COMPARING SIGNALING LOADS FOR BOTH GSM AND IS-136 CELLULAR SYSTEM

Thienne Mesquita, Obionor Nóbrega, Marcone Almeida e Djamel Sadok
Centro de Informática – Universidade Federal de Pernambuco – UFPE
P.O. Box: 7851, ZIP: 50732-970, Recife – PE – Brasil
Phone.: +55 81 3271-8430 r. 3301, Fax: +55 81 3271-8438
E-mail: {tmsm,oon,mpa,jamel}@cin.ufpe.br

ABSTRACT

The advent of second and third generation cellular systems forces cellular operators to face considerable increase in the signaling traffic over their mobile networks. Service providers are therefore required to have appropriate planning tools in order to maintain adequate service quality levels.

This paper presents a proposal of a simulation architecture for analysis of signaling in GSM and IS41/136 mobile cellular networks. Procedures like Power Up, Power Down, Call Setup, Handover and Location Updating are implemented. The simulation tool CELSA[1] (Cellular Signaling Analyzer) has implemented this architecture. Simulation results for exchanged signaling load in example network architecture are presented.

1. INTRODUCTION

Digital cellular systems arose as a direct result of the growing popularity of mobile voice services. The deployment of Global Systems for Mobile Communications (GSM) and Time Division Multiple Access (TDMA) based cellular systems is a worldwide success, in operation in Europe, China, the United States, Australia, South Africa, and large parts of Asia. Furthermore, the buildup of networks for personal communications services (PCS) services in the United States and most of the South American countries is under way. Today, more than 100 countries use digital GSM and TDMA technology [1].

As the number of users increases, more capacity is needed. Wireless service providers are in the process of preparing their networks for the expected onslaught of wireless data users [2].

The characterization of user mobility has a basic role in the study of mobile systems; user mobility directly affects the performance of the network. Network procedures exchange signaling messages between its diverse elements. Such procedures are performed to guarantee transparent user's mobility, but contribute to the increase of network traffic load.

Although cellular operators have to face a significant increase of the signaling load that passes through the mobile network infrastructure, very few of these actually use appropriate network planning tools to predict such traffic variation. Signaling loads are critical because signaling links are often limited in capacity by the overlay signaling network that carry signaling messages [3].

The mobility model is fundamental in the forecasting and sizing of the traffic generated by user mobility, allowing better planning and resource allocation in the construction and maintenance of a mobile/cellular network [4]. He mobility management procedures affect the signaling load in a network, call establishment time and update and operation invocation rates at network nodes [3].

1- *Tool that is being developed by the Center of Computer Science of the UFPE, together with the CETUC - PUC-RJ, in the research project NOMADIC, sponsored by FINEP/PADCT-III and SIEMENS of Brazil.*

The object of this article is to present a simulation architecture for signaling load analysis of cellular mobile communications network environments. GSM and IS41/136 systems are simulated and their signaling load is measured. The modules that form this architecture and the simulation tool (CELSA, Cellular Signaling Analyzer) implemented in the SIMSCRIPT II.5 language are described.

This article is organized as follows: section 2 describes IS41/136 and GSM cellular telephony systems. Section 3 presents the simulation platform architecture for signaling networks, with the implemented modules in a discrete event simulator. Section 4 shows the topology used for simulation and the results achieved with the implementation of a cellular network architecture and, finally, in section 5 some final considerations are given.

2. CELLULAR MOBILE SYSTEMS

Some systems use Time Division Multiple Access (TDMA) techniques to share a given radio channel between users. TDMA uses time assignments to divide a single channel into a successive series of time slots that can be shared among a group of users (each time slot carries information for a specific user).

The primary TDMA standard in the USA is IS 136 (also known as Digital AMPS or D AMPS). Global System for Mobile communication (GSM) may be seen as the world's dominant cellular standard. This system is widely deployed in Europe, Asia and in the USA by several PCS carriers.

IS 136 defines the Technical requirements of how a cellular channel is shared among one or more users for the US TDMA system. This approach to channel sharing achieves a higher level of efficiency and results in a higher capacity network than the traditional analog cellular system that it replaces. Although quite different in its details, GSM uses the same TDMA technique for channel sharing and was the first true international standard for cellular [1].

