# A failure restoration approach to congestion control in ATM networks

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**Abstract**

The use of backup virtual channels for traffic and congestion control is proposed and evaluated, as a complementary technique to be used by the network operation and management sub-system of Asynchronous Transfer Mode (ATM) networks. The basic idea behind backup virtual channels is to consider congested virtual paths as partially broken paths, and to deviate some of the traffic to virtual circuits on alternate virtual paths. Thus, this technique is an extension of failure restoration techniques, and treats congestion as a kind of failure that – as any other failure – leads to performance degradation.

The proposed technique is based on the pre-establishment of backup VCs that can be used immediately after the detection of a congestion state. This technique can be at the basis of complementary tools for ATM network operation and management, and thus is not intended to replace existing traffic and congestion control methods in ATM networks.

In order to evaluate the effectiveness of the proposed technique analytical methods are used, which enabled the quantification of the achieved congestion reduction for a variety of scenarios. Additionally, an algorithm for backup VCs establishment/deletion and traffic re-routing is presented, with the aim to illustrate the operation of the proposed technique when applied to the prevention of and reaction to QoS degradation.

**Keywords -** congestion control, network operation and management, backup VCs

## 1. Introduction and related work

ATM traffic control is basically made up of preventive procedures. When a service requests a connection, network resources are analysed and the connection is accepted only if the available bandwidth is enough, and if the established services are not affected.

Although Constant Bit Rate (CBR) services have well defined properties – which allows an easy estimation of relative network degradation – congestion is still possible when non-CBR

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services are also present, especially Variable Bit Rate (VBR) and Available Bit Rate (ABR) services.

As preventive methods are not sufficient for congestion avoidance, ATM networks must be prepared to detect service contract violations and react (e.g. selective cell discard, traffic shaping, fast resource management) when the network cannot guarantee the established services QoS.

In the presence of a congestion state, performance degradation can become equivalent to a complete failure, which suggests that one possible way to overcome this problem is the use of backup virtual channels.

The present study picks up and extends the work of [KAW94] and [AND94] to the resolution of congestion situations, using backup VCs. The referred studies were based in self-healing techniques suitable to ATM networks, in order to realise an highly-reliable B-ISDN with the ability to reconfigure itself in the occurrence of failures.

[KAW94] discusses the benefits of VPs and proposes the use of backup VP routes to create a fast restoration network. The route and bandwidth of a VP are defined independently, as the route is defined in the path routing tables of cross-connect nodes while the bandwidth is logically defined in the data base of the VP terminator and/or cross-connects as needed. So, the bandwidth of a backup VP is proposed to be 0. When a failure occurs it is only necessary that each node receives a restoration message, captures the appropriate bandwidth and retransmits the message to the next node on the backup route.

In [AND94] it is proposed not only the use of ATM network re-routing strategies but also the use of ATM error detection capabilities for enhanced failure detection, spare capacity allocation, as well as the use of the network control architecture and related implementation aspects.

The work presented in the current paper provides an analysis of the use of backup virtual channels for traffic and congestion control. The paper is organised as follows. In the next section the basic idea behind the use of backup VCs for traffic and congestion control is presented. In section 3 backup VC techniques are evaluated in terms of the ability to reduce congestion in a variety of scenarios. Next, in section 4, an algorithm for backup VCs establishment/deletion and traffic re-routing is proposed. The conclusions and topics for further work are presented in section 5.

## 2. Backup VCs for traffic and congestion control

### *2.1. Concept*

Self-healing ATM algorithms use re-routing techniques in the event of disrupted links. The same approach can be used when a VP becomes congested and cannot offer the requested QoS to established services, by re-routing a sufficient number of VCs in order to decrease the degree of congestion. For efficiency reasons, this re-routing should be done using pre-established backup VCs.

Backup VCs should be established when the total reserved bandwidth exceeds some threshold, as a way to account for temporary lack of capacity of the main VP. Another possibility is the permanent establishment of backup VCs for high priority and/or high QoS services, when the connection is requested. This will conciliate failure problems with congestion problems. The flow diagram for backup VC establishment is depicted in Figure 1.

