Influence of a Few More Channels for Voice Support in B3G Multi-Service Traffic in the Presence of Mobility

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***Abstract*—The analysis of the impact of voice-over-IP into HSPA and LTE multi-service traffic is a challenge. The validation of a Bernoulli-Poisson-Pascal multi-service traffic model in the presence of mobility is explored for different values for the number of channels. A mixture of voice (VOI) and video telephony (VTE) is considered. In a previous work, a critical situation was assumed where the total number of channels was exactly the same as needed by four VTE sessions. However, when few extra channels are added there is a significant reduction on VTE on/off blocking probability. With this few extra resources, VOI can now be easily supported. Since it is supported on top of a system saturated with VTE sessions, $P_{b_{onoff}}$ decreases 4.6 times for VTE. Since the number of resources is not critical anymore, the range of values of the offered traffic for which the theoretical model agrees with simulation results becomes wider. There is no significative difference between the multi-service traffic results for the seven cell geometry and the roundabout (or ring) cellular topologies in the presence of mobility.**

I. INTRODUCTION

The first step in the evolution of radio access of the Wideband Code Division Multiple Access (WCDMA) was the introduction of High-Speed Downlink Packet Access (HSDPA) in the specifications of Release 5 of 3GPP/WCDMA. Although packet data communications have been supported since the first release of WCDMA, HSDPA allows for additional support for new packet services in a more efficient way. Improvements in downlink data packet transmission from HSDPA are complemented by Enhanced Uplink, introduced as part of Release 6 of 3GPP/WCDMA. The HSDPA and Enhanced Uplink, when joined together, are referred to as the High Speed Packet Access (HSPA). Release 7 introduces a few improvements to HSPA that help to reduce the power consumption for packet services like web browsing and voice-over-IP (VoIP) [1].

The most important requirements for cellular systems is to provide high-speed packet data, enhanced throughput and reduced delays, while simultaneously maintaining an optimal coverage and system support. To achieve these requirements, HSPA introduces several techniques over the WCDMA, described in [2], leading to higher data rates. Another objective in release 7 is to support continuous packet connectivity services with "Always-on" terminals.

A number of features have been introduced to 3GPP releases 6 and 7 to improve the efficiency of low bit-rate, delay-critical applications, such as VoIP. Details are presented in [1].

The discontinuous uplink transmission not only reduces the power consumption, but also less interference is caused by the terminal. Consequently, higher capacity can be achieved [1]. The discontinuous uplink transmission can be applied for VoIP calls as well. The terminal can shut down the transmitter between the VoIP packets making usage of the on/off bursty behaviour. As a consequence, the VoIP capacity gain for release 7 discontinuous uplink transmission is approximately 50 percent compared to release 6. While in release 8/LTE the gain will be 200-400%.

The circuit-switched capacity with release 99 is estimated to be 60-70 users per cell, whereas the VoIP capacity with HSPA release 7 increased to 120 users.

The analysis of the impact of VoIP into the multi-service traffic is therefore a challenge, and the mixture of voice traffic with other types of traffic, e.g., video telephony (VTE), needs to be analysed in the presence of mobility. In other works, mobility was only taken into account with single-service [3]. In the multi-service case, there are some authors that address similar problems with the partition of resources among different classes with movable boundaries. However, none of these works present an efficient closed formula/algorithm account for the flow equilibrium between new and handover sessions as it was proposed in [4] and considered here.

One specific issue that needs to be addressed is how few extra resources for voice support may impact the overall multi-service system performance. In this work, we also address the comparison of the results between different cellular topologies, and we specifically consider the roundabout and the seven hexagonal shaped cells geometries.

The remaining of the paper is organized as follows. Section II presents the traffic model at the application and the service levels. Section III addresses simulation concepts and parameters, and the purpose of the developed simulator as

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well. In Section IV, results are presented for the comparison between the 7 cell geometry and the roundabout or ring cellular configuration. The impact of a few more channels onto the multi-service behaviour in the presence of voice traffic is analysed. The multi-service traffic model is addressed for a wide range of values for the handover rate. Several values of the offered traffic are also considered. Finally, Section V presents the conclusions.