2.1 THE IS41/136 STANDARDS

Network standards like TIA IS 41 specify how individual cellular systems communicate over the Public Switched Telephone Network (PSTN). IS 41 provides a common operating framework for different technologies and network connectivity that AMPS, TDMA, CDMA, and PCS systems need for interworking.

Automatic roaming with a cellular phone is made possible by the TIA/EIA 41 standard that provides intersystem handoff, call delivery, remote feature control, short message delivery, validation and authentication through an inter system messaging protocol.

IS 136 is an enhancement to IS 54 (the first implementation of AMPS digital cellular used TDMA) that includes a more advanced control channel (known as the digital control channel DCCH) to distinguish it from the analog control channel) [5].

2.1 THE GSM STANDARD

GSM allows subscribers to have full access to the networks of the various PLMN (Public Land Mobile Network) providers in countries that have adopted the GSM standard. This standard represents a second generation mobile communication system.

Phase 1 of these standards was adopted by ETSI (European Telecommunications Standards Institute) in 1990 [6], including several forms of call forwarding and call barring.

In 1995, Phase 2 was adopted and the corresponding service features were introduced in 1996, including additional supplementary services, such as caller identification, call waiting, multi party conversation [7] and SMS (Short Message Service).

An extension of the second phase (Phase 2+) meets the requirements that have arisen from practical operation since the introduction of the GSM standard. This extension involves new services and technical precautions for new applications based on the GSM900/GSM1800 standard, such as Virtual Private Networks and Packet Radio.

This work is based on Phase 2+ of GSM900/GSM1800 standard.

2.3 THE ENTITIES OF A MOBILE SYSTEM

Figure 1 shows the following functional entities.

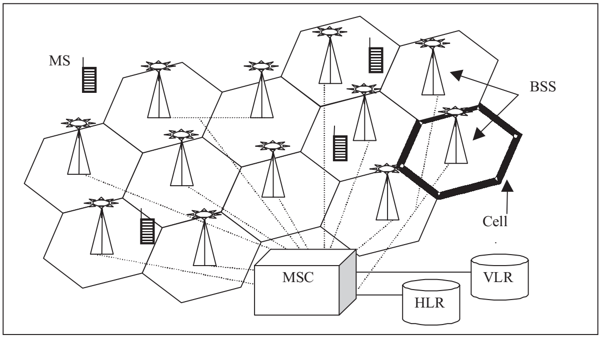

Figure 1: Architecture of a Cellular Network

The **Mobile Station (MS)** consists of the physical equipment used by a PLMN subscriber.

The **Base Station System (BSS)** is the base station equipment (transceivers, controllers, etc.) responsible for communicating with Mobile Stations in a certain area. The radio equipment of a BSS may support one or more cells. A BSS may consist of one or more base stations.

The **Mobile-services Switching Center (MSC)** is an exchange that performs all the switching and signaling functions for mobile stations located in a geographical area designated as the MSC area.

The **Home Location Register (HLR)** is the location register to which a mobile subscriber is assigned for record purposes such as subscriber information. A PLMN may contain one or several HLRs: depending on the number of mobile subscribers, on the capacity of the equipment and on the organization of the network.

The **Visitor Location Register (VLR)** is the location register used by an MSC for, e.g., to retrieve user information required for handling of calls to or from roaming mobile stations currently located in its area.

The GSM system includes other two entities: the **Authentication Center (AuC), that** is associated with an HLR, and stores an identity key for each mobile subscriber registered with the associated HLR, and the **Equipment Identity Register (EIR),** that is the logical entity responsible for storing in the network the International Mobile Equipment Identities (IMEIs), used in the GSM system.

2.4 BASIC PROCEDURES

The cellular cost structure is influenced by the user movement and call pattern and the system architecture. To estimate the signaling load, we need to know the number of messages generated for each key activity and the frequency at which the activity occurs.

