An ATM Protocol for Local Access and Control of Internal/External Traffic

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Abstract

A new protocol is proposed to regulate the Local Media Access to a private Asynchronous Transfer Mode (ATM) switch as well as to control the flow of traffic that is either internal or external to such a switch. A mechanism, which guarantees a certain bandwidth by providing a fixed number of credits per timeslot to competing terminals, is modified to permit intermediate resets for those unsatisfied terminals. The intermediate resets are issued by a "master" that provides extra credits depending on the state of the total local network. These intermediate resets, together with a defined advanced granting procedure, are shown to significantly improve performance while guaranteeing an acceptable bandwidth provided by the wide area network. This work and related simulation results use only the emerging star configuration in local ATM networks.

I. Introduction

ATM switches with star configurations are becoming the new emerging Local Area Networks for customer premises. These switches are expected to support bursty traffic and constant bit rate terminals that range from video, to computer and voice equipment. The wide area access to these ATM switches is usually a transmission line with a predetermined bandwidth that can not be exceeded. Such a line can either connect to a public ATM switch or another private ATM switch. Also, the connection can be a SONET "pipe" or it can be a DS-1 or a DS-3 point-to-point or switched service. All these scenarios are possible and different industry segments have differing views on how it should be done. However, if one considers the emerging topology of a local star network connected by an external line of specified bandwidth (Figure 1), it is clear that a protocol is needed to regulate two key aspects. First the B-TE access to the ATM switch needs to be defined. Second and preferably simultaneously, a mechanism needs to be introduced to ensure that the aggregate traffic from B-TEs accessing external destinations does not exceed the specified bandwidth of the external line. Historically LANs had their own local contention protocols and complex gateways had to be built to permit LAN access to wide area lines without exceeding the available bandwidth in such lines. Current ATM standards assign these functions in ATM networks to the Network Termination unit (NT) between a switch and B-TEs. Private ATM switches incorporate these functions in the switch. Therefore, in our view, the private ATM switch in the middle of Figure 1, serves the function of a NT. The terms NT, control station, and private switch refers to the same unit in the context of GFC functions. In Figure 1 the links connecting switches and B-TEs are all refers to as User Network Interface (UNI).

Previous contributions to the ATM standards bodies addressed the continually changing requirements for ATM Generic Flow Control (GFC). Two competing proposals were analyzed by Chang et. al. [1]for a shared medium configuration. The AT&T proposal involved an adaptation of the Distributed Queue Dual Bus protocol while the competing BT/NTT proposal [2] was based on a modification of the Orwell slotted dual ring protocol [3]. Trends in the market place as well as the standard's bodies have recently emphasized only point-to-point star configurations while rings and buses are excluded. However, the protocol initially proposed by BT and NTT uses a credit authorization mechanism initiated by the control station, via a periodic reset, to the contending B-TEs; can still be applied to a star configuration. We have modified the elements of such a protocol to allow for intermediate resets with an advanced granting procedure. In addition, we show how this protocol can throttle the traffic that is either incoming from or outgoing to the Wide Area Network. Local

throttling and conservation of bandwidth is also provided. This paper defines the operation of such a protocol, describes the results of a simulation of a mix of typical traffic generators for an ATM network, and demonstrates the value added performance by this Intermediate Reset mechanism.

Since one single B-TE terminal can establish more than one single connection with local or remote terminals we will use here the conventions adopted by the standards bodies for virtual circuits and virtual paths (VCs and VPs).

II. Proposed Protocol

This proposal has some additions and enhancements to the BT/NTT protocol[2] for access control. In addition, this work defines an ATM layer link level flow control with a feedback mechanism in a customer premises network (CPN). The original BT/NTT protocol works as follows: a credit is allocated for each B-TE based on the average rate of expected traffic from that B-TE. A B-TE can transmit cells up to the limit of credit within a RESET cycle. At the end of the reset cycle of T (6 ms), a RESET is issued to every B-TE and allocated credit is restored. In [1] we have demonstrated that the protocol does not allow full utilization of the available bandwidth with bursty traffic, since B-TEs cannot transmit after using up their allocations, even when the bandwidth is available. Furthermore, the protocol does not address the case where a B-TE establishes multiple VP or VC connections, each with a different traffic requirement.

Our new protocol uses the same credit/reset mechanism with the reset cycle time of T (6 ms) and the priority mechanism. Some differences and additional features are:

- A request/grant mechanism is introduced to improve efficient sharing of available bandwidth. A source B-TE can request and be granted bandwidth that exceeds its credit limit in any cycle, using bandwidth that would otherwise be wasted.

- Bandwidth can also be given to all connections by shorting reset cycles with Intermediate Resets.

- This protocol operates per virtual channel connection rather than per interface link. The credit is periodically (every 6 ms) allocated per virtual channel for every B-TE.

- The use of this protocol as an ATM layer channel-by-channel (per virtual channel connection) flow control in a customer premises network is introduced. This can be extended within an ATM network with some provision.

II.1 Overview of the Proposed GFC Protocol

Upon initialization of a virtual channel connection, credit is allocated to a B-TE based on the channel's average rate or some operational traffic management criteria. Every reset cycle (6 ms), the control station (the NT) issues a RESET to every B-TE and the allocated credit for every virtual channel connection is restored. A B-TE can transmit cells up to the limit of credit for each of its connections within a RESET cycle. Among multiple connections within a B-TE, higher priority cells are to be transmitted first. The priority indication is tagged on each transmitted data cell. When a source exhausts the credit and if there are more data to send, a source can either wait until the next reset cycle to get the credit restored, or request to send by marking a REQUEST on the last credit data cell being sent. If there is a REQUEST outstanding, a GRANT may be issued by the NT, based on the availability of spare capacity within the RESET interval. Each GRANT may allow the source to transmit one cell, or a predetermined number of cells. In addition to granting requested additional bandwidth to individual connections, the NT could also send an Intermediate Reset before the end of cycle which will make the unused bandwidth available to all.

When a destination entity (e.g., a receiving B-TE, a local public switch output port) reaches a temporary congestion state, The destinationentity marks the FLOW CONTROL INDICATION to indicate the beginning of the flow control request (FCI REQUEST) and the end of the flow control request (FCI RELEASE). Upon receipt of the FCI, this protocol's function block immediately takes action to restrict the input flow of the source link traffic. The action is either to issue the STOP indication to halt the incoming traffic temporarily when the credit of the link is not exhausted, or to withhold the GRANT when the B-TE is in a request mode

This protocol uses the 4 bits GFC field in the ATM cell header reserved by the current ATM standard[4]. Codes for the field must be assigned to perform signalling of these functions: access priority, request/grant, traffic flow control indication and the traffic flow stop. Table 1 contains the summary of the signalling requirements for this protocol. The details of each mechanism for this protocol are described in the following sections.

II.2 CREDIT/RESET Mechanism

Basically the credit is assigned per virtual channel connection base and permission for sending traffic is automatically granted within the limit of the credit for the duration of reset cycle time of T (6 ms).This may be considered as an automatic grant mode.

Constant bit rate (CBR) traffic is guaranteed by assigning a credit equivalent to the peak rate and a high priority. Hence, CBR traffic is not controlled by this protocol. The minimum bandwidth of variable bit rate (VBR) traffic is guaranteed by assigning credit based on the predefined rate of a VBR source for the duration of the reset cycle T (6 ms).

Credit can be assigned fairly based on this protocol's operational policy among multiple VBR sources. For example, the credit range can be from 1 up to a value equivalent to the peak rate. Credit size of 1 is one ATM cell per RESET time which is approximately equivalent to 64 kbps (rate of 48 octets per 6 milliseconds).

The RESET indication is simultaneously effective on every connection of the B-TE and it restores the allocated credit for every connection accordingly. Unused credit is lost and is not accumulated when the next RESET is encountered. Regardless of which ATM connection cell the RESET indication is marked in, the RESET indication applies to all ATM connections on that interface. If the RESET indication cannot be piggybacked on an incoming data cell, a special cell is generated using any assigned ATM connection.

The RESET frequency (default is every 6 ms) may be changed to have the effect of dynamic credit allocation when there is sufficient bandwidth available among active users. The boundary condition would be that the sum of credits used in each RESET plus credits granted to individual connections within the master RESET period of T (6 ms) should not exceed the maximum allowable credit limit (with the rate of 150 Mbps, approximately 2120 credits).

In this way, dynamic credit allocation can improve the throughput and bandwidth utilization when the overall traffic load is light. The use of this variable RESET interval may depend on the management decision of the GFC control process and need not be subject to standardization.

For connectionless delay-tolerable data (such as LAN type traffic), some or no credits can be assigned based on the implementation. If no credit is allocated, the source has to request bandwidth before sending. Alternatively, a streamed RESET can be issued for an unlimited permit for sending without receiving requests and the flow control mechanism can be resumed when traffic load reaches the provision of a certain control level.

II.3 REQUEST/GRANT Mechanism

This mechanism is introduced to allow use of spare bandwidth. When an allocated credit of a bursty VBR source is exhausted during a reset cycle period, the source can send a request indication for additional traffic. Request indication has to be marked on a user data cell. When it arrives at the NT, it is automatically processed.

The request can be granted by the NT based on the predefined threshold value of the traffic load at that instant. This is considered to be a restrictive grant mode. This will prevent excessive traffic transmitted into a network. By issuing the GRANT based on availability, at any instant the spare bandwidth can be dynamically shared by other active sources that have exhausted their allocated credits. Each Grant allows transmission of one or more cells. The default is one cell, other values need to be negotiated.

II.4 PRIORITY Mechanism

This protocol supports the priority mechanism introduced by the BT/NTT in [3]. The user traffic will have three different priorities based on the sensitivity to cell delay variations (CDV): low CDV CBR traffic, low CDV VBR traffic, and other VBR traffic (e.g., connectionless best effort traffic.) When a B-TE maintains multiple concurrent ATM connections, it must transmit cells for high priority

connections first. Cells must be tagged with appropriate priority indication before transmission.

II.5 FLOW CONTROL INDICATION and STOP

When a destination entity (e.g., a receiving B-TE, a local switch output port) reaches a temporary congestion state, a flow control mechanism can be used to ease the situation by throttling the source. The congestion state can be declared by a predefined decision process based on a buffer status depending on a user implementation and is not subject to standardization.

A destination B-TE can mark the FLOW CONTROL INDICATION (FCI) to indicate the beginning of the request (FCI REQUEST) and the end of the request (FCI RELEASE).

If a source and a receiver are within the jurisdiction of the same control entity for this protocol, marking a flow control indication in this protocol field from the receiver to the control entity is sufficient. The control station can take immediate action to throttle the source. The public switches on the edge of a network can also issue the FCI towards a network termination (or control station) when necessary.

Upon receipt of the FCI-Request, this protocol function block can immediately take action to restrict the input flow of the source connection rate. The action can be one of the following:

- Issuing STOP indication when the credit of the B-TE is not exhausted: The credit is decremented by a half at the STOP instant in order to prevent a potential bursty situation when it resumes transmitting cells. Once the situation is relieved by the NT, the source resumes transmitting within the credit limit for the remaining duration of the RESET interval if the credit is greater than one. Otherwise, the source must run in a request mode. The STOP mechanism is effective within one RESET interval.

- Withholding the GRANT when the credit of the connection is exhausted and is in a request mode:

- The flow control state can be released by issuing the GRANT. This protocol releases control and the traffic on a connection resumes as usual when a release indication (FCI-Release) is received by a receiver entity.

The flow control state can be extended if necessary by issuing the STOP along with RESET indication at the next RESET cycle. Then the credit is restored (decremented by half immediately) but data transmission is stopped until the flow control state is released.

If an ATM connection is through a wide area network of public ATM switches, this flow control mechanism still applies, but would require conversion from the FCI to the network's backward or forward congestion control mechanism. Basically, the FCI Request from the source would be transmitted to the destination public switch using the Backward Explicit Congestion Control (BECC). The destination switch will then generate an ATM cell with FCI Request. Internal network congestions could also be handled similarly.

If an ATM connection is within an ATM LAN consisting of private ATM switches, the GFC flow control function applies to each link through the network, as each switch behaves as a control station for this protocol.

With this flow control mechanism at the ATM layer, a receiver entity doesn't have to depend on a higher layer flow control mechanism to throttle the source input rate. Consequently, the ATM layer transport function can admit traffic into a network more aggressively thanks to an effective and prompt feedback from a receiver entity. This will improve the effectiveness of flow control by reducing latency due to the control process delay and will result in higher network performance.

II.6 Granularity of the RESET Cycle

When an ATM cell is filled with one octet of data per 125 microseconds, the period, T, is 6 milliseconds (125 microseconds x 48), with a rate of 64 kbps. With such a granularity, the voice packetization delay is 48/8k = 6 ms when the 48 octets are considered as the information field size. If the layer above the ATM layer, the ATM Adaptation layer (AAL) uses AAL type 1, the packetization delay would be 47/8k = 5.875 ms. The additional procedural delay will be expected to introduce

approximately 1 ms from arrival at the ATM layer to transmission at a terminal. Therefore, the proposed reset time interval, T, is a minimum of 6 ms to 7 ms (default is 6 ms).

In an ATM switch in an ATM LAN environment, each output port of the ATM switch is a common pool of shared bandwidth. In this view, the output port connected to the public UNI is the output port for remote traffic heading for the public ATM network. Although the guaranteed CBR traffic is given preference over VBR traffic by the GFC function, the statistical sharing of bandwidth between competing B-TEs without prior bandwidth reservation is a great concern for GFC control.

III. Performance Simulations

This section presents the results of a simulations of this protocol under various traffic load conditions. We first present the configurations of the network simulated, and the traffic pattern used. Next we discuss experiments done on variations of the protocol elements to examine the effectiveness of the control functions. Finally, the results of simulations are presented.

III.1 Configurations and Traffic Patterns

All simulations use a star network configuration with 32 terminals. The effect of the lengths of the links between the control station and the B-TE's is also considered by taking into account the propagation delay (at 5 microsecond/km) of the line.

Tests are performed using different traffic types and configurations (link lengths). In the following tables the values for these parameters are given. Table 2 shows the two traffic patterns used in the tests. Table 3 shows the link lengths chosen for each link in each of the seven test scenarios.

As shown in Table 2, the traffic patterns consists of a combination of CBR and VBR sources. The CBR traffic can be divided in high and low bit rate and the VBR has different mean bit rates as well as different burst characteristics. There are two types of VBR traffic sources: deterministic, which have always the same burst rate and exponential, which have an exponential distribution for the burst length. Table 2 also shows the traffic type of each B-TE for the two different traffic patterns.

III.2 Variations on Properties of the Protocol

The first set of simulations represent only the basic elements of this protocol a fixed number of credits per reset cycle, which guarantee a certain bandwidth for each B-TE, and a Request/Grant mechanism to allow the VBR B-TE's to exceed this minimum guaranteed bandwidth.

In later simulations a new mechanism is introduced, called "Intermediate Resets". This mechanism allows the control station to issue Intermediate Resets to increase the performance above the guaranteed bandwidth for all VBR sources. A decision making process then determines if the "Intermediate Reset" is possible within the total available bandwidth.

The access delay for the very bursty B-TE's can become a problem because the number of credits given to each B-TE is only based on the "mean bit rate". In a separate series of simulations an "advanced granting" mechanism is introduced which grants each request a fixed number of credits. This number is based on both the mean bit rate and the burst rate, thus improving the performance of the very bursty traffic sources.

Intermediate Resets

Intermediate Resets are issued before a normal reset is initiated. The normal reset is given every 6 ms (2119 cell times) and the Intermediate Resets are issued according to the process described below. This process is initiated when a B-TE has used up its allocation and sends it Request for more bandwidth. Whenever a REQUEST is received an Intermediate Reset is issued if the following inequality is true:

Cell_Ctr + TOT_credit <= Max_Ctr - CBR_credit - Margin

where, Cell_Ctr: number of cells transmitted since the last reset;
TOT_credit: total amount of credits given per reset;
Max_Ctr: total number of available slots during one cycle;
CBR_Credit: total amount of credits given for CBR traffic;
Margin: maximum number of cells transmitted by the B-TE before reset is received.

This way it is possible to assure there will be enough

bandwidth left for the credits issued. If no such check is made, it would be possible to issue more credits than available slots. The "Margin" parameter is used to account for the cells the B-TE's could have transmitted cells between the time the calculation is made and the reset reaching the B-TE. "Margin" is the maximum possible number of cells in transit and is based on the length of the link and the number of B-TE's. Long links need a margin of about 500 cells since there are 32 B-TE's and the delay between the control station and B-TE is 16 cell times (10km links). The Intermediate Resets can be issued any time within the reset cycle because the rule will make sure the credits will not exceed the available bandwidth. The Request/Grant mechanism will be used in case no more resets can be given. The protocol "fine tunes" the performance in this way.

Advanced Granting

The Intermediate Resets improves the performance for bursty VBR B-TE's by issuing extra credits. The amount of credits assigned to each B-TE is calculated using only the mean data rate. The performance for VBR can be improved by also taking the burst length into account. In the advanced granting mechanism, each request can be granted with multiple credits instead of only one. The number of credits issued with a grant signal is calculated by:

$$Credit[k] = TE[k].mean_data_rate * TE[k].burst_length / 10$$

where, Credit[k]: the number of credits issued per grant;
TE[k].mean_data_rate: mean data rate of this B-TE;
TE[k].burst_length: number of cells generated during a burst.

A decision making process has to be used to assure that the grant will not issue more credits than available slots. Grants may be issued when the following inequality is true:

$$Cell_Ctr + Credits < Max_Ctr - Margin$$

where, Cell_Ctr: number of cells transmitted since the last reset
Credits: total amount of credits given per Grant;
Max_Ctr: total number of available slots during one cycle;
Margin: maximum number of cells transmitted by the B-TE before reset is received.

This will ensure that there will be enough slots for the credits given. The "Margin" parameter has the same role as in the Intermediate Reset equation and is calculated using the same values.

III.3 Tests Performed

A total of seven test scenarios were simulated. Test 1 and test 2 are similar with test 1 simulating long links, while test 2 simulates short links. Both represent the most straightforward implementation of the protocol. Test 3 investigates the influence of link length. Different link lengths are used with alternative traffic pattern as given in table 2 (traffic pattern II). This is also an implementation of the normal Request-Grant mechanism. Test 4 and test 5 are the same simulations as test 1 and 2 respectively but now with Intermediate Resets. Test 6 uses the same configuration and traffic pattern as test 3, but with Intermediate Resets. Test 7 simulates a configuration with long links and Advanced Granting.

A reference test run was also made. This test is the simulation with long links without any form of Request/Granting or Intermediate Resets. It is clear that the results are not acceptable. Mean access delay and mean queue length are very long, especially for the VBR B-TE's.

III.4 Analysis of Expected Delay Times

To verify the simulation results, a simple statistical analysis has been made of the different traffic types. Based on the burst length and distribution, it is easy to give an indication of some maximum and minimum access delay times.

For CBR traffic, it is all very easy. Each time, a cell is generated there are enough credits allocated for the cell to be transmitted immediately. This implies that the Mean Access Delay time for CBR can be 1 cell time at most.

Deterministic VBR will always generate 200 cells at a time. If there are enough credits, all cells can be sent after each other. The mean access delay time will be:

This is the absolute minimum mean access delay and

$$\frac{1}{200}\sum_{n=1}^{200} n = 100 \ \textit{cell times}$$

only the simulations with the best performance (Intermediate Reset, enhanced granting) will be able to show figures close to 100 cell times. If there are a limited number of credits (12 per 6 ms in this case), extra delay will be introduced by the reset waiting time. In the worst case this will be:

$$\frac{1}{200}\sum_{n=1}^{12}(n*T_{slot}+T_{res}) + \ldots\ldots \sum_{n=1}^{12}(n*T_s$$

$$\frac{1}{200} * 3{,}747{,}676 = 18738 \ \textit{cell times}$$

The reference test will show a mean access delay time in the same order, but slightly lower than this worst case estimate.

The analysis of the exponential VBR traffic types is harder to make than for the deterministic traffic type. Mean access delay is determined by the number of cells generated in a burst and number of credits given. All exponential traffic types have a high average bit rate which gives a high credit allocation. Due to this high allocation, the B-TE seldom waits for a reset. If a burst of 20 cells is generated, the mean access delay for these cells will be 10 cell times. But since the burst length is distributed exponentially, it is possible that one burst with 40 cells is generated while another could have zero cells, i.e. an average of 20 cells. The first burst has a mean access delay of 20 cell times, while the second "burst" is not accounted for in the results. Therefore, based on the average burst length, the mean access delay times of the exponentially distributed VBR sources will be much higher than expected. A more precise analysis of the different VBR sources is beyond the scope of this paper.

III.5 Simulation Results

The performance of the protocol is measured in terms of mean access delay and queue length at the B-TEs. The access delay is defined to be the delay between the time a cell is generated and transmitted. The simulation results are shown in Figures 2 through 7.

The results for Test 1 are good compared to the reference test, offering short delay times and queue lengths for the CBR terminals and reasonable delays and queue lengths for the VBR sources. Only the very bursty B-TE's have considerable delays. This is because their credits will be exhausted in a short time (the number of credits is based upon the mean data rate) and since only one single request can be outstanding the data rate is very limited under the request grant mechanism. The typical round trip delay for a request-grant pair is in the order of 0.1 ms, which is about 30 cell times.

The results for Test 2 are comparable to the results for the long link. The only important difference is noticeable for the type 4 B-TE's (very bursty traffic type). The round trip delay for the Request/Grant on a short link is only 0.02 ms, which is about 6 cell times.

Test 3 shows there is a direct relation between the mean access delay for traffic type 4 and the link length. The Request/Grant mechanism is only feasible for very short links.

Test 4 shows that the introduction of Intermediate Resets gives a spectacular reduction of the mean access delay and mean queue lengths, especially for the most bursty traffic type (type 4). It is obvious, however, that an increase in the traffic load of the network will reduce the impact of the Intermediate Resets since there will be no more credits to spare.

Test 5 shows that the impact of Intermediate Resets on the mean access delay and the mean queue length on the short link configuration is less spectacular than that for the long link. However, this configuration shows the important improvement introduced by the Intermediate Resets.

Test 6 shows the impact of Intermediate Resets on the different link lengths. Again it is clear that the Intermediate Resets cause a big reduction of both mean access delay and mean queue length.

Advanced granting in Test 7 is used to realize a reduction especially for the bursty VBR B-TE's. The simulation shows that indeed a good improvement can be obtained with enhanced granting. The performance reached with enhanced granting depends

to a large extent on the number of credits given with each grant.

IV. Performance with Increasing UNI Interface Speed

The protocol is suitable for all UNI interface rates, and its performance gets more interesting with higher rates. Compared to protocols with a fixed credit allocation and no Intermediate Resets or Advanced Granting, this proposal can scale up to higher rates and take advantage of the higher bandwidth. The original BT/NTT GFC protocol which allocates credits based on mean data rates of the B-TEs, could be configured in such a manner that it utilizes almost 100% of the offered bandwidth at the interface. If, however, the interface rate is increased, say from OC-3 to OC-12, the utilization drops to 25%. Our proposal, with its Intermediate Resets, is able to fill the additional bandwidth by issuing extra Resets, even if the allocation stays the same.

References

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[3] J. Adams, "T1S1.5/93-146 Features and Codepoint Assignment of the BT/NTT GFC," June 7-11, 1993.

[4] CCITT Recommendation I.361, B-ISDN ATM Layer Specification, June 1992

Acronyms

AT&T American Telephoneand Telegraph Corporation
ATM Asynchronous Transfer Mode
B-NT2 Broadband ISDN Netw orTerminal 2
BT British Telecom Corporation
B-TE Broadband ISDN Terminal Equipment
CBR Constant Bit Rate
CDV Cell Delay Variation
CPN Customer Premise Network
DS-1,3 Digital Hierarchy Rates
FCI Flow Control Indication
GFC Generic Flow Control
LAN Local Area Network
NT Network Terminal
NTT Nippon Telephonand Telegraph Corporaon
SONET Synchronous Optical Network
UNI User Network Interface
VBR Variable Bit Rate
VC Virtual Channel
VP Virtual Path

Table 1 Signalling Requirements for theProposed GFC protocol

GFC Signalling Requirement	
Signal	Signalling Mechanism
B-TE towards NT & Network*	
PRIORITY	On every data cell for the VC
REQUEST	On the last data cell exhausting VC's allocation
FLOW CONTROL REQUEST	On any data cell for the VC or special cell
FLOW CONTROL RELEASE	On any data cell for the VC or special cell
NT to B-TE	
RESET	On any data cell for any VC or special cell
GRANT	On any data cell for the VC or special cell
STOP	On any data cell for the VC or special cell
Network to NT	
FLOW CONTROL REQUEST	On any data cell for the VC or special cell
FLOW CONTROL RELEASE	On any data cell for the VC or special cell

*The NT should pass transparently all signals to the network, except for REQUEST which it must process.

Table 2 Patterns of Traffic Sources Simulated

Traffic Type	**CBR/VBR**	**Mean Bit Rate**	**Mean Burst Length (cells)**	**Traffic Pattern I (B-TE number)**	**Traffic Pattern II (B-TE number)**
I	CBR	34 Mbit/s		25	
II	CBR	2 Mbit/s		1	
III	CBR	64 Kbit/s		2,9,10,17,18,26	1,9,17,25
IV	det. VBR	700 Kbit/s	200	6,11,16,22,27,32	2,8,10,16,18,24,26,32
V	expo. VBR	25 Mbit/s	2	4	
VI	expo. VBR	25 Mbit/s	20	20	7,15,23,31
VII	expo. VBR	1 Mbit/s	3	3,5,7,8,12,13,14,15,19,21,23,24,28,29,30,31	4,12,20,28
VIII	expo. VBR	20 Mbit/s	30		
IX	expo. VBR	6 Mbit/s	3		6,14,22,30
X	expo. VBR	700 Kbit/s	10		3,11,19,27
XI	expo. VBR	1.4 Mbit/s	10		5,13,21,29

Table 3 Link Length Configurations

Test Number	**Link Length [km] B-TE 1-8**	**Link Length [km] B-TE 9-16**	**Link Length [km] B-TE 17-24**	**Link Length [km] B-TE 25-32**
1, 4 and 7	10	10	10	10
2 and 5	2	2	2	2
3 and 6	0.2	1	5	10