PERFORMANCE MEASUREMENTS IN ATM NETWORKS

M Luoma K Kilkki M Ilvesmäki SJ Ovaska

Helsinki University of Technology
Laboratory of Telecommunications Technology
Otakaari 5A, FIN-02150 Espoo, Finland
Email: Marko.Luoma@hut.fi

ABSTRACT

In this paper, several performance measurements of ATM (Asynchronous Transfer Mode) networks are performed and analysed. Especially, measurement of the buffer size, the traffic management functions and the cell transfer delay in a switching system are studied as a function of various traffic patterns and loading levels. These values have great importance for establishing reliable media for broadband traffic and contributing to the implementation of services in ATM networks.

ABBREVIATIONS

AAL	ATM adaptation layer
ABR	available bit rate
ATM	asynchronous transfer mode
BER	bit error rate
B-ISDN	broadband integrated services digital network
CBR	constant bit rate
CDR	cell discarding ratio
CDVT	cell delay variance tolerance
CLP	cell loss priority
CLR	cell loss ratio
CTD	cell transfer delay
EPD	early packet discard
FIFO	first in first out
GCRA	generic cell rate algorithm
HOL	head of line
ITU-T	International Telecommunications Union - Telecommunications Standardization Sector
NPC	network parameter control
OAM	operations and maintenance
PPD	partial packet discard
QoS	quality of service
SDH	synchronous digital hierarchy
TAXI	transparent asynchronous transmitter/receiver interface
UBR	unspecified bit rate
UPC	usage parameter control
VBR	variable bit rate

INTRODUCTION

B-ISDN is an acronym for the new broadband integrated services digital network. The chosen technology for B-ISDN by ITU-T is ATM. ATM is a fast packet switching protocol with little or no error control [1]. To implement networks with highly simplified error control one must fully understand the limitations that come from the existing infrastructure and capabilities of new broadband elements. For this we need effective measures that the elements must fulfil and the means to measure them in real applications. Those means are new measurement principles, methods and equipment, and they will be considered in this paper.

SHORT INSIGHT TO ATM

ATM is a fast packet switching protocol using fixed 53-byte frames or cells. A cell contains 48 bytes of payload and a 5-byte header [1]. ATM is a very light protocol; it does rely on correctness of the underlying transmission infrastructure. That is a natural result of increased utilisation of fiberoptics and its low bit error ratio (BER). To justify the absence of link-by-link error control we can consider an ATM connection using fiberoptic transmission with maximum BER ~ 10^{-10}. If we suppose that errors occur randomly, e.g., due to noise in optical systems, we get probability of less than 10^{-7} for a cell being erred, see Figure 1. On the other hand, if the errors occur in bursts with high instantaneous bit error probability, the cell error probability is smaller.

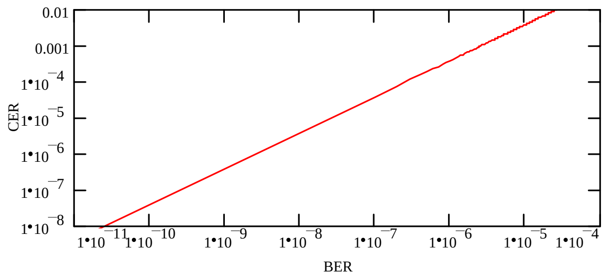


Fig. 1: Cell-error-ratio as a function of bit-error-ratio

ATM LAYER AND QUALITY OF SERVICE

Quality of Service (QoS) is one way to describe the characteristics of a connection on user point of view. QoS can be defined in many ways, but for the measurement purposes, the network performance is a key feature. Network performance refers to the set of parameters that measures the ability of the network to provide its service between users [1].

ITU-T has defined a subset of performance parameters, which form the ATM layer QoS statement. Half of the parameters are in some level negotiable in connection set-up while others are variables which rise from the momentary errors in communications systems. Those errors are identified by the network operator.

Table 1. ATM layer performance parameters from ITU-T Recommendation I.356

Negotiable parameters	
CLR	Cell Loss Ratio
Mean CTD	Mean Cell Transfer Delay
Max. CTD	Maximum Cell Transfer Delay
CDV	Cell Delay Variation
Non negotiable parameters	
CER	Cell Error Ratio
CMR	Cell Misinsertion Rate
SECBR	Severely Erred Cell Block Ratio

CLR is the actual ratio for losing a cell, and it counts all possible means of losing a cell or its information. Possible ways to lose information is more than one bit error in a cell header or a total misreception of the transmitted cell. CER is, on the other hand, a value that can be derived from the bit-error-ratio in communications systems.