Cellular systems define a number of procedures, that generate messages exchanges between the network elements, for basic operation, including:

- **Power Up**

This procedure starts the moment the Mobile Station (MS) is turned on initiating a series of procedures that make possible the MS preparation for a new status that allows the reception or the setup of calls.

- **Power Down**

This procedure executes when the MS is turned off. It represents the end of an MS operation, initiating the exchange of a number of messages between the component entities, in order to free resources allocated by the mobile station [8,9,10].

- **Location Updating**

The location management procedure is concerned with the procedures that enable the system to know the current location of a powered on mobile station so that incoming call routing can be completed [7,8,11,12].

Cells are grouped into location areas (an area in which a mobile station may move freely without updating the VLR; a location area may include one or several cells). Update messages are required only when moving between location areas, and mobile stations are paged in the cells of their current location area.

The location updating procedures, and subsequent call routing, use the MSC and the Home and Visitor location registers. When a mobile station is switched on in a new location area, or moves to a new location area or different operator's PLMN, it must register with the network to indicate its current location. In the normal case, a location update message is sent to the new MSC/VLR, which records the location area information and then sends the location information to the subscriber's HLR.

This location update causes a signaling load on the air interface and the fixed mobile network. In case of long distances between the visited location area and the HLR, the load in the fixed mobile network is immense [11].

- **Call Setup**

This procedure is concerned with the placement of a telephone call, when the MS sends the solicited number to the MSC along with a profile solicitation in order to configure services pertinent to this MS [8,13].

- **Handover**

The handover happens when the MS is moving from a BSS area of coverage to another one in the course of a conversation. Handover is initiated by the network based on radio subsystem criteria (RF level, quality, distance) as well as network directed criteria (e.g. current traffic load per cell, maintenance requests, etc.). In order to determine if a handover is required due to RF criteria, the MS takes radio measurements from neighboring cells that are then reported to the serving cell on a regular basis. Additionally, the handover decision by the network may take into account both the measurement results from the MS and network directed criteria [4,7,14].

3. THE SIMULATION TOOL

CELSA (Cellular Signaling Analyzer) is a cellular network simulation tool developed in the Simscript language. It simulates cellular signaling traffic over North American TDMA and GSM cellular networks, with the implementation of procedures and messages related to these systems.

The developed simulation tool allows to configure a cellular network by varying the number of cells, MSC, VLR, HLR entities, user population and performance parameters for mobility and traffic (Table 1).

Parameter	Type	Comment
Cell Residence Time	Mobility	Time a user spends in cell i.
Cell Crossing Rate	Mobility	May be obtained from the hazard rate of the p.d.f. of the residence time.
Call Duration	Traffic	Duration of a call.
New Call Rate	Traffic	Given as the number of new calls per hour.
Call Completation Rate	Traffic	Obtained from the hazard rate of the p.d.f. for cell residence time.
Handoff Residence Time	Traffic and Mobility	Cell residence time for a handoff call.
Cell Handoff Rate	Traffic and Mobility	Number of new handoffs arriving at a cell per unit of time.
New Call Blocking Probability	Traffic and Mobility	Probability that there is no channel available at a cell at a new call initiation.
Handoff Call Blocking Prob.	Traffic and Mobility	Probability that there is no channel available at a cell at the time a handoff is attempted.
Call Blocking Probability	Traffic and Mobility	The sum of both events above.
Call Dropping Probability	Traffic and Mobility	Probability that a call that has been initiated is the blocked because of handoff problems.

Table 1: Mobility Performance Parameters

CELSA is based on a modular platform, which allows the simulator to be more encompassing and more flexible. Next, these modules are included.

MODULE 1 - The "**Mobility and Traffic Generation**" Module is the main feeder of the system. It receives information relative to which procedures are occurring, their quantities, and states.

In the traffic generation, the tool must simulate the use of the network by its users in accordance with different scenarios. In this module the number of calls by unit of time, the call's average duration, the type of service used in the cell, and the user's mobility behavior, among others parameters, are described.

The majority of the literature models makes simplifications to facilitate the mobility analysis: in [15] the author assumes that the number of user in a cell always remains constant, in [16] the user speed user is assumed as being constant and in [15,17] the users movement route is modeled as being uniformly distributed between [0, 2π[.

