTS has two available TCH channels, and four MSs are considered to be subscribed in the network.

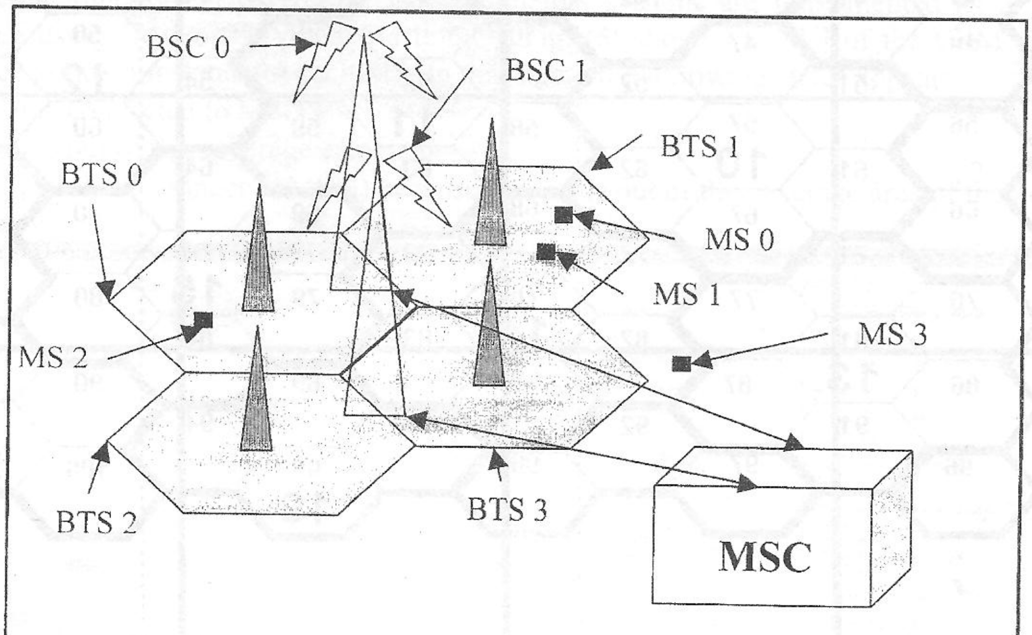

Fig. (3) Schematic Diagram for Network Simulation Model.

Practically, the subscriber (MS) has full freedom in her/his movement throughout talking time. Hence, this freedom of moving should be represented completely in the simulation software. In this work MS's movement has been represented into two ways, as the operator of the software package desires. These are: either using the mouse tool to drag the MS anywhere the operator wants throughout the cells of the network, by making the MS move randomly using some built-in functions that generate random numbers then modify these numbers to a visual movement.

The implemented cellular network is serving a medium size city. The mobile network has 100 cells controlled by a single MSC with 1 VLR, 20 BSCs, and 9 location areas as shown in **Fig. (4).** Each cell is represented by a hexagonal shape and is numbered from 1 to 100. The locations of BSCs are denoted by the 20 numbers with a larger font size. Each BSC controls a cluster of cells which are outlined by a heavy line with a maximum of 7 cells per BSC. For example, BSC 5 controls the set of cells numbered {36, 26, 31, 41, 46}. The location areas can be differentiated by the shade of cells and are also marked by the two long horizontal and vertical dotted lines. The standard GSM system has 124 radio channels which are equally divided into two set of channels for different network providers in the same