From the list of parameters in Table 1, it is obvious to see that there are two dimensions in the QoS parameter space. One that has values over time (delay) and other depending on the probability of the cell loss. Those parameters are mostly independent of each other which, in fact, means that there is a possibility to create priorities using QoS parameters.

Every connection in a network must have some value for each parameter. Statistical multiplexing can be used with connections using, to certain extent, the same set of parameters. To be able to mix different kind of traffic profiles (parameter sets) in one virtual path, the connections have to be treated in a manner that satisfies the most demanding connection. If the variation of parameters is too large or network is not capable to support such a large number of demanding connections, they have to be separated into different virtual paths. This can be quite unsatisfactory in the real world where there is a natural limitation in simultaneous traffic parameter sets due to the management complexity. Neural network-based methods for efficient traffic management are discussed in [2].

As we can see, negotiation of individual parameters can become intolerable if there are many simultaneous connection requests and different kind of parameter sets. That is the main reason for suggestions the that parameters should be fixed in some way. On that case, there would be no negotiation in values of an individual parameter, only in a class that would contain some set of collected parameter values. Those grouped QoS parameters are called as the defined QoS classes, and these are usually defined on the basis of the existing networks (telephone, data, etc.) and their QoS [3]. Another way to classify the parameters would be on the basis of applications and their demands.

MEASUREMENT CONSIDERATIONS AND RESULTS

Performing ATM measurements is similar when compared to other communications measurements. First, the system under test has to be verified by a layered approach from bottom to top in the protocol stack. Every protocol layer has its own specification to satisfy. Those specifications are called PICS (Protocol Implementation Conformance Statement). PICS specifies every function that the protocol layer must conform and which of the functionalities are optional. After verification of an ATM system, its ability to operate under traffic load is tested. On the performance point of view, the most interesting part is the ATM layer and its ability to transfer cells under different levels of background traffic load.

In our work, performance characteristics are evaluated with simulated traffic. This traffic either emulates some real world situation or it has a strong theoretical justification for its use. Simulated traffic is generated by one or more foreground sources and several background sources. Foreground sources are probe sources that perform the actual measurement. They have an editable payload with a time-stamp, sequence number, and error correction. Background sources are more fixed, but still the traffic generation is performed with a strong relation to the real world events [4].

ATM traffic has different time scales. We chose the time scales as the cell scale, burst scale, rate-variation (dialogue) scale, connection scale and subscription scale. The simulated traffic behaves in a similar way to real traffic in different time scales [5], [6], [7]. It is hard to realise a traffic generator that fulfils all the previous requirements. However, the results presented in [6] indicate that in most cases the different times scales can be evaluated separately. A suitable description of the aggregate traffic process can be formed based on these separate evaluation results.

MEASUREMENT ENVIRONMENT

Our measurement environment in the Helsinki University of Technology consists of the following equipment:

- FORE ASX-200 ATM-switch with:

  4 units of 4*155 Mbit/s SDH, multimode-fiber ST-connections.

  2 units of 4*155 Mbit/s SDH, Category 5 twisted pair RJ45-connections.

  1 unit of 4*100 Mbit/s TAXI, multimode-fiber ST-connections.

- ADTECH AX/4000 ATM-measuring device with two 155 Mbit/s SDH-port generator/analyser components installed.

MEASUREMENT OF SWITCHING DELAY

Switching delay in ATM-switches consists of several different factors. In the input module, the delay is produced when UPC-functions (Usage Parameter Control) and the pre-processing of the cells is performed. A distributed realisation of the above functions in the switch is recommended to minimise the delay in the input module. The switching fabric itself creates some delay as it has to correctly direct cells in and out of the fabric. Finally, the output module contributes to the delay as OAM-cells (Operations and Maintenance) are inserted. These different delay factors are related to each other in a complex manner and a straightforward handling of numerical results is not possible (i.e., adding variances etc.).

We measured the switching delay with a periodic 4831 cells/s foreground traffic source. Background traffic was slowly increased up to 1.487 Gbit/s. The results obtained for switching delay are shown in Figure 2. These results were determined by taking 8192 cell samples from the received traffic streams.

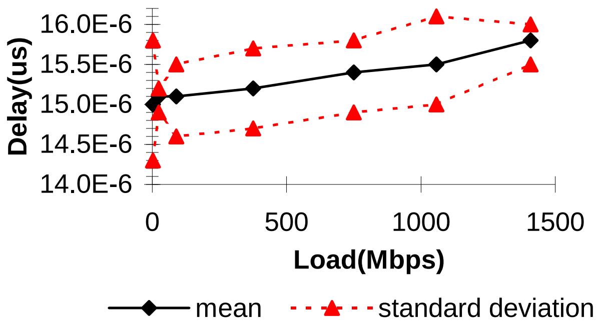


Fig. 2: Switching delay as a function of load

The relative stability (15.3±0.3 µs) of the switching delay results from the non-blocking structure of the switch. We concluded that the switching delay of FORE's switch is independent of the background load provided that the background traffic does not overload the outputs.

