

Numerical Solution of One GSM Cell Using MOSEL-2 Language

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Abstract: *This paper presents a numerical solution of one GSM cell using the Modeling Specification and Evaluation Language (MOSEL-2) which is the new version of MOSEL, developed at the University of Erlangen, Germany. In this regard, the frequency spectrum of GSM cell is divided into two layers (super and regular) according to the intelligent underlay-overlay principle. Based on this principle, the super frequencies have better Carrier-to-Interference (C/I) ratio than the regular frequencies and usually used near the base station in hot spot areas, while the regular frequencies are used for the whole cell. In this paper, and based on the above assumptions, the queuing model of GSM systems is suggested and the numerical solution of this model is presented by MOSEL-2. As a result of this, the critical performance measures such as: loss probability, mean queue length and utilization are presented and discussed.*

Keywords: *Performance modelling, GSM systems, MOSEL-2, underlay-overlay, performance measures, queuing model.*

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1. Introduction

GSM stands for Global Systems for Mobile communication. Today's GSM platform is a hugely successful wireless technology and an unprecedented story of global achievement. In less than ten years since the first GSM network was commercially launched, it became the world's leading and fastest growing mobile standard, spanning over 200 countries. Radio spectrum is the essential resource for all GSM networks. Without it, the wide range of mobile services available today simply would not exist. The wireless communications industry has grown significantly over recent years, in terms of the technologies available, the services on offer and, of course, the number of users. However, spectrum is a finite resource and must be managed effectively across all technologies and every region of the world.

Radio spectrum is very valuable but finite natural resources. Spectrum is the key requirement for the provision of any wireless service. Therefore, it is very important to allocate it as efficient as possible. Intelligent underlay-overlay architecture can be used to increase system capacity, performance and coverage. Some research papers have discussed this issue from different point of views. Some proposals to increase system capacity exist, such as; using frequency hopping [7, 9], using of micro-cells [11], or hierarchical cell structures [7].

1.1. Underlay-Overlay Principle

Moving from a single cell layer towards hierarchical multilayer system can solve many problems related to

the single cell architecture. Different cell layers can be dedicated to different user groups based on their mobility and traffic demands. Nokia Intelligent Underlay-Overlay (IUO) solution has been proven to increase capacity significantly (up to 40 %) while reducing the number of dropped calls without adding any new sites [6, 10]. Nokia has combined its intelligent underlay-overlay solution with frequency hopping. Alternatively, frequency hopping can be used to improve only the quality if the existing frequency plan is retained. The dynamic layer selection of Nokia IUO, based on the interference levels, guarantees good quality call connections in all conditions. Operators can enjoy combined capacity and quality gain in their existing base station sites. This is accomplished through the implementation of two-layer network structure as shown in Figure 1, in which one layer provides seamless coverage, and the other high capacity [10]. The cell is assumed to have two layers, regular and super. For example, a single cell can be divided into two underlay and overlay layers with different reuse factor for each layer. The IUO solution splits the available frequency spectrum into two bands. One consisting of frequencies that can only be used when a high C/I ratio is ensured, the super frequencies, which are usually used only near the base station. The other band contains frequencies that can be used throughout the whole cell, the regular frequencies.

The analytical solution of the underlay-overlay principle is presented in [1] using the maximum entropy principle. In this paper, the queuing model is presented and solved numerically using the universal modelling and specification language MOSEL-2 which is initially developed at the university of Erlangen,

Germany by the name of MOSEL [2, 8] and now the new version of this language is introduced which enhances all the new features that make this language very useful for modelling and evaluation of different type of systems.

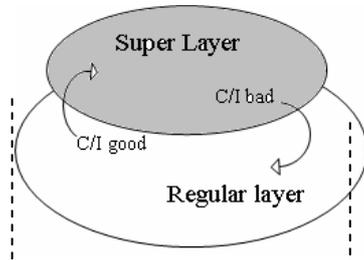


Figure 1. One GSM cell with super/regular layers.