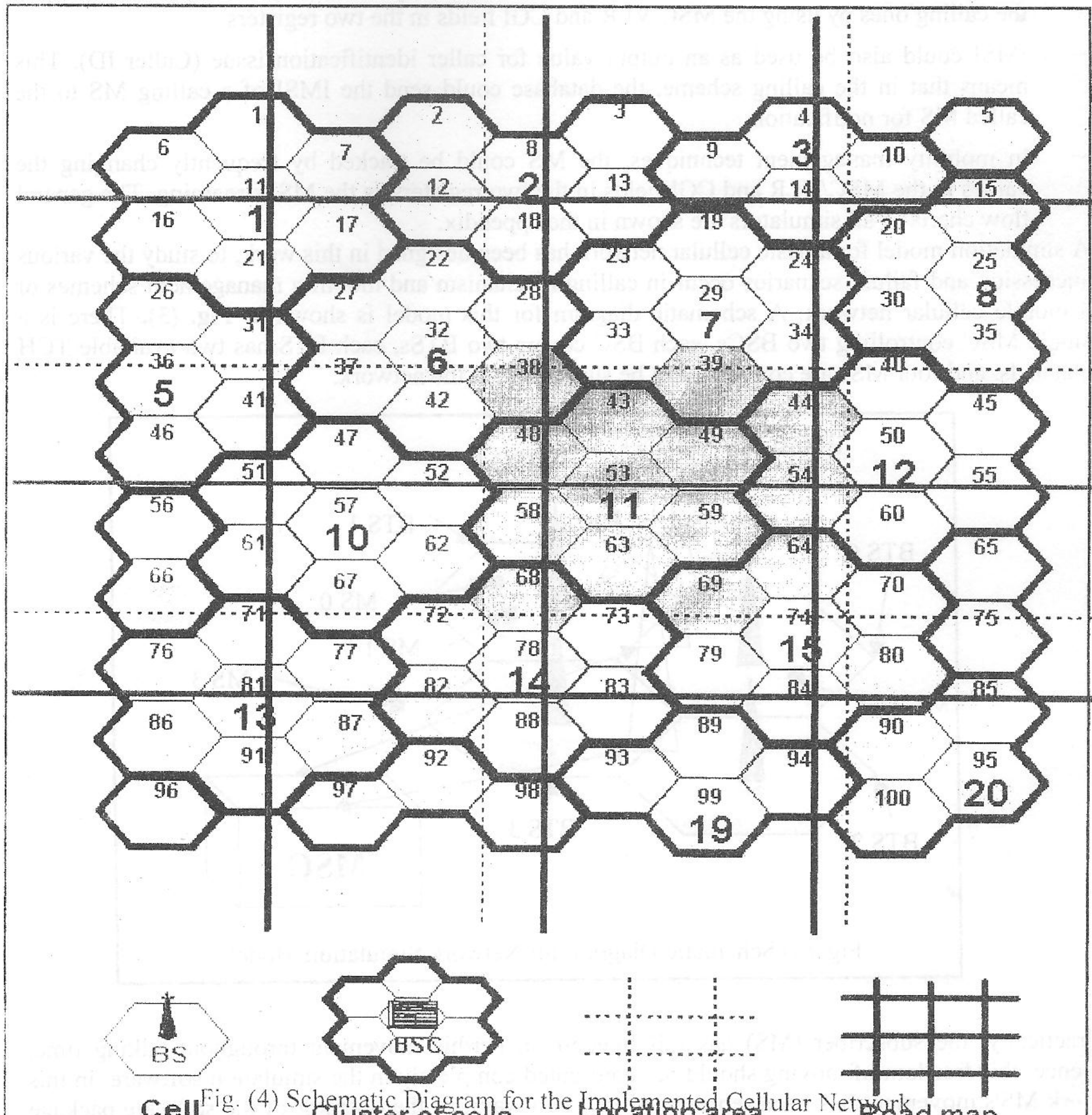

Fig. (4) Schematic Diagram for the Implemented Cellular Network

Service area. Thus, the system is assumed to have 62 radio channels, with a frequency reuse cluster size of seven. Therefore, in a cluster of cells, there are 6 cells with 9 radio channels per cell, and one cell with 8 radio channels per cell. A GSM radio channel has 8 time slots, and there is one control channel per cell. This results in an average of 70 traffic channels per cell.

In this work, the designed systems are implemented using Object Oriented Programming (OOP) techniques, for the following reasons:

- Object technologies lead to reuse of program components, and reusability leads to faster software development and high quality programs.
- The internal implementation details of the software simulators e.g. (MS simulator, BTS simulator, BSC simulator, and MSC simulator) are hidden from each other. This reduces the propagation of side effects when changes occur, and makes testing of system components easier.
- Interfaces among encapsulated objects are simple. An object that sends data need not to be concerned with the details of internal data structures in the receiving object. Hence, interfacing is simplified and system coupling tends to be reduced, which makes software modules easier to maintain.

For most modern applications, Human-Computer Interface (HCI) represents a critically important subsystem that should be implemented. Since the aim of these GSM simulators systems is to assist a typical operator to automatically establish links among MSs over the simulated cellular platform, the interaction between the operator and the GSM simulators systems should be effective. The design of GSM simulators software package using GUI tools is very powerful interims of HCI. The design of GUI elements is not necessary, as reusable classes already exist such as windows, icons, mouse operations, and a wide variety of other interactive functions. Hence, the GSM simulators systems are implemented as a software package using "Microsoft Visual Basic 6.0". **Fig. (5)** shows the GUI of the GSM simulator package at random status for each MS. In this figure the following states appear:

- MS(0) is connected to MS(1),
- MS(3) is out of the coverage area, and
- MS(2) couldn't connect to MS(3) because the last is out of the coverage area of the network.

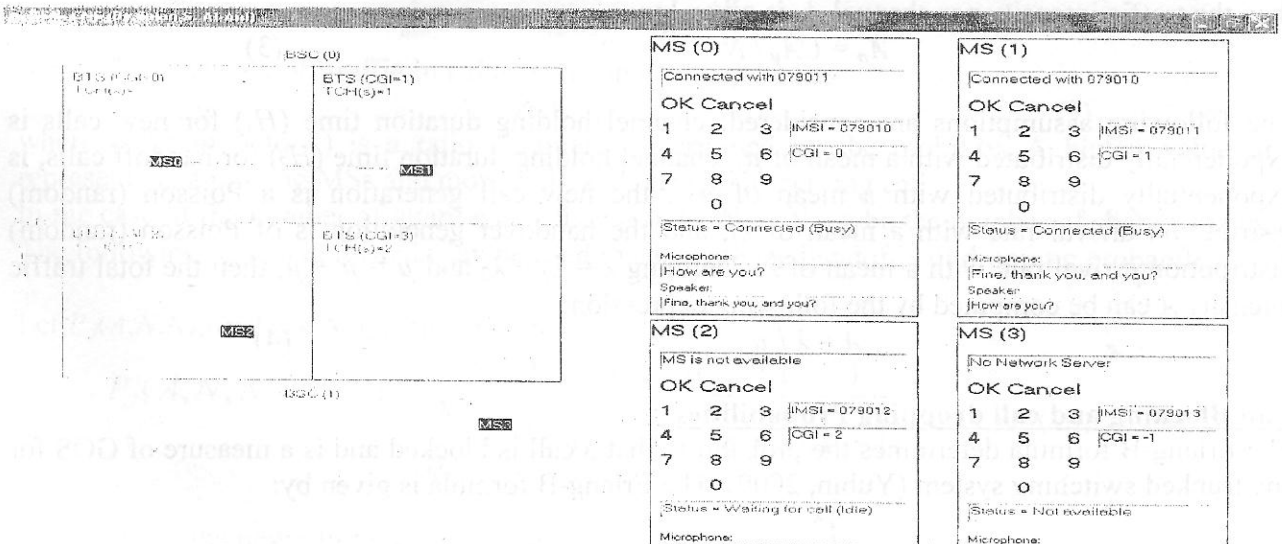

Fig. (5) GSM Simulator Package GUI

THE PERFORMANCE ANALYSIS

The design efforts regarding wireless networks aim to improve the system performance while fulfilling certain constraints. There are several criteria that are usually used to measure the performance of wireless networks. Some of these measures are the data transfer rate, probability of error, new call rejection rate (call blocking probability), and forced termination rate for the ongoing call (handover failure probability) (Valko, 1999).