MEASUREMENTS OF TRAFFIC MANAGEMENT

As a connection is established in an ATM-network, a *traffic contract* is negotiated. The traffic contract consists of different negotiable parameters described in Table 1. Because these parameters may not describe accurately the actual traffic process of separate connections, overload situations are possible. The UPC and NPC (Usage and Network Parameter Control) are meant to prevent one connection from interfering with another with respect to the QoS of individual connections. The recommendations also state that the parameter control should be fast, transparent and error-free.

The management of overload

Overload can be managed by using one of several methods. Cells may be discarded according to its CLP-bit. However, with this kind of traffic management we cannot obtain the optimal performance because the upper protocol layers usually cannot manage partial re-sending of packets [8].

Selective cell discarding is another way to manage traffic overload. Two different methods, EPD (Early Packet Discard) and PPD (Partial Packet Discard), exist and these are based on recognition of AAL-5 frames. These methods improve in some degree the overall network performance since they decrease the number of cells in buffers without increasing the number of lost frames.

Finally, virtual channels or even paths may be terminated to reduce the overloading.

Figure 3 shows the measuring arrangement for cell discarding ratio.

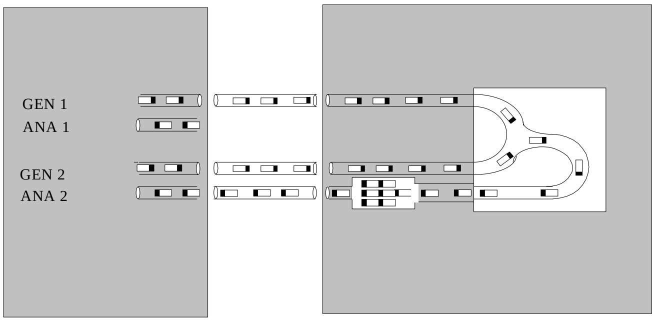


Fig. 3: Measuring arrangement for cell discarding ratio

Cell discarding ratio (CDR) was measured with CBR-, VBR-, and UBR-connections. The measurements were made with FORE's series A and series C access cards. The C-series card utilises dynamic sharing of buffer memory and different priorities for different connection types. Considering the measurements, it was concluded that the older A-series card does not contain these qualities. It was also noted that when measuring VBR-traffic with the C-series card the results resembled the results measured with CBR-traffic and the A-series cards. For CBR-connections it was found that the CDR was under 10^{-8} for both of the card types.

The measurement of UPC

The process of UPC (and NPC) is based on GCRA-algorithm presented in ITU-T recommendation I.371 [9]. The UPC measurement is described in Figure 4. The cell stream under study is first made to agree with the traffic contract in the measuring equipment. Then the stream is directed to the switch and back to the measuring equipment. Finally the received stream is examined with the analysers GCRA-algorithm.

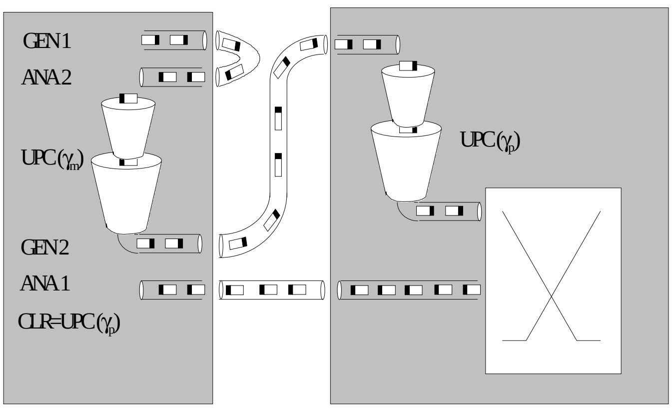


Fig. 4: Measuring arrangement for UPC

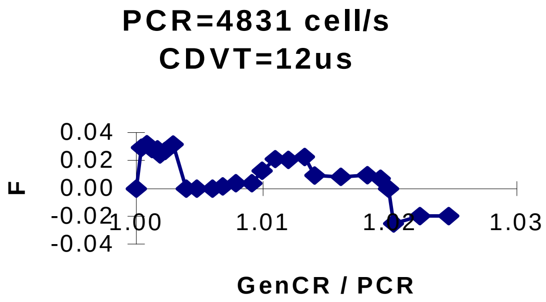
With this arrangement, we have established a dependency between parameter changes and parameter control process. ATM Forum has defined a parameter that tells the goodness of the measured GCRA compared to the ideal GCRA [3]:

$$F = \gamma_M - \gamma_p \qquad (1)$$

γ_M = the reference policing ratio based on the ideal GCRA algorithm

γ_p = the actual policing ratio

A positive value of F means that the UPC is taking less policing action than allowed and a negative value indicates that the UPC has taken unduly actions.



