CHAPTER 3

ATM Network and Congestion Control

3.1 ATM Network

It has been envisioned that future applications will require higher bandwidths and generate a mix of heterogeneous network traffic [19]. Applications that are largely based on multimedia and interactive services are becoming increasingly popular. Applications such as video conferencing and interactive services like audio/video retrieval are now being used in the corporate and educational sector. Sooner or later, these applications may be accessible to home users as well. This has prompted increased demand for a communication network that can support a higher bandwidth and provide different service to a variety of traffic types. Existing networks such as TCP/IP are unsuitable and incapable to fulfill the needs of these future applications. Over the years, the focus on satisfying the above requirements is being placed on the ATM network. ATM is potentially able to support all classes of traffic including voice, video and data in a single transmission and switching technology. The ATM network promises greater efficiency in handling different kind of traffic types without compromising the desired quality of service requested by the applications or users. It offers an integrated approach and more flexibility in gaining access to the network. Another important aspect is that it can offer these services in an economical manner.

In ATM networks, information is carried in short fixed-size data packets called cells. The use of fixed-size cells has its advantages. Firstly, choosing a fixed-size cell enables a more simple design of switching and multiplexing function. Fixed-size cells can be switched more efficiently, thus better suited for the high data rates of ATM. Therefore, ATM cells can be sent across the network faster because of minimal switching performed on the cells en route to its destination. This also reduces delay variance, making it suitable for integrated traffic consisting of voice, video and data. Through multiplexing, the transmission resources can be shared among users. This encourages efficient utilization of network resources thus providing an economical service to network users. The use of small cells may reduce queuing delay, especially for a high-priority cell that is waiting to gain access to a resource currently used by a lower priority cell.

By enforcing proper traffic management, ATM promises to satisfy different quality of service (QoS) required by different types of traffic thus ensuring efficient operation of the network.

3.1.1 Basic Principles of ATM

ATM networks are very much different from existing networks such as packet switch and frame relay. Among some of the key features of ATM are:

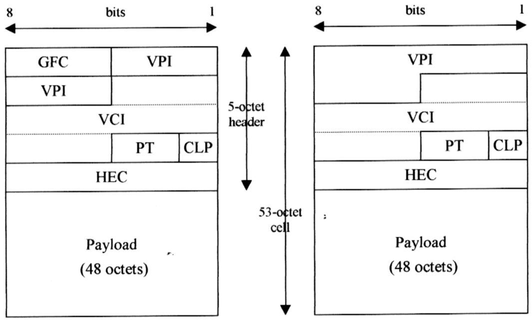
a) As mentioned before, information is sent through short fixed-size cells. Using fixed-size cells simplifies the processing required at each ATM node. Also, short cells reduce waste and delay in packetization. The flexibility needed to support various transmission rates is provided by transmitting necessary number of cells per unit time.
b) ATM network uses a connection-oriented approach. A path is set up between the source and destination before any information can be exchanged between the two parties. It involves a connection setup procedure at the start and a tearing down procedure at the end. Since ATM network is connection-oriented, the order of cells is preserved. Each connection has assigned capacity, allocated to the user's request but subjected to sufficient capacity available.
c) The cell is switched according to the virtual path identifier or virtual channel identifier (VPI/VCI) value in the cell header. The VPI/VCI values will be used in multiplexing and represents the routing address. These identifiers which are originally set at the connection setup, will be translated into a new set of VPI/VCI value when the cell passes each switch.
d) The information in the payload is transparent to the network. Flow control and error recovery are performed on an end-to-end basis. The network only performs header error control through cyclic redundancy check (CRC) on the cell header.

e) ATM resources are shared among users, and only used when the user has something to transmit. Thus, statistical multiplexing is used to improve effective throughput.

f) ATM network must provide guarantee to users that he/she will get the desired quality of service (QoS) agreed at the connection setup.

3.1.2 ATM Cell Format

ATM uses short fixed-size cells to transmit information. An ATM cell consists of a 5-octet header and a 48-octet information field. There are two types of cell header format, one for the user-network interface (UNI), and the other for the network-network interface (NNI). The UNI format for the cell header is used between the user and the ATM network (e.g. ATM switch) whereas the NNI format is used internal to the network. Figure 3.1(a) and 3.1(b) below illustrates the ATM cell format for both the UNI and NNI:



(a) user-network interface (b) network-network interface

Figure 3.1 ATM Cell Format

An ATM cell header consists of the following fields:

Generic Flow Control (GFC) – used for control of cell flow only at the local user-network interface. This field contains 4 bits.