Trunking and Grade of Service:

Cellular radio systems rely on *trunking* to accommodate a large number of users in a limited radio spectrum. The concept of trunking allows a large number of users to share the relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channels (Briley, 1983 and Boucher, 1988). In a trunked radio system, each user is allocated a channel on a per call basis, and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

To design trunked radio systems that can handle a specific capacity at a specific *grade of service*, it is essential to understand trunking theory (Boucher, 1988). According to this theory one Erlang represents the amount of traffic intensity carried by a channel that is completely occupied (i.e. one call-hour per hour or one call-minute per minute). The *grade of service* (GOS) is a measure of the ability of a user to access a trunked system during the busiest hour. The GOS is a benchmark used to define the desired performance of a particular truncked system by specifying a desired likelihood of a user obtaining channel access, given a specific number of channels available in the system. The maximum capacity required should be estimated, and the proper number of channels should be allocated in order to meet the GOS. GOS is typically given as the likelihood that a call is blocked.

The traffic intensity offered by each user is equal to the call request rate multiplied by the holding time. That is, each user generates a traffic intensity of A_u Erlangs given by (Boucher, 1991):

$$A_u = \lambda H \tag{1}$$

where H is the average duration of a call and λ is the average number of call requests per unit time for each user. For system containing U users and an unspecified number of channels, the total offered traffic intensity A is given as:

$$A = UA_u \tag{2}$$

Furthermore, in N channels trunked system, if the traffic is equally distributed among the channels, then the traffic intensity per channel A_n is given by:

$$A_n = UA_u / N \tag{3}$$

The following assumptions are considered: channel holding duration time (H_1) for new calls is exponentially distributed with a mean of μ_1, channel holding duration time (H_2) for handoff calls, is exponentially distributed with a mean of μ_2 , the new call generation is a Poisson (random) distribution arrival rate with a mean of λ_1, and the handover generation is of Poisson (random) distribution arrival rate with a mean of λ_2. Defining $\lambda = \lambda_1 + \lambda_2$ and $\mu = \mu + \mu$, then the total traffic intensity A can be computed by the following expression:

$$A = \lambda / \mu \tag{4}$$

Call Blocking and call dropping Probabilities

The Erlang-B formula determines the probability that a call is blocked and is a measure of GOS for any trunked switching system (Yubin, 2000). The Erlang-B formula is given by:

$$P_b = \frac{\frac{A^N}{N!}}{\sum_{k=0}^{N} \frac{A^k}{k!}} = GOS \tag{5}$$

where N is the number of available channels offered by the trunked switching system and A is the total offered traffic. However, this formula has been modified using recursive computation, in order to avoid overflow problems, resulted from the large factorials and powers generations;
Let $E_B(A,0)=1$, then compute

$$E_B(A,N)=\frac{\frac{A}{N}E_B(A,N-1)}{1+\frac{A}{N}E_B(A,N-1)} \quad (6)$$

In the case of cellular networks where handover is a dominated phenomenon, when an ongoing call of a mobile station moves across a cell boundary the channel in the earlier cell is released, and an idle channel is required in the target cell. If an idle channel is available in the target cell the handoff call is resumed nearly transparently to the subscriber. Otherwise the handoff call is dropped. The dropping of handoff call is generally considered more serious than blocking of new call. One way of reducing the dropping probability of a handoff call is to reserve a fixed number of channels (called guard channels) exclusively for the handoff calls (Lin, 1994 and Hong, 1986).
Consider g as the number of guard channels. It is assumed that $g<N$ in order to exclude new calls altogether. Then the call blocking probability can be rewritten as:

$$P_b(A,N,g)=A^{N-g}\frac{\sum_{k=0}^{g}\frac{A_1^k}{(k+N-g)!}}{\sum_{n=0}^{N-g-1}\frac{A^n}{n!}+\sum_{n=N-g}^{N}\frac{A^{N-g}}{n!}A_1^{n-(N-g)}} \quad (7)$$

While the dropping of handoff calls probability would be:

$$P_d(A,N,g)=\frac{\frac{A^{N-g}}{N!}A_1^g}{\sum_{n=0}^{N-g-1}\frac{A^n}{n!}+\sum_{n=N-g}^{N}\frac{A^{N-g}}{n!}A_1^{n-(N-g)}} \quad (8)$$

where A_1 is the handoff traffic in Erlangs. It can be computed as :

$$A_1=\alpha A \quad (9)$$

where α (from 0 to 1) is a ratio parameter determined by the mobility. A higher value of α represents fast moving MSs and more calls will change the serving cell.
In the case of the number of guard channels $g>0$, let $N_1=N-g$ be the number of shared channels. The following recursive formula can be used to calculate the handoff call dropping probability:
Let $P_d(A,N,N_1,0)=E_B(A,N_1)$, then compute

$$P_d(A,N,N_1+g,g)=\frac{P_d(A,N,N_1+(g-1),g-1)}{\frac{N}{\alpha A}+P_d(A,N,N_1+(g-1),g-1)} \quad (10)$$

Similarly for the new call blocking probability:
Let $P_b(A,N,N_1,0)=E_B(A,N_1)$, then compute

$$P_b(A,N,N_1+g,g)=\frac{\frac{N}{\alpha A}P_b(A,N,N_1+(g-1),g-1)+P_d(A,N,N_1+(g-1),g-1)}{\frac{N}{\alpha A}+P_d(A,N,N_1+(g-1),g-1)} \quad (11)$$

EVALUATION TESTS

Different cases of operation for the implemented packages are investigated and tested. These cases depict the ability of the implemented system to simulate the various practical-life scenarios of operations at different successful and failed calling conditions:

Case One

Successful New Call Attempt. In this case, an attempt has done successfully to establish a new call. Table (7) describes the anatomy of this case in detail as it really appears throughout the real implementation. The "CGI column" represents the cell identity where the given MS is in, the "TCH column" represents the number of available speech channels in the specified cell, the "Status column" shows the current status for the given MS, while the "Action, Data column" illustrates the action taken by the given element and which data to be sent. Furthermore, the arrows depict the change that occurs in the data of the specified column.

