

A Simulation Environment for Analysis of Quality of Service in Mobile Cellular Networks

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Abstract- This paper presents a simulation environment for mobile cellular networks called *CELSA*, which implements a mobility model based on users, regions and time period characteristics. This environment was used to obtain Quality of Service (QoS) parameters of a mobile cellular network and to evaluate the performance of a non-uniform channel allocation scheme called *CA-STV* compared to fixed and dynamic channel allocation.

I. INTRODUCTION

The rapid growth in demand for mobile communications has led to intense research efforts in developing simulation tools and environments for evaluating the use of the scarce spectrum allocated for cellular communications [6].

In this paper we present a simulation environment for mobile cellular networks that uses a three-dimensional mobility model. In this model, users are classified in different groups; and the cells are grouped depending on their “attraction” to the users. The time is also classified in zones in which users present similar mobility characteristics. Using this model its possible to obtain a more realistic mobility and traffic generation processes.

The simulation environment and the mobility model are used to evaluate the performance of channel allocation schemes, which have influence on QoS system parameters.

The paper is structured as follows: in section II we present a three-dimensional mobility model. In the section III we describe the simulation environment. The channel allocation schemes and the simulation results are presented in sections IV and V, respectively. Finally we draw some conclusions in section IV.

II. THE MOBILITY MODEL

The problem of creating a model, which predicts mobile user movements, is a complex task because it tries to predict human behavior to which there are many related parameters. In order to construct an efficient model it is necessary to consider different factors like geographical characteristics of the regions, users economical characteristics and the time of the day. With this information, it is possible to classify users, regions and periods of time in different groups defining a multidimensional mobility model.

Many models found in the literature use simplifications that turn mobility analysis and solutions to the analytical models easier. In some cases, the number of users in a cell remains constant at all time, as in [9]. In [8], for example, the rate of handoff attempts arriving in one cell is equal to the rate of users leaving this cell and trying to allocate a channel in another cell. Handoff attempts in each cell are generally considered as generated according to independent Poisson

processes, as in [5]. The users speed is considered constant in [3] and in [9], the direction of users movements is uniformly distributed between $[0, 2\pi[$.

Although all these simplifications are useful to establish the QoS parameters of the cellular system, they can damage the mobility model credibility. The model used in this paper was initially proposed in [1], and classifies the mobility in different profiles; attempting to cover as many users behavior patterns as possible. The environment is divided in three dimensions:

Personal Dimension: describes different user classes depending on their mobility behavior.

Time Dimension: describes periods of time with different mobility characteristics.

Space Dimension: describes the “attraction” characteristics of each region (cell).

The following types of users are defined in the personal dimension: Working User (WR), Residential User (RE) and High Mobility User (HM).

The mobility pattern is highly influenced by the time. During the first hours in the morning, for example, there is a big flux of users leaving their homes and going to work places. At the end of the afternoon the movements are more intense from work places to residential areas. The model defines six time zones where users have specific mobility characteristics as shown in Table I.

The Space dimension classifies each cell in the system depending on the “attraction power” over users during some period of time. This attraction is related to geographical and economical characteristics and it depends on the time of the day. The following types of cell are considered: Home (H), Working (W), Bank (B), Shopping (S) and Entertainment (E) cells.

TABLE I
TIME ZONES DESCRIPTIONS

Time Zone	Time Period	Description
1	06 to 08	Rush Hours
2	08 to 12	Working Hours
3	12 to 14	Day Free Hours
4	14 to 18	Working Hours
5	18 to 20	Night Rush Hours
6	20 to 24	Night Free Hours

Fig. 1. shows that different profiles of mobility can be defined combining information from the three dimensions.