II. TRAFFIC MODEL

A. Initial Considerations

To address the multi-service traffic in Enhanced UMTS or HSPA, a traffic model has to be established. In the general model of a loss system with R_e=1 type of resources shared by J classes (i.e., service components), a customer arrival at the resources follows a specific random process [5]. Each customer, i.e., service components users, requests a fixed number of resource units, i.e., channels, which are granted if available. If not, the request is cleared and the customer is blocked. The classification of customers is done on the basis of their arrival process, capacity requirement and mean holding time [5]. In this work, one of the performance measures that one is interested in, is the customer or connection blocking probability, P_b. Besides, this problem involves bursty traffic, with on and off periods, one needs to address on/off blocking probability. Because of terminal mobility and the resulting handovers, one is also interested in the handover failure probability, whose limitation directly results from the existence of a threshold for the call-dropping probability. The Bernoulli-Poisson-Pascal (BPP) model for the superposition of various types of traffic sources is considered [5].

B. Basis of the Model

The capacity of the resource facilities is partitioned into capacity units. A customer is assumed to need a given number of units of each facility, and the demand is granted on a first come first served basis. If a customer demand cannot be granted, it is cleared and the new customer is blocked. A more detailed explanation can be found in [5], [6].

Blocking takes place if a request cannot be granted entirely, i.e., a class j request arrives when the system is in the set, [5],

$$\mathrm{B}_j = \{\boldsymbol{n} \in \mathcal{N} : \boldsymbol{n} \cdot \mathbf{A} + a_j > c\}. \tag{1}$$

For exponential holding times, the BPP process can be modelled by a Markov chain, although this model allows for considering more general distributions for the holding times.

As the equilibrium probability mass function (*pmf*) of the state $N(t)$, $p(n)$, has a product form, in [5] an algorithm is proposed to compute the occupancy *pmf*, $q(y)$. This algorithm for BPP traffic is economic in terms of computation time and storage space if the number of resources is not too high. BPP processes are those whose arrival intensity (corresponding to an exponential distribution of the inter arrival time), conditioned to n_j customers being in the system, is of the form

$$\lambda_j(n_j) = \alpha_j + n_j \cdot \beta_j, \text{with } \alpha_j > 0, \tag{2}$$

where $(-\beta_j)$ is the activation rate and α_j is the arrival rate. In the Poisson case, as $\beta_j = 0$, the *pmf* of the number of active customers in an infinite resource is $\lambda_j(n_j) = \alpha_j$ [5].

Due to the applied normalization, mean holding times are unitary, thus, death rates are integer values. The description and the pseudo-code for the algorithm for the computation of time and call blocking probabilities, P_{bt} and P_b, respectively, are presented in [5], [7].

C. User Model and Equivalent User

There are a total number of c available resources (or channels) in each cell, being used by a total number of equivalent users, M_T. Furthermore, one is considering two applications, voice (VOI) and VTE, i.e., a total of K_{app}=2 applications. The index k (k=VOI, VTE) refers to these applications. Given this traffic mixture, the model for applications activation (by users) is presented in Fig. 1. Each user can be either in an idle state or using one of the two applications, with generation rate, Λ_k, and total service rate, H_k, respectively.

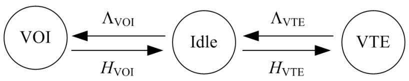

Fig. 1. Application activation

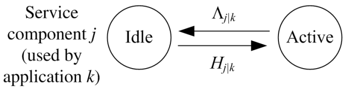

Fig. 2. Service components activation

principiocomentários Once application k is active, the service components are activated with rate $\Lambda_{j|k}$ and extinguished with total service rate $\mathrm{H}_{j|k}$, $j = 1, ..., J$, Fig. 2; they can be simultaneously active, or not, and some can even not be activated for a given application. This is a loss system, whose performance can be measured by the blocking probability of each service component, which simplifies the analysis (because one only needs to consider the service components, and not each application).

From Fig. 1 it is straightforward to derive the probability of a user having application k active

$$p_k = \frac{\Lambda_k/\mathrm{H}_k}{1 + \sum_{i=1}^{K_{app}} \Lambda_i/\mathrm{H}_i}. \tag{3}$$

In [6] it was demonstrated how to achieve the fraction of active users, f_a, as a function of traffic, ρ,

$$f_a = \frac{\rho}{1+\rho}. \tag{4}$$

III. SIMULATION CONCEPTS AND PARAMETERS

Packet switched traffic is commonly modelled as *on/off* processes. Our simulator models the voice *on/off* behaviour of traffic by using active/inactive time periods that follow different distributions, e.g., exponential, Pareto or Weibull, according to [8]. Although a more detailed model could be used in simulations it was considered that VTE has continuous occupation of channels along all the call duration.

