A Comparison of ATM Service Categories with a Modification of the ABR Control Scheme

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ABSTRACT

Over the last few years, LAN technologies have been driven by the need to support an increasing number of users as well as bandwidth intensive applications. As new and existing network applications evolve to embrace high-resolution graphics, video and other rich media types, pressure is growing at the desktop, the server, the hub and the switch for increased bandwidth. All this has led to new network protocols needed to support the amount of information required.

In this thesis, we will briefly review conventional networking protocols and internetworking devices. Then we present a table comparing different ATM service categories. Also we propose a modification of a proposed finite ABR control scheme with a fewer number of states.

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CHAPTER I

PROBLEM DEFINITION

Over the past years, LAN technologies have evolved from increasing number of users as well as from bandwidth intensive applications. Yet a major constraint in the design of today's computer network still persists due to the available bandwidth. As a result, today's users are facing many problems due to delays in data transmission, interruption in service, difficulties in relocating work stations and limited flexibility. In addition, as the number of workstations annexed to each network segment increased, the amount of bandwidth per station decrease resulting in poor performance on some networks. Consequently, fewer networks are capable of running multimedia applications such as workstation based video conferencing or video on demand (VOD).

As the new and existing network applications evolve to embrace high-resolution graphics, video and other rich media data types, pressure is growing at the desktop, the server, the hub and the switch for increased bandwidth. In other words, the majority of existing networks, connected by bridging and routing technologies have neither the throughput nor the performance characteristics required for this type of problems.

In other words, few conventional solutions were presented: The first solution could be to replace the current LANs, such as Ethernet and Fast Ethernet with fast LANs, that provide 100 Mbps of shared bandwidth [16] which is no more than a short-term solution as we shall later demonstrate.

The second solution would shift from shared to switched media knowing that switches and bridges are similar but nevertheless switches have higher aggregate bandwidth and lower latency. Furthermore, switches support full-duplex operations and provide users with dedicated ports. On the other hand, the usage of switches facilitates the migration from an architecture to another, thus rendering any connection to ATM or Fast Ethernet LAN possible, namely Gigabit Ethernet networks. Moreover, switches can form logical LANs overlaying physical LANs creating VLANs and facilitating eventually the broadcasting task [16].

Previous solutions give a temporary solution for the congestion on existing desktop LANs, and they do not provide the user with adequate relief in most backbone situations.

Another problem is that today, in most instances, separate networks are used to carry voice, data and video information. This is simply because these traffic types have different characteristics. For instance, data traffic tending to be "bursty" (not needing to communicate for an extended period of time and then needing to communicate large quantities of information as large as possible). Voice and video tend to be more even in the amount of information required, that is because of their sensitivity when and in what order the information arrives.

In this thesis different network protocols are presented, three kinds of internetworking devices; in addition to an overview on the asynchronous transfer mode. The first comparison is made between different networking protocols, the other between different ATM, and finally a modification of the ABR control scheme is proposed.

This thesis is organized as follows: Chapter 2 makes the introduction and presents different existing networking protocols, Chapter 3 introduces the inter-networking devices and Chapter 4 is an overview on ATM. Chapter 5 compares different ATM category of service, and the Chapter 6 proposes a formal specification of ATM control scheme. Finally, the conclusion and future research are in chapter 7.

CHAPTER II

INTRODUCTION

Networking has become an integral and rapidly growing part of every aspect of our life. With more users, the addition of new data intensive applications, and the increased needs for the latest high performance PCs and servers, today's networks are inundated. Keeping up-to-date is often a challenge and high speed networking technologies are becoming necessity because of the increase in bandwidth requirements of different types of traffic. Some of those traffic types along with their bandwidth requirements are shown in figure 1 below [16].

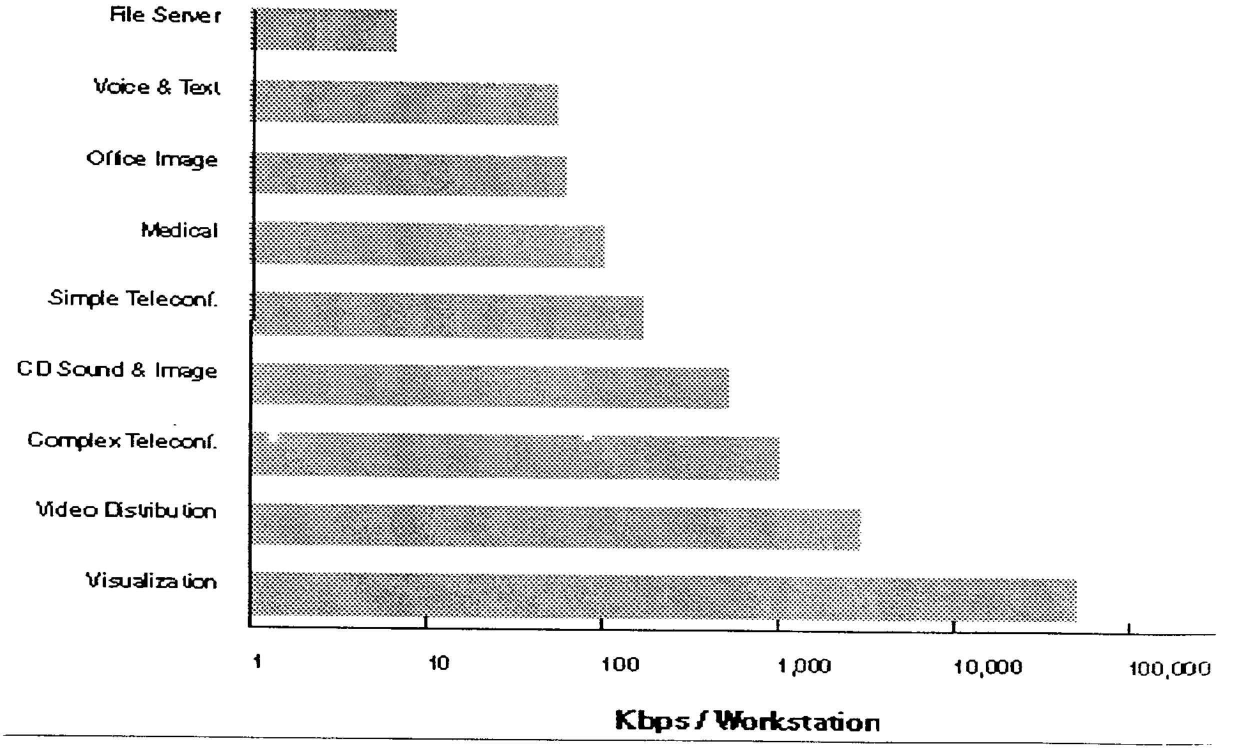

Fig. 1. CURRENT BANDWIDTH REQUIREMENTS. (study done in 1997, by IBM corporation).

We note, for example, that a traffic type which includes CD sound and image and complex teleconferencing requires about 1,000 Kbps, video distribution requires approximately 1,500 Kbps, and visualization requires more than 16,000 Kbps. In the following sections, we will briefly review the basic elements needed to form a computer network.

2.1. Connection Types

A computer network is used to link a number of computers , together, in order to share information and network other resources such as CD-ROMs, printers, plotters, etc. A Local Area Network (LAN) is a computer network situated in a small geographical area like a single building. In order to form a LAN each computer has to contain a Network Interface Card (NIC) connected to a networking device such as a hub or a switch using wire (coaxial, twisted pair, fiber optic, or even wireless using, for example, radio frequency). Information usually transmitted from one station to another in the form of packets that contain a header and a trailer used to identify the destination address.

The following sections describe the common connecting devices, mainly hubs and switches.

2.1.1. Hubs:

A hub is one form of central connection point used to link all the ingredients of the network in order to form it. A typical hub has multiple user ports to which computers and peripheral devices such as servers are attached. When a packet is transformed to the hub by one station it is repeated over onto all of the other ports of the hub. Using this technique all of the stations can "see" every packet (a hub being a shared media), which is only copied, inside the destination station [11].

2.1.2. Switches:

A switch is another type of device used to form a LAN or to link several separate LANs. A switch comes with multiple ports, each of which can support a single end station or an entire LAN. Switches can occupy the same place as hubs, but unlike hubs, they examine each packet and forward it to the destination port rather than simply repeating it to all ports (referred to as filtering) [11]. This way a switch reserves a dedicated bandwidth for every connection allowing multiple connections to take place in parallel.

The following figures depict the main difference between a shared media hub and a switched (dedicated) connection using a switch.

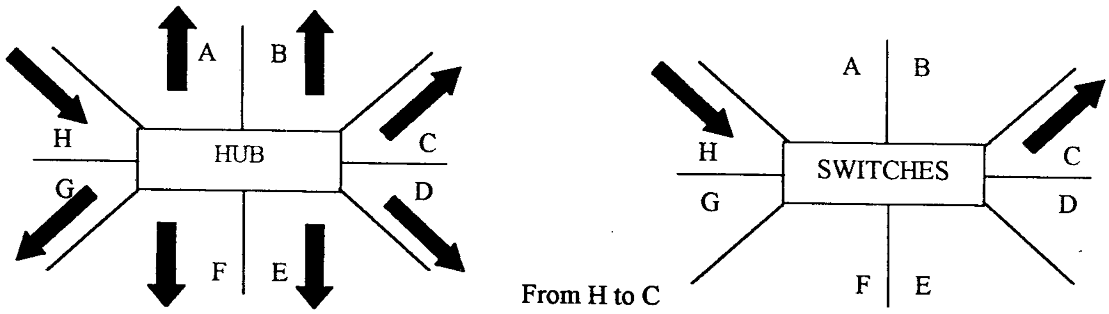

Fig. 2. HUBS VERSUS SWITCHES

In the next section, we continue our discussion by briefly reviewing main LAN protocols.

2.2. Networking Protocols

Network protocols are standards that allow computers to communicate. A protocol defines how computers should identify one another on a network, the form that the data should take in transit, and how this information should be processed once it reaches its final destination. Protocols also define procedures for handling lost or damaged transmissions or packets. The following section review major LAN protocols beginning with the Ethernet and ending with the Asynchronous Transfer Mode, better known as ATM.

2.2.1. Ethernet

Ethernet is the historical name of a protocol known as CSMA/CD (Carrier Sensor Multiple Access with Collision Detection) specified in the IEEE 802.3 standard. Using Ethernet, before a station can send data, it has to sense the network media first, if the network is free the station transmits its data, if not it wait and tries to transmit later. The major disadvantage of Ethernet protocol is that it is possible for two stations to transmit simultaneously resulting in a collision.

2.2.2. Token Ring

The access method used on token ring networks is called token passing which only one station can transmit at any given time. This is accomplished by passing a special token frame or packet around the ring. A station can only transmit when it gets the free token else it has to wait for another turn [21].

2.2.3. FDDI

FDDI is a 100 Mbps networking technology, based on timed-token-passing-network-access methodology that employs a dual ring topology, i.e. which is comprised of two token rings.

2.2.4. Fast Ethernet

Recent advantages in computing technology have caused a bandwidth crunch where simple Ethernet has proved to be insufficient because it no more fulfill the need of the client. This bandwidth crunch is due to three factors, high speed of computer processors, increased number of users in a network, and last but not least bandwidth-intensive applications. These factors resulted in the 100 Mbps Fast Ethernet protocol [14].

2.2.5. Gigabit Ethernet

Gigabit Ethernet is a local area network transmission standard which provides a data rate of 1 billion bits per second (1 gigabit). It is generally used as an enterprise backbone transmission line that carries data together from smaller lines that are interconnected with it. The Gigabit Ethernet offers a natural upgrade path for current Ethernet based networks as it uses the same CSMA/CD protocol, frame format, and frame size as in Ethernet and Fast Ethernet.

2.3. A Comparison of Different LAN Protocols

The objective of this section is to strike out a critical comparison between the advantages and disadvantages offered by many network protocols. It aims at showing that when dealing with video conferencing, video distribution and interactive multimedia all those protocols yield place to the ATM network (to be discussed later).

2.3.1. Token Ring Advantages Over Other Protocols

The Token Ring protocol presents many advantages over the other protocols. First, it prevents data collision by sending one token, with a large maximum frame length sent at one time over the network. It uses the network effectively by using 70 to 75 % of the total bandwidth available, compared to Ethernet which uses up to 40 % of the total bandwidth. In addition, token ring has an excellent traffic handling compared to Ethernet (17.8 Kbps in token ring versus 15 Kbps in Ethernet). The token ring supports transmission priority, which eliminates fluctuating responses. Token ring bypasses inactive stations, offers a high reliability by carrying out the normal operation against possible breakdowns. Besides, its easy tracking method for hardware problems enables it to repair automatically some network errors, for instance, the initiation of a new token ring when the old one is lost [23].

2.3.2. Ethernet Based Protocols Advantages

The Ethernet networks are usually built after the star-wired technology. It is a reliable technology in that if one connection is lost the others will continue working.

A major advantage of Ethernet based networks is their scalability whereby the uniqueness of the frame format for all Ethernet based protocols and the existence of fast Ethernet and Gigabit Ethernet, the migration to a higher performance for a higher bandwidth without disturbing the existing network becomes possible. Moreover, the existence of 10/100 and 100/1000 switches, allow the users to upgrade the backbones without having to change the original architecture.

Two other additional points make the Ethernet more advantageous. First the low cost of the Ethernet technology peripherals. The second one is the diversity of cabling, i.e. thin, thick, twisted pair, or fiber optic.

2.3.3. Gigabit Ethernet Advantages

Upgrading existing Ethernet networks to Gigabit Ethernet or installing a Gigabit Ethernet as the network backbone will result in an increase of the bandwidth provided by Fast Ethernet and Gigabit Ethernet. Moreover, the emergence of new protocols such as Resource Reservation Protocol (RSVP) will provide bandwidth reservation, and that of new standards such as 802.1Q and 802.1p, which will provide VLAN and explicit priority information for packets in the network. Finally, such upgrade will help facilitate the widespread use of advanced video compression such as MPEG-2.

2.4. A Look to the Future

Past literature has revealed that the emerging, Ethernet-based shared media fast LANs, which provides significantly more bandwidth per station than comparable Ethernet and Token Ring LANs, helps relieve congestion on existing desktop LANs. In relation to the workgroup, the switched Ethernet and switched Token-Ring implementations are very effective for running legacy applications. The addition of an ATM uplink (the main subject of this thesis) to an ATM backbone helps relieve the access bottlenecks from workgroups to servers and other resources located on the backbone. In brief, some legacy applications of shared media LANs, for e.g., data entry, will always be easily accommodated on today's low cost networks. However the more important workstations (telephone, storage facility, backboard, fax and virtual conferencing room) will eventually fall back onto dedicated-media ATM for all the optimal services the new applications necessitate.

In recent times, ATM networks are being implemented across desktops, backbones, and wide area networks (WANs). The cell-swifting technology, rather than packet switching, is the basis for ATM and ensures high-speed, scalable bandwidth with excellent network performance (A cell is a fixed size packet). ATM also integrates mixed isochronous traffic (image, video, voice, and audio) with traditional data.

Although ATM can be considered as an extension to LAN switching, yet it differs from LAN in a number of ways, which makes ATM networks superior. In addition to all the advantages of LAN switching, ATM is scalable, compatible with existing LANs and applications (such as LAN emulation, classical Internet Protocol (IP)) and supportive of all standards-based cabling system. Furthermore, ATM provides an excellent network performance, a minimized routing function, seamless LAN-to-WAN migration and reduced ownership costs as a result of simplified network management. In conclusion, applications demanding higher bandwidth or employing voice, video (multiple video streams and simultaneous file transfer), or multimedia, ATM seems to be the answer for the future.

