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The ATM Forum

Technical Committee

Traffic Management Specification

Version 4.0

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This specification consolidates the dedication and creativity of many individuals. This work would not have been possible without the involvment of the numerous members of The ATM Forum Traffic Management Working Group who made contributions to enhance, analyze, challenge, discuss, and review the specification.

The following individuals deserve mention for their involvment in the production of this specification:

- Shirish Sathaye, Editor, Traffic Management Working Group.
- Vijay Samalam, Vice-chair, Traffic Management Working Group.
- Jim Ormord, former Vice-chair, Traffic Management Working Group

This specification also includes previous Traffic Management concepts which were specified as part of UNI 3.1. Special thanks are extended to the following people for producing these parts of the specification:

- Dave McDysan, former Chair, Traffic Management Working Group
- Lou Wojnaroski, former Editor, Traffic Management Working Group

Natalie Giroux, Chair
The ATM Forum Traffic Management Working Group

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Preface

This is Version 4.0 of the ATM Forum Traffic Management Specification. The previous version of the traffic management specification may be found in:

- ATM User-Network Interface (UNI) Specification Version 3.1, September 1994, Prentice Hall PTR, Upper Saddle, NJ 07458, ISBN 0-13-3933828-X.

This document uses the following three levels for indicating the degree of compliance necessary for specific functions/procedures/coding associated with traffic management:

- **Requirement (R):** functions, procedures, and coding necessary for operational compatibility.
- **Conditional Requirement (CR):** functions, procedures, and coding necessary provided the specified optional functional is implemented.
- **Option (O):** functions, procedures, and coding that may be useful, but are not necessary for operational compatibility.

When a level is not specified, the level **"Requirement (R)"** should be assumed to hold.
In this specification, annexes are normative and appendices are informative. The major advances of this version are:

- Definition of the ABR service category.
- Detailed ATM service architecture.
- Modifications to conformance definitions.

1. Introduction

ATM technology is intended to support a wide variety of services and applications. The control of ATM network traffic is fundamentally related to the ability of the network to provide appropriately differentiated Quality of Service (QoS) for network applications. This specification defines procedures and parameters related to Traffic Management and Quality of Service. A primary role of traffic management is to protect the network and the end-system from congestion in order to achieve network performance objectives. An additional role is to promote the efficient use of network resources.

A set of five service categories are specified. For each one, a set of parameters is given to describe both the traffic presented to the network, and the Quality of Service (QoS) which is required of the network. A number of traffic control mechanisms are defined, which the network may utilize to meet the QoS objectives.

1.1 Generic Functions

To meet these objectives, the following functions form a framework for managing and controlling traffic and congestion in ATM networks and may be used in appropriate combinations depending on the service category.

- Connection Admission Control (CAC) is defined as the set of actions taken by the network during the call set-up phase in order to determine whether a connection request can be accepted or should be rejected (or whether a request for re-allocation can be accommodated).
- Feedback controls are defined as the set of actions taken by the network and by end-systems to regulate the traffic submitted on ATM connections according to the state of network elements.
- Usage Parameter Control (UPC) is defined as the set of actions taken by the network to monitor and control traffic, in terms of traffic offered and validity of the ATM connection, at the end-system access. Its main purpose is to protect network resources from malicious as well as unintentional misbehavior, which can affect the QoS of other already established connections, by detecting violations of negotiated parameters and taking appropriate actions. Such actions may include cell discard and cell tagging.
- Cell Loss Priority control: For some service categories the end system may generate traffic flows of cells with Cell Loss Priority (CLP) marking. The network may follow models which treat this marking as transparent or as significant. If treated as significant, the network may selectively discard cells marked with a low priority to protect, as far as possible, the QoS objectives of cells with high priority.
- Traffic Shaping: Traffic shaping mechanisms may be used to achieve a desired modification of the traffic characteristics.
- Network Resource Management (NRM): The service architecture allows logical separation of connections according to service characteristics. Although cell scheduling and resource provisioning are implementation and network specific, they can be utilized to provide appropriate isolation and access to resources. Virtual Paths are a useful tool for resource management.
- Frame Discard: A congested network that needs to discard cells may discard at the frame level rather than at the cell level. The concept of a frame is defined in Section 5.8.
- ABR Flow Control: The ABR flow control protocol may be used to adaptively share the available bandwidth among participating users.
- Other generic functions are for further study.

1.2 Relation with Other Documents

This specification expands on some topics in ITU-T Recommendations I.371-draft, I.356, and I.150. Section 4 of this specification is closely related to ITU-T Recommendation I.371-draft. Some differences are as follows:

- The service categories of the ATM Forum are called ATM transfer capabilities in I.371-draft. Some of the ATM service categories of the ATM Forum are equivalent to some of the ATM transfer capabilities in I.371-draft but have different names: Constant Bit Rate (CBR) is called Deterministic Bit Rate (DBR) in I.371-draft and Variable Bit Rate (VBR) is called Statistical Bit Rate (SBR) in I.371-draft. In general, a mapping between the ATM Forum service categories and the ATM transfer capabilities can be made with the following discrepancies:
  - The ATM Forum distinguishes between real-time VBR and non-real-time VBR while I.371-draft so far specifies non-real-time SBR and leaves real-time SBR for further study.
  - The ATM Forum has a service category Unspecified Bit Rate (UBR) which has no equivalent ATM transfer capability in I.371-draft.
  - I.371-draft partially specifies an ATM transfer capability, ATM Block Transfer (ABT), which has no equivalent in this specification.
  - ABR is fully specified in this specification, but the ABR transfer capability is only partially specified in I.371-draft and is still under study.
- Differences from ITU-T Recommendation I.356 include:
  - This specification provides for negotiation of the following QoS parameters on a connection basis:
    - Peak-to-peak Cell Delay Variation,
    - Maximum Cell Transfer Delay
    - Cell Loss Ratio
  - ITU-T Recommendation I.356 only defines QoS classes. However, in this specification, individual QoS parameters are specified and QoS classes are retained for backward compatibility.

    Note: ITU-T SG 13 intends to include a single end-to-end objective applicable for all connections for CER, SECBR, and CMR, in ITU-T Recommendation I.356.
- The text in Section 1.5 of ITU-T Recommendation I.371-draft is not consistent with Sections 3.4.2.1 and 3.4.2.2 of ITU-T Recommendation I.150. Moreover the text in Section 2.3.2 of ITU-T Recommendation I.371-draft is open to different interpretations. In an effort to provide a consistent interpretation of the above basic concept in this specification, the QoS classes have been divided into two categories: Specified QoS classes and the Unspecified QoS class (see Annex B.3). For each direction of an ATM layer connection, an end-system requests one QoS class at connection setup or subscription time. Also, differences exist in the use of RM-cell fields QL and SN defined in ITU-T Recommendation I.371-draft, and the source, destination and switch behaviors (not yet specified in ITU-T Recommendation I.371-draft).
- ITU-T Recommendation I.371-draft (Section 6.2.3) states that “The use of a UPC function is recommended, and the use of an NPC function is a network option.” In this specification, the UPC is optional.

2. ATM Service Architecture

The architecture for services provided at the ATM layer consists of the following five service categories:

- **CBR** Constant Bit Rate
- **rt-VBR** Real-Time Variable Bit Rate
- **nrt-VBR** Non-Real-Time Variable Bit Rate
- **UBR** Unspecified Bit Rate
- **ABR** Available Bit Rate

These service categories relate traffic characteristics and QoS requirements to network behavior. Functions such as routing, CAC, and resource allocation are, in general, structured differently for each service category. Service categories are distinguished as being either real-time or non-real-time. For real-time traffic, there are two categories, CBR and rt-VBR, distinguished by whether the traffic descriptor contains only the Peak Cell Rate (PCR) or both PCR and the Sustainable Cell Rate (SCR) parameters. The three non-real-time categories (nrt-VBR, UBR, and ABR) are compared and distinguished in some detail in Section 2.3. All service categories apply to both VCCs and VPCs. Throughout this document, the term "connection" refers to either VCCs or VPCs.

The specification of a real-time service category that uses a feedback flow control mechanism similar or identical to that used for ABR is for further study.

This specification uses Resource Management cells, (RM-cells) to control the cell flow of ABR connections. The use of RM-cells for the control of CBR, rt-VBR, nrt-VBR or UBR connections is not defined in this specification. However, RM-cells are allowed on such connections. If RM-cells are present on such connections, then they are considered as part of the user data cell flow.

Informative Appendix IV illustrates this service architecture by discussing how different applications may map into each service category.

2.1 Definitions for Service Categories

This section defines the ATM service categories using the following QoS parameters. These QoS parameters are defined in Section 3.6.

- Peak-to-peak Cell Delay Variation (peak-to-peak CDV)
- Maximum Cell Transfer Delay (maxCTD)
- Cell Loss Ratio (CLR)

Each of the following service categories will have one or more conformance definitions, as defined in Section 4.5. These Conformance Definitions are distinguished by the manner in which the QoS parameters, particularly CLR, apply to the CLP=0 or CLP=0+1 cell flows.

2.1.1 Constant Bit Rate (CBR) Service Category Definition

The Constant Bit Rate service category is used by connections that request a static amount of bandwidth that is continuously available during the connection lifetime. This amount of bandwidth is characterized by a Peak Cell Rate (PCR) value.

The basic commitment made by the network to a user who reserves resources via the CBR capability is that once the connection is established, the negotiated ATM layer QoS is assured to all cells when all cells are conforming to the relevant conformance tests. In the CBR capability, the source can emit cells at the Peak Cell Rate at any time and for any duration and the QoS commitments still pertain.

CBR service is intended to support real-time applications requiring tightly constrained delay variation (e.g., voice, video, circuit emulation) but is not restricted to these applications. In the CBR capability, the source may emit cells at, or below the negotiated Peak Cell Rate (and may also even be silent), for periods of time. Cells which are delayed beyond the value specified by the maximum cell transfer delay (maxCTD) are assumed to be of significantly reduced value to the application.

The CBR service category may be used for both VPCs and VCCs.

2.1.2 Real-Time Variable Bit Rate (rt-VBR) Service Category Definition

The real-time VBR service category is intended for real-time applications, i.e., those requiring tightly constrained delay and delay variation, as would be appropriate for voice and video applications. rt-VBR connections are characterized in terms of a Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), and Maximum Burst Size (MBS). Sources are expected to transmit at a rate which varies with time. Equivalently the source can be described as "bursty". Cells that are delayed beyond the value specified by maxCTD are assumed to be of significantly reduced value to the application. Real-time VBR service may support statistical multiplexing of real-time sources.

2.1.3 Non-Real-Time (nrt-VBR) Service Category Definition

The non-real-time VBR service category is intended for non-real-time applications which have bursty traffic characteristics and which are characterized in terms of a PCR, SCR, and MBS. For those cells which are transferred within the traffic contract, the application expects a low cell loss ratio.
Non-real-time VBR service may support statistical multiplexing of connections. No delay bounds are associated with this service category.

2.1.4 Unspecified Bit Rate (UBR) Service Category Definition

The Unspecified Bit Rate (UBR) service category is intended for non-real-time applications, i.e., those not requiring tightly constrained delay and delay variation. Examples of such applications are traditional computer communications applications, such as file transfer and email.
UBR service does not specify traffic related service guarantees. No numerical commitments are made with respect to the CLR experienced by a UBR connection, or as to the CTD experienced by cells on the connection. A network may or may not apply PCR to the CAC and UPC functions. In the case where the network does not enforce PCR, the value of PCR is informational only. When PCR is not enforced it is still useful to have PCR negotiated, since this may allow the source to discover the smallest bandwidth limitation along the path of the connection. Congestion control for UBR may be performed at a higher layer on an end-to-end basis.
The UBR service is indicated by use of the Best Effort Indicator in the ATM User Cell Rate Information Element.

2.1.5 Available Bit Rate (ABR) Service Category Definition

ABR is an ATM layer service category for which the limiting ATM layer transfer characteristics provided by the network may change subsequent to connection establishment. A flow control mechanism is specified (Section 5.10) which supports several types of feedback to control the source rate in response to changing ATM layer transfer characteristics. This feedback is conveyed to the source through specific control cells called Resource Management Cells, or RM-cells. It is expected that an end-system that adapts its traffic in accordance with the feedback will experience a low cell loss ratio and obtain a fair share of the available bandwidth according to a network specific allocation policy. The ABR service does not require bounding the delay or the delay variation experienced by a given connection. ABR service is not intended to support real-time applications.
On the establishment of an ABR connection, the end-system shall specify to the network both a maximum required bandwidth and a minimum usable bandwidth. These shall be designated as peak cell rate (PCR), and the minimum cell rate (MCR), respectively. The MCR may be specified as zero. The bandwidth available from the network may vary, but shall not become less than MCR.
Further information on the ABR flow control model and service model can be found in Section 2.4.

2.2 ATM Service Category Parameters and Attributes

Table 2-1 provides a list of ATM attributes (traffic parameters, QoS parameters, and feedback characteristics) and identifies whether and how these are supported for each service category. Traffic parameters are defined in Section 4 and Section 5. QoS parameters are defined in Section 3.

Attribute	ATM Layer Service Category				
	CBR	rt-VBR	nrt-VBR	UBR	ABR
Traffic Parameters:					
PCR and CDVT(4,5)	specified			specified[2]	specified[3]
SCR, MBS, CDVT(4,5)	n/a	specified		n/a	
MCR[4]	n/a			n/a	specified
QoS Parameters:					
peak-to-peak CDV	specified		unspecified		
maxCTD	specified		unspecified		
CLR[4]	specified			unspecified	See Note 1
Other Attributes:					
Feedback	unspecified				specified[6]

Table 2-1: ATM Service Category Attributes

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 refers to the Cell Delay Variation Tolerance (see Section 4.4.1). 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.
6. See Section 2.4.

2.3 Relationship between nrt-VBR, UBR, and ABR Service Categories

Three service categories are intended for non-real-time applications. They differ as to the nature of the service guarantees provided by the network and the mechanisms which are implemented in end-systems and networks to realize them. Selection of an appropriate service category is application specific.

2.3.1 Nature of Service Guarantees

The nrt-VBR service category provides commitments for a cell loss ratio for those connections which remain within the traffic contract negotiated with the network at the time the connection is established. The CLR for cells sent that do not conform to the traffic contract is not guaranteed. Also, some degree of isolation is assumed; that is, connections which exceed their traffic contract are expected not to cause the negotiated CLR to be exceeded on connections which do not exceed their traffic contract.

The UBR service category offers no traffic related service commitments. No numeric commitment is made as to the cell loss ratio experienced by a connection, or as to the cell transfer delay experienced by cells on the connection. Fairness among connections cannot be assumed, although local policy in some network elements may have this effect.

The ABR service category provides a low cell loss ratio for those connections whose end-stations obey a specified reference behavior. No numeric commitment is made about cell transfer delay. If the endpoints fail to observe the reference behavior, the cell loss ratio is not guaranteed. Fairness among connections is assumed, modified by the MCR, local policy in network elements, and a potentially significant error term. Specific examples of fairness criteria are documented in Appendix I.3. A sufficient degree of isolation between connections is necessary so that connections which fail to observe the reference behavior do not cause quality degradation on connections which do observe the reference behavior.

2.3.2 Mechanisms

The non-real-time VBR service category is inherently open loop and has a traffic contract. The traffic contract may be met by the source end-system by use of traffic shaping, and enforced by the network and/or destination end-system by use of UPC. It is assumed that resources are reserved in network nodes to meet the traffic contract and QoS commitments, and thus connection admission control is provided in the network. This document does not specify a flow-control scheme for nrt-VBR.