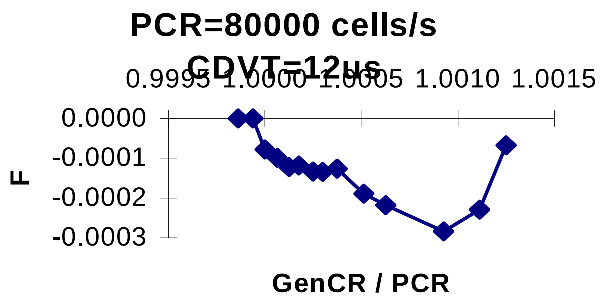


Fig. 5: The goodness of UPC method with two cell streams, CDVT = 12 µs, (note the differing scales).

Our measurements showed that UPC is difficult to realise exactly according to the recommendations. This is even more so in slow-speed connections (4831 cells/s). The difference is so small that in most real cases it may not have any significant effect on the QoS of the connection. However, the measurements show that the CDVT parameter should be determined properly in order to avoid excessive cell loss due to too stringent UPC parameters.

CBR-connections are easier to manage than VBR-connections due to smaller number of traffic parameters. The burstiness of VBR-traffic is managed within reasonable accuracy, although the GCRA reacts sometimes even before the traffic contract is violated. This is because GCRA is defined in time whereas the devices used measure parameters in relation to burst size. However, the difference between the GCRA of the switch and measuring equipment is relatively small, and significant differences occurs in a narrow region when offered rate is higher than the allowed one. These results establish faith in the functionality of the process as it is.

MEASUREMENTS OF BUFFERING

The use of statistical multiplexing makes it possible to overload the switch. Most of the problems caused by intermittent overload situations can be avoided by sufficient buffer capacity and proper scheduling algorithms. There exists a number of different buffering techniques as shortly discussed in the previous chapter, but in this chapter we assume the buffers to be FIFO-queues for the sake of simplicity.

The determination of buffer locations

The location of buffers may be determined if we bear in mind the HOL-blocking in input buffering. The measuring arrangement and possible locations of buffers are described in Figure 6. If traffic is generated at full speed from generator 2, there should not be any room left for cells from generator 1. If the switch uses input buffering, the connection from generator 1 should experience congestion. If output buffering is used, no congestion should be experienced. It should be emphasised that the buffer place may have a significant effect on the switch performance especially with high load, e.g., due to HOL-blocking, see [10]. Therefore this type of measurement should be done before the switch is used in commercial ATM network.

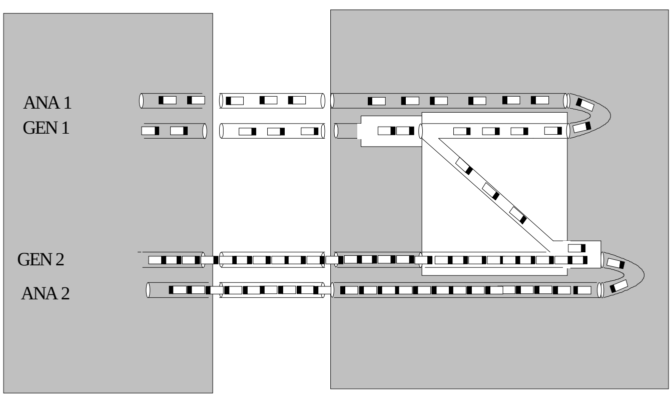


Fig. 6: The measuring arrangement for determining the buffer size and location

Our measurements confirmed that the FORE switch utilises either output buffering or very advanced input buffering. The blocking in the cross-connected connection did not cause any lost cells in either of the straight-connected connections.

The determination of buffer size

To determine the size of the buffer is a much more complicated task. The queuing-models used in buffering are extremely complex [7], and any exact results regarding the buffer size are difficult to obtain especially when advanced buffer scheduling algorithms are applied.

If we presume the buffer to be a simple FIFO-queue we can measure the buffer size by directing two traffic streams to the buffer. One stream is just below the maximum capacity of the link and the other is an ON/OFF-type traffic stream. We name this method as the overflow-method (Figure 6.).

