

Optimality and Sensitivity Study of Admission Control Policies for Multimedia Wireless Networks

David García, Jorge Martínez and Vicent Pla

Grupo de Interconexión de Redes de Banda Ancha (GIRBA)

Universidad Politécnica de Valencia (UPV)

Valencia, Spain

dagarro@doctor.upv.es, (vpla,jmartinez)@dcom.upv.es

Abstract— We evaluate different admission control (AC) policies in various mobile cellular scenarios with multimedia support and QoS guarantees defined by the expected blocking probabilities for new call set up and handover requests. For each of the studied policies we determine the maximum calling rate that can be offered to the system while satisfying the QoS objective, using a hill-climbing algorithm. This approach drastically reduces the computational complexity of the optimization process. Additionally we study how sensitive these policies are to the tolerance of system parameters and to overloads. In regard to the system capacity, preliminary results show that policies of the trunk reservation class outperform policies that produce a product-form solution and the improvement ranges approximately between 5 and 15%.

Keywords— *cellular multimedia networks, admission control, QoS, hill-climbing optimization*

I. INTRODUCTION

Admission Control (AC) is a key aspect in the design and operation of mobile cellular communication networks with multimedia support and QoS guarantees. Different AC strategies have been proposed in the literature which differ on the amount of information that the decision process has available. We study a set of AC policies for which the decision to accept a new call, say for example of the multimedia service class r , depends only on either the number of resource units occupied by the calls in progress of that class r (which produce a product-form solution) or the number of free resource units in the system (trunk reservation). The physical meaning of a unit of resources will depend on the specific technological implementation of the radio interface.

One of the objectives of our study is the determination of the optimum configuration for each policy. The configuration of an AC policy specifies the action (accept/reject a new/handover request from each class) that must be taken in each system state in order to maximize the offered calling rate

while meeting the QoS objective. It should be noted that in order to bound the probability of calls being forced to terminate, the AC policy may reject new setup requests.

For a single service class scenario, it has been shown in [1] that two trunk reservations polices named the *Guard Channel* and the *Fractional Guard Channel*¹ are optimum for common QoS objective functions. More recently, the multimedia scenario has been studied in [2], where using an approximate fluid model the optimum admission policy is also found to be of the trunk reservation class.

We study two policies that can be considered representative of two broad families, *Integer Limit* (IL), (which belongs to the family for which the steady state distribution of the continuous-time Markov chain has a product-form solution) and *Multiple Guard Channel* (MGC), (a trunk reservation policy) [12]. A methodology to define product-form AC policies with integer and fractional thresholds per service is described in [4]. Details of them are given in the next section.

To gain an additional insight into the problem, the solution spaces (admissible combinations of policy configuration and offered traffic) for the two policies are studied in detail. For each policy we define the system capacity as the maximum value for the offered traffic within the solution space. The shape of the two solution spaces suggests an optimization methodology based on a *hill-climbing* algorithm to find the optimum configuration. This approach drastically reduces the computational complexity of the optimization process and compares quite favorably to the one proposed in [8] for the Fractional Multiple Guard Channel policy.

The main contributions of our work are: (1) the proposal of a hill-climbing algorithm as a suitable optimization method for the determination of the optimum configuration of the AC policies under study; (2) the study of the system capacity for each admission policy; and (3) the sensitivity analysis of the performance of the different policies to both the tolerance of the values of the configuration parameters and overloads.

This work has been supported by the Spanish *Ministerio de Ciencia y Tecnología* under projects TIC2003-08272 and TIC2001-0956-C04-04 and by the *Oficina de Ciencia y Tecnología* of the *Generalitat Valenciana* under grant CTB/PRB/2002/267.

¹ In [1] FGC is referred to as *Limited FGC*.

The remaining of the paper is structured as follows: in Section II we describe the model of the system as well as the AC policies under study. Section III justifies the interest of using a hill climbing algorithm. In Section IV we compute the system capacity for each of the AC policies under study. Section V discusses the sensitivity of the AC policies to both the tolerance of the values of the configuration parameters and overloads. Finally, Section VI concludes the paper.