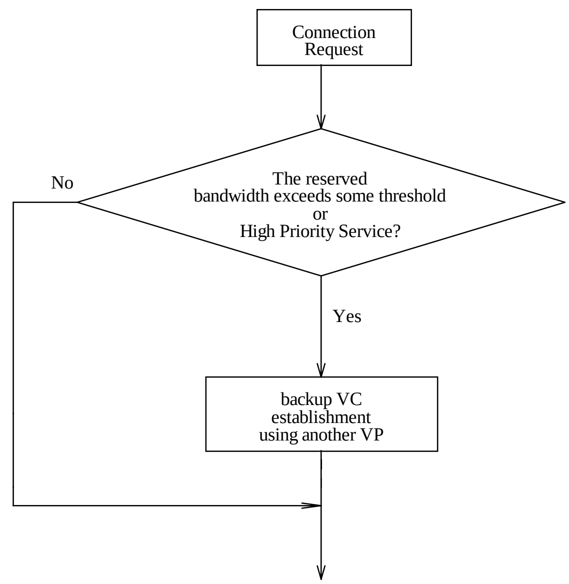


Figure 1 - Flow diagram for backup VC establishment

With this technique, when a congestion state occurs backup VCs are already established, and congestion recovery can be performed by simply changing the VPI and VCI values. Moreover, the network manager can effectively assign several backup VCs to very high-priority VPs in order to improve reliability.

In the time period following the re-routing phase – and before congestion is reach again – new backup VCs can be established to replace backup VCs which are being used and/or backup VCs that are being affected by the congestion.

Return-to-normal can be a complex problem if multiple re-routing occurs simultaneously. Moreover, return-to-normal transition can cause undesired traffic perturbation. As it will be describe in section 4, it is possible to avoid costly transitions if the congestion thresholds for the establishment and deletion of backup VCs differ by a given amount. Another approach to eliminate undesired traffic perturbation is to consider newly used backup VCs as main VCs. In this case it is also possible that the initial VCs become the backup VCs.

The establishment of backup VCs can be efficiently done by the network operator, in the context of network management operations, as the operator can have an accurate and updated knowledge of the committed resources and congestion state of all nodes.

*2.2. Zero bandwidth backup VCs*

Although it is necessary to respect the QoS level required by the service, the bandwidth initially requested for a given backup VC can be zero. With this approach it is possible to save bandwidth and only put it to use when congestion arises. Nevertheless, this strategy can only be applied to ATM networks. Other networks cannot offer an independence between routing and bandwidth. In ATM networks, this independence is due to different routing and bandwidth tables.

The establishment of zero bandwidth VCs is a compromise between the establishment of fully operational backup VCs – which consume network resources – and the non-use of backup VCs. With this approach, if congestion arises it will only be necessary that the source sends a restoration message along the backup VC. Each node receives the restoration message, captures the appropriate bandwidth on the backup VC, and then it is possible to re-route the respective services with the required QoS in order to diminish the VP congestion degree. Such a signalling mechanism will be much faster than the search for and the establishment of a new connection using broadcasting algorithms. The proposed technique simplifies the message transmission process and reduces the number of generated messages.

Each VP must be able to resize the required bandwidth in the presence of backup VC activation. It is also possible the multi-level use of backup VCs if there is an high probability of VP resize refuse.

## 3. Backup VCs evaluation

This section provides an evaluation of the effectiveness of the proposed congestion control technique. In order to evaluate this, some form of QoS measurement must be used. This is presented in sub-section 3.1. The assessment of QoS parameter values can be made in a number of ways. The present study uses analytical models for this purpose, which are referred to in sub-section 3.2. Sub-section 3.3 is the main sub-section of section 3, and presents a number of studies concerning the impact of the use of backup VCs on the reduction of the congestion level.