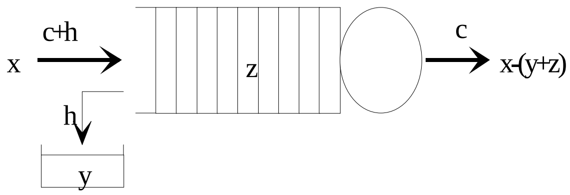


Fig. 7: The measurement of queue-length using the overflow-method

To clarify Figure 7, the explanation of symbols is presented: x is the rate of the sent cells, c is the link rate, y measures the lost cells, h is the rate of overload traffic (ON/OFF-source) and z states the number of cells in the buffer. The ON/OFF-stream is varied in a way that the ON-phase of the traffic equals to the maximum capacity of the link. The buffer size can then be determined by measuring the maximum variation of the cell transfer delay.

Another possible method is to generate traffic that exceeds the link capacity and then to measure the maximum CTD. The filling-up of the queue makes the transmitted cells experience the maximum CTD. The size of the buffer determined in this way is:

$$Z = \frac{CTDmax - CTDmin}{2.8316\mu s} \quad (2)$$

The transmit time of one cell in a 155 Mbit/s SDH-link is 2.8316 µs.

Our measurements gave the longest buffer length of 9126 cells for the C-series card when using UBR-traffic and CBR-traffic in the background. This buffer size, available in our measurements but not the maximum size, makes possible to realise a feasible UBR service in a relatively large area but it may not be sufficient for guarantee a high QoS with ABR-service (Available Bit Rate, see [3]).

CONCLUSIONS

The main goal of this work has been to collect information on the performance measurements in ATM switching systems and additionally to verify their usability in a real, commercial, testing environment. Work has provided several important results. First of all, measuring the rare events has proved to be even more difficult than expected. Laboratory environment was hard to keep stable enough to run through all the tests in exactly equal conditions. The statistical independence of the background sources seemed to have a stronger effect than first expected. That is due to the traffic generator used, which consisted of two 155 Mbit/s generators with each one having seven logical sources. That does not give enough independence to the traffic streams when the load has to be shared to 16 ports.

The results of the measurements met mainly with the requirements stated to an appropriate ATM switch; the measuring of switching delay gave even better results than expected. The measurements of traffic management demonstrated that the behaviour and modelling of traffic for the measuring device requires further study. The switch performed traffic management functions exceptionally well and consistently. This enables the spread of ATM networks, because problems in traffic management (and lack thereof) have slowed down the widespread utilisation of broadband networks.

ATM networks will be built up in the near future. Broadband infrastructure has a remarkable value for universities and research centres in Africa, because it makes it possible to offer new applications like medical imaging, shared designing systems, and new interactive video applications. Results of our paper are necessary knowledge when those networks are built up. This concerns not just the Africa but the whole world.

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REFERENCES

[1] RO Onvural, Asynchronous Transfer Mode Networks: Performance Issues, Artech House, Norwood, MA, 1994.

[2] B Yuhas and N Ansari (Eds.), Neural Networks in Telecommunications, Kluwer Academic Publishers, Boston, Ma, 1994, pp 63-142.

[3] Traffic Management Specification v4.0, ATM Forum, 1995.

[4] HG Diavolitsis, BE Helvik, R Lehnert, and JC Michelsen, “Traffic generation for ATM systems testing environment, modelling and feasibility studies,” in Proceedings of 13th International Teletraffic Congress, Copenhagen, Denmark, June 1991, pp 83-90.

[5] BE Helvik, “A model for real-time generation of ATM traffic from a large number of sources,” in Proceedings of 9th Nordic Teletraffic Seminar, Kjeller, Norway, August 1990, Session VI-3.

[6] K Kilkki, “Traffic characterisation and connection admission control in ATM networks,” Doctoral Dissertation, Helsinki University of Technology, Espoo, Finland, 1994.

[7] JW Roberts (Ed.), COST 224 - Performance Evaluation and Design of Multiservice Networks, Commission of European Council, 1992.

[8] T Holmström and U Körner, “Two algorithms for enhancing the performance of end-to-end transport protocols on top of ATM”, Proceedings of 12th Nordic Teletraffic Seminar, Espoo, Finland, August 1995, pp 325-338.

[9] ITU-T Recommendation I.371, Traffic control and congestion control in B-ISDN, International Telecommunication Union, 1994.

[10] RY Awdeh and HT Mouftah, "Survey of ATM switch architectures", Computer Networks and ISDN Systems, vol 27, pp 1567-1613, 1995.