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Tele-Traffic Simulation for Mobile Communication Systems Beyond 3G

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Abstract

European projects like Simulation of Enhanced UMTS Access and Core Network (IST-SEACORN) proposed a set of enhancements to UMTS. By considering the deployment scenarios and tele-traffic parameters from the Vehicular scenario of SEACORN, a simulator was produced to extract conclusions about blocking and handover failure probabilities. Simulation, which consider the burstiness of traffic, 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. As the theoretical and the simulation results agree, the validation was achieved.

Keywords

Multi-service, traffic from mobility, event-based simulation, beyond 3G, source traffic.

Working Group 1 & 2

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European projects like Simulation of Enhanced UMTS Access and Core Network (IST-SEACORN) proposed a set of enhancements to UMTS. By considering the deployment scenarios and tele-traffic parameters from the Vehicular scenario of SEACORN, a simulator was produced to extract conclusions about blocking and handover failure probabilities. Simulation, which consider the burstiness of traffic, 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. As the theoretical and the simulation results agree, the validation was achieved.

1. Introduction

The goal of Third Generation (3G) 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 second generation (2G) networks. For example, in initial versions of Global System for Mobile communications (GSM) only data rates of 9.6 kbit/s were supported. Universal Mobile Telecommunications System (UMTS) 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 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 assurance. Enhanced UMTS (E-UMTS) is a UMTS evolution step which provides bit rates higher than 2Mbit/s in the uplink and the downlink directions over 5 MHz frequency carrier. So E-UMTS enables the provision of new wideband services and significant reduction of the price per bit, running over flexible Quality of Service (QoS) enabled IP based access and core networks, and making possible an effective end-to-end packet based transmission.

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 useful for validation purposes. The simulator was developed with AweSim [1], 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 (HO) failure probabilities, and extracting conclusions about the results and the validation of traffic models, with very simple hypothesis.

Section 2 briefly explains E-UMTS applications and deployment scenarios, as well as the simulation scenario and the parameters used in the SEACORN Vehicular scenario. In Section 3, the commercial simulation language AweSim V3.2 is described, and the simulator built with the VISUAL SLAM tool is explained in detail. In Section 4, the definitions applied to call blocking and handover failure probabilities are presented. Then, simulation results are presented. Section 5 describes our efforts on the traffic model validation, and discusses the results. Finally, Section 6 contains conclusions, and future work.

2. E-UMTS simulation scenarios

2.1. E-UMTS applications and scenarios

In the SEACORN project [2] there are various services and environments defined. However, the more relevant environments and applications need to be selected in order to have reasonable simulation times. On the one hand, the Office (OFF) scenario was selected as the most interesting one for the indoor environment because of the density of users and application use. On the other, the Business City Centre (BCC) is an outdoor environment that provides a dense, pedestrian environment, while the Vehicular (VEH) scenario is an outdoor one with high mobility.

E-UMTS services are grouped into five large classes according to data-rate requirements, namely Sound, High Interactive Multimedia, Narrowband, Wideband and Broadband. The forecast for usage in the three scenarios can be selected from Table I. In this work we only consider the applications defined for the VEH scenario which correspond to all classes of services except the broadband one. They are Voice (VOI) at 12.2 kb/s, Video Telephony (VTE) at 144 kb/s, Multimedia Web Browsing (MWB) at 384 kb/s, and Assistance in Travel (ATR) at 1536 kb/s, respectively.

TABLE I
ASSUMPTIONS FOR E-UMTS SERVICE USAGE [3]

Services	Data rate [kb/s]	Usage [%]		
		OFF	BCC	VEH
Sound	≤ 64	25	27	42
High Int. MM	≤ 144	15	16	16
Narrowband	]144, 384]	20	26	18.5
Wideband	]384, 2048]	25	31	23.5
Broadband	> 2048	15	-	-

