Complete Partitioning Schemes for Call Access Control in ATM Networks

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ABSTRACT: In this paper a CAC scheme is considered and different alternatives to compute the maximum number of acceptable calls for each traffic class involved are evaluated. The traffic is considered divided in traffic classes, characterised by statistical parameters like peak and average bandwidth and burstiness, and by specific performance requirements. A 'feasibility region' where performance requirements are surely satisfied is defined and a model to describe the call acceptance method is presented. Then, three alternative strategies to get the maximum number of acceptable connections, by taking into account the probability of blocking a call at the call set-up, are described. The first one is intended to minimise an overall measure of the call blocking probability, the second is aimed to balance the probability between the different traffic classes while the last one allows to have a constraint on the call blocking probability. All the strategies are tested by simulation and compared with other mechanisms already in the literature.

1. Introduction

Since the introduction of the ATM technique, in 1987, many topics, both practical and theoretical, have been analysed and developed. From the theoretical point of view, many studies have been performed to get suitable models for bursty traffic sources as in [1, 2, 3], and [4], for a complete survey, or to provide a good estimation of the cell loss probability [5, 6, 7]. Produced results have been utilised to design efficient CAC schemes [8, 9, among others], or routing algorithms [10, 11, 12] in order to guarantee performance requirements for each traffic class in the network. Also the definition of a cell-space area ('feasibility region') has been an object of research, in order to find out the optimal feasible space [13, 14], or to have a complete separation between the problem of guaranteeing performance quality and the problem of accepting a new call in the network [15]. Other works were dedicated to obtain a fair resource allocation in the network [16, 17, 18, 19, among others]

In previous works (e.g., [20]), the authors proposed a hierarchical two-level control to manage the topics mentioned above, even though not obtaining a complete division between them. In this paper performance requirements for each traffic class are considered satisfied due to the definition of a 'feasibility region'. The region is computed by using a model already in the literature, but the computation mechanism is not a restriction for the strategies introduced in the paper; other computation methods could be used.Then a simple CAC scheme is structured by defining a maximum number of acceptable connections for each class that allow to guarantee the required performance quality. The choice of the maximum number of calls is performed by using three strategies based on the proposed model of the CAC scheme.

The paper is structured as follows: the next Section is dedicated to the definition of the 'feasibility region' and to the presentation of the CAC scheme and associated model. Section 3 contains the strategies to compute the maximum number of acceptable calls. The results are presented in Section 4, while Section 5 contains the conclusions.

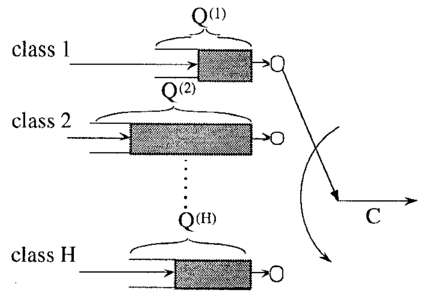

Fig.1. System model.

2. System model and CAC scheme

The system model is depicted in Fig. 1. It is an output queueing model with possibly several output links (a single link of capacity C is considered here for the sake of simplicity). The traffic entering the node is segregated into traffic classes (h=1,...,H) characterised by statistical parameters (peak bandwidth $B_p^{(h)}$ and burstiness $b^{(h)}$) and by performance requirements, whose definition will be clarified in the following. Each buffer is dedicated to the traffic of a specific class and has a length $Q^{(h)}$, h=1,...,H, considered fixed in this approach. In correspondence of the output link, a Call Admission Controller decides if a new call has to be accepted or rejected, while a Scheduler picks up the cells of the output buffers following a strategy defined in [20].