Virtual Path Identifier/Virtual Channel Identifier (VPI/VCI) – VPI consists of a routing field for the network. It is 8 bits at the UNI and 12 bits at the NNI. VCI is used for routing to and from the end user.

Payload Type (PT) – indicates the type of information in the cell payload. It is a 3 bits field. PT indicates whether user information or network information is carried in the cell payload.

Cell Loss Priority (CLP) – CLP is a 1 bit field that may be set by the user or the network (switch) to indicate lower priority cells. Cells with CLP bit set to 1 are subjected to being discarded in the event of congestion. This bit can be set by the network for any cells that violate the agreed traffic parameters between user and network. A value of 0 for the CLP bit indicates a cell of relatively higher priority.

Header Error Control (HEC) – HEC field consists of 8 bits and is used to detect any errors in the header. The error control covers the whole cell header. The error protection function provides recovery (correction) from single-bit error and detection of multi-bit error.

3.1.3 ATM Virtual Path/Virtual Channel

The relationship between physical transmission path, virtual path (VP) and virtual channel (VC) is illustrated in Figure 3.2 below. A transmission path contains one or more virtual paths, while inside each virtual path contains one or more virtual channels. Therefore, multiple virtual channels can be grouped into a single virtual path. Switching can be done on the transmission path, virtual path or virtual channel level.

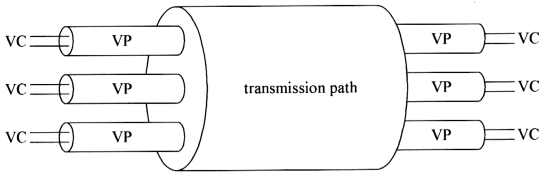


Figure 3.2 ATM Connection Relationships

Logical connections in ATM are referred to as virtual channels (VCs). A virtual channel is setup between two end users through the network, and a variable-rate, unidirectional flow of fixed-size cells is exchanged over the connection. The series of virtual channels that is established is called a virtual channel connection (VCC). The VCI in each cell header identifies which virtual channel the cell belongs to. VCCs are used in between end users to exchange user data, between end user and the network for control signaling, and between two network entities for network traffic management and routing functions.

Also, a second sublayer of processing is introduced that deals with the concept of virtual path (VP). A virtual path is a bundle of virtual channels that have the same endpoints. Thus, all cells flowing over all VCs in a single VP are switched along the same path. Virtual path links are concatenated to form a virtual path connection (VPC). The VPI in the cell header identifies the virtual path for each cell.

Some of the advantages of using virtual paths [20]:

Simplified network architecture – network transport functions can be separated into those related to an individual logical connection (virtual channel), and those related to a group of logical connections (virtual path).

Increased network performance and reliability – network deals with fewer aggregated entities.

Reduced processing and short connection setup time – the processing required to setup new virtual channels can be minimized once the virtual path involved is established.

Enhanced network services – the user may defined closed user groups or closed networks of virtual channel bundles because the use of virtual path is visible to the end user.

The characteristics of virtual channel connections (VCCs) are listed below [20]:

Quality of service – A user of a VCC is provided with a quality of service (QoS) specified by parameters such as cell loss ratio and cell delay variation.

Switched and semipermanent virtual channel connections – A switched VCC is setup on demand and is tear down after usage, through call control signaling. A semipermanent VCC is of a longer duration and is setup by configuration or network management action.

Cell sequence integrity – cells sequence is preserved in a VCC; cells arrive in the order that they were sent.

Traffic parameter negotiation and usage monitoring – User and the network can negotiate the traffic parameters for each VCC. The network will then monitor the input cells flowing through the VCC to ensure that the negotiated parameters are not violated. Details of the operation will be discussed in Section 3.6.

The characteristics for virtual path connections (VPCs) are identical to those for VCCs, coupled with:

Virtual channel identifier restriction within a VPC – one or more VCIs may be reserved for network use (e.g. network management) and thus not available to the user of the VPC.