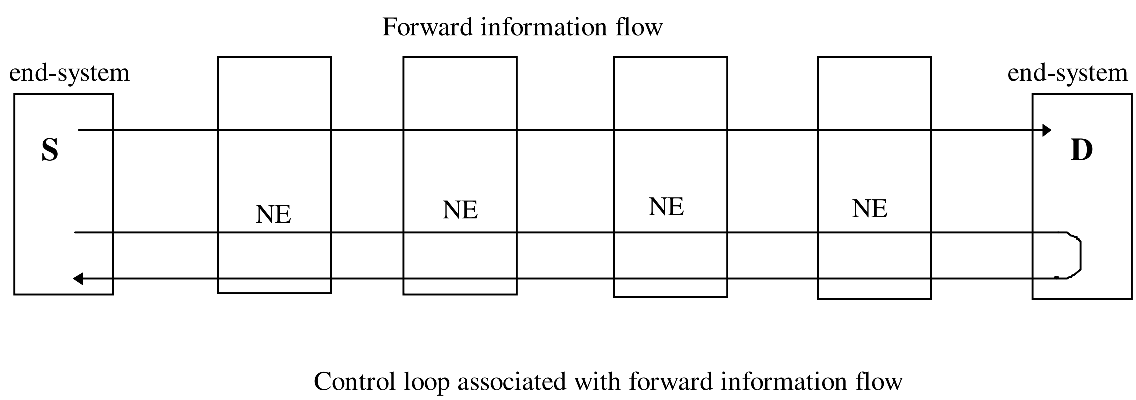
The UBR service category is inherently open loop. UBR is not subject to a specific traffic contract but may be subject to a local policy in individual switches and end-systems.

The ABR service is inherently closed loop. The source performs dynamic traffic shaping based on feedback received from the network. This behavior may be enforced by the network using UPC. A minimum cell rate (MCR) is negotiated. If the MCR is non-zero, then it is assumed that resources are reserved in network nodes to ensure that the feedback never causes the available cell rate to fall below the MCR, and that low CLR is achieved; thus, connection admission control is provided in the network. Local policy in network elements contributes to fairness and isolation, with the objective of achieving low CLR for those connections which obey the source behavior.

2.4 Flow Control Model and Service Model for the ABR Service Category

2.4.1 Flow Control Model for ABR

ABR flow control occurs between a sending end-system (source) and a receiving end-system (destination). Sources and destinations are connected via bi-directional connections. For a bi-directional ABR connection, each connection termination point is both a source and a destination. For the sake of simplicity, only the information flow from the source to the destination with its associated RM-cell flows is considered. The forward direction is the direction from the source to the destination, and the backward direction is the direction from the destination to the source. As shown in Figure 2-1, for the forward information flow from the source to the destination, there is a control loop consisting of two RM-cell flows, one in the forward direction and one in the backward.



S: Source
D: Destination
NE: Network Element

Figure 2-1: Example of a source to destination ABR control loop

A source generates forward RM-cells which are turned around by the destination and sent back to the source as backward RM-cells. These backward RM-cells carry feedback information provided by the network elements and/or the destination back to the source. A network element may:

- Directly insert feedback control information into RM-cells when they pass in the forward or backward direction
- Indirectly inform the source about congestion by setting the EFCI bit in the data cell header of the cells of the forward information flow. In this case, the destination will update the backward RM-cells based on this congestion information.
- Generate backward RM-cells.

2.4.2 Detailed Service Model for ABR

The following points summarize some properties of ABR service:

- A goal of ABR service is to provide rapid access to unused network bandwidth at up to PCR, whenever the network bandwidth is available.
- A reference behavior of the source end-system (Section 5.10.4), destination end-system (Section 5.10.5), and switch (Section 5.10.6) is specified. Performance commitments by the network will apply only for end-systems which follow the reference behavior. These performance commitments are in terms of a cell loss ratio that is network specific.
- An ABR end-station must always implement both the source and destination behavior.
- In ABR, user data cells shall have CLP=0. However RM-cells may have CLP=1. Since the CLR objectives for ABR cover only cells with CLP=0, the network may selectively discard RM-cells marked CLP=1. Tagging is currently not supported by ABR. It is for further study whether ABR may also use CLP=1 user data cells and whether tagging may be applied.
- The ABR service may apply to both VCCs and VPCs.
- A network element may divide an ABR connection into separately controlled segments by closing the feedback loop using the virtual source and virtual destination function described in Section 5.10.7. Segmentation may be desirable at administrative boundaries, or when the magnitude of round-trip delay differs between two segments, or due to the preferences of the network operator.
- Fairness: No set of connections should be arbitrarily discriminated against and no set of connections should be arbitrarily favored, although resources may be allocated according to a defined policy. The results of the bandwidth allocation process for ABR service approaches some fairness criteria. A number of fairness criteria are possible. See Appendix I.3 for examples.
- Acceptable values of Cell Loss Ratio are network specific. The objective is to minimize CLR provided the end-system adapts the traffic to the changing ATM layer transfer characteristics.
- The rate of any ABR flow has two components: an MCR component, which could be zero, for which there is a quantitative commitment made by the network, and an “elastic” component for which the commitment made by the network is only a relative assurance that bandwidth will be shared fairly among the ABR flows.
    - MCR is negotiated independently for each direction of a bi-directional ABR connection. A source is not precluded from sending at a rate less than MCR, when MCR > 0 is negotiated.
    - The actual cell rate sent by the end-system on the ABR connection need never be less than MCR[1]. The MCR agreed between the end-systems and the network(s) carrying the connection may range from zero to the maximum value supported by the network(s). This maximum may be zero. If the calling end-system does not indicate a requested MCR, the default value of MCR is zero.
    - The method for fairly allocating bandwidth after MCR commitments are met is an area for implementation latitude. However, whatever the interpretation, it must be consistent and predictable within a range of error. The ideal fair share of a connection in a given

[1] See Section 5.10.2.2 for details on negotiating MCR.

configuration can be calculated given global knowledge. This is described in detail in Appendix I.3.

- If no connections have MCR requirements, and all connections are equally weighted[2], the max-min fairness criteria can be applied. Fairness cannot be observed in isolation by a user of the service. For non-zero MCR requirements and for the case of weighted[1] allocation of bandwidth, other fairness criteria may apply.

- Although the network commits to support MCR, a source may receive indications to reduce its rate below MCR. If a source receives such indication and its rate is above MCR it should reduce its rate to MCR. Likewise, if a source receives such indication, and its rate is at or below MCR, the source need make no change to its rate.
- During a connection establishment for a connection with MCR=0, it is not expected that the CAC function will block the connection because of bandwidth (e.g., MCR) allocated to other connections. Blocking due to CAC for other reasons is not precluded.
- When ABR connections with MCR >0 are set up, they may block future requests for connections with MCR >0. The management of bandwidth allocation between ABR and other service categories is implementation dependent.
- Because RM-cells cannot convey the EFCI code point, a switch that relies exclusively on EFCI feedback to convey its congestion state may (depending on implementation) be unable to effectively control the rate of in-rate RM-cells on a connection, during periods when no data cells are transmitted on the connection. In the absence of mechanisms to maintain control during such periods a network may choose to reserve a certain amount of bandwidth in order to increase the network's tolerance of the in-rate RM-cell stream. The amount of bandwidth reserved for this purpose is network specific and may support only a limited number of connections. This may result in rejection of setup requests including those with MCR=0.

  One mechanism that can be used to maintain control of the in-rate RM-cell stream during periods when no data cells are transmitted on a connection is via switch behavior #1 b, "relative rate marking" (see Section 5.10.6).

2.4.2.1 Point-to-multipoint ABR Connections

The support of ABR point-to-multipoint connections is not required for ABR compliance as defined in this specification. However, the guidelines provided here are intended as a basic framework for a complete specification of point-to-multipoint ABR service in the future.

The defining characteristics of an ABR point-to-multipoint connection are its dynamic allocation of available bandwidth and its flow-controlled transport of data from the root to each responding leaf. Under one possible operation, achieving the latter characteristic requires the root of the tree to transmit data at a rate that the slowest branch can carry and that the slowest leaf can accept, although all branches and leaves are expected to support a rate greater than or equal to the MCR of the connection at all times. Nevertheless, because the ABR source behavior requires a decrease in rates in the absence of feedback, strict adherence under all circumstances to the requirement for flow-controlled transport would result in the degradation of performance for the entire tree whenever a single leaf became unresponsive. Therefore, a branch may be designated as in the "non-responding state" if no RM-cells have been received from the branch for some time, the length of which is implementation specific but indicates the unavailability of the branch. The branch point need not consider the presence of branches in the non-responding state in sending feedback to the root, and cells lost on non-responding branches are not counted against cell-loss objectives.

Point-to-multipoint behavior is addressed in Section 5.10.8. Branch points, which must replicate cells traveling from root to leaves and consolidate feedback traveling from leaves to root, are functionally

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[2]Weighted allocation implies that the available bandwidth can be divided in proportion to per connection weights. These weights could be equally related to MCR or independent of MCR.

defined, but their operating policies are implementation specific. An ABR branchpoint should ensure that cell flows on its branches observe the same conformance definitions as point-to-point cell flows. It must replicate data and forward RM-cells, consolidate backward RM-cells, (to ensure that the volume of RM-cells returning to the source do not increase with the number of leaves in the tree), and it must support CLR objectives. Because the expected behavior of the ABR flow on a point-to-multipoint branch is the same as on a point-to-point connection, each branch and leaf must be prepared to accept cells at a rate greater than or equal to the negotiated MCR at all times.

The behavior of switches (located on a branch), sources and destinations (located at the root or at leaves), and of virtual sources and virtual destinations (located on a branch) are the same for multipoint operation as for point-to-point operation, except that data traffic is not allowed in the direction from the leaves to the root of the point-to-multipoint tree. Availability of bandwidth on the return path (from leaf towards root) is necessary for the propagation of return RM-cells. Hence, MCR > 0 and PCR > 0 are allowed for the return path. When MCR = PCR = 0 is used for the return path, only out-of-rate RM-cells are allowed, as specified in Section 5.10.8.1. The MCR (PCR) used from leaf to root may differ from the MCR (PCR) used from root to leaf, but must be the same for all leaves. The flow of data cells from the leaves to the root is precluded because data cells, unlike RM-cells, cannot be consolidated at branch points. The cell-loss ratio required of a point-to-multipoint ABR connection by some applications may depend on the size of the point-to-multipoint tree. Some applications need to retransmit a cell to all leaves whenever it does not successfully arrive at any leaf. For such applications, it is recommended that the CLR parameter, which applies at each interface to an individual leaf, should be chosen to control the probability of unsuccessful delivery of each cell to one or more leaves. As an example, under the conservative assumption that the unsuccessful delivery of a given cell to each of N different leaves are independent events, the expected relationship between (a) the proportion CLR_total of cells transmitted by the root that are not successfully received by at least one leaf and (b) the CLR for each individual leaf is

$$\text{CLR\_total} = 1- (1-\text{CLR})^N$$

and CLR would be chosen accordingly.

The ABR branch point may segment the control loop by placing virtual sources at the interface to one or more branches and virtual destinations at the branches feeding them. The use of buffering at virtual sources allows the temporal decoupling of the feedback received from the leaves and transmitted to the root. It also allows the decoupling of the ABR parameters downstream and upstream of the branch point. For delivery with low CLR within a subtree between virtual sources/destinations, the source parameters at the root must be chosen to accommodate all the branches allowed on the tree. Architectural options, beyond the use of virtual sources/virtual destinations, for further decoupling the ABR control loop include the use of multicast servers that terminate the ATM layer, but such options are beyond the scope of this document.

3. ATM Layer Quality of Service

The ATM layer Quality of Service (QoS) is measured by a set of parameters characterizing the performance of an ATM layer connection. These QoS parameters quantify end-to-end network performance at the ATM layer. In ITU-T Recommendation I.356, they are referred to as network performance parameters.

3.1 Quality of Service Parameters

Six QoS parameters are identified in this specification which correspond to a network performance objective. Three of these may be negotiated between the end-systems and the networks. One or more values of the QoS parameters may be offered on a per connection basis, corresponding to the number of related performance objectives supported by the network. Support of different performance objectives can be done by routing the connection to meet different objectives, or by implementation-specific mechanisms within individual network elements. The following QoS parameters are negotiated:

- Peak-to-peak Cell Delay Variation (peak-to-peak CDV)
- Maximum Cell Transfer Delay (maxCTD)
- Cell Loss Ratio (CLR)

The following QoS parameters are not negotiated:

- Cell Error Ratio (CER)
- Severely Errored Cell Block Ratio (SECBR)
- Cell Misinsertion Rate (CMR)

Further information on ATM layer QoS may be found in ITU-T Recommendation I.356.

3.2 Nature of QoS Commitments

A network may support one or more performance objectives for each of the QoS parameters. For each direction of a connection, a specific QoS is negotiated among the network(s) and the end-systems. The network agrees to meet or exceed the negotiated QoS as long as the end-system complies with the negotiated traffic contract (see Section 4 and ITU-T Recommendation I.371-draft).

QoS commitments are probabilistic in nature, and are intended to be only a first order approximation of the performance that the network expects to offer over the duration of the connection. Since there is no limit to the duration of connections, and the network can only make decisions based on information available at the time the connection is established, the actual QoS may vary over the duration of the connection. In particular, transient events (including uncontrollable impairments in transmission systems) can cause short term performance observations to be worse than the agreed QoS commitment. Thus, QoS commitments can only be evaluated over the long term and over multiple connections with similar QoS commitments.

The precision with which the various QoS values can be coded may be significantly greater than the accuracy with which the network can predict, measure or maintain a given performance level. Thus, the number of significant digits in the encoding of the QoS parameters that are expressed as numeric values (rather than orders of magnitude) should not be misconstrued as a commitment to that level of precision in performance management.

3.3 Negotiation of QoS Parameters

The mechanisms whereby QoS may be negotiated between the end-system and the network in quantified numeric units are defined in UNI Signaling 4.0 and PNNI 1.0. These mechanisms supplement the “QoS class” procedures defined in UNI 3.1 and ITU-T Recommendation I.356. Implementations must at a minimum support QoS indication via QoS classes. In addition implementations capable of stating QoS in terms of individual numeric parameter values may do so using the procedures defined in UNI Signaling 4.0 and PNNI 1.0.

3.4 Terminology

3.4.1 Cell Events

The following two events are defined based on ITU-T Recommendation I.356. These events will be used in defining the QoS performance parameters.

- A "cell exit event" occurs when the first bit of an ATM cell has completed transmission out of an end-system to a Private ATM network element across the "Private UNI" Measurement Point, or out of a Private ATM network element to a Public ATM network element across the "Public UNI" Measurement Point, or out of an ATM end-system to a Public ATM network across the "Public UNI" Measurement Point.
- A "cell entry event" occurs when the last bit of an ATM cell has completed transmission into an end-system from a Private ATM network element across the "Private UNI" Measurement Point, or into a Private ATM network element from a Public ATM network element across the "Public UNI" Measurement Point or into an ATM end-system from a Public ATM network element across the "Public UNI" Measurement Point.

3.4.2 Cell Transfer Outcome

The following possible cell transfer outcomes between measurement points for transmitted cells are defined based on ITU-T Recommendation I.356:

- Successful Cell Transfer Outcome: The cell is received corresponding to the transmitted cell within a specified time T_{max}. The binary content of the received cell conforms exactly to the corresponding transmitted cell payload and the cell is received with a valid header field after header error control procedures are completed.
- Errored Cell Outcome: The cell is received corresponding to the transmitted cell within a specified time T_{max}. The binary content of the received cell payload differs from that of the corresponding transmitted cell payload or the cell is received with an invalid header field after header error control procedures are completed.
- Lost Cell Outcome: No cell is received corresponding to the transmitted cell within a specified time T_{max}. (Examples include "never received" or "late".)
- Misinserted Cell Outcome: A cell is received for which there is no corresponding transmitted cell.
- Severely-Errored Cell Block Outcome: When M or more Lost Cell outcomes, Misinserted Cell Outcomes, or Errored Cell outcomes are observed in a received cell block of N cells transmitted consecutively on a given connection.

3.5 QoS Reference Configuration

QoS parameters are defined at measurement points which coincide with interfaces shown in Figure 3-1.

Quantitative values for performance objectives are not defined in this document. However, alternative means to measure, or estimate the value of defined performance parameters will be described. QoS performance of switches and QoS performance objectives of networks are stated in terms of the parameters defined in this section.