Performance requirements allow to define a feasibility region, i.e., a region in call-space where they are surely satisfied. The computation of this area has been the object of many studies, as mentioned in the previous Section. In this paper, we refer to a strategy introduced in [20] where a maximum threshold value is set for the average cell loss rate ($P_{loss}^{(h)}(n^{(h)})$) and for the average delayed cell rate ($P_{delay}^{(h)}(n^{(h)})$), with $n^{(h)}$ calls in the active state out of $N^{(h)}$ accepted calls. In formula:

$$\sum_{n^{(h)}=1}^{N^{(h)}} P_{loss}^{(h)}(n^{(h)})\, v_{n^{(h)},N^{(h)}} \le \varepsilon^{(h)} \qquad (1)$$

$$\sum_{n^{(h)}=1}^{N^{(h)}} P_{delay}^{(h)}(n^{(h)})\, v_{n^{(h)},N^{(h)}} \le \delta^{(h)} \qquad (2)$$

where $\varepsilon^{(h)}$ is an upper limit on the time-averaged value of the cell loss rate and $\delta^{(h)}$ has the same meaning for the time-averaged value of cells that suffer a delay longer than a fixed value ($D^{(h)}$ in Section 4). The quantity $v_{n^{(h)},N^{(h)}}$ is the probability of having $n^{(h)}$ active connections if $N^{(h)}$ have been accepted. To perform this computation an Interrupted Bernoulli Process (IBP) has been used to model the state of a call.

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In this context, the computation of the 'feasibility region' should be just a tool to describe the CAC schemes. The used technique could be changed without affecting the access control as should be clear in the next Section.

The goal of this paper is the definition of an acceptance control rule following a fixed cost function. In [14], different classes of control policies have been defined and some possible algorithms are proposed to get a sub-region which allows to obtain a lower average call blocking probability. In that context, a general multiple service, multiple resource (MSMR) problem is solved, and a linear model for the definition of the state space is assumed. In our case, a complete modelling and characterisation of the call space is quite complex and will be object of future work. So, here, we do not consider the more general class of control policies (named 'Dynamic Programming',), where decisions are taken '*not only upon what state admission would place the system in, but also what type of service is requested*', [14]. Only 'Coordinate Convex' policies (where admission decisions depend only on the state the system would enter if the new requested admission was accepted) are treated and, in particular, the case of 'Complete partitioning' policies is investigated.

This class of policies allows to define a rectangular sub-region (if the two-classes case is approached; more generally, a N-cube sub-region if the general N-classes case is considered) inside the 'feasibility region'. So, the acceptance rule can be simply described as follows. A maximum number of acceptable connections $N_{max}^{(h)}$, whose computation is presented in the next Section, shall be defined for each class. $N_c^{(h)}$ being the number of accepted connections, a new call is accepted if the number of calls in progress in the node and the new one does not exceed the maximum number of acceptable calls for that traffic class. It can be said that:

$$\begin{aligned} N_c^{(h)} + 1 \leq N_{max}^{(h)} \quad & \text{new call accepted} \\ N_c^{(h)} + 1 > N_{max}^{(h)} \quad & \text{new call rejected} \end{aligned} \tag{3}$$

So, the CAC blocking can be modelled, for the generic class (h), as in Fig. 2

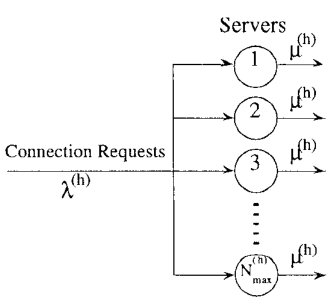

Fig. 2. The CAC blocking model.

where the number of servers is equal to the maximum number of acceptable calls of that class. The quantity $\lambda^{(h)}$ represents the average call arrival rate, according to a Poisson process, while $1/\mu^{(h)}$ is the average duration of a call, which is supposed to be exponentially distributed. The quantity $N_a^{(h)} = \rho^{(h)} = \frac{\lambda^{(h)}}{\mu^{(h)}}$ (in Erlangs) is the average traffic intensity for traffic class (h).

Considering the number $N_{max}^{(h)}$ fixed, the probability of blocking a call is given by the well known Erlang-B distribution:

$$P_B^{(h)}\left(N_{max}^{(h)}\right) = \frac{\left(N_a^{(h)}\right)^{N_{max}^{(h)}} / N_{max}^{(h)}!}{\sum_{l=0}^{N_{max}^{(h)}} \frac{\left(N_a^{(h)}\right)^l}{l!}} \tag{4}$$

This probability is used in the next Section, where cost functions are defined and the strategy to find the maximum number of acceptable connections is presented.

