Comparative Evaluation of Adaptive Trunk Reservation Schemes for Mobile Cellular Networks *

David Garcia-Roger,[†] M.ª Jose Domenech-Benlloch,[‡] Jorge Martinez-Bauset and Vicent Pla,
Departamento de Comunicaciones, Universidad Politécnica de Valencia , UPV
ETSIT Camino de Vera s/n, 46022, Valencia, Spain
Telephone: +34 963877767, +34 963879733, Fax: +34 963877309
E-mail: (dagarro, mdoben)@doctor.upv.es
(jmartinez, vpla)@dcom.upv.es

Abstract

We propose a novel adaptive reservation scheme designed to operate in association with the well-known Multiple Guard Channel (MGC) admission control policy. The scheme adjusts the MGC configuration parameters by continuously tracking the Quality of Service (QoS) perceived by users, adapting to any mix of aggregated traffic and enforcing a differentiated treatment among streams during underload and overload episodes. We provide two implementations of that scheme. The numerical evaluation performed confirms that the QoS objective is met with an excellent precision. We compare our adaptive scheme with two previously relevant proposals of this approach in a single service scenario. The comparative performance evaluation carried out verifies that our scheme outperforms the two previous proposals in terms of both of carried traffic and convergence speed to new operating conditions. Other key features of our scheme are its simplicity, its oscillation-free behavior, and its integrated strategy to deal with multiservice scenarios.

1 Introduction

Session Admission Control (SAC) is a key mechanism in the design and operation of multiservice mobile cellular networks that guarantee a certain degree of Quality of Service (QoS). The mobility of terminals make it very difficult to insure that the resources available at session setup will also be available along the session lifetime, as the terminal moves from one cell to another. The design of SAC policies must take into consideration not only packet related parameters like maximum delay, jitter of losses, but also session related parameters like setup request blocking probabilities and forced termination probabilities.

In this paper we focus on a novel adaptive strategy introduced in [1] This adaptive scheme operates in coordination with a trunk reservation policy named *Multiple Guard Channel* (MGC) [2]. A distinct characteristic of trunk reservation policies is that the admission/rejection decisions are taken based only on the number of free resources available in the system. The scheme described in this paper is a particularization to a single service scenario of the one proposed in [1].

For stationary multiservice scenarios, different SAC policies have been evaluated in [2], where it was found that the performance of the *Multiple Fractional Guard Channel* (MFGC) policy is very close to the performance of the optimal policy and that the performance of both MGC and MFGC policies tend to the optimal as the number of resources increase. In [2] the performance is evaluated by obtaining the maximum aggregated call rate that can be offered to the system, which we call the system capacity, while guaranteeing a given QoS objective. The QoS objective is defined in terms of an upper bound for the blocking probabilities of both new session and handover requests. Although for simplicity in this paper we only provide implementations for the adaptive scheme when operating with an integer number of guard channels , it can be readily extended to operate with a fractional number of them.

*This work has been supported by the Spanish Government and the European Commission through projects TIC2003-08272 and TEC2004-06437-C05-01 (30% PGE and 70% FEDER)

[†]This author was supported by Generalitat Valenciana under contract CTB/PRB/2002/267.

[‡]This author was supported by the Spanish Ministry of Education and Science under contract AP-2004-3332.

For the class of SAC policies considered in [2] the system capacity is a function of two parameter sets: those that describe the system as a Markov process and those that specify the QoS objective. Two approaches are commonly proposed for the design of the SAC policy. First, consider the parameters of the first set as stationary and therefore design an static SAC policy for the worst scenario. Second, consider them as nonstationary and either estimate them periodically or use historical information of traffic patterns.

In this paper we study the design of a SAC scheme that adapts the configuration of the MGC policy according to the QoS perceived by users. The configuration of a policy specifies the action (accept/reject) that must be taken at each system state when a new session or handover request occurs.

Recently, different SAC adaptive schemes have been proposed for mobile cellular networks. In these schemes the configuration of the SAC policy is adapted periodically according to estimates of the traffic or QoS parameters. A significant part of this paper is devoted to compare our adaptive scheme to two previously relevant proposals of this approach in a single service scenario [3, 4]. In [3] Zhang et al. propose a four parameter algorithm based on estimates of the blocking probability perceived by handover requests to adjust the number of guard channels. A two hour period is defined during which the system accumulates information to compute the estimates. This period is too long to capture the dynamics of operating mobile cellular networks. Besides, the value of the parameters proposed in [3] do not work properly when some traffic profiles are offered [4], (i.e. QoS objectives are not met). In [4] Wang et al. propose a three parameter probability-based adaptive algorithm, somewhat similar to that of *Random Early Detection* (RED), in order to overcome these shortcomings. Its main advantage compared to the scheme in [3] is that it reduces the new request blocking probability, once the steady state has been reached, and therefore higher resource utilization is achieved. Nevertheless, the convergence period is still of the order of hours. The scheme we propose is also probability-based like in [4] but it has a considerably lower convergence period and can be applied to single service and multiservice scenerios.