In the next chapter, we continue our discussion of networking devices, mainly bridges, routers, and switches.

CHAPTER III

INTERNETWORKING

Internetworking means linking many LANs together to go beyond what a LAN can support, and to be able to share the traffic between multiple inter-worked LANs. Internetworking is accomplished by connecting different LANs using three major types of inter-networking devices: bridges, routers and switches. This chapter reviews the characteristics of bridges, routers, and switches for better insight into the coming chapters.

3.1. Bridges

There is a time when the number of stations on network can go beyond what a single LAN supports. Bridges are introduced to split a physical network into two or more independent physical segments. Bridges operate on layer 2 and hence are faster than routers though less intelligent. Hence additional protocols are vital in order to "route" traffic across them and to prevent loops and broadcast storms [18].

Figure 3 and 4 below, illustrate a complete bridge topology and a broadcast operation.

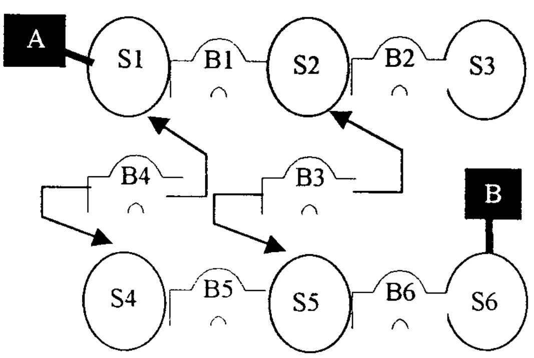

Fig. 3. BRIDGES TOPOLOGY

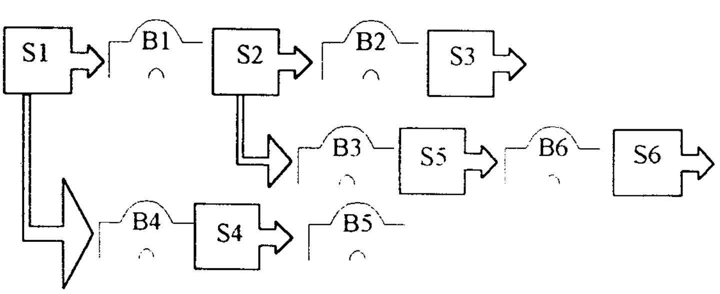

Fig.4. BROADCASTING USING BRIDGES

3.2. Routers

Routers are more expensive than bridges. In addition to their use of the Network Layer Protocol Information (NLPI) to determine whether to filter the packet or not, routers also try to determine the best path by inter-communicating. In addition routers recalculate the checksum and rewrite the MAC header of every packet, but the price paid is an extra time spent inside the routers, and the benefit of routers is their automating filtering or broadcast. Since routers operate at layer 3 of the OSI reference model, as shown in figure [5], hence they are slower than bridges, and they distinguish between different network layer protocols (IP, IPX, AppleTalk,.....). Consequently, routers have enhanced intelligence over bridges and switches. They have more software features than a switch, and make more promising forwarding decisions than switches. Routers also eliminate broadcast storm propagation, transmission of packets from unsupported protocols and so forth [18].

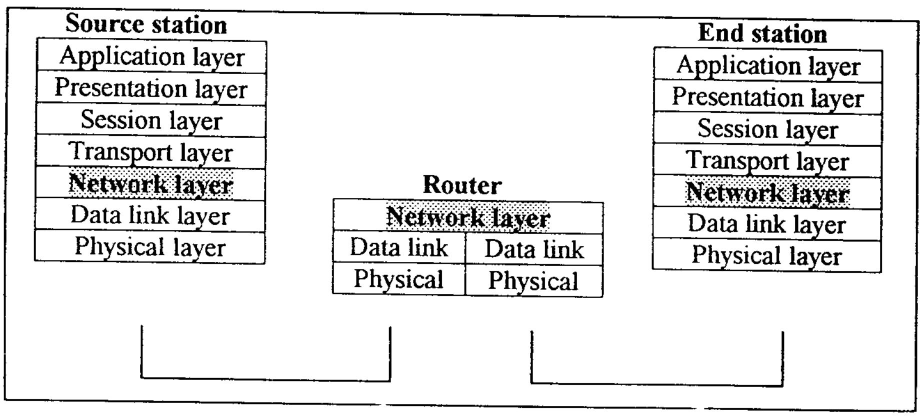

Fig. 5. LAYER 3 OF THE SEVEN LAYERS OSI REFERENCE MODEL.

To create and maintain a routing table, one must have a routing protocol. Actually, any additional frame processing performed by a router increases latency, especially if the latter belonged to the new generation of routers which are quite faster.

Bridges and routers are used to link adjacent LANs together, in order to provide inter-network connectivity particularly over long distances where hubs have their limitations. They can also be used in order to segment LANs, filter packets from one LAN in another decreasing as such the number of users by segment.

3.3. Switching

In relation to switching, bridges and routers can also act as linkers between many LANs. In other words, their different ports, that connect each with a different kind of LANs, are able to filter a certain packet between them. Filtering the data in a switch occurs after the packet has been examined and processed through the destination address.

Switches can be considered as intelligent as bridges supporting numerous transmissions simultaneously. Like bridges, they segment large network into many smaller collision domains providing thus higher percentage of bandwidth to each end-station, less congested networks and increasing the network performance (by providing dedicated bandwidth to power users). In addition, switches allow bandwidth to be scaled in both shared and dedicated LAN segments.

The switches' protocol transparency allows them to be installed in a network running multiple protocols with little software configuration that can use the available cable plants and end-stations adapters [12].

Moreover, switches are totally transparent to end-stations making administrative overhead very low. They are scalable which allows for growth and are available for 10, 100, and 1000 Mbps.

In the following chapter we present an overview of ATM.

CHAPTER IV

AN OVERVIEW OF ATM

ATM was devised by the International Telecommunication Union & Telecommunication Standardization Sector (ITU-T) Study Group XVIII set out to develop Broadband Integrated Services Digital Network (BISDN) for a higher speed transfer of voice, video, and data through public network. This venture dates back to 1991 when Cisco systems, NET/ADAPTIVE, Northern Telecom, and Sprint founded the ATM Forum.

Nowadays "Asynchronous Transfer Mode" (ATM) networks are being implemented across desktops, backbones, and wide area networks (WANs). The basic characteristic of the ATM is the cell-swifting technology which provides high-speed, scalable bandwidth with excellent network performance. Another seminal characteristic is the ATM integration of mixed isochronous traffic (image, video, voice, and audio) with traditional data as shown in the below figure.

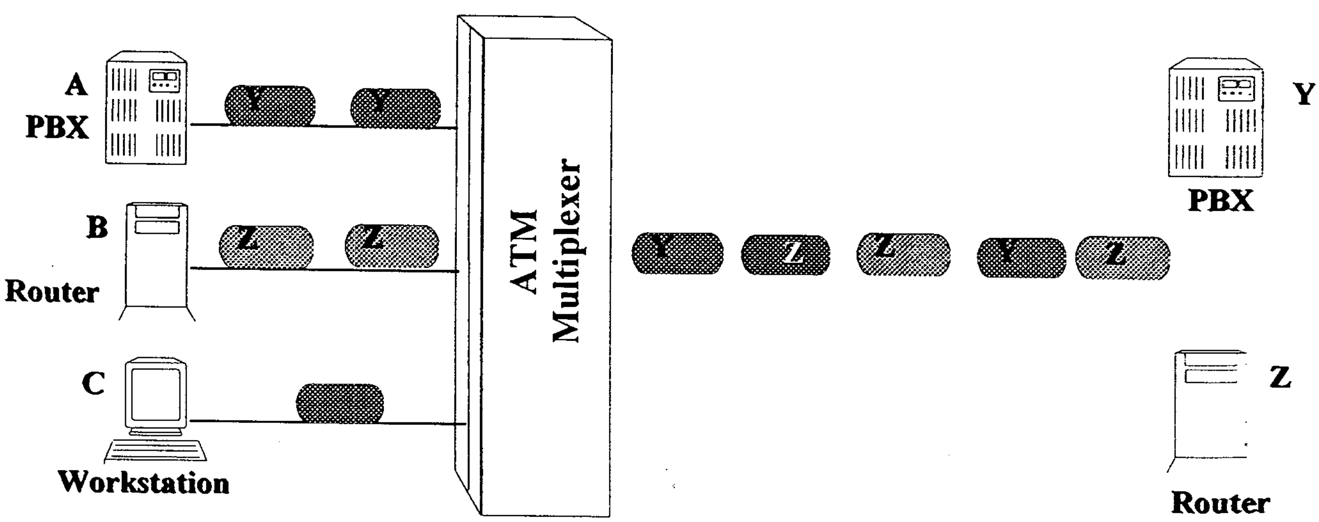

Fig. 6. ASYNCHRONOUS TRANSFER MODE

The asynchronous transfer mode is thus a method of formatting, multiplexing, cross-connecting, and switching information which is divided into small cells, each labeled with a connection identifier. Hence its name "Asynchronous", which implies that cells do not necessarily arrive, nor are they delivered at constant rate.

Figures 7, 8 and 9 show where the ATM layers fits compared to the OSI reference model.

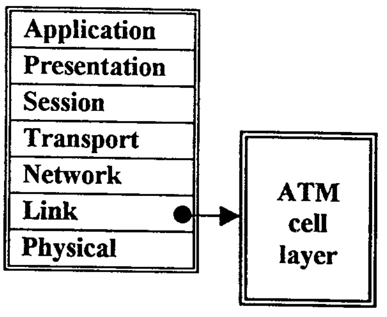

Fig. 7. WHERE ATM FITS.

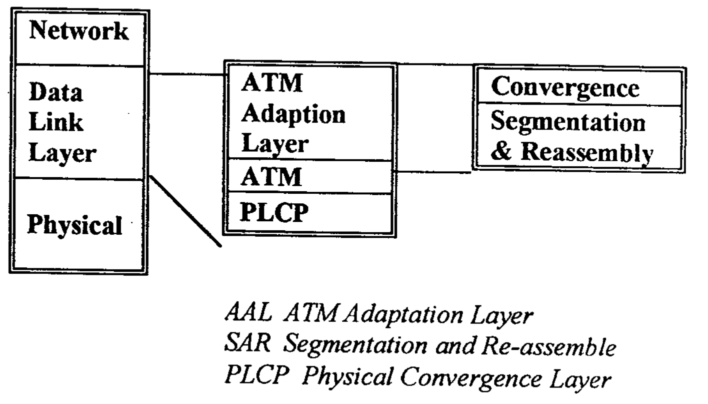

Fig. 8. LAYERS ASSIGNED WITH ATM

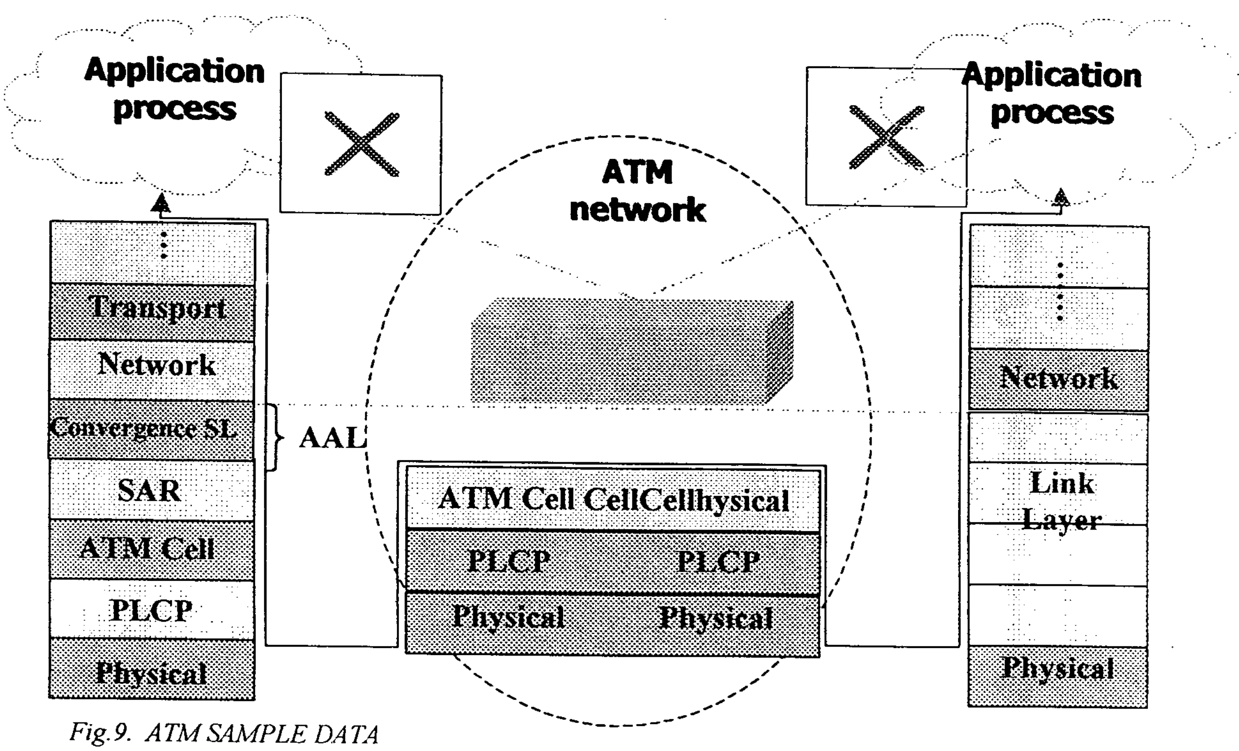

Fig.9. ATM SAMPLE DATA

4.1. ATM Cell Characteristics

The ATM uses VLSI technology to segment data (e.g. frames from the data link layer of the OSI reference model) at a high speed. The hardware is much easier to design when the cell size is known in advance. Small fixed cell buffers in an ATM switch can be designed at the hardware level because the queue size needed is accurately predicted. The small fixed size unit of five bytes for the header and 48 bytes for the payload facilitate the transmission of the time sensitive traffic types and that by minimizing the response time.

The addressing and control are contained in each cell allowing low processing overhead, flexibility to support multiple services, and independence of transmission interface. As shown in Figure 10 the cell header format of an ATM cell can have two different formats.

UNI cell header format [2]

GFC	VPI	VCI	PT	CLP	HEC
4 bits	8 bits	16 bits	3 bits	1 bit	8 bits

NNI cell header format [20]

VPI	VCI	PT	CLP	HEC
12 bits	16 bits	3 bits	1 bit	8 bits

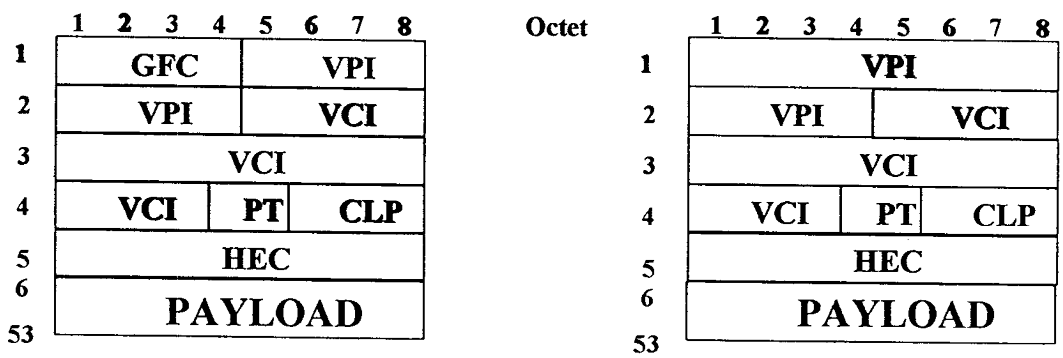

Fig. 10. ATM CELL HEADER FORMAT

- Generic Flow Control (GFC): Identifying multiple stations that share a single ATM interface (not used yet).
- Virtual Path Identifier (VPI): Identifying the next destination of a cell as it pass through an identifier series of ATM switches through to its destination.
- Virtual Channel Identifier (VCI): Identifying next destination of a cell as it passes through an identifier series of ATM switches in its way to its destination.
- Payload Type (PT):

  1st bit = data or control data.