2.2. Physical and mobility scenario

The physical scenario has 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, 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

$$\bar{\tau} = \frac{1}{\mu}, \qquad (1)$$

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 (HO). 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

$$\bar{\tau}_h = \frac{1}{\eta}, \qquad (2)$$

where η is the cross-over rate, given by

$$\eta = \frac{V_{av}}{2 * \ln(2)} * \frac{1}{(2R)}. \qquad (3)$$

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

The handover rate γ is given by

$$\gamma = \frac{\eta}{\mu}, \qquad (4)$$

and the channel occupancy time is given by

$$\bar{\tau}_c = \min(\bar{\tau}, \bar{\tau}_h). \qquad (5)$$

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

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

$$BHCA_{j[\min^{-1}]} = \frac{Usage_j}{\bar{\tau}_{j[\min]}} * M_T * \bar{f}, \qquad (6)$$

where M_T is the number of user in the cell, $\bar{\tau}_j$ the average call/session duration of application j, and $\bar{f}$ is 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 is exponentially distributed. The time between calls during the busy hour is obtained, in seconds, by multiplying the inverse of the $BHCA_{[\min^{-1}]}$ for sixty, in order to convert minutes into seconds

$$Time\_between\_calls_{[s]} = \frac{60}{BHCA_{[\min^{-1}]}}. \qquad (7)$$

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 [3]. A special model is used for real-time video-based applications like VTE due to the high level of burstiness introduced by compression techniques like MPEG-4. However, in simulations one consider that it has continuous occupation of channels.

In a roundabout scenario, the traffic is homogeneous, Fig. 1. As a consequence, there is a homogeneous probability of generating new and handovers calls in the three cells. Hence, $\lambda_i = \lambda \, \forall i$, $\eta_i = \eta \, \forall i$, and $\sum_{k=1}^{N^o\,cells} p_{ki} = 1 \forall i$, where p_{ki} is the probability that a call may attempt a handover from cell k to cell i.

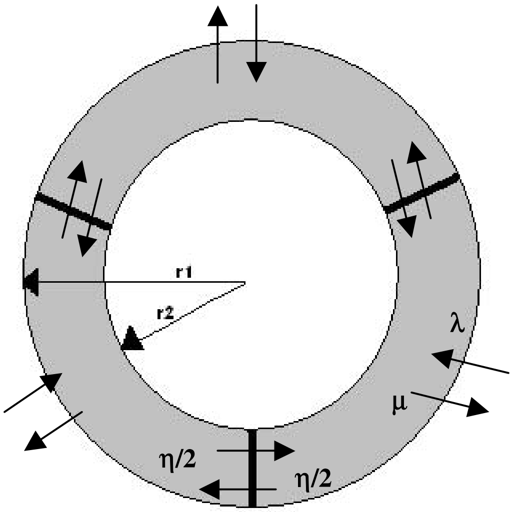


Fig. 1. Physical roundabout scenario.

By considering values of 300, 450 and 600 m for the perimeter in the roundabout, the number of user is calculated as follows:

For *Perimeter = 300 m*:

$$r_{in\_the\_centre} = \frac{Perimeter}{2*\pi} = 47.7465\,m\,. \tag{8}$$

By considering that the road width is 20 meters one obtains

$$r_1 = 57.7465\,m \qquad r_2 = 37.7465\,m \tag{9}$$

$$Area = \pi * r_1^2 - \pi * r_2^2 = 6000\,m^2 \tag{10}$$

$$Number\,of\,users = 6000 * 0.012 = 72 \tag{11}$$

The constant value 0.012 users/m^2 is the density of users for the VEH scenario [3]. 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, one for each cell, working simultaneously. Each generator models the calls of one third of the users in the entire roundabout.

3. Hypothesis and AweSim

3.1. Simulation Parameters

Simulation call duration parameters are presented in Table II, while call generation parameters are presented in Table III. Table IV presents the parameters related with handovers. Tables V and VI present the session activity parameters for the active and inactive states, respectively.

TABLE II
CALL DURATION PARAMETERS

Applications	$\mu_{[min^{-1}]}$	$1/\mu_{[s]}$	Distribution
VOI	0.333	180	Exponential
VTE	0.333	180	Exponential
MWB	0.066	900	Exponential
ATR	0.05	1200	Exponential

TABLE III
CALL GENERATION PARAMETERS FOR f =1

Applications	$\lambda_{[min-1]}$		
	24 users	36 users	48 users
VOI	3.36	5.04	6.72
VTE	1.28	1.92	2.56
MWB	0.296	0.444	0.592
ATR	0.282	0.423	0.564

TABLE IV
SOJOURN TIME IN CELLS FOR AN AVERAGE VELOCITY OF 50 KM/H

Cell length [m]	$\eta_{[min^{-1}]}$	$1/\eta_{[s]}$	Distribution
100	6.011	9.981	Exponential
150	4.007	14.972	Exponential
200	3.006	19.963	Exponential

TABLE V
SESSION ACTIVITY PARAMETERS [3]

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

TABLE VI
SESSION ACTIVITY PARAMETERS [3]

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

AweSim and Microsoft Visual C++ 6.0 were installed in a personal computer with Pentium 4 CPU at 2.66 GHz, and with 248 MB of RAM.

