Event-Based Simulation for Multi-rate Multi-service Traffic Validation in B3G Systems

Jesús M. Juárez, Rui R. Paulo and Fernando J. Velez
Instituto de Telecomunicações, DEM-University of Beira Interior
6201-001 Covilhã, Portugal
Email: jejuva@iespana.es, rfrpaulo@e-projects.ubi.pt, fjv@ubi.

Abstract—**A multi-service traffic model is briefly presented, and its validation is achieved by using event-based simulation results which consider the burstiness of traffic. A simulator was produced to extract conclusions about blocking and handover failure probabilities in a multi-service bursty traffic context. Simulations, were performed for different cases, from single- to multi-service situations, and from absence to presence of mobility. Besides quality of service results in the air interface, including blocking and handover failure probabilities, the simulator allows for extracting conclusions about the validation of the Bernoulli-Poisson-Pascal model for the computation of the *on/off* blocking probability, the ratio between the number of call rejected at the beginning of an *on* period and the total number of bursts generated during a session. In the single-service case, the theoretical and the experimental values of *on/off* blocking probability are close to each other, and there is an almost perfect concordance between theoretical and simulation values when the average sojourn time in cells is equal to the average holding time. In the multi-service case, the behaviour is not exactly the same but a coherent behaviour is achieved for an average traffic per user up to 0.10 Erl.**

Keywords-Traffic control and engineering, beyond 3G and 4G, multi-service traffic, handover, simulation.

I. INTRODUCTION

The goal of 3G (Third Generation) mobile communication systems is the delivery of multimedia services to the user in the mobile domain. This requires the provision of user data rates that are substantially higher than those provided by 2G (Second Generation) networks. For example, in initial versions of GSM (Global System for Mobile communications) only data rates of 9.6 kbit/s were supported. UMTS (Universal Mobile Telecommunications System) users will provide data rates from 144 kbit/s, in macrocellular environments, up to 2 Mbit/s, in picocellular environments and the absence of mobility. The IST-SEACORN [1] project proposed a set of enhancements to UMTS, which include, among others, advanced modulation and radio transmission techniques, improved strategies for IP routing and QoS (quality of service) assurance. E-UMTS (Enhanced UMTS) is a UMTS evolution step which provides bit rates higher than 2 Mbit/s in the uplink and the downlink directions over 5 MHz frequency carriers.

The study of E-UMTS tele-traffic behaviour drove us to build a simulator that represents source traffic and its aggregation. For testing the enhancements, various models were built with the most relevant activity/inactivity characteristics of this technology, in different scenarios, very useful for validation purposes. The simulator was developed with AweSim [2], a general purpose simulation system for network discrete-event and continuous simulation approaches. The most fundamental feature of the AweSim architecture is its openness and interconnectivity to databases, spreadsheets, and word processing programs, such as Microsoft Office. The main objective of this work consists of producing the simulator to obtain results for blocking and handover failure probabilities, and extracting conclusions about the results and the validation of the traffic model in the presence of mobility, with very simple hypothesis.

In Section II the teletraffic engineering aspects are presented. First, one defines the main parameters of the model, and then one presents the model itself. Section III briefly presents E-UMTS applications and deployment scenarios, as well as the physical and mobility simulation scenario and their parameters. In Section IV, simulation concepts and parameters are presented in detail, and the structure of the VISUAL SLAM simulator is briefly explained. The definitions applied to call blocking and handover failure probabilities are explained. Then, simulation results are presented in Section V. Finally, Section VI presents conclusions.

II. TRAFFIC MODEL

A. Main Parameters

One should start by defining the parameters being used in the model[3]:

N	is the number of available channels/codes per cell. It is obtained from simulations [4], dividing the total amount of resources (in kb/s) by the basic code channel bit rate;
M	is the number of potential users in a cell;
C	is the capacity vector and gives the number of code channels that each application demands;
K	is the number of available applications in a cell;
$U(t)$	is the vector that defines the number of active users of each application in a time instant t;
λ_k	is the arrival rate for the static case (Λ_k when mobility is taken into account); the arrival process follows a Bernoulli distribution;
μ_k	is the service rate for the static case (H_k whith mobility), and is Poisson distributed;

A_k	is obtained by dividing λ_k by μ_k (or $\mathit{\Lambda}_k$ by H_k when mobility is considered), and it is the traffic generated per user, for each application k;
$prop_k$	is the proportion of users of an application k among the K available ones i.e., the usage;
b_k	is the application k data rate.