  2nd bit = data congestion.

3rd bit = last in a series of cells that represent a simple AAL5 frame.

- Congestion Loss Priority (CLP): If the cell should be discarded upon encountering extreme congestion when moving through the network.
- Header Error Control (HEC): Checksum calculated only on the header itself

5.2. How ATM Works: Adaptation and Multiplexing.

Using the ATM adaptation layers different kinds of traffic can be formatted to fit into ATM cells, then inside the ATM switch they will be multiplexed in order to be transported as an ATM output trunk consisting of many kinds of traffic types.

Adaptation and multiplexing can be shown explicitly using two graphs as shown below.

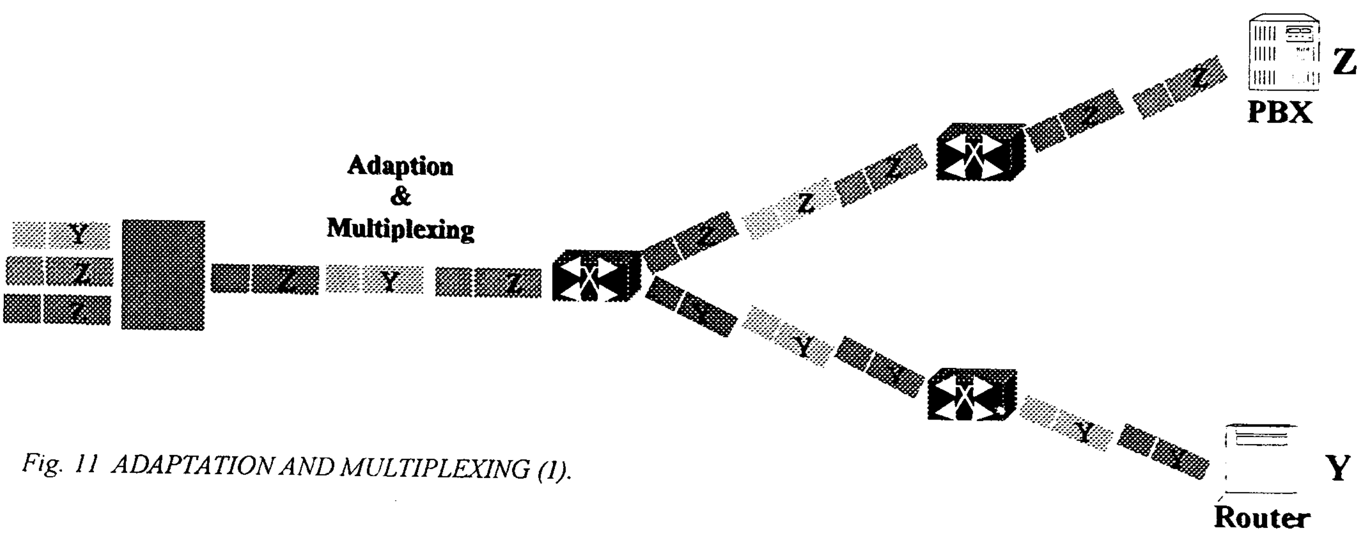

Fig. 11 ADAPTATION AND MULTIPLEXING (1).

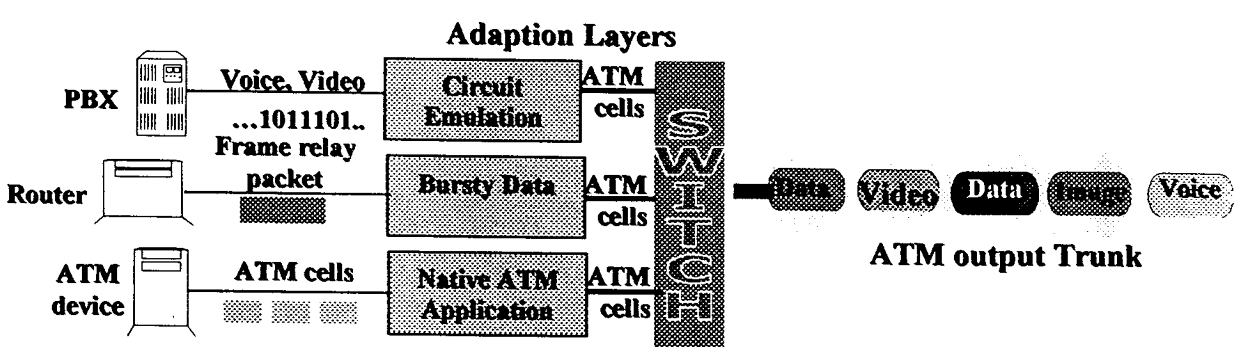

Fig. 12. ADAPTATION AND MULTIPLEXING (2).

A keyword of ATM configurability and flexibility: One of the prime goals of ATM is to support different kinds of services with different traffic characteristics. ATM services are split into four classes. Class A & B for critical application such as speech, sound and video- having a constant bit rate for variable ones can not be tolerated. Class C, for the typical data channel between two end-points, where timing is not important and cell loss is unacceptable. Finally the class D, which simulates connection-less data-transmission, which is very common in LANs.

4.2.1. ATM Adaptation Layer

Classes that require correct time rather than correctness of data such as class A, compensate for cell loss by using previously received information. Others that require correctness of data such as C, retransmit the data in the case of cell loss[1].

	Description	Bit-rate	Type	Class
AAL1	ATM adaptation layer1 supports connection-oriented services that require constant bit rate and have specific timing and delay requirements. A typical translation of this can be found in digitized voice or video (which consists of a constant stream of data).	Const.	Connection-oriented.	A
AAL2	ATM adaptation layer 2 supports connection-oriented services that do not require constant bit rates, but which have timing and delay requirements. It is targetted on compressed video or sound.	Var.	Connection-oriented.	B
AAL3/4	ATM adaptation layer 3/4 is intended for both connectionless and connection-oriented services with variable bit rates. AAL3/4 were originally two separate adaptation layers, but have since been merged into a single AAL.	Var.	Connection-oriented and connection less	C/D
AAL5	ATM adaptation layer 5 supports connection-oriented	Var.	Connection-	C/D

	services that require variable bit-rates. A typical translation of computer communication, which is characterized by short bursts of data transfer. Delay and timing are not crucial. AAL5 is a simpler AAL than AAL3/4, at the expense of error correction and automatic retransmission, but pays off with less bandwidth overhead and reduced implementation complexity. AAL5 can be also implemented in silicon.		oriented and connection less	

Table 1. ATM ADAPTATION LAYER DIVISION.

4.2.2. ATM Reference Model

Figure 13 presents the ATM reference model.

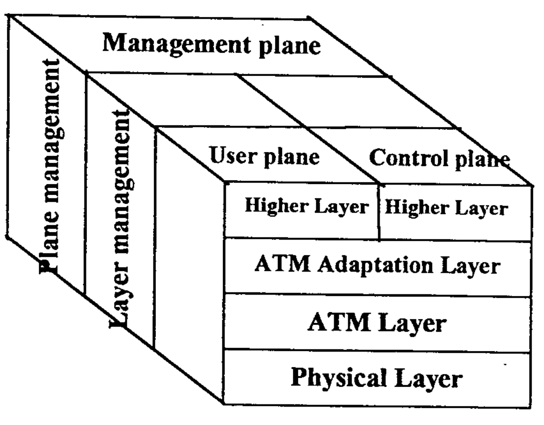

Fig. 13. ATM REFERENCE MODEL.

The OSI reference layer is not supported by the ATM which has its own reference model. Whereas ATM layer and ATM adaptation layer are similar to the data link layer of the OSI reference model, the ATM physical layer is also similar to that of the OSI reference model. Secondly the control plane is responsible for generating and manipulating signaling requests, the user plane is responsible for managing the transfer of data. We may safely conclude saying that ATM adaptation layers, such as AAL1, AAL2, AAL3/4, AAL5 are higher layer protocols representing traditional transports and applications [19].

4.3. Addressing

ATM uses the sub-network model of addressing which is responsible for mapping network layer addresses to ATM addresses [19].

Data Country Code (DCC)

AFI (39) 1	DDC 2	DFF 1	AA 3	Reserved 2	RD 2	Area 2	ESI 6	Sel 1

International Code Designator (ICD)

AFI (47) 1	ICD 2	DFF 1	AA 3	Reserved 2	RD 2	Area 2	ESI 6	Sel 1

Network Service Access Point (NSAP) or E-164

AFI (45) 1	E-164 8	RD 2	Area 2	ESI 6	Sel 1

AFI	Authorization and format identifier	Area	Area identifier
DFI	Domain specific part (DSP) form identifier	ESI	End of system identifier or IEEE802 MAC
AA	Administrative authority	Sel	NSAP selector
RD	Routing domain		

Table 2. ADDRESSING METHODS

4.4. Connection Types and Services

ATM supports the point-to-point connection type that can be unidirectional or bi-directional and also the point-to-multi-point which is unidirectional only as shown in figure [14].

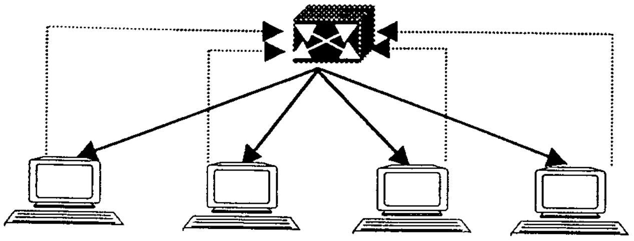

Fig. 14. MULTIPOINT-TO-MULTIPOINT BROADCAST

ATM does not support multi-point-to-multi-point links. Since the AAL5 standard does not provide a way for the receiver to identify individuals cells from specific resources - when cells are interleaved from multiple sources- a proper re-assembly of the cells of a specific frame are sent in proper order, without any interleaving. A solution for the multipoint-to-multipoint disability is the use of multicast server which can exist in an ATM network, where all members of a multicast group can establish point-to-point VCCs to it. The multicast server would then create a point-to-multipoint VCC to all members of the group, with itself at the root.

4.4.1. ATM Virtual Circuits

ATM Permanent virtual connection (PVC) service operates similar to a frame relay, where virtual connection mesh, partial mesh, or star is administratively established through ATM network. Such architecture offers a direct ATM connection between routers, simple specification and subsequent implementation.

Figure 15, represents a physical channel, divided into virtual paths and virtual circuits.

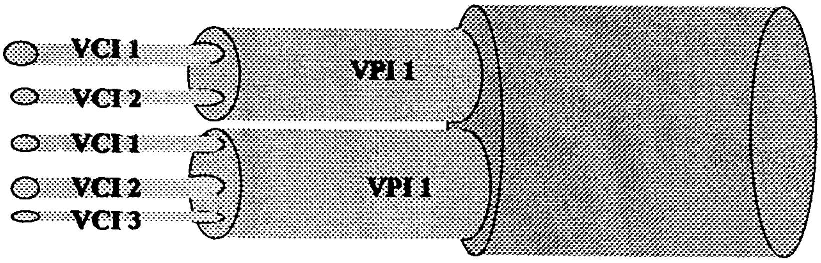

Fig.15. VIRTUAL CIRCUITS.

Virtual circuits represent logical connections between end points. We may have two types of virtual circuits: Firstly, the permanent virtual circuits (PVC) are always up (persists for long intervals), and need human intervention because they are created by network operators. Secondly, the switched virtual circuits (SVC) which are established on demand and exist for the life of a call, require call signaling procedures (which are requested via signaling from user to network and include bandwidth and QoS in request).

Virtual channels and virtual paths are jointly called virtual circuits, knowing that virtual channels are multiplexed into virtual paths [19].

Virtual Channel service.	Virtual path service
6 Each network has committed information rate 6 Network switches on both VPI and VCI 6 Each VC can only have one class of traffic only	6 Each VP has committed information rate 6 Network switches on VPI only 6 Each VP can only have one class of traffic only

Table 3. VIRTUAL CHANNEL AND PATHS SERVICES.

4.4.2. ATM Switches

ATM switches use the VPI and VCI fields of the cell header to identify the next network segment that a cell needs to transmit on its way to its final destination. Whereas a virtual path is a logical grouping of virtual circuits, which allows an ATM switch to perform operations on groups of virtual circuits, a virtual channel is equivalent to a virtual circuit that is both describes a logical connection between the two ends of a communication connection. Thus, the main function of an ATM switch is to receive cells on port and switch them to the proper output port based on the VPI and VCI values of the cell. A switching table that maps input ports to output ones is dedicated to this switching [19].

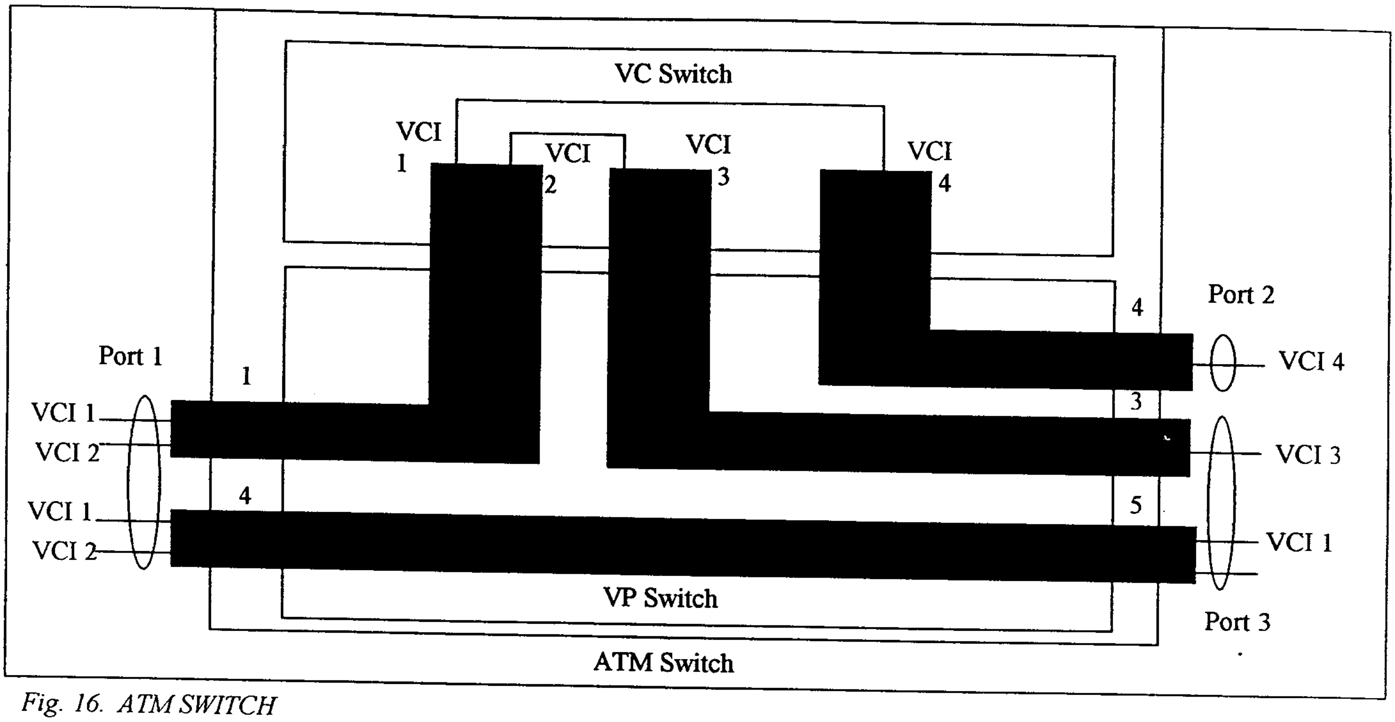

Fig. 16. ATM SWITCH

The diagram above reveals that the cells entering ATM switch on port 1 having a VPI =4 are processed through the "VP switch", which in its turn changes the VPI value of each cell to 5, leaving the VCI intact and sending the cell on to port 3. Concerning the cells entering the ATM switch on port 1 having a VPI =1 and VCI = 1, the VC switch changes the VPI to 4 and the VCI to 2 and sends them on to port 2. As to cells entering the ATM switch on port 1 having a VPI = 1 and VCI= 1 2, they are processed by the VC on to port 3 with a VCI = VPI = 3.