Table (7) Anatomy of Successful Call – Case One

Calling MS				MSC	Called MS			
CGI	TCH	Status	Action, Data	Action, Data	Action, Data	Status	TCH	CGI
0	2	Idle	Dial			Idle	2	3
0	2	Idle	Make a call			Idle	2	3
0	2	Idle		Make a call		Ringing	1	3
0	1	Waiting		OK to make a call		Ringing	1	3
0	1	Waiting			Accept	Connected	1	3
0	1	Connected		Call acceptance		Connected	1	3
0	1	Connected	Mic., Hi	Speech, Hi	Speaker, Hi	Connected	1	3
0	1	Connected	Speaker, Hi	Speech, Hi	Mic., Hi	Connected	1	3
0	1	Connected	Cancel			Connected	1	3
0	2	Idle	End call			Connected	1	3
0	2	Idle		End call		Idle	2	3

In this case, a new call attempt has successfully been done; due to the normal conditions which the calling MS and the called MS have. That is, there are free speech channels for both of the calling MS and the called MS, and the called MS's status are idle (waiting for call).

Case Two

:Failed Attempt to Establish a Call (Network Busy). In this case, a failed attempt to establish a new call is performed. **Table (8)** describes the anatomy of this case. The cause of the failure in this case is that there is no free TCH for the called MS (the network of the called MS is busy).

Table (8) Anatomy of Call Failure (Network Busy)

Calling MS				MSC	Called MS			
CGI	TCH	Status	Action, Data	Action, Data	Action, Data	Status	TCH	CGI
0	2	Idle	Dial			Idle	0	3
0	2	Idle	Make a call			Idle	0	3
0	2	Idle		Make a call		Idle	0	3
0	2	Idle		User network busy		Idle	0	3

Case Three

Failed Attempt to Establish a Call (User Busy). **Table (9)** depicts the designed package output, when an attempt to establish a call has failed, due to status of the called MS being "Busy".

Table (9) Anatomy of Call Failure (User Busy)

Calling MS				MSC		Called MS		
CGI	TCH	Status	Action, Data	Action, Data	Action, Data	Status	TCH	CGI
0	2	Idle	Dial			Connected	1	3
0	2	Idle	Make a call →			Connected	1	3
0	2	Idle		Make a call		Connected	1	3
0	2	Idle ←		User busy ←		Connected	1	3

Case Four

Successful Handover. In this case, a connected MS (an MS having a call) is moving towards another cell boundary. This requires a handover operation in order not to interrupt the calling process of the specified MS. **Table (10)** illustrates the anatomy of successful handover operation. The handover operation is successfully implemented in this case, due to the fact that the target cell has a free TCH channel to handle the incoming call process.

Table (10) Anatomy of Successful Handover

Calling MS				MSC		Called MS		
CGI	TCH	Status	Action, Data	Action, Data	Action, Data	Status	TCH	CGI
0	1	Connected	Move, BTS 3			Connected	1	3
3 ←	1	Connected	Location update request →			Connected	1	3
3	1	Connected		Update new location in VLR		Connected	1	3
3	1	Connected	Handover request →			Connected	1	3
3	0 ←	Connected ←		Handover success		Connected	→ 0	3

Case Five

Handover Failure. Like case four, a connected MS is moving towards another cell boundary, which requires a handover operation in order not to interrupt its calling process. But unlike case four, **Table (11)** illustrates the anatomy of failed handover operation. In this case, the handover operation fails to implement, because there is no free TCH channel in the target cell. This results in interrupting the call process for both the called MS and the calling MS making their statuses idle (waiting for call).

Table (11) Anatomy of Failed Handover (No Free TCH)

Calling MS				MSC		Called MS		
CGI	TCH	Status	Action, Data	Action, Data	Action, Data	Status	TCH	CGI
0	1	Connected	Move, BTS 2			Connected	1	3
2 ←	0	Connected	Location update request →			Connected	1	3
2	0	Connected		Update new location in VLR		Connected	1	3
2	0 →	Connected	Handover request →			Connected	1	3
2	0	Connected		Handover failure		Connected	1	3
2	0	Idle ←		End call, network failure		Connected	1	3
2	0	Idle		End call, network failure →		→ Idle	→ 2	3

Moreover, a software GUI has been designed, **Fig. (6)**, to evaluate the designed systems performance using Erlang-B formula. The probability of call blocking for the designed and implemented cellular network has been measured using Erlang-B formula. It is drawn versus the traffic (A) in **Fig. (7).** It is clear from this figure that as the traffic increases the probability increases also.

However, the blocking probability is always at the minimum rate until the traffic load (A) reaches the maximum available channels (N; which is equal to 70) for a particular cell. Therefore, it is designer's job to estimate the maximum channels required by each cell for statistical traffic intensity offered.