3.1.4 ATM Protocol Architecture

The ITU-T has developed a set of standards for ATM based on the protocol architecture illustrated in Figure 3.3 below. Communication from higher layers is adapted to the lower ATM layer through the ATM adaptation layer (AAL). The information is then passed from the ATM layer to the physical layer for transmission over a selected physical medium. Therefore, three layers are defined: the ATM adaptation layer (AAL), the ATM layer, and the physical layer.

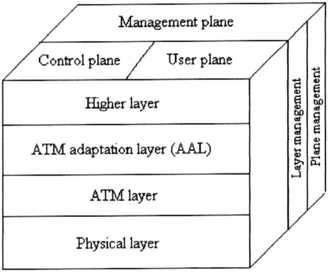


Figure 3.3 ATM Protocol Architecture (adapted from [20])

ATM adaptation layer (AAL)

The AAL layer serves as an interface between the higher layer protocols and the ATM layer. Information from upper layers is segmented by the AAL layer into ATM cells, and later passed on to the ATM layer. On the other hand, cells received by the ATM layer is relayed to the AAL layer, which reassemble the cells into a format understood by the higher layers. Four types of AALs are proposed, each supporting a different type of traffic or service [19]. However, each AAL is not restricted to a specific type of traffic, and can be used for others. The significance is that each AAL is optimized for the designated traffic type. More information on AALs and the different traffic classes supported can be found in [19, 20]

ATM layer

The ATM layer defines the transmission of data in fixed-size cells and also defines the use of logical connections. When this layer is in an end system, its task is to transmit cells received from the AAL layer through the physical layer. In a switch, the ATM layer handles buffering of incoming and outgoing cells, and performs traffic management functions such as cell loss priority marking, congestion indication and generic flow control access. It also performs traffic policing functions.

Physical layer

The physical layer defines the signal encoding/decoding scheme used for transmission and reception of data on a specific physical medium. The physical medium can be fibre optic or twisted-pair wire.

In addition to the three layers, the ATM protocol reference model includes three separate planes [20]:

User plane – provides for user information transfer, flow control and error control
Control plane - carry out call control and connection control functions
Management plane - consists of plane management and layer management. Plane management provides coordination between all planes and manages the system as a whole. Layer management manages the resources and parameters residing in its protocol entities.

3.2 ATM Traffic and Congestion Control

In ATM networks, information is transmitted using short fixed-length packets, called cells, which reduces the delay variance, making it suitable for integrated traffic consisting of voice, video and data. Because ATM network offers multiple user access to high speed connection with different quality of service, proper traffic management needs to be implemented. This is to ensure that the requirements for different types of traffic are met. By proper traffic management, ATM is able to provide efficient operation to meet different quality of service (QoS) desired by different types of traffic.

3.2.1 The Need for Congestion Control

The assumption that statistical multiplexing can be used to improve link utilization is that the users do not take their peak rate values simultaneously. However, since the traffic demands are stochastic and cannot be predicted, congestion is unavoidable. When input rate is greater than output rate, buffer will overflow and cells are dropped. Therefore, congestion control is needed to protect and ensure users get the desired quality of service and fair share of bandwidth.

Although many realize the importance of congestion control, but there are still several misunderstandings about the cause and solutions for it [21]:

a) Congestion is caused by the shortage of buffer space. The problem will be solved when the cost of memory becomes cheap enough to allow very large memories.

   Larger buffer is useful only for very short-term congestion and will cause undesirable long delays. Even if the buffer is increased to a larger size, the buffer will still overflow if the situation persists. A larger buffer size can only postpone or delay the discarding of cells but cannot prevent it. However, the long queues and long delays introduced by large memories is undesirable for some applications.

b) Congestion is caused by slow links. The problem will be solved when high-speed links become available.

   It is not always the case; sometimes increases in link bandwidth can aggravate the congestion problem because higher speed links may make the network more unbalanced.

c) Congestion is caused by slow processors. The problem will be solved when processor speed is improved.

   This statement is rather similar to the second one. Faster processors will transmit more data per unit time. If several nodes begin to transmit to one destination simultaneously at their peak rate, the destination will be congested soon.

As can be seen from above, these myths are based on belief that congestion will automatically be solved, as resources become cheaper. All the issues presented above are symptoms, not the causes of congestion. Congestion is a dynamic problem; any static solutions are not sufficient to solve the problem. Thus, proper congestion management mechanisms are very important.