3. Definitions of cost functions

The aim of this Section is to present some different cost functions, each generating a different admission scheme. All the cost functions are based on the computation of the call blocking probability, which has been shown in the previous Section. It should be remembered that the problem is considered in the stationary case; in fact, we suppose $\lambda^{(h)}$and $\mu^{(h)}$ constant for a long period with respect to the call dynamics. If these values are slowly variable, the minimisation procedure has to be applied again after a certain period.

The first function considered is simply intended to minimise an overall measure of the call blocking rate, and it is defined as

$$P_B(\mathbf{N}_{max}) = \sum_{h=1}^{H} \alpha^{(h)} P_B^{(h)}\left(N_{max}^{(h)}\right) \tag{5}$$

where $\mathbf{N}_{max} \equiv \left[N_{max}^{(h)}, h = 1, \ldots, H\right]$, $P_B^{(h)}\left(N_{max}^{(h)}\right)$ is the call blocking probability of class h, as defined in the previous Section, and $\alpha^{(h)}$ is a weighting coefficient, to allow a distinct priority level for each traffic class. It has to be noted that, if $\alpha^{(h)}$ is assumed equal to the ratio $\lambda^{(h)} / \sum_{h=1}^{H} \lambda^{(h)}$, the quantity (5) represents the average call blocking probability of the whole system.

The maximum number of acceptable connections for each traffic class is obtained by the minimisation of $P_B(\mathbf{N}_{max})$ over the 'feasibility region'. So, defining the "feasibility region", as the set F_R of H-tuples $\mathbf{N} \equiv [N^{(h)}, h=1,\ldots,H]$ that satisfy performance requirements ((1) and (2), in this context), it can be said that:

$$\mathbf{N}_{max}^{opt} = \arg\left\{ \min_{\mathbf{N}_{max} \subset F_R} P_B(\mathbf{N}_{max}) \right\} \tag{6}$$

The associated CAC scheme is named Erlang Scheme (ES). The minimisation of the function (5) allows to find the minimum overall call blocking probability, without taking into account possible requirements for each single class (in terms of blocking probability) or some balancing criterion among the classes. In this case, the solution obtained might strongly favour a class with respect to the others, as shown in an example in the next Section. To avoid this problem, we have considered two other different cost formulations, which might be better suited for a real application.

Concerning the first one of them, whose corresponding scheme has been called Balanced Erlang Scheme (BES), the balancing among classes is the main goal, so that the cost function is defined as

$$P'_B(\mathbf{N}_{max}) = \max_h \left\{ \alpha^{(h)} P_B^{(h)}\left(N_{max}^{(h)}\right) \right\} \tag{7}$$

$\mathbf{N}_{max}^{opt}$ can be obtained in the same way as in (6), by substituting the quantity $P_B(\mathbf{N}_{max})$ with the quantity $P'_B(\mathbf{N}_{max})$. In formula:

$$\mathbf{N}_{max}^{opt} = \arg \min_{N_{max} \subset F_R} P'_B(N_{max}) \tag{8}$$

The overall call blocking performance given by (8) is worse than that of (6), but all the classes are managed in a fair way (with $\alpha^{(h)}=1$, $\forall$ h). The type of balancing can be simply controlled by changing the weights $\alpha^{(h)}$.

The last function we present is defined by fixing a constraint on the maximum call blocking probability for every class, that is:

$$P_B^{(h)}\left(N_{max}^{(h)}\right) \le \gamma^{(h)} \qquad h = 1,\ldots,H \tag{9}$$

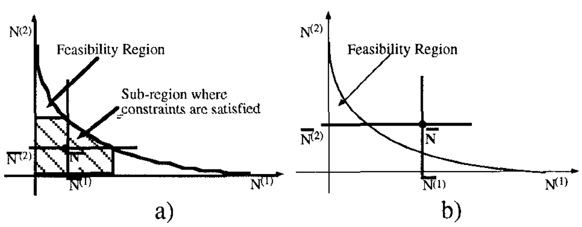

Fig. 3. The effect of constraints (10) on the feasibility region in the case of $\overline{\mathbf{N}} \in F_R$ (a) and in the case of $\overline{\mathbf{N}} \notin F_R$ (b).

