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Application of Importance Sampling in Simulation of Buffer Policies in ATM networks

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Abstract:- The analysis of cell loss probability in ATM is very important in switch design, buffer dimensioning and developing congestion control techniques. This probability in ATM network is very low, in order of 10^{-6} to 10^{-12}, to satisfy the most demanding quality of service requirements of diverse services of future. In such case, traditional Monte Carlo simulation method would either be very costly or too long to be feasible. We would need a new simulation and modelling tool apart-from direct stochastic simulation to deal with such rare event cases like cell loss in ATM. We have used a simulation and modelling technique based on dynamic important sampling, to compare the performance of two buffer control policies in ATM networks known as Simulated Protected Policy (SPP) and Extended Simulated Protected Policy (ESPP).

Key-Words: - ATM, Simulation, Importance Sampling, Buffer Policies

1 Introduction

In B-ISDN (Broadband Integrated Services Digital Network) we expect to have integrated access, transmission and switching of the voice, data and video traffic at very high speed, up to Gbit/sec. The Asynchronous Transfer Mode (ATM) has been recommended as the preferred transport method (switching and multiplexing) for the broadband integrated services digital network (Figure 1).

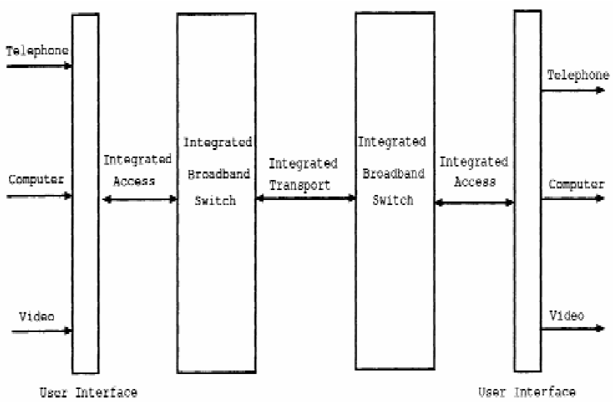

Figure 1: Integration of services in ATM

ATM could be defined as a transfer mode in which information is organised into cells of 53 octets (48 bytes information and 5 byte header). Since different types of information have different quality of service requirements, we need to have in place congestion control techniques, to protect the quality of service requirements in overloaded networks.

As the cell loss is very low in ATM networks (in order of 10^{-6} to 10^{-12}), traditional Monte Carlo simulation cannot be used to evaluate the cell loss as it takes a very long time. One can expect that the number of observations needs to be at least one hundred times the inverse of the probability of loss in order to obtain results with reasonable confidence [1]. Generally, the traditional Monte Carlo technique can be used to analyse situations that result in the probabilities higher than 10^{-5}. In this paper, dynamic importance sampling is used to simulate the operation of some buffer policies in ATM and calculate the cell losses of upto 10^{-18}.

The organisation of this paper is as follows, next section discusses SPP and ESPP buffer policies

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in ATM, Section 3 covers the dynamic importance sampling. Section 4 outlines the traffic model followed by results in Section 5. Section 6 is the conclusion.

2 SPP and ESPP Buffer Control Policies in ATM

The buffer protocols ensure that the more important cells in ATM will have the guaranteed QOS (Quality of Service), in the sense of the maximum cell loss rate. Data traffic is loss sensitive and must be protected against cell loss while voice traffic is delay sensitive (not loss sensitive).

2.1 Simulated Protected Policy (SPP)

These protected policies that are based on Reference System Simulation, are Simulated Protected Policy (SPP) and Extended Simulated Protected Policy (ESPP). The main idea is that we simulate another queue, reference buffer, with the size less than the main queue, and the same departure rate as the main queue. Every high priority cell arrival is sent to both main buffer and to the reference buffer. Let us call the cells belonging to more privileged class as “green cells”, and less privileged cells as “red cells”. Note that the reference buffer only included green cells (Figure 2).