These simplifications make the network quality parameters calculations simpler, but these models forecasts can be very distant of the real world environment.

The proposal in this model is to classify mobility in different profiles. CELSA use mobility according to a profile based model in order to cover a wider range of users behavior. The mobility model is seen in 03 (three) dimensions, as shown in Figure 2. A mobility profile is associated to each combination of the personal, spatial and temporal dimensions of each user.

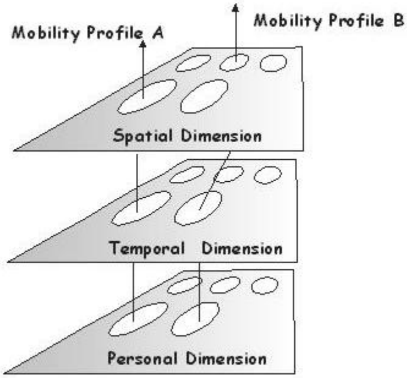

Figure 2: Profile Based Multidimensional Mobility Model

Personal dimension – Classifies the users in accordance with their movement. The "normal worker" user spends most of the day in a fixed location.

There are users with profile of "high mobility": although this user spends the night in his house sleeping, during the day he spends most of the time moving from one place to another one, not remaining much time in each visited place.

The "residential user", who does not work, spends most of the time in house, carrying out sporadic movements during the day.

Temporal dimension – describes the profile of different time periods in accordance with the features of mobility of each schedule. Mobility is highly influenced by the time of day.

Spatial dimension – describes the profile of each class of different regions. It classifies each network cell in accordance with the mobility profile of the region where it is situated. Cells located in residential quarters are characterized by the user permanence during the night until the beginning of the morning. In the morning the users move from residential areas to their offices, then the cells located in work regions typically have a great capacity "to attract" the movement of users in the beginning of working hours. We can observe that the sociologic economic profile of the region influences in the user mobility that area.

These 3 dimensions show that one determined user type (personal dimension), in one determined hour of the day (temporal dimension), in one given region (spatial dimension) has a certain mobility profile. Some combinations are impossible: a "normal worker" user in the night shift schedule never (or practically never) will be in a commercial region, for example.

MODULE 2 - The "**Scenarios and Messages Signaling Load**" Module supplies necessary information on each scenario. This information includes all exchanged messages when one determined procedure occurs (e.g. messages between the entities of a network when a handover procedure must be executed), in which interfaces each message passes through, the load of each message and its time of processing in each entity.

CELSA implements procedures such as Power Up, Call Setup, Location Update, Handover and Power Down, for GSM and IS41/136 systems.

Each procedure is implemented for each cellular standard, considering signaling messages and their lengths. The signaling load is the bytes exchanged between the network entities during the course of a period of time.

MODULE 3 - The "**Network Architecture**" Module is responsible for platform management and direct use of the information received from the other modules. It is desired, from this configuration, to get the signaling load and the performance responses related to the different scenarios, those are the immediate objectives of this platform.

This module allows the evaluation of very complex systems, making possible changes and/or upgrades in the number of location areas for each switch, allowing the identification of unbalanced loads, operation and testing of new procedures and/or services, and evaluation of the increase in generated signaling and user load, among other measures.

4. STUDY OF THE SIGNALING LOAD

In this section some results achieved with the use of the simulation tool are presented, including a comparison of the GSM and IS41/136 scenarios. Some simulations have been executed with the goal of verifying the behavior of the signaling traffic due to varying users profiles pertaining to a hypothetical metropolitan region, in both Cellular Systems.

The main procedures considered in these simulations are Power Up, Call Setup, Location Update, Handover and Power Down. Despite these procedures not provide a great impact in the total signaling load in a cellular mobile environment, it allows an initial analysis of the relationship of the new model of mobility implemented in this simulation platform with the signaling messages generated.

4.1 THE ADOPTED TOPOLOGY

To demonstrate the use of the simulation tool, a sample hypothetical cellular network was used composed of 17 cells.