Adaptive SAC mechanisms have also been studied, for example in [5–7], both in single service and multiservice scenarios, but in a context which is somewhat different to the one of this paper. There, the adjustment of the SAC policy configuration is based on estimates of the mobility pattern and of the handover arrival rates derived from the current number of ongoing calls in neighbouring cells. It is expected that the performance of our scheme would improve when provided with such predictive information but this is left for further study.

Our SAC adaptive scheme differs from previous proposals in: i) the simplicity of the proposed scheme, which does not rely on measurement intervals to estimate the QoS experienced by each arrival stream; ii) the high precision in the fulfillment of the QoS objective; and iii) the possibility of identifying several arrival streams as protected (with an operator defined order of priorities) and one as *best-effort*, being it useful to concentrate on it the penalization that unavoidably occurs during overloads. For comparison purposes this last feature is outside of the scope of this paper, due to the fact that the schemes devised in [3, 4] deal with a single service scenario. Please refer to [1] for additional details on this capability in multiservice scenarios.

The remaining of the paper is structured as follows. Section 2 describes the model of the system and defines the relevant SAC policies. Section 3 illustrates the fundamentals of the adaptive scheme, introducing the policy adjustment strategy and how the two arrival streams (new and handover requests) are handled. Section 4 applies these ideas to a system providing two different implementations of our scheme (with and without a QoS objective for new requests). Section 5 summarize some important details of the two other schemes being compared. Section 6 presents the comparative performance evaluation of our scheme with respect to the schemes and scenario in [3, 4], both under stationary and nonstationary traffic conditions. Finally, Section 7 concludes the paper.

2 System Model and Relevant SAC Policies

We consider a homogeneous single service scenario where all cells are statistically identical and independent,consequently the global performance of the system can be analyzed focusing on a single cell. Nevertheless, the proposed adaptive scheme could also be deployed in multiservice [1] and nonhomogeneous scenarios. In each cell, mobile users contend for C resource units, where the meaning of a unit of resource depends on the specific implementation of the radio interface. Without loss of generality it is assumed that each session requires one resource unit. There are two types of arrivals distinguished: new and handover. From now on, for convenience, we will denote by s^n (s^h) the arrival stream associated to new (handover) requests, and by s^i anyone of them.

Abusing from the Poisson process definition, we say that new requests arrive according to a Poisson process with time-varying rate $\lambda^n(t)$. The duration of a session is exponentially distributed with rate μ^s. The cell residence (dwell) time of a session is exponentially distributed with rate μ^d. Hence, the resource holding time for a session in a cell is exponentially distributed with rate $\mu = \mu^s + \mu^d$. We consider that handover requests arrive according to a Poisson process with time-varying rate $\lambda^h(t)$. Although our scheme does not require any relatioship between $\lambda^h(t)$ and $\lambda^n(t)$, for simplicity we will suppose that $\lambda^h(t)$ is a known fraction of $\lambda^n(t)$.

Let P^n (P^h) be the blocking probability perceived by new (handover) requests andB^n (B^h) the upper bound for the blocking probability of new (handover) requests. Let the system state be $n \equiv (n_n, n_h)$, where n_n (n_h) is the number of sessions in progress in the cell initiated as new (handover) requests. We denote by $c(n) = n_n + n_h$ the number of busy resource units in state n.

The definition of the SAC policies of interest are as follows: 1) *Complete-Sharing* (CS). A request is admitted provided there are enough free resource units available in the system. 2) *Multiple Guard Channel* (MGC). One parameter per arrival stream is defined, l^n and l^h, , l^n, $l^h \in \mathbb{N}$. When a new arrival happens in state n, it is accepted if $c(n) + 1 \leq l^n$ and blocked otherwise. Similarly if a handover arrival happens in state n, it is accepted if $c(n) + 1 \leq l^h$ and blocked otherwise. We denote by l^i the configuration of the MGC policy associated to s^i and by P^i the blocking probability perceived by s^i. Therefore, l^i is the averrage amount of resources that stream i has access to and increasing (decreasing) it reduces (increases) P^i.

In a wireless scenario a session being forced to terminate due to a handover failure is considered more harmful than the rejection of a new session request, and therefore all handover requests are admitted provided that free resources are available, (i.e. $l^h = C$ or simply it does not exist like in [3, 4]).

The performance evaluation of the adaptive schemes are carried out for the scenario described in [3, 4] and that has been summarized in Table 1. Notice that the QoS parameter B^h is expressed as percentage value. A distinctive capability of our algorithm is that it can operate managing l^n and l^h simultaneously, the implications of which will become clear later.

Table 1: Definition of the scenario under study

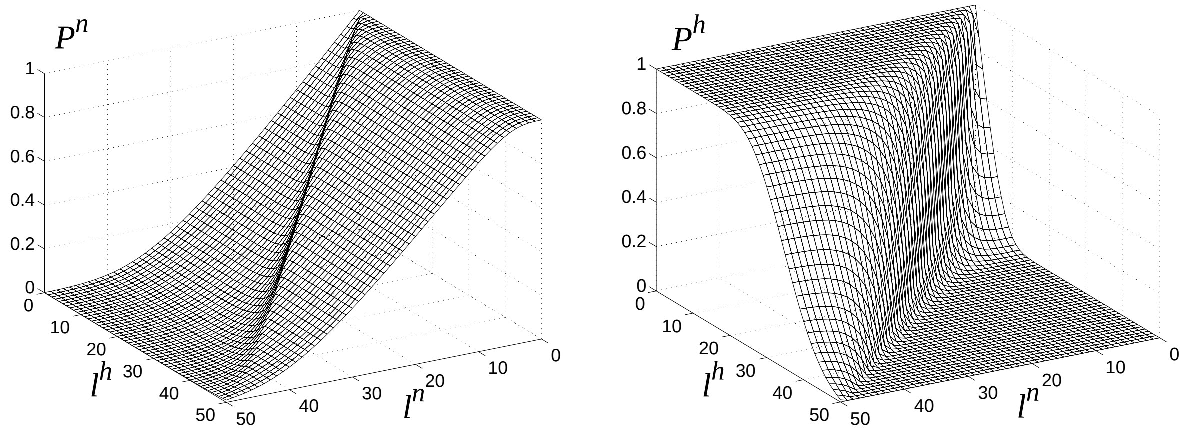
C	50 (resource units)
$B^h\%$	1
λ^h	$0.2\lambda^n$ (sessions/second)
μ	$1/180$ (seconds^{-1})

3 Fundamentals of the Adaptive Scheme

Most of the proposed adaptive schemes deploy a reservation strategy based on *guard channels*, increasing its number when the QoS objective is not met. The extension of this heuristic to a multistream scenario would consider that adjusting the configuration parameter l^i only affects the QoS perceived by s^i (P^i) but has no effect on the QoS perceived by the other arrival streams. As an example, Fig. 1 shows the dependency of P^n and P^h with l^n and l^h, respectively. It has been obtained in the scenario introduced in Table 1 when deploying the MGC policy and when offering an arrival rate equal to $\lambda = 0.175$. As shown, the correctness of the heuristic is not justified (observe Fig. 1(a)) although it might work in some cases (observe Fig. 1(b)).

Our scheme has been designed to handle this difficulty and to fulfill two key requirements that have an impact on its performance: one is to achieve a convergence period as short as possible and the other is to enforce a certain response during underload or overload episodes. For these purposes we classify the different arrival streams into two generic categories: i) those that the operator identifies as "protected" because they must meet specific QoS objectives; ii) one *Best-Effort Stream* (BES), with no specific QoS objective.

Additionally, the operator can define priorities at its convenience in order to protect more effectively some streams than other, i.e. handover requests. Therefore in a single service scenario, s^h due to its importance, must be a protected stream, and indeed it is the *Highest-Priority Stream* (HPS). Conversely, s^n must be the *Lowest-Priority Stream* (LPS). We study two treatments of the LPS. First, when the LSP has a QoS objective, which must be met when possible (undeload episodes). In this scenario our algorithm adapts both l^n and l^h.



(a) Arrival stream s^n (b) Arrival stream s^h

Figure 1: Dependency of the blocking probability with the configuration parameters.

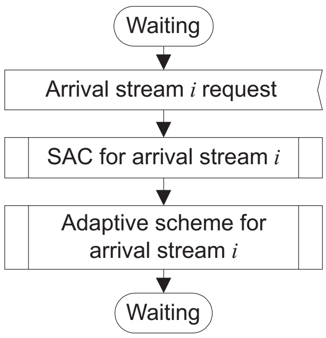


Figure 2: Conceptual operation of the adaptive reservation scheme.

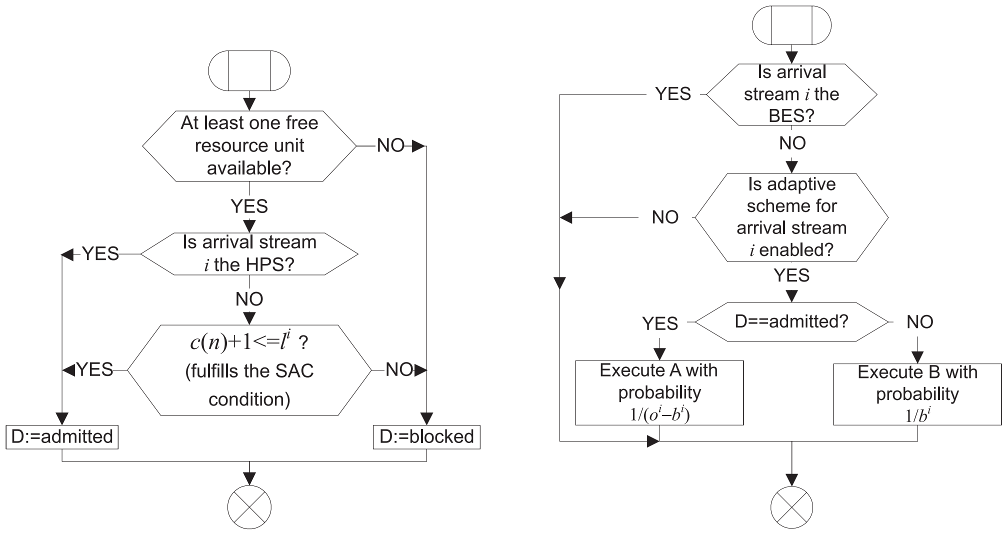
Second, when the LSP is a BES with no QoS objective. In this scenario our algorithm only adapts l^n. While the first treatment has received very much attention in the literature (e.g. it is the approach of [3, 4]), to the best of our knowledge, the second treatment has not been proposed before.

3.1 Probabilistic Setting of the Configuration Parameters

A common characteristic of previous schemes like those in [3, 4] and [5–7] is that they require a time window (*update period*) to produce the required estimates. The design of this update period must trade-off the time required to adapt to new conditions for the precision of estimates. The adaptive scheme we propose overcomes this limitation. The scheme tracks the QoS perceived by each arrival stream and performs a continuous adaptation of the configuration parameters of the SAC policy.

Let us assume that arrival processes are stationary and the system is in steady state. If the QoS objective for s^i can be expressed as $B^i = b^i/o^i$, where $b^i, o^i \in \mathbb{N}$, then it is expected that when $P^i = B^i$ the stream i will experience, in average, b^i rejected requests and $o^i - b^i$ admitted requests, out of o^i offered requests. It seems intuitive to think that the adaptive scheme should not change the configuration parameters of those arrival streams meeting their QoS objective. Therefore, assuming integer values for the configuration parameters, like those of the MGC policy, we propose to perform a probabilistic adjustment each time a request is processedin the following way: i) accepted, do $(l^i - 1)$ with probability $1/(o^i - b^i)$; ii) rejected, do $(l^i + 1)$ with probability $1/b^i$.

Figure 2 shows the general operation of the proposed scheme. As seen, when a stream i request arrives, the SAC decides upon its admission or rejection and this decision is used by the adaptive scheme to adjust the configuration of the SAC policy.



(a) Description of the *SAC for arrival stream* i block in Fig. 2.

(b) Description of the *Adaptive scheme for arrival stream* i block in Fig. 2.

Figure 3: Operation of the SAC policy and adaptive scheme.

4 Operation of the SAC Adaptive Scheme

Figure 3 shows the operation of the SAC subsystem and the adaptive scheme. As shown in Fig. 3(a), to admit an arrival stream i request it is first checked that at least one free resource unit is available. Note that once this is verified, HPS requests are always admitted, while the LPS must also fulfill the admission condition imposed by the MGC policy.

To be able to guarantee that the QoS objective for the HPS is always met, particularly during overloads episodes or changes in the load profile (λ^n and λ^h), the probabilistic adjustment described in Section 3.1 requires additional mechanisms. Two ways are possible to change the configuration when the QoS objective for HPS is not met. The direct way is to increase the configuration parameter l^h but its maximum value is C, i.e. when $l^h = C$ full access to the resources is provided and setting $l^h > C$ does not provide additional benefits. In these cases, an indirect way to help the HPS is to limit the access to resources of the LSPby reducing its associated configuration parameter l^n.

As shown in Fig. 4(b), upon a rejection, the adaptive scheme uses first the direct way and when exhausted it resorts to the indirect way, in which case the adaptive scheme of the LPS must be disabled. Figure 4(a) shows the reverse procedure. When the LPS is the BES then its adaptive scheme is never enabled. Note also that we allow the values of the l^i parameters to go above C and below zero as a means to remember past adjustments.

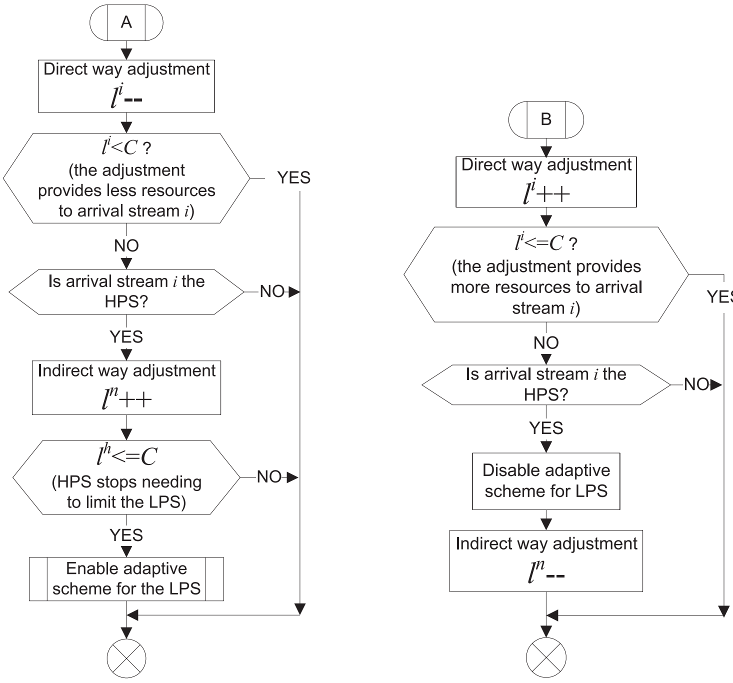
5 The other adaptive schemes studied

From now on we will refer to the proposed adaptive scheme as *our scheme*. We will also refer to the one in [3] as ZL and to the one in [4] as WZZZ, after its authors' initials. ZLWZZZ Details about them are now briefly described.

5.1 Adaptive scheme ZL

The adaptive scheme ZL has four parameters, namely α_u, α_d, N and τ. It operates as follows: i) after a blocked handover request, if it is detected that $P^h \geq \alpha_u B^h$, then l^n will be decreased by one ; ii) if for N consecutive handover requests it is found that $P^h \leq \alpha_d B^h$, then l^n will be increased by one.

This scheme (like the WZZZ scheme) estimates the ratio of the rejected to the total number of handovers requests during one update period $\tau$of fixed length. It is suggested in [3] that in order to achieve a given accuracy, the smaller the blocking probability objective is, the longer the estimation interval must be. Due to the low B^h required, this update period might be excessively long (e.g. $\tau = 2$ hours for the ZL scheme). However, this scheme ambiguously defines the *estimator*, i.e. how the measure of the ratio of the rejected to



(a) Adjustment algorithm after an admission decision.

(b) Adjustment algorithm after a rejection decision.

Figure 4: The adaptive algorithm.

the total number of handovers requests is performed. Two possibilities arise: i) the easy approach resets the measure of the ratio each τ units of time; ii) the complex approach measures the ratio experienced in the last τ units of time and needs to handle an event table. This ambiguity leads the authors of [4] to let $\tau \rightarrow \infty$ removing thus the dependency of both the ZL and the WZZZ schemes with respect to the τ parameter (i.e. the estimated ratio equals to P^h the blocking probability experienced so far). This last choice is assumed for both the ZL and WZZZ schemes in our comparative evaluation (Section 6). Note that our adaptive scheme does not rely on measurement intervals.

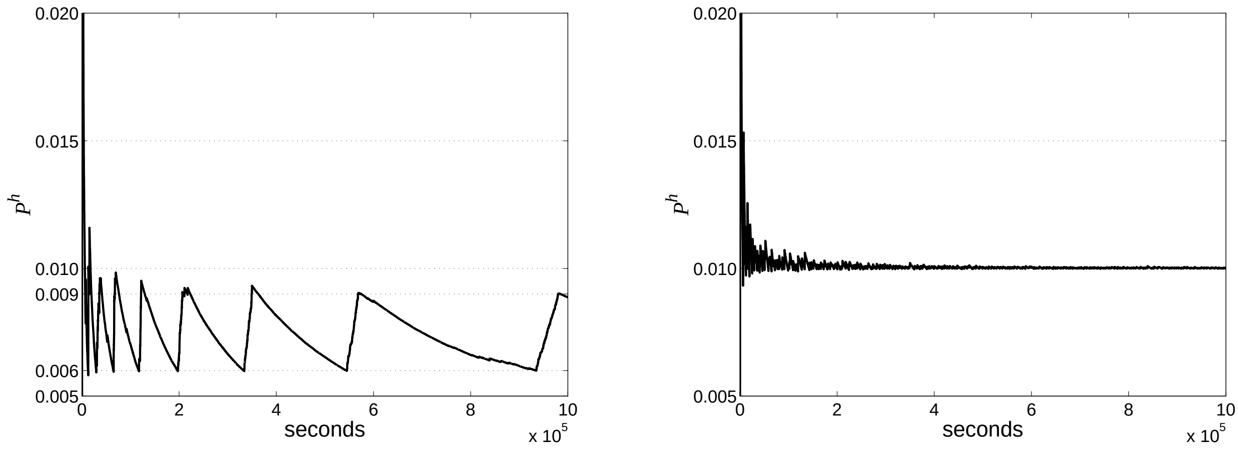
Additionally, developing our comparative evaluation it was also found that both α_u and α_d parameters are not needed by the ZL scheme in order to obtain the desired performance ($P^h \leq B^h$). The suggested values in [3] are $\alpha_u = 0.9$ and $\alpha_d = 0.6$. Although these parameters succeed in their task of maintaining $\alpha_d B^h \leq P^h \leq \alpha_u B^h$, they also prevent P^h from reaching a steady-state regime, and therefore P^h oscillates forever between the two boundary values, as shown in Fig. 5(a). It was found that making $\alpha_u = \alpha_d = 1.0$ allows the adaptive scheme to reach a steady-state regime in which $P^h = B^h$. This is illustrated in Fig. 5(b), which was obtained using the parameters of Table 1 and $\lambda^n = 0.333$. It also provides a more fair way to make a comparison with our scheme (see Section 6). Section 6 shows that N is also unneeded because waiting for N consecutive handover requests other than $N = 1$, makes adaptation speed slower without any clear compensation.