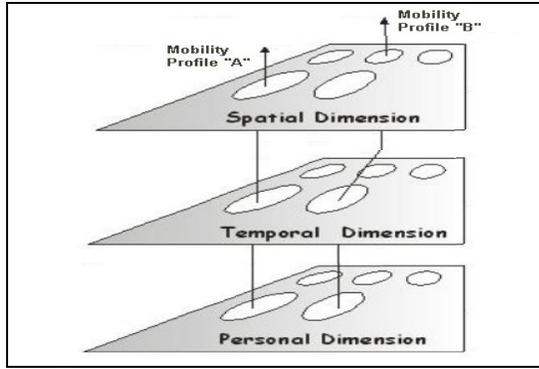


Fig. 1. Three dimensional mobility model

Each profile is represented by an algorithm that chooses the destination cell of each user, the time user stays in each cell (cell residence time) before reaching the destination and the destination cell residence time. The cell residence time is modeled as a random variable exponentially distributed with mean μ minutes and the destination residence time is considered uniformly distributed between $[t_1, t_2]$ minutes.

The algorithm chooses the destination cell depending on the personal profile of each user and on the time. High mobility users have a random behavior and the destination can be any cell of the system in any instant of time with the same probability. Workers and Residential users are more predictable and each one has a schedule with probabilities for each type of attraction point (H, W, B, S and E cells) and for each time zone, as we can see in Tables II and III, respectively. These probabilities determine the user destination.

After a destination has been selected, the next step is to define the route that the mobile user will take on his trip. A route is a sequence of cells defined in the simulation environment. There are some routes that can be chosen from and the simulator selects the first one that connects the current user cell and the destination cell.

TABLE II
ATTRACTION POINTS PROBABILITIES (RE)

Zone	H	W	B	S	E
1	1	0	0	0	0
2	0,2	0,1	0,2	0,4	0,1
3	0,4	0,1	0,4	0,1	0
4	0,3	0,1	0,1	0,2	0,3
5	0,5	0	0	0,3	0,2
6	0,6	0	0	0,1	0,3

TABLE III
ATTRACTION POINTS PROBABILITIES (WR)

Zone	H	W	B	S	E
1	1	0	0	0	0
2	0,1	0,8	0,1	0	0
3	0,4	0,1	0,3	0,2	0
4	0,1	0,7	0,1	0,1	0
5	0,4	0,2	0,1	0,2	0,1
6	0,6	0	0	0,2	0,2

III. THE SIMULATION ENVIRONMENT

The *CELSA* (*Cellular Signaling Analyser*) is a simulation environment developed initially for the analysis of the signaling in TDMA mobile cellular networks [4], but it has been extended in this work to perform resource dimensioning and performance analysis of channel allocations schemes.

The main procedures of a IS-136 cellular network were implemented in *CELSA* including: Power on, Call Origination, Handoff, Location update and Power off. During the execution of each procedure, the tool simulates the messages exchanged between the network components (RBS – Radio Base Station, MSC - Mobile Switch Center, VLR – Virtual Location Register, HLRL – Home Location Register and MU – Mobile Unit). The messages have different sizes in bytes and each procedure has its own messages that are exchanged in a specific sequence. By computing the messages sizes for each procedure, it is possible to estimate the signaling load in the network.

The simulation platform implementation was divided into three modules: Mobility and Traffic Generation; Signaling Messages and Network Structure Configuration

In this paper, we will use *CELSA* to do performance analysis of three channel allocation schemes that will be explained in the next section. We will also obtain Quality of Service parameters of a cellular network that we have defined as blocking probability and handoff failure probability.

The SIMSCRIPT II.5 language was used for implementing the simulation environment, since it offers high flexibility. The modular implementation makes it possible to examine different mobility models, traffic distributions and topologies, as well as new procedures that can be implemented.

The *CELSA* simulation tool has a graphical interface that was developed in Delphi. Using this interface the user can construct a simulation of any topology, by just selecting, connecting and defining the properties of the network components. It's possible to have a map in the background that helps to place the components and simulate a real network over a specific city.

It is possible to configure component properties, such RBS coverage area and number of channels available. In addition we can define the space dimension classification for each cell (Residential, Working, Bank, Shopping or Entertainment area) and the possible routes in the topology. The information about personal profiles, such as the total number of users, the percentage of users in each profile and the attraction point's probabilities schedules for the Working and Residential users can also be defined in the graphic interface. All this configuration information reflects the mobility model described in the previous section.