There are 4 location areas, each one with one MSC. The cells are classified in 5 points of attraction: cells pertaining to residential, work, shopping, banking and leisure regions. All the cells have equal radius of 3 km, typical of metropolitans regions. The lines that connect the cells represent the paths defined for user mobility, as shown in Figure 3.

The users mobility is represented the following profile distribution:

- Common Users (Workers) 60%
- High Mobility Users 25%
- Residential Users 15%

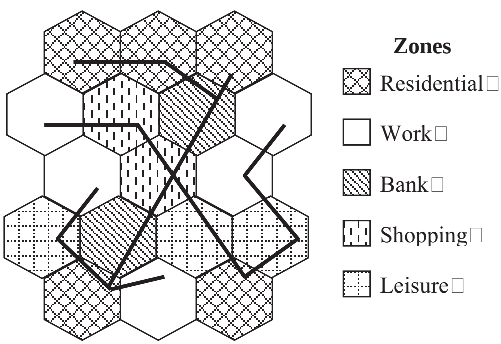

Figure 3: Paths defined for user mobility

The user's speed is uniformly distributed between 40 and 80 km/h. These values correspond to the variations of speeds for users who use the public transport system and private transport. In this study, pedestrians are not taken in consideration.

Tables 2 and 3 represent the probability of the attraction points for residential and worker user classes, respectively. High mobility users do not have this table of probabilities; therefore they can move to any destination cell with the same probability.

Hour(h)	Residential(%)	Work(%)	Bank(%)	Shopping(%)	Leisure(%)
6 – 8	90	0	0	0	10
8 – 12	20	30	40	10	0
12 – 14	40	10	40	10	0
14 – 18	40	10	10	30	0
18 – 24	50	0	0	20	30

Table 2 – Attraction Points Probabilities for Residential Users

Hour(h)	Residential(%)	Work(%)	Bank(%)	Shopping(%)	Leisure(%)
6 – 8	90	0	0	0	10
8 – 12	10	80	10	0	0
12 – 14	40	10	30	20	0
14 – 18	10	80	5	5	0
18 – 24	50	0	0	20	30

Table 3 – Attraction Points Probabilities for Normal Worker Users

4.2 SIMULATION RESULTS

Having assumed the network configuration described in the last section and determined both the procedure invocation rates and the number of bytes generated in each procedure, we can calculate, for example:

- the signaling load for each cell in the network;
- the signaling load generated by each user;
- the total signaling load for the network.

The general expression for the signaling load for cell "i" due to all mobility management procedures is given by:

$$T_{Ci} = T_{PU} + T_{CS} + T_{HD} + T_{LU} + T_{PD}$$

where

T_{PU} = total signaling load for Power up messages, generated when the MS is turned on;
T_{CS} = total signaling load for Call setup messages, generated when the MS solicits a call;
T_{HD} = total signaling load for Handover messages, generated when the MS moves from one cell to another one;
T_{LU} = total signaling load for Location Updating messages, generated when the signaling can be activated in any cell crossed by the user, depending on the moment when it is scheduled;
T_{PD} = total signaling load for Power down messages, generated when the MS is turned off.

The total signaling load for a network composed by "i" cells can be computed by:

$$T_N = \sum_I T_{ci}$$

Considering the network topology showed in Figure 6, the simulations include one BSS per cell, three MSC, three VLR and one HLR for entire network. For the simulations, it is considered a five hours period.

Figure 4 shows the total generated messages in the network during five hours simulation, varying the population (number of MS users), for both cellular systems.

For each population simulated, the IS41/136 system generated more exchanged messages in the network during the same period of time than GSM. The exchanged messages includes all messages related do signaling between MS and BSC, BSC and HLR e VLR, not including users data (voice conversation or data transmission).

Considering the messages lengths (number of bytes for the messages transmitted within the network entities), Figure 5 shows the amount of bytes that crosses the network during the simulation.

Since IS41/136 generated more messages than GSM, as showed in Figure 4, and due to the different lengths for the same procedures for each system, GSM generates more signaling bytes during operation, for the simulated procedures.

For example, as showed in Figure 6, the Location Updating procedure for IS41/136 generates more bytes per execution than GSM. The same occurs to Call Setup. Only GSM handover generates more bytes per execution than IS41/136.