### *3.1. Congestion measurement*

Several congestion quantification methods have been proposed in the literature [ABE94], [BAI91], [ECK91], [SAI94]. Typically, these are based in one or more characteristics such as buffer occupation, throughput, delay, error rate, or cell loss probability.

For the sake of simplicity, the congestion measurement used in the present work is solely based on the cell loss probability. Cell loss probability is directly connected to the cell loss rate, which is specified for CBR services, real time Variable Bit Rate services and non-real time VBR services[3].

In ATM networks cell losses are mainly because of buffer overflows, synchronism loss and header errors. With the cell loss probability and the maximum buffer length under control, is also possible to get under control the per node cell delay. When the buffer has a length of K cells, the maximum possible delay is K*d, with d being the transmission time delay per cell. So, the cell is lost if the delay is greater than K*d [NAG91].

Table 1 shows different cell loss probability requirements for a variety of services.

Table 1 - Cell loss probability demands [LEE93], [ONV94]

[3] ATM-Forum group services

| | *Cell Loss Probability* |
|---|---|
| Voice | $10^{-3}$ |
| High Quality Voice | $8*10^{-6}$ |
| hi-fi stereo | $10^{-7}$ |
| File Transfer | $5*10^{-4}$ |
| Real Time Video | $5*10^{-6}$ |
| Videoconference | $5*10^{-6}$ |
| Video Retrieval | $10^{-6}$ |
| Broad. Inf. Retrieval | $10^{-4}$ |
| HDTV | $10^{-8}$ |

Cell loss probabilities presented in table 1 are specified between the source and the receiver. Assuming that the per node cell loss probability is very small and assuming n nodes with equal cell loss probabilities, $P_i$, the end-to-end cell loss probability is given by

$$P_t = P_i + (1-P_i)P_i + (1-(1-P_i)P_i)P_i + ... = n*P_i - (n-1)P_i^2 + (n-2)P_i^3 ... \approx n*P_i$$

Taking into account the example presented in [KAW94], where n is always less than 100:

$$P_i \geq P_t / 100$$

Usually, ATM switches guarantee a cell loss probability of $10^{-9}$ per node for CBR services and $10^{-7}$ per node for VBR services.

*3.2. Analytical methods for cell loss probability calculation*

In the last few years the scientific community has studied mathematical methods to analyse ATM switches and/or networks, with emphasis on the calculation of cell loss probabilities [SAI94], in ATM statistical multiplexing environments. In the present study, analytical methods for the calculation of cell loss probabilities were used, in order to reduce approximations and inaccuracies to an acceptable level.

A FIFO queue with a single server (figure 2) can offer accurate results when rigorous signal superposition methods are used, in order to respect the cell arrival correlation values. In the present work several analytical methods were used and evaluated [SIL96]: M/M/1, M/D/1, N*D/D/1, $N_1*D_1+...+N_XD_X/D/1$ and MMPP/M/1/K. These are summarised in Table 2, in what concerns the cell loss probability calculation.

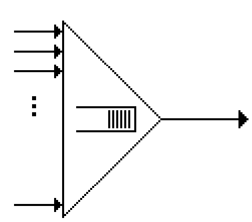

Figure 2 - FIFO Model

Table 2 - Cell loss probability (K = k = buffer length) for different analytical methods