3.2. Visual SLAM and AweSim

AweSim [4] is a general purpose simulation system providing network discrete-event and continuous modelling approaches. 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 called 'Rotunda', two additional types of files were used: an user insert file, and a note file.

1) Network file – A Visual SLAM network model is a set of interconnected symbols that emulate the operation of the simulated system. The modeller can assemble the available routing and processing functions [4]. In our case, all developed network models are composed by six types of Visual SLAM network symbols: CREATE NODE, ACTIVITY, ASSIGN NODE, COLCT NODE, GOON NODE and TERMINATE NODE. Fig. 2 presents all these components. This network models the VOI application in a roundabout composed by three cells, and considering traffic burstiness.

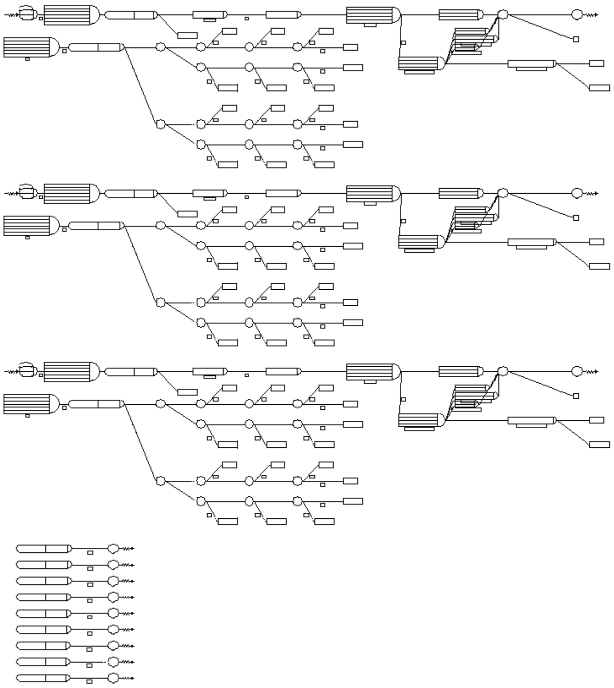


Fig. 2. AweSim network model for a single service in the roundabout scenario, considering three cells.

However, by introducing other parameters in this network other applications can be modelled. For the multi-service model, four networks like this are put together into the same network file, one for each application (but sharing the channels available in cells).

The 'CREATE NODE' generates a structure of variables, called entity, whose value can be manipulated in the time. Each call is modelled with one of these entities. Moreover the 'CREATE NODE' has a parameter for controlling the interval of time between each entity generation. So, this parameter can be used to model the new call generation in the cells for all applications considered in this work. For each application, it is necessary one 'CREATE NODE' in each cell.

The 'ACTIVITY' symbols connect the nodes of the network. It drives the entities through the right path, by means of the condition parameter. If this parameter is specified, and the entity does not accomplish the condition it will not be able to pass through. The condition parameter is used to model decisions like finishing the call, if there are not enough free channels in the cell, distinguishing the instant of time in which the handover event happens, and choosing the cell when the call makes a handover.

The duration parameter is used to delay the entities, i.e., to model the time that a call is occupying channels or the time the user remains without using any channel when the call is still ongoing, i.e., the ON and OFF periods, respectively. For obtaining statistics in the ACTIVITY component a label has to be specified.

The 'ASSIGN NODE' allows for modifying the value of the entity variables, and global variables. It is used to assign values to the parameters of each entity after its generation in the 'CREATE NODE', assigning the correspondent random values to the entity variables, to assign the call duration, the sojourn time in the cell, the ON-OFF periods, and the number of channel occupied for the call. In the handover implementation, the 'ASSIGN NODE' is also used to update the value of the entity parameters before going into another cell. Another important function of the 'ASSIGN NODE' is to extract or add, the channels occupied for each application to a global variable.

The 'COLCT NODE' is used to complete the final simulation report with the remaining simulation data.

The 'GOON NODE' is used along with the 'ACTIVITY' one to model the decisions. It is used to connect different paths in the network. But it is always guarantee that each entity has only one possible route because the output exit conditions are exclusive.

The 'TERMINATE NODE' is used to eliminate the entity of the network. So it models the call end in cells.