II. SYSTEM MODEL AND ADMISSION CONTROL POLICIES

We consider a single cell, where a set of R multimedia service classes contend for C resource units. For any class r , ($1 \leq r \leq R$), new setup requests arrive according to a Poisson process with mean rate λ_r^n , request c_r resource units per call and the resource units holding time in the cell is exponentially distributed with parameter μ_r . We consider that handover requests arrive according to a Poisson process with mean rate λ_r^h . Although the value of λ_r^h can be determined by a fixed point iteration method that balances the incoming and outgoing handover flows of a cell as described [11], we will suppose it is a known fraction of the value of λ_r^n . The QoS objective is expressed as blocking probabilities for both new setup requests (B_r^n) and handover requests (B_r^h). Let the system state vector be $n = (n_1^n, n_1^h, \dots, n_R^n, n_R^h)$, where $n_r^{n,h}$ is the number of service class r calls in progress in the cell that where initiated as a successful setup request or a handover request respectively. We will denote by $c(n) = \sum_{r=1}^R (n_r^n + n_r^h) \cdot c_r$ the number of busy resource units in state n .

The stochastic process $n(t)$, which gives the system state at time t , is an irreducible finite-state continuous-time Markov chain with a unique steady-state probability vector π .

The detailed definition of the AC policies of interest thorough this document are as follows: (1) *Complete-Sharing* (CS): A request is admitted provided there are enough free resource units available in the system; (2) IL: Two parameters are associated with service class r : l_r^n for new setup requests and l_r^h for handover requests, $l_r^n, l_r^h \in \mathbb{N}$. A service class r request that arrives in state n is accepted if $(n_r^{n,h} + 1) \leq l_r^{n,h}$ and blocked otherwise; (3) MGC: Two parameters are associated with service class r : $l_r^n, l_r^h \in \mathbb{N}$. A service class r request that arrives in state n is accepted if $c(n) + c_r \leq l_r^{n,h}$ and blocked otherwise.

III. DETERMINATION OF THE OPTIMUM POLICY CONFIGURATION

The study of the optimum configuration for each policy is carried out for five different scenarios (A, B, C, D and E) that are defined in Table I, where the $B_r^{n,h}$ are specified as percentages.

Fig. 1 and Fig. 2 show the values of the solution spaces for the two policies in the scenario A with $C = 10$. These policies have been selected because they have solution spaces with shapes that can be considered as representing two different families (with and without product form solution respectively). We have chosen a simple example with two service classes without their associated handover streams to represent the solution space in only three dimensions.

TABLE I. DEFINITION OF THE SCENARIOS UNDER STUDY

	A	B	C	D	E
c_1	1	1	1	1	1
c_2	2	4	2	2	2
f_1	0.8	0.8	0.2	0.8	0.8
f_2	0.2	0.2	0.8	0.2	0.2
$B_r^n \%$	5	5	5	1	1
$B_r^h \%$	1	1	1	2	1
	A, B, C, D, E				
$B_r^h \%$	$0.1B_r^n$				
λ_r^n	$f\lambda$				
λ_r^h	$0.5\lambda_r^n$				
μ_1	1				
μ_2	3				

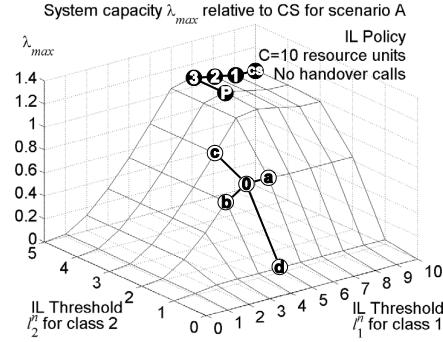


Figure 1. An example of solution space using IL policy.

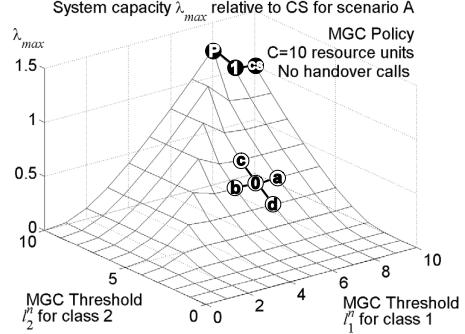


Figure 2. An example of solution space using MGC policy.