III. CHANNEL ALLOCATION SCHEMES

In mobile cellular networks radio channels are the resources available for connected active mobile users. The more users the network has, the more important is the efficiency in the reuse of the limited frequency spectrum available. The channel allocation algorithms are responsible for getting the efficient reuse of channels and contribute for determining the QoS level of the system.

However, this reutilization is restricted by the co-channel interference, which limits the use of one channel by more than one mobile at the same time. Two mobiles can use the

same channel only if at least the co-channel reuse distance separates them.

Many allocation schemes can be found in the literature [7], but they can be classified in two extremes: Fixed Channel Allocation (FCA) and Dynamic Channel Allocation (DCA). In the FCA schemes, each cell has its own set of channels. In the DCA there is no relationship between channels and cells, examples are found in [3], [7] and [10]. All channels are kept in a central pool and are assigned dynamically to cells as new calls arrive in the system, and the number of channels in each cell is adaptively changed to accommodate traffic fluctuations.

Current standards developments of TDMA/FDMA digital cellular mobile networks support fixed channel allocation [6]. In FCA, the allocation relies heavily on frequency planning and will not be able to adapt dynamically to the changing condition of the offered traffic as DCA schemes.

In view of this “deficiency” of FCA, some systems have already applied the DCA schemes, as the digital enhanced cordless telecommunication system (DECT) and the Japanese personal handy phone system (PHS). DCA is also currently supported by GSM and will be supported by PCS and D-AMPS in the near future as the incorporation of DCA into their evolving standards is in an advanced stage. The evaluation of the benefits of DCA over FCA is therefore important to telecommunications providers who are considering upgrading their existing channel allocation equipment [6].

In this paper we will examine the performance of the following channel allocation schemes:

- FCA – If M is the total number of channels, each cell has its set of $S=M/7$ channels, where 7 is the reuse factor;
- DCA-First Available (DCA-FA) – In this scheme the first available channel within the reuse distance encountered during a channel search is assigned to the call;
- Channel Allocation with Space and Time Variations (CA-STV) – This scheme, initially proposed in [2], uses information about users mobility profiles. With this information we can predict the traffic characteristics and channels can be distributed in a non-uniform way so that the number of channels in each cell can also vary depending on the time.

The CA-STV scheme assumes that each cell is classified into one of the five profiles defined in the space dimension of the model explained above. The time zones have also to be defined according to the same mobility model. Each cluster has a channel allocation matrix that defines the fraction of channels assigned for each type of cell during each time zone.

As in DCA schemes, for implementing the CA-STV scheme, additional transmitters/receivers will have to be added onto all base stations so that they are capable of transmitting and receiving in all available frequency carriers. The CA-STV also tries to adapt to the changing condition of the offered traffic, but not dynamically.

IV. SIMULATION RESULTS

We consider a 28-cell network as shown in Fig 2. The cells are organized in four clusters, each of seven cells. The connections between cells that form the possible routes defined in the mobility model are also indicated in Fig 2.

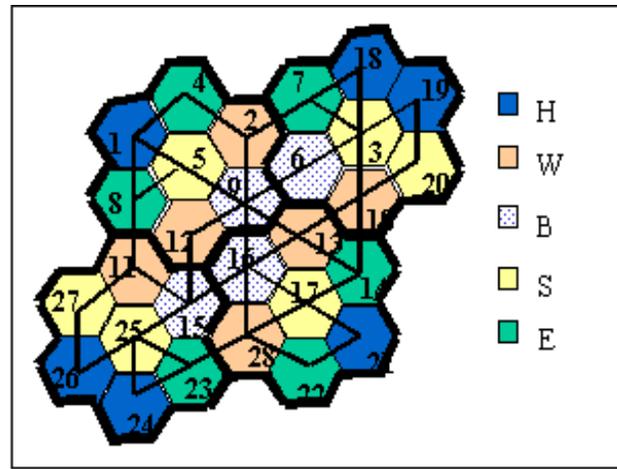


Fig. 2. Simulated Topology

The following assumptions are considered in the simulation:

1. The call duration time is random and exponentially distributed with an expected value t_{call} minutes;
2. Blocked calls are cleared;
3. The call arrival in the system is a Poisson process with mean λ ;
4. There are 5000 mobile users in the system and 60% are Workers (WR), 15% are Residential (RE) users and 25% are High Mobility (HM) users;
5. There are 105 channels available in the system.