2) Control file – The control statements are required to define the general parameters of the simulation, like run length, initial conditions, output options and file characteristics [4]. In our project these files are composed by six sentences: GEN, LIMITS, INTLC, NETWORK, INITIALIZE and FIN. The most important are LIMITS, INTLC and INITIALIZE.

The 'LIMITS' statement defines the type and size of the variables to be used in the simulations. In this case, a maximum of 300 entities are established simultaneously, 12 real global variables (XX[I]), three integer global variables (LL[I]), 9 real attributes (ATRIB[I]), and one integer attribute (LTRIB[I]).

The 'INTLC' statement is used to assign initial values to global variables. Each application uses three global variables of the type 'real' for containing the parameters needed for the call generation, call duration, and sojourn time in the cell. In the multi-service case three global variables of the type 'integer' are shared. They are used to contain the number of channels available in the cell.

The 'INITIALIZE' statement is used to indicate the time for beginning and finishing the simulation. The simulation time is one year, but in some simulations where the variability of the values obtained was high, this time was increased until 10 years.

3) User insert file – This file is used to give additional facilities to the simulator, in this work a C++ function was written in order to generate randomly numbers with Pareto distributions, a probability distribution not included in AweSim.

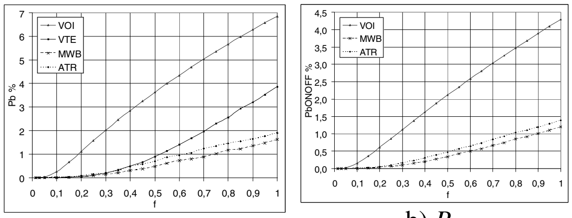
4. Simulation results

The results presented on the *Y* axis of the graphics are: the call blocking, P_b, the handover failure probability, P_{hf}, the ON-OFF blocking, P_{bONOFF}, and the ON periods handover failure probability, $P_{hfONOFF}$, Fig. 3. The *X* axis represents the average traffic per user, *f*, in Fig. 3 a), b) and c), and the handover rate, γ, in Fig. 3. d),

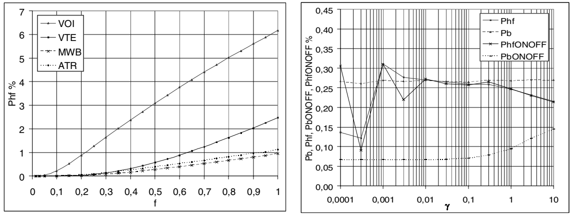
$$\gamma = \frac{\eta}{\mu}. \tag{12}$$

The call blocking is the ratio between the number of new calls that are rejected (in the process of trying to obtain channels) and the total number of new calls generated. 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) and the total number of handovers produced. The ON-OFF blocking probability is the ratio between the number of calls that are rejected at the beginning of an ON period (in the process of trying to obtain channels) and the total number of ON periods generated. The ON-OFF handover failure probability is the ratio between the number of handovers produced during an ON period that are rejected at the new cell (in the process of trying to obtain channels) and the total number of handovers produced during the ON period.

Fig. 3 corresponds to the scenario composed by three cells with traffic burstiness. In these simulations each service is working alone and using a different number of channels in the cell. So, with 12kbps channels (for VOI simulation) 4 channels are necessary, while for VTE 48 (4x12) channels are needed, for MWB 128 (4x32) channels are considered, and for ATR the number of channels is 512 (4x128). It will be accepted a maximum of four users using the application simultaneously in the cell.



a) Blocking probability.   b) P_{bONOFF}.



c) HO failure probability   d) Dependence on γ.

Fig. 3. Comparison of the P_b, P_{hf}, P_{bONOFF} for single service obtained by scaling the cell capacity.

The maximum value of P_b obtained for VOI is 6.8% (for f=1), 3.8% for VTE, 1.6% for MWB, and 1.8% for ATR. For P_{hf}, the values are 6.1% for VOI, 2.4% for VTE, 0.9% for MWB, and 1.1% for ATR. Finally, the maximum value of P_{bONOFF} is 4.3% for VOI (for f=1), 1.2% for MWB, and 1.4% for ATR. One fact to emphasize is that by comparing P_b with P_{hf}, they are relatively near. However, P_{hf} is always lower than P_b, despite of the absence of any priority algorithm for HO. In both cases the VOI application has always the highest value, followed by VTE, ATR and MWB. It could be related with the application offered traffic