Let $\overline{\mathbf{N}} = \mathrm{col}\left[\overline{N}^{(h)}, h = 1,\ldots,H\right]$ be the solution of (9) with equality, with respect to $\mathbf{N}_{max}$.To satisfy the constraints in (9) we must have

$$N_{max}^{(h)} \ge \overline{N}^{(h)} \ , h = 1,\ldots,H \tag{10}$$

We can distinguish two cases: $\overline{\mathbf{N}} \in F_R$ and $\overline{\mathbf{N}} \notin F_R$. In the first case, a sub-region S_R which satisfies the constraints (9) (shaped as shown in Fig. 3a for a system supporting two classes) can be found. Otherwise, the sub-region does not exist (Fig. 3b) and we can only try to approximate the constraint by minimizing some "distance" measure. On the basis of these considerations, we compute $\mathbf{N}_{max}^{opt}$ as

$$\mathbf{N}_{max}^{opt} = \begin{cases} \arg\left[\min\limits_{\substack{N_{max} \subset F_R \\ N_{max} \ge \overline{N}}} P_B(\mathbf{N}_{max}),\right] & \overline{\mathbf{N}} \in F_R \\ \arg\left[\min\limits_{N_{max} \subset F_R} D_{P_B}(\mathbf{N}_{max})\right] & \overline{\mathbf{N}} \notin F_R \end{cases} \tag{11}$$

where

$$D_{P_B}(\mathbf{N}_{max}) = \sum_{h=1}^{H} \left[P_B^{(h)}\left(N_{max}^{(h)}\right) - \gamma^{(h)}\right]^2 \tag{12}$$

It should be clear from (11) that, if $\overline{\mathbf{N}} \in F_R$ we apply the same cost function (6) of the ES method inside the sub-region identified by the constraints (10); otherwise, when (10) cannot be satisfied, the cost function (12) is minimized; that is, the configuration at 'minimum distance' is taken as the optimum one. We call this scheme Rectangular Sub-Region scheme (RSR).

4. Results

The purpose of this Section is to investigate the behaviour of the three schemes proposed in the previous Section and to test and verify the efficiency of the overall strategy by showing some simulation results. Four traffic classes with very different characteristics have been chosen to obtain the results in the following. The first traffic class represents medium quality video, the second one bulk data transfer, while the third and the fourth class denote, voice and image retrieval respectively, as in [29]. For the sake of simplicity each test has been carried out with a couple of traffic classes and only the most meaningful results have been depicted. The following parameters classes have been used:

$B_P^{(1)}=1$; $B_P^{(2)}=10$ [Mbit/s]; $B_P^{(3)}=64$ [Kbit/s]; $B_P^{(4)}$ =[2 Mbit/s]; (peak bandwidth)

$b^{(1)}=2$; $b^{(2)}=10$; $b^{(3)}=2$; $b^{(4)}=23$ (burstiness)

$B^{(1)}=100$; $B^{(2)}=1000$; $B^{(3)}=58$; $B^{(4)}=2604$ [cells] (average burst length)

$1/\mu^{(1)}=20$; $1/\mu^{(2)}=25$; $1/\mu^{(3)}=30$; $1/\mu^{(4)}= 60$ [s] (average connection duration)

$\varepsilon^{(1)}=\varepsilon^{(2)} = 1\cdot 10^{-4}$; $\varepsilon^{(3)} = \varepsilon^{(4)} = 1\cdot 10^{-6}$ (upper limit orfthe average cell loss rate)

$\delta^{(1)} = \delta^{(2)}=1\cdot 10^{-3}$; $\delta^{(3)}=\delta^{(4)}=1\cdot 10^{-5}$ (upper limit of the average delayed loss rate)

$D^{(1)}=400$; $D^{(2)}=100$; $D^{(3)}=200$; $D^{(4)}=1000$ [slots] (delay threshold)

$N_a^{(1)}=80$; $N_a^{(2)}=40$; $N_a^{(3)}=250$; $N_a^{(4)}=92$ [Erlangs] (global average traffic intensities offered to the network; call arrival processes follow independent Poisson distributions)

$Q^{(1)}=20$; $Q^{(2)}=10$; $Q^{(3)}=15$; $Q^{(4)}=15$ [cells] (buffer length)