| Analytical Method | Cell Loss Probability when *buffer length* =K |
|---|---|
| M/M/1 | $\rho)^{k+1}(1-\rho)/(1-\rho^{k+1})$ ρ = input rate / output rate <1 |
| M/D/1 | $1-(1-\rho)\sum_{s=0}^{k}\frac{((s-k)\rho)^{s}}{s!}e^{-(s-k)\rho}$ ρ = input rate / output rate <1 |
| N*D/D/1 | $\begin{cases} 0 & <= \quad k \geq N \\ \sum_{s=1}^{N-k}\binom{N}{k+s}(s/D)^{k+s}(1-s/D)^{N-k-s}\frac{D-N+k}{D-s} & <= 0 \leq k \leq N \end{cases}$ |
| $N_1{*}D_1+...+N_X D_X/D/1$ | (1-ρ) $\sum_{s=1}^{\infty} p_s(K) \leq Q_t(K) \leq \sum_{s=1}^{\infty} p_s(K)$ $Q_t$(K)-> cell loss probability<br>with<br>$p_s(K)=\begin{cases} q_s(K+s-\sum_i N_i[s/D_i] <= N_i[s/D_i] \leq K+s \leq N_i[s/D_i] \\ 0 \quad <= Others \end{cases}$<br>$q_s(K) = \sum_{\sum_i ki=K} (\prod_{i=1}^{m} b_{si}(k_i)) \quad <= \quad 0 \leq K \leq \sum N_i$<br>$b_{si}(K) = \begin{cases} \binom{N_i}{K}\alpha_{si}^{K}(1-\alpha_{si}^{K})^{Ni-K} & <= 0 \leq K \leq N_i \\ 0 & <= Others \end{cases}$ |
| MMPP/M/1/K | $\begin{cases} PQ_p = 0 \\ Q_p 1 = 0 \\ P1 = 1 \end{cases}$<br>Where Qp is the infinitesimal generator and P is the stationary state probability |

MMPP/M/1/K methods offer accurate results but, on the other hand, they need high computational time. CPU time is excessive when a large number of signals are superposed with MMPP models. To reduce computational time, 2-state MMPPs or 4-state MMPPs were tried.

M/D/1 and M/M/1 methods are fast methods, at the expense of inaccurate results. A Poisson distribution cannot offer rigorous results in statistical multiplexing. Cell loss probability results are always greater than the real ones. Only when a large number of signals are present can the Poisson distribution approach the accuracy of other models.

Given the above limitations, we decided to consider the queue which is produced when the burst composition remains fixed and each burst generates a periodic streams of cells, which means that the N*D/D/1 method could be used. N*D/D/1 had low computational times and could offer reasonably accurate results.

*3.3. Evaluation of re-routing scenarios*

The first part of this sub-section presents a set of studies that are intended to show how the cell loss probability depends on the type of the re-routed services. In general, the number of services to be re-routed in order to the cell loss probability to decrease to a given value depends not only on the re-routed bandwidth but also on other traffic properties. In the final part of this sub-section the backup VCs technique is evaluated in terms of its ability to reduce congestion. For congestion quantification, the deviation index concept is used, as mentioned in sub-section 3.1.

It is easy to understand that when the re-routed signals correspond to a high bandwidth the cell loss probability of the remaining signals will diminish abruptly. But the relationship is not linear. As it is shown later on, it is preferable to re-routed 45 signals of 128 Kbps than 1 signal of 28 Mbps. The studies presented in this sub-section use several types of services, which are identified in table 3.

Table 3 - Service types

| Signal Type | Service | Required Bandwidth |
|---|---|---|
| A | Compressed VBR High Definition TV | 28 Mbps |
| B | Compressed VBR Real Time Video | 2 Mbps |
| C | Compressed hi-fi | 128 Kbps |
| D | Compressed Voice | 4.8 Kbps |

The initial study corresponds to a situation where there are no re-routed signals and the overall traffic is made up of 2 signals of type A, 20 signals of type B, 50 signals of type C and 100 signals of type D. For this situation, the calculated cell loss probability was $10^{-13}$. In addition to the initial study, eleven other studies were made, corresponding to a variety of re-routing scenarios. These are identified in table 4.

Table 4 - Studied re-routing scenarios

| Study No. | Description | Total re-routed Bandwidth |
|---|---|---|
| 1 | 1 signal of type A re-routed | 28 Mbps |
| 2 | 2 signals of type A re-routed | 56 Mbps |
| 3 | 1 signal of type B re-routed | 2 Mbps |
| 4 | 5 signals of type B re-routed | 10 Mbps |
| 5 | 15 signals of type B re-routed | 30 Mbps |
| 6 | 1 signal of type C re-routed | 128 Kbps |
| 7 | 10 signals of type C re-routed | 1.25 Mbps |
| 8 | 45 signals of type C re-routed | 5.625Mbps |
| 9 | 1 signal of type D re-routed | 4.8 Kbps |
| 10 | 20 signals of type D re-routed | 96 Kbps |
| 11 | 90 signals of type D re-routed | 432 Kbps |

The next figure shows the resulting cell loss probability for each of the studied situations.