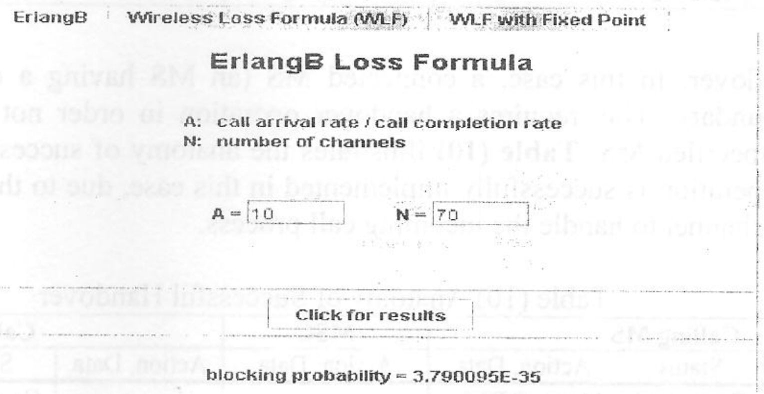

Fig. (6) Erlang-B Formula GUI

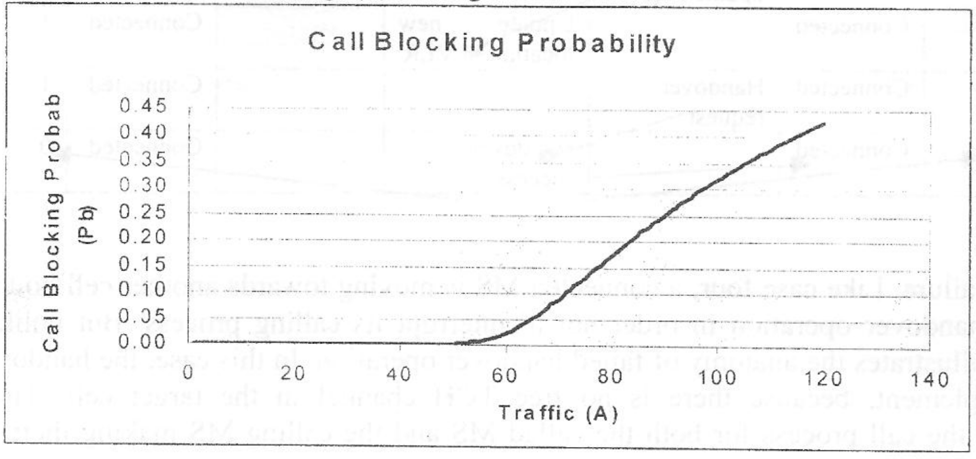

Fig. (7) Erlang-B Call Blocking Probability

The results obtained to assess the performance of the implemented network, with the principle of the guard channels being applied, are shown in **Figs. (8) and (9).**

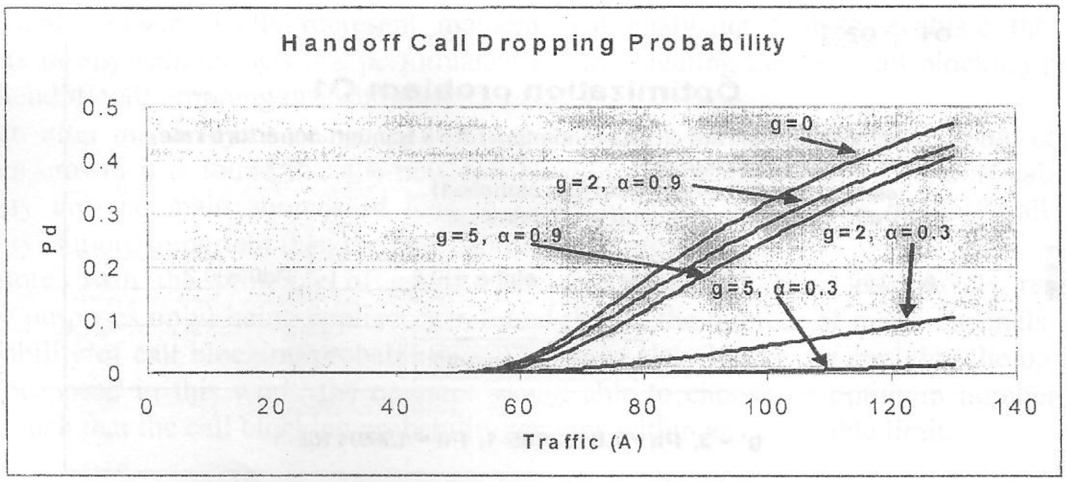

Fig. (8) Handoff Call Dropping Probability

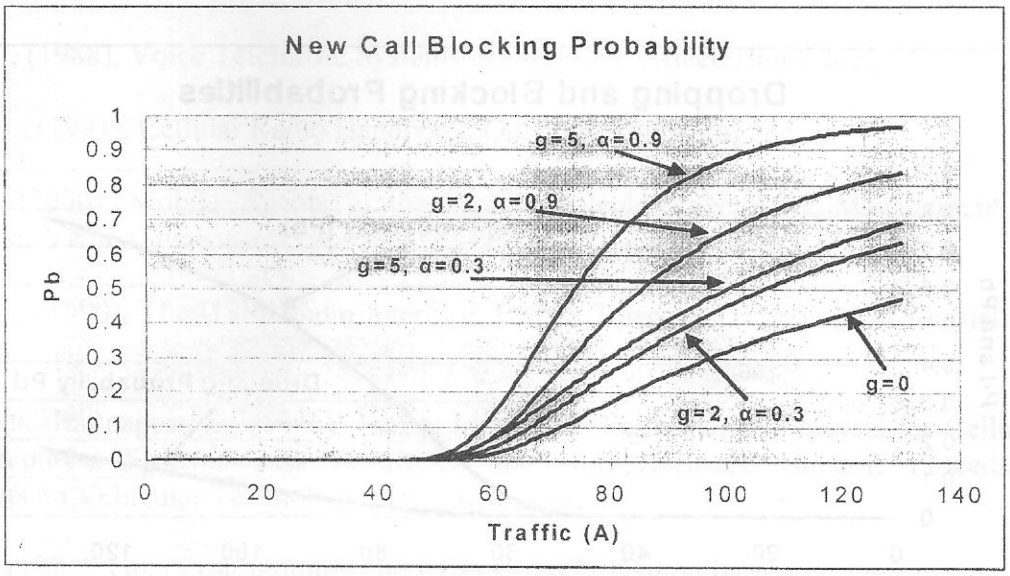

Fig. (9) New Call Blocking Probability

As the number of guard channels is increased the dropping probability will reduce, while the blocking probability will increase. Thus, it is important to derive an optimal number of guard channels subject to given constrains on the dropping and blocking probabilities. Since it is desired to minimize both the blocking probability as well as the dropping probability, there is a multiobjective optimization problem [J. Jgnizio, 1976]. The decision variable is the number of guard channels (g). Given A, N, and α, determining the optimal integer value of g that minimize $P_b(g)$ such that $P_d(g) \leq P_{d0}$, where P_{d0} represents the maximum dropping probability. The smallest value of g can be determined such that $P_d(g) \leq P_{d0}$, this value of g will minimize $P_b(g)$. Thus the optimal value of g is obtained using a one-dimensional search over the range $\{0,1,2,\ldots,N\text{-}1\}$ for g such that :

$$g = \min \{g \mid P_d(g) \leq P_{d0}\} \qquad (12)$$

This optimization process is implemented as a software package to calculate an optimum number of guard channels. The designed GUI, **Fig. (10),** and the results obtained, **Fig.(11),** are shown.