3.2.2 Requirements for ATM Traffic and Congestion Control

The ATM network poses entirely different requirements for traffic and congestion control. This is because the types of traffic and transmission characteristics of ATM network are very much different from packet-switched network or frame relay. Most of the traffic carried by packet switching network and frame relay is bursty in nature and non time-sensitive. Therefore,

a) The network does not need to replicate exact timing pattern of incoming traffic at exit node.
b) Because the traffic is bursty, simple statistical multiplexing can be used to accommodate multiple logical connections over a single physical interface between user and network. Thus, user-network interface (UNI) only needs to provide capacity greater that the sum of the average data rates for all connections.

Currently, there are many approaches and tools to control congestion. However, these approaches are mainly designed for packet switched and frame relay networks. Therefore, when these are applied to control congestion in ATM networks, a number of problems arise. The reasons are [20]:

a) Feedback is slow because of drastically reduced cell transmission time compared to propagation delay across network.
b) ATM traffic such as voice and video is not amenable to flow control.
c) The wide variety of supported service (from few kilobits to hundreds megabits) by ATM requires more intelligent congestion control method. Simple-minded congestion control method cannot ensure fairness.

d) ATM networks are more volatile in terms of congestion and traffic control because of its high transmission and switching speed.

Latency and speed effects have a great influence on congestion control schemes in ATM networks. Assume that a node is transmitting a long file to a destination far away. If only implicit congestion control is used, the source will only detect congestion in the network if cells are dropped. If congestion do occur in the network, cells are discarded and the destination will return a reject message to source. The source will then need to retransmit the cells that are lost and possibly all subsequent cells. Due to the high transmission speed and low cell transmission time compared to propagation delay, by the time the notification arrives at source, the source has already transmitted a large amount of cells.

3.3 ATM Traffic and Quality of Service (QoS) Attributes

As mentioned earlier, effective traffic management mechanisms are needed to ensure that the ATM network can deliver the guaranteed quality of service on demand while maximizing the utilization of available network resources. The ATM Forum had defined a number of traffic attributes and quality of service parameters to characterize an ATM connection.

When user setups a connection in ATM networks, the user can specify these traffic attributes and quality of service parameters related to the connection. These parameters will be used to determine the input traffic characteristics and the desired quality of service.

3.3.1 Traffic Descriptor

The ATM Forum has defined a set of traffic descriptors to characterize the traffic pattern of cells flowing over an ATM connection. For a given connection, traffic descriptors are grouped into a source traffic descriptor, which in turn is a component of a connection traffic descriptor. These terms are defined below [2]:

3.3.1.1 *Source Traffic Descriptor*

A source traffic descriptor is the set of traffic descriptors for the ATM source. It is used during the connection establishment to capture the intrinsic traffic characteristics of the connection requested by a particular source. It includes:

Peak Cell Rate (PCR) – The maximum instantaneous rate at which the user will transmit. It defines an upper bound on the traffic that can be submitted by a source on an ATM connection.

Sustainable Cell Rate (SCR) – The average rate as measured over a long interval. It defines an upper bound on the average rate of an ATM connection over a long period.

Maximum Burst Size (MBS) – The maximum number of cells that can be sent continuously at the peak cell rate.

Minimum Cell Rate (MCR) – The minimum cell rate desired by a user.

3.3.1.2 *Connection Traffic Descriptor*

The connection traffic descriptor specifies the traffic characteristics of the ATM connection. The connection traffic descriptor includes the source traffic descriptor, the cell delay variation tolerance (CDVT), and the conformance definition that is used to unambiguously specify the conforming cells of the connection.

Cell delay variation tolerance (CDVT) – a measure of the amount of variation in cell delay that is introduced by the network interface and at the UNI. CDVT is expressed as time variable.

Conformance definition – used to specify unambiguously the conforming cells of the connection at the UNI. Cells that do not conform may be marked or dropped.

3.3.2 Quality of service (QoS) Attributes

The ATM Forum has defined the following QoS attributes [2]:

Peak-to-peak Cell Delay Variation (peak-to-peak CDV) – The difference between the maximum and minimum cell transfer delay (CTD) experienced during the connection. CTD is defined as the delay experienced by a cell between network entry and exit points. It includes propagation delays, queuing delays at various intermediate switches, and service time at queuing points.

