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A NETWORK SIMULATION TOOL FOR ROUTING IN ATM NETWORKS

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ABSTRACT.

An event-driven simulation tool aimed at testing routing mechanisms in an Asynchronous Transfer Mode (ATM) environment is presented. The simulator has been designed to test routing strategies for an ATM network.

The paper is dedicated to the description of the network model. In this context, the most important 'object' to be described is the interconnection among the nodes, i.e., the network topology. In the simulator, the 'network' is only a 'matrix', whose elements contain important information for each link, so that the network model is very simple due to the relatively high level of abstraction. The physical connection between two nodes is identified by the parameter 'connected' appearing in each matrix element. The meaningful events, in this approach, are identified and described.

Along with the description of the simulator, a short theoretical description of the routing strategy utilized during the simulations is reported. The implementation of the simulator tool is not strictly connected with the theory utilized; the strategy reported should be considered an example even if it is useful for a good comprehension of the presented results.

Several simulation results are discussed, in order to assess their performance and to evaluate the flexibility of the simulation tool.

1. INTRODUCTION.

Due to the increasing complexity of telecommunication systems and networks and to the large number of technical details to be accounted for, simulation tools have reached considerable importance for performance analysis in this area. Analytical modeling of details of data transmission through a computer network (or, more generally, of services in an integrated services network) is often a very difficult task, because it may involve many functionalities throughout a layered architecture: from application layer protocols, which are substantially software procedures, to the hardware devices used for transmission over the physical channel. On the other hand, the implementation of a prototype for the analysis of a network, with a research aim, is complex and expensive, and both universities and R&D laboratories inside a company often prefer the utilization of simulation tools, which can describe the behaviour of the system under analysis. Another advantage of the simulation is that a small part of a system can be picked out, if of interest, and other complex parts, even though essential for a real implementation, can be temporarily by-passed.

In the computer network world, high speed networks have received a great deal of attention in these last few years. In more detail, ATM networking has been the object of research from many points of view, from physical transmission (ITU-T G.709 1993) to switching (Hui 1990) from operation and maintenance (ITU-T I.610 1993) to CAC (Hong and Suda 1991; Bolla *et al.* 1994; Shim *et al.* 1994; Guérin *et al. 1991*; Bolla *et al.* 1996) to routing at the call level. As far as the latter is concerned, (Bolla *et al.* 1995; Gupta *et al.* 1992; Gupta and Gandhi 1994; Hyman *et al.* 1994; Maunder and Min 1994; Chen and Liu 1994; Plotkin 1995; Murakami and Kim 1996) is a list of references on the topic. Most of the listed papers use a simulator to get the results, even if the details about the simulator are not explicitly indicated, as instead in (Alquaed and Chang 1994; Freebersyser and Townsend 1996) or (Aly and Dowd 1991; Lin 1994; Huang *et al.* 1995).

The simulator described in this paper has been used to test the efficiency of the routing policies in (Bolla *et al.* 1995), and it is a part of a larger set of ATM simulation programs (Bolla *et al.* 1997a); so, the objective is not the design of a general purpose simulator of an ATM network, but it is the description of a tool that explicitly suits the routing in a particular environment. The quantities needed to be measured here are the number of blocked calls and of the total call requests.

The traffic is divided into classes (assuming Service Separation, as discussed in (Ross 1995; Bolla *et al.* 1997b)), which are characterized by performance requirements as packet loss rate and delayed cell rate, and by statistical parameters as peak and average bandwidth. Each switch considered in the network is an output buffer one, where a buffer of fixed length is dedicated to each traffic class at each outgoing link. The number of input links is limited only by the number of accepted connections, as is often done in the literature. The arrival of the connection requests, as described below, is modelled by a Poisson process.

The paper is structured as follows. The network simulator and the performed routing strategy are described in Section 2, organized in sub-sections. Simulation results are shown in Section 3. Section 4 contains the conclusions.