$$\rho \overset{\Delta}{=} \frac{\lambda}{\mu}. \tag{13}$$

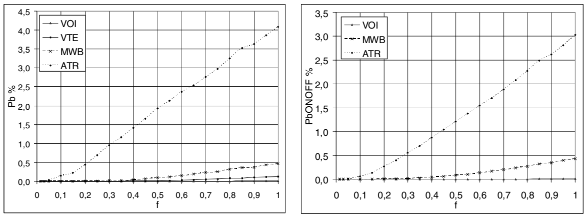
However, the value of ρ is 10.9 Erl for VOI, 3.8 Erl for VTE, 4.4 Erl for MWB, and for 5.64 Erl ATR, and this order is consistent only in the absence of mobility, not considering the traffic burstiness. The curves of

P_{bONOFF} follows the same behaviour of P_b and P_{hf} but with lower values.

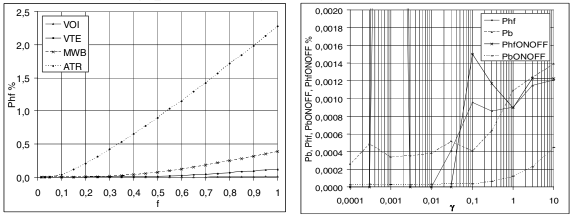
Fig. 3 d) presents P_b, P_{hf}, P_{bONOFF} and $P_{hfONOFF}$ as a function of γ for VOI. P_{hf} and $P_{hfONOFF}$ values show a trend to decrease when γ is higher than 0.1. The $P_{hfONOFF}$ curve is almost coincident with the P_{hf} one. For low values of γ, the fact of obtaining high variability in P_{hf} and $P_{hfONOFF}$ values is owing to the small number of handover, and consequently there are less handover failures.

It is worthwhile to note that the P_b and P_{bONOFF} curves have a more stable behaviour. The shape of the P_{bONOFF} curve here is different from the P_b, P_{hf} and $P_{hfONOFF}$ ones. It has a trend to grow for the highest values of γ.

Fig. 4 also corresponds to the hypothesis of the three cells scenario, considering the traffic burstiness, and multi-service. Hence, all the services are working together and sharing 512 channels per cell. Any user will be accepted in cells while there are enough free channels for the call/session. No priority is given to any traffic class.



a) Blocking probability. b) P_{bONOFF}.



c) HO failure probability d) Dependence on γ.

Fig. 4. Comparison of P_b, P_{hf}, P_{bONOFF} in the multi-service case for each application.

The maximum value of P_b obtained for VOI is 0.0104% (for f=1), while for VTE it is 0.1312%, 0.4695% for MWB, and 4.087% for ATR. For P_{hf} the values are 0.0100% for VOI, 0.1176% for VTE, 0.3889% for MWB, and 2.279% for ATR. Finally, maximum values of P_{bONOFF} are 0.0082% for VOI, 0.4294% for MWB, and 3.026% for ATR.

By comparing these values with the ones from Fig. 3, the results have changed considerably, Fig. 4. Now, P_b is the lowest for VOI. In all cases except in ATR, P_b values are lower than in Fig. 3 because, now, there are more channels available. The exception is ATR, which has 512 channels available, but now it shares the resources with the other applications.

Fig. 4.d) presents P_b, P_{hf}, P_{bONOFF} and $P_{hfONOFF}$ as a function of γ for VOI. We can observe that the high variability of the values produce strange shapes. The exception is the P_{bONOFF} curve which maintains certain stability. For example, the $P_{hfONOFF}$ and the P_{hf} have values relatively high when γ is 0.001 (out of the graphic area). Going deeply into the results to find and explanation, one obtains a $P_{hfONOFF}$ of 0.029%, and a P_{hf} of 0.013%. However, these values are being caused by a unique handover failure in one of the cells. The same set of values was used for η in these simulations, corresponding to the same average velocity for all the users, independently of the application that is being used.

As in Figs. 4.a)-c) it was impossible to see the curve for VOI due to its low values, Fig. 5 presents the amplification of the results. As in other multi-service results, there is a mountain shape in the curves. This shape is extended between fs that vary from 0.1 to 0.5. Besides, P_{bONOFF} has also this shape. Now, all the applications are sharing 512 channels, and lower data rate it is easier to obtain resources, in comparison with higher data rate applications. Higher data rate applications have higher probabilities of being blocked because they need batches of channels which, sometimes, cannot be available. For instance, when there are less than 12 channels available only VOI users can obtain resources.