A. Scenario 1

In this scenario the traffic distribution by cell was analyzed in order to define the more suitable values of the channel allocation matrix used in the CA-STV algorithm. The following parameters were used: $t_{call}=2$ min; $\lambda=0,8$ calls/sec; $\mu= 3,6$ min (mean cell residence time) and the destination residence time distributed between $[t_1=48, t_2=60]$ minutes. The percentage of the total traffic by cell for each class of cell (H, W, B, S and E) is shown in Fig. 3. The results were obtained by computing the new call requests in the system during a simulation from 6:00 (Zone 1) to 24:00 (Zone 6).

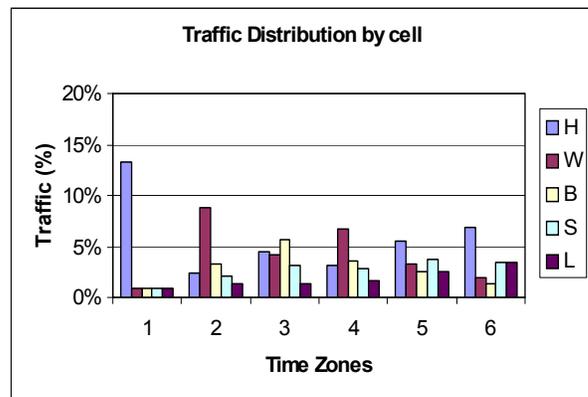


Fig. 3 Traffic Distribution for Each Time Zone

During the Zone 1, for example, home cells have a high traffic load, because of the values in the attraction points tables (Tables II and III). During the Zone 2, the traffic is more intense in the Working cells, where most of the 60% of users (Workers) are supposed to be. In Zone 3 we can see a more equilibrated situation, what represents the users going home, users going to center areas, such as Bank and Shopping cells, or users who stay in the work place. The others zones results are also in line with the mobility model.

Observing the traffic conditions, we have chosen the values of the channel allocation matrix for the CA-STV scheme and the matrix used in the following experiments is showed in Table IV. Using the *CELSA*'s graphic interface, the simulation designer can change these values easily at any time.

In this scenario we have also obtained the blocking probability by cell for simulations between 9:30 and 10:30 am (Fig. 4) and between 21:30 and 22:30 in the night (Fig. 5). This probability was estimated by the mean percentage of calls blocked by cell for each type of cell.

As we can see in Fig 4, the CA-STV scheme had a much better performance than FCA or DCA-FA in the Working and Bank cells. These types of cell have a more intense traffic during this time. In the Bank cells the blocking probability using CA-STV was very low compared to the other schemes. Moreover, in the Home, Shopping and Entertainment cells the CA-STV had a high blocking probability than FCA and DCA-FA. But, as specified in the mobility model, these types of cell, at this time of the day, have a lighter traffic load.

TABLE IV
CHANNEL ALLOCATION MATRIX

Zone	H	W	B	S	E
1	0,5	0,2	0,1	0,1	0,1
2	0,2	0,4	0,1	0,2	0,1
3	0,3	0,3	0,2	0,1	0,1
4	0,2	0,4	0,1	0,1	0,2
5	0,3	0,2	0,1	0,2	0,2
6	0,4	0,1	0,1	0,1	0,3