The arrival rate can be obtained through

$$\lambda_k = (U_k - M_k)\cdot(-\beta_k)\ , \tag{1}$$

where U_k is the number of active users of the application k, M_k is the number of potential users of the application k being in the system and β_k is the activation rate (β_k<0 in the Bernoulli case of the Bernoulli-Poisson-Pascal model [3]). Fig. 1 shows the way applications are activated. A user can be either in an idle state or using one of the K applications.

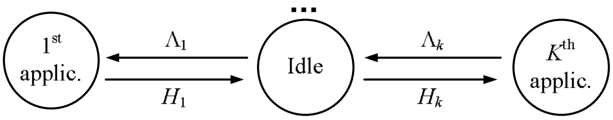

Figure 1. Model for user applications activation.

The proportion of users of an application among all the available ones can be expressed by its usage,

$$prop_i = \frac{\Lambda_i/\eta_i}{\sum_{k=1}^{K} \Lambda_k/H_k} = \frac{\rho_i}{\sum_{i=1}^{K}\rho_k} \tag{2}$$

where

$$\rho_i = \rho \cdot prop_i\ , \tag{3}$$

$$\rho = \sum_{i=1}^{k} \rho_i\ , \tag{4}$$

and ρ is the average traffic per user. By writing the system of equations for the probability of transition between states (plus the normalization equation), it is straightforward to obtain the probability of a user having an active application,

$$p_i = \frac{\rho_i}{1+\sum_{k=1}^{K}\rho_k} = \frac{\rho}{\rho+1}\cdot prop_i = f \cdot prop_i\ , \tag{5}$$

where f is the fraction of active users,

$$f = \frac{\rho}{1+\rho}\ . \tag{6}$$

By multiplying f by the population of potential users, M, one obtains the number of users being simultaneously active in a cell. The system cell average load can be obtained by (in kb/s or Mb/s)

$$L = f \cdot c_{av} \cdot M\ , \tag{7}$$

where

$$c_{av} = \sum_{i=1}^{K} prop_i \cdot b_i\ , \tag{8}$$

c_{av} gives information about the average amount of resources (in kb/s or Mb/s) that is used by each user.

B. *Theoretical Model*

The main objective of the model is to obtain an algorithm to compute P_b, having the parameters defined above (f and L) as inputs. The number of channels used in a time instant t is given by

$$Y(t) = U(t)\cdot C\ . \tag{9}$$

The set of feasible states gives the number of active users of each application that can be served by the system and is defined by

$$U = \{n \in N^K : n \cdot C \le N\}\ . \tag{10}$$

Blocking situations, i.e., the ones when a new user arriving to the system does not find enough resources available can be expressed by

$$B_k = \{n \in U : n\cdot C + C_k > N\}\ , \tag{11}$$

where B_k is the set of blocking states for application k, and C_k is the number of channels requested by application k. In the case of blocking the request is cleared, and the system remains in the same state. Application k blocking probability is obtained by dividing the expectation of the number of blocked requests by the total number of class k requests,

$$P_b^k = \frac{\sum_{n\in B_k}\lambda_k(n_k)\cdot p(n)}{\sum_{n\in U}\lambda_k(n_k)\cdot p(n)}\ . \tag{12}$$

The state probability marginal function, $p(n)$, represents the probability of the system being in the state n or, equivalently, the probability of n users being in the system,

$$P_b^k = \frac{\prod_{k=1}^{K}\nu_k(n_k)}{\sum_{n\in U}\prod_{k=1}^{K}\nu_k(n_k)}, \text{ for } n\in U, \tag{13}$$

where the non-normalized marginal probabilities, $\nu_k(n_k)$, are obtained for each applications and give the probability of having exactly n_k users of the application k in the system,

$$\nu_k(n_k) = \binom{M_k}{n_k}\cdot(-\beta_k)^{n_k}\ . \tag{14}$$

A standard algorithm for multi-service traffic [3] was used for P_b computations, which does it in a time-efficient way.

Results are obtained for P_b as a function of the fraction of active users or, alternatively, as a function of the average load. Based on these results, a P_b threshold of 2 % can then be considered, and the maximum number of simultaneous active users supported by the system is obtained, as well as the cell resource occupancy (i.e., the spectral efficiency). A similar approach could also be followed for the consideration of the handover failure probability, P_{hf}.