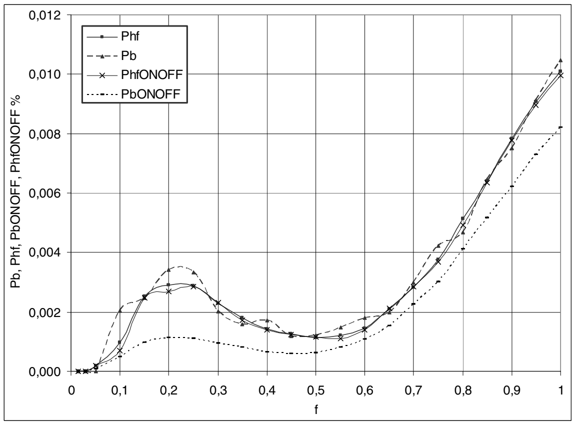


Fig. 5. $P_b(f)$, $P_{hf}(f)$, $P_{bONOFF}(f)$, and $P_{hfONOFF}(f)$ for VOI in the multi-service case.

5. Validation

Our simulator can be used for the validation of traffic models. One performs a comparison between the theoretical values obtained by considering the Bernoulli/Poisson/Pascal (BPP) model for multi-service traffic [5], [6], and the results obtained by using the AweSim simulator. Results for bursty VOI are presented in Fig. 6, example for $f = 0.1$ and 4 channels.

Simulations were run for 10 years time. By considering exponential distributions for the active/inactive periods, an average call/session duration of 60 s, and a time interval between arrivals of 128.6 s, the theoretical and the experimental values of P_{bONOFF} agree being coincident for $\gamma \approx 3$. Validation was achieved up to $\gamma \approx 10$, Fig. 6, corresponding to a dwell time in cells at least ten times higher than the duration of the ON burst duration. When higher values of γ, e.g., $\gamma = 100$, are considered, corresponding to dwell times of the order of the ON burst duration, the system behaviour degrades. These results clearly show the extreme usefulness of the simulator.

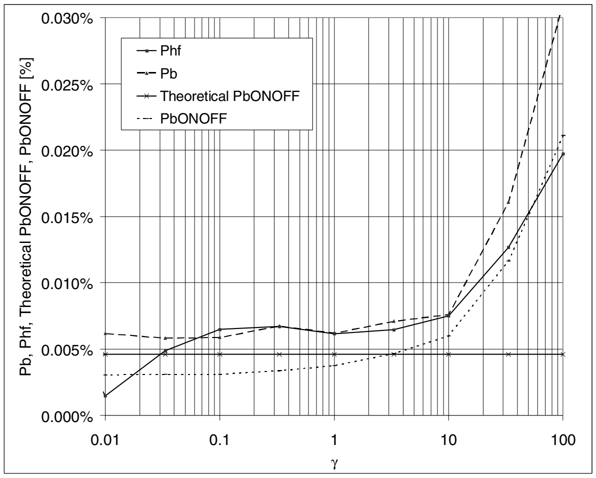


Fig. 6. $P_b(\gamma)$, $P_{hf}(\gamma)$, theoretical $P_{bONOFF}(\gamma)$ and simulated $Pb_{ONOFF}(\gamma)$ for VOI in the multi-service model (f=0.1).

Finally it is worthwhile noting that the model validation was only achieved for the bursty behaviour of a single application (VOI in this case), and a next step will be to use our simulator to validate the model for the multi-service case.

6. Conclusions

ITU-T recommendation E.771 [7] proposes a limit of 1% for blocking probability in future mobile systems, including the radio channel blocking probability. So, for the number of channels specified in the multi-service hypothesis only for low percentage of active users the recommendation is accomplished for all the applications. This is due to the higher data rate services. Comparing call blocking and handover failure probabilities we can observe that they have very similar values in all graphics, as that there is no privilege for handover calls relatively to new ones. However, the difference between call blocking and handover failure probabilities increases when the average velocity of users increases, or if the size of the cell is reduced.

The validation of the BPP model to compute P_{bONOFF} from [5], [6] was achieved for a single application, and handover rates up to 10.

The Vehicular scenario is not the only one defined in SEACORN. One of the next steps of this work will be to simulate the Office and Business City Centre scenarios, by changing scenario parameters in the Control and the Network files. Another step will be to use our simulator to validate the model for the multi-service case.

7. Acknowledgments

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