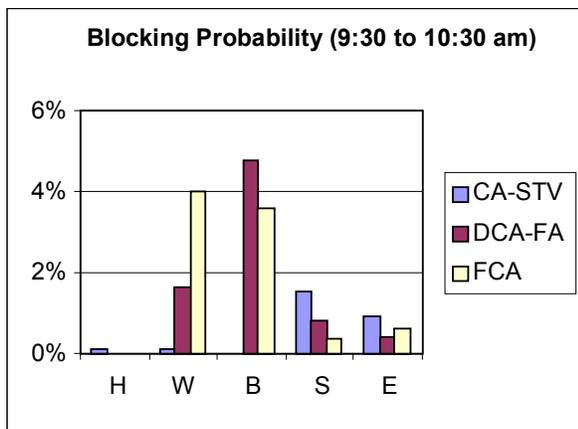


Fig. 4. Blocking Probability by cell (Time Zone 2)

The results in Fig. 5 show again the efficiency of CA-STV in heavy loaded cells, which are represented by Home and Entertainment cells during this time of the day. Even in Bank cells CA-STV performed better than FCA or DCA-FA. Only in Working and Shopping cells other schemes had lower blocking probability, but this regions have a light traffic load during the simulation period.

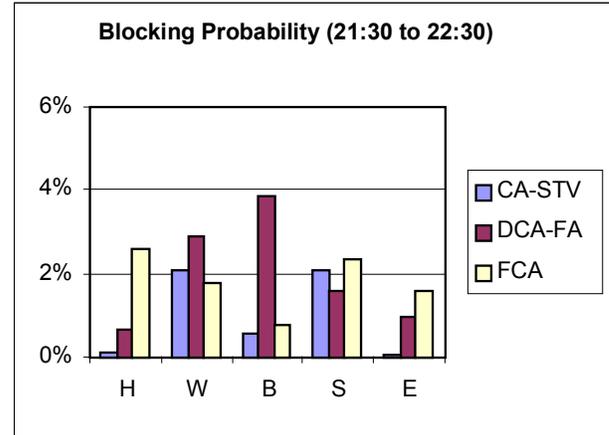


Fig. 5. Handoff Failure Probability (Time Zone 6)

The numerical results obtained provide insight into efficiency gain of CA-STV in the cells under heavy traffic conditions, where the CA-STV scheme presented the lowest blocking and handoff failure probability. Even in lighter load cells the performance of the proposed algorithm was not so bad compared to FCA and DCA.

B. Scenario 2

In this second scenario, we will evaluate the performance of channel allocation algorithms under high handoff traffic. The parameters values were the following: $t_{call} = 4$ min; $\lambda = 0,8$ calls/sec; $\mu = 2$ min (mean cell residence time) and the destination residence time were distributed between $[t_1=30, t_2=42]$ min. The mean call time was increased and at the same time the cell residence time and the destination residence time were reduced. The changes in scenario 2 increase the probability of handoff procedures by the users.

The handoff failure probability is presented in Fig. 6 for a simulation in zone 3. As we can see, the DCA-FA scheme had the worst performance in all kinds of cell in the zone simulated. The FCA scheme presented the lowest failure probability and the CA-STV results were close to FCA only in Working cells.

Fig. 7 shows the percentage of new call requests that execute handoff procedure using each channel allocation algorithm in a simulation between 12:30 and 13:30. Although FCA had the lowest handoff failure probability, as presented above, the system supported higher handoff traffic using CA-STV than FCA or DAC-FA. Considering that the more traffic the system can handle, the more efficient is the channel allocation algorithm, the CA-STV had a good performance.

The bad results obtained by DCA-FA showed that as the handoff traffic increase the gain of a dynamic allocation decrease drastically compared with the fixed allocation techniques.