The concepts associated with bursty traffic simulation parameters are represented in Fig. 3. ON_i is the number of *on* bursts 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 occurs during the *on* period in cell i $Hand\_f\_ON_i$ is the number of handover failures produced during the *on* period in cell i, and $Hand\_failure_i$ is the number of handover failures produced in cell i without taking into account if it happens during or at the beginning of *on* periods. The on/off blocking probability, $P_{b_{onoff}}$, is the ratio between the number of *on* periods that are rejected in the process of trying to obtain channels and the total number of generated *on* periods,

$$\begin{aligned} Attempts = \sum_{i=1}^{Ncell} N\_call\_block_i + \sum_{i=1}^{Ncell} ON\_block_i + \\ \sum_{i=1}^{Ncell} Hand\_failure_i - \sum_{i=1}^{Ncell} Hand\_f\_ON_i \end{aligned} \quad (5)$$

$$P_{b_{onoff}} = \frac{Attempts}{Attempts + \sum_{i=1}^{Ncell} ON_i - \sum_{i=1}^{Ncell} Hand\_ON_i}, \quad (6)$$

where $Ncell$ is the number of cells in the topology.

A more complex nomenclature was added to our network simulator to count the total number of *on* periods, dealing with the precise moment for handover events [4]. The collection and analysis of the results follows the AweSim approach [9], [10]. A duration of 10 year for the simulations ensure the statistical relevance.

In comparison to others simulators, ours supports very high handover rates [9], [10], which may correspond to high mobile terminal velocities. The simulator was used for the validation of traffic models. One performed a comparison between the theoretical values obtained by considering the BPP model for multi-service traffic from [9], [11] and the simulation results obtained by using AweSim. In the previous work [9], [11], however, a critical situation was assumed where the total number of channels was exactly equal to the value needed by four VTE sessions. In this work, in order to avoid such critical situation, new hypothesis regarding the number of channels are assumed.

A mixture of VOI and VTE was chosen for the multi-service cases. When it is active (60 s), voice has a burst behaviour; *on* and off periods have exponential distributions with average durations 1.4 and 1.7 s, respectively. However, the VTE (60 s) application does not present a bursty behaviour and is permanently active. The time intervals between arrivals are the ones presented in Table I.

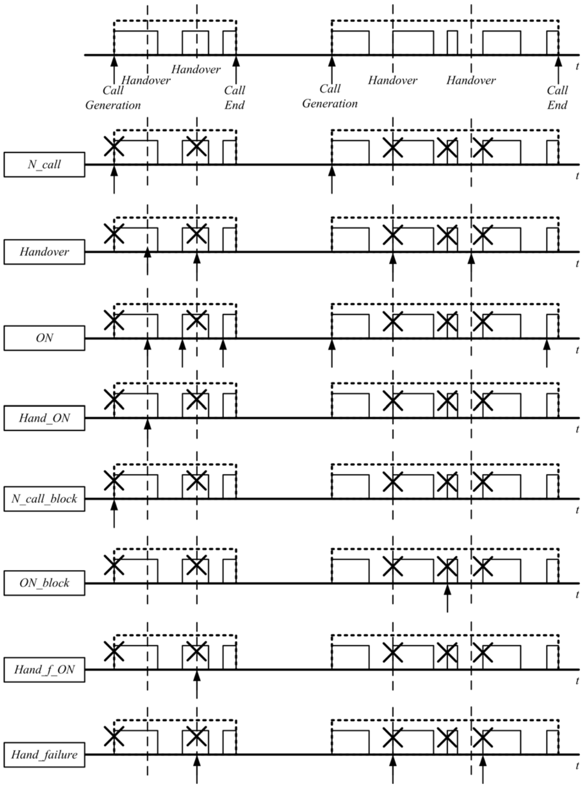

Fig. 3. Graphical explanation of the parameters used in the formulationfor bursty traffic, i.e., *on/off* periods

TABLE I
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

IV. RESULTS

A. Physical and mobility scenario

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

$$\overline{\tau} = \frac{1}{\mu}, \quad (7)$$

where μ is the service rate. During handover if there are not enough channels available in the new cell this call will be dropped, and there will be handover failure. The sojourn time is the time period that each user stays in a cell. It follows an exponential distribution with average

$$\overline{\tau}_h = \frac{1}{\eta}, \tag{8}$$

where η is the cross-over rate, given by

$$\eta = \frac{V_{av}}{2 * ln(2)} * \frac{1}{2R}. \tag{9}$$

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

The handover rate, γ, is given by

$$\gamma = \frac{\eta}{\mu}, \tag{10}$$

while the channel occupancy time is given by

$$\overline{\tau}_c = min(\overline{\tau}, \overline{\tau}_h). \tag{11}$$

As the minimum of two variables exponentially distributed is also exponentially distributed, τ_c is exponential. Other mobility models are considered in [8], but are out of the scope for this work.