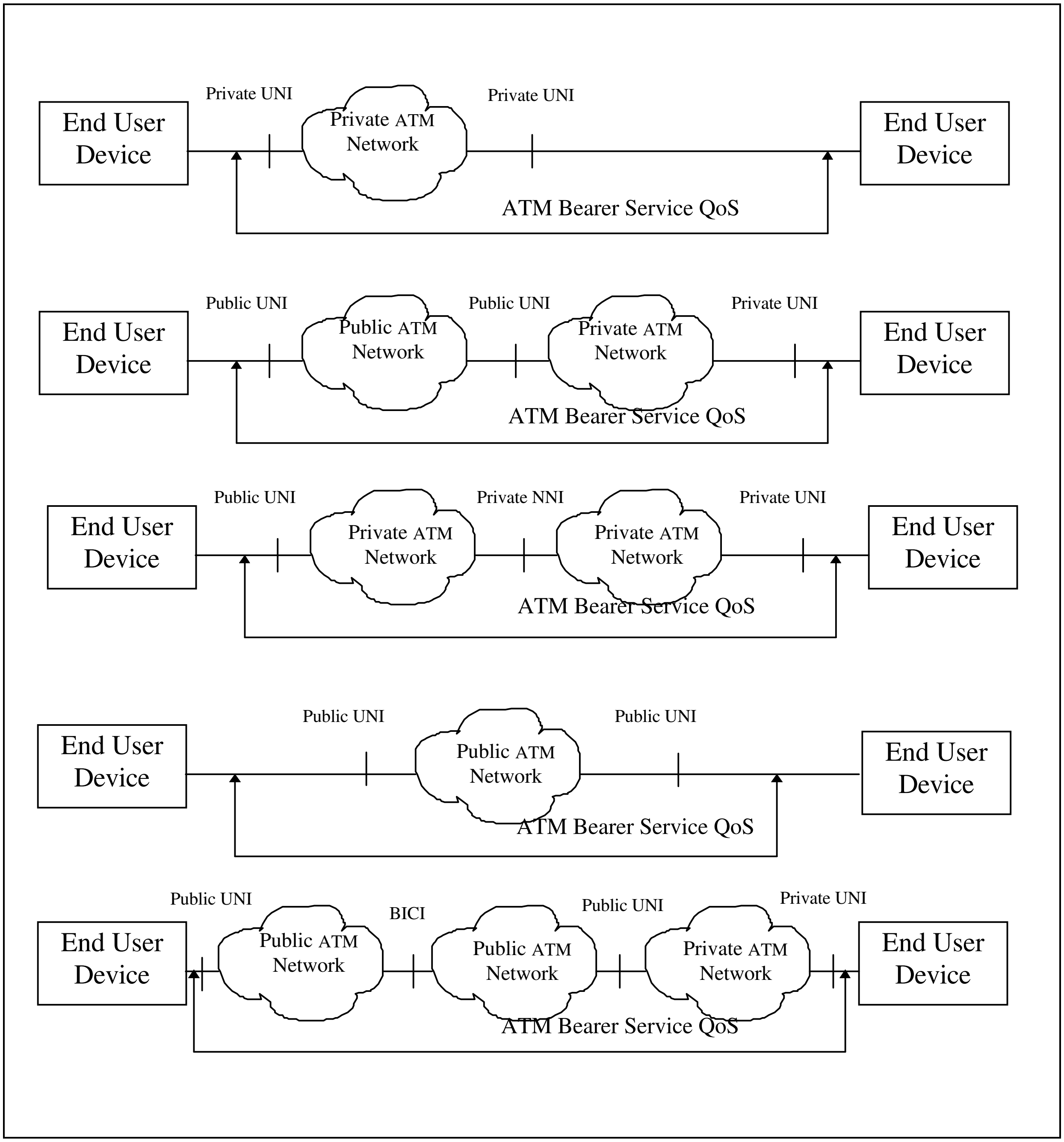


Figure 3-1: ATM QoS Reference Configurations

3.6 Definition of Negotiated QoS Parameters

This section describes QoS parameters that may apply to a connection. These parameters are defined in terms of:

a) a method for measuring the transfer characteristics of the network as observed on a single ATM cell (or a sequence of ATM cells) during the lifetime of an ATM virtual connection, and

b) a statistical objective that is negotiated, such that the network agrees to meet at least the value negotiated over a large sample of cells.

Measurements are useful for determining network performance (including determination of whether negotiated statistical objectives for the connection are being met). Measurements occur at measurement points, as defined in ITU-T Recommendation I.356.

One or more measurements and one or more objectives apply to each relevant aspect of QoS. The measurement of network performance on a virtual connection is likely to be different from the negotiated objective for the connection at any given time. This is because:

- The negotiated objective is the worst case of network performance (measured over a sample of cells that is appropriately large for the given QoS parameter) that the network will allow, including periods of peak loading. The mechanisms described in Section 5 are used to ensure that the QoS experienced by existing connections meets at least the negotiated objective. During periods when network loading is much less than the engineered capacity, the measured performance may be significantly better than the negotiated objective.
- Transient events can cause the measured performance of a connection to be worse than the negotiated objective, when a measurement is inappropriately used over an insufficiently large sample of cells.

3.6.1 Delay Parameters

The measured Cell Transfer Delay (CTD) is defined as the elapsed time between a cell exit event at measurement point 1 (MP_1) (e.g., at the source UNI) and the corresponding cell entry event at measurement point 2 (MP_2) (e.g., the destination UNI) for a particular connection. The Cell Transfer Delay between two measurement points is the sum of the total inter-ATM node transmission delay and the total ATM node processing delay between MP_1 and MP_2. The various components of the Cell Transfer Delay are described in more detail in Annex B of I.356.

Two end-to-end delay parameter objectives are negotiated:

- peak-to-peak CDV
- maxCTD.

Figure 3-2 below illustrates the probability density function of the CTD in CBR and real-time VBR services, and relates it to the peak-to-peak CDV and maxCTD parameters.

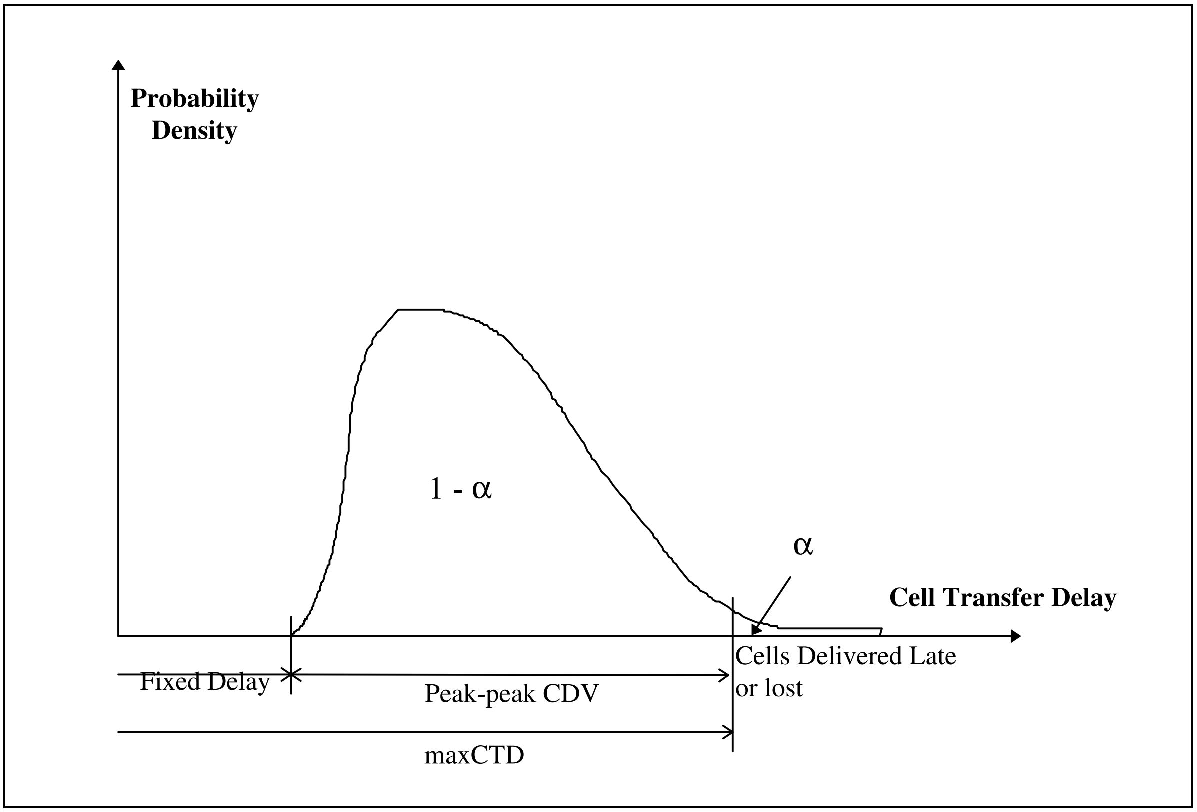


Figure 3-2: Cell transfer delay probability density model (for real-time service categories)

The components of the fixed delay include propagation through the physical media, delays induced by transmission system, and fixed components of switch processing delay. CDV is induced by buffering and cell scheduling.

3.6.1.1 Maximum Cell Transfer Delay (maxCTD)

The maximum Cell Transfer Delay (maxCTD) specified for a connection is the (1 - α) quantile of CTD. The CLR at connection request time is used to place an upper bound on α. When a switch accumulates maxCTD or CDV it may choose a smaller α which may have the effect of over estimating the cumulative maxCTD or CDV. The assumed relationship between CLR and α is for further study.
Refer to UNI Signaling 4.0 for the coding of maxCTD.

3.6.1.2 Cell Delay Variation (CDV)

Two measurement methods are defined for CDV. These are:

- One-point cell delay variation (one-point CDV)
- Two-point cell delay variation (two-point CDV).

The negotiated objective for CDV performance is expressed in terms of peak-to-peak CDV.
Note: The QoS parameter CDV should not be confused with the connection traffic parameter CDVT (see Setion 4.4.1).

3.6.1.2.1 One-Point CDV

The one-point CDV describes the variability in the pattern of cell arrival events observed at a single measurement point with reference to the negotiated peak rate 1/T (as defined in ITU-T Recommendation I.371-draft).

The one-point CDV for cell k (y_k) at a measurement point is defined as the difference between the cell's reference arrival time (c_k) and actual arrival time (a_k) at the measurement point: $y_k = c_k - a_k$. The reference arrival time (c_k) is defined as follows:

$$c_0 = a_0$$

$$c_{k+1} = \begin{cases} a_k + T & \text{if } c_k \le a_k \\ c_k + T & \text{otherwise} \end{cases}$$

Positive values of the one-point CDV correspond to cell clumping; negative values of the one-point CDV correspond to gaps in the cell stream. The reference arrival time defined above eliminates the effect of gaps and provides a measurement of cell clumping.

3.6.1.2.2 Two-Point CDV

The two-point CDV describes the variability in the pattern of cell arrival events observed at the output of a connection portion (MP_2) with reference to the pattern of the corresponding events observed at the input to the connection portion (MP_1).

The two-point CDV for cell k (v_k) between two measurement points (MP_1 and MP_2) is the difference between the absolute cell transfer delay of cell k (x_k) between the two MPs and a defined reference cell transfer delay ($d_{1,2}$) between MP_1 and MP_2: $v_k = x_k - d_{1,2}$.

The absolute cell transfer delay (x_k) of cell k between MP_1 and MP_2 is the same as Cell Transfer Delay defined in Section 3.6.1. The reference cell transfer delay ($d_{1,2}$) between MP_1 and MP_2 is the absolute cell transfer delay experienced by a reference cell between the two MPs.

ITU-T Recommendation I.356 provides more details on the CDV measurements.

3.6.1.2.3 Peak-to-peak Cell Delay Variation (peak-to-peak CDV)

The peak-to-peak CDV is the $(1 - \alpha)$ quantile of the CTD minus the fixed CTD that could be experienced by any delivered cell on a connection during the entire connection holding time.
The term "peak-to-peak" refers to the difference between the best and worst case of CTD, where the best case is equal to the fixed delay, and the worst case is equal to a value likely to be exceeded with probability no greater than α. Assuming that the fixed delay is the reference delay for the two point CDV the range of the distribution of the two-point CDV is the same as the peak-to-peak CDV.
Refer to UNI Signaling 4.0 for the coding of peak-to-peak CDV.
Networks have a finite ability to control peak-to-peak CDV. Therefore, end-systems cannot expect to negotiate arbitrarily small values of peak-to-peak CDV as their sole means of meeting jitter and wander tolerances (as specified in ITU-T Recommendations G.822 and G.823).

3.6.2 Accumulation of QoS Parameters

This section specifies accumulation algorithms for the two delay parameters, maxCTD and peak-to-peak CDV. These algorithms are intended to be used in path calculations and to accumulate delay parameters in signaling protocols as a call progresses. As a result, the accumulation algorithms provide estimates of the end-to-end values of these parameters along a path. A simple accumulation based on worst case assumptions is supported in this specification. An example enhancement to the simple method, called the

asymptotic method, is described in Appendix V. This enhanced method is for further study for future versions of this document.
The simple accumulation for peak-to-peak CDV is the following: A switch receives the accumulated peak-to-peak CDV and adds its contribution of the peak-to-peak CDV(α) to the accumulated peak-to-peak CDV.
The simple accumulation for maxCTD is the following: A switch receives the accumulated maxCTD and adds its contribution of the maxCTD(α) to the accumulated maxCTD.
In signaling, maxCTD is accumulated only in the forward direction ($maxCTD_F$). However, the CDV is accumulated in both forward and backward directions (CDV_F, CDV_B). Consequently the maxCTD for the backward direction is derivable as:

$$maxCTD_B = CDV_B + maxCTD_F - CDV_F$$

This is because the fixed delay in the forward direction ($maxCTD_F - CDV_F$) is the same as the fixed delay in the reverse direction ($maxCTD_B - CDV_B$).

3.6.3 Dependability Parameters

One end-to-end dependability parameter is presently negotiated:

- Cell Loss Ratio (CLR)

This end-to-end dependability parameter applies to all service categories except the Unspecified Bit Rate (UBR) service.

3.6.3.1 Cell Loss Ratio (CLR)

The Cell Loss Ratio is defined for a connection as:

$$\text{CLR} = \frac{\text{Lost Cells}}{\text{Total Transmitted Cells}}$$

Lost and transmitted cells counted in severely errored cell blocks should be excluded from the cell population in computing cell loss ratio.

The CLR parameter is the value of CLR that the network agrees to offer as an objective over the lifetime of the connection. Refer to UNI Signaling 4.0 for the coding of CLR.
The CLR objective applies either to the CLP=0 cell flow or to the aggregate CLP=0+1 cell flow, as determined by the applicable conformance definition in Section 4.5.

3.6.4 Accumulation of Dependability Parameters

The CLR parameter is not explicitly accumulated. Each network element accepts or rejects the call based on a comparison between the loss rate supported by the network element and the requested CLR. Details of the CAC are network specific. See UNI Signaling 4.0 for details of CLR signaling.

3.7 Non-negotiated QoS Parameters

3.7.1 Dependability Parameters

3.7.1.1 Cell Error Ratio

The Cell Error Ratio (CER) is defined as follows for a connection:

$$\text{CER} = \frac{\text{Errored Cells}}{\text{Sucessfully Transferred Cells} + \text{Errored Cells}}$$

Successfully transferred cells and errored cells contained in cell blocks counted as severely errored Cell Blocks should be excluded from the population used in calculating cell error ratio.

3.7.1.2 Severely-Errored Cell Block Ratio

The Severely Errored Cell Block Ratio (SECBR) is defined as follows for a connection:

$$\text{SECBR} = \frac{\text{Severely Errored Cell Blocks}}{\text{Total Transmitted Cell Blocks}}$$

A cell block is a sequence of N cells transmitted consecutively on a given connection. A severely errored cell block outcome occurs when more than M errored cells, lost cells, or misinserted cell outcomes are observed in a received cell block.
For practical measurement purposes, a cell block will normally correspond to the number of user information cells transmitted between successive OAM cells. Refer to ITU-T Recommendation I.610 for the size of cell blocks.

3.7.1.3 Cell Misinsertion Rate

The Cell Misinsertion Rate (CMR) is defined as follows for a connection:

$$\text{CMR} = \frac{\text{Misinserted Cells}}{\text{Time Interval}}$$

Severely Errored Cell Blocks should be excluded from the population when calculating the cell misinsertion rate. Cell misinsertion on a particular connection is most often caused by an undetected error in the header of a cell being transmitted on a different connection. This performance parameter is defined as a rate (rather than the ratio) since the mechanism producing mis-inserted cells is independent of the number of transmitted cells received on the corresponding connection.

3.7.1.4 CLR for the ABR Service Category

See Section 3.6.3.1.