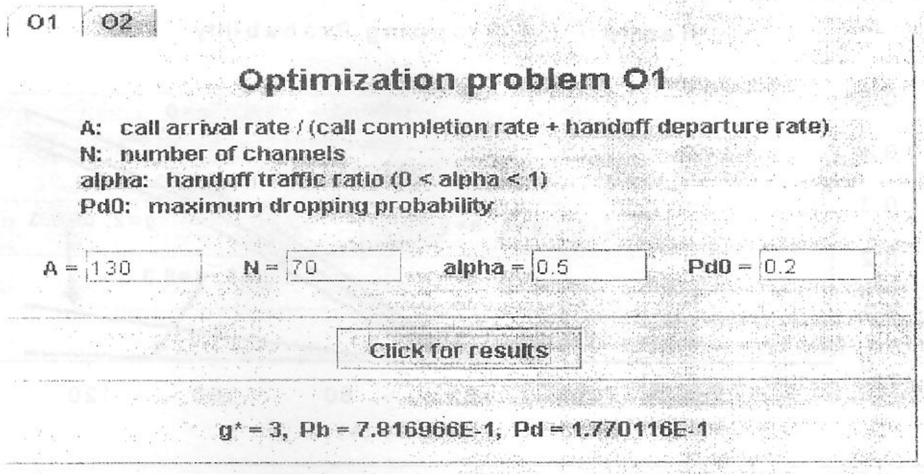

Fig. (10) Optimal Number of Guard Channels (g) GUI

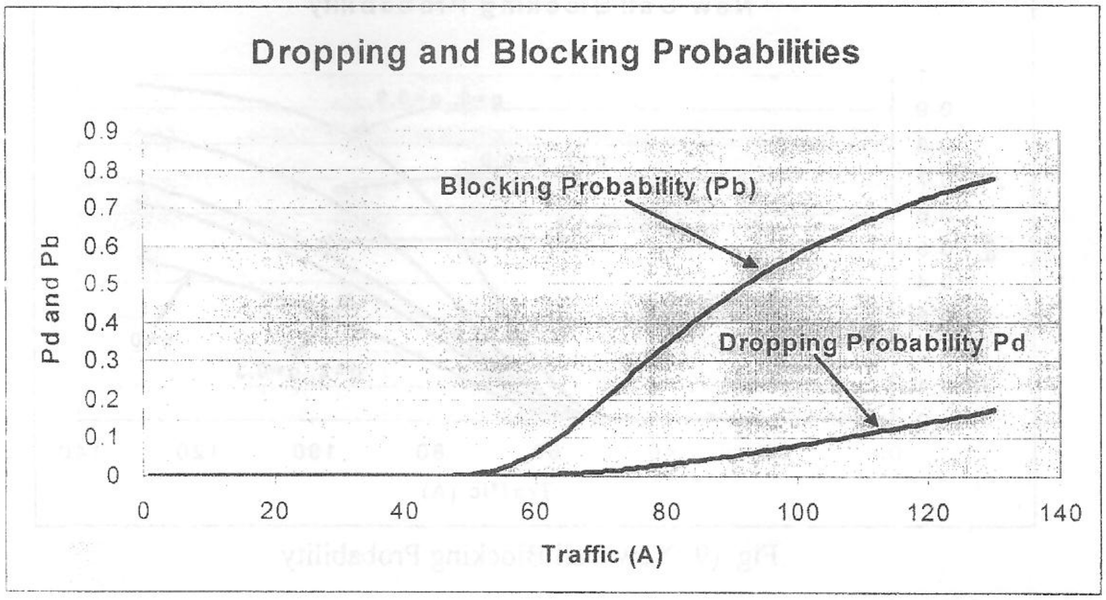

Fig. (11) Call Blocking and Handoff Dropping Probabilities with Optimal Value of g=3

It is obvious that the optimal number of guard channels (g) for the simulated network, is equal to 3 for a maximum handoff call dropping probability (P_{d0}) of 0.2, maximum traffic intensity (A) at 130, and normal mobility speed ratio (α) at 0.5. However, handoff call dropping probability is always lower than the specified maximum handoff call dropping probability (P_{d0}=0.2) even when the traffic intensity (A) exceeds the maximum available channels (N=70). But unfortunately, the call blocking probability remains high; due to the three guard channels that are exclusively reserved for the handover operation.

CONCLUSIONS

In this work, the GSM cellular network has been simulated. Toward this objective, several software system simulators have been designed, implemented, and tested. These are the GSM cellular network simulator, mobile station simulator, base transceiver station simulator, base station controller simulator, and the mobile switching center simulator. These simulators provide high ability to control calling mechanism and mobility management.

With all of these simulators being available under hand, the GSM network operator will benefit much more by adopting such friendly-use GSM simulators and performance analyzing GUIs. The

implemented software GUIs represent mathematical analyzing tool to evaluate the designed simulators or any cellular network performance by investigating the new call blocking probability and the handoff call dropping probabilities.
Moreover, after this analyses being applied to the designed network simulator. Some conclusions have been drawn: it is found that the new call blocking probability and the handoff call dropping probability are the main sources of loss in GSM networks. Also, the handoff call dropping probability is more important than the new call blocking probability.
Furthermore, with the principle of guard channels (several channels exclusively reserved for handover purposes only) being applied, it is found that as the number of guard channels increases, the probability of call blocking probability will increase also. Hence, by applying the optimization process proposed in this work, the operator would able to choose an optimum number of guard channels such that the call blocking probability remains within an acceptable limit.