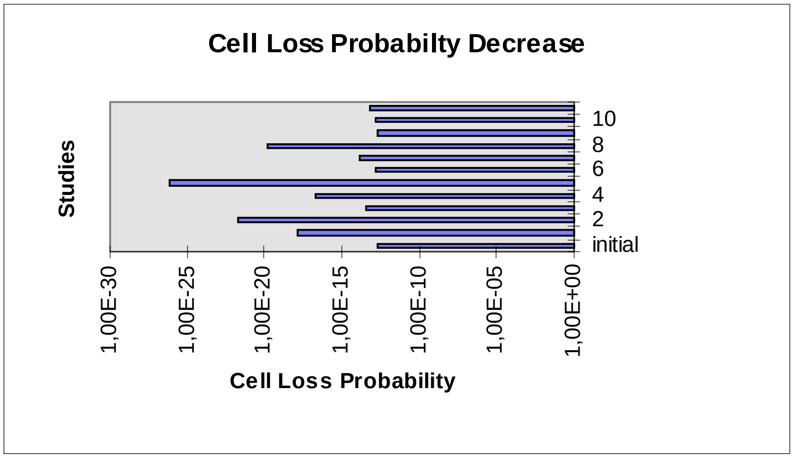


Figure 3 - Cell loss probability for the studied scenarios

As can be observed, the re-routed service bandwidth is not the only factor that diminishes the cell loss probability. For instance, figure 3 shows a greater cell loss probability decrease in study 5 than in study 2, although the total re-routed bandwidth in study 2 is higher. This can be understood if one considers that when a large number of signals are re-routed (even if they sum a small bandwidth) the probability of simultaneous arrivals decreases.

Lets now evaluate the effect of VCs re-routing on the congestion degree of a given VP. For this purpose we will calculate the deviation index of the cell loss probability QoS parameter of a 155 Mbps VP, when loaded with a varying number of tributary identical signals.

Figures 4, 5 and 6 present the cell loss probability when the VP tributary signals are VBR image transmission, file transfer and compressed VBR high definition TV, respectively. As can be seen in the figures, it is only necessary to re-route a small number of signals for the VP load to go down to satisfactory values.

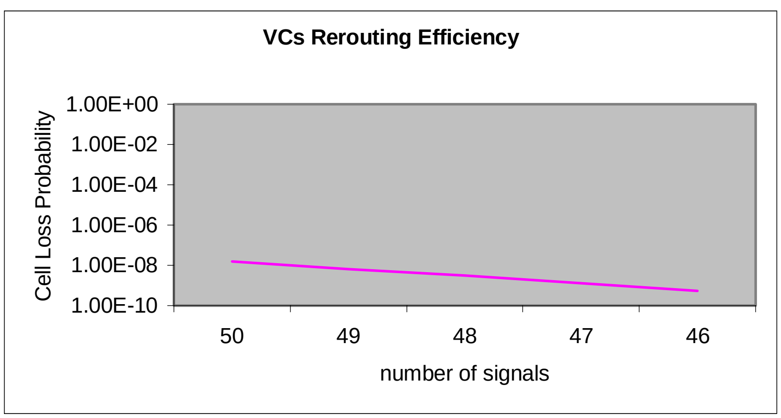


Figure 4 - VCs re-routing efficiency with VBR Image Transmissions
(compressed peak rate = 2 Mbps)