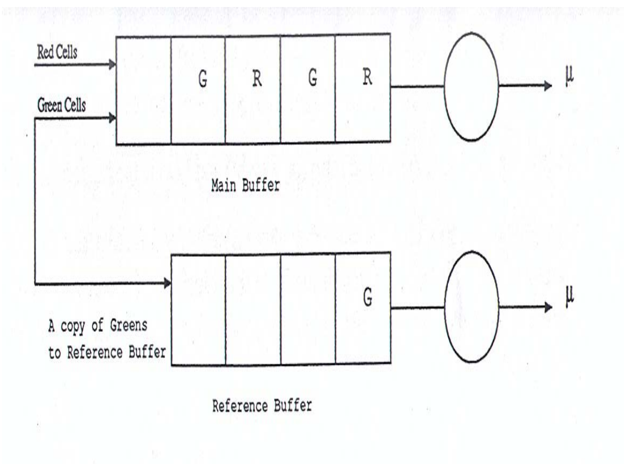

Figure 2: Simulated Protective Policy (SPP) used to manage the buffers in ATM

The information available to us in a simulation run enables us to identify the number of more privileged cells in both of the reference and main buffers. We ensure that the number of buffer spaces in the main system is always greater than or equal to the reference buffer. Note that 1ess-privileged cells can be pushed out and we could count such a cell in the main buffer as a potential space for cells of higher priority class.

The following rule must be observed in Simulated Protected Policy (SPP) [2,3].

- A red cell is always accepted if a space is available in the main buffer as the red cell could be later pushed-out if the room is required for the green cells.
- A green cell is accepted into the main buffer if it is accepted into the reference buffer. If there is not enough room in the main buffer one red cell is pushed out (Figure 3).
- A green cell is lost if there is no room in the reference buffer, even if there is room in the main buffer.
- Once a green cell is accepted into buffer, it will go into service and will not be lost in any way.
- We must ensure that there is always more or equal room for green cells in the main buffer than the reference buffer. We therefore check every red cell for discarding before it enters the service.

The above criteria is specially needed when a burst of green cells arrives and many spaces are required in the main buffer.

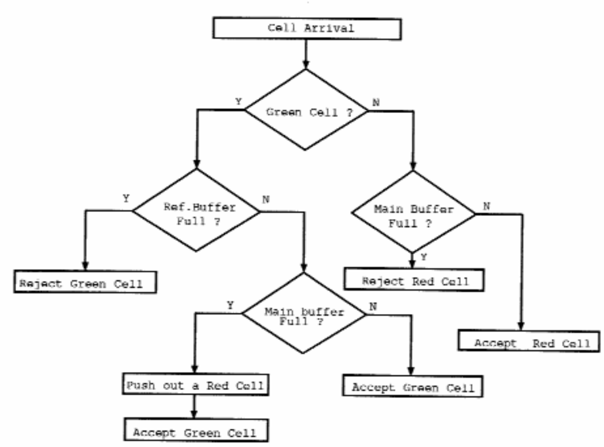

Figure 3: Flow chart of SPP when a cell arrives

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2.2 Extended Simulated Protected Policy (ESPP)

In this policy, one could find out in advance if a red cell is doomed and whether will be discarded just before it enters the service. This would free some room for arriving red cells that otherwise would have been discarded. This protocol we would call Extended Simulated Protected Policy (ESPP)[2, 3].

3 Dynamic Important Sampling

Dynamic Important Sampling is recognised as potentially very powerful tool for reducing simulation run times especially when studying the overflow probability for buffers in ATM networks with very low level of cell loss. This method has been sufficiently developed for this particular purpose and its applications are limited to some classes of Markovian processes[1]. One purpose of my research project is to investigate possibilities of applying Important Sampling to study specific congestion control protocols, proposed but not fully analysed yet.

The basic idea in important sampling is that the events would occur more frequently under a new and biased pdf (probability density functions) to that of the reference pdf. Let *p(x)* and *p*(x)* be two probability density functions, where *p*(x)* is obtained by biasing *p(x)*.

$$E[L(x)] = \int L(x) p^*(x) dx = \int L(x) W(x) p(x) dx \qquad (1)$$

$$W(x) = p^*(x) / p(x) \qquad (2)$$

where *W(x)* is the Likelihood ratio (or weight) and *L(x)* is the random variable. To efficiently simulate the queueing system with regenerative simulation[2], we increase the load on the system initially so that blockages (important events) occur more frequently (Figure 4b). Let ρ_{EE} mean the increased traffic level for purpose of speeding up simulation i.e.

$$\rho^*_{EE} > 1 \qquad (3)$$

This stage of dynamic important sampling is called *EE* or *Efficient Estimation*.