Maintenance of virtual connections through an ATM switch when two cells arrive on port 1 of the ATM switch: the switch examines at first the VPI and VCI fields of cell 1, coming on port 1, and check if the fields have values of 6 and 4, respectively (corresponding to the output port 3m where VPI =2 and VCI = 9). The switch then examines the VPI= 1 and VCI =8 of the second cell coming out of port 2 (corresponding to the output port 2, where VPI = 4 and VCI = 5).

	Input			Output	
Port	VPI	VCI	Port	VPI	VCI
1	1	8	2	4	5
2	4	5	1	1	8
1	6	4	3	2	9
3	2	9	1	6	4
.	.	.	.	.	.
.	.	.	.	.	.

Table 4. SWITCH INPUT OUTPUT

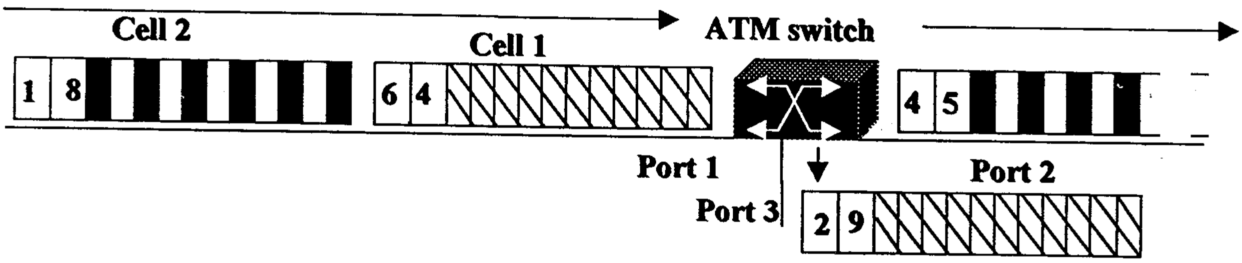

Fig. 17. SIMPLE PRESENTATION

4.5. Signaling

When two ATM devices such as Routers A and B want to establish a connection, router A sends a signaling request packet to its directly connected ATM switch, where the signaling packet is reassembled, examined and then forwarded through the switch address table.

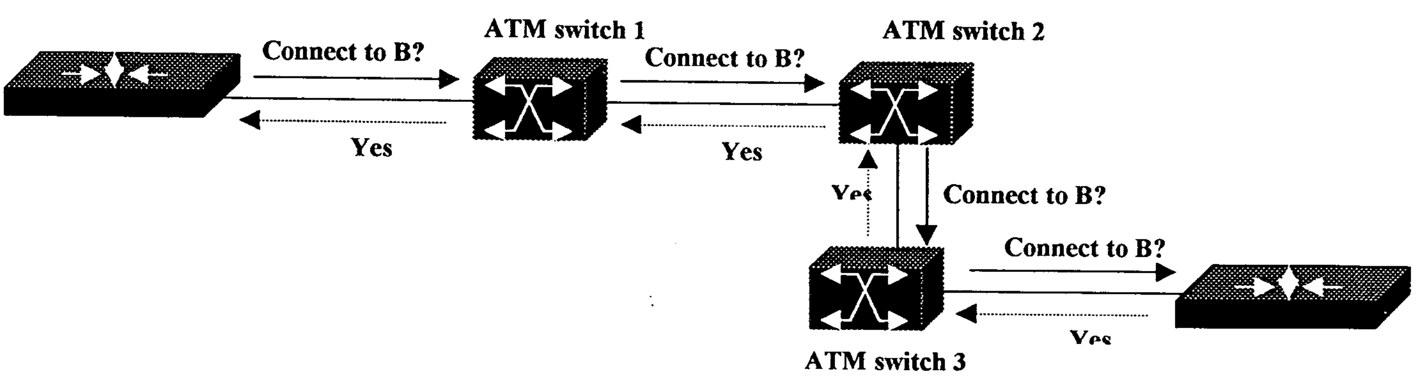

Fig.18. SIGNALING SIMULATION

While the message is forwarded from one switch to another, it is either rejected and sent back to the originator of the request- if any switch along the path can not accommodate the requested QoS parameters- or it is reassembled and evaluated when the signaling packet arrives at the endpoint (router B). If the endpoint can support the desired QoS it responds with an "accept" message [19].

4.6. Quality of service (QoS)

When an ATM end-station with an ATM network, it is essentially making contract with the network based on QoS parameters. The latter are mainly the value of the peak cell rate(PCR), the average sustained cell rate (SCR), burst size (BS), the cell loss ratio (CLR), cell transfer delay (CTD), cell delay variation (CDV). The contract specifies an envelope that describes the intended traffic flow. The QoS are divided into two parts: traffic shaping and traffic policing. At first it is the responsibility of the ATM device to adhere to the contract by means of shaping:

- Use of queues to constrain data bursts
- Limit peak data rate
- Smooth jitter for the traffic to fit into the promised envelope

Second, ATM switches have the option of using traffic policing to enforce the contract by measuring the actual traffic flow and comparing it against the agreed upon traffic envelope. If the traffic is outside the agreed upon parameters, the switch can set off the CLP bit of the offending cells- makes it eligible to be discarded, that means the cell can be dropped by any switch when handled in congestion period [19].

The congestion control is the primary concern of ATM designers. In FDDI dropping one cell results of the retransmission of 93 cells, which can lead to more congestion. Traffic policing and shaping are simulated in figure 19.

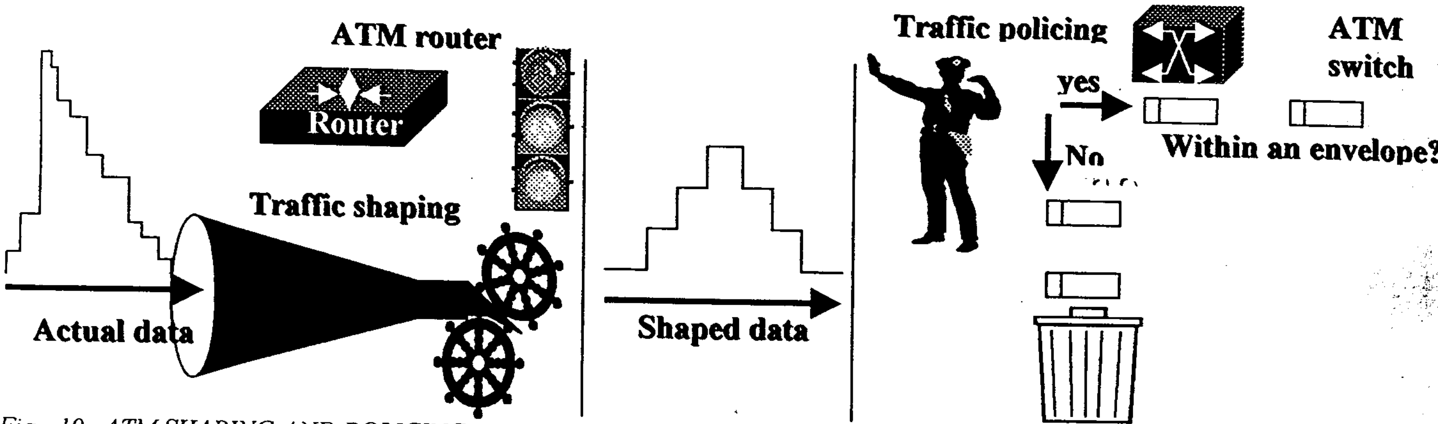

Fig. 19. ATM SHAPING AND POLICING

4.6.1. The Purpose of Traffic Management

The traffic management main functions are to protect the network and the user in order to achieve "adequate" network performance, optimize and control the usage of network resources, prevent the network from becoming a bottleneck. Moreover, it is easy to accomplish the traffic management in circuit-switched network because of the random traffic patterns, contention for network resources, and the buffer overflow, cell loss, especially that retransmission can create devastating conditions in the network

4.6.2. Elements of Traffic Management in ATM

When a call arrives with a certain class request, traffic descriptors and quality of service requirements the network decides to accept or reject it using the Call Admission Control (CAC) algorithm. Once a call is accepted, traffic is shaped for it. This is a network policy by means of which intelligent making and multimedia applications are for a better investment of resources and quick remedy to congestion [19].

4.6.3. Traffic Class Definitions

In an ATM network, service classes can be used for both PVCs and SVCs. They are the constant bit rate (CBR), where the user declares a specific bit rate and where the throughput, delay and delay variation, are guaranteed. The variable bit rate (VBR) is divided into two parts, the real-time variable bit rate (rt-VBR) where maximum delay and delay variation are guaranteed and the non-real-time variable bit rate (nrt-VBR) where only the maximum delay is guaranteed. The fourth class of service, the available bit rate (ABR) takes the available bandwidth, works upon feedback instruction, and gives maximum throughput with minimum loss. At last, the user can send whenever he wants without feedback and guarantees using the unspecified bit rate with one constraint through, that cells may be dropped during congestion.

4.7. Advantages and Benefits of ATM

- It supports all traffic types (voice, data, video, multimedia, internet/intranet, image).
- Arrival of data in bursts, tolerant of delay variation.
- Multimedia-combination of traffic types.
- Supports a wide range of connection speeds through high-speed information transfer: (1.5 Mbps 2.4 Gbps and beyond).
- Can be applied in LAN, MAN, WAN.
- Efficient use of network resources.
- Integrated protocol conversions, multiplexing, and switching.
- Cost savings from traffic integration and statistical multiplexing.
- Single network to support multiple services.
- Integration of network infrastructure and operations integrated for all services.
- Less expensive high speed cell processing hardware.
- Investment protected as user demand changes.
- Standards based.
- High performance for data networks.
- Bandwidth on demand capabilities.
- Integrating: Data, voice, and video.
- New productivity/information capabilities.

4.8. Summary

All in all, ATM is a variant of fast packet switching with connection-oriented transmission based on virtual channels and virtual paths. Packets, called cells, have the same length for all connections. They are small in order to reduce packetization delay and to limit information loss- when a cell is lost or misguided in a switch. There is no error protection or flow control on a link-by-link basis, just headed error protection by means of suitable codes e.g. BCH-code, which is tolerable because of high quality links.

By statistical multiplexing, a result of the packet-oriented transmission, an ATM network can profit from VBR sources. Higher flexibility and efficiency must be paid for by higher complexity with respect to connection admission. They also require actions to guarantee the quality of service (QoS) of each connection taken by so called policing functions, which do not exist in STM networks- a policing function limits the cell rate of each connection according to the agreement made when the connection was admitted.

We conclude this chapter with Figure 20, showing the power of a full network service.

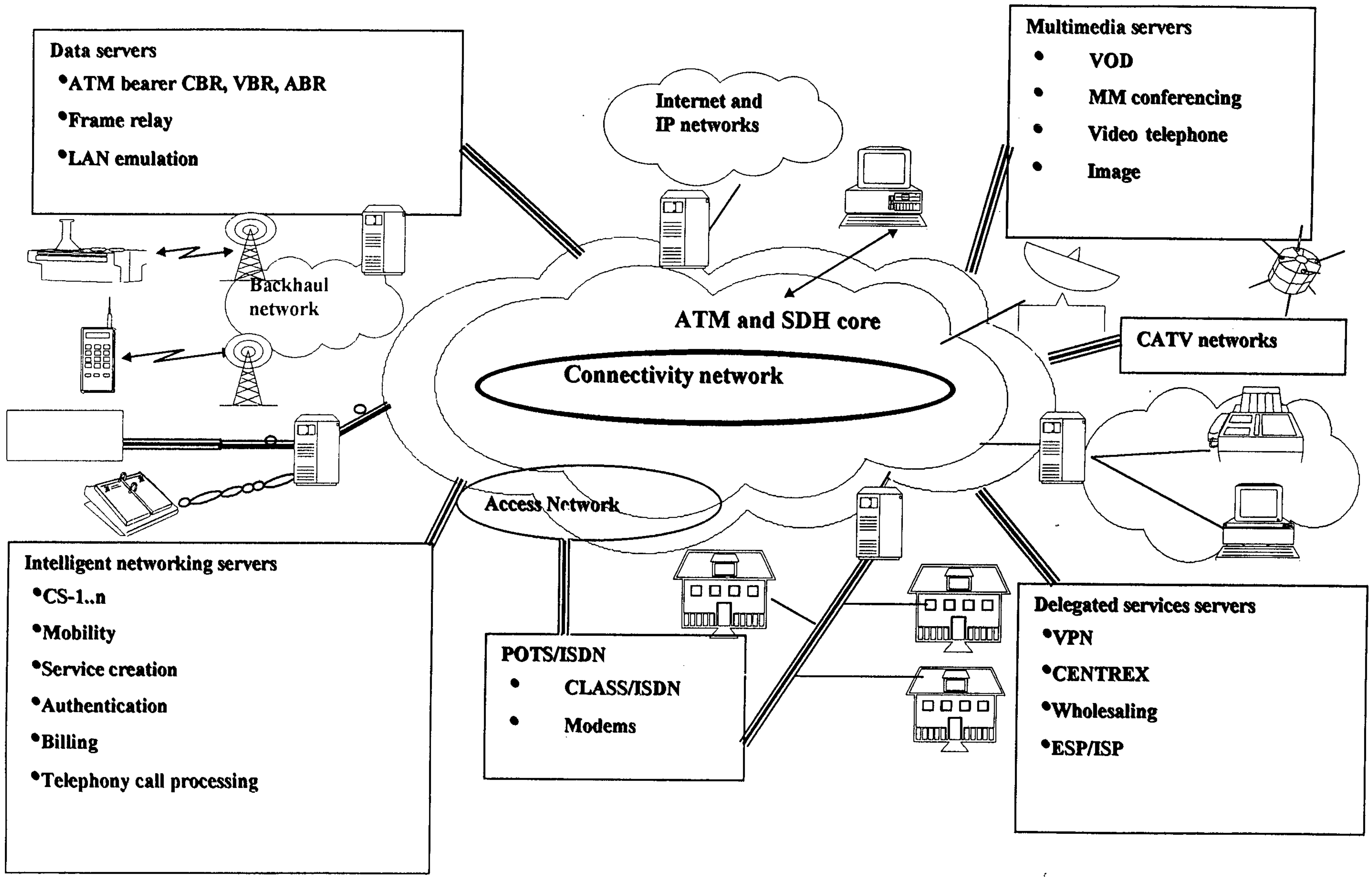

Fig. 20.. A FULL NETWORK SERVICE.