2. THE ATM NETWORK SIMULATOR.

2.1. Traffic Generation.

As already mentioned, the traffic is divided into a number H of classes, and each connection is considered statistically independent from the others and described by statistical parameters like the peak rate $B_p^{(h)}$, the average rate $B_a^{(h)}$ (or the burstiness, $b^{(h)} = B_p^{(h)} / B_a^{(h)}$) and the average burst length $B^{(h)}$. The duration of a connection is considered exponentially distributed with average value $1/\mu^{(h)}$. Concerning the arrival process of the connection requests, a Poissonian arrival has been chosen.

It can be observed that the description of a connection is maintained to a level high enough to by-pass many functions which are not meaningful in this context (e.g., the physical layer, both the Physical Medium Dependent (PMD) and the Transmission Control (TC) sub-layers). As far as a connection is concerned, only two events are relevant: the generation and the termination of a call.

2.2. Network Model.

The most important 'object' to describe in this context is the interconnection among the nodes, i.e., the network topology. In the simulator, the 'network' is only a 'matrix', whose elements contain important information for each link, so the network model is very simple due to the high level of abstraction. The physical connection between two nodes is identified by the parameter 'connected' appearing in each matrix element. It can assume the value '1', if there is direct connection, and '0' otherwise. A simple six node network is depicted in Fig. 1.A., along with the associated abstract view (Fig. 1.B.). It can be noted that this model takes into account the direction of the links (i.e., node 1 is connected with node 2, but not vice versa).

The mentioned matrix is replicated for each traffic class, because other quantities have a meaning only on a class basis: the maximum number of acceptable calls, the number of connections currently in progress, the bandwidth allocated to the link (sub-section 2.4), and so on.

The 'cell level' part, that would be very important for a single node description, is by-passed here. Only the routing strategy is taken into account .

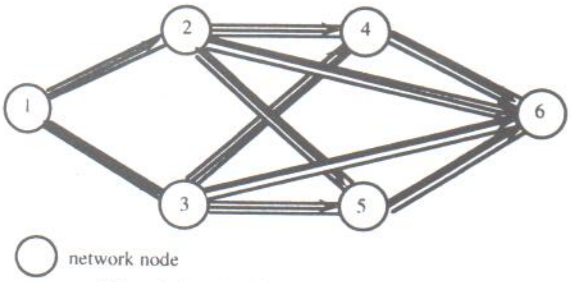

Fig. 1.A. A simple network.

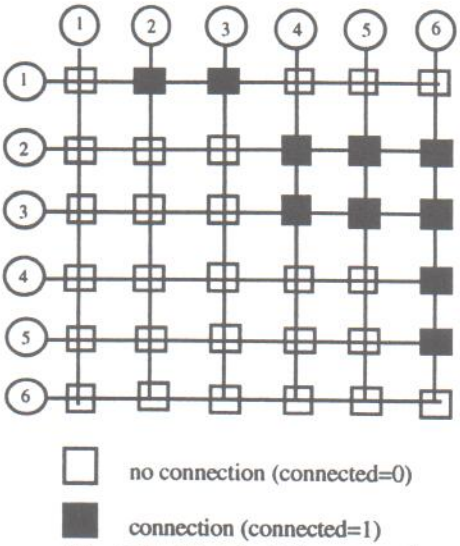

Fig. 1.B. Model of the network.

2.3. Event Scheduling.

The list of the events is very limited because, in this context, the network performance is measured in terms of connections accepted and blocked. So, the main events to be considered are: *connection_request* and *connection_end*.

connection_request contains the decision about the acceptance or rejection of a call and the choice of the best path to get to the selected destination. The best path is decided step by step by re-scheduling the event *connection_request* at each node chosen until the destination is reached; the complete routing procedure is described in the next sub-section. The implementation of the strategy is embedded in a software routine. If a connection is accepted (i.e., the destination has been reached and a route from the source to the destination has been found) the event *connection_end* is scheduled. Otherwise a routine to free the resources already reserved at the previously visited nodes is necessary. Then the next *connection_request* is scheduled.

connection_end contains only the upgrading of some quantities (i.e., the costs of the next sub-section) and of the resource status. This operation is performed by using software routines and, as in the previous case, cannot be considered as an actual part of the simulator.

Other two events are:

resource_allocation, which implements, as will be mentioned in sub-section 2.4, the computation of the maximum number of acceptable calls for each link and the bandwidth allocation for each traffic class. The resource allocation strategy is not the object of the paper and the periodic reallocation mechanism explained in (Bolla *et al.* 1994) and (Bolla *et al.* 1993) is used here. Anyway, if resources are not off-line statically allocated, the event *resource_allocation* is necessary. The temporal scheduling (each K [slots], in the simulations reported) of this event depends on the algorithm used. But, if the scheme is completely dynamic, the event is not needed, because it can be substituted by a software routine re-called at each *connection_request*.

cost_communication: this event will be clarified in the next sub-section because it is strictly dependent on the routing algorithm.

Due to the high level of abstraction, the network simulator is very fast and hours of network behaviour can be simulated in few seconds.

2.4. Routing Strategy.

At connection set-up, a call request packet is forwarded from node to node in a hop-by-hop fashion. At each VC-switching node along the route, the set of available outgoing links (if any) to the destination is determined by checking the available resources, according to the CAC rule in use. If no link can carry it, the connection is dropped, and the resources previously allocated along the route are freed. If the set of available links is non-empty, a choice is made among them, by using the mechanism described below. At the arrival of a connection request (supposed to be at the generic slot k) a generic node i chooses the link to which to forward a class h connection request, by minimizing (over all successor nodes j, i.e., the subset of neighbouring nodes which that destination can be reached from) the quantity

$$c_{ij}^{(h)}(k,s) = c_{ij,L}^{(h)}(k) + \alpha_j c_j^{(h)}(s) \tag{1}$$

where $c_{ij,L}^{(h)}(k)$ is a local cost related to link ij and $c_j^{(h)}(s)$ is a "global" cost, referring to the traffic conditions of node j and its neighbours at some time slot s<k. $\alpha_j \in [0, 1]$ is a weighting coefficient, used to balance the influence of the local and global cost. $c_{ij,L}^{(h)}(k)$ should weight the local congestion of link ij, and we have chosen it to be of the following form

$$c_{ij,L}^{(h)}(k) = \begin{cases} \dfrac{1}{N_{ij,\max}^{(h)}(k) - N_{ij,A}^{(h)}(k)} & \text{if } N_{ij,A}^{(h)}(k) < N_{ij,\max}^{(h)}(k) \\ Z & \text{if } N_{ij,A}^{(h)}(k) = N_{ij,\max}^{(h)}(k) \end{cases} \tag{2}$$

where $N_{ij,\max}^{(h)}(k)$ and $N_{ij,A}^{(h)}(k)$ are, respectively, the maximum number of acceptable connections and the number of connections in progress on link ij at instant k. Z is a very large number (namely, large enough to ensure that no saturated link will be chosen if non-congested links are available). The difference in (2) represents, in all these cases, the "available space". The computation of the maximum number of acceptable connections of each link depends on the used CAC scheme and can be implemented, in the event *resource-allocation*, by a software routine. The CAC strategy proposed in (Bolla *et al.* 1994) has been used to obtain the simulation results presented in the following; but it could be varied without affecting the general structure of the simulator.

To complete the description of the algorithm, we define the cost referred to a generic node j in (1) to be composed by two terms

$$c_j^{(h)}(s) = c_{j,L}^{(h)}(s) + \beta_j c_{j,A}^{(h)}(s) \tag{3}$$

where β_j is a weighting coefficient. $c_{j,L}^{(h)}(s)$ represents the average situation of the node with respect to the congestion state of its links, and $c_{j,A}^{(h)}(s)$ is an aggregate information on the average congestion of its successor nodes. More specifically,

$$c_{j,L}^{(h)}(s) = \frac{1}{L_j} \sum_{k \in Out(j)} c_{jk,L}^{(h)}(s) \tag{4}$$