4. Traffic Contract

4.1 Traffic Parameters and Descriptors

Traffic parameters describe traffic characteristics of a source. For a given connection, traffic parameters are grouped into a source traffic descriptor, which in turn is a component of a connection traffic descriptor. These terms are defined below.

4.1.1 Traffic Parameters

A traffic parameter describes an inherent characteristic of a traffic source. It may be quantitative or qualitative. Traffic parameters defined in this specification include Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size (MBS), and Minimum Cell Rate (MCR).

4.1.2 Source Traffic Descriptor

A source traffic descriptor is the set of traffic parameters of the ATM source. It is used during the connection establishment to capture the intrinsic traffic characteristics of the connection requested by a particular source. Section 2.2 identifies a relationship between source traffic descriptors and ATM service categories.

4.1.3 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 CDVT, and the conformance definition that is used to unambiguously specify the conforming cells of the connection. CAC procedures will use the connection traffic descriptor to allocate resources and to derive parameter values for the operation of the UPC. The connection traffic descriptor contains the necessary information for conformance testing of cells of the connection at the UNI. These traffic parameters (and any new traffic parameters that may be defined in future specifications) should fulfill the following requirements:

- be understandable by the end-system; conformance testing should be possible.
- be useful in resource allocation schemes meeting network performance requirements.
- be enforceable by the UPC.

These criteria should be respected since end-systems may have to provide these traffic parameters and CDVT at connection establishment. In addition, the connection traffic descriptor should be useful to the CAC procedure so that network performance objectives can be maintained once the connection is accepted. Finally, they should be enforceable by the UPC in order to maintain network performance.

4.2 Traffic Contract Specification

A traffic contract specifies the negotiated characteristics of a connection.

(R) The traffic contract at the Public UNI shall consist of a connection traffic descriptor and a set of QoS parameters for each direction of the connection and shall include the definition of a compliant connection.

(O) The Private UNI may optionally support the same traffic contract as the Public UNI or a different traffic contract.

The connection traffic descriptor consists of all parameters and the conformance definition used to specify unambiguously the conforming cells of the connection, i.e.,:

- the source traffic descriptor (i.e., PCR, SCR, MBS, and MCR),
- the CDVT,
- the conformance definition.

For CBR, rt-VBR, nrt-VBR, and UBR, a conformance definition based on the GCRA is used to unambiguously specify the conforming cells of a connection at the UNI. See Section 4.4.2 for further details on the conformance definition. Examples of conformance definitions using the GCRA are provided in Appendix II. For ABR, the conformance definition refers to the behavior specified for ABR sources, destinations, and switches, but allows for delays between the source and the UNI, which may perturb the traffic flow.

The conformance definition should not be interpreted as the UPC algorithm. For example, although cell conformance at the UNI is defined by the conformance definition based on the GCRA for CBR, rt-VBR, and nrt-VBR, the network may use any UPC algorithm, as long as the operation of the UPC does not violate the QoS objectives of compliant connections.

The values of the traffic contract parameters can be specified either explicitly or implicitly. A parameter value is explicitly specified when its value is assigned by the end-system using signaling for SVCs, or when it is specified by the Network Management System (NMS) for PVCs. A parameter value specified at subscription time is also considered to be explicitly specified. A parameter value is implicitly specified when its value is assigned by the network using default rules, which in turn, depend on the information explicitly specified by the end-system. A default rule is a rule used by a network to assign a value to a traffic contract parameter that is not explicitly specified. In the case where no default rules are specified, they are network specific.

The CAC and UPC procedures are network specific and should take into account the knowledge of the specified traffic contract to operate efficiently.

In order to accommodate additional, experimental traffic parameters at the UNI, signaling messages have the capability to encode network specific information elements. See UNI Signaling 4.0 for details.

4.3 Cell Conformance and Connection Compliance

Conformance applies to cells as they pass the UNI and are, in principle, tested according to some algorithm. The first cell of the connection initializes the algorithm and from then on each cell is either conforming or non-conforming. Even under ideal conditions some cells may be non-conforming. Therefore it is inappropriate for the network to only commit to the QoS objectives for those connections for which all cells are conforming. In effect, connection compliance does not imply that all cells associated with the connection are conforming.

4.3.1 Compliance for CBR, rt-VBR, nrt-VBR, and UBR

(R) The precise definition of a compliant CBR, rt-VBR, nrt-VBR, or UBR connection is network specific. However, it is required that any definition of a compliant connection for these services shall identify a connection for which all cells are conforming to be a compliant connection.

Based on actions of the UPC function, the network may decide whether or not a connection is compliant. The network commits to support the QoS for all connections that are compliant.

(R) For CBR, rt-VBR, nrt-VBR, and UBR connections that are compliant at the UNI, the agreed QoS objective shall be supported for at least the number of cells equal to the number of conforming cells according to the conformance definition.

For non-compliant connections, the network does not need to respect the agreed QoS objective.

The conformance definition defines conformity at an interface according to one or more instances of the GCRA algorithm as specified in Section 4.5. For example, the conformance definition may use two instances of GCRA, once for PCR of the aggregate (CLP=0+1) cell stream and once for the SCR of the CLP=0 cell stream. Appendix II provides more details and further examples of the conformance definition for CBR, rt-VBR, nrt-VBR and UBR connections. The network may offer a limited set of alternative conformance definitions (all based on the GCRA) which the end-system may choose from, for a given connection.

4.3.2 Compliance for ABR

For ABR connections conformance applies to CLP=0 cells which are tested upon their arrival at the UNI. At this point each cell is then identified either as conforming or non-conforming. For a PVC, after reinitialization of a source, some cells may be judged as non-conforming.

(R) The precise definition of a compliant ABR connection is network specific. An ABR connection whose cells all conform (see Section 4.5.5) and whose RM-cells are received in relation to one another and to other cells as specified in Section 5.10 is a compliant connection.

Appendix III.4 has examples of tests for the compliant generation of RM-cells.

(R) For compliant ABR connections at the Public UNI, the agreed QoS objectives shall be supported for at least the number of cells equal to the number of conforming cells.
(R) The conformance and compliance definitions used at an interface shall be the same for point-to-multipoint connections as for point-to-point connections, except that data cells are not allowed on point-to-multipoint connections in the direction from the leaves to the root.

4.4 Traffic Contract Parameters and Related Algorithms

4.4.1 Cell Delay Variation Tolerance (CDVT) for PCR and SCR

ATM layer functions (e.g., cell multiplexing) may alter the traffic characteristics of connections by introducing Cell Delay Variation. When cells from two or more connections are multiplexed, cells of a given connection may be delayed while cells of another connection are being inserted at the output of the multiplexer. Similarly, some cells may be delayed while physical layer overhead or OAM cells are inserted. Consequently with reference to the peak emission interval T (i.e., the inverse of the contracted PCR), some randomness may affect the inter-arrival time between consecutive cells of a connection (i.e., the inverse of the contracted PCR) as monitored at the UNI (public or private). The upper bound on the "clumping" measure is the CDVT. A few examples that illustrate the allowed cell clumping are given in Annex C.3.
Similarly, with reference to the sustained emission interval T_S (i.e., the inverse of the contracted SCR), some randomness may affect the inter-arrival time between consecutive cells of a connection (i.e., the inverse of the contracted SCR) as monitored at the UNI (public or private).
The CDVT allocated to a particular connection at the private UNI (denoted by CDVT*) represents at this interface a bound on the connection cell clumping phenomenon due to the slotted nature of ATM, the physical layer overhead, and the ATM layer functions, i.e., cell multiplexing performed within the end-system. The CDVT allocated to a particular connection at the public UNI (denoted by CDVT) represents at this interface a bound on the connection cell clumping phenomenon due to the slotted nature of the ATM, the physical layer overhead, and the ATM layer functions performed within the private network equipment before the public UNI.
CDVT and $CDVT^*$ may impact the allocation of network resources for a connection. It is therefore recommended that both the CDVT and $CDVT^*$ be upper-bounded.
(R) An end-system shall explicitly or implicitly select a value for the CDVT at the public UNI for an ATM connection from a set of values supported by the network. Whether the set of values is to be standardized or to be determined by the network is for further study.
(R) The CDVT shall be explicitly specified at the PNNI, BICI, and at the UNI: CDVT and $CDVT^*$ are specified at subscription time. Note: Signaling for CDVT or $CVDT^*$ is desirable from a traffic management viewpoint, but not supported in UNI Signaling 4.0.

4.4.2 Generic Cell Rate Algorithm (GCRA)

The GCRA is used to define conformance with respect to the traffic contract. For each cell arrival, the GCRA determines whether the cell conforms to the traffic contract of the connection. The UPC function may implement the GCRA, or one or more equivalent algorithms to enforce conformance. Although traffic conformance is defined in terms of the GCRA, the network is not required to use this algorithm (or the same parameter values) for the UPC. Rather, the network may use any UPC as long as the operation of the UPC supports the QoS objectives of a compliant connection.
The GCRA is a virtual scheduling algorithm or a continuous-state Leaky Bucket Algorithm as defined by the flowchart in Figure 4-1. The GCRA is used to define, in an operational manner, the relationship between PCR and the CDVT, and the relationship between SCR and the Burst Tolerance (BT). The BT can be derived from PCR, SCR, and MBS according to Annex C.4. In addition, the GCRA is used to specify the conformance, at the public or private UNI, of the declared values of the above two tolerances, as well as declared values of the traffic parameters PCR and SCR and MBS. See Section 4.4.3.2 and Annex C.4 respectively.
The GCRA is defined with two parameters: the Increment (I) and the Limit (L).

The notation "GCRA(I, L)" means the Generic Cell Rate Algorithm with the value of the increment parameter set equal to I and the value of the limit parameter set equal to L.
Note: I and L are not restricted to integer values.
The GCRA is formally defined in Figure 4-1. Figure 4-1 is a generic version of Figure 1 in Annex 1 of I.371-draft. The two algorithms in Figure 4-1 are equivalent in the sense that for any sequence of cell arrival times, $\{t_a(k), k >= 1\}$, the two algorithms determine the same cells to be conforming and thus the same cells to be non-conforming. The two algorithms are easily compared by noticing that at each arrival epoch, $t_a(k)$, and after the algorithms have been executed, TAT = X + LCT, as in Figure 4-1. An explanation of each algorithm is given in Annex C.

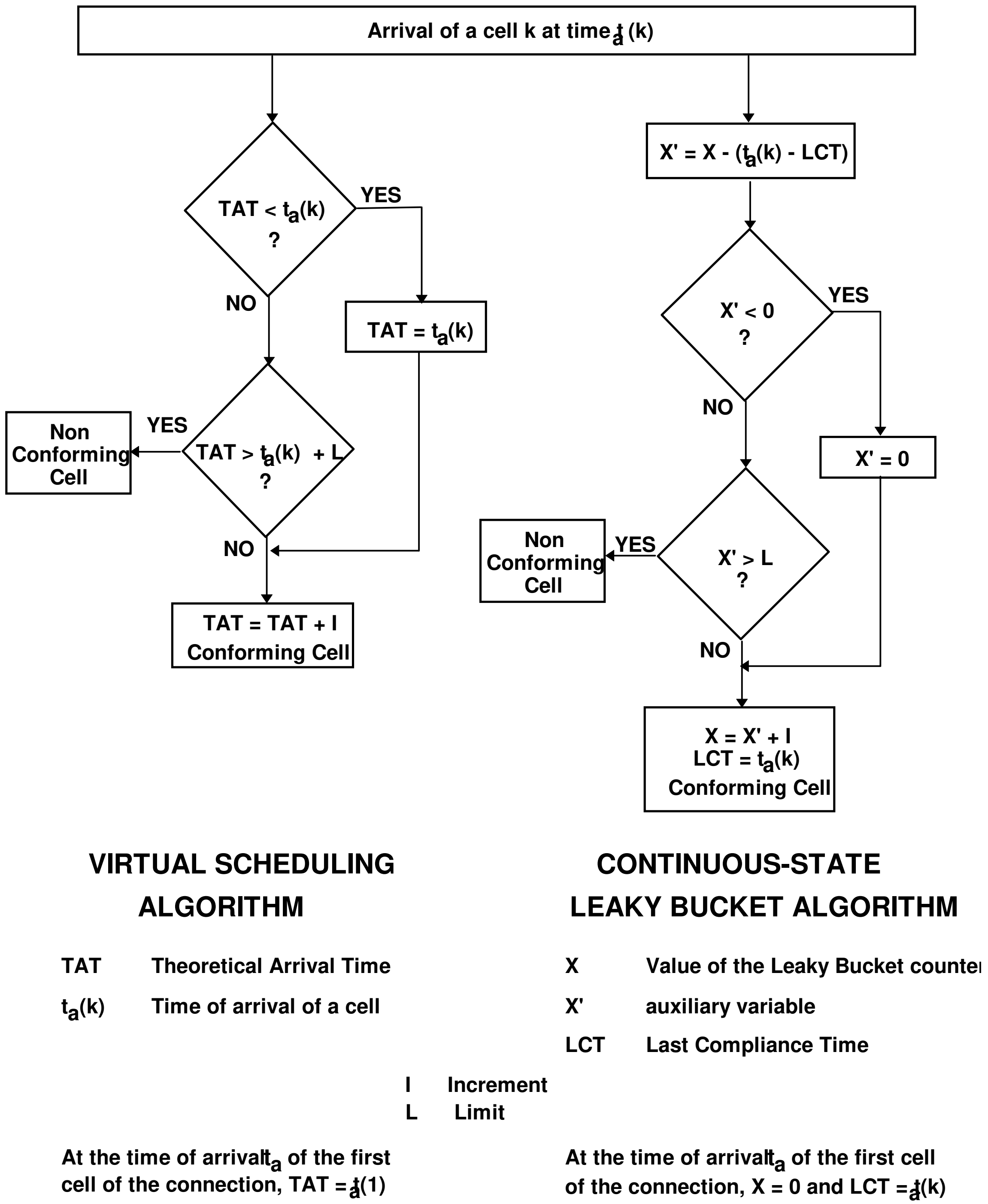


Figure 4-1: Equivalent versions of the Generic Cell Rate Algorithm

Multiple instances of the GCRA with possibly different I and L parameters may be applied to multiple flows (CLP=0 and CLP=0+1) of the same connection, or to the same flow. A cell is then conforming only if it conforms to all instances of the GCRA against which cells with its CLP state are tested. For example, if one instance of the GCRA tests the CLP=0 flow and one instance tests the CLP=0+1 flow, then a CLP=0 cell is conforming only if it conforms to both instances of the GCRA. In this same configuration, a CLP=1 cell is conforming only if it conforms to the instance of the GCRA that tests the CLP=0+1 flow. If tagging is used, a tagged cell is conforming only if it conforms as a CLP=1 cell. The state of a particular instance of the GCRA is updated only by the cells that conform as part of a flow tested by that instance of the GCRA. For example, a conforming tagged cell will not update the state of an instance of the GCRA that tests the CLP=0 flow, since the tagged cell conforms as a CLP=1 cell. Detailed flow-charts illustrating the interaction between multiple instances of the GCRA algorithm are given in ITU-T Recommendation I.371-draft.

4.4.3 Peak Cell Rate Conformance

The Peak Cell Rate (PCR) traffic parameter specifies an upper bound on the rate at which traffic can be submitted on an ATM connection. Enforcement of this bound by the UPC allows the network to allocate sufficient resources to ensure that the network performance objectives (e.g., for Cell Loss Ratio) can be achieved.

In the signaling message, the PCR is coded in cells per second (see UNI Signaling 4.0). The defined coding for the PCR in the signaling message does not imply that any UPC mechanism has to support the same linear granularity for the PCR across the complete defined cell rate range.

4.4.3.1 PCR Reference Model

The equivalent-terminal configuration is given in Figure 4-2. It provides an abstract framework for describing the UPC at the public UNI. A similar model applies when UPC is implemented at the private UNI. Traffic sources, the multiplexer and the shaper define the equivalent-terminal. This is an abstraction which does not preclude any particular implementation of the end-system. This figure shows one or more private network elements which contain ATM layer switching and/or multiplexing, and therefore contribute to CDV, as observed at the public UNI.

All traffic sources (AALs, etc.) offering cells to a connection are put together in the equivalent-terminal. Each source generates requests to send ATM cells at its own rate. All requests are multiplexed in a Multiplexer (MUX in Figure 4-2) before entering the virtual shaper.