The hill-climbing algorithm works as follows. Given an starting point in a k -dimensional discrete search space (for example, point **0** in both figures), the hill-climbing algorithm begins by computing the value of the function (the system capacity λ_{max}) for the two adjacent neighbors in each of the k dimensions (points **a**, **b**, **c** and **d** in both figures). Then the algorithm selects as the new starting point the adjacent point with the largest function value (point **c** in both figures) and the process repeats iteratively until a local maximum is found. In this way the algorithm makes a number of successive unitary steps along each dimension of the search space and stops when it reaches the peak.

The plotted surfaces are obtained as follows. At each point, the system capacity λ_{max} is computed by a binary search process which has as inputs the value of the system parameters μ_r, c_r, C and the thresholds $l_r^{n,h}$, and produces as outputs the blocking probabilities $p_r^{n,h}$. The binary search process stops when it finds the λ_{max} that meets the QoS objective ($B_r^{n,h}$).

It should be noted that the system capacity is expressed as a relative value to the capacity obtained for the CS policy. When the solution space is continuous [8], a gradual refinement process is used to reduce the size of the step once a promising region has been found, which is possibly close to the optimum.

A further improvement can be obtained by observing that the optimum configuration (point P) for any policy is near the CS configuration (point CS), and therefore it is a good idea to select it as the starting point. In Fig. 1 points 1 to 3 and in Fig.2 points 1 and 2 illustrate a typical progression of the algorithm starting from the CS configuration and ending at the peak.

IV. SYSTEM CAPACITY

In this section we obtain the system capacity that an operator can expect when deploying one of the AC policies under study. As defined before, the system capacity is defined as the maximum arrival rate of new calls ($\lambda = \sum_{r=1}^R \lambda_r^n$) that allows the system to meet the QoS requirements, i.e. that produces blocking probabilities lower or equal than the $B_r^{n,h}$. The study is done for the five scenarios described in Table I. Selected results for the capacity are displayed in Table II. The results are expressed as relative values referred to the capacity obtained for the CS policy, while for this policy we display absolute values.

TABLE II. SYSTEM CAPACITY FOR SOME OF THE AC POLICIES STUDIED

	A			B			C			D			E		
C	10	20	40	10	20	40	10	20	40	10	20	40	10	20	40
CS	1.54	5.61	15.76	0.36	2.77	10.38	1.36	5.77	17.61	1.74	6.04	16.54	1.54	5.61	15.76
IL	1.13	1.11	1.09	1.05	1.03	1.06	1.07	1.05	1.05	1.03	1.04	1.03	1.05	1.04	1.03
MGC	1.23	1.26	1.24	1.10	1.21	1.21	1.11	1.20	1.15	1.13	1.13	1.10	1.13	1.13	1.10

As observed, the trunk reservation policies (MGC) perform better than those that produce a product-form solution (like IL and ULGM) and the improvement ranges between 5 and 15% approximately, although in some configurations can be lower and in other a bit higher. However, the relative gain diminishes when the number of resource units C increases.

V. SENSITIVITY TO TOLERANCES AND OVERLOADS

For the IL policy, Fig. 3 plots the variation of system capacity λ_{max} (expressed as a relative value to the capacity obtained for the CS policy) as a function of each configuration parameter (l_1^n, l_1^h, l_2^n and l_2^h) while keeping the others constant at their optimum values in scenario A with $C=40$. An interesting observation is that the peak value seems insensible to the values of some configuration parameters in a quite large region. Unfortunately, the peak value seems quite sensible to

the value of l_1^n , that is to the threshold defined for new calls of service class 1.

For the MGC policy, Fig. 4 plots the variation of system capacity λ_{max} (expressed again as a relative value to the capacity obtained for the CS policy) as a function of each configuration parameter (l_1^n, l_1^h, l_2^n and l_2^h) while keeping the others constant at their optimum values. For this policy, there is no plateau but a clear half-pyramidal or near-half-pyramidal shape with the maximum located at the apex. In this case, the position of the apex is of capital significance since no far away from this point the system capacity is poor compared to the one obtained for the CS policy. This solution space suggests that the definition of the configuration parameters requires more precision, unless we are willing to accept a degradation of the system capacity. Nevertheless, the slope of the curves are now less steep. It should also be noted that, as mentioned before, the optimum configuration is close to the CS configuration (all thresholds set to C).