III. E-UMTS SERVICES AND SCENARIOS

In SEACORN there are various services and environments including the OFF (Office), BCC (Business City Centre) and VEH (Vehicular) scenarios [5].

In this work we only consider the applications defined for the VEH scenario which correspond to the Sound High Interactive Multimedia, Narrowband, Wideband and Broadband classes of services. The representative applications are VOI (Voice) at 12.2 kb/s, VTE (Video Telephony) at 144 kb/s, MWB (Multimedia Web Browsing) at 384 kb/s, and ATR (Assistance in Travel) at 1536 kb/s, respectively.

We consider a cellular architecture composed by three cells with the shape of a roundabout. The cellular architecture consists of a backbone network which interconnects fixed base stations, and mobile units communicating with the base stations via wireless links. Each cell has access to the same capacity, i.e., N channels. When a mobile user wants to communicate, first it has to obtain a channel from its base station. When there are not enough channels available the new call is blocked, and there is new call blocking. The call holding time is the average call duration if the call is not prematurely dropped, and it is assumed to be exponentially distributed with average

$$\bar{\tau} = \frac{1}{\mu}, \tag{15}$$

where μ is the service rate. The transference of a mobile communication from one cell to another, while a call is in progress, is called handover. If there are not enough channels available in the new cell this call will be dropped, this phenomenon is known as handover failure. The sojourn time is the time that each user stays in a cell, and it follows an exponential distribution with average

$$\bar{\tau}_h = \frac{1}{\eta}, \tag{16}$$

where η is the cross-over rate, given by

$$\eta = \frac{V_{av}}{2*\ln(2)} \cdot \frac{1}{2R}, \tag{17}$$

where V_{av} is the average velocity, and the parameter is normalized to the cell length $2R$, where R is the cell coverage distance.

The handover rate γ is given by

$$\gamma = \frac{\eta}{\mu}, \tag{18}$$

and the channel occupacy time is given by

$$\bar{\tau}_c = \min(\bar{\tau}, \bar{\tau}_h). \tag{19}$$

As the minimum of two variables exponentially distributed is also exponentially distributed, τ_c is exponential.

In a roundabout scenario, the traffic is homogeneous, Fig. 2. As a consequence, there is a homogeneous probability of generating new and handovers calls in the three cells. Hence,

$$\lambda_i = \lambda \forall_i, \tag{20}$$

$$\eta_i = \eta \forall_i, \tag{21}$$

and

$$\sum_{k=1}^{N\,cells} p_{ki} = 1 \forall_i, \tag{22}$$

where p_{ki} is the probability that a call may attempt a handover from cell k to cell i.

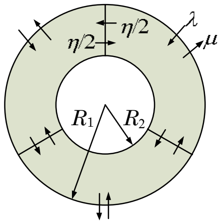

Figure 2. Physical roundabout scenario.

By considering values of 300, 450 and 600 m for the perimeter in the roundabout, the number of user is calculated by the area of the crown defined by the street. As an example, for a perimeter of 300 m, R_1=57.75 m, R_2=37.75 m, and the area of the crown 6000 m^2. Therefore, for a density of users of 0.012 users/m^2, the number of user is 72.

For the other perimeters, i.e., 450 and 600 m, values of 108 and 144 users were obtained, respectively. In the simulation model one uses three call generators working simultaneously each of them modelling the calls of one third of the users in the entire roundabout.

The *BHCA* (busy hour call attempts) is an important parameter in the traffic generation model, and represents the total number of call attempts for a given time duration,

$$BHCA_{j[\min]} = \frac{Usage_j}{\bar{\tau}[\min]} \cdot M \cdot \rho, \tag{23}$$

where M is the number of user in the cell, $\bar{\tau}_j$ the average call duration of applications, and ρ the average traffic per user.

The new calls are generated following a Poisson distribution with rate λ (which is represented by the *BHCA* in this case). So, the time between calls (t_{bc}) is exponentially distributed. The time between calls during the busy hour is obtained by multiplying the inverse of the $BHCA_{[\min^{-1}]}$ by sixty, in order to convert minutes into seconds,

$$t_{bc} = \frac{60}{BHCA[\min^{-1}]}. \tag{24}$$

Packet switched traffic is commonly modelled as *on/off* processes. Our simulator models the *on/off* behaviour by using active/inactive time periods, according to [6].