The virtual shaper is intended to reflect some smoothness in the cell flow offered to the connection: at the PHY_SAP, the minimal inter-arrival time between two consecutive requests is greater than or equal to T which is called the peak emission interval of the connection. The output of the virtual shaper at the PHY_SAP of the equivalent-terminal conforms to GCRA(T, 0). This conformity cannot be required at the Private or Public UNIs since CDV is allowed in the private network elements as well as in the end-system.

The output of the virtual shaper is affected by functions in the equivalent-terminal that cause CDV characterized by $CDVT^*$. The value of $CDVT^*$ is chosen such that the output cell flow conforms to GCRA(T, $CDVT^*$).

The output of the equivalent-terminal is affected by functions in other CPE which may modify the CDV at the Public UNI characterized by CDVT. The value of τ is chosen such that the output cell flow conforms to GCRA(T, CDVT).

The value of the peak emission interval T is user specific to allow for intelligent multiplexing within the end-system. For instance, AALs producing sporadic traffic may be synchronized to share the same transmission capacity. In other cases, T may be set to account for the combined activity of all traffic sources, e.g., the PCR of a VPC may be the sum of the PCRs of the VCCs contained in the VPC.

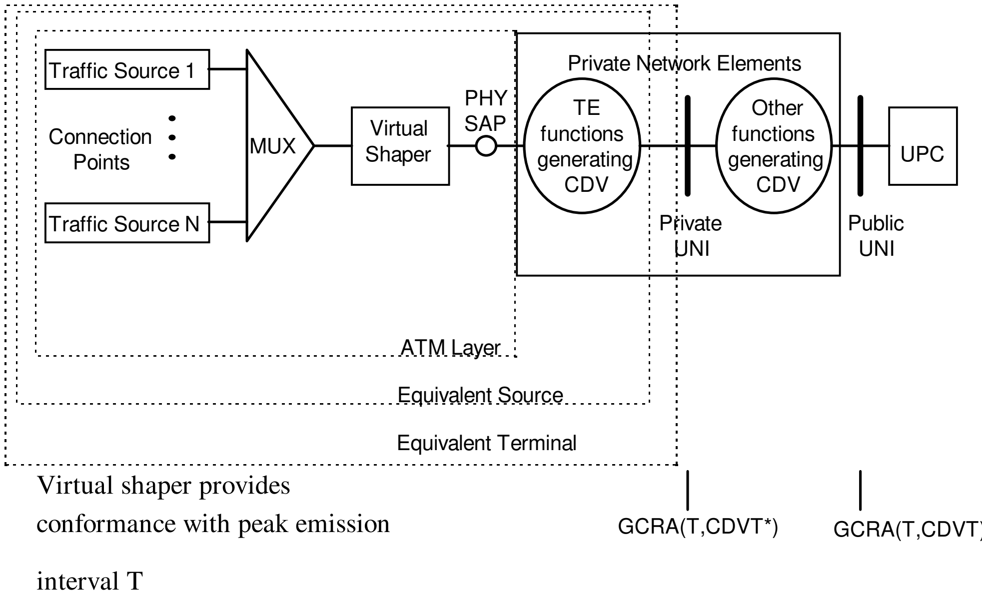


Figure 4-2: PCR Reference Model

The PCR traffic parameter is defined at the PHY_SAP within an equivalent-terminal. The CDVT specified at the private UNI (CDVT*) (i.e., that directly connects an end-system to a private network) accounts for the cell clumping introduced by the end-system. The CDVT specified at the public UNI (CDVT) (i.e., that connects an end-system to a public network through a private ATM network via a private UNI) accounts for the cell clumping introduced by the end-system and the private ATM network.

4.4.3.2 PCR Parameter Definition

The following definition applies to connections supporting CBR, rt-VBR, nrt-VBR, ABR, and UBR, services.

The PCR definition for a connection is as follows:

- **Location:** At the PHY_SAP in an equivalent-terminal representing the connection (this is only a reference configuration; see Figure 4-2).
- **Basic Event**: Request to send an ATM_PDU in the equivalent-terminal.
- **Definition:** The PCR of the ATM connection is the inverse of the minimum inter-arrival time T between two basic events above. T is called the peak emission interval of the connection.

An interpretation of the definition of PCR and the equivalent terminal is given in Annex C.2.

4.4.3.3 CDVT

As shown in Figure 4-2, the CDVT is defined in relation to the PCR according to the GCRA. In particular, the CDVT at the public UNI, is defined in relation to the PCR according to the algorithm GCRA(T, CDVT), where T is the inverse of PCR. Likewise, the CDVT at the private UNI, CDVT*, is defined in relation to the PCR according to the algorithm GCRA(T, CDVT*).

4.4.4 Sustainable Cell Rate and Burst Tolerance

The SCR is an upper bound on the average rate of the conforming cells of an ATM connection, over time scales which are long relative to those for which the PCR is defined. Enforcement of this bound by the UPC could allow the network to allocate sufficient resources, but less than those based on the PCR, and still ensure that the performance objectives (e.g., for Cell Loss Ratio) can be achieved.

Note: ITU-T Recommendation I.371-draft refers to Burst Tolerance as Intrinsic Burst Tolerance (IBT).

4.4.4.1 SCR and BT Reference Model

The SCR Reference Model is defined with reference to Figure 4-3.

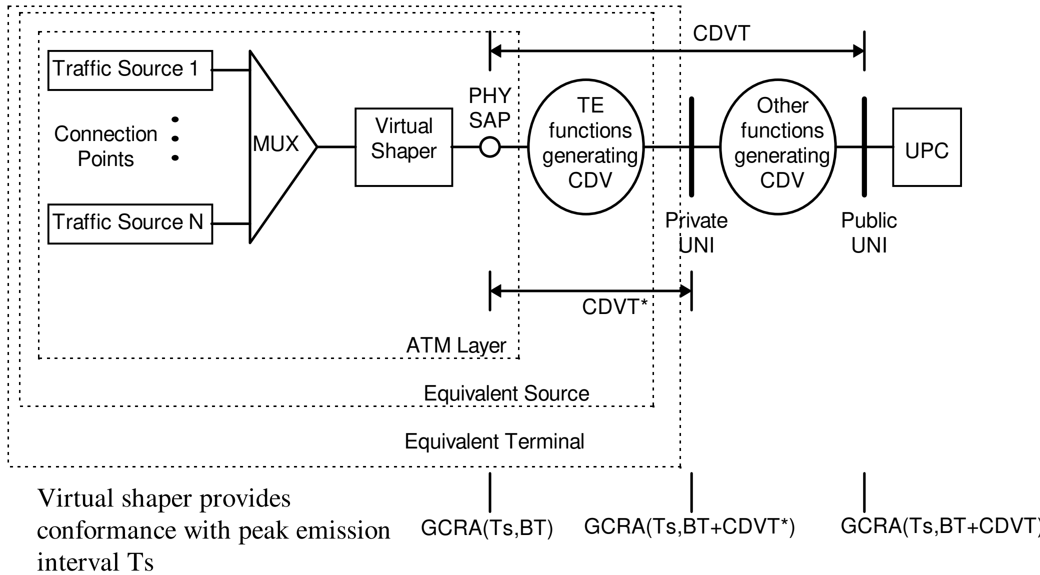


Figure 4-3: SCR and BT Reference Model

The SCR and BT traffic parameters are defined at the PHY_SAP within an equivalent-terminal.

4.4.4.2 SCR and BT Definitions

The following definition applies to connections supporting rt-VBR and nrt-VBR services. The SCR and BT parameters for a connection are defined according to the GCRA (Section 4.4.2) as follows:

- **Location:** At the PHY_SAP in an equivalent-terminal representing the connection (this is only a reference configuration; see Figure 4-3).
- **Basic Event:** Request to send an ATM_PDU in the equivalent-terminal.
- **Definition:** The SCR, and the BT denoted as of the ATM connection are defined by the GCRA(1/SCR, BT) based on the arrivals of the basic event defined above. The increment parameter of the GCRA is 1/SCR and BT is the limit parameter of the GCRA.

In the signaling message, the SCR is coded as cells per second. The granularity supported by the signaling message is 1 cell/s. The defined coding for the SCR in the signaling message does not imply that any UPC mechanism has to support the same linear granularity for the SCR across the complete defined cell rate range.

An interpretation of the definition of SCR and BT in conjunction with PCR is given in Annex C.4.

4.4.4.3 CDVT

As shown in Figure 4-3, the CDVT is defined in relation to the SCR according to the GCRA. In particular, the CDVT at the public UNI, is defined in relation to the SCR according to the algorithm GCRA(T_S, BT+CDVT), where T_S is the inverse of SCR. Likewise, the CDVT* at the private UNI, is defined in relation to the SCR according to the algorithm GCRA(T_S, BT+CDVT*).

4.5 Traffic Contract and Conformance Definitions

The conformance of cells of a connection at an interface is defined in relation to the conformance algorithm and corresponding parameters specified in the connection traffic descriptor. This conformance definition is specified in the traffic contract. The set of conformance definitions that is supported at the public UNI is network specific. Future service categories may require the definition of new traffic contract parameters.

The ITU-T provides a definition of the granularity of PCR, SCR, CDVT, and BT used for defining conformance of a CBR or VBR connection, see ITU-T Recommendation I.371-draft.

For network operations, there are two models for the CLP=1 cell flow:

- **CLP-transparent**: The network generally disregards the CLP bit. The CLR objective applies only to the aggregate CLP=0+1 cell flow, for which the CLP=1 cells experience the same CLR as the CLP=0 cells. The tagging option does not apply to this model (see Section 5.3.5).
- **CLP-significant**: The CLR objective applies only to the CLP=0 cell flow. The CLR for the CLP=1 flow is unspecified, as is the CLR for the aggregate flow (CLP=0+1). Network tagging applies as an option. The network may make a best-effort attempt to transmit the CLP=1 flow. In such a case, the network is likely to employ selective discard (but this will not count against the CLR objective of the connection).

For the conformance definitions listed below, the CLP-transparent model is used for CBR.1 and VBR.1, and the CLP-significant model is used for VBR.2 and VBR.3.

4.5.1 Traffic Contract Conformance Definition for CBR Service

Conformance for a CBR connection is characterized by PCR and the corresponding CDVT for the CLP=0+1 traffic flow.
(R) PCR for CLP=0+1 is a mandatory traffic parameter in any CBR source traffic descriptor.
(R) For CBR SVCs, the PCR for CLP=0+1 shall be explicitly specified by the source for each direction in the initial connection establishment message.
(R) The CDVT is a mandatory parameter in any CBR connection traffic descriptor.
(R) The CDVT shall be either explicitly specified at subscription time or implicitly specified for any CBR connection.
(R) For SVCs, the signaling message shall be capable of conveying information that identifies at least the following set of conformance definitions. For PVCs, the conformance definition shall be explicitly identified at subscription time.

4.5.1.1 CBR.1: Conformance Definition for PCR (CLP=0+1)

The following is a conformance definition for a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream:

1. One GCRA(T_{0+1}, CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream. T_{0+1} is the inverse of the PCR specified for the CLP=0+1 cell flow.
2. A cell that is conforming to the GCRA in (1) is said to be conforming to the connection traffic descriptor.

The tagging option is not applicable to this conformance definition since no separate rate is specified for CLP=0. The CLR objective applies to the aggregate CLP=0+1 cell stream.

4.5.2 Traffic Contract and Conformance Definition for rt-VBR and nrt-VBR

Conformance for a rt-VBR or nrt-VBR connection is characterized by an SCR parameter and corresponding MBS parameter for one or more traffic flows, in addition to a PCR parameter and corresponding CDVT for at least the CLP=0+1 flow. Real-time VBR and nrt-VBR are typically distinguished by their QoS parameters, but also by the magnitude(s) of the MBSs supported. Larger MBSs are more typical for nrt-VBR connections. The relationship between BT and MBS is given in Annex C.4.
(R) PCR for CLP=0+1 is a mandatory traffic parameter in any source traffic descriptor for a rt-VBR or nrt-VBR connection.
(R) For rt-VBR or nrt-VBR SVCs, the PCR for CLP=0+1 must be explicitly specified for each direction in the initial establishment message.
(R) CDVT is a mandatory parameter in any connection traffic descriptor for a rt-VBR or nrt-VBR connection.
(R) CDVT shall be either explicitly specified at subscription time or implicitly specified for any rt-VBR or nrt-VBR connection.
(R) For SVCs, the signaling message shall be capable of conveying information that identifies at least the following set of conformance definitions. For permanent connections the conformance definition shall be explicitly identified at subscription time.

4.5.2.1 VBR.1: Conformance Definition for PCR (CLP=0+1) and SCR (CLP=0+1)

The following is a conformance definition for a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream and SCR for the CLP=0+1 cell stream:

1. One GCRA(T_{0+1}, CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream. T_{0+1} is the inverse of PCR (CLP=0+1).
2. One GCRA(T_{s0+1}, BT_{0+1}+CDVT) defining the sum of the $CDVT_{CSR}$ and the BT in relation to the SCR of the CLP=0+1 cell stream. T_{s0+1} is the inverse of SCR (CLP=0+1).
3. A cell that is conforming to both GCRAs (1) and (2) above is said to be conforming to the connection traffic descriptor.

The tagging option is not applicable to this conformance definition. The CLR objective applies to the aggregate CLP=0+1 cell stream.

4.5.2.2 VBR.2: Conformance Definition for PCR (CLP=0+1) and SCR (CLP=0)

The following is a conformance definition for a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream and SCR for the CLP=0 cell stream:

1. One GCRA(T_{0+1}, CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream. T_{0+1} is the inverse of PCR (CLP=0+1).
2. One GCRA(T_{s0}, BT_0+CDVT) defining the sum of the CDVT and the BT in relation to the SCR of the CLP=0 cell stream. T_{s0} is the inverse of SCR (CLP=0).
3. A CLP=0 cell that is conforming to both GCRAs (1) and (2) above is said to be conforming to the connection traffic descriptor. A CLP=1 cell that is conforming to GCRA (1) above is said to be conforming to the connection traffic descriptor.

This conformance definition allows a connection to send CLP=1 cells at a PCR equal to the specified PCR of the CLP=0+1 cell stream. The CLR objective applies to the CLP=0 cell stream. The CLR of the CLP=1 cell-stream and the aggregate stream is undefined.

4.5.2.3 VBR.3: Conformance Definition for PCR (CLP=0+1) and SCR (CLP=0)

The following is a conformance definition for a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream and SCR for the CLP=0 cell stream:

1. One GCRA(T_{0+1}, CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream. T_{0+1} is the inverse of PCR (CLP=0+1).
2. One GCRA(T_{s0}, BT_0+CDVT) defining the sum of the CDVT and the BT in relation to the SCR of the CLP=0 cell stream. T_{s0} is the inverse of SCR (CLP=0).
3. A CLP=0 cell that is conforming to both GCRAs (1) and (2) above is said to be conforming to the connection traffic descriptor. A CLP=1 cell that is conforming to GCRA (1) above is said to be conforming to the connection traffic descriptor.
4. If the end-system requests tagging, and if tagging is supported by the network, a CLP=0 cell that is not conforming to GCRA (2) above, but is conforming to GCRA (1) above, will have its CLP bit changed to 1 and is said to be conforming to the connection traffic descriptor.

This conformance definition allows a connection to send CLP=1 cells at a PCR equal to the specified PCR of the CLP=0+1 cell stream. The CLR objective applies to the CLP=0 cell stream. The CLR of the CLP=1 cell-stream and the aggregate stream is undefined.

4.5.3 Traffic Contract and Conformance Definition for UBR Service

Conformance for a UBR connections is characterized by a single PCR and corresponding CDVT for the CLP=0+1 flow. The use of PCR for CAC, and enforcement of PCR by UPC, is network specific. However, if the user requests a non-zero minimum acceptable PCR that cannot be supported by the network, then the network may reject the call.

(R) PCR for CLP=0+1 is a mandatory traffic parameter in any source traffic descriptor of a UBR connection.

(R) The CDVT is a mandatory parameter in any connection traffic descriptor for a UBR connection.

(R) The CDVT shall be either explicitly specified at subscription time or implicitly specified for a UBR connection.
(R) For UBR SVCs, the PCR for CLP=0+1 shall be explicitly specified for each direction in the initial establishment message.
It is desirable that the source end-system conforms to PCR, but the enforcement of this is network specific.

4.5.3.1 UBR.1: Conformance definition for PCR (CLP=0+1), Tagging not applicable

The tagging option does not apply. The network shall not overwrite the CLP bit.