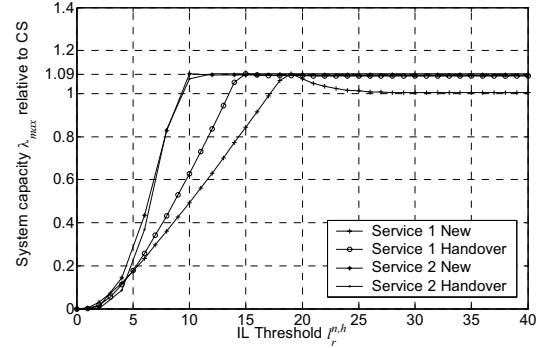


Figure 3. Sensitivity to tolerances of the IL policy in the scenario A with $C=40$.

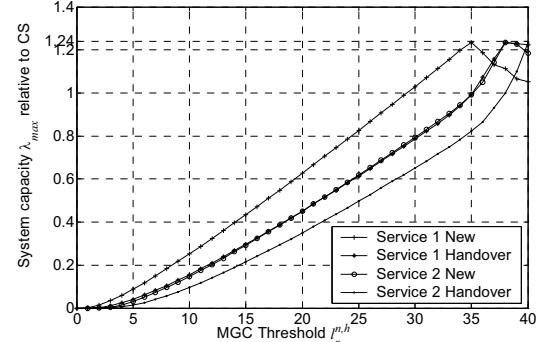


Figure 4. Sensitivity to tolerances of the MGC policy in the scenario A with $C=40$.

With respect to the sensitivity to overloads, IL and MGC policies are also compared. in scenario B with $C=20$ bandwidth units. Clearly, for IL policy it is the handover blocking probability of service class 2 the one which prohibits to increase λ_{max} , and when overload occurs is p_2^h the one which goes beyond its objective first.

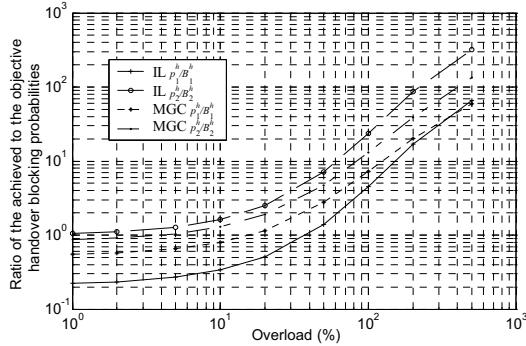


Figure 5. Ratio of the achieved to the objective handover blocking probabilities in the scenario B with $C=20$

Fig. 5 shows the ratio of the achieved to the objective handover blocking probabilities for each service class and degree of overload. For example, for the IL policy and a 10% of overload the achieved handover blocking probability of service class 1, p_1^h , is a 33.75% of its objective ($B_1^h = 5\%$).

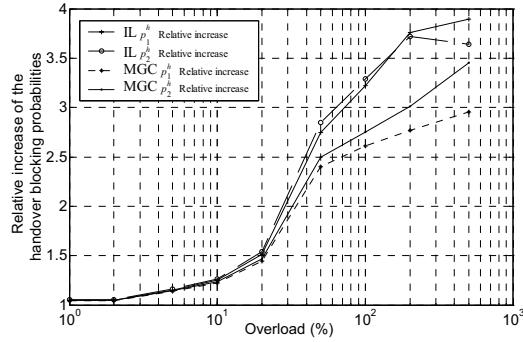


Figure 6. Relative increase of the handover blocking probabilities in the scenario B with $C=20$

Fig. 6 shows the relative increase of the p_r^h in relation to the previous degree of overload. For example, for the IL policy the achieved handover blocking probability of service class 1 for an overload of 10% is 25.23% higher (1.2523) than the achieved handover blocking probability of service class 1 for an overload of 5%.

VI. CONCLUSIONS

The form of the solution spaces suggested a hill-climbing algorithm as a promising optimization approach to reduce the computational complexity of the determination of the optimum configuration for each admission policy.

For the system capacity, preliminary results show that policies of the trunk reservation class outperform policies that produce a product-form solution and the improvement ranges approximately between 5 and 15%. However, the relative gain diminishes when the number of resource units C increases.

The sensitivity analysis of the performance of IL and MGC policies to the tolerance of the values of the

configuration parameters shows that the peak capacity value of the IL policy seems insensible to the values of some configuration parameters in a quite large region while the solution space of the MGC suggests that the definition of the configuration parameters requires more precision, unless we are willing to accept a degradation of the system capacity. Given that in practice the system parameters must be estimated and are non stationary, trunk reservation policies could become less attractive.

Finally, two are the main conclusions that can be drawn from the sensitivity analysis to overloads. First, in general, deploying an admission control policy is convenient because it introduces a certain degree of fairness in sharing the penalty that supposes the increase of the blocking probabilities among the different service classes. Second, in general, the MGC policy tend to handle similarly (in the low to medium overload region) or better (in the high overload region) the overload, than the IL policy in the sense that the increase of the achieved handover blocking probabilities are lower.

REFERENCES

- [1] R. Ramjee, R. Nagarajan, D. Towsley, "On Optimal Call Admission Control in Cellular Networks," *ACM/Baltzer Wireless Networks Journal*, vol. 3, no. 1, pp. 29-41, 1997.
- [2] E. Altman, T. Jimenez, G. Koole, "On optimal call admission control in resource-sharing system," *IEEE Transactions on Communications*, vol. 49, no. 9, pp.1659-1668, Sep. 2001.
- [3] V.B. Iversen, "The Exact Evaluation of Multi-Service Loss Systems with Access Control", in *Proceedings of the Seventh Nordic Teletraffic Seminar (NTS-7)*, Aug. 1987, Lund, Sweden.
- [4] Chin-Tau Lea and A. Alyatama, "Bandwidth Quantization and States Reduction in the Broadband ISDN," *IEEE/ACM Trans. on Networking*, vol.3, no.3, pp.352-360, Jun. 1995.
- [5] G.L. Choudhury, K.K. Leung, and W. Whitt, "Efficiently Providing Multiple Grades of Service with Protection Against Overloads in Shared Resources", *AT&T Technical Journal*, vol. 74, no. 4, pp. 50-63, 1995.
- [6] B. Li, C. Lin, and S. T. Chanson, "Analysis of a hybrid cutoff priority scheme for multiple classes of traffic in multimedia wireless networks," *ACM/Baltzer Wireless Networks Journal*, vol. 4, no. 4, pp. 279-290, 1998.
- [7] H. Heredia-Ureta, F. A. Cruz-Pérez, and L. Ortigoza-Guerrero, "Multiple fractional channel reservation for optimum system capacity in multi-service cellular networks," *Electronic Letters*, vol. 39, pp. 133-134, Jan. 2003.
- [8] ———, "Capacity optimization in multiservice mobile wireless networks with multiple fractional channel reservation," *IEEE Transactions on Vehicular Technology*, vol. 52, no. 6, pp. 1519 – 1539, Nov. 2003.
- [9] V. Pla and V. Casares-Giner, "Optimal Admission Control Policies in Multiservice Cellular Networks," in *Proceedings of the International Network Optimization Conference (INOC2003)*, Paris, France, Oct. 2003.
- [10] S. M. Ross, *Applied Probability Models with Optimization Applications*. Holden-Day, 1970.
- [11] Y.-B. Lin, S. Mohan, and A. Noerpel, "Queueing priority channel assignment strategies for PCS hand-off and initial access," *IEEE Transactions on Vehicular Technology*, vol. 43, no. 3, pp. 704–712, Aug. 1994.
- [12] D. García, J. Martínez, V. Pla, "Comparative Evaluation of Admission Control Policies in Cellular Multiservice Networks", in *Proceedings of the 16th International Conference on Wireless Communications (Wireless2004)*, Calgary, Canada, Jul. 2004, in press.