CHAPTER V

COMPARION OF DIFFERENT ATM SERVICE PROTOCOLS

ATM is a connection-oriented packet-switched technology. Before two applications communicate, a connection must be established between them. A new connection requests certain Quality of Service (QoS) and is admitted by the network only if the network has sufficient resources to provide the requested QoS. One of the advantages of ATM is its support of all traffic types and combinations; for instance, voice, data, video signaling, multimedia, internet/intranet, image. However, providing the desired QoS for different applications is very complex. For example, voice is delay-sensitive but not loss-sensitive, contrary to data which is loss sensitive but not delay-sensitive. To make it easier to manage, ATM is divided into five service classes. The purpose of this chapter is to investigate each service category and evaluate them with respect to each other.

5.1. Classes of Service

In order to specify the classes of service and define them, major network application characteristics were studied and grouped together in relation to their parameter values. To illustrate, file server, voice and text, publication, office image, medical data transfer, scientific modeling, simple teleconferencing, CD sound and image, complex teleconferencing, video distribution and visualization are among those applications furthering network growth.

Having studied the parameter values belonging to those applications it is possible to group them into 5 groups upon which the ATM classes of service have been built [9]:

- UBR (Unspecified bit rate): using leftover capacity, the user sends whenever he wants. No feedback mechanism. No CTD, CDV, or CLR guarantee. Cells may be dropped during congestion. E.g. Emails and news feed.

- ABR (Available bit rate): using the capacity of the network when available and controlling the source rate by following feedback instructions to achieve a minimum CTD, CDV, and CLR. Network gives maximum throughput with minimum loss. E.g. Critical data transfer, remote procedure call and distributed file service.
- CBR (Constant bit rate): user declares required constant cell rate, throughput, delay and delay variation (CTD and CDV are tightly constrained and the CLR is low). For example, interactive video and audio.
- VBR (Variable bit rate): user declares average and maximum rate (variable cell rate and small nonzero random cell loss is possible).
- rt-VBR (real-time variable bit rate): maximum delay and delay variation guaranteed (CTD and CDV are tightly constrained). For example, conferencing and interactive compressed video.
- nrt-VBR (non-real-time variable bit rate): mean delay guaranteed. e.g. stored video and response time critical transaction processing.

5.2. Connection Parameters

As mentioned, in order to set a connection some parameters have to be set. The set of parameters is divided into two parts QoS and usage parameters.

5.2.1. Quality of Service

By quality of services mean the parameters negotiated when a connection is set up on ATM networks. These parameters are used to measure the QoS of a connection and quantify end-to-end network performance at ATM layer. The network should guarantee the QoS by meeting certain values of these parameters [9].

- Cell Transfer Delay (CTD): the delay experienced by a cell between the first bit of the cell is transmitted by the source and the last bit of the cell is received by the destination.

Maximum Cell Transfer Delay (Max CTD) and Mean Cell Transfer Delay (Mean CTD) are used.

- Peak-to-peak Cell Delay Variation (CDV): the difference between the maximum and minimum CTD experienced during the connection. Peak-to-peak CDV and Instantaneous CDV are used.
- Cell Loss Ration (CLR): the percentage of cells that are lost in the network due to error or congestion and are not received by the destination.

5.2.2. Usage Parameters

Another set of parameters is also negotiated when a connection is set up. These parameters discipline the behavior of the user. The network only provide the QoS for the cells that do not violate these specifications [9].

- Peak Cell Rate (PCR): the maximum instantaneous rate at which the user will transmit.
- Sustained Cell Rate (SCR): the average rate as measured over a long interval.
- Burst Tolerance (BT): the maximum burst size that can be sent at the peak rate.
- Maximum Burst Size (MBS): the maximum number of back-to-back cells that can be sent at the peak cell rate. BT and MBS are related as follows:

$$\text{Burst Tolerance} = (\text{MBS} - 1)\,(1/\text{SCR} - 1/\text{PCR})$$

- Minimum Cell Rate (MCR): the minimum cell rate desired by a user.

5.3. Comparison criteria

To draft out a full detailed comparison of the five services, we have divided the comparison criteria into three main parts:

A- Application area source category (traffic type).

a- Critical data.

b- LAN emulation.

c- Data transport. (TP-FR-SMDS).

d- Circuit emulation.

e- ISPN video conferencing.

f- Compressed video.

g- Video distribution.

h- Interactive multimedia.

B- Original classes of traffic.

a- Time synchronization.

b- Bit rate.

c- Connection.

d- ATM adaptation layer.

C- Traffic management.

a- Guarantees

  1- Minimum loss CLP.

  2- Delay/variation.

  3- Bandwidth.

a- Attributes (connection parameters).

  1- Use of feedback.

  2- Usage parameters.

  - PCR/CDTV.
  - SCR/MBS, CDTV.
  - MCR.

  3- Quality of Service (QoS).

  - Peak-to-peak CDV.
  - Mean CTD.
  - Maximum CTD.

- CLR.

5.3.1. Application Area Source Category (Traffic Type)

Comparing the application area source category, or traffic type and the service category has a main target: To show that service categories are built depending on the parameters values of the traffic types and that in order to be set back at the time of making the connection.

LAN emulation, or the fact of imitating a LAN over an ATM network, and data transport needs no guarantee; therefore, the unspecified bit rate (UBR), using any left-over capacity with no constrained on the CTD, CDV, or CLR, can be used. Actually, such service will neither burden the network nor oblige its providing resources for UBR connection. Consequently, when a UBR service is employed, any cell discarded affect seriously the overall performance of the system: e.g. when one cell is discarded in a 192-cell packet (default size for an IP packet when using classical IP over ATM) retransmission of the whole packet is triggered. The same symptoms can be found in an ordinary LAN and in data transmission.

In UBR data loss is acceptable. In order to transmit the traffic types transmitted by the UBR along with compressed video- which is transformed into data- (where loss can not be tolerated), he available bit rate (ABR) calls on a specific capacity of the network or the minimum cell rate (MCR) (desired by the source and negotiated when the connection is set up). The main difference between the UBR and the ABR is that, the ABR does not accept the left-over bandwidth if the latter is not greater or equal to the required one and sets the MCR to 0. The ABR also uses feedback technique to minimize congestion and provides the end system with information about congestion. Incidentally, the CTD, CDV, and CLR are minimized as well.

Critical functions or real time applications (like video-conferencing, video distribution and interactive multimedia) in addition to the transport of critical data have stringent requirements in terms of the maximum delay and delay variation between 150 and 400 ms. For instance, the video which is produced by displaying frames at a fixed frame rate known as playback rate (NTSC = 30 frames/s, PAL = 25 frames/s). In order to transport similar traffic types, constant bit rate (CBR) has to be organized. We can safely say then that having a constant cell rate CTD and CDV tightly constrained with low CLR.

Some of the types transported over the ATM network by means of the CBR service can also be transported over a VBR service. However, other types such as compressed video or coded video are given a minimum required throughput by the mean bit rate (MBR), which is known by many compression techniques. Because of the fluctuation of the bit rate, the actual throughput is typically higher than the mean rate. Variable bit rate service is deducted to serve similar traffic types using a variable cell rate, where a non-zero cell loss is possible. To be able to serve all kinds of traffic types requiring a variable bit rate, this service has been divided into two parts:

- Real-time variable bit rate (rt-VBR) guaranteeing a peak-to-peak CDV.
- Non real-time variable bit rate (nrt-VBR) guaranteeing mean CTD.

The first transports traffic requiring a variable cell rate and a time synchronization. By contrast the second transports only traffic requiring variable cell rate.

5.3.2. Original Classes of Traffic

The second part of the five ATM services will deal with the original classes of traffic or the original parameters of traffic types. First of all the time synchronization between audio and video requires that the inter-arrival time between video and audio packets to be less than 80 ms for one way communication. The only traffic types which need synchronization are those which transport video, voice and high-quality audio application, with CTD and CDV tightly constrained; that means the difference between maximum CTD and minimum CTD is minimum. Traffic type requiring such services are transported only during CBR and rt-VBR.

The bit rate or data rate comes second in the original classes of service. It was demonstrated earlier with the group of traffic types requiring fixed data rate, and delivered to be transported by the CBR service.

Finally the ATM adaptation layers, which are no more than links between the ATM layer and the application supported. The AAL isolates the service / application from the ATM transport by mapping higher layer protocol data units into the information field of the ATM cell. AAL(s) are the essence of the ATM configurability and flexibility. In fact one of the prime goals of ATM is that it should support different kinds of service with different traffic characteristics; as in the case of ATM AALs which receive packets from the upper-level protocols (AppleTalk, Internet protocols (IP), and Netware), and break them into 48-byte segments (that will form the payload field of an ATM cell).

After grouping the traffic types into 5 categories, and supported each by one service category, each one was dedicated a different AAL:

- AAL1supports the CBR service requiring a constant bit rate plus timing between source and destination.
- AAL2 supports the rt-VBR service category, reduces the cell assembly delay as well as optimizes the bandwidth usage. AAL2 also maps the low-bit-rate voice symbol into a cell.
- AAL3/4 prepares cell for transmission using nrt-VBR service.
- AAL4 supports the UBR service category using a connectionless method.
- AAL5 or adaptation layer transfers most data, such as classical IP over the ATM and local area network emulation.

5.3.3. Traffic management

After comparing the application area source category or traffic types and the original classes of traffic for different ATM services category, below we will compare the traffic management which is divided into two parts: The guarantees, and the attributes. Noticing that the attributes are divided into use of feedback, usage parameters, and quality of service.

5.3.3.1. Guarantees

The guarantee settings depend on the service categories that have inherited their parameter values from the traffic type needs. At first, cell loss priority parameter is set to 0 or to 1 in the cases of all service categories except for the UBR because all cells are considered equally important and can be discarded and retransmitted in case of congestion without affecting the network work. In relation to other services, losses are kept under control for they may have considerable impact on the percentage quality. The network has to provide a video stream with multiple loss rates (between 10^{-2} & 10^{-6}), depending on the importance of the transmitted data. Those other services take into account the cell loss priority indication in each cell. The CLP streams are the least likely to be discarded.

Secondly, and with respect t the delay/variation, parameters are important in the cases where time synchronization is required, that means in the CBR and rt-VBR service categories which transmit interactive multimedia- because interactive communications have stringent requirements in terms of maximum delay and delay variation (jiiter). Acceptable values for the one-way delay lie within a range of 150-400 ms. For the jiiter, the requirements depend on the amount of smoothing at the sender and receiver. Assuming a constant playback rate of f frames/s and no smoothing, the receiver requires a frame every 1/f s (33 ms if f=30).

Finally, and as far as the bandwidth reservation parameter is concerned, ATM can provide various video quality ranging from VHS to broadcast quality. High quality video requires a minimum reserved bandwidth size. Services such as VBR and CBR, by using different coding techniques can reduce the bandwidth requirements by half while preserving the same video quality, and reserving still a bandwidth. Concerning the kinds of traffic transported by the UBR service, no reservation of the bandwidth is required because the transported traffic does not need to set the parameters for the cell loss ratio (CLR) and the minimum cell loss priority (CLP). As a result, no bandwidth reservation is required, and in case of congestion cells may be dropped and retransmitted. In the case of the ABR , there is a combination of the previous services since the ABR was first designed to provide support for delay in insensitive data applications. Nevertheless it requires a minimum of cell rate (MCR) guarantees. The ABR switch schemes assume MCRs to be zero. Therefore to the ABR service the bandwidth allocation for a connection is its MCR plus equal share of the available bandwidth with used MCR removed. Like the UBR service, the ABR takes the left over bandwidth and divides it; however and unlike the UBR, it will reserve this bandwidth until another feedback arrives and renews the setups of the network parameters.

5.3.3.2. Attributes

The second kind of traffic management to be set are the attributes or the connection parameters, which are divided into three groups. Let us begin by the use of feedback. The fact that ABR uses the available bandwidth should ensure that a minimum cell rate (MCR) is always available. In order to achieve this mission, periodically, a connection polls the network and based upon the feedback it receives, adjusts its transmission rate in order to be conform with the available bandwidth.

The setting of the usage parameters group come next for they are second in the attributes. First, the peak cell rate or the maximum instantaneous rate at which the user will transmit is specific for all the service category kinds. The next usage parameter are the sustained cell rate and the maximum burst size. VBR coding which results in widely varying frame size (vertical lines) maintains constant quality throughout the video session. Besides scene activity, the VBR behavior of video source is strongly dependent on the underlying compression technique. It should be noted that high quality video applications are inherently non-adaptive, and often require stringent deterministic QoS guarantees and attributes. In such cases and in addition to PCR, a sustainable cell rate (SCR) and a maximum burst size (MBS) are established. The sustainable rate is the upper limit of the average rate, and the maximum burst rate limits the duration of cell transmission at peak rate. These additional parameters allow the network to achieve statistical multiplexing by allocating fewer resources for the connection than would be required by the peak cell rate. Summarizing, the VBR service is the only service transporting traffic needing statistical multiplexing thus it is the only service specifying those two parameters. The last usage parameter is the minimum cell rate (MCR) (desired by the user).

The third set of attributes to deal with are the QoS connection parameters. Once more, our objective is to show that the quality of service has to inherit the original values of the traffic type to be transported, in order to be able to transmit it.

The first quality of service to deal with is the cell transfer delay which depending on the traffic type is divided into two kinds: The mean CTD or the average delay experienced by a cell between the first bit of the cell, is transmitted by the source and the last bit of the cell is received by the destination. The second kind of delay specification is to compare it to the maximum CTD. Video streams are typically compressed before being transported over a network. As indicated before, for constant quality video, the video encoder generates a sequence of variable-size compressed frames. The goal of the following is to prove that CBR and rt-VBR category services require a specification for the maximum CTD while the other three services require a specification for the mean CTD. Video services differ in their support for interactivity. At one extreme, interactivity is limited to establishing and terminating video sessions. At the other, a video service may offer a full range of VCR-like interactive functions- fast-forward, rewind, ... Interactivity brings with it a host of issues related to many parameters including the CTD. The CTD depends on the variability in the frame rate and the variability in the distortion factor. To ensure continuous streaming of video, the rate at which frames are transported over the network must, on average, be no smaller than the playback rate. Moreover, CBR and rt-VBR are the only two services offering time synchronization meaning that the maximum delay has to be equal to the maximum delay that can be experienced in the playback rate (E.g: NTSC = 30 f/s). We may conclude that maximum CTD is specific to CBR and rt-VBR in contrast to UBR, ABR, and nrt-VBR which specify the mean CTD.

The peak-to-peak cell delay variation (CDV) means the difference of the maximum and minimum CTD experience during the connection. Video quality is measured by the distortion in a video frame. Distortion is a measure of the loss of the compression algorithm (i.e., the difference between the quality of the original image before encoding and that obtained after decoding). One common approach to controlling the level of distortion in a frame is to adjust the quantization values used to encode that frame. The rate distortion curves, shown in the figure below, define a region of operation for video encoders. This region is bounded by two orthogonal lines of operation [17]:

- VBR coding (vertical line), which maintains constant quality throughput in the video session, but results in a widely varying frame sizes.
- CBR coding (horizontal line), which maintains a constant frame size throughout the video session.

Below the Figure 21 [17] contains two curves representing the VBR coding and the CBR coding showing the trade-off between the quality and the bit rate.