IV. SIMULATION CONCEPTS AND PARAMETERS

AweSim is a general purpose simulation system providing network discrete-event and continuous modeling approaches [7]. AweSim is built in Visual Basic and C/C++, and programs written in these languages are easily incorporated into its architecture. An AweSim project consists of one or more scenarios; each one represents a particular system alternative.

A scenario contains component parts, and AweSim provide software programs, called builders, to create each component. To be able to run a simulation in the AweSim project, a network file and a control file are essential components. In our project, two additional types of files were used: an user insert file, and a note file. More detail can be found in [8]. In order to enable the discussion of results and their comparison with other simulation results, it is important to define the main concepts and service parameters involved in our simulation.

Table I presents the parameters related with handovers. Tables II and III present the session activity parameters for the active and inactive states, respectively.

TABLE I. SOJOURN TIME FOR AN AVERAGE VELOCITY OF 50 KM/H

Cell Lenght	**η [min]$^{-1}$**	**1/ η [s]**	**Distribution**
100	6.011	9.981	Exponential
150	4.007	14.972	Exponential
200	3.006	19.963	Exponential

TABLE II. SESSION ACTIVITY PARAMETERS [6]

Applications	**Active state (*on*)**		
	Avg.[s]	**File size [kb]**	**Distribution**
VOI	1.4	2.14	Exponential
VTE	-	-	-
MWB	5	240	Pareto(α=1.1, k=14.426 s)
ATR	60	11520	Weibull(α=1.1, k=63.781s)

TABLE III. SESSION ACTIVITY PARAMETERS [6]

Applications	**Inactive state (*off*)**	
	Avg. [s]	**Distribution**
VOI	1.7	Exponential
VTE	-	-
MWB	13	Pareto(α=1.1, k =3 s)
ATR	14	Pareto(α=1.1, k=3 s)

The call blocking is the ratio between the number of new calls that are rejected in the process of trying to obtain channels (represented by the $N\_call\_block_i$ variable) and the total number of new calls generated, N_call variable,

$$P_b = \frac{\sum_{i=1}^{i=Ncells} N\_call\_block_i}{\sum_{i=1}^{i=Ncells} N\_call_i} . \tag{25}$$

The handover failure is the ratio between the number of handovers that are rejected at the new cell in the process of trying to obtain channels, represented by *Hand_failure*, and the total number of handovers produced, *Handover*,

$$P_{hf} = \frac{\sum_{i=1}^{i=Ncells} Hand\_failure_i}{\sum_{i=1}^{i=Ncells} Handover_i} . \tag{26}$$

Fig. 3 presents the concepts of: New call (*N_call*), which can suffer blocking (*N_call_block*). The blocking of a call/session is marked with a cross and the absence of a cross means that it can be accepted. A new call attempt causes a unitary increase in *N_call*, independently of it being blocked or not. However blocking causes a unitary increase in *N_call_block*. A handover produced between neighbour cells (*Handover*) can suffer handover failure (*Hand_failure*). This fact is marked with a cross in Fig. 3.

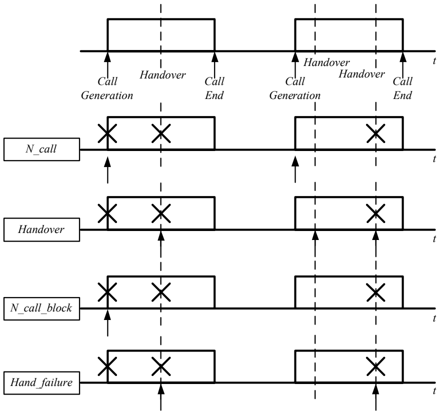

Figure 3. Parameters used in the formulation whithout the bursty behaviour.

When the traffic is being modeled by *on/off* periods, these definitions of these call level parameters will be maintained. However, new parameters are needed at the burst level.