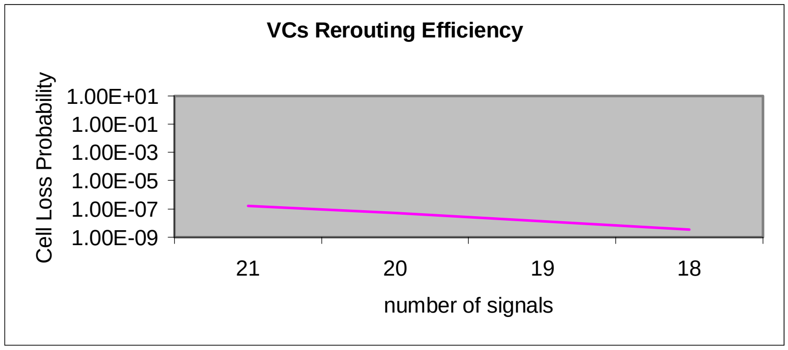


Figure 5 - VCs re-routing efficiency with File Transmissions
(compressed peak rate = 4 Mbps)

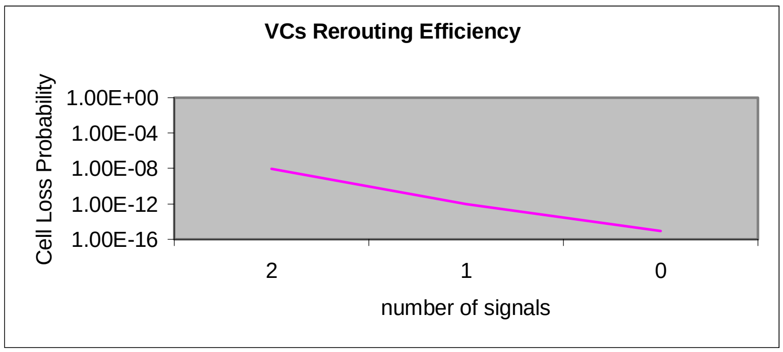


Figure 6 - VCs re-routing efficiency with type A signals re-routed

## 4. Procedures for backup VCs operation

The establishment and deletion of backup VCs, as well as the re-routing of tributary signals, can only be done efficiently by the network management and operation sub-system. This section presents basic procedures to be implemented by network management and operation, regarding backup VCs.

The birth, use and death of backup VCs depend on the observed congestion degree of each active VP. The general procedure for backup VCs operation is illustrated in figure 7.

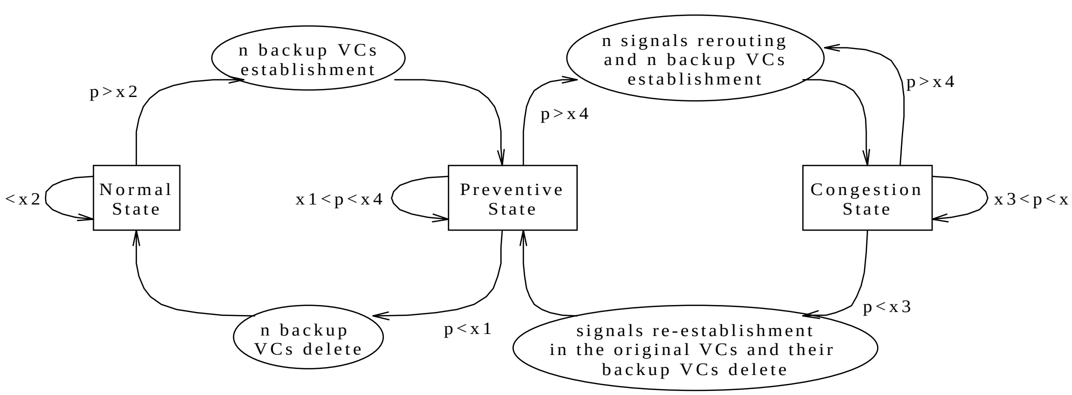

Figure 7 - General procedure for backup VCs operation

In this figure, **p** represents the congestion parameter, and $x_i$ are thresholds obeying the following relations: $x_1 < x_2 < x_3 < x_4$.