Figs. 4, 7, 8, 13 and 14 are referred to the couple class 1 - class 2 (called couple A in the following) and a channel capacity C = 150 Mbits/s (T_S = slot duration = $2.83\cdot 10^{-6}$ s (53 bytes/cell)); Figs. 5, 9, and 10 are obtained by using the couple class 3 - class 4 (called couple B in the following), and a channel capacity C=30 Mbits/s (T_S = slot duration = $14.1\cdot 10^{-6}$ s (53 bytes/cell)); Figs. 6, 11 and 12 are obtained by using the couple class 2 - class 4 (called couple C in the following), again with a channel capacity C = 150 Mbits/s. The duration of the simulations performed, which have been carried out on a Sun Sparc 10 workstation, corresponds to 1 hour and 30 minutes of real network time.

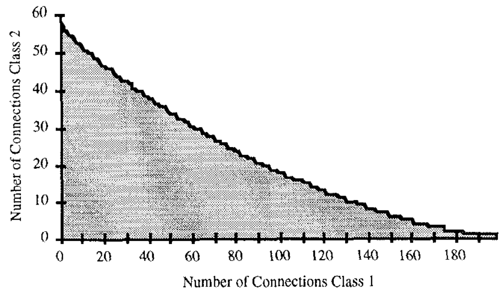

Fig. 4. Feasibility region F_R for class 1 and 2.

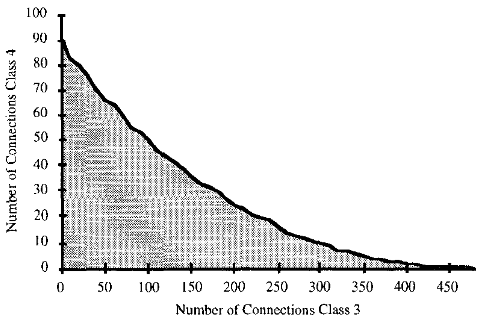

Fig. 5. Feasibility region F_R for class 3 and 4

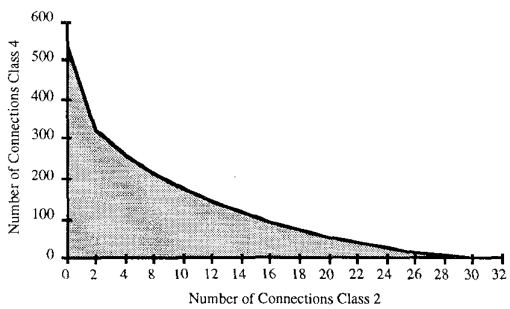

Fig. 6. Feasibility region F_R for class 2 and 4

Figs. 4, 5 and 6 depict the 'feasibility region' for the couples A, B and C, respectively. The regions have been obtained by using the inequalities (1) and (2) and the data reported above; however, any other 'feasibility region', obtained by using different techniques, could be utilised without affecting the global strategy.

The traffic flow generated by the above data is considered to be a 'normalised offered load' of value 1; an offered load 'x' corresponds to the same data, except for the traffic intensities (defined in Section 2) $N_a^{(h)}$, h=1, 2, 3, 4 ,which are multiplied by x.

The overall percentage of blocked calls versus the offered load is depicted in Figs. 6 - 12. Moreover, Figs. 7 (couple A), 9 (couple B) and 11 (couple C) compare the results obtained by using ES and BES with the results obtained by using a strategy, called Feasibility Region Scheme (FRS) here, that does not compute a maximum number of acceptable connections, but always accepts a call with the only constraint of the "feasibility region"; in other words, if a new call in the system keeps the total number of connections within F_R, the call is accepted. The same figures also report a comparison with the strategy considered in [20], called Reallocation Scheme (RS) here. The improvement in the percentage of blocked calls by using ES is noticeable; in fact, the cost function (5) has the only purpose of minimising the overall call blocking probability without consideration of balancing among classes. In Figs. 8 (couple A), 10 (couple B) and 12 (couple C) the same results of the figures described above are reported, but concerning the schemes ES, BES, RSR and CSR (Complete Sub-Region). The CSR scheme is the same as the RSR, except when the sub-region S_R (defined in Section 3) exists; in this case, it does not find the optimum rectangle inside it, but it accepts a call if the total number of calls in progress remains inside S_R. The simulations have been performed by fixing $\alpha^{(h)}$=a, $\forall$ h=1,2,3,4, and for two values of a (a=0.2 and a=0.4). The performance of RSR appears to be similar to the performance of CSR (the schemes are the same over a certain load threshold). Of course, a larger value of a gives better results for both RSR and CSR because there is more freedom in the search of the minimum by increasing the value of a. Moreover, for lower offered loads, the behaviour of RSR (and CSR) is more satisfying than that of BES, while it becomes comparable for the higher loads.

This behaviour can be better explained by observing Figs. 13 and 14 (couple A), where the percentage of blocked calls for each traffic class is shown versus the offered load, by using the ES, BES and FRS (Fig. 13), and by using BES and RSR with a=0.2 and a=0.4 (Fig. 14). It can be seen that the blocking percentages of the two classes are completely unbalanced for the FRS scheme and ES case, so that the lower overall call blocking percentage of ES is 'paid' with a conspicuous unbalancing effect.

On the contrary, the utilisation of BES does not guarantee the lowest overall percentage of blocked calls, but it assures a fair division among the classes. Concerning lower loads, where the sub-region S_R exist, the RSR scheme shows a certain unfairness which is due to the use of a cost like that of the ES scheme, even if in a smaller area. For higher loads, where S_R does not exist, the minimization of (12) gives results similar to those obtained with the BES scheme (this, clearly, happens only when the coefficients $\alpha^{(h)}$ are all equal).

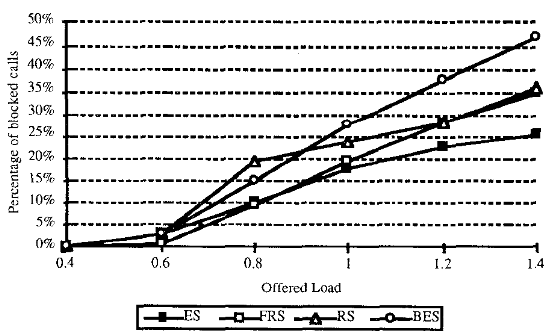

Fig. 7. Overall percentage of blocked calls versus offered load, class 1 and 2.

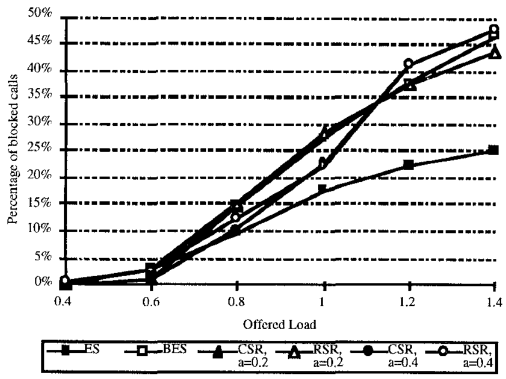

Fig. 8. Overall percentage of blocked calls versus offered load, class 1 and 2

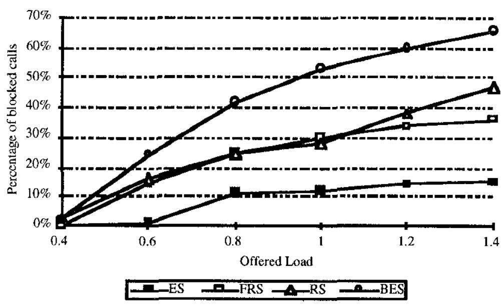

Fig. 9. Overall percentage of blocked calls versus offered load, class 3 and 4.

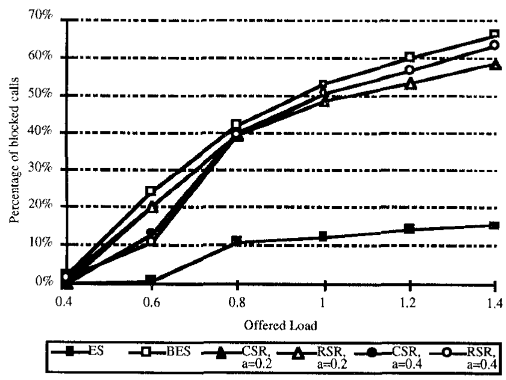

Fig. 10. Overall percentage of blocked calls versus offered load, class 3 and 4.