1.2. Possible Handovers

- For the connection of non-moving mobile, the call is served at the same layer chosen according to the value of “C/I” until its normal termination.
- For the connection of moving mobile, the “C/I” value may change after the connection is authorized. Therefore, this implies a set of handover possibilities between the super and the regular layer as follows:
 1. For the connection which is going to the super layer, two possible handovers are existing due to the movement of the mobile.
 - If the value of C/I ratio falls below “good C/I” threshold, but there is another free channel in the super layer where C/I is suitable, then the handover is accepted in the super layer.
 - If there is no suitable frequency available in the super layer for this connection, then the connection is transferred to the regular layer, but if all channels in the regular layer are occupied then the call will be lost.
 2. For the connection which is going to the regular layer, also two possible handovers are existing due to the movement of the mobile.
 - If the value of “C/I” reaches the “good C/I” value and there is free channel in the super frequency, then the call is moved to the super layer.
 - Intra-cell handover to regular layer in the same cell.
 - Inter-cell handover to regular layer from neighbouring cells.

Figure 2 summarizes all possible handovers.

2. MOSEL-2 Environment

The Modelling Specification and Evaluation Language version 2 (i. e., MOSEL2) is like the predecessor MOSEL [2], which is developed at the university of

Erlangen, Germany. The main objectives behind MOSEL2 are to:

- Provide system oriented language.
- Have easy to understand and learn language.
- Be universal, applicable but with independent evaluation method.
- Have a language which comprises translators for several already existing, well-tested and good performance evaluation tools.

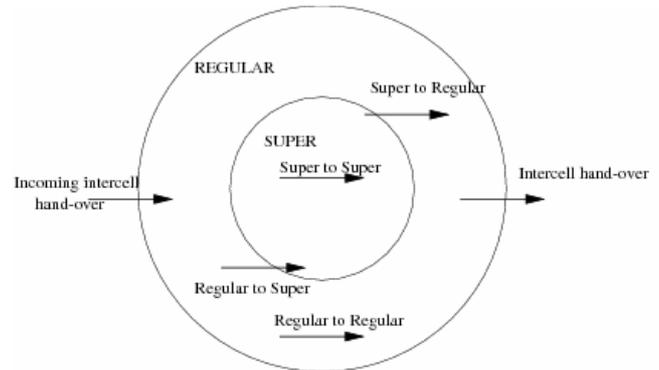


Figure 2. Possible handovers.

The following six steps are to describe the workflow of the performance evaluation procedure using MOSEL2:

1. Inspecting the real system and the modeller builds a high-level, textual system description using the MOSEL2 specification language and specifies the desired performance and reliability measures.
2. The MOSEL2 environment checks the input file for syntactical and semantic errors. If no errors occur, the MOSEL2 model gets translated to the system description of the evaluation tool selected by the user.
3. The chosen tool is started by MOSEL2 environment.
4. The tool evaluates the model by using numerical analysis methods or discrete-event simulation.
5. The evaluation tool saves its results in one or more tool-specific output files.
6. The MOSEL2 environment provides the results in a single textual and graphical file.

Figure 3 shows the above steps explained graphically.

3. System Description in MOSEL-2

As an example to show the main constructs in MOSEL2, we consider a homogeneous multi-server system with one queue and two identical servers using First-Come-First-Service (FCFS) strategy, see Figure 4.

The queueing model in Figure 4 could be described in MODSEL-2 as it is shown in Figure 5. Please note that the line numbers are used just to explain MOSEL-

2 statements and should not be included in MOSEL-2 program.

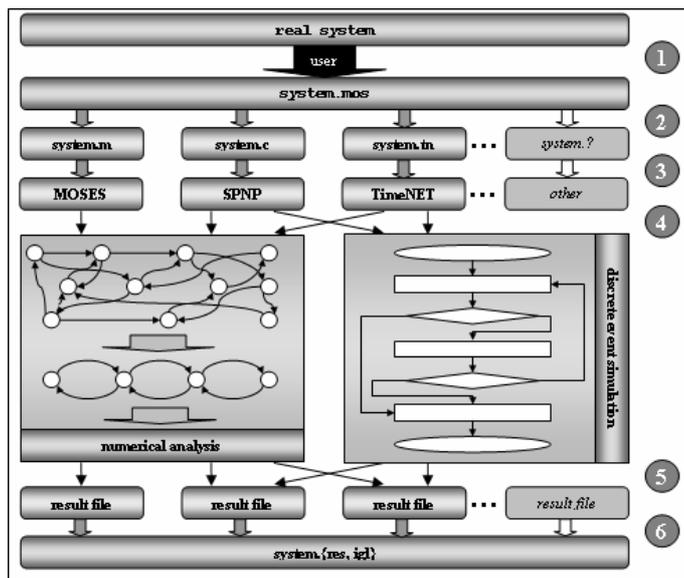


Figure 3. Modelling and analysis process in MOSEL2 environment [14]

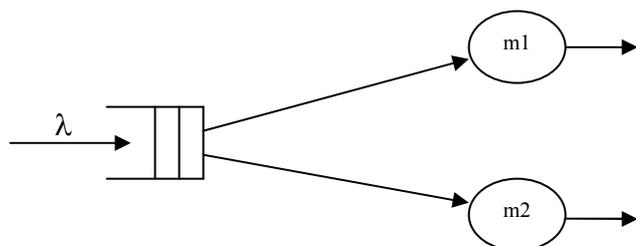


Figure 4. Queuing model with one queue and two servers.

This system is homogeneous in which the service rate is similar for both servers. Two figures are given. Figure 6 shows the utilization for both servers. It shows clearly that the utilization of server m1 is always better as it has higher priority in this type of strategy. Figure 7 shows the mean queue length and the throughput of the whole system. The above example is just given to describe the modelling of the queuing system using MOSEL-2.

MOSEL-2 description in Figure 5 can be divided into six parts:

- CONST and PARAMETER part (lines 1-5). This part is used to define and give values to constants and parameters in the program.
- NODE part (lines 6-8). Is used to define the nodes in the queuing system. At line 7, “@” is used to refer to loop in MOSEL-2. Loop is used in MOSEL-2 to avoid repetition because the statement at line 7 can be written without using loop as:

```
NODE    m1 [1];
NODE    m2 [1];
```

- Function and condition part (not used in this program). If the program needs any functions or conditional statements, they are usually defined in this part.

- Rule part (lines 9-13). Represents the transition states of the system.
- Result part (lines 14-17). The performance measures are computed in this part.
- PICTURE part (lines 18-27). It is used to visualize the performance measures graphically using the Intermediate Graphical Language (IGL), which is the software associated with MOSEL-2 language.
- Please note that MOSEL-2 is case-sensitive. Therefore, all reserved words in MOSEL-2 program should be written in capital letters (i. e., NODE, IF, RATE, ...etc).
- Additionally, in MOSEL-2, comments can be written either after “//” or between “/* */”. Both type of comments are used in Figure 5.

Each MOSEL-2 program has an extension “.mos”. MOSEL-2 program can be edited using any text editor. The program is compiled using the following command line:

```
> mosel2 -option filename.mos
```

The option “-option” tells MOSEL-2 to translate the model to a specified evaluation tool:

(i. e., “-cs” for SPNP [4, 13], “-ms” for MOSES [4] or “-Ts” for TimeNET [4, 15]). If the program is compiled successfully without any mistakes then MOSEL-2 will automatically generate two output files (i. e., result file “filename.res”) and (IGL file “filename.igl”). This is accomplished by the second option “-s” which orders MOSEL-2 to generate the suitable outputs. One can then browse the result file to see the results of different performance measures. Additionally, to visualize the results by IGL file, the following command line is used:

```
> igl filename.igl
```

It is possible by igl to visualize different graphs and make the necessary changes with a very friendly and helpful environment. IGL interpreter is a part of MOSEL-2 package. Furthermore, it is possible to export the file and save it in different forms to satisfy the needs of the users.

The following outputs (i. e., Figures 6 and 7) of MOSEL-2 program are generated using the transient evaluation over time. This can be achieved by the following command line:

```
> mosel2 -cs -t0,16,2 filename.mos
```

This command evaluates the result measured for $t = 0, 2, 4, \dots, 16$ where $t = 0$ is the time instant in which the model is in the deterministic state described by the initial values of its nodes.

```
//=== Constant and parameter part =====
1 CONST Q := 10; /* number of customers in the queue */
2 CONST n := 2;
3 CONST mue := 1.9; // service rate
4 CONST lambda := 3; // arrival rate
5 CONST K := Q + n; // number of customers in the system

//==== Nodes part =====
6 NODE p1[Q];
7 @<1..n > {NODE m# [1];}
8 NODE num [K];

//==== Rules =====
9 FROM EXTERN TO p1, num RATE lambda;
10 FROM p1 TO m1;
11 FROM p1 TO m2 IF (m1==1);

12 FROM m1, num TO EXTERN RATE mue;
13 FROM m2, num TO EXTERN RATE mue;

//===== Results =====
14 PRINT mean_q_length := mean (p1);
15 PRINT rho1 := util (m1);
16 PRINT rho2 := util (m2);
17 PRINT throughput := rho1 * mue + rho2 * mue;

//===== Picture Part =====
18 PICTURE "utilization_rho1"
19 PARAMETER time
20 XLABEL "time"
21 YLABEL "utilization"
22 CURVE rho1, rho2;

23 PICTURE "mean_queue_length"
24 PARAMETER time
25 XLABEL "time"
26 YLABEL "mean_queue_length & throughput"
27 CURVE mean_q_length, throughput;
//===== End of the program =====
```

Figure 5. Modelling of queuing model of Figure 3 by MOSEL2.

4. Modelling Assumptions

- One GSM cell is considered.
- The traffic over the network is homogeneous.
- The arrival rate over the network is exponentially distributed with rate λ .
- The incoming handover is assumed to be Poisson process with rate $\lambda \cdot h$.
- The cell is divided into two layers, super and regular with two groups of frequencies. The super frequencies (channels) can be used by mobile with good C/I ratio, while the regular frequencies are used over the whole cell.
- The call duration is generalized exponentially distributed random variable with rate μ .
- No movement is considered in this analysis.
- The square coefficient of variation (SCV) is assumed to be one. This means that the inter-arrival and service times are assumed to be exponentially distributed. Besides, it is assumed that there is no variability in the inter-arrival and service time distributions.
- According to the above assumptions, when the mobile station is connected, the C/I is calculated

immediately. Then if C/I value is less than a given value “say $C/I < G$ ” where G is a predefined threshold and there are free channels in the regular layer, then the connection is transferred to the regular layer otherwise the call is lost. On the other hand, if “ $C/I > G$ ” and there is an available channel in the super layer then the connection is transferred to the super layer. If all channels in the super layer are busy, then the call is transferred to the regular layer. If both the regular and the super layer are busy, then the call is lost.

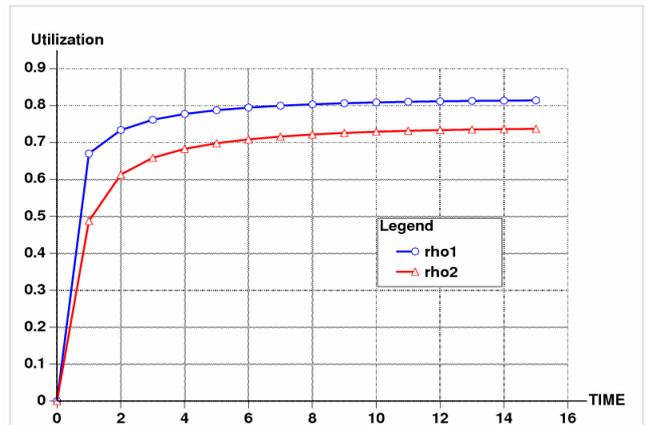


Figure 6. Utilization for both servers 1 & 2 (transient analysis).

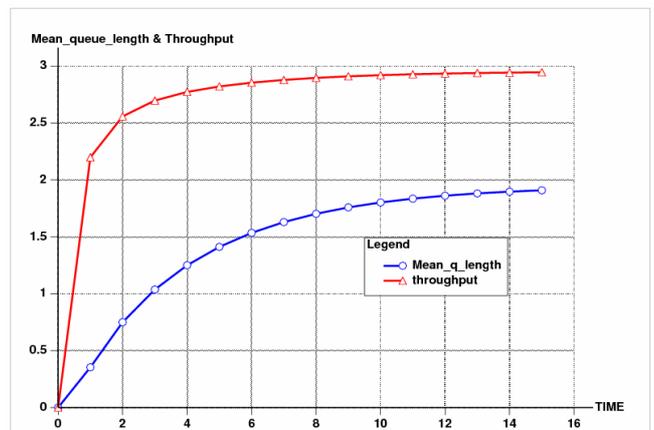


Figure 7. Mean queue length & throughput (transient analysis).

5. Queuing Model

The queuing model is presented in Figure 8, which is similar to the model which has been solved analytically in [2]. The only difference is that in this model the Square Coefficient of Variation (SCV) is assumed to be one. Additionally, it is important to mention that three nodes are assumed in the analysis (i.e. super, regular and reg_sup). Therefore, the system behaves as a Continuous-Time Markov Chain (CTMC) with random variable X which has three parameters:

$$X = (super, regular, reg_sup)$$

- Super is the number of connections served by the super frequencies, i. e., SC channels.

- Regular is the number of connections served by the regular frequencies, i. e., RC channels.
- Reg_sup is the number of connections served by the regular frequencies when all the super frequencies are occupied.
- The number of frequencies in both nodes (i. e., regular and reg_sup) should not exceed RC.
- All possible transitions of the system are shown in Figure 8.

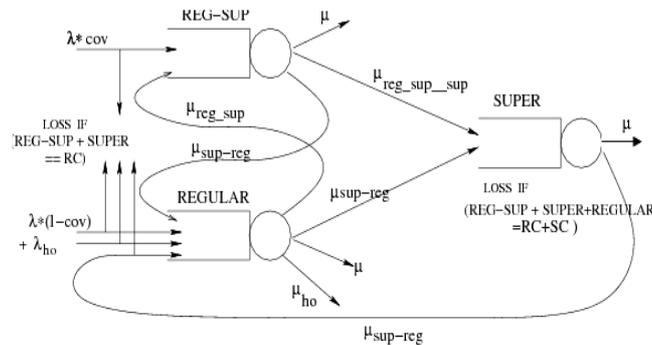


Figure 8. The queuing model of super/regular layers.

6. Numerical Solution by MOSEL-2

The numerical solution of the queuing model of Figure 8 is given in Figure 9 using MOSEL-2 language. Some of the important statements that represent the transition rates of the system under consideration are labelled in Figure 9 with numbers (i.e. 1-20). Please note that no line numbers are used in MOSEL-2 program and these numbers are used only to explain the transition part of the program.

- Lines 1-6. In line 1, there is a condition to ask whether there are available free channels in the system. If the condition is true, then the call moves from outside population to both “reg_sup” and “regular” nodes with given rates. Both rates are computed based on the coverage of the super layer.
- Lines 7-8. As explained before, if there are available channels in the super layer, then the call moves immediately to the super layer.
- Lines 9-14. The call moves from super to regular layer, if there is free channel in the regular layer, otherwise, the call is lost.
- Lines 17-18. The call moves from the regular to the super layer, if there are no free channels in the regular layer but there are free channels in the super layer.
- The last lines 19-20. The call moves to the outside world after it finishes its service.

7. Numerical Results and Discussion

Table 1 shows the assumed (default) values for different parameters used in the following analysis. The analysis concentrates on the coverage issue which is defined in MOSEL-2 program to have different ratios for the coverage factor in the super layer. The

regular layer usually provides high coverage and used in low traffic density areas, while, the super layer is usually used to support high traffic in hot spot environments.

Our system here is a loss system. Loss is happened in the regular layer if all channels are occupied. On the other hand, loss happened in the super layer only if all channels are occupied in both regular and super layers. Therefore, in the following results, it is expected that the loss probability in the regular layer to be higher than the super layer, although the main objective of this suggested structure is to have balance between both layers even at different coverage factors in order to achieve the main objective of the hierarchical structure of cellular systems.

Table 1. System parameters.