We assume that traffic is homogeneous over the cellular topologies from Figs. 4 and 5. As a consequence, there is a homogeneous probability of generating new and handovers calls in the different cells. Hence, $\lambda_i = \lambda \forall i$, $\eta_i = \eta \forall i$, and $\sum_{k=1}^{Ncell} p_{ki} = 1, \forall i$, where λ_i is the traffic generation rate, p_{ki} is the probability that a call may attempt a handover from cell k to cell i. Details on the busy hour call attempt, $BHCA$, i.e, the traffic generation rate in this case, and its relation with the number of users, the offered traffic, and the average call/session duration are given in [4].

B. 7 Cells Vs Roundabout Cellular configuration

Here we address the impact of the cellular geometry (or topology) in the simulations. The 10 cell roundabout or ring geometry, Fig. 4 (where r_1 and r_2 are the inner and outer roundabout radii), and a second geometry with 7 hexagonal-shapped cells, Fig. 5, are considered. An example for the first topology are the rings around cities.

As simulations may be computationally heavy, in order to justify the use of a ring/roundabout topology where each cell only has two neighbour cells, we also considered the hexagonal-shaped cellular and mobility topology.

The simulation conditions and assumptions are the same for the two topologies. In the construction of the simulation topology with 7 cells, note that the hypothesis of toroidal reuse has been taken into account, to ensure the feeding of the mobile handover users to corresponding cell on the topology itself whilst guaranteeing the statistical relevance of the simulations [3]. This assumption was also taken into account in the roundabout scenario with 10 cells, but in the scenario with 7 hexagonal cells the programming challenge lays in the number of boundaries that exist in each cell. Instead of two neighbouring cells (as in the roundabout configuration with 10 cells) there are now 6 neighbouring cells for each individual cell.

By analysing the results for bursty VOI from Fig. 6 for P_b, P_{hf} and $P_{b_{onoff}}$ (where P_{hf} is the handover failure probability), it seems that the results arising from the simulation with a geometry with 10 cells arranged in roundabout does not present results very different from the ones in the case with 7 cells, i.e., very similar results are obtained for the two cellular topologies. Hence, in future developments of the simulator, scenarios with 7 hexagonal-shaped cells may be disregarded (as they are much more complex).

For ρ=0.01 Erl, when the handover rate is very low (where the user mobility is in the range of nomadic), i.e., $0.001 < \gamma < 0.01$, the results for P_{hf} are not smooth since very few handovers occur, and it is difficult to achieve improvements into the statistical relevance of the P_{hf} results, from Fig. 6, in this interval for γ.

C. Impact of using a few more channels into multi-service

In the context of multi-service, i.e, when when VOI and VTE are supported simultaneously in the network, with 48 channels [4], for VOI, the value of $P_{b_{onoff}}$ obtained via simulations is always lower than its theoretical value ($P_{b_{onoff\,Theoretical}}$, [5], [7]) while for VTE its value is higher than the theoretical one, Figs 7 and 8. Note, however, that as each VTE session occupies 12 channels, 48 channels is 4×12, i.e., exactly the amount of resources needed to support four simultaneous “permanent application” VTE sessions, it seems that the negative effect of VOI has been magnified (relatively to the few extra resources it occupies). This fact, motivates the need for a comparison of the previous results with the ones arising from an analysis where a few more channels are used. The intention is to test if these few extra resources allow for a statistical multiplexing gain, resulting from a decrease in the blocking (of VOI calls on top of VTE) when there are high loads of VTE (the case when there may be four VTE users simultaneously active).

With 48 dedicated channels, from the simulations for VOI alone we observe that no blocking, handover failure or on/off blocking occur at all. For long sessions, usually P_b decreases for larger values of γ, after behaving steadily for the lowest

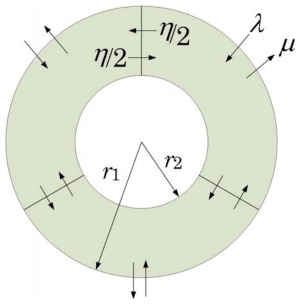

Fig. 4. Roundabout Cellular Configuration (only tree cells are depicted)

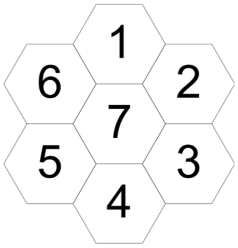

Fig. 5. Hexagonal-shaped Cellular 2D Topology

values of γ. In turn, with bursty on/off traffic periods the observed behaviour for $P_{b_{onoff}}$ is to increase to medium/larger γs. In Fig. 7, for the largest γs the decreasing behaviour for $P_{b_{onoff}}$ occurs only when the average length of the on period enables the mobile terminal traverses the whole cell during the session completion, i.e., for $\gamma > 10$.