The *on/off* blocking probability is the ratio between the number of calls that are rejected at the beginning of *on* periods in the process of trying to obtain channels and the total number of generated *on* periods,

$$\begin{aligned} attempts = & \sum_{i=1}^{i=ncells} N\_call\_block_i + \sum_{i=1}^{i=ncells} on\_block_i + \\ & + \sum_{i=1}^{i=ncells} Hand\_failure_i - \sum_{i=1}^{i=ncells} Hand\_f\_on_i \end{aligned} \tag{27}$$

$$P_{b\,ONOFF} = \frac{Attempts}{Attempts + \sum_{i=1}^{i=ncells} on_i - \sum_{i=1}^{i=ncells} Hand\_on_i} . \tag{28}$$

on_i is the number of *on* burst in cell *i*. on_block_i is the number of *on* attempts which suffer blocking, $N\_call\_block_i$ is the number of blocking occurrences in the first *on* attempt of a session in cell *i*, while $Hand\_on_i$ is the number of handover which occur during the *on* period in cell *i*. $Hand\_f\_on_i$ is the number of handover failure produced during the *on* period in cell *i*, and $Hand\_failure_i$ is the number of handover failure produced in cell *i* without taking into account if it happens during or at the beginning of *on* periods.

This more complex nomenclature was the solution to count the total number of *on* periods. Because of this improvement, a more complex structure had to be added to the simulation network in order to deal with the precise moment for handover events, which allows for the computation of the parameters needed to obtain appropriated results.

V. RESULTS

The simulator was used for the validation of traffic models. One performed a comparison between the theoretical values obtained by considering the Bernoulli-Poisson-Pascal model for multi-service traffic [9], [10] and the results obtained by using the AweSim simulator. However we started by analyzing the single-service case. Results for bursty VOI are presented in Fig. 4, where a comparison of theoretical and simulation results for $P_{b\ ONOFF}$ is performed for different ρs, with γ as a parameter (VOI, N=4).

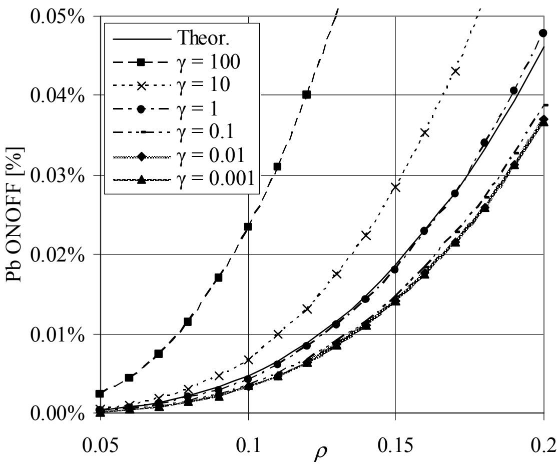

Figure 4. Comparison of theoretical and simulation results for $P_{b\ ONOFF}$ for different ρs, with γ as a parameter (VOI, N=4).

Exponential distributions are considered for the active/inactive periods, an average session duration of 60 s is assumed, and the time intervals between arrivals are the ones presented in Table 4. The theoretical and the experimental values of $P_{b\ ONOFF}$ are close to each other, Fig. 5 (example for ρ=0.15 Erl for the latter), and there is an almost perfect concordance between theoretical and simulation values for γ=1, i.e, when the average sojourn time in cells is equal to the average holding time. The curves for P_b and P_{hf} follows a similar behaviour but P_{hf} takes lower values.

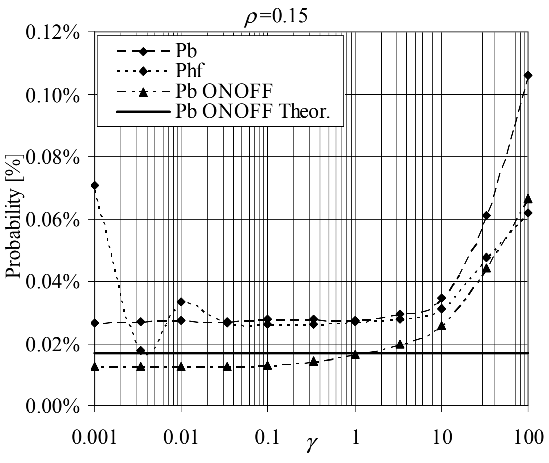

Figure 5. P_b, P_{hf}, $P_{b\ ONOFF}$ and theoretical $P_{b\ ONOFF}$ as a function of γ for ρ=0.15 Erl (VOI, N=4).

A mixture of VOI and VTE was chosen for the multi-service cases. When it is active (60 s), voice has a burst behaviour, and *on*/*off* periods have exponential distributions with average durations 1.4 and 1.7 s, respectively. However, the video-telephony (60 s) application does not present a bursty behaviour and is permanently active. The time intervals between arrivals are the ones presented in Table V. While for VOI values of P_b are different from $P_{b\ ONOFF}$, for VTE the curves for P_b and $P_{b\ ONOFF}$ are coincident, Figs. 6-7.

TABLE IV. TIME INTERVALS ARRIVALS FOR SINGLE-SERVICE

ρ	Time between VOI calls [s]
0.05	257.14
0.10	128.57
0.15	85.71
0.20	64.29

TABLE V. TIME INTERVAL BETWEEN ARRIVALS FOR MULTI-SERVICE

ρ	Time between calls [s]	
	VOI	VTE
0.05	149.17	391.30
0.10	74.59	195.65
0.15	49.72	130.43
0.20	37.29	97.83

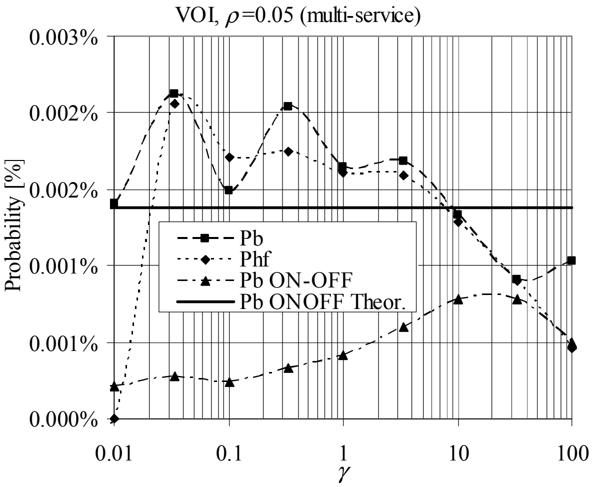

Figure 6. *Pb, Phf, Pb ONOFF and theoretical Pb ONOFF for VOI in the multi-service case (N=48, and ρ=0.05 Erl.)*

In this case, while the theoretical $P_{b\ ONOFF}$ is always higher than the simulated values for VOI, for VTE, it takes values lower than the simulation ones for γs up to ~10. The theoretical and simulation values are close to each other for $\gamma\approx10$ in both cases. Fig. 8 presents the dependence of $P_{b\ ONOFF}$ on ρ for VTE. One concludes that the simulation values for $\gamma\approx10$ agree with the theoretical ones for the lowest values of ρ, i.e., $0.05\leq\rho\leq0.10$ Erl. Then, the values diverge.

VI. CONCLUSIONS

A model was proposed for multi-rate multi-service traffic engineering purposes which is based in the BPP model. Simulations were ran for a roundabout vehicular scenario in the presence of mobility to obtain results for multi-service QoS measures like blocking, and *on*/*off* blocking probabilities.

Simulations were run for 1 year time. By comparing call blocking and handover failure probabilities we can observe that they have similar values in all cases, as there is no privilege for handover calls relatively to new ones. However, the difference between call blocking and handover failure probabilities increases when average velocity of users increases, or if the size of the cell is reduced.

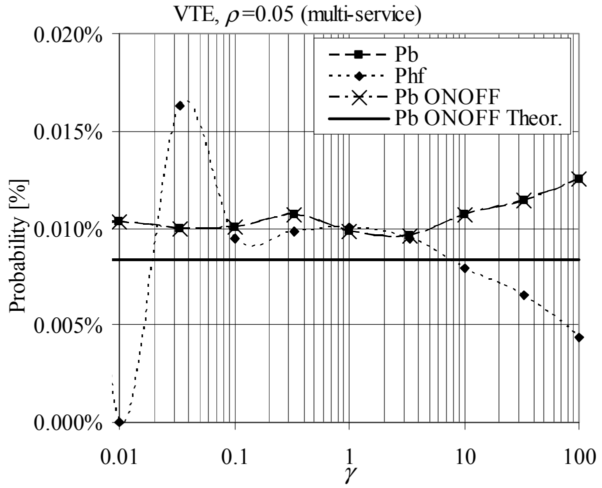

Figure 7. P_b, P_{hf}, $P_{b\ ONOFF}$ and theoretical $P_{b\ ONOFF}$ for VTE in the multi-service case (N=48, and ρ=0.05 Erl.)