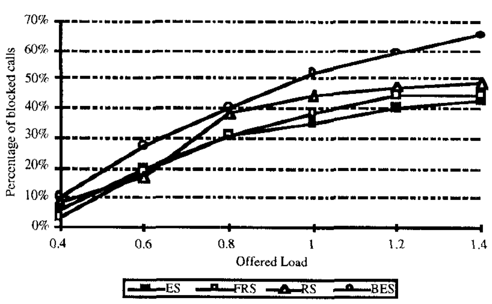

Fig. 11. Overall percentage of blocked calls versus offered load, class 2 and 4.

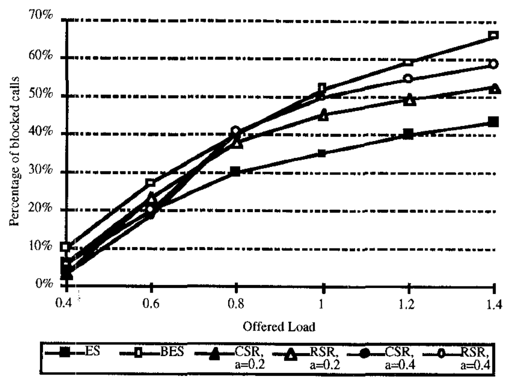

Fig. 12. Overall percentage of blocked calls versus offered load, class 2 and 4.

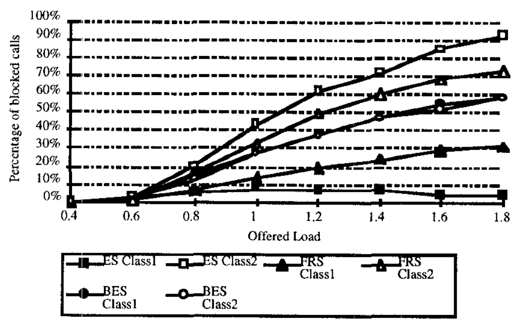

Fig. 13. Percentage of blocked calls for each traffic class versus the offered load by using the ES, FRS and BES for couple A.

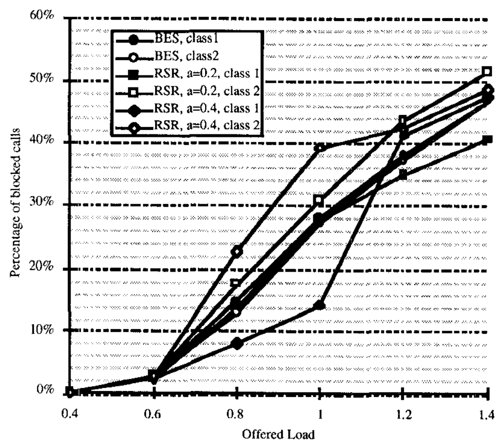

Fig. 14. Percentage of blocked calls for each traffic class versus the offered load by using the BES, RSR with a=0.2 and RSR with a=0.4, for couple A.

5. Conclusions

In this paper some simple CAC schemes for traffic integration in ATM networks at the call set-up level are proposed. The first scheme, named Erlang Scheme (ES), is aimed to minimise the overall call blocking probability; the second one, named Balanced Erlang Scheme (BES), has the main purpose of balancing the number of blocked calls among traffic classes, while the last one takes into account a set of constraints on the minimum call blocking probability, and applies the ES scheme to a sub-region where these constraint are satisfied, if it exists; otherwise the configuration at minimum distance is taken by the minimization of the cost function (12). In all the schemes presented the minimisation is performed by taking into account the constraint of the 'feasibility region'.

Four traffic classes, with different characteristics, are considered to test the proposed strategies. Simulation results have shown the difference among the various schemes, and verified the good efficiency of ES, BES and RSR with respect to other CAC strategies already presented in the literature. More specifically, ES allows the lowest overall call blocking probability, BES offers a very good balancing among the different traffic classes, while RSR can be consider a good compromise for a real implementation. The extreme simplicity of the cost functions makes the computation quite fast and the algorithms well suited for control mechanisms.

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