Once the sufficient blockages have occurred we force the system to regeneration by changing the load to a very small value.

Within each regenerative cycle, the number of blockages tends to converge to a value as the number of blockages increases in a cycle [6]. This usually happens after after twenty to fifty blockages. This is when we could push the system to regeneration state. This phase we call *Accelerated Simulation*, or *AR* phase (Figure 4c). During this stage:

$$\rho^*_{AR} << 1 \text{ and } \rho^*_{AR} << \rho \qquad (4)$$

Once the buffer is cleared, one regenerative cycle has finished. We now increase the load again (*EE* phase) and then initiate *AR* phase again. The above sequence of *EE* and *AR* cycles continue until we get the number of regeneration cycles for each run. The number of runs will stop when we meet the stopping condition of simulation, which is the relative precision of confidence intervals of estimates.

The detailed discussion on dynamic important sampling is given in [1, 4, 5]. In summary, since simulation of events that do occur very rarely under normal load ρ takes a very long time (Figure 4a). we simulate another system with much higher load, ρ^*_{EE}, so that important events, cell losses in our case, happen more frequently (Figure 4b). The theory behind the dynamic important sampling allows us to transform the statistics obtained at ρ^*_{EE} level back to the original load level of ρ, where the cell loss happens very rarely.

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[1] A Markov process is a stochastic process in which the future state of the system depends on the current state of the process and is independent of the history of the system (memoryless property). A Markov process with discrete state space is called a Markov Chain. We could refer to the outcome of the nth trial as X_n [6].

[2] In regenerative simulation, there is a state m the system that will be repeated over and over again, like as when the queue length is zero at which the system start afresh.

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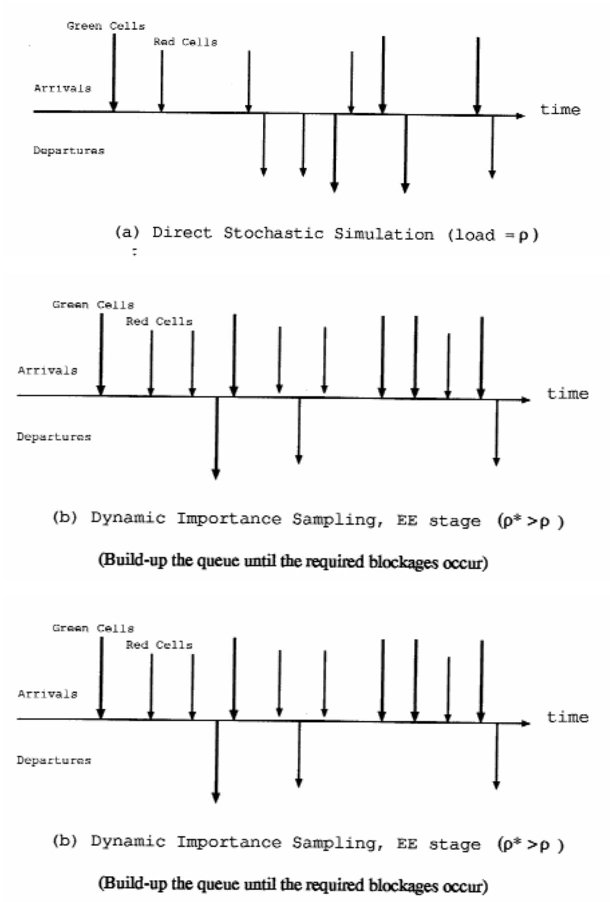

Figure 4: Possible arrival and departure patterns in M/D/1/K queue with two sources of traffic for (a) direct stochastic simulation and (b,c) Dynamic importance sampling stages.

4. The Traffic Model Used

The data structure used in the traffic model for storing the calls is a circular queue, chosen because it is easy to implement. The head continuously chases the tail of the queue and the space is used again and again (Figure 5).