4.5.3.2 UBR.2: Conformance definition for PCR (CLP=0+1), Tagging applicable

The tagging option applies. The network may overwrite the CLP bit to 1 for any cell of that connection. However, such action does not necessarily imply a condition of non-conformance, as would be the case for other service categories.

4.5.4 Summary of Conformance Definitions for CBR, rt-VBR, nrt-VBR, and UBR

Table 4-1 summarizes the conformance definitions discussed in this section for the CBR, VBR, and UBR service categories.

Conformance Definition	PCR flow	SCR flow	Tagging option active	CLR on
CBR.1	0 + 1	ns	na	0 + 1
VBR.1	0 + 1	0 + 1	na	0 + 1
VBR.2	0 + 1	0	No	0
VBR.3	0 + 1	0	Yes	0
UBR.1	0 + 1	ns	na	U
UBR.2	0+1	ns	Yes[4]	U

Table 4-1: Summary of conformance definitions

Notes for Table 4-1:

1. ns means that SCR is not specified.
2. na means that tagging is not applicable.
3. U means that CLR is unspecified (for both CLP=0 & CLP=1).
4. When the tagging option is used for a UBR connection the network may overwrite the CLP bit to 1 for any cell of that connection. However, such action does not necessarily imply a condition of non-conformance, as would be the case for other service categories.

4.5.5 Traffic Contract and Conformance Definition for ABR Service

The algorithm that defines conformance at an interface for each CLP=0 cell on a connection implicitly defines the response expected of the ABR end-system to feedback contained in backward RM-cells on the reverse connection. This feedback may include information in the Explicit Rate (ER) field or the Congestion Indication (CI) or No Increase (NI) bits of each backward RM-cell.
(R) The ABR conformance definition is network specific, but must satisfy the following design constraints relative to parameters τ_1, τ_2, and τ_3 as specified for the connection, and delays t_1 and t_2 as defined in Section 4.5.5.1.

1. The conformance definition shall identify each CLP=0 cell as either conforming or non-conforming.
2. The conformance definition shall identify all CLP=0 cells on a connection conforming if all CLP=0 cells on a connection conform to $GCRA(MCR^{-1},\tau_1)$.

3. The conformance definition used at an interface shall find a CLP=0 cell non-conforming only if its arrival time there and those of the preceding conforming CLP=0 cells on the connection could not have resulted from the ideal transmission times (as defined in Section 4.5.5.1) of an ABR source and delays t_1 and t_2 for the connection satisfying $\tau_3 \le t_2 \le \tau_2$ and $\max(t_1) - \min(t_1) \le \tau_1$. In determining whether a CLP=0 cell is conforming, the network may assume that the inter-cell interval between that cell and the previous CLP=0 cell on the connection (i) shall account for feedback conveyed in backward RM-cells transmitted across the interface on the backward connection more than τ_2 units before that previous CLP=0 cell and (ii) shall not account for feedback conveyed in backward RM-cells transmitted across the interface on the backward connection less than τ_3 units before that previous CLP=0 cell.

The parameter τ_1 is the CDVT for the ABR connection. τ_2 and τ_3 are, respectively, the upper and lower bounds on the delay after which the rate change induced by a backward RM-cell departing from an interface (in the backward direction) is expected to be observed at the interface (in the forward direction). An example of a conformance test satisfying (1)-(3) above is described in Appendix III and referred to as ER-conformance which is defined through the algorithm *DGCRA*$(MCR^{-1}, PCR^{-1}, ICR^{-1}, \tau_1, \tau_2, \tau_3)$.

ER-Conformance accounts only for feedback information conveyed in the ER field of the backward RM-cell and hence does not test whether the connection observes feedback conveyed in the CI or NI bits of the RM-cell. However, ER-conformance may be an adequate conformance definition for a network that does not rely on the CI or NI bits to convey feedback.

The minimal conformance definition for ABR is $GCRA(PCR^{-1}, \tau_1)$ where the PCR is defined for CLP=0 flow, according to Section 5.10 on ABR.

(O) The definitions of conformance and compliance optionally may be applied to the Private UNI or Private NNI.

4.5.5.1 Definitions of ABR Delays

The characteristics of traffic received at the private or public UNI on a given ABR connection depend critically on the delays between that interface and the source/destination (or virtual source/virtual destination) that generates the traffic. The delays most relevant to the characteristics of a flow received at the interface are defined relative to the transmission times of each CLP=0 cell by the traffic source. A transmission time for a CLP=0 cell is called an *Ideal Transmission Time (ITT)* if the difference between itself and the transmission time for the previous CLP=0 cell on the connection is greater than or equal to the minimum of (a) the inverse of the Available Cell Rate (ACR) in effect immediately after the transmission time of the first of the two cells and (b) the inverse of the ACR in effect immediately before the transmission time of the second of the two cells. The transmission time for the first cell on the connection is automatically an ***ITT*.** The ACR is calculated as specified in Section 5.10.4. The minimum is taken of (a) and (b) above, because an ABR source has the option of rescheduling the next cell to be transmitted on a connection when new feedback is received.

Two delays, t_1 and t_2 are particularly relevant to traffic characteristics at an interface. The delay t_1 denotes the time from a cell's transmission time by the traffic source to its receipt at the interface in question. The second delay t_2 denotes the sum of:

- the delay from the departure at the interface in question of a backward RM-cell on the backward connection to the receipt of the RM-cell by the traffic source, and
- the delay from the next transmission time for a CLP=0 cell on the connection (following the receipt of the RM-cell by the traffic source) to the arrival at the interface in question of that CLP=0 cell.

Hence, t_1 is the one-way transfer delay from the source to the interface and t_2 is the round-trip feedback delay between the interface and the source, excluding the residual of the inter-cell interval between successive transmission times.

5. Functions and Procedures for Traffic Management

5.1 Introduction

Functions referred to as congestion control functions in this specification are intended to react to network congestion in order to minimize its intensity, spread and duration.

The following set of traffic and congestion control functions are described in this specification. ATM networks can implement one or a combination of these functions in order to meet QoS objectives of compliant connections.

- Connection Admission Control (Section 5.2)
- Usage Parameter Control (Section 5.3)
- Selective Cell Discarding (Section 5.4)
- Traffic Shaping (Section 5.5)
- Explicit Forward Congestion Indication (Section 5.6)
- Resource Management using Virtual Paths (Section 5.7)
- Frame Discard (Section 5.8)
- Generic Flow Control (Section 5.9)
- ABR Flow Control (Section 5.10).

Different levels of network performance may be provided on connections by proper routing, traffic shaping, priority control and resource allocation to meet the required QoS for these connections.

5.2 Connection Admission Control

The Connection Admission Control (CAC) function is defined as the set of actions taken by the network at SVC establishment or by Network Management during PVC establishment in order to determine whether a connection can be progressed or should be rejected.

(R) The information contained in the traffic contract (Section 4) shall be accessible to the CAC function.

Based on the CAC function, a connection request is progressed only when sufficient resources are available at each successive network element to establish the connection through the whole network based on its service category, traffic contract, and QoS, and in order to maintain the agreed QoS of existing connections.

For each connection request, the CAC function shall be able to derive the following information from the traffic contract (see Section 4.2):

- Values of parameters in the source traffic descriptor (Section 4.1.2);
- Requested and acceptable values of each QoS parameter and the requested QoS class (Section 3);
- Value of the CDVT (Section 4.4.1);
- Requested conformance definition (Section 4.5).

The CAC function makes use of the traffic contract and the network's definition of a compliant connection to determine:

- whether the connection can be accepted or not;
- the connection traffic parameters (see Section 4.1.3) needed by usage parameter control (see Section 5.3.1);
- allocation of network resources.

Different strategies for network resource allocation may be applied for CLP=0 and CLP=1 traffic flows. In addition, information such as the measured network load may be used when performing the CAC function. This may allow a network to achieve higher network utilization while still meeting the network performance objectives.
The CAC function is network specific.

5.3 Usage Parameter Control

(O) The UPC function is optional at the UNI.

5.3.1 UPC Functions

Usage Parameter Control (UPC) is defined as the set of actions taken by the network to monitor and control traffic. Its main purpose is to protect network resources from malicious as well as unintentional misbehavior which can affect the QoS of other already established connections by detecting violations of negotiated parameters and taking appropriate actions.
Connection monitoring at a UNI (private or public) is referred to as UPC. Connection monitoring at an NNI (private or public) is referred to as NPC. UPC is used as a more generic term (includes NPC) unless otherwise specified. Connection monitoring encompasses all connections crossing the interface where UPC is used. UPC applies to both user connections and signaling channels. Methods for monitoring meta-signaling channels and OAM flows are for further study.
The monitoring task for UPC is performed for VCCs and VPCs respectively by the following two actions:

1. checking the validity of VPI and VCI (i.e., whether or not VPI/VCI values are associated with active VCCs) and monitoring the traffic entering the network from active VCCs in order to ensure that parameters agreed upon are not violated;
2. checking the validity of VPI (i.e., whether or not VPI values are associated with active VPCs), and monitoring the traffic entering the network from active VPCs in order to ensure that parameters agreed upon are not violated.

5.3.2 UPC Requirements

UPC algorithms are network specific. However, the UPC function shall support the QoS objectives for compliant connections (see Section 4.3).
When a traffic contract conformance violation occurs, policing actions performed on the cells sent in excess of the traffic contract are not to be included in the network performance degradation allocated to the UPC.
The CTD and the CDV introduced by the UPC is also part of the CTD and CDV allocated to the network.
A method to determine whether a traffic flow is conforming to a negotiated PCR at a given interface is defined for network performance purposes. Non-conformance is measurable by a 1-point measurement process in terms of the ratio γ_M between the number of cells exceeding the traffic contract and the total number of submitted cells.
An ideal UPC implementing the one-point measurement process would only take policing actions on a number of cells according to this ratio. Although the process allows for a cell-based decision, it is not possible to predict which particular cells of a connection with non-conforming cells will suffer from the policing action (because of measurement phasing).
According to the definition of the conformance of a traffic flow to a PCR, the transparency of a UPC mechanism can be defined by the accuracy with which this mechanism approaches the ideal mechanism, i.e., the difference between the reference policing ratio γ_M and the actual policing ratio γ_P. A positive difference means that the UPC is taking less policing action than allowed. A negative difference means that policing actions are unduly taken by the UPC.
The above description also applies to the SCR and the MBS traffic parameters. The exact way of measuring the transparency of a given mechanism for the UPC and its dependence on time is for further study.
For further information on UPC/NPC accuracy and transparency see ITU-T Recommendation I.371-draft.

5.3.3 UPC Location

UPC is performed at the points where the VP or VC link connected to the NT is terminated in the network. Three possibilities are shown in Figure 5-1.

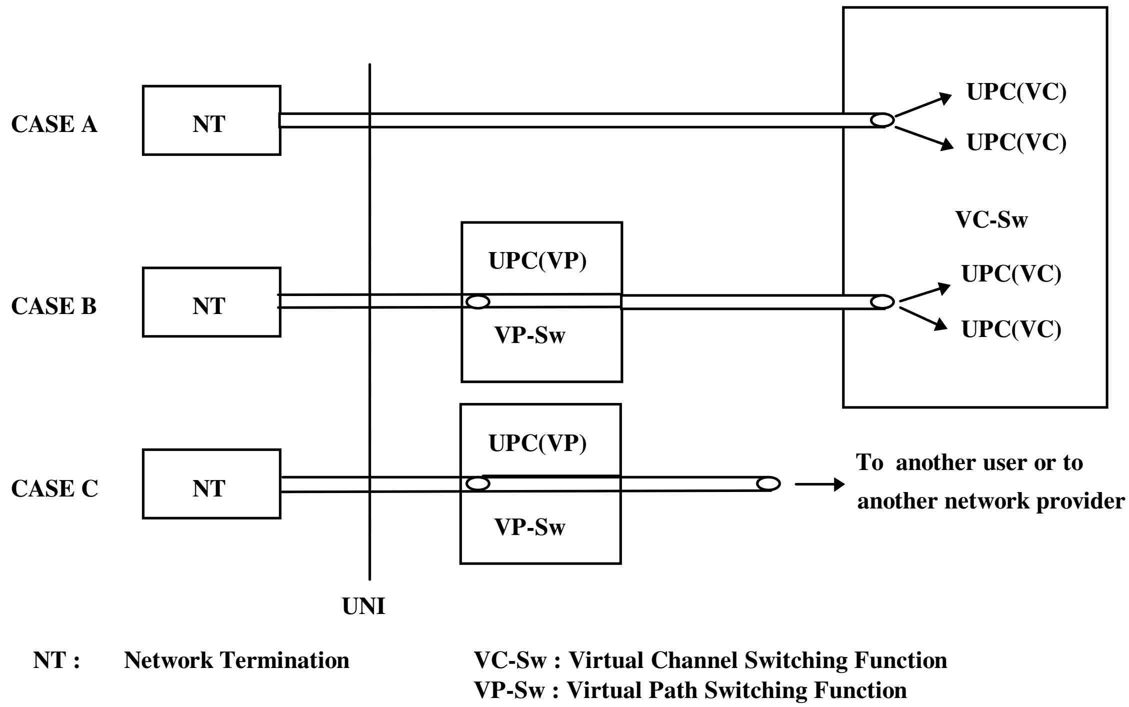


Figure 5-1: Location of the UPC Functions

Note: Provision of UPC at other locations is for further study.

In the following, VC-Sw stands for Virtual Channel Switching Function, and VP-Sw stands for Virtual Path Switching Function. The following VC-Sws and VP-Sws refer to the first switches on the public network side of the Public UNI (or on the network side of the private UNI, or on the private network side of the public UNI when UPC is implemented in private network elements). A VC-Sw or a VP-Sw may respectively be a VC or VP concentrator.

(CR) If connected directly to a VC-Sw (CASE A of Figure 5-1), the UPC function shall be performed within the VC-Sw on VCCs before the switching function is executed (action 1, Section 5.3.1).

(CR) If connected directly to VC-Sw via VP-SW (CASE B of Figure 5-1), the UPC function shall be performed within the VP-Sw on VPCs only (actions 2, Section 5.3.1) and within the VC-Sw on VCCs only (action 1, Section 5.3.1).

(CR) If connected to an end-system or to another network via VP-Sw (CASE C of Figure 5-1), the UPC function shall be performed within the VP-Sw on VPCs only (action 2, Section 5.3.1).

In CASE C of Figure 5-1, the VCC usage parameter control will be done by the first public network (if any) where VC-Sw is present.

5.3.4 Traffic Parameters Subject to UPC Enforcement

The traffic parameters that may be subject to UPC enforcement are those included in the source traffic descriptor.

(R) The PCR of the CLP=0+1 cell flow shall be subject to UPC for all types of connections at the Public UNI.

(O) Even when the parameters are specified, the enforcement of SCR and MBS is network specific.

(O) The PCR of the CLP=0+1 cell flow may be subject to UPC for all types of connections at the Private UNI.

5.3.5 UPC Actions (Cell Tagging and Discard)

The UPC is intended to ensure conformance by a connection with the negotiated traffic contract. The objective is that a connection will never be able to exceed the traffic contract.

At the cell level, actions of the UPC function may include:

- cell passing;
- cell tagging (network option); cell tagging operates on CLP=0 cells only, by overwriting the CLP bit to 1;
- cell discarding.

A cell tagging function exists which is optional for both the network and the user. If supported by the network, the user may select tagging when the connection is established. The availability of tagging depends on the conformance definition of the connection.

If the tagging option is used for a connection, CLP=0 cells identified by the UPC function to be non-conforming to the CLP=0 cell stream are converted to CLP=1 cells. Those cells that have the CLP bit converted from ‘0’ to ‘1’ are called tagged cells. A tagged cell that is identified by the UPC function to be conforming to the CLP = 0 + 1 cell stream is passed; otherwise, it is discarded. Likewise, a cell submitted by an end-system with CLP=1, that is identified by the UPC function to be conforming to the CLP = 0 + 1 cell stream is passed; otherwise, it is discarded.[3] 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. If a CLP=0 cell is not conforming to the aggregate CLP=0+1 flow, tagging will not make it conforming. Therefore, the tagging option never applies to the aggregate CLP=0+1 flow, but applies to the CLP=0 flow.