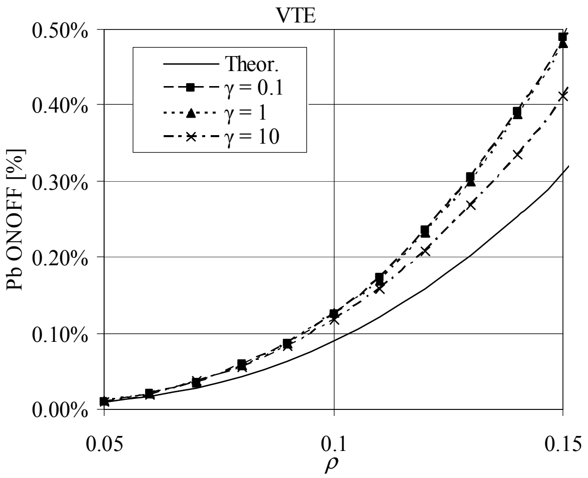

Figure 8. Comparison of theoretical and simulation results for $P_{b\ ONOFF}$ for different ρs, with γ as a parameter, in the multi-service case (VTE, N=48).

By comparing theoretical results with the ones from 10 years time simulations, a perfect validation was achieved in the single-service case when the sojourn time in cells is equal to the average duration of voice calls. In the multi-service case, the behaviour is not exactly the same but a coherent trend is achieved. For γ=10 simulation values consistently agree with the theoretical ones for the lowest values of ρ, i.e., $0.05 \leq \rho \leq 0.10$ Erl. achieved. For γ=10 simulation values consistently agree with the theoretical ones for the lowest values of ρ, i.e., $0.05 \leq \rho \leq 0.10$ Erl.

ACKNOWLEDGMENT

This work was partially funded by MULTIPLAN and CROSSNET (Portuguese Foundation for Science and Technology POSI and POSC projects with FEDER funding), MobileMAN (an internal project from Instituto de Telecomunicações/LA), and by "Projecto de Re-equipamento Científico" REEQ/1201/EEI/2005 (a Portuguese Foundation for Science and Technology project).

REFERENCES

[1] http://seacorn.ptinovacao.pt/

[2] A. Alan B. Pritsker and Jean J. O'Reilly, *Simulation with Visual SLAM and AweSim*, John Wiley & Sons, New York, New York, USA, 1999.

[3] G. A. Awater and H.A. van de Vlag, "Exact Computation of Time and Call Blocking Probabilities in Large, Multi-traffic, Multiresource Loss Systems", *Performance Evaluation*, Vol. 25, No. 1, Mar. 1996, pp.41-58.

[4] H. R. Pinto, J.G. da Silva and A. Rodrigues, "Uplink Capacity of the WCDMA FDD Mode in UMTS Networks for Mixed Services", in *Proc. of VTC'2000 Fall - IEEE Vehicular Technology Conference*, Boston, MA, USA, Sep. 2000.

[5] Josephine Antoniou and George Hadjipollas, "Final Report on Simulation of Enhanced UMTS", IST SEACORN CEC Deliverable 34900/UCY/DS/046/f1, IST Central Office, Brussels, Belgium, Mar. 2004.

[6] Jaime Ferreira, "Final report on traffic estimation and services characterization", IST SEACORN CEC Deliverable 34900/PTIN/DS/014/d6, IST Central Office, Brussels, Belgium, Sep. 2003.

[7] Pritsker Corporation, *Visual SLAM Quick Reference Manual*, Pritsker Corporation, New York, New York, USA, 1997.

[8] Jesús M. Juárez Valero, Rui R. Paulo and Fernando J. Velez, "Tele-Traffic Simulation for Mobile Communication Systems Beyond 3G," in *Proc. of AICT'06 - The 2nd Advanced International Conference on Telecommunications*, Guadeloupe, French Caribbean, Feb. 2006.

[9] R. M. Carvalho, Multi-service Traffic Models for Cellular Mobile and Personal Communication Systems, (in portuguese), Graduation Report, Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal, Jan. 1998.

[10] J. M. J. Valero, *Tele-Traffic Simulation for Mobile Communication Systems Beyond 3G*, Graduation Thesis, University of Beira Interior, Covilhã, Portugal, Sep. 2005.