Parameter	Values
Number of channels in regular layer	32
Number of channels in super layer	16
Super area coverage factor	0.50,0.70,0.90
Call holding time, μ	30 seconds
The arrival rate, λ	0.60,1.0,1.4,1.8
Time for C/I ratio calculation	5 seconds
Ratio of calls leave the whole cell before termination	0.60
Ratio of new and incoming handover calls	0.40

The following numerical results are generated by MOSEL-2 and prepared by IGL which is associated with MOSEL-2. Six figures are presented in this section. The arrival rate to the cell, λ , varies from 0.60 to 1.8. Figures 10 and 11 show the loss probabilities to both regular and super layers for different coverage ratios. The two figures show that the loss probability in the super layer is less than the regular at different traffic values and coverage ratios, although the super layer supposed to have high traffic density because it represents hot spot areas. This is because the loss probability in the super layer only happened when there are no channels left in both the regular and the super layer. While the loss of the regular layer is only depends on the availability of its own channels. This is logical in this type of structure as the regular layer overlays the super layer. Therefore, it is possible to transfer some calls from the super layer to the regular layer when all channels in the super layer are fully occupied. After some time, as the rate increases the system reaches a stable state where we have a balance in the system at different coverage factors.

Figures 12 and 13 show the mean number of jobs in each layer. It is clear that the regular layer has always higher number of users at different traffic loads as it supposed to have higher coverage and its frequencies are used over the whole cell. On the other hand, the

super frequencies are used only in the super layer with higher C/I ratio.

The last two Figures: 14 and 15 show the utilization for both layers. Again, it can be noticed that higher utilization can be achieved in the super layer as all its frequencies are always occupied and many calls are transferred to the regular layer.

```

/* Model of underlay-overlay of one GSM cell */

/*-----Consts and parameters -----*/
CONST RC:= 32; // number of channels in regular layer
CONST SC:= 16; // number of channels in super layer

PARAMETER sup_cov:= 0.50, 0.70, 0.90;
/* part of cell covered by super channels*/
CONST mm:= 0.6; /* ratio of moving mobiles i.e., the fraction of
calls leave the whole cell before termination */
CONST hor:= 0.4; /* ratio of new and incoming handover calls */
/*--Input load and service times --*/
PARAMETER lambda:= 0.6, 1.0, 1.4, 1.8;
CONST mue:= 0.03333; // 1/30 [1/sec];
CONST mue_reg_sup := 1.0/5;
CONST lambda_handover:= hor * lambda;
CONST mue_sup_reg := mue * mm/(1-mm) * Sup_cov;
CONST mue_reg_sup:= mue * mm/(1-mm) * Sup_cov;
// from reg to super handover
CONST mue_reg_oho:= mue * mm/(1-mm);
// from reg to outgoing handover
/*----- Nodes -----*/
NODE reg_sup [RC];
NODE regular [RC];
NODE super [SC];

/*-----Events that control the transitions rates -----*/
/*-----New and handover arrival -----*/
1. IF(reg_sup+regular < RC)
2. THEN
3. {
4. FROM EXTERN TO reg_sup RATE lambda * Sup_cov;
5. FROM EXTERN TO regular RATE lambda * (1 -
Sup_cov)+ lambda_handover;
6. }

/*---Reg_sup --->s uper --- */
7. IF (super < SC)
8. FROM reg_sup TO super RATE reg_sup *
mue_reg_sup_sup;
/*-Super --->r egular and departure --*/
9. IF(r eg_sup+regular < RC)
10. THEN
11. {
12. From super TO regular RATE
super * mue_sup_reg;
13. From super TO EXTERN RATE super * mue;
14. }
15. IF (reg_sup + regular == RC)
16. FROM super TO EXTERN RATE super *
(mue+mue_sup_reg);

/*---Regular --->s uper ----- */
17. IF (super < SC)
18. FROM regular TO super RATE regular *
mue_sup_reg;

/*--Termination of call and outgoing handover request ----*/
19. FROM reg_sup TO EXTERN RATE reg_sup * (mue);
20. FROM regular TO EXTERN RATE regular * (mue +
mue_reg_oho);

/*-----Results-----*/
PRINT mean_super := mean (super);
PRINT mean_reg_sup := mean (reg_sup);
PRINT mean_reg := mean (regular);
PRINT mregular := mean_reg_sup + mean_reg;
PRINT reg_loss := prob (reg_sup + regular == RC);