Maximum Cell Transfer Delay (maxCTD) – the maximum requested delay for a particular connection.

Cell Loss Ratio (CLR) – The percentage of cells that are lost in the network due to error or congestion and are not received by the destination. CLR is the ratio of lost cells to total transmitted cells on a connection.

$$\text{Cell Loss Ratio} = \frac{\text{Lost Cells}}{\text{Transmitted Cells}}$$

3.4 ATM Service Categories

ATM technology is intended to support a wide variety of services and applications. Therefore, providing the desired quality of service for different applications is very complex. As an example, voice traffic is delay-sensitive but not loss-sensitivity. On the other hand, data is not delay-sensitive but loss-sensitive. Some applications' data might be both loss-sensitive and delay-sensitive. Thus, to make it easier to manage, the ATM Forum has defined five ATM service categories to cater for different applications. These five service categories are [2]:

Constant Bit Rate (CBR)

It is used by applications that require a constant fixed cell rate throughout the connection lifetime. It has tightly constrained CTD and CDV.

Example of applications: video conferencing, interactive audio/video, audio/video distribution, and audio/video retrieval

Real-Time Variable Bit Rate (rt-VBR)

It is used by applications that require tightly constrained CTD and CDV but do not require constant cell rate. It is intended for time-sensitive applications. rt-VBR applications transmit at a variable cell rate, hence the name VBR. Able to use statistical multiplexing.

Example applications: interactive compressed video.

Non-Real-Time Variable Bit Rate (nrt-VBR)

This service category is similar to rt-VBR except that only CTD are tightly constrained and certain low CLR is allowed. It is able to make greater use of statistical multiplexing to increase network efficiency.

Example applications: response time critical transaction processing such as airline reservations, banking transactions and process monitoring.

Unspecified Bit Rate (UBR)

It is designed for applications that wishes to use any left-over capacity not used by CBR and VBR and are not sensitive to cell loss or delay. It is referred to as a best-effort service because no guarantee is given to a UBR source and no congestion feedback is provided. The application is subjected to cell losses and delay.

Example applications: text/data/image transfer, distribution and retrieval, remote terminal such as telnet.

Available Bit Rate (ABR)

ABR provides applications with a guaranteed minimum cell rate (MCR). Any unused capacity is then shared among all ABR sources in a fair and controlled manner. Explicit feedback is used for this purpose. Applications using ABR also specify a PCR that it may use. Any capacity not used by ABR sources will be available for UBR applications.

Example applications: critical data transfer, distributed file service and remote procedure call.

Table 3.1 below provides a list of ATM attributes (traffic descriptors, QoS attributes and feedback characteristics) and identifies whether and how these attributes are supported for each service category [2]:

Attributes	ATM Layer Service Category				
	CBR	rt-VBR	nrt-VBR	UBR	ABR
Traffic Descriptors					
PCR and CDVT(4,5)	specified			specified(2)	specified(3)
SCR, MBS, CDVT(4,5)	N/A	specified		N/A	
MCR(4)	N/A				specified
QoS Parameters					
peak-to-peak CDV	specified		unspecified		
maxCTD	specified		unspecified		
CLR(4)	specified			unspecified	(1)
Other Attributes					
Feedback	unspecified				specified

Table 3.1 ATM Service Categories Attributes (adapted from [2])

Notes:

1. CLR is low for sources that adjust cell flow in response to control information. Whether a quantitative value for CLR is specified is network specific.
2. May not be subject to CAC and UPC procedures.
3. Represents the maximum rate at which the ABR source may ever send. The actual rate is subject to the control information.
4. These parameters are either explicitly or implicitly specified for PVCs or SVCs.
5. CDVT is not signaled. In general, CDVT need not have a unique value for a connection. Different values may apply at each interface along the path of a connection.

3.5 ATM Traffic Management Framework

Among the objectives of ATM traffic and congestion control are [2]:

a) To provide support for a set of QoS classes and parameters sufficient for all ATM services
b) To minimize the complexity of network and end-system while maximizing network utilization
c) The ATM traffic and congestion control should not be network or application specific.