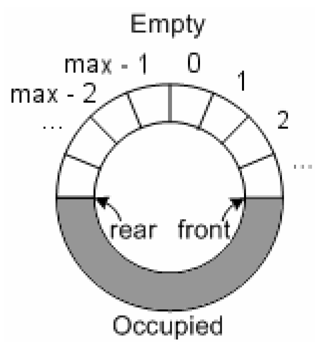

Figure 5: Circular queue

We have assumed that both cell arrival streams (of green and red cells) are Poissonian. The service rate is constant as the cell size is fixed.

The problems that needed to be solved was connected with finding the best biasing scheme of traffic for the total stream of arrivals (red and green cells) and departure rates (by how much the probability distributions, and hence arrival and service rates, are to be biased). This was done by drawing a separate normalised variance curve for each load and each biasing. Then the minimum point at the normalised variance curve for the number of blockage per cycle can be determined, to find the the near-optimal biasing scheme for SPP and ESPP. When the traffic biasing scheme is determined we follow the following steps:

- In a separate run, bias both red and green cells arrivals by the above biasing (Figure 4a).
- Draw two exponential inter-arrival times for red and green cells, using the biased inter-arrival times.
- Find the order of arrival and departures and the number of cells in the main queue.
- Send a copy of Green cells to the reference buffer with the same departure rate as the main buffer.
- Calculate the transition probability ratio on every arrival and multiply by the previous ones.
- Whenever there is a red cell loss or push-out in SPP or ESPP, calculate the current unbiased number of cell loss in that cycle.
- Whenever any further cell loss has insignificant effect, force the cycle to regeneration by decreasing the $\lambda^* = \lambda / 2000$. When the queue is empty, start the biasing again and the next regenerative cycle starts.
- Continue the regenerative cycles for the number of regenerative cycles required (in order of 1000 to 10000).
- We ignore the cycles that do not have red cell loss in them (say one green cell arrival and departure).

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- Average the number of cell loss for all regenerative cycles. One run is complete now.
- Run the regenerative cycles for more runs (each with 1000 – 10000 cycle), and calculate the precision and probability of loss of runs. Stop the simulation when the precision required is reached.
- In a separate stochastic simulation run, calculate the number of cells arrival per cycle for the same load.
- Calculate the probability of loss by dividing number of cell loss by number of cell arrivals per cycle. Repeated the above for every different load and for both SPP and ESPP.

5. Results

The dynamic importance sampling simulation was performed and the results were adjusted to account for the biasing used as explained in the previous sections. The service rates for both the main queue and the reference queue (Figure 2) were assumed to be one (μ=1). The probability of losses for red and green cells for various arrival rates are graphed in Figures 6 and 7. Unless otherwise mentioned in the graphs, the results reported in figures are for the main queue size of 58 and reference queue size of 20. For the cases considered, the simulation results indicated that the blocking probabilities of ATM cells for green and red cells varied from 10^{-2} to 10^{-18}. Note that the blockage probability of green cells in Figure 7 is independent of red cell arrival rates as red cells are pushed out of the buffer if there is not enough space for green cells.

6. Conclusion

Traditional Monte Carlo simulation techniques cannot be used in situations that the probability of loss is very low, such as cell loss in ATM networks. Importance sampling was used in this study to compare two buffer policies in ATM and calculate the probability of cell loss upto 10^{-18}.

The results shown in Figures 6 and 7 indicate that the Extended Simulated Policy (ESPP) leads only to marginally less priority of loss for red cells (the difference is so little that cannot be seen in the graph). Given the more complexity of the ESPP, it appears that the SPP would be in general a better policy as it is simpler. In ESPP the first red cell needs to be checked for discarding when a green cell arrives, but also every red cell needs to be checked before it goes into service. This makes the buffer management more complex to that of SPP that we only check a red cell for discarding only before it goes to service.

We could guarantee a maximum probability of loss for an important data. The probability of red loss could be more or less than this value depending on red arrival rate and reference buffer size.