Backup VCs are established using alternate VPs, before the detection of a congestion state in the main VP. According to the proposed procedure, backup VCs are established when the congestion parameter **p** exceeds threshold $x_2$. The services will be re-routed to backup VCs when **p** exceeds threshold $x_4$. $x_2$ corresponds to the beginning of a congestion prevention zone. $x_4$ corresponds to the beginning of the congestion zone. When **p** goes below $x_3$ the services will come back to the original VCs, and at values less than $x_1$ the backup VCs will be deleted. $x_3$ and $x_1$ define the end of the congestion zone and the end of the prevention zone, respectively.

When a congestion state occurs the proposed algorithm has backup VCs already established, and so it is only necessary to send restoration messages to the VPs that accommodate backup VCs. Flooding algorithms generate a lot of messages and give rise to an exponential traffic increase. On the other hand, the proposed algorithm can offer low traffic processing overhead at low response times.

In the case of Available Bit Rate (ABR) services, it is interesting to study the combination of this algorithm with the controlled-rate cell flow, based on feedback information contained in Resource Management (RM) cells coming from the destination and/or the network switching nodes. One possible way of integration would be to issue the feedback information contained in the RM cell on its way back to the source only if there were no possibilities to establish and/or use backup VCs with the required quality of service.

## 5. Conclusions and further work

Typically, Asynchronous Transfer Mode backup virtual channels (VCs) and/or virtual paths (VPs) are used in the context of failure restoration. In the presence of a congestion state the Quality of Service (QoS) degradation can become so severe as a complete failure, and so it is interesting to study the use of backup channels in the context of congestion handling. In the present paper the use of backup VCs in ATM networks for traffic and congestion control was proposed and explored.

The evaluation of the proposed technique was done for a variety of scenarios and showed that – although extremely simple – the technique can effectively reduce the congestion level of affected virtual paths. The main properties of the proposed technique can be summarised as follows:

- efficiency - it is only necessary to re-route a small number of signals for the VP congestion to go down to satisfactory values;
- rapid response time - as the backup VCs are established before congestion is installed, the response time to congestion situations can be very short;
- low overhead - this technique imposes a minimal overhead, either in terms of bandwidth and in terms of additional control messages;
- efficient use of resources - bandwidth for backup VCs is only put to use when necessary ; after the resolution of the congestion situation, backup VCs can be deleted, which means

the corresponding resources will not be wasted;

- complementary to other congestion control techniques - the proposed technique should not replace existing congestion control techniques; it should be looked at as a network operations and management technique to be used in specific situations where it is possible to use alternate paths, and when it is important to assure certain QoS levels;
- simplicity - the technique is simple and does not require special protocols and/or complex control mechanisms.

In spite of these appealing characteristics, the technique is not problem-free. The main limitation is that the technique is only applicable when alternate virtual paths exist – preferably using distinct physical links – and thus it can only be viewed as a complement to other traffic and congestion control techniques. The main challenge – common to any congestion control technique – is to base its implementation on an effective way to measure congestion in real time.

On other hand, the proposed technique provides a number of issues that may be the subject of further work. For instance, it is necessary to devise ways for the calculation of the number of signals to be re-routed in order to decrease the congestion to a given level. The presented study used a N*D/D/1 model to calculate the cell loss probability, as a way to assess the congestion degree of virtual paths. In practice, what the network management tools will need is the opposite process.

One pragmatic solution to this problem could consist of simple algorithms that, according to the traffic properties, would re-route a fixed number of VCs on each iteration until the desired congestion decrease was achieved.

In order to evaluate the proposed technique, the present study was carried out using analytical methods. Although the evaluation showed promising results, these must be further explored by prototyping and/or simulation studies. We began to build our first prototype in software, to test the proposed technique. Plans are currently under way to use a MMC's ATMs2000 ATM Switch Engine that implements the complete core functionality of an ATM switch, in order to install and test our prototype software. In addition, we plan to complement the analytical work with simulation studies. For this purpose we will use [IMA97] and the NIST ATM simulator [NIS95].

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