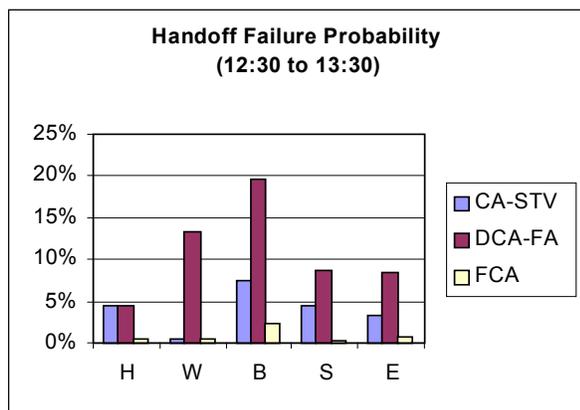


Fig. 6. Handoff Failure Probability (Zone 3)

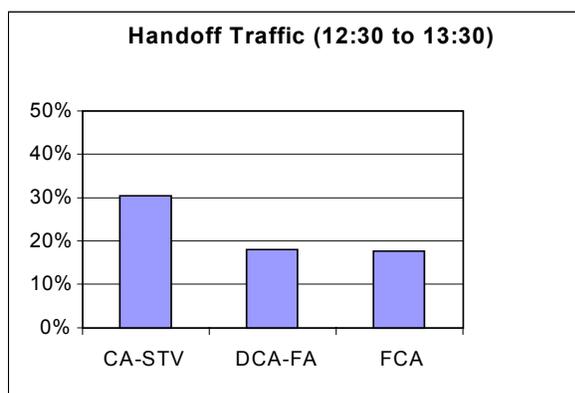


Fig. 7. Handoff Traffic (Zone 3)

V. CONCLUSIONS

We have presented the simulation environment *CELSA* developed for the analysis of signaling load and Quality of Service parameters in mobile cellular networks.

We have considered a three dimensional model that takes in account different characteristics of mobile users, regions and periods of time to define mobility profiles.

The simulation environment implementation is modular and it is possible to add new mobility models and networks procedures. It also allows the total configuration of the experiments by using a graphical interface.

We have evaluated the efficiency of the following channel allocation schemes: FCA, DCA-FA and CA-STV. The numerical results provide insights into efficiency gain of CA-STV in the cells under heavy traffic conditions. The analysis of handoff failure probability showed that although FCA had the lowest values, the CA-STV supported higher handoff traffic.

We have demonstrated the efficiency of a simulation environment on performance analysis of channel allocation schemes, which determines the QoS provided by mobile cellular networks.

REFERENCES

- [1] B. G. Alencar, "An user mobility model for cellular communications networks", in proceedings of the WCSF 2000, (Belo Horizonte, Brazil, May 1999).
- [2] D. Cavalcanti, "Space and time variations on channel allocation in mobile cellular networks", 19th Brazilian Simposium of Computers Networks, Florianópolis, Brazil, May 2001.
- [3] E. Del Re, R. Fantacci and G. Giambene, "Handover and dynamic channel allocation techniques in mobile cellular networks", *IEEE Trans. on Vehicular Technology*, Vol. 44, No 2 (May), 229-237, 1997.
- [4] K. Dias, J. Oliveira, D. Filho and D. Sadok, "An architecture for analyses of signalling load in mobile cellular communications networks", in proceedings of the 18th Brazilian Simposium of Computers Networks, Belo Horizonte, Brazil, May, 286-301, 2000.
- [5] R. Fantaci, "Performance evaluation of prioritized handoff schemes in mobile cellular networks", *IEEE Trans. on Vehicular Technology*, Vol. 49, No 2, March 2000.
- [6] P. Hiew and M. Zukerman, "Efficiency comparison of channel allocation schemes for digital mobile communications networks", *IEEE Trans. on Vehicular Technology*, Vol. 49, No 3, May, 2000.
- [7] M. Katzela and M. Naghsineh, "Channel assignment schemes for cellular mobile telecommunications systems", *IEEE Personal Communications*, June, 1996.
- [8] Y. Lin, "Performance modeling for mobile telephone networks", *IEEE Networks*, (Nov/Dez), 63-68, 1997.
- [9] R. Thomas, H. Gilbert and G. Mazziotto, "Influence of the moving of the mobile stations on the performance of a radio mobile cellular network", in *proceedings of the 3rd Nordic Seminar*, Copenhagen, Denmark, September 1988.
- [10] R. Prakash and M. Singhal, "Distributed dynamic channel allocation for mobile computing", Department of Computer and Information Science, The Ohio State University, 1996.