While in Fig. 8 results were obtained for VTE in the context of multi-service, the analysis corresponding to Fig. 9 corresponds to VTE operating alone as a single service. Taking as reference a value for the handover rate γ=1 we can observe that the values of P_b and P_{hf} tend to be 4.6 times lower in this latter case (compared to multi-service).

As a consequence of this analysis, a slight increase in the number of channels to serve the voice traffic was proposed. Note that 48 channels can support four VTE sessions simultaneously, not leaving any channels available for VOI. The choice was to add 4 more channels to the 48 available, i.e., an increase of 8.3 % in the number of available resources. The intention is to verify if VOI traffic will not degrade the values of the on/off blocking probability anymore. From the simulations, Figs. 7 and 8, it is observed that, for both applications, the on/off blocking probability decreased drastically. With 52 channels in the multi-service case, the values of $P_{b_{onoff}}$ for VOI became similar to the ones for VOI operating alone. $P_{b_{onoff}}$ values, e.g., for γ=1, decrease from $4.15\cdot10^{-5}$ Erl to $1.02\cdot10^{-7}$ Erl (for 48 channels and 52 channels, respectively), values more than 407 times lower than with 48 channels.

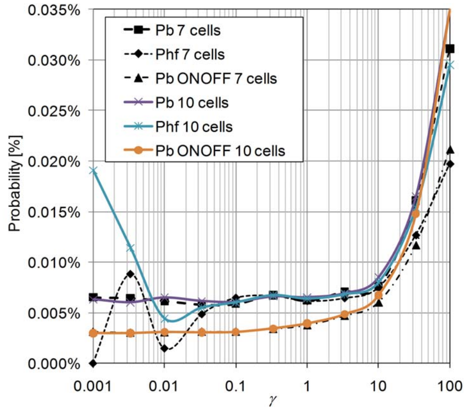

Fig. 6. Comparison of P_b, P_{hf}, $P_{b_{onoff}}$ and $P_{b_{onoff\,Theoretical}}$, as a function of γ between 7 hexagonal and 10 roundabout shaped cells for VOI and ρ=0.10 Erl

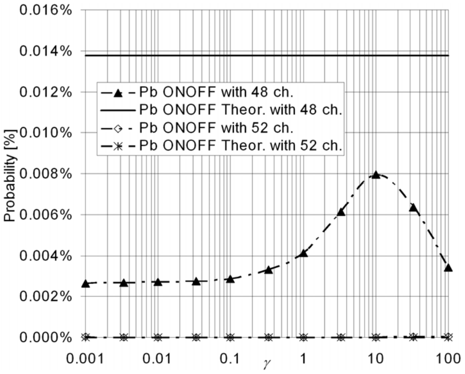

Fig. 7. $P_{b_{onoff}}$ and $P_{b_{onoff\,Theoretical}}$, as a function of γ for VOI and ρ=0.10 Erl, in the multi-service case with 48 and 52 shared channels (the theoretical value 0.0139% is the model output and substitutes the one erroneously represented in Fig. 12 from [4])

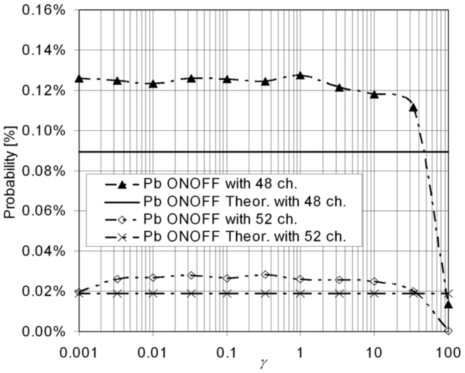

Fig. 8. $P_{b_{onoff}}$ and $P_{b_{onoff\,Theoretical}}$, as a function of γ for VTE and ρ=0.10 Erl, in the multi-service case with 48 and 52 shared channels