```

```

PRINT super_loss := prob (reg_sup + regular + super == RC +
SC);
PRINT util_reg := (mean (reg_sup) + mean (regular)) / RC;
PRINT util_sup := mean (super)/SC;

/*----- Pictures -----*/
PICTURE "loss1"
PARAMETER lambda
XLABEL "lambda"
YLABEL "loss probability"
CURVE reg_loss

PICTURE "loss2"
PARAMETER lambda
XLABEL "lambda"
YLABEL "loss probability"
CURVE super_loss

PICTURE "mean-super"
PARAMETER Lambda
XLABEL "lambda"
YLABEL "mean"
CURVE mean_super

PICTURE "mean"
PARAMETER lambda
XLABEL "lambda"
YLABEL "mean"
CURVE mregular

PICTURE "utilization_reg"
PARAMETER lambda
XLABEL "lambda"
YLABEL "utilization-reg"
CURVE util_reg

PICTURE "utilization_sup"
PARAMETER lambda
XLABEL "lambda"
YLABEL "utilization-reg"
CURVE util_sup

-----End of MOSEL-2 program-----

```

Figure 9. Modelling of underlay-overlay of one GSM cell.

8. Conclusions and Future Work

This paper presents a queuing system of the underlay-overlay structure in GSM systems, which is suggested by Nokia telecommunications. The suggested queuing system is solved numerically by MOSEL-2 language. With MOSEL-2 language, it is possible to have modelling specification and evaluation to any system which can be represented graphically by queuing system or Petri Net.

In the above results, it is shown that with underlay-overlay principle, it is possible to have lower loss probabilities in both regular and super layer as well as higher utilization. Additionally, it is possible to have balance performance over the whole cell and hence, achieving higher capacity for the whole network. This is of course, the main objective of the intelligent underlay-overlay principle.

It is planned to have an extension to this work in the future. By MOSEL-2 language, it is possible to use different distributions for both the arrival and service

times. Therefore, in the future work of this paper, the square coefficient of variation (i. e., SCV) will be taken into consideration in the analysis where the cell will be analysed using different values of SCV as well as studying the effect of the variability of both arrival and service times. Furthermore, it is planned to consider the movement in the future by suggesting a new mobility model and study the effect of the ratio of moving mobiles on both the loss probabilities and the utilization. Consequently, the speed of moving mobiles is very important issue and should be considered in the future work as the mobility model should take into account different propagation environments with different speed values. Additionally, the combination of intelligent underlay-overlay and frequency hopping can be done in the future work of this paper with micro and macro cells.

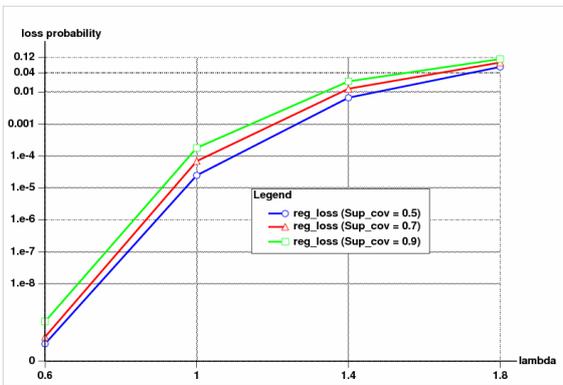


Figure 10. Loss probability of regular layer for different super coverage factors.

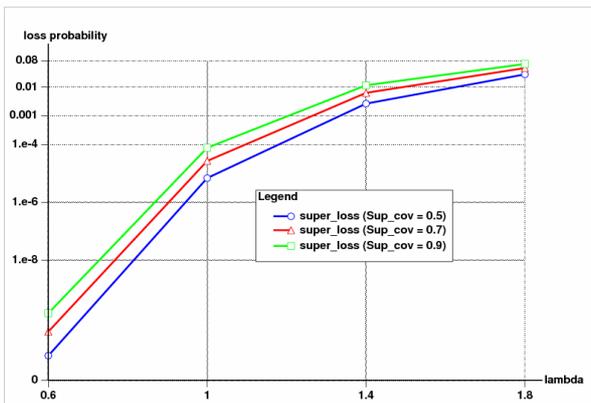


Figure 11. Loss probability of super layer for different super coverage factors.