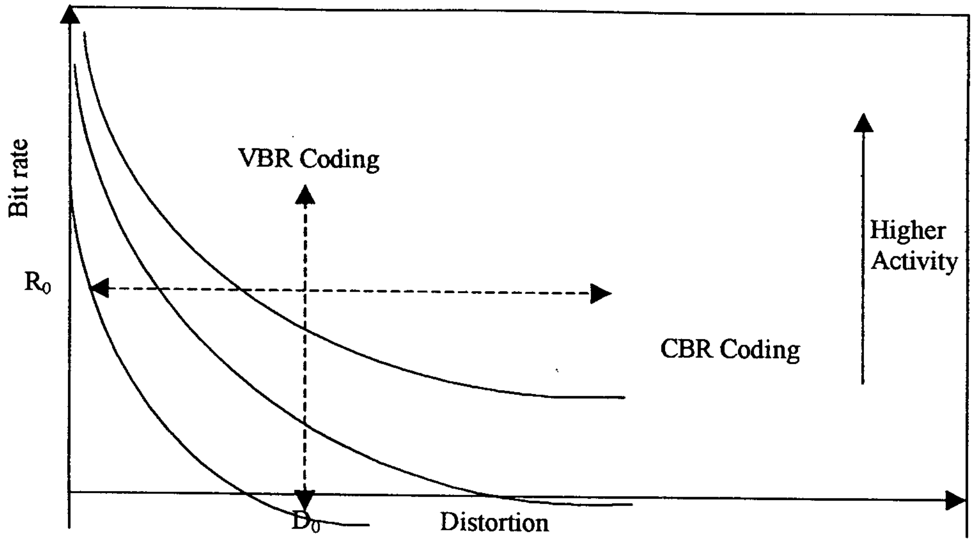

Fig. 21. TRADE-OFF BETWEEN QUALITY AND BIT RATE

In order to calculate the peak-to-peak CDV, we should have the maximum CTD- which is set by the CBR and rt-VBR services only. Moreover, those are the only two services requiring an average delay in order to keep a balanced trade-off between quality and bit rate in video compression.

The last quality of service attribute to be set is the cell loss ratio. This parameter can not be set by the UBR service because it has no minimum cell loss priority. However, all the other category services require that the ratio of cells that are lost in the network due to error or congestion and not received by the destination, be calculated. The CLR value will help measuring the QoS of a connection and quantify end-to-end network performance at an ATM layer.

	Application Area Source Category (Traffic Type)								Comparison of ATM service Original Classes Of Traffic			
Service Category	Critical Data	LAN Emulation	Data Transport TP-FR-SMDS	Circuit Emulation	ISPN Video Conference	Compressed Video	Video Distribution	Interactive Multimedia	Time Synchro-nization	Bit Rate	Connection	ATM Adaption Layer
UBR Unspecified Bit Rate	Not Suitable	Good	Good	Not Suitable	Not Suitable	Fair	Not Suitable	Fair	Not Required	Variable	Connect. Less	AAL4
ABR Available Bit Rate	Fair	Optimum	Optimum	Not Suitable	Not Suitable	Good	Not Suitable	Good	Not Required	Variable	Connect. Oriented & Connect. Less	AAL5
CBR Constant Bit Rate	Good	Fair	Fair	Optimum	Optimum	Fair	Optimum	Optimum	Required	Constant	Connect. Oriented	AAL1
rt-VBR Real-Time Variable Bit Rate	Fair	Fair	Fair	Good	Not Applicable	Optimum	Good	Optimum	Required	Variable	Connect. Oriented	AAL2
nrt-VBR Non-Real-Time Variable Bit Rate	Optimum	Good	Good	Not Suitable	Not Applicable	Good	Fair	Good	Not Required	Variable	Connect. Oriented	AAL3

Table 9. RELATION BETWEEN THE SERVICE CATEGORIES AND SOME OF THE PARAMETERS USED TO DESCRIBE DESIRE

categories.

Attributes & Guarantees

Guarantees: Min Loss CLP, Delay / Variation, Bandwidth. Attributes: Use of Feedback through CLR.

Examples	Min Loss CLP Cell Loss Priority	Delay / Variation	Bandwidth	Use of Feedback	PCR/CDTV (4,5)	SCR/MBS CDTV (4,5)	MCR (4)	Mean CTD	Max CTD	Peak-to-Peak CDV	CLR (4)
SMDS	Not Available	Not Available	Not Reserved	Not Available	Specified 2	Not Available	Not Available	Specified	Un-Specified	Un-Specified	Un-Specified
Data	Available	Not Available	Mix	Available	Specified 3	Not Available	Specified	Specified	Un-Specified	Un-Specified	Specified
Circuit Emulation	Available	Available	Reserved	Not Available	Specified	Not Available	Not Available	Un-Specified	Specified	Un-Specified	Specified
Comp. Video	Available	Available	Reserved	Not Available	Specified	Specified	Not Available	Un-Specified	Specified	Un-Specified	Specified
Frame Relay	Available	Not Available	Reserved	Not Available	Specified	Specified	Not Available	Specified	Un-Specified	Specified	Specified

D QoS.

CHAPTER VI

FORMAL SPECIFICATION OF ATM CONTROL SCHEMES

With advanced computer technology, new communication protocols are being constantly introduced, to fulfill more complicated tasks. This does not necessarily mean that protocols are becoming more reliable. In this chapter we consider the Available Bit Rate (ABR) protocol. The ATM Forum's Traffic Management working group has been working on a specification for the class of ABR service [6]. This service is meant to address the needs of bursty data transfers, and therefore is based on the effective operation of a rate-based congestion control/avoidance mechanism.

The source and destination policies have been specified using an English description in the main body of the draft Traffic Management Specification [ATM] (see appendix A). Given an English description of the protocol, we may find different interpretations for the same description. For this reason a group of researchers have modeled the ABR protocols by parameterized communicating extended finite machines with timers at Bell labs [9]. This chapter presents a flow chart presentation of the finite machines in the hope of providing a non-implementation-dependent solution.

6.1. ABR State Machine

The ATM forum technical committee specified the source, destination, and switch behavior for the ABR service. In his paper [9], Fang Lu highlighted the behavior of this service and give, in English, a brief algorithm for those behaviors. Another paper by David Lee, K.K. Ramakrishnan, and W. Melody Moh, [7] gave a formal specification for the ATM ABR rate control scheme.

This chapter extends by presenting a graphical visual aid representing the way ABR works. We have two charts representing the source, switch and destination behavior; in addition, to a simple modification of the algorithm [7].

6.2. Graphical Organization of the Sate Machines

The source and destination protocols for the ABR traffic management scheme are part of a closed-loop feedback control system, and the VC is full duplex. The management of the communication between those two is performed using and end-end protocol involved with both sending information and receiving feedback from the remote system. We have listed below the responsibilities of each type of machine.

The source station (Sending station):

- Containing the source protocol machine.
- Initialization.
- Sending data cells.
- Sending FRM cells.
- Receiving BRM cells.
- Modifying the ACR rate.

The source behavior is divided into 2 machines the source and the scheduler machines. The source machine models all of the non-timing related functions of changing Allowed Cell rate (ACR) and servicing the backward RM (BRM).

The scheduler machine models all the timing related functions. It keeps track of time (T) which is the time of the transmission of the last FRM cell and of time (t) representing the time of successive transmissions of cells on the VC separated by time interval 1/ACR.

The interface between the source machine and the scheduler machine forming the source behavior happens through three queues. The first queue, the only one, physical contains the turned-around BRM cells from source to schedule to destination. The other two queues are virtual, first there is the data cells queue picked up from the user to be transmitted when it is time to be sent. Next, the FRM cells queue generated and filled with the relevant information, and sent each Nrm-1 data cells sent.

The destination machine behavior receives the data cells and sends back the RM cells as "Turned-around BRM". The interface between the destination and the source behavior is done through the scheduler machine. The destination machine contains a queue of turned-around BRM cells (From B to the scheduler A). Moreover the scheduler of "A" receives the BRM and alters the transmission rate ACR.

The way the state machine works is graphically shown below.

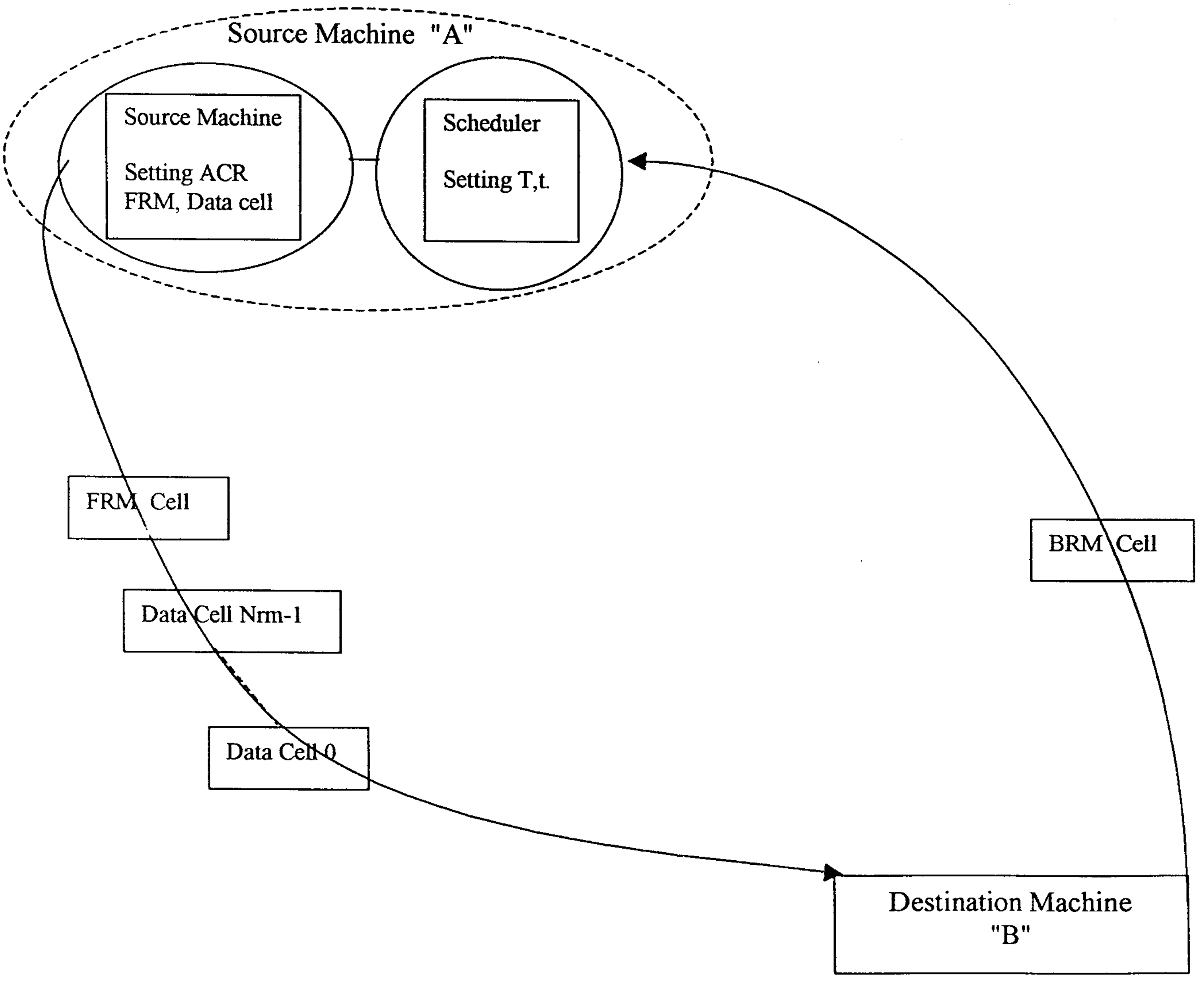

Fig. 22. RM-CELL TRAFFIC.

6.3. RM-Cell Structure

The feedback mechanism of the ABR switch is what specifies it over other service protocols. In order for us to draw the flow chart of the ABR service machines: Source, scheduler and destination machines, we need to define the structure of the RM-cell which is either a forward-RM sent from the source to the destination or a backward RM sent from the destination to the source.

The structure of the RM-cell is as following:

- Header: The first five bytes of an RM-cell are the standard ATM header with PTI=110 for a VCC and VCI=6 for a VPC.
- ID: The protocol ID. This is set to 1 for ABR service.
- DIR: Direction of the RM-cell with respect to the data flow, in which it is involved with. It is set to 0 for forward RM-cells and 1 for backward RM-cells.
- BN: Backward Notification. It is set to 1 for switch generated (BECN) RM-cell and 0 for source generated RM-cell.
- CI: Congestion Indication. It is set to 1 to indicate congestion and 0 otherwise.
- NI: No Increase. It is set to 1 to indicate no additive increase of rate allowed when a switch senses impeding congestion and 0 otherwise.
- ER: Explicit Rate. It is used to limit the source rate to a specific value.
- CCR: Current Cell Rate. It is used to indicate the current cell rate at the source.
- MCR: Minimum Cell Rate. The minimum cell rate desired by the source.

In the following section, we present two flow chart diagrams found in the algorithm in [9].

6.4. States Machines Flow Chart Presentation

In [6] and [7] an algorithm is presented in addition to an English description in order to explain the work of the source and destination machines. The same is done in graph 23 and 24 but instead we use a flowchart presentation.

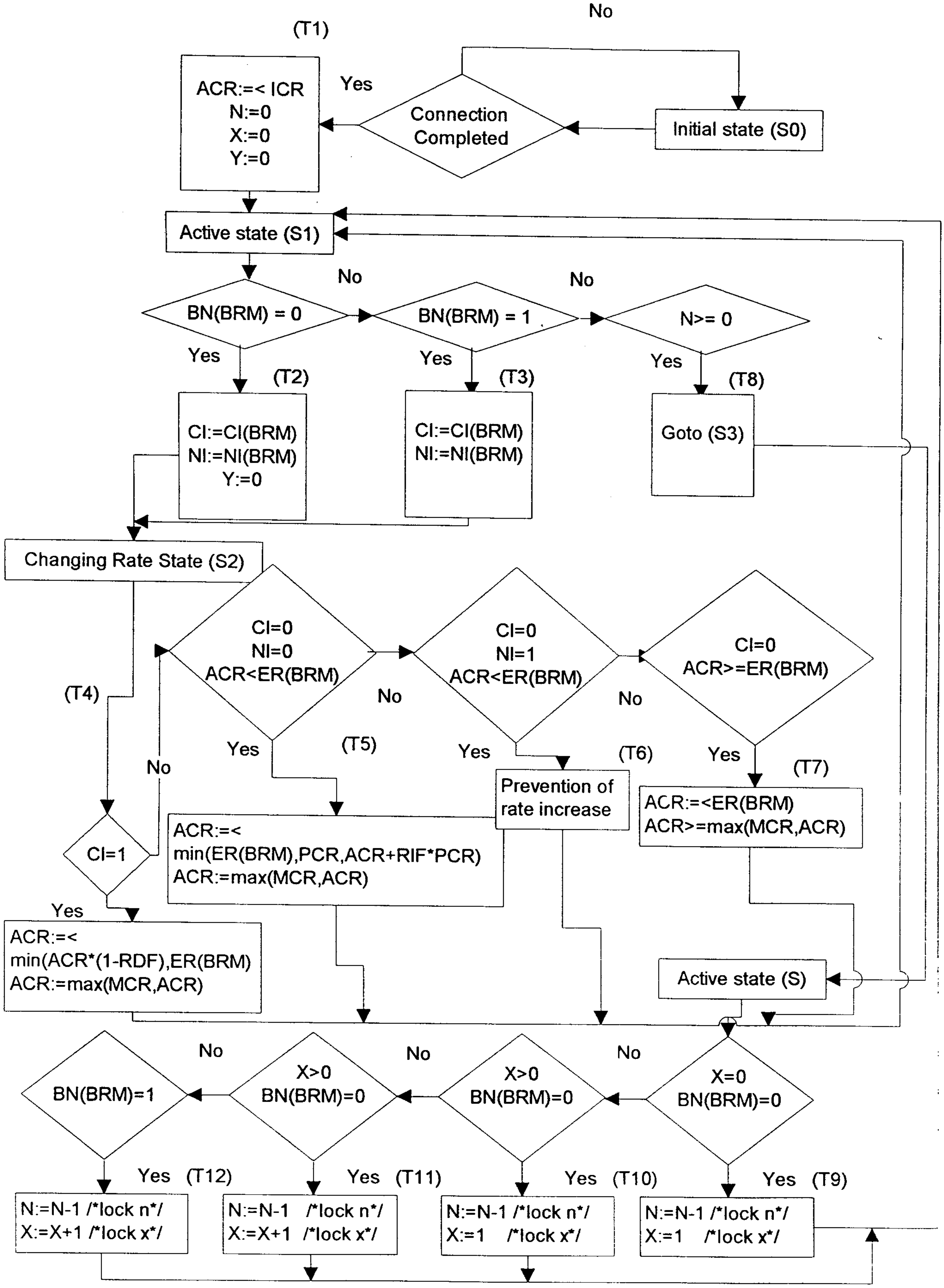

Fig. 23. SOURCE MACHINE FLOWCHART.