$$c_{j,A}^{(h)}(s) = \frac{1}{L_j} \sum_{k \in Out(j)} c_k^{(h)}(s) \tag{5}$$

Out(j) being the set of nodes outgoing from node j. In detail, $c_{j,L}^{(h)}(s)$ represents the average 'free space' left for the links outgoing from node j; whereas $c_{j,A}^{(h)}(s)$ is the average of the costs related to each node connected to node j. As can be seen, the values related to the nodes connected to the outgoing links are referred to the instants s, where s=T, 2T, ..., with T equal to a fixed number of time slots. This means that each node i sends its costs $c_i^{(h)}(s)$, h=1,...,M, to its incoming links every T slots and then, after receiving the costs from its outgoing links, recomputes its new aggregate information on the congestion of the network. This function is performed by the simulator by using the event *cost_communication*, with the scheduling time T.

It is worth noting that the proposed strategy, named DLCP (Distributed Least Cost Routing) in (Bolla *et al.* 1995) is distributed, based on a mix of local real time (dynamic) and overall delayed aggregate information, and does not require the presence of a real time supervisory controller, which might be questionable in a wide area network.

3. SIMULATION RESULTS.

This part is dedicated to show some examples of possible utilization of the simulator. The data in Table 1 have been used with a channel capacity C = 150 Mbits/s and a related slot duration $T_S = 2.83 \cdot 10^{-6}$ s (53 bytes/cell).

TRAFFIC CLASS: h	h=1	h=2	h=3
PEAK BANDWIDTH: $P^{(h)}$	1 Mbits/s	2 Mbits/s	10 Mbits/s
BURSTINESS: $b^{(h)}$	2	5	10
AVERAGE BURST LENGTH: $B^{(h)}$	100 cells	500 cells	1000 cells
AVERAGE CONNECTION DURATION	20 s	15 s	25 s
Ploss UPPER BOUND: $\epsilon^{(h)}$	0.0001	0.0001	0.0001
Pdelay UPPER BOUND: $\delta^{(h)}$	0.001	0.001	0.001
DELAY CONSTRAINT: $D^{(h)}$	400 slots	200 slots	100 slots
BUFFER LENGTH: $Q^{(h)}$	20 cells	15 cells	10cells

Table 1. Characteristics of the traffic classes used for the tests.

The reference traffic load $\rho^{(1)}=120$; $\rho^{(2)}=100$; $\rho^{(3)}=15$ Erlangs is used in the twelve-node network depicted in Fig. 2 (only node 11 is a destination).

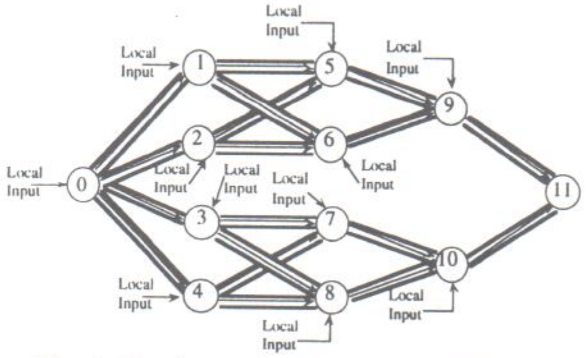

Fig. 2. Topology of the first test network.

The traffic flow generated by the above data is considered to be a "normalized offered load" of value 1; an offered load "x" corresponds to the same data, except for the traffic intensities $\rho^{(h)}$, h=1, 2, 3, which are multiplied by x. The coefficients α_i and β_i, i=0,...,11, are the same at each node, that is, $\alpha_i=\alpha$ and $\beta_i=\beta$, $\forall i$.

All the simulations have been stopped with a confidence interval of 3% of the measured values. *Resource_allocation* has been scheduled every 226.13 s.

Many results can be obtained, both by varying the traffic load or the aggregate cost communication time (*cost_communication* event), and by changing the network topology.