Finally, aothors of [4] comment that the ZL scheme does not work properly when some traffic profiles are offered, besides it is indicated that it takes a long time for the scheme to reach the steady-state regime ¿???????.

5.2 Adaptive scheme WZZZ

To minimize the number of parameters, improve system's adaptability to different traffic profile, and to improve system's response time, two new probability-based adaptive schemes based on the ZL scheme are proposed in [4]. We focus exclusively on the first one of them, given that the specification of the other one provided in [4] contains errors. The WZZZ scheme needs three parameters: α_u, α_d and P_{inc} (probability to decrease l^n). The WZZZ scheme is slightly more complicated that the ZL scheme, performing probabilistic adjustments only for each blocked handover request.

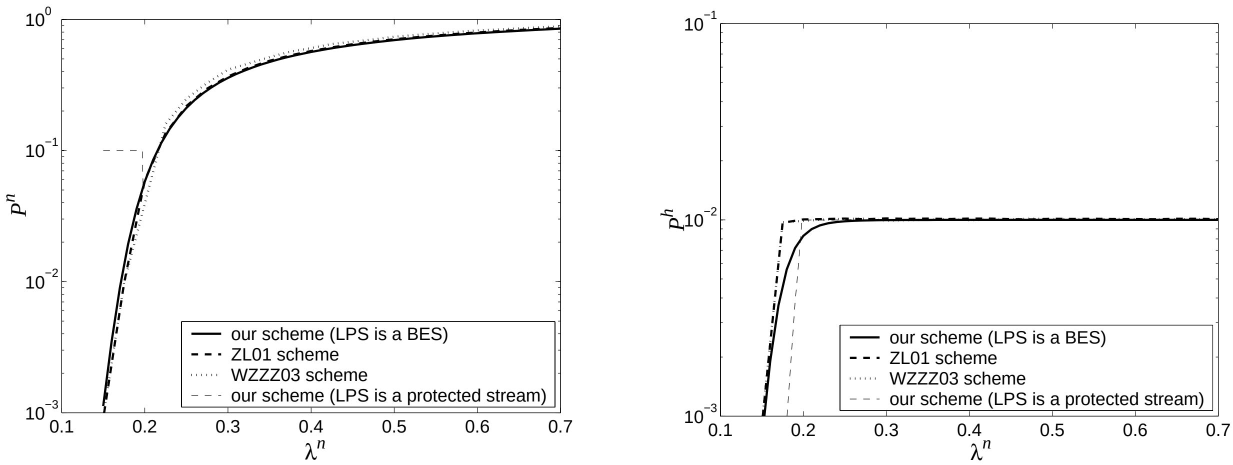
Our comparative work shows that as with the ZL scheme, both α_u and α_d are still unneeded. The suggested value $P_{inc} = 0.2$ also seems to be counter-productive resulting in extremely low P^h and very high P^n. This



(a) $\alpha_u = 0.9, \alpha_d = 0.6$

(b) $\alpha_u = \alpha_d = 1.0$

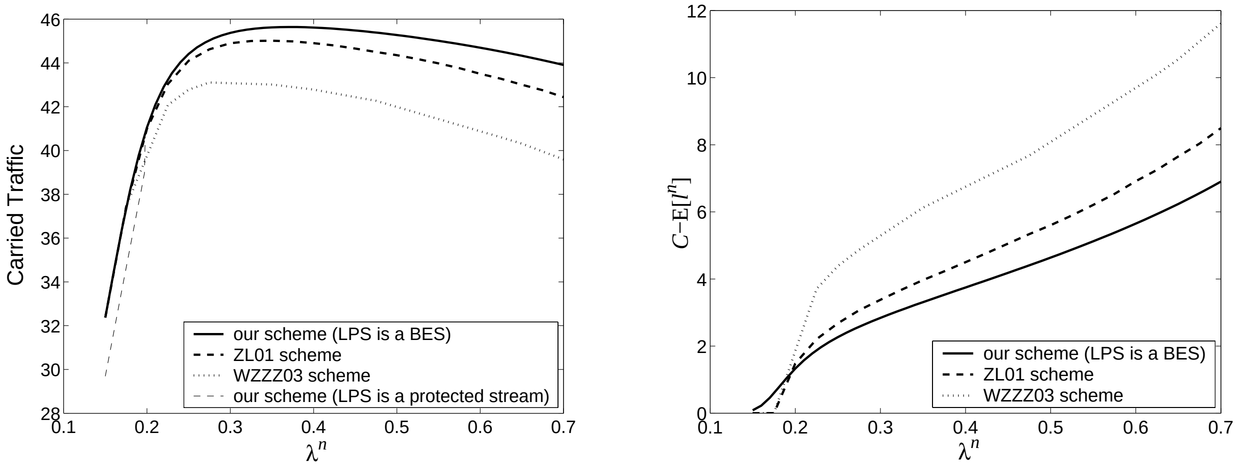
Figure 5: Example of the handover blocking probability for two different execution instances of the ZL scheme with stationary load.



(a) New blocking probability.

(b) Handover blocking probability.

Figure 6: Blocking probabilities with stationary load.



(a) Carried traffic.

(b) Mean quantity of guard channels needed.

Figure 7: Other parameters with respect to the stationary load.

is due to the fact that P_{inc} controls the speed at which the WZZZ scheme limits new requests the access to resources. Rather than the recommended $P_{inc} < 0.5$, a value of $P_{inc} = 1.0$ is best. Besides, the fact that it only performs probabilistic adjustments for each blocked handover request (as opposed to the ZL scheme that performs adjustments for each offered handover request) leads the WZZZ scheme to achieve an even slower adaptation speed.

6 Comparative Performance Evaluation

In this section we show the results of a comparative study of the three schemes for the scenario defined in Table 1. For our scheme we deploy the implementation in which the LPS (s^n) is the BES. Additionally, some exclusive results of our scheme when the LPS is considered a protected stream are provided, in which case a value of $B^n = 10\%$ is assumed.

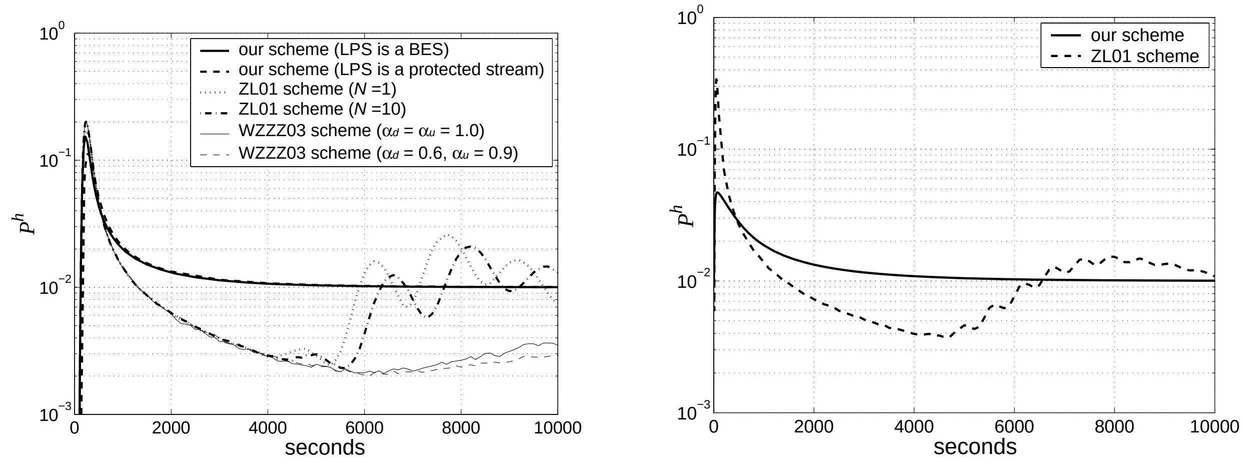
The comparative performance evaluation has been carried out using Möbius™ [8], which is a software tool that supports *Stochastic Activity Networks* (SANs). Möbius™ allows to simulate the SANs that model the type of systems of interest in our study, and under certain conditions, even to numerically solve the associated continuous-time Markov chains. In particular the ZL and WZZZ are simulated while our adaptive scheme meets the conditions to be numerically solved.

6.1 Performance under Stationary Traffic

Figures 6(a), 6(b), 7(a) and 7(b) show the variation of P^n, P^h, carried traffic and mean numer of guard channels needed (equivalent to $C - E[l^n]$) with the arrival rate of new sessions when assuming stationary traffic. As seen, while P^h are similar, P^n is slightly better for our scheme. Fig. 7(a) and 7(b) show that this minor improvement, due to a more precise management of the guard channels needed , allows our scheme to carry more traffic than the others. Fig. 6(a), 6(b) and 7(a) showthe performance of our scheme when the LPS is considered a protected stream. As seen in Fig. 6(a), during underload episodes the system tends to reject more requests from s^n than required in order to adjust $P^n = B^n$ i.e. s^n does not benefit from the capacity surplus. Therefore it is s^h which benefits from this extra capacity, experiencing an even lower P^h, as shown in Fig. 6(b). The drawback is that the carried traffic is lower than when the LSP is a BES. In summary, the capability of our scheme to operate in two different modes, provides the operator with additional flexibility to specify the QoS objective.

6.2 Performance under Nonstationary Traffic

In this section we study the transient regime. To provide an initial insight on the performance of each scheme we first show the transient behavior after an step-type traffic increase from $\lambda^n = 0$ to $\lambda^n = 0.333$. Before the step increase is applied the system is in the steady state regime, i.e. in this case, empty.



(a) Step-type traffic increase from $\lambda^n = 0$ to $\lambda^n = 0.333$.

(b) Step-type traffic increase from $\lambda^h/\lambda^n = 0.2$ to $\lambda^h/\lambda^n = 0.4$, with $\lambda^n = 0.416$

Figure 8: Transient behavior of the adaptive schemes in the presence of a step-type traffic increase.

Figure 8(a) shows the transient behavior of the handover blocking probabilities. As observed, our scheme (either considering the LPS as a protected or a BES) achieves the fastest convergence speed. On the contrary the ZL scheme (either with $N = 1$ or 10) shows a slower, oscillating behavior around B^h. So while our scheme needs only $t = 3400$s to reduce P^h to a $\pm 10\%$ interval around its objective ($B^h = 0.01$), the ZL scheme needs $t \approx 30000$s, about ten times higher, to achieve the same. Note that the ZL scheme with $N = 10$ behaves slower than $N = 1$. Finally the WZZZ scheme ($P_{inc} = 0.2$) oscillates exactly as ZL but with an even more unacceptably slowness.

As an initially empty system is improbable, a more realistic transient scenario is now discussed. It studies the transient behavior after an step-type increase in the λ^h/λ^n ratio from 0.2 to 0.4. A value of $\lambda^n = 0.416$ is assumed. Again, before the step increase is applied the system it is in the steady state regime. As the WZZZ scheme has not a very competitive speed it is discarded from this study. Figure 8(b) shows the transient behavior of P^h using our scheme (considering LPS as a BES), and the ZL scheme (with $N = 1$). Again our scheme outperforms the ZL scheme in terms of speed and stability. Note that the convergence period will be even shorter when the offered load is above the system capacity thanks to the increase in the probabilistic-adjustment actions rate, which is an additional advantage of the scheme. Despite the higher convergence speed of our scheme, sometimes it might be desirable a slower speed in exchange for more accuracy, therefore additional mechanisms have been developed that allow to trade-off convergence speed for the precision in the fulfillment of the QoS objective, but will not be discussed due to paper length limitations.

7 Conclusions

We developed a novel adaptive reservation scheme that operates in coordination with the Multiple Guard Channel policy but can be readily extended to operate with the Multiple Fractional Guard Channel policy. Three relevant features of our proposal are: its simplicity, its ability to continuously track and adjust the QoS perceived by users and its capability to handle multiple services. However in order to compare our scheme to previous proposals only a direct application of the scheme to a single service scenario is described. We provide two implementations of the scheme. First, when the LPS (new requests stream) has a QoS objective defined, which obviously must be met when possible. Second, when the LPS is treated as a best-effort stream and therefore obtains an unpredictable QoS, which tends to be "good" during underload episodes but is "quite bad" as soon as the system enters the overload region.

The comparative performance evaluation shows that our scheme meets the QoS objective with an excellent precision while achieving both a higher carried traffic and an oscillation-free convergence period of 10 to 100 times shorter than in previous proposals. This confirms that our scheme outperforms the other proposals in handling satisfactorily the nonstationarity of a real network.

Future work will include the evaluation of the scheme when operating with other SAC policies, for example those for which the stationary probability distribution has a product-form solution. Another interesting extension would be to base the adjustment of the configuration parameters not only on the decisions of the SAC subsystem but also on predictive information, like movement prediction.

References

[1] D. Garcia-Roger, M. J. Domenech-Benlloch, J. Martinez-Bauset, and V. Pla, "Adaptive admission control scheme for multiservice mobile cellular networks," in *Proceedings of the 1st EuroNGI Conference on Next Generation Internet Networks Traffic Engineering (NGI)*, Apr. 2005.

[2] D. García, J. Martínez, and V. Pla, "Admission control policies in multiservice cellular networks: Optimum configuration and sensitivity," *Lecture Note in Computer Science, Springer-Verlag Berlin Heidelberg*, vol. Mobile and Wireless Systems, LNCS 3427, pp. 121–135, Feb. 2005.

[3] Y. Zhang and D. Liu, "An adaptive algorithm for call admission control in wireless networks," in *Proceedings of the IEEE Global Communications Conference (GLOBECOM)*, Nov. 2001.

[4] X.-P. Wang, J.-L. Zheng, W. Zeng, and G.-D. Zhang, "A probability-based adaptive algorithm for call admission control in wireless network," in *Proceedings of the International Conference on Computer Networks and Mobile Computing (ICCNMC)*, Oct. 2003.

[5] O. T. W. Yu and V. C. M. Leung, "Adaptive resource allocation for prioritized call admission over an ATM-based wireless PCN," *IEEE Journal on Selected Areas in Communications*, vol. 15, no. 7, pp. 1208–1225, Sept. 1997.

[6] P. Ramanathan, K. M. Sivalingam, P. Agrawal, and S. Kishore, "Dynamic resource allocation schemes during handoff for mobile multimedia wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 7, pp. 1270–1283, July 1999.

[7] O. Yu and S. Khanvilkar, "Dynamic adaptive QoS provisioning over GPRS wireless mobile links," in *Proceedings of the IEEE International Conference on Communications (ICC)*, Apr. 2002.

[8] *Möbius^{TM}. Model-Based Environment for Validation of System Reliability, Availability, Security, and Performance. User Manual. Version 1.7.0*, Performability Engineering Research Group (PERFORM), 2005. [Online]. Available: http://www.perform.csl.uiuc.edu/mobius/manual/MobiusManual_160.pdf