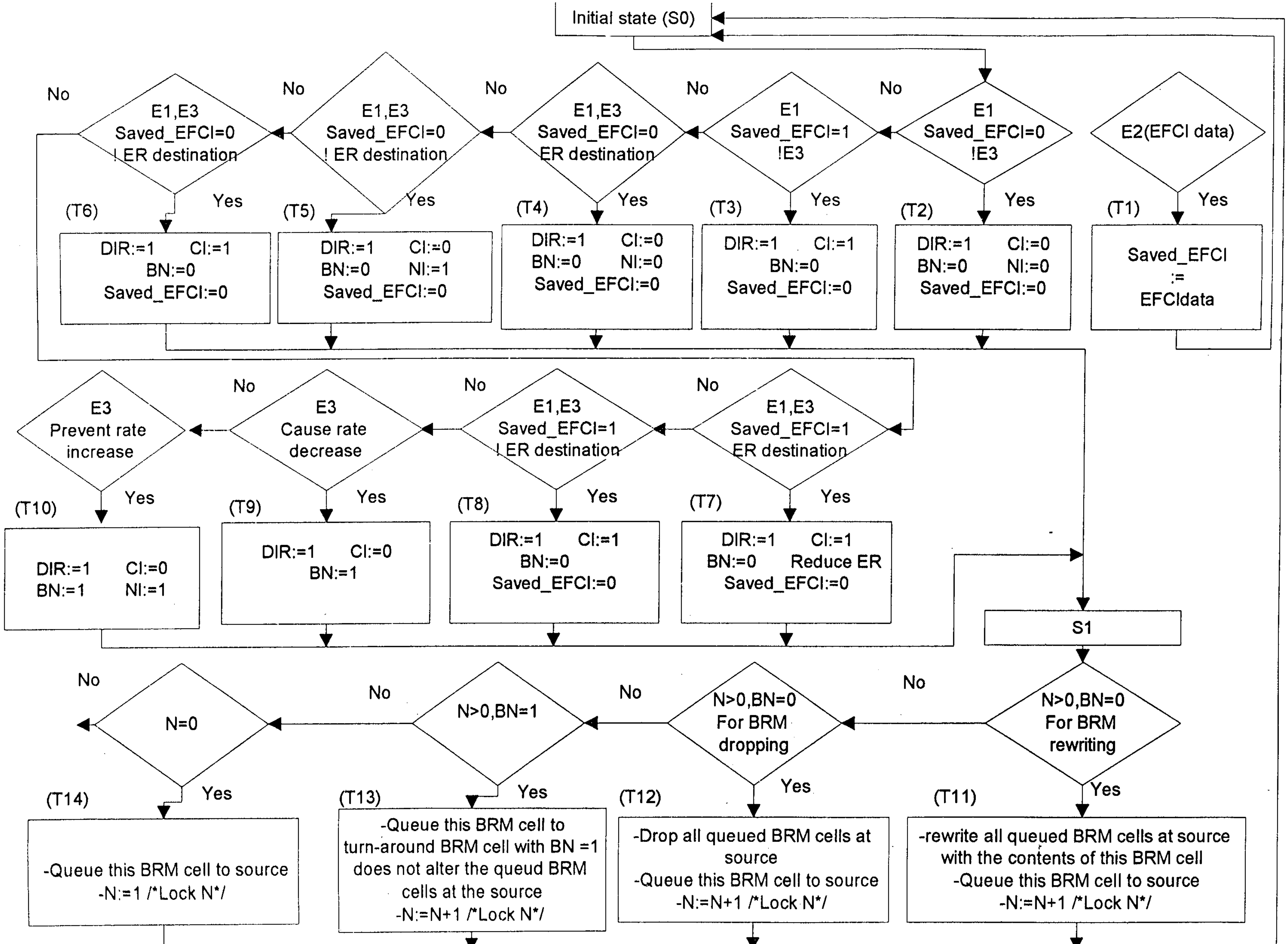

Fig 24 DESTINATION MACHINE FLOW CHART

6.5. New Model for the State Machine

In this section, we are primarily concerned with modeling the state machine algorithm in [6] which aims for more bandwidth, more speed, and less overhead communication. The main actions of the source behavior are (i) change in the rate upon the arrival of the BRM cell returned from the remote destination, & (ii) providing the interface between the destination protocol machine and the scheduler to transmit turned-around BRM-cell. The interface with the destination protocol machine is through a queue of BRM cells queued to the source.

6.5.1. Source Machine

The source machine originally contains 4 states:

- S0: Initial state. Connection set up and first data cell available.
- S1: Active state.
- S2: State in which rate may be changed.
- S3: State in which queued BRM cells are altered.

In addition to the RM-cell parameters we need three variables:

- N: Number of turned around BRM cells queued to source by destination (shared with destination).
- X: Number of BRM cells queued to Scheduler (shared with scheduler).
- Y: Number of FRM cells sent by scheduler since last BRM cell with BN=0 received by source (shared with scheduler).

In order to achieve the objective of the modulation a new transition (T'2) is created containing shared modifications of the old transitions T2 and T3 replaced by T'3 and T'.4.

The original English Specifications-in the destination policy- specifies that if there are turned-around BRM cells in the queue two solution may occur in a non-deterministically method by choosing between transitions to reflect the fact that is an implementation dependent. The first conflict is between the two transitions T5 and t6 where the transition T5 increases the ACR and the T6 prevents any increase. A second conflict is between T10 and T11 where T10 transaction drops all the previously queued BRM cells at scheduler queue and queue the available BRM cell to scheduler. Whereas the 11th transaction (T11) rewrite all queued BRM cells at scheduler queue and queue the available BRM cell to scheduler.

SOURCE MACHINE

STATES

S 0 : initial state: connection set up and first data cell available

S 1 : active state

S' 1: Transition state

S 2 : state in which rate may be changed

S 3 : state in which queued BRM cells are altered

VARIABLES

N: number of turned-around BRM cells queued to Source by Destination /* shared variable with Destination */

X: number of BRM cells queued to Scheduler /* shared variable with Scheduler */

Y: number of FRM cells sent by Scheduler since last BRM cell with BN=0 received by Source /* shared variable with Scheduler */

EVENTS

E 1 : BRM cell received by Source

E 2 : data cell waiting to be sent

TRANSITIONS

T'1 (Source 2)

current state: S 0

next state: S 1

event:

connection set up complete and E 2

actions:

ACR :<= ICR;

N : = 0;

X : = 0;

T' 2 (Source 8)

current state: S1

next state: S'1

event:

E1 && N<0

Actions:

CI := CI(BRM)

NI := NI(BRM)

T' 3 (Source 8)

current state: S1

next state: S3

event:

N>=0

Actions:

Goto S3

T'4 (Source 8)

current state: S' 1

next state: S 2

event:

BN (BRM) = 0

actions:

Y : = 0; /* lock Y */

T'5 (Source 8)

current state: S' 1

next state: S 2

event:

BN BRM not = 1

actions:

goto S2

T' 6 (Source 8 and 9)

current state: S 2

next state: S 1

event:

CI = 1

actions:

ACR : = max {MCR , min {ACR*(1 - RDF) , ER BRM }};

T' 7 (Source 8 and 9)

current state: S 2

next state: S 1

event:

((CI = 0) && (NI = 0)) && (ACR < ER BRM)

actions:

ACR : = max{MCR , min {ER BRM , PCR , ACR + RIF*PCR}};

T' 8 (Source 8 and 9)

current state: S 2

next state: S 1

event:

((CI = 0) && (NI = 0)) && (ACR < ER BRM)

actions:

Prevention of rate increase;

T' 9 (Source 8 and 9)

current state: S 2

next state: S 1

event:

(CI = 0) && (ACR ^{3} ER BRM)

actions:

ACR : = max{MCR , ER BRM };

T' 10 (Destination 3; Source queues BRM cell)

current state: S 3

next state: S 1

event:

(X >= 0) /* Scheduler queue has no BRM cells */

BN(BRM)=0;

actions:

queue this BRM cell to Scheduler;

N : = N - 1; /* lock N and X */

X : = 1;

T' 11 (Source queues BRM cell with BN BRM = 1)

current state: S 3

next state: S 1

event:

(X > 0) && (BN BRM = 1) /* Scheduler queue has BRM cells */

actions:

N : = N - 1; /* lock N */

queue this BRM cell to Scheduler; /* Destination turned-around BRM cell with BN=1 does not alter the queued BRM cells in Scheduler */

X : = X + 1; /* lock X */

The flowchart of this modified algorithm for the source machine is represented by figure 25.

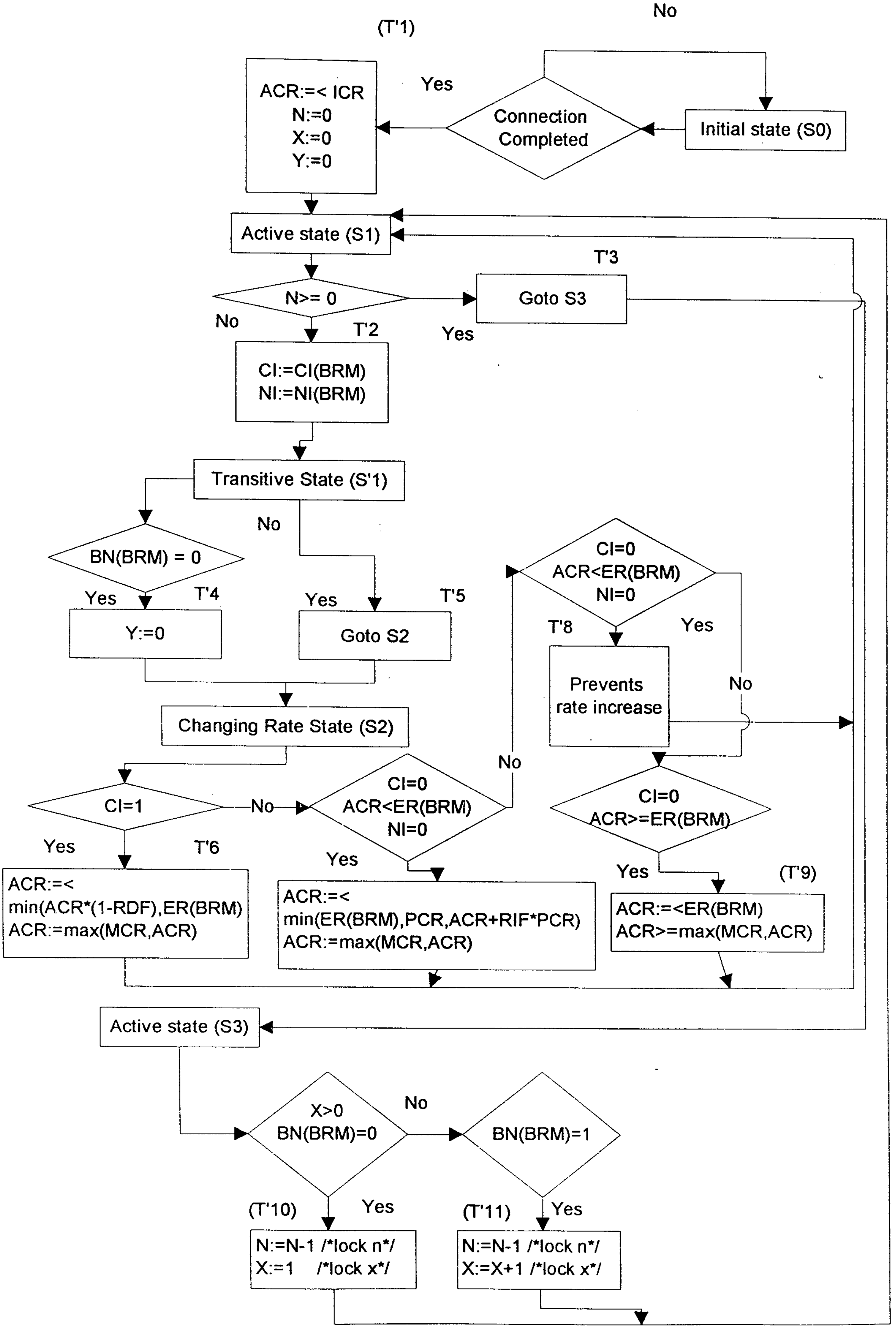

Fig. 25. MODELED SOURCE BEHAVIOR: SOURCE MACHINE FLOWCHART.

6.5.2. Modeled Destination Algorithm

Following is a proposed modification for the ABR destination machine.

The destination machine contains only 2 states:

- S0: Wait for cells.
- S1: State in which BRM cells are queued to source and source queued of BRM cells may be altered.

In addition to the RM-cell parameters we need three variables:

- N: Counter of the number of turned around BRM cells turned around by destination machine and queued to source (shared with source).
- Saved_EFCI: EFCI state of connection saved at destination.

The destination machine as the source one presents sometimes two solutions to the same events which may occur in a non-deterministically method by choosing between transitions to reflect the fact that is an implementation dependent. The first conflict is between the two transitions T5 and t6 where the transition T5 indicates that no additive increases of rate allowed contrary to 6 which permit a rate increase. A second conflict is between T9 and T10 reflecting the destination 6^{th} rule of the English specification which allows the destination to generate a BRM cell exogenously when it is congested. Since it is implementation dependent, as to whether the NI bit is set or not, the choice to follow transitions T9 which causes a rate reduction or T10 which prevent a rate increase is again non-deterministic. Third, the only shared variable is the counter N, which is incremented in transition T11, when a turned-around BRM cells are queued. Another alternative to transition T11 is transition T12 where all queued turned-around BRM cells are dropped. Once again the choice between T11 and T12 is implementation dependent.