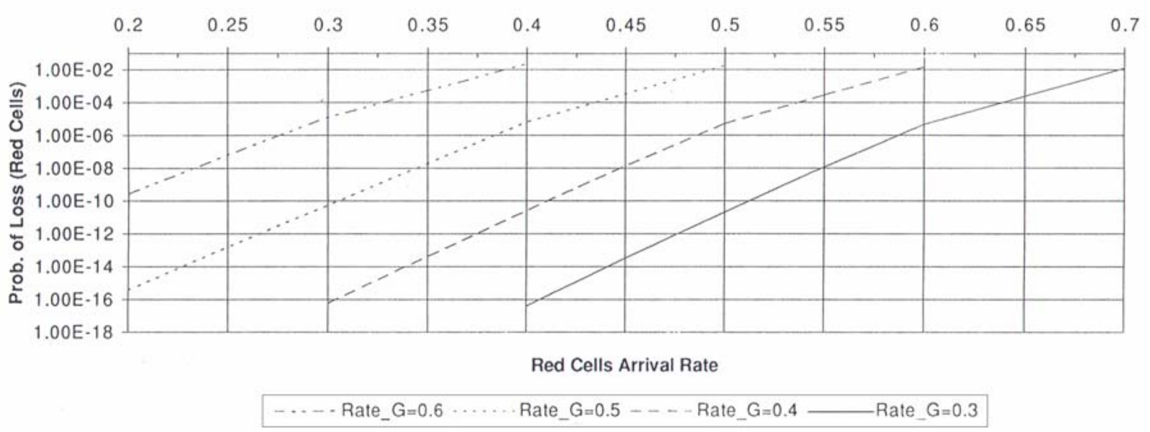

Figure 6: Probability of red cell loss against red cell and green cell arrival rates (Rate_G) for both SPP and ESPP policies.

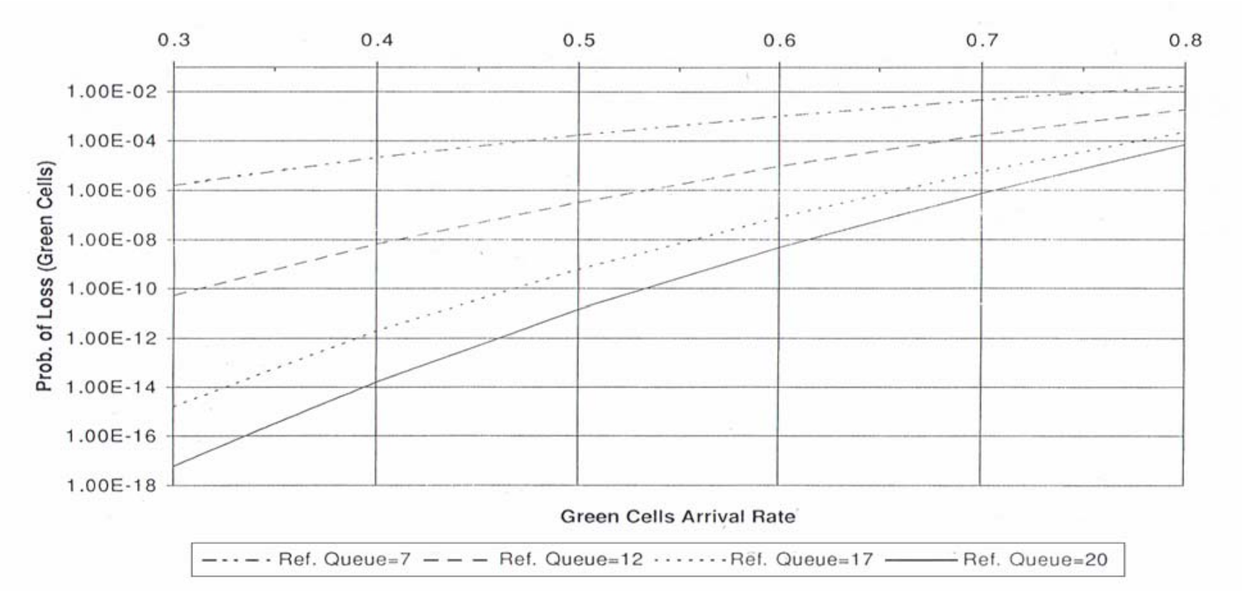

Figure 7: Probability of green cell loss against green cell arrival rate and reference buffer size for SPP and ESPP policies.

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