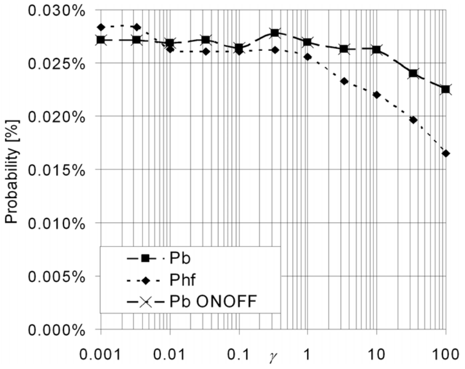

Fig. 9. P_b, P_{hf} e $P_{b_{onoff}}$, as a function of γ and ρ=0.10 Erl, for VTE, in the multi-service case with 48 dedicated channels

In the case of VTE, the increase on the number of resources from 48 to 52 channels also results on a reduction on the value of $P_{b_{onoff}}$. For γ= 1 the reduction varies between 4.6 and 4.7 times. This clearly shows that the use of a few more channels for VOI support is advantageous while helping an efficient VTE service support.

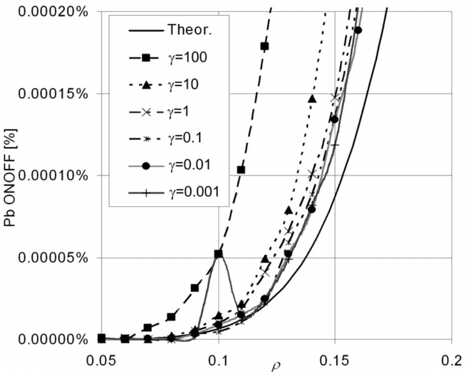

Fig. 10. Comparison of theoretical and simulation results for $P_{b_{onoff}}$ for different ρs, with γ as a parameter, for VOI with 52 shared channels

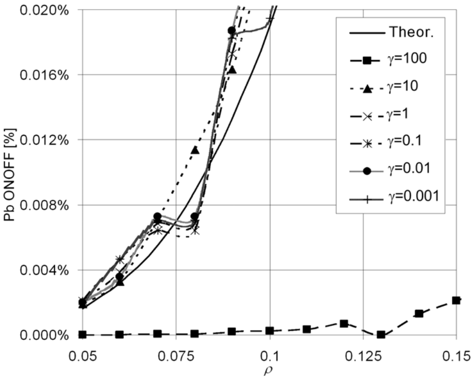

Fig. 11. Comparison of theoretical and simulation results for $P_{b_{onoff}}$ for different ρs, with γ as a parameter, for VTE with 52 shared channels

D. Multi-service Traffic Model Validation

Figures 10 and 11 present the curves for $P_{b_{onoff}}$ as a function of ρ, with γ as a parameter in the multi-service case. For VOI, a coherence between theoretical and simulated values is verified for $0.05 \leq \rho \leq 0.12$ Erl. Then, for $\rho > 0.12$ Erl, the theoretical model becomes optimistic relatively to the curves obtained via simulation, i.e., the theoretical values for $P_{b_{onoff}}$ are lower than the simulated ones. For VTE, the coherence between theoretical and simulated results also occurs for $0.05 \leq \rho \leq 0.09$ Erl, for $\gamma < 10$ Erl. Then, for $\rho > 0.9$ Erl, the theoretical model becomes optimistic. Note that, with 52 channels, this behaviour for larger ρs (i.e., the theoretical model being optimistic) is similar to the behaviour with 48 channels [4]. However, with 52 channels there is a correspondence between the theoretical model and the simulation results for a wide range of values of ρs.

V. CONCLUSION

In this paper, the validation of a multi-service traffic model in the presence of mobility is analysed for a mixture of VOI and VTE, with new hypothesis for the number of channels. This multi-service traffic model may be applied as a part of a tele-traffic component in cellular planning tools.

In a previous work, a critical situation was assumed where the total number of channels was exactly the same as needed by four VTE sessions. When few extra channels are added to the initial 48 available, there is a reduction on VTE on/off blocking probability. Since VOI can be easily supported with this few extra channels, now $P_{b_{onoff}}$ decreases 4.6 times for VTE. This way, VOI can easily be supported on top of a system saturated with VTE sessions. Since the number of resources is not critical anymore, and it slightly overcomes the minimum required value for a fixed amount of VTE sessions, the range of ρs for which the theoretical model agrees with simulation results is wider.

By comparing the seven cell geometry and the roundabout (or ring) cellular configuration, one also learned from this work that this change in topologies does not significatively change the multi-service results in the presence of mobility.

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