Traffic and congestion control functions are designed to operate across a spectrum of timing intervals. These intervals refer to the response time of the functions. Four levels of timing are considered [20]:

- Cell insertion time – reacts as cells are transmitted
- Round-trip propagation time – network responds within the lifetime of the cells in the network and may provide feedback to source.
- Connection duration – decides whether the network can accommodate a new connection at a desired QoS without affecting current connections and causing congestion.
- Long term – used for long term and affects all ATM connections under control.

Table 3.2 below illustrates the traffic control and congestion control functions with respect to their response time:

Response Time	Traffic Control Functions	Congestion Control Functions
Long Term	♦ Resource management using virtual paths	
Connection Duration	♦ Connection admission control (CAC)	
Round-trip Propagation Time	♦ Fast resource management	♦ Explicit forward congestion indication (EFCI) ♦ ABR flow control
Cell Insertion Time	♦ Usage parameter control (UPC) ♦ Priority control ♦ Traffic shaping	♦ Selective cell discard ♦ Frame discard

Table 3.2 Traffic control and congestion control functions (adapted from [20])

Details of these functions will be discussed in the next section.

Congestion control schemes can also be classified by the stage that the operation is performed: congestion prevention, congestion avoidance and congestion recovery. Congestion prevention is the methods utilized to prevent congestion or make congestion impossible. Congestion avoidance means that congestion may happen, but the method will try to maintain a balanced network state. Congestion recovery is the remedy steps taken to pull the system out of the congestion state as soon as possible. It also tries to lessen the damage being done after the congestion had happened.

3.6 ATM Traffic Control and Congestion Control Functions

Among the problems and difficulties of ATM traffic and congestion control are the burstiness of the traffic flow, unpredictable demand for resources, and the latency/speed effect due to low cell transmission time compared to large propagation delay.

To meet the above objectives of ATM traffic and congestion control, the ATM Forum has defined a set of generic functions. These generic functions formed a framework for managing and controlling traffic and congestion in ATM networks and will be used in appropriate combinations depending on the service category. The generic functions are:

- Connection admission control (CAC)
- Usage parameter control (UPC)
- Selective cell discard
- Traffic shaping
- Explicit forward congestion indication (EFCI)
- Resource management using virtual path
- Frame discard
- ABR flow control

Explanation for each of the functions will be presented below. Emphasis will be given to the usage parameter control (UPC) and selective cell discard functions because of its' usage in the proposed ATM fuzzy logic controller.

3.6.1 Connection Admission Control (CAC)

The Connection Admission Control (CAC) is defined as the set of actions taken by the network during call setup to either accept or reject a connection. The CAC algorithm will only accept a connection if the network is able to allocate its resources along the path of the connection to support the desired service category, traffic contract and QoS requested by user while maintaining the agreed QoS of existing connections. The CAC function will use the information contained in the traffic contract for each connection request. The traffic contract consists of the following:

- Service category (e.g. CBR, rt-VBR, ABR)
- Connection traffic descriptor – consists of source traffic descriptor (e.g. PCR, SCR), CDVT and requested conformance definition
- Requested and acceptable values for each QoS parameters (e.g. CLR, maxCTD)

Based on the information derived from the traffic contract and also the state of the network (e.g. the number and condition for existing connections), the CAC function will evaluate and decide on the following:

- Accept or reject the connection
- Allocate network resources
- Connection traffic parameters needed by UPC function

The network will form a traffic contract with the user once the connection has been accepted. The user may also requests for two levels of cell loss priority (CLP) and specifies different traffic parameters for each flow of cells. This will enable more efficient allocation of network resources. Another strategy is to obtain information on the current network load when performing the CAC function. This approach may improve network utilization. The CAC function is network specific.

3.6.2 Usage Parameter Control (UPC)

Usage parameter control (UPC) is defined as the set of actions taken by the network to monitor and control the flow of cells in the connection. If UPC detects that the traffic is in violation of the traffic contract and negotiated traffic parameters, it will take appropriate actions accordingly. This is to ensure that the network is protected from excessive load and also to guarantee the QoS of existing connections.

UPC Location

UPC can be implemented at the virtual path or virtual channel levels. The UPC location depends on the points where virtual channel or virtual path link connected to a network termination point, is terminated in the network. The more important is virtual path level because network resources are allocated based on virtual path.