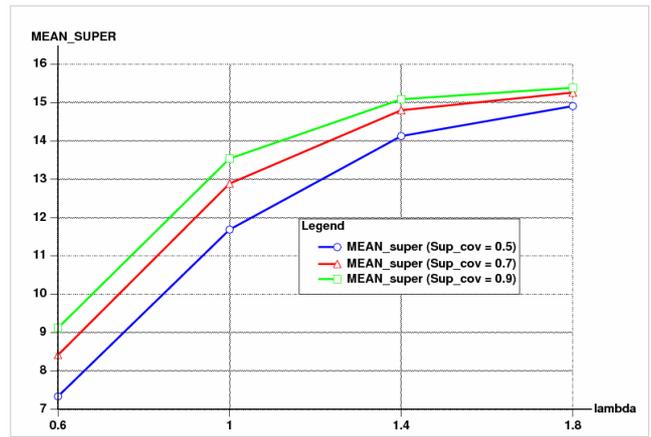


Figure 12. Mean number of jobs in a super layer.

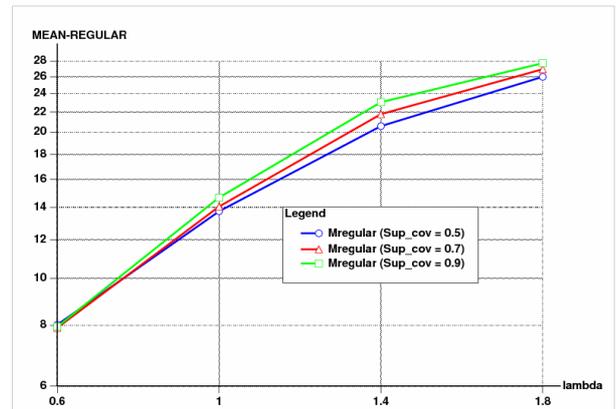


Figure 13. Mean number of jobs in a regular layer.

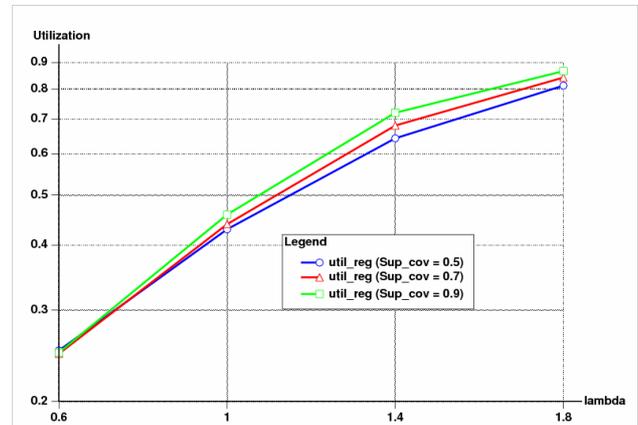


Figure 14. Utilization of regular layer.

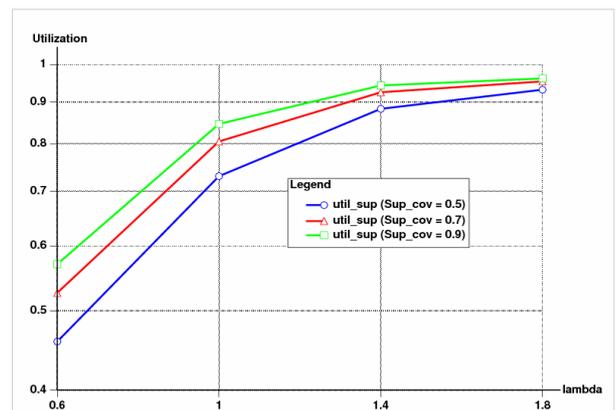


Figure 15. Utilization of super layer.

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