In Fig. 3 the percentage of blocked connections versus the weighting coefficient β is shown, with respect to two different values of the updating interval T (scheduling time of *cost_communication*) of the aggregate information, and a constant value of $\alpha=1$: the test is performed by updating the aggregate information 10 and 2 times every reallocation interval, (T=K/10 and T=K/2). It has to be remembered that K is the scheduling time of *resource_allocation*). The improvement obtained by using a more frequent updating is clear, except for $\beta=0$, where the aggregate information is ignored. In this case, as in the next one, the offered load network configuration is 37.5% to node 0, 62.5% to node 9, because the aim is to show the effect of the knowledge of the aggregate information. Fig. 4 depicts the total percentage of blocked calls versus the offered load. The DLCP routing, with $\alpha=1$ and $\beta=1$, is compared with a SPR strategy, where the cost of each link is the same as in (2), and with a local Hot Potato strategy, which is considered as a possible lower bound on performance. The percentage of blocked calls for DLCP is close to that of SPR. The results for SPR and Hot Potato have been obtained by using the same simulation tool, changing the software routine to choose the best path.

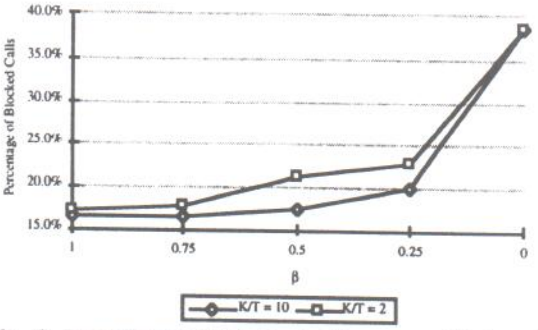

Fig. 3. Percentage of blocked calls vs. coefficient β.

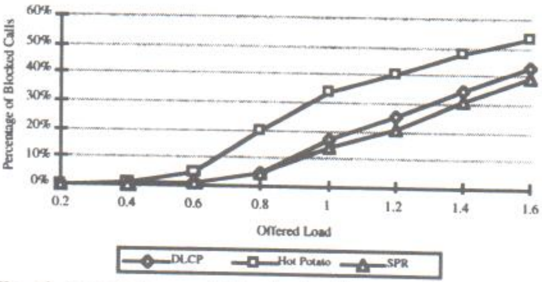

Fig. 4. Percentage of blocked calls vs. offered load.

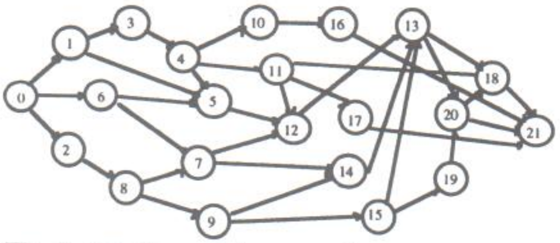

Fig. 5. Topology of the second test network.

In Fig. 5 a different network topology is shown. The last graph shown (Fig. 6) depicts the same quantities (except for the Hot Potato) as in Fig. 4 for the topology in Fig. 5. In this case all the nodes generate traffic; only traffic classes 1 and 3, in Table 1 at the beginning of the Session, have been used; the traffic reference values are: $\rho^{(1)}=168$, $\rho^{(3)}=21$ Erlangs. The values concerning Hot Potato have not been shown here.

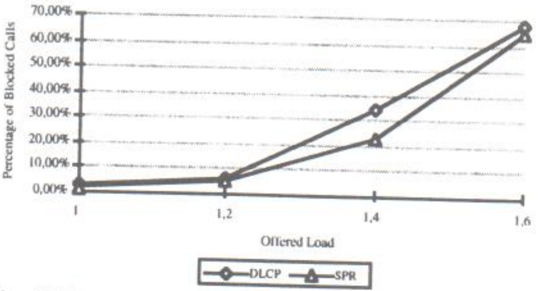

Fig. 6. Percentage of blocked calls vs. offered load.

4. CONCLUSIONS.

An event-driven ATM network simulator has been introduced in the paper. The purpose is to test routing schemes: to this aim, a high level of abstraction is maintained and many details (e.g., physical transmission and switching fabric) are not considered.

The model of the network and the events have been explained, along with a specific routing strategy. Simulation results have been presented with the purpose of showing some examples of utilization. The network simulator has been tested with routing strategies, by changing both some performance parameters and the network topology.

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