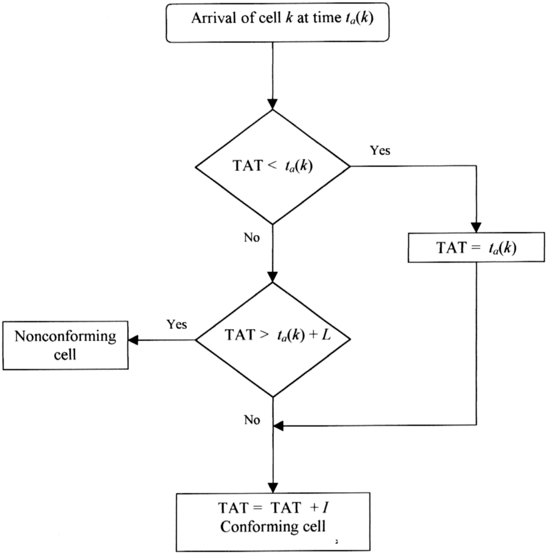
Generic Cell Rate Algorithm (GCRA)

The ATM Traffic Management Specification provides an algorithm to be used for usage parameter control to monitor conformance with the traffic contract. The algorithm is called Generic Cell Rate Algorithm (GCRA). For each cell arrival, the GCRA will determine whether the cell conforms to the traffic contract of the connection. If the cell is in violation, then the cell is nonconforming. Equivalent versions of the algorithm may be performed by the UPC function. GCRA algorithm has two parameters: an increment (I) and a limit (L), and its notation is GCRA (I, L).

Two equivalent versions of GCRA algorithm is presented below,

a) Virtual scheduling algorithm
b) Continuous state leaky bucket algorithm

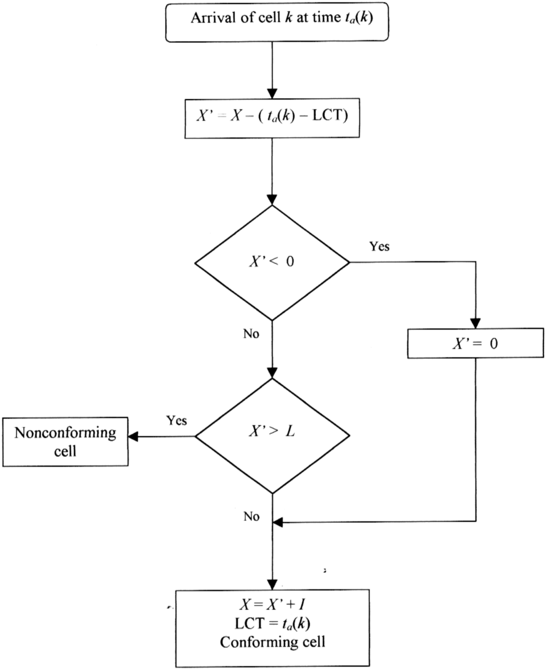
Flowcharts for both algorithms are presented in Figure 3.4 below to illustrate the operation of the algorithms.



I = increment
L = limit
$t_a\ (k)$ = time of arrival of a cell

TAT = Theoretical arrival time
At the time of arrival t_a of the first cell of the connection, TAT = $t_a\ (1)$

Figure 3.4 (a) Virtual Scheduling Algorithm



X = Value of the leaky bucket counter
X' = auxiliary variable
LCT = last compliance time
At the time of arrival t_a of the first cell of the connection, $X = 0$, LCT = t_a (1)

Figure 3.4 (b) Continuous-state Leaky Bucket Algorithm

The virtual scheduling algorithm works as follows:

When the first cell arrives at time $t_a(1)$, the theoretical arrival time (TAT) is initialized to this values. The TAT is the expected time of arrival for the next cell. If a cell arrives later than TAT, the cell is compliant and TAT is updated to arrival time plus increment. If the cell arrives within the delay tolerance, the cell is compliant and TAT is added by increment. If the cell arrives earlier and outside the delay tolerance, then the cell is noncompliant and TAT remains unchanged.