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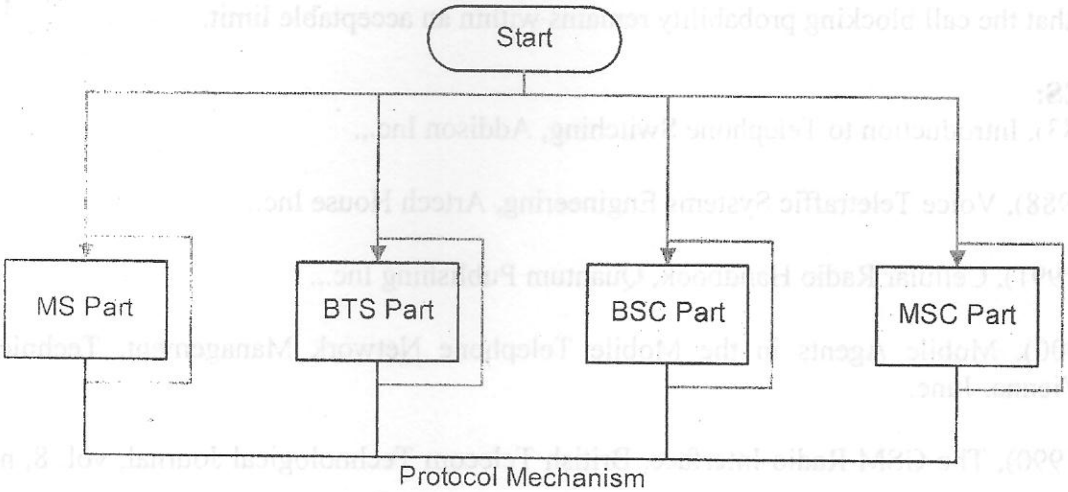

Fig. (A-1) Software Main Program (Branches Operate in Parallel)

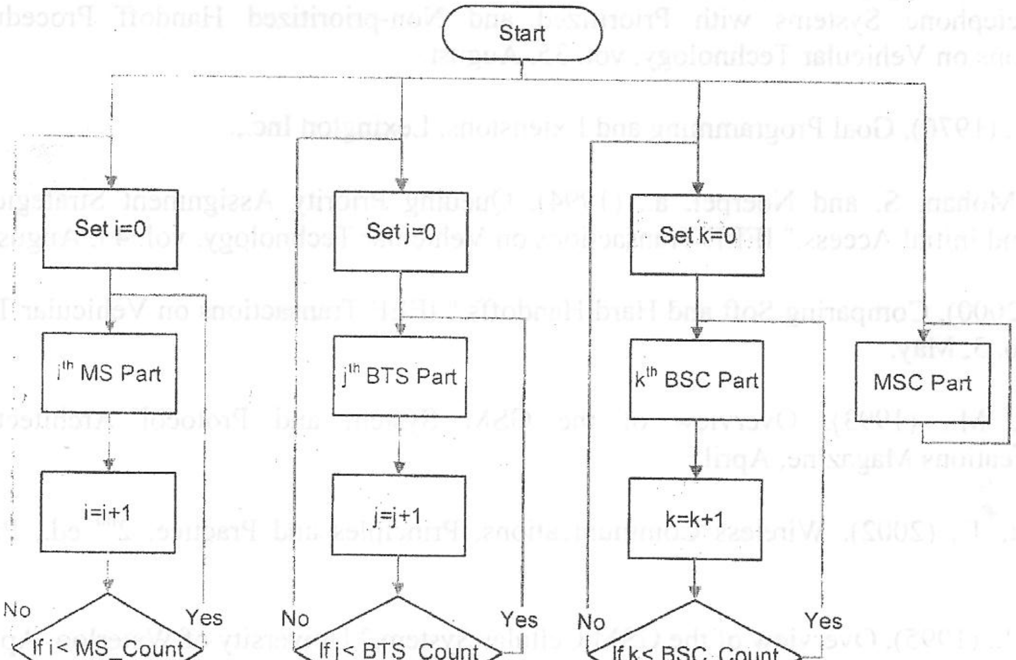

Fig. (A-2) Internal Parts of the Main Simulator (Branches Operate in Parallel)

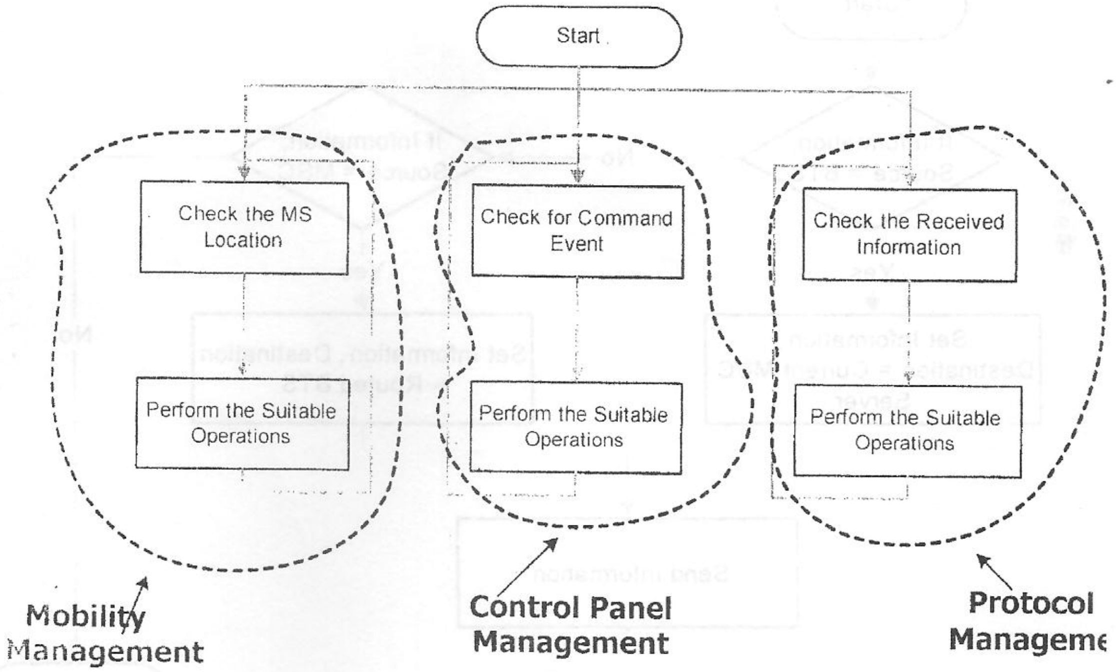

Fig. (A-5) Main Structure of the MS Simulator (Branches Operate in Parallel)