DESTINATION MACHINE

STATES

S 0 : wait for cells

S'0 : Transitive state

S 1 : state in which BRM cells are queued to Source and source queue of BRM cells may be altered

VARIABLES

saved_EFCI: EFCI state of connection saved at Destination

N: counter of the number of BRM cells turned around by destination machine and queued to Source /* shared variable with Source */

EVENTS

E 1 : an FRM cell received

E 2 : a data cell received

E 3 : destination has internal congestion

TRANSITIONS

T' 1 (Destination 1)

current state: S 0

next state: S 0

event:

E 2 (EFCI DATA)

actions:

saved_EFCI : = EFCI DATA ;

T'2 (Destination 2b, for ER Destination)

current state: S 0

next state: S 1

event:

E 1 && E 3 && (saved_EFCI = 1) && ER destination

actions:

DIR : = 1;

BN : = 0;

CI : = 1;

saved_EFCI : = 0;

reduce ER;

T'3 (Destination 2a or 2b)

current state: S 0

next state: S' 0

event:

E 1

actions:

DIR : = 1;

BN : = 0;

T' 4 (Destination 2a or 2b)

current state: S' 0

next state: S 1

event:

saved_EFCI = 0

actions:

CI : = 0;

NI : = 0;

T' 5 (Destination 2b)

current state: S' 0

next state: S 1

event:

saved_EFCI = 1

actions:

CI : = 0;

Saved_EFCI := 0

T'6 (Destination 5, prevent rate increase)

current state: S 0

next state: S 1

event:

E 3

actions: /* Destination generates BRM cell */

DIR : = 1;

BN : = 1;

CI : = 0;

NI : = 1;

T' 7 (Destination implicit)

current state: S 1

next state: S 0

event:

N = 0 /* queue is empty */

actions:

N : = 1; /* lock N */

queue this BRM cell to Source;

T' 8 (Destination implicit for BRM cell with BN BRM = 1)

current state: S 1

next state: S 0

event:

(N > 0) && (BN = 1)

actions:

queue this BRM cell to Source; /* Destination turned-around BRM cell with BN=1 does not alter the queued BRM cells at Source */

N : = N + 1; /* lock N */

T 9 (Destination implicit for BRM dropping)

current state: S 1

next state: S 0

event:

(N > 0) && (BN = 0)

actions:

drop all queued BRM cells at Source;

queue this BRM cell to Source;

N : = 1; /* lock N */

The flowchart of this modified algorithm for the destination machine is represented in figure 26.

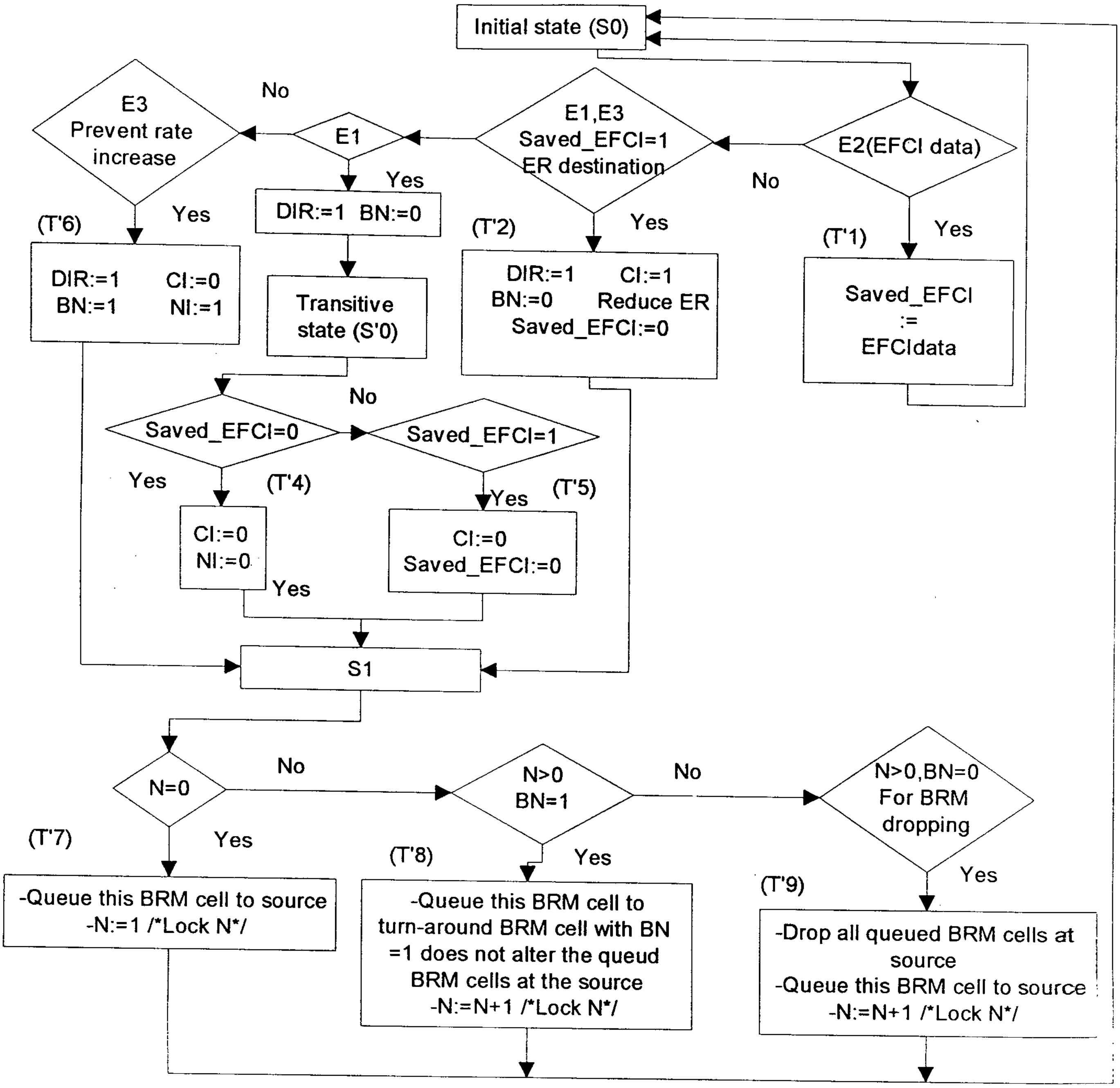

Fig. 26. MODELED DESTINATION MACHINE.

6.6. Summary

In this final chapter a modeled state machine for the ATM Forum's ABR service specification is presented. Summarizing, in the English specification if there are turned around BRM cells in the queue, they allow a non-deterministic choice. The first offers a non-deterministic choice in order to drop all the previously queued turned around BRM cells and put the available one in the queue. Another alternative is to rewrite all of them and put the additional one in the queue. Such decision were implementation dependent. The modification in this chapter mainly aimed to offer a deterministic algorithm, and implementation independent.

CHAPTER VII

CONCLUSION AND FUTURE RESEARCH

In this thesis we have shown that present protocols in computer networks suffer from delay in data transmission, flexibility and bandwidth limitations especially when applied to large networks. For example, network bandwidth is one of the major factors that impact the cost of video service. We have compared the different existing protocols with emphasis on ATM service categories. We have also proposed a modification of the ABR control scheme.

In the proposed modification of the ABR control scheme, there has been considerable work done in the past to understand various aspects of the mechanism in different state conditions. Given the English description in the main body of the draft Traffic Management Specification [ATM] and the English description of the protocol, a group of researches modeled the ABR protocols by parametrized communicating extended finite machines with timers. Our modification aims to provide a non-implementation dependent generation of transitions.

Future researches may deal with the worst-case delay for a destination to turn-around RM cells that carry the network feedback to the source, using the modified algorithm.

Another issue is to set guidelines for the ABR source parameters to provide support for multi-point connections transporting multimedia traffic.

APPENDIX A

ATM FORUM TRAFFIC MANAGEMENT SPECIFICATION V4.0

For reference, I include the English specification from [ATM] for the source, destination, and switch behavior.

SOURCE BEHAVIOR

The following items define the source behavior for CLP=0 and CLP=1 cell streams of a connection. By convention, the CLP=0 stream is referred to as in-rate, and the CLP=1 stream is referred to as out-of-rate. Data cells shall not be sent with CLP=1.

(1) The value of ACR shall never exceed PCR, nor shall it ever be less than MCR. The source shall never send in-rate cells at a rate exceeding ACR. The source may always send in-rate cells at a rate less than or equal to ACR.

(2) Before a source sends the first cell after connection setup, it shall set ACR to at most ICR. The first in-rate cell sent shall be a forward RM-cell.

(3) After the first in-rate forward RM-cell, in-rate cells shall be sent in the following order:

(a) The next in-rate cell shall be a forward RM-cell if and only if, since the last in-rate forward RM-cell was sent, either:

(i) at least Mrm in-rate cells have been sent and at least Trm time has elapsed,

or

(ii) Nrm-1 in-rate cells have been sent.

(b)The next in-rate cell shall be a backward RM-cell if condition (a) above is not met, if a backward RM-cell is waiting for transmission, and if either:

(i) no in-rate backward RM-cell has been sent since the last in-rate forward RM-cell,

or

(ii) no data cell is waiting for transmission.

(c) The next in-rate cell sent shall be a data cell if neither condition (a) nor condition (b) above is met, and if a data cell is waiting for transmission.

(4)Cells sent in accordance with source behaviors #1, #2, and #3 shall have CLP=0.

(5) Before sending a forward in-rate RM-cell, if ACR > ICR and the time T that has elapsed since the last in-rate forward RM-cell was sent is greater than ADTF, then ACR shall be reduced to ICR.

(6) Before sending an in-rate forward RM-cell, and after following behavior #5 above, if at least CRM in rate forward RM-cells have been sent since the last backward RM-cell with BN=0 was received, then ACR shall be reduced by at least ACR*CDF, unless that reduction would result in a rate below MCR, in which

case ACR shall be set to MCR.

(7) After following behaviors #5 and #6 above, the ACR value shall be placed in the CCR field of the out-going forward RM-cell, but only in-rate cells sent after the outgoing forward RM-cell need to follow the new rate.

(8) When a backward RM-cell (in-rate or out-of-rate) is received with CI=1, then ACR shall be reduced by at least ACR*RDF, unless that reduction would result in a rate below MCR, in which case ACR shall be set to MCR. If the backward RM-cell has both CI=0 and NI=0, then the ACR may be increased by no more than RIF*PCR, to a rate not greater than PCR. If the backward RM-cell has NI=1, the ACR shall not be increased.

(9) When a backward RM-cell (in-rate or out-of-rate) is received, and after ACR is adjusted according to source behavior #8, ACR is set to at most the minimum of ACR as computed in Source Behavior #8, and the ER field, but no lower than MCR.

(10) When generating a forward RM-cell, the source shall assign values to the various RM-cell fields as specified for source-generated cells in Table 5-4.

(11) Forward RM-cells may be sent out-of-rate (i.e. not conforming to the current ACR). Out-of-rate for-ward RM-cells shall not be sent at a rate greater than TCR.

(12) A source shall reset EFCI on every data cell it sends.

(13) The source may implement a use-it-or-lose it policy to reduce its ACR to a value which approximates the actual cell transmission rate. Use-it-or-lose-it policies are discussed in Appendix I.8.

DESTINATION BEHAVIOR

The following items define the destination behavior for CLP=0 and CLP=1 cell streams of a connec-

tion. By convention, the CLP=0 stream is referred to as in-rate, and the CLP=1 stream is referred to as

out-of- rate.

(1) When a data cell is received, its EFCI indicator is saved as the EFCI state of the connection.

(2) On receiving a forward RM-cell, the destination shall turn around the cell to return to the source. The DIR bit in the RM-cell shall be changed from "forward" to "backward", BN shall be set to zero, and CCR, MCR, ER, CI, and NI fields in the RM-cell shall be unchanged except:

(a) If the saved EFCI state is set, then the destination shall set CI=1 in the RM-cell, and the saved EFCI state shall be reset. It is preferred that this step is performed as close to the transmission time as possible;

(b) The destination having internal congestion may reduce ER to whatever rate it can support and/or set CI=1 or NI=1. A destination shall either set the QL and SN fields to zero, preserve these fields, or set them in accordance with I.371-draft. The octets defined in Table 5-4 as reserved may be set to 6A (hexadecimal) or left unchanged. The bits defined as reserved in Table 5-4 for octet 7 may be set to zero or left unchanged. The remaining fields shall be set in accordance with Section 5.10.3.1 (Note that this does not preclude looping fields back from the received RM-cell).

(3) If a forward RM-cell is received by the destination while another turned -around RM-cell (on the same connection) is scheduled for in-rate transmission:

(a) It is recommended that the contents of the old cell are overwritten by the contents of the new cell;

(b) It is recommended that the old cell (after possibly having been over-written) shall be sent out-of-rate; alternatively the old cell may be discarded or remain scheduled for in-rate transmission;

(c) It is required that the new cell be scheduled for in-rate transmission.

(4) Regardless of the alternatives chosen in destination behavior #3 above, the contents of an older cell shall not be transmitted after the contents of a newer cell have been transmitted.

(5) A destination may generate a backward RM-cell without having received a forward RM-cell. The rate of these backward RM-cells (including both in-rate and out-of-rate) shall be limited to 10 cells/second, per connection. When a destination generates an RM-cell it shall set either CI=1 or NI=1, shall set BN=1, and shall set the direction to backward. The destination shall assign values to the various RM-cell fields as specified for destination generated cells in Table 5-4.

(6) When a forward RM-cell with CLP=1 is turned around it may be sent in-rate (with CLP=0) or out-of-rate (with CLP=1).

ABBREVIATIONS

AA	Administrative Authority
AA L	ATM adaptation Layer
ABR	Available Bit Rate
ACR	Allowed Cell Rate
AFI	Authorization and Format Identification
AMP	Active Monitor Present
ATM	Asynchronous Transfer Mode
BRM	Backward Resource Management
BISDN	Broadband and Integrated Services
CATV	Digital Network
CBR	Constant Bit Rate
CLP	Congestion Loss Priority
CSMA/CD	Carrier Sensor Multiple Access with Collision Detection
DCC	Data Country Code
DFI	DSP Form Identifier
DSP	Domain Specific Part
EFCI	Explicit Forward-Congestion Indication
EI	Electromagnetic Interface
ER	Explicit Cell Rate
ESI	End of System Identification or IEEE 802 MAC
ETR	Early Token Release
FDDI	Fiber Distributed Data Interface
FRM	Forward Resource Management
GFC	Generic Flow Control
HEC	Header Error Control
ICD	International Code Designator
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ITU-T	International Telecommunication Union-Telecommunication
LAN	Local Area Network
MAC	Media Access Control
MAN	Medium Area Network
MAU	Multi-station Access Unit
Mbps	Million Bits Per Seconds
NAUN	Next Active Upstream Neighbor
NIC	Network Interface Card
NLPI	Network Layer Protocol Interface
Nrt_VBR	Non Real-Time Variable Bit Rate
NSAP	Network Service Access Point
OSI	Open System Interconnect
PDP	Priority Driven Protocol
PT	Payload Type
PVC	Permanent Virtual Connection
QoS	Quality of Service
RD	Routing Domain
RMON	Remote Monitor
RSVP	Resource reSerVation Protocol
Rt-VBR	Real-Time Variable Bit Rate
Sel	Selector
SMP	Stand-by Monitor Present
SNMP	Simple Network Management Protocol
STM	Synchronous Transfer Mode
STP	Shielded Twisted Pair
SVC	Switched Virtual Connection
TCP/IP	Transmission Control Protocol/Internet Protocol
TR	Token Ring
TTP	Timed Token Protocol
UBR	Unspecified Bit Rate
UTP	Unshielded Twisted Pair
VC	Virtual Channel
VCC	Virtual Channel Connection
VCI	Virtual Channel Identifier
VGAnyLAN	Voice Grade Any LAN
VLAN	Virtual Local Area Network
VOD	Voice On Demand
VP	Virtual Path
VPI	Virtual Path Identifier
WAN	Wide Area Network

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