Figure 7 presents results for a 5000 users population and a 4 hours period of time. The results are collected to show the average number of procedures activated by attraction area (composed by cells showed in Figure 3). For example, results for the residential area include the average number of activated procedures in the cells that belong to this type of attraction point.

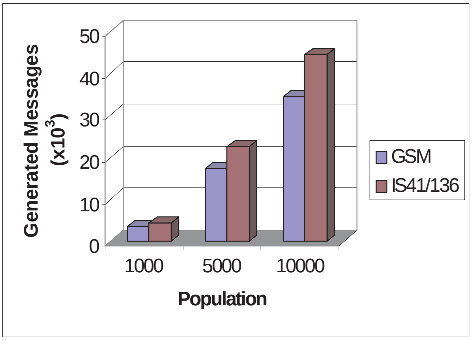

Figure 4: Total Generated Messages

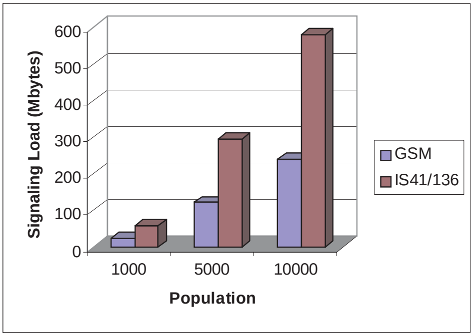

Figure 5: Total signaling load

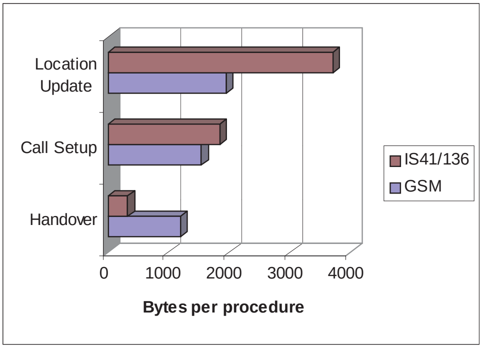

Figure 6: Signaling load per procedure execution

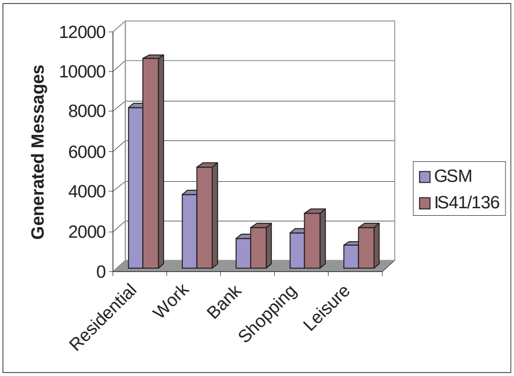

Figure 7: Generated Messages per Zone Area

As the simulation was executed for the morning period, when cellular users turn on their mobile stations and move to work areas, there are a great number of Power on, Handoff and Location Updating procedures, what generate more messages than the other areas.

Some factors can influence the simulation results of a cellular mobile communication environment.

Given the origin and final destination cells, and depending on the attraction point probabilities for users, the topology and on possible paths through the cells, different results can be achieved. Thus, the results depend heavily on the topology adopted for the simulation.

These simulations illustrate how CELSA works and can generate results. The analysis of signaling in cellular networks is very important for network planning, as the increase of signaling load may require the addition of more signaling links and switches to carry messages; otherwise, the network will operate at its limit or fail if not modified.

5. FINAL CONSIDERATIONS AND FUTURE WORK

In this article an architecture for the analysis of signaling in GSM and IS41/136 mobile cellular networks was presented, along with an implementation of the model in the simulation platform CELSA (Cellular Signaling Analyzer). Results of example simulations for signaling load analysis for both cellular systems using this platform were also presented.

The proposed architecture allows the modeling of different networks topologies and mobility profiles. It can be easily extended to include new procedures that take into account new data and multimedia services as proposed by the advent of the third generation cellular networks. Future studies using GPRS and EDGE are being considered as important extensions to this work.

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