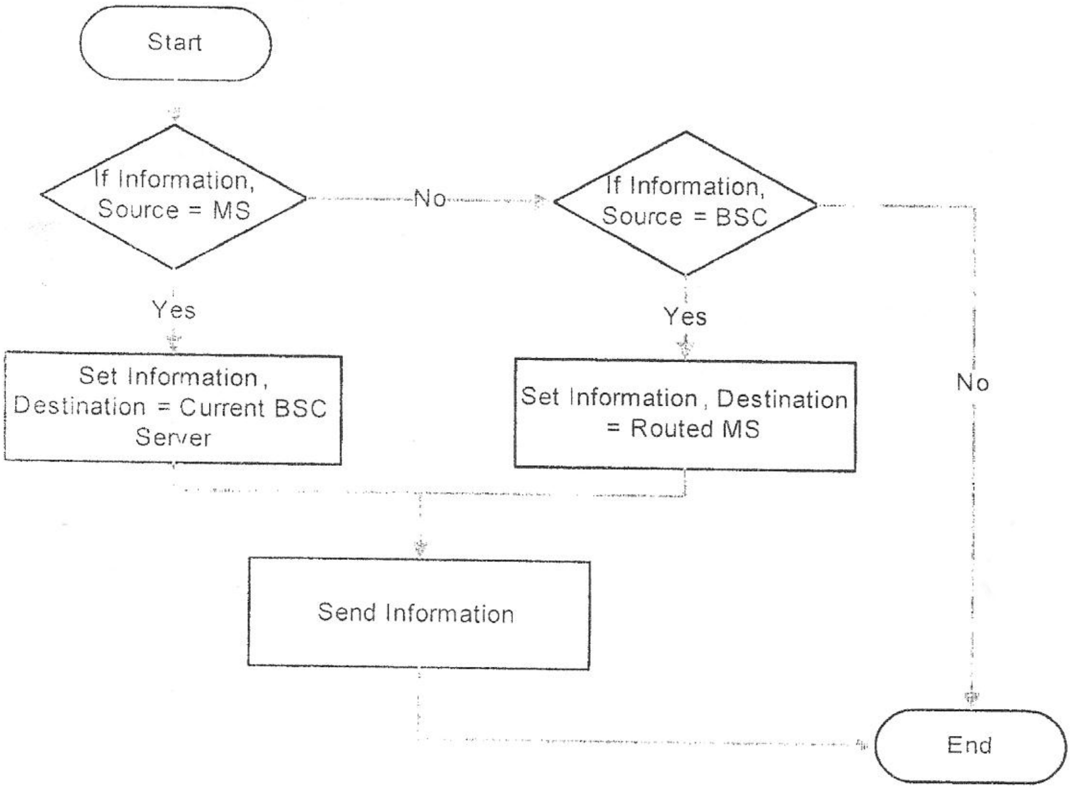

Fig. (A-9) BTS Simulator

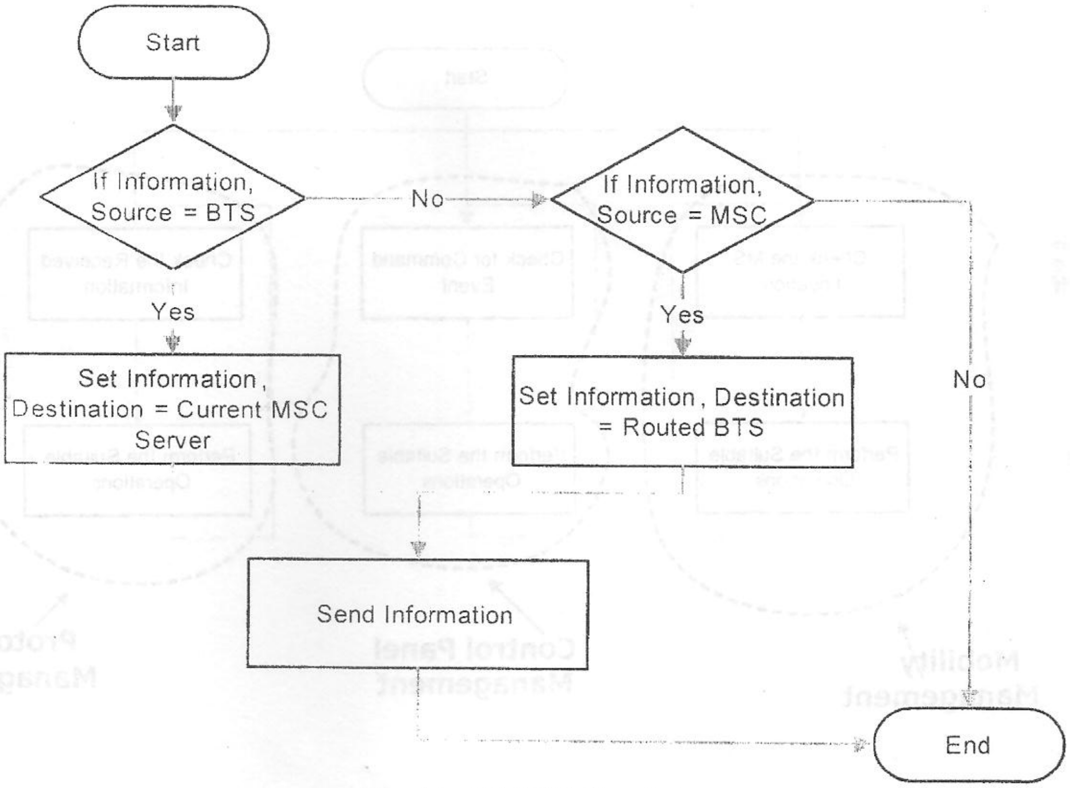

Fig. (A-10) BSC Simulator