The continuous-state leaky bucket algorithm operates as follows:

The algorithm works like a bucket with a hole at the bottom. The algorithm maintains a count of the cumulative amount of data inside the bucket. The bucket leaks at a constant rate thus decreasing the counter by one unit per time unit, to a minimum of zero. On the other hand, each time a cell arrives, the counter is incremented by I. Any cell arrival that causes the counter to exceed its maximum value, $I + L$ (i.e. bucket size) is defined as nonconforming.

Figure 3.5 below illustrates the leaky bucket algorithm:

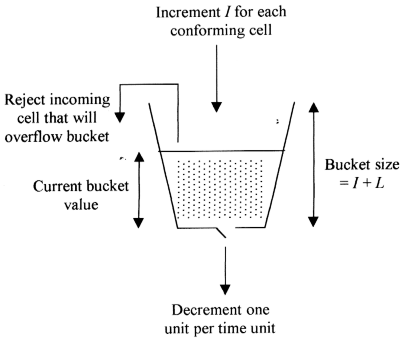


Figure 3.5 The leaky bucket algorithm

UPC Action

At cell level, UPC may:

a) pass cells
b) discard/drop cells
c) mark/tag cells

Tagging cells is optional for both the network and user. If enabled, CLP=0 cells that are nonconforming are converted to CLP=1 cells. These cells are considered tagged. If these cells are conforming to CLP=0+1, they are passed, otherwise they are dropped. Tagging is used to transform a non-conforming CLP=0 cell into a conforming CLP=1 cell when the cell is conforming to the aggregate CLP=0+1 flow.

3.6.3 Selective Cell Discard

Selective cell discard comes into operation when it detects nonconforming cells or when the network is congested. Cells that may be discarded are cells:

a) which belong to a non-compliant ATM connection;
b) which have CLP=1.

The purpose is to protect higher priority (CLP=0) cells from performance degradation cause by network congestion.

3.6.4 Traffic shaping

Traffic shaping is a mechanism that smoothes out the stream of cells and reduces cell clumping. Cell sequence integrity on a connection is maintained during traffic shaping. The purpose of traffic shaping is to improve network efficiency whilst meeting the QoS objectives.

3.6.5 Explicit forward congestion indication (EFCI)

If implemented, this mechanism is used by network elements that are anticipating congestion or in a congested state. The network element will set an EFCI in the ATM cell header to indicate to the destination end system that it is anticipating or experiencing congestion. Therefore, the end system may use a protocol to lower the cell rate of the connection in order to relieve the congestion.

3.6.6 Resource management using virtual path

This is a long term traffic and congestion control function. Virtual path connections (VPC) are used to group similar virtual channel connections (VCCs) together. By grouping VCCs, it can:

a) simplify CAC
b) implement priority control by grouping VCCs according to service category
c) simplify task of sending messages to manage traffic control functions

Resources can be allocated to a VPC and then, the capacity of the VPC will be shared among the VCCs contained within. By resource management and allocation using VPC, there are three situations to consider:

- user-to-user application – VPC extends between a pair of UNIs. Network has no knowledge of the QoS for each VCCs in the VPC. User is responsible to make sure that the VCCs can be accommodated by the VPC
- user-to-network application – VPC extends between a UNI and a network node. Network knows the QoS for each VCCs and has to accommodate for them in the VPC
- network-to-network application – VPC extends between two network nodes. Same as user-to-network application

There are two ways to allocate capacity to VPC according to the traffic parameters of VCCs contained within:

a) Aggregate peak demand – network allocates capacity to accommodate the total aggregate peak rates of all VCCs in the VPC.
b) Statistical multiplexing – network allocates capacity to be slightly greater or equal to average data rates of all VCCs in the VPC.

3.6.7 Frame discard

Sometimes it may be more effective to discard cells at the frame level than at the cell level. A frame is an AAL protocol data unit. The network is able to discard frames when it can detect frame boundaries (indicated by a field in ATM cell header).

3.6.8 ABR flow control

As mentioned in the earlier section, the ABR connections share any available capacity unused by CBR and VBR. The ABR source adapts its rate to changing network conditions, often varying its rate between MCR and PCR. ABR sources adapt transmission rates based on the feedback received from the network. Feedback is in the form of special control cells called Resource Management Cells (RM-cells). Information about the state of the network like bandwidth availability, state of congestion, and impending congestion, is conveyed through RM-cells. Thus, the ABR flow is limited to available capacity.