(R) Cells shall be passed when they are identified by the UPC as conforming. If a tagged cell is passed, then it is considered to be conforming.

(R) Cells shall be discarded when they are identified by the UPC as non-conforming.

(O) Following the UPC function, traffic shaping may be used to perform cell re-scheduling (e.g., to reduce cell clumping) on cells identified by the UPC as conforming.

In addition to the above actions at the cell level, one other action performed at the connection level may optionally be initiated by the UPC.

(O) The UPC function may initiate the release of an identified non-compliant SVC.

5.3.6 Relationship between UPC, CLP, and Network Performance

When an end-system sets the CLP bit, network resources are allocated to CLP=0 and CLP=1 traffic flows as described in Section 5.2. By controlling the connection traffic flows, allocating adequate resources and selecting suitable routes, a network may provide the requested service category and QoS parameters for CLP=0 and CLP=0+1 cell flows.

When no additional network resource has been allocated for the CLP=1 traffic flow (either on user request or due to network provisioning), CLP=0 cells identified by the UPC as non-conforming are discarded. In this case, tagging is not applicable.

Section 5.3.2 addresses undue UPC actions on compliant ATM connections. This is part of the network performance degradation allocated to the UPC and should occur with very low probability.

When cells of the aggregate CLP=0+1 flow are non-conforming to the parameters negotiated for the aggregate stream, the UPC function performed on the aggregate flow may discard CLP=0 cells that would not be considered in excess by the UPC function performed on the CLP=0 cell stream.

5.3.7 Relationship between UPC and OAM

For OAM cell flows across the UNI, the network may require the user to specify traffic parameters for the OAM traffic of an ATM connection. Regardless of whether an end-system explicitly or implicitly specifies

[3] Note that in principle the cell flow that is passed by the UPC with the tagging option is no greater than what might be passed by a UPC without the tagging option when the end-system sets the CLP bit to 1 on those cells that would otherwise have been tagged under the tagging option.

the OAM cell stream, the network may police OAM cell flows separately from user data cell streams or may police OAM cell flows together with user data cell streams. However, neither UNI 3.1 nor UNI 4.0 signaling support indication of an OAM traffic descriptor. Traffic parameters for OAM cell flow across the UNI may be explicitly specified at subscription time, or implicitly by a default rule.
(R) At the service subscription time, the network shall negotiate the upper limit on the OAM traffic as a function of the connection traffic descriptor for the user data traffic of an ATM connection.
The function used to limit the OAM flow is determined by the network. The network may offer alternative limits from which the end-system may select. If the network polices the OAM cell flows together with user data cell flows, the UPC parameters are adjusted appropriately to accommodate the OAM flow.

5.3.8 Reaction to UPC Failures

Due to equipment faults (e.g., in UPC devices and/or other network elements) the controlled traffic characteristics at the UPC/NPC could be different from the values agreed to during the call set-up phase. To cope with these situations, specific procedures of the management plane should be designed (e.g., in order to isolate the faulty link).

5.4 Selective Cell Discard

(O) A congested network element may selectively discard cells which meet either or both of the following conditions:
a) cells which belong to a non-compliant ATM connection;
b) cells which have CLP=1.
This is to protect the CLP=0 flow as much as possible. However, if CLP=1 cells are dropped from a compliant ATM connection it is expected that the CLR objective for the connection, as determined by its conformance definition, will be still met.

5.5 Traffic Shaping

Traffic shaping is a mechanism that alters the traffic characteristics of a stream of cells on a connection to achieve better network efficiency whilst meeting the QoS objectives, or to ensure conformance at a subsequent interface.
(R) Traffic shaping shall maintain cell sequence integrity on a connection.
Examples of traffic shaping are peak cell rate reduction, burst length limiting, reduction of CDV by suitably spacing cells in time, and cell scheduling policy.
The decision whether or not to implement traffic shaping, and if implemented, the location where shaping is done, is network specific. As an example a network may choose to perform traffic shaping in conjunction with suitable UPC/NPC functions and/or virtual source/destination.
As a consequence, any connection may be subject to traffic shaping.
The options available to the network include:
a) No shaping

- Dimension the network in order to accommodate any flow of conforming cells at the ingress whilst ensuring conformance at the egress without any shaping function.

b) Shaping

- Dimension and operate the network so that any flow of conforming cells at the ingress is conveyed by the network or network segment whilst meeting QoS objectives and apply output shaping to the traffic in order to meet conformance tests at the egress.
- Shape the traffic at the ingress of the network or network segment and allocate resources according to the traffic characteristics achieved by shaping, whilst meeting QoS objectives and subsequent conformance tests at the network or network segment egress.

Traffic shaping may also be used within the end-system to ensure that the cells generated by the source or at the UNI are conforming to the negotiated traffic contract as defined in Section 4.5.

5.6 Explicit Forward Congestion Indication (EFCI)

(O) A network element in an impending congested state or a congested state may set an EFCI in the cell header so that this indication may be examined by the destination end-system. For example, the end-system may use this indication to implement a protocol that adaptively lowers the cell rate of the connection during congestion or impending congestion. A network element that is not in a congested state or an impending congested state will not modify the value of this indication. An impending congested state is the state when a network element is operating around its engineered capacity level.

Since the use of EFCI by the end-system is optional for CBR, rt-VBR, nrt-VBR, and UBR, the network should not rely on this mechanism to control congestion. For ABR the end-system behavior is specified in Section 5.10.

The mechanism by which a network element determines whether it is in an impending-congested or a congested state is implementation specific. The mechanism by which the congestion indication is indicated to or used by the higher layer protocols in the end-system is beyond the scope of this specification.

5.7 Resource Management using Virtual Paths

Virtual Paths are an important component of traffic control and resource management in ATM networks. With relation to traffic control, VPCs can be used to:

- simplify CAC;
- implement a form of priority control by segregating groups of virtual connections according to service category;
- efficiently distribute messages for the operation of traffic control schemes (for example to indicate congestion in the network by distributing a single message for all VCCs comprising a VPC);
- aggregate user-to-user services such that the UPC can be applied to the traffic aggregate.

VPCs also play a key role in resource management. By reserving capacity on VPCs, the processing required to establish individual VCCs is reduced. Individual VCCs can be established by making simple connection admission decisions at nodes where VPCs are terminated. Strategies for the reservation of capacity on VPCs will be determined by the trade-off between increased capacity costs and reduced control costs. These strategies are network specific.

The peer-to-peer network performance on a given VCC depends on the performances of the consecutive VPCs used by this VCC and on how it is handled at the VPC end-point. See Figure 5-2.

When VCCs within a VPC require a range of QoS, the VPC performance objective should be set suitably for the most demanding VCC carried. The impact on resource allocation is network specific.

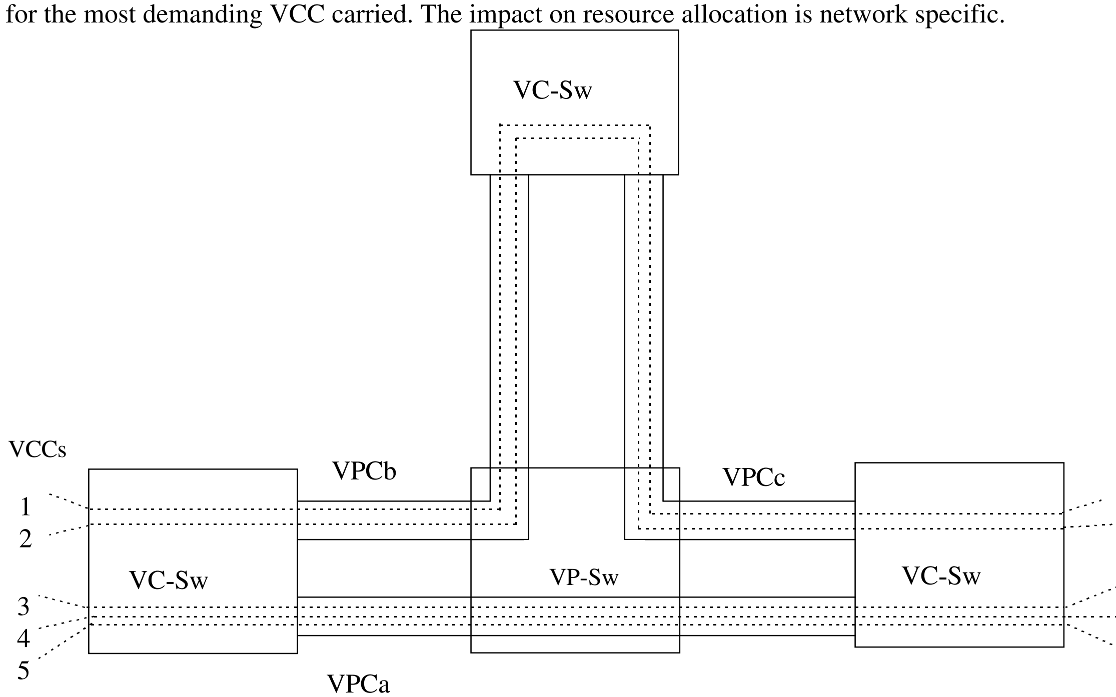


Figure 5-2: Mapping cell loss ratios for VCC and VPC

Figure 5-2 illustrates how the network performance offered on VCCs relates to the network performance offered by VPCs that support them. In the figure, VCCs 1 and 2 experience a network performance which depends on network performance on VPCs b and c and on how these VCCs are handled at the VPC end-points in the VC-Sw element. It may differ from network performance experienced by VCCs 3, 4 and 5, at least due to different network performances provided by VPCs.

VCCs 3, 4 and 5 experience similar network performances in terms of CTD and CDV if handled similarly at the VPC end-points in the VC-Sw element.

Section 3.2 of ITU-T Recommendation I.311 provides three applications of VPCs. These are:

A) User-user application: the VPC extends between a pair of ATM end-systems

B) User-network application: the VPC extends between a UNI and a network element

C) Network-network application: the VPC extends between network elements.

The above cases imply:

In case A: because the network has no knowledge of the traffic contract, service category, and QoS of the VCCs within the VPC, it is the responsibility of the end-system to determine the appropriate service category and QoS parameters for the VPC in accordance with the network capabilities.

In cases B and C: the network is aware of the QoS of the VCCs carried within the VPC and has to accommodate them.

The relationship between the service category of the VPC and the service categories of the VCCs it carries is implementation specific.

Statistical multiplexing of VCCs within a VPC, where the aggregate peak of all VCCs may exceed the VPC capacity, is only possible when all VCCs within the VPC can tolerate the QoS that results from this statistical multiplexing. The way this is managed is network specific. As a consequence, when statistical multiplexing of Virtual Channel Links is applied by the network, VPCs may be used in order to separate traffic thereby preventing statistical multiplexing with other types of traffic. This requirement for separation implies that more than one VPC may be necessary between network origination/destination pairs to carry all of the service categories, traffic contract parameter values, and/or QoS parameter values supported by the network. See Section 5.10.9 for a discussion of ABR Virtual Paths.

5.8 Frame Discard

If a network element needs to discard cells, it is in many cases more effective to discard at the frame level rather than at the cell level. The term “frame” means the AAL protocol data unit. The network detects the frame boundaries by examining the SDU-type in the payload type field of the ATM cell header. Frame discard may be used whenever it is possible to delineate frame boundaries by examining the SDU-type in the payload type field of the ATM cell header.

Frame discard may help avoid congestion collapse and can increase goodput.

If a network supports frame discard, it can treat user data as frames only if the user requests such treatment, either via signaling or at subscription time. The network may invoke frame discard mechanisms, only for connections for which it is specifically enabled. The mechanism by which a network element decides to drop frames is implementation-specific.

5.9 Generic Flow Control

The use of GFC at the UNI is neither assumed nor precluded in this specification. The GFC function is specified in ITU-T Recommendation I.150 and ITU-T Recommendation I.361.

5.10 ABR Flow Control

5.10.1 Introduction

In the ABR service, the source adapts its rate to changing network conditions. Information about the state of the network like bandwidth availability, state of congestion, and impending congestion, is conveyed to the source through special control cells called Resource Management Cells (RM-cells). The following sections specify the format and contents of the RM-cell, the source, destination, and switch behavior, and the parameters used in the service. Optional segmentation of networks, support for virtual paths, and a framework for point-to-multipoint behavior is also specified. For a description of the ABR flow control model, see Section 2.4.

5.10.2 ABR Service Parameters

This section defines the parameters which are used to implement ABR flow-control on a per-connection basis. All parameters are defined, including those which are actually constants and not altered by signaling.

5.10.2.1 Parameter Descriptions

Label	Description	Units and range
PCR	The Peak Cell Rate, PCR, is the cell rate which the source may never exceed.	In Cells/Sec, See Note 1 for range
MCR	The Minimum Cell Rate, MCR, is the rate at which the source is always allowed to send.	In Cells/Sec, See Note 1 for range
ICR	The Initial Cell Rate, ICR, is the rate at which a source should send initially and after an idle period.	In Cells/Sec, See Note 1 for range
RIF	Rate Increase Factor, RIF, controls the amount by which the cell transmission rate may increase upon receipt of an RM-cell.	RIF is a power of two, ranging from 1/32768 to 1.
Nrm	Nrm is the maximum number of cells a source may send for each forward RM-cell.	Power of 2 Range: 2 to 256
Mrm	Mrm controls allocation of bandwidth between forward RM-cells, backward RM-cells, and data cells.	Constant fixed at 2
RDF	The Rate Decrease Factor, RDF, controls the decrease in the cell transmission rate.	RDF is a power of 2 from 1/32,768 to 1
ACR	The Allowed Cell Rate, ACR, is the current rate at which a source is allowed to send.	Units: Cells/Sec
CRM	Missing RM-cell count. CRM limits the number of forward RM-cells which may be sent in the absence of received backward RM-cells.	CRM is an integer. Its size is implementation specific.
ADTF	The ACR Decrease Time Factor is the time permitted between sending RM-cells before the rate is decreased to ICR.	Units: seconds ADTF range: .01 to 10.23 sec: with granularity of 10 ms.
Trm	Trm provides an upper bound on the time between forward RM-cells for an active source.	Units: milliseconds Trm is 100 times a power of two Range: $100*2^{-7}$ to $100*2^{0}$
FRTT	The Fixed Round-Trip Time, FRTT, is the sum of the fixed and propagation delays from the source to a destination and back.	Units : 1 microseconds Range: 0 to 16.7 seconds
TBE	Transient Buffer Exposure, TBE, is the negotiated number of cells that the network would like to limit the source to sending during startup periods, before the first RM-cell returns.	Units: Cells Range: 0 to 16,777,215
CDF	The Cutoff Decrease Factor, CDF, controls the decrease in ACR associated with CRM.	CDF is zero, or a power of two in the range 1/64 to 1.
TCR	The Tagged Cell Rate, TCR, limits the rate at which a source may send out-of-rate forward RM-cells.	TCR is a constant fixed at 10 cells/second

Table 5-1: ABR parameter descriptions

Note 1: Rates are signaled as 24 bit integers which have a minimum value of zero, and a maximum value of 16,777,215. However, RM-cells use a 16-bit floating point format (see Section 5.10.3.2) which has a maximum value of 4,290,772,992.

5.10.2.2 Signaled Parameters

The following parameters are to be signaled and negotiated separately during connection establishment. If any parameter but PCR is unspecified by the source, the first switch will fill in the default value (before negotiation). MCR is optionally negotiable; if MCRmin is missing, then MCR is not negotiable.

Name	Negotiation	Default
PCR	down	mandatory
MCR	down to MCRmin if MCRmin is signaled, else no	0
ICR	down	PCR
TBE	down	16,777,215

FRTT	accumulated	Note 1
RDF	down	1/16
RIF	down	1/16

Table 5-2: Mandatory parameters to be signaled

Note 1: FRTT (Fixed Round-Trip Time) should be set by the source to the fixed source delay. FRTT is then accumulated during the call setup. FRTT is used to determine other parameters (see Section 5.10.2.4). It should be the sum of all the RM-cell fixed delays plus propagation delays in the round trip call path.

Note 2: Because of the downward negotiation of RIF and RDF, a given switch may not be able to support the RIF and RDF values selected by switches farther from the source. This may occur because the RIF or RDF value is smaller that the given switch can support or because the ratio RIF/RDF is incompatible with other ABR connections using the given switch. When a switch cannot support the values negotiated during the forward pass of the call setup, it may decide to clear the call. Additionally, the specification of the QoS class may be signaled. If the QoS class is missing, the default is class zero.

5.10.2.3 Optionally Signaled Parameters

The following additional parameters can be optionally specified by the source during call setup but are optional for the source to specify. If not specified, the default value will be inserted upon call completion (without negotiation). Also, if any network element does not support Table 5-3, or a parameter in this group, the default value will be the value used.

Parameter	Negotiation	Default Value
Nrm	no	32
Trm	no	100
CDF	up	1/16
ADTF	down	0.5

Table 5-3: Optionally signaled ABR parameters

5.10.2.4 Parameter Computation After Call Setup

The following parameters are computed or updated by the forward and backward sources upon completion of the call setup when FRTT and the other parameters are known.

CRM CRM is computed as:

$$CRM = \left\lceil \frac{TBE}{Nrm} \right\rceil$$

ICR ICR is updated after call setup is complete to insure TBE compliance as:

$$ICR = \min\left(ICR, \frac{TBE}{FRTT} \right)$$

5.10.3 RM-Cell Structure

Table 5-4 shows the fields and their position within the Resource Management (RM) cell format.

FIELD	OCTET	BIT(s)	DESCRIPTION	Initial Value	
				if source-generated	**if switch-generated or destination-generated**
Header	1-5	all	ATM Header	RM-VPC: VCI=6 and PTI=110 RM-VCC: PTI=110	
ID	6	all	Protocol Identifier	1	
DIR	7	8	Direction	0	1
BN	7	7	BECN Cell	0	1
CI	7	6	Congestion Indication	0	either CI=1 or NI=1 or both
NI	7	5	No Increase	0 or 1	
RA	7	4	Request/ Acknowledge	0 or set in accordance with I.371-draft	
Reserved	7	3-1	Reserved	0	
ER	8-9	all	Explicit Cell Rate	a rate not greater than PCR parameter	any rate value
CCR	10-11	all	Current Cell Rate	ACR Parameter	0
MCR	12-13	all	Minimum Cell Rate	MCR Parameter	0
QL	14-17	all	Queue Length	0 or set in accordance with I.371-draft	
SN	18-21	all	Sequence Number	0 or set in accordance with I.371-draft	
Reserved	22-51	all	Reserved	6A (hex) for each octet	
Reserved	52	8-3	Reserved	0	
CRC-10	52	2-1	CRC-10	See Section 5.10.3.1	
	53	all			

Table 5-4: Fields and their position in RM-cells

8	7	6	5	4	3	2	1
DIR	BN	CI	NI	RA	Res.	Res.	Res.

DIR = 0 for forward RM cells
= 1 for backward RM cells
BN = 1 for Non-Source Generated (BECN) RM cells
= 0 for Source Generated RM cells
CI = 1 to indicate congestion
= 0 otherwise
NI = 1 to indicate no additive increase allowed
= 0 otherwise
RA - Not used for ABR. See description below

Figure 5-3: Message Type Field (Octet 7)

5.10.3.1 Description of RM-cell Fields

This section describes how each field of the RM-cell is used. See Table 5-1 for requirements and options for initializing these fields. See also sections 5.10.5 through 5.10.7 for requirements and options for modifying the values in these fields.

- **Header:** The first five bytes of an RM-cell are the standard ATM header with PTI=110 (binary) for a VCC, and additionally VCI=6 for a VPC. The CLP bit is 0 if the RM-cell is in-rate and 1 if it is out-of-rate.
- **ID:** The protocol ID identifies the service using the RM-cell. The ITU has assigned protocol ID = 1 to ABR service.
- **Message Type Field**

  DIR: The DIR bit indicates which direction of data flow is associated with the RM-cell. A forward RM-cell, indicated by DIR=0, is associated with data cells flowing in the same direction. A backward RM-cell, indicated by DIR=1, is associated with data cells flowing in the opposite direction. DIR is changed from 0 to 1 when an RM-cell is turned around at a destination.

  BN: The BN bit indicates whether the RM-cell is a Backward Explicit Congestion Notification (BECN) cell (i.e., non-source generated) or not. BN=0 indicates a source generated RM-cell while BN=1 indicates a BECN RM-cell generated by a destination or a switch.

  CI: The CI (congestion indication) bit allows a network element to indicate that there is congestion in the network. When a source receives a backward RM-cell with CI=1 it decreases its ACR. When turning around a forward RM-cell, a destination will set CI=1 to indicate that the previous received data cell had the EFCI state set.

  NI: The NI (no increase) bit is used to prevent a source from increasing its ACR. In contrast to CI=1, NI=1 does not require any decrease. A network element might set NI to 1 to indicate impending congestion. Normally, a source will initialize NI to 0 so that it might be allowed to increase its ACR, but it can indicate that it does not need a higher ACR by initializing NI to 1.

  RA: The RA bit is not used for ATM Forum ABR.
- **ER:** The ER (Explicit Rate) field is used to limit the source ACR to a specific value. For each RM-cell ER is set by the source to a requested rate (such as PCR). It may be subsequently reduced by any network element in the path to a value that the element can sustain. ER is formatted as a rate as defined in Section 5.10.3.2.
- **CCR**: The CCR field is set by the source to its current ACR. It may be useful to network elements in computing a value to place in ER. For BECN cells, CCR=0. CCR is formatted as a rate as defined in Section 5.10.3.2.
- **MCR:** The MCR field carries the connection's Minimum Cell Rate. It may be useful to network elements in allocating bandwidth among connections. For BECN cells, MCR=0. MCR is formatted as a rate as defined in Section 5.10.3.2.
- **QL:** The QL field is not used for ATM Forum ABR.
- **SN:** The SN field is not used for ATM Forum ABR.
- **CRC-10:** The RM CRC is the same CRC used for all OAM cells. It is computed as the remainder of the division (modulo 2) by the generator polynomial of the product of x^{10} and the content of the RM-cell payload excluding the CRC field (374 bits). Each bit of this payload is considered as a coefficient (modulo 2) of a polynomial of degree 373 using the first bit as the coefficient of the highest order term. The CRC-10 generating polynomial is: $1+x+x^4+x^5+x^9+x^{10}$. The result of the CRC calculation is placed with the least significant bit right justified in the CRC field. See ITU-T Recommendation I.610 for examples.

5.10.3.2 Rate Representation

Rates in the RM-cell and in the Source Behavior are represented in a binary floating point representation employing a 5 bit exponent, *e*, a 9 bit mantissa, *m*, and a 1 bit Nonzero flag, *nz*, as described below:

$R=[2^e (1+m/512)]*nz$ cells/seconds where,

1 bit reserved	Bit 16, most significant bit of 16 bit field
$nz \in \{0,1\}$	Bit 15 If nz=0 the rate is zero. If nz=1, the rate is as given by the fields e and m.
$0 \le e \le 31$	Bit 14 through bit 10. The mantissa is a 5 bit unsigned
$0 \le m \le 511$	Bit 9 through bit 1

represent all rates used in the RM-cells and source behavior for ABR service. The bit positions of a floating point rate within a 16 bit word are given below:

	1 bit	1 bit	5 bits	9 bits
	reserved	*nz*	exponent(*e*)	mantissa(*m*)
bits	16	15	14 - 10	9 - 1

Figure 5-4: Rate format used in RM-cells

Note: Bits 16-9 are transmitted before bits 8-1 when using this encoding in the RM-cell.

5.10.3.3 In-rate and Out-of-rate Cell Types

ABR RM-cells shall be sent with CLP=0. ABR RM-cells with CLP=1 may be sent under the conditions explicitly stated in Sections 5.10.4, 5.10.5, and 5.10.6. All other ABR cells shall be sent with CLP=0. For ABR, CLP=0 cells are called “in-rate” cells, and CLP=1 cells are called “out-of-rate” cells.

One use of out-of-rate RM-cells is to enable a rate increase for a connection that has an ACR of zero. The source would use the out-of-rate cells as probes to learn when it may increase its rate.

5.10.4 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 outgoing 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 forward 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.

Notes:

1. In-rate forward and backward RM-cells are included in the source rate allocated to a connection.
2. The source is responsible for handling local congestion within its scheduler in a fair manner. This congestion occurs when the sum of the rates to be scheduled exceeds the output rate of the scheduler. The method for handling local congestion is implementation specific.

5.10.5 Destination Behavior

The following items define the destination 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.

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 ITU-T Recommendation 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).

Notes:

1. "Turn around" designates a destination process of transmitting a backward RM-cell in response to having received a forward RM-cell.
2. It is recommended to turn around as many RM-cells as possible to minimize turn-around delay, first by using in-rate opportunities and then by using out-of-rate opportunities as available. Issues regarding turning RM-cells around are discussed in Appendix I.7.

5.10.6 Switch Behavior

The following items define the switch 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.

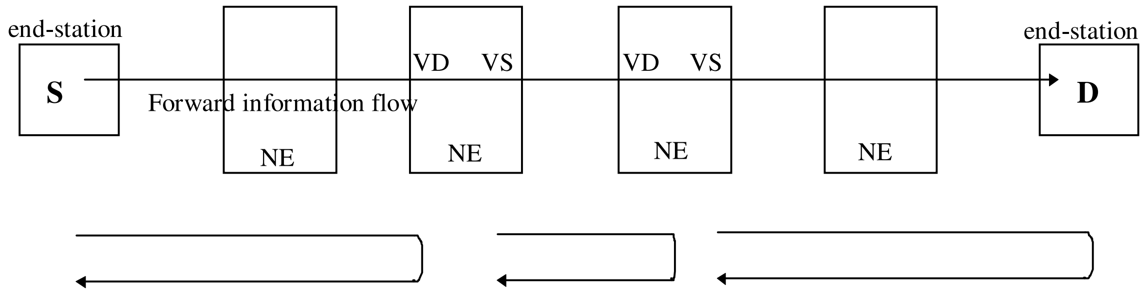
1. A switch shall implement at least one of the following methods to control congestion at queuing points:
   a) *EFCI marking*: The switch may set the EFCI state in the data cell headers;
   b) *Relative Rate Marking:* The switch may set CI=1 or NI=1 in forward and/or backward RM-cells;
   c) *Explicit Rate Marking:* The switch may reduce the ER field of forward and/or backward RM-cells (Explicit Rate Marking) ;
   d) *VS/VD Control*: The switch may segment the ABR control loop using a virtual source and destination.
2. A switch may generate a backward 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 switch 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 switch shall assign values to the various RM-cell fields as specified for switch-generated cells in Table 5-4.
3. RM-cells may be transmitted out of sequence with respect to data cells. Sequence integrity within the RM-cell stream must be maintained.
4. For RM-cells that transit a switch (i.e., are received and then forwarded), the values of the various fields before the CRC-10 shall be unchanged except:
   a) CI, NI, and ER may be modified as noted in #1 above
   b) RA, QL, and SN may be set in accordance with ITU-T Recommendation I.371-draft
   c) MCR may be corrected to the connection's MCR if the incoming MCR value is incorrect.
5. The switch may implement a use-it-or-lose-it policy to reduce an ACR to a value which approximates the actual cell transmission rate from the source. Use-it-or-lose-it policies are discussed in Appendix I.8.

Notes:

1. A switch queuing point is a point of resource contention where cells may be potentially delayed or lost. A switch may contain multiple queuing points.
2. Some example switch mechanisms are presented in Appendix I.5.
3. The implications of combinations of the above methods is beyond the scope of this specification.

5.10.7 Virtual Source and Virtual Destination Behavior

VS/VD behavior divides an ABR connection into two or more seperately controlled ABR segments. The coupling between adjacent ABR control segments associated with an ABR connection is implementation specific. Figure 5-5 illustrates an ABR virtual connection which incorporates segmentation.



Control loops associated with forward information flow

S: Source VS: Virtual Source
D: Destination VD: Virtual Destination
NE: Network Element

Figure 5-5: Example of a segmented ABR virtual connection

The following applies to VS/VD behavior:

1. Each ABR control segment, except the first, is sourced by a virtual source. A virtual source assumes the behavior of an ABR source end point. Backward RM-cells received by a virtual source are removed from the connection.
2. Each ABR control segment, except the last, is terminated by a virtual destination. A virtual destination assumes the behavior of an ABR destination end point. Forward RM-cells received by a virtual destination shall be turned around as defined in destination behavior #2, and shall not be forwarded to the next segment of the connection.
3. The coupling between two adjacent ABR control segments associated with an ABR connection is implementation specific.
4. MCR shall be conveyed across VS/VD boundaries.
5. Setting of other parameters at VS/VD is network specific.

5.10.8 Point-to-Multipoint Behavior

The support of ABR point-to-multipoint connections is not required for ABR compliance as defined in this specification. However, the guidelines provided here are intended as a basic framework for a complete specification of point-to-multipoint ABR service in the future.

The operation of an ABR point-to-multipoint connection is functionally divided into behaviors for ABR sources/virtual sources, destinations/virtual destinations, switches, and branch points. According to their functional definitions, a source and destination is located at the root of the point-to-multipoint tree and at each of the leaves,

- one or more virtual sources/virtual destinations may be located on each branch of the tree,
- one or more switches may be located on each branch of the tree, and
- a branch-point is located at the intersection of two or more branches.

Note that switches, which determine the feedback sent from queuing points, are considered as functionally separate from branch points, which replicate cells traveling from root to leaves and consolidate feedback traveling from leaves to root. A branch is defined as any point-to-point segment of the point-to-multipoint tree. A branch may be classified as in the "non-responding state" if it has not transmitted (e.g., turned around) RM-cells towards the root for a time, the length of which is network specific but indicates the unavailability of the branch. Otherwise, the branch is in the "responding state." The classification of a branch as in the "non-responding state" is optional.

5.10.8.1 Behavior for Sources, Destinations, Switches, and VS/VDs of point-to-multipoint Connections

For a point-to-multipoint connection, the source behavior is the same as in Section 5.10.4, except that data cells shall not be transmitted in the direction from the leaves to the root. The destination behavior is the same as in Section 5.10.5, the switch behavior the same as in Section 5.10.6, and the virtual source/virtual destination behavior the same as in Section 5.10.7.

5.10.8.2 Behavior for Branch Points on Point-to-Multipoint Connections

1. An ABR branch point shall replicate each data cell and RM-cell received from the root onto each branch that leads to a leaf, whenever the branch is in the responding state. RM-cells may be transmitted onto the leaves out of sequence with respect to data cells, but the sequence integrity within the RM-cell stream transmitted to each branch must be preserved.
2. An ABR branch point shall transmit forward and backward RM-cells towards the root. This may be done by consolidating the information from forward and backward RM-cells received in the leaf-to-root direction from each branch in the responding state. However, a branch point is responsible for assuring that the ABR flow transmitted to each branch (both towards the leaves and towards the root) conforms to the expected behavior for a point-to-point ABR flow, given that the ABR flows received by the branch point do. There are network elements which support traditional multicasting (i.e., cell duplication) but cannot consolidate RM-cells. Their role within the framework of point-to-multipoint ABR service requires further study.
   Branch points may send fewer RM-cells to the root than they receive from the leaves of a point-to-multipoint connection. The method of assigning values to the ER, CI, and NI fields is implementation specific. When a branch point sets the BN bit, it also sets either CI or NI.
3. An ABR branch point may:
   - buffer data and generate ABR feedback from queuing points as defined by the switch behavior in Section 5.10.6;
   - implement virtual sources and virtual destinations at one or more branches as defined in Section 5.10.7.

5.10.9 Support for Virtual Paths

This section clarifies three distinct configurations with respect to ABR VPC support:

1. Operation of ABR VCCs contained within a VPC

ABR VCCs within a VPC share its capacity, in the same way ABR connections share the capacity of a physical link. The method used to divide this VPC capacity among these VCCs is implementation specific.

2. Operation of an ABR VPC carrying VCCs

Each end-point of an ABR VPC shall comply with the ABR source and destination behavior. RM-cells for VPC operation shall have VCI=6 and PTI=110 (binary). VCI 6 shall not have other functions assigned to it. This coding is used to distinguish the RM-cells controlling the VPC from any RM-cells belonging to contained ABR VCCs. Switches operating at the VP level on an ABR VPC shall only act on VPC RM-cells and shall ignore any VCC RM-cells within the VPC. On reception, all cells with VCI=6 may be treated as VP RM-cells, even when the coding of the PTI field is not 110.

The method used by an ABR VPC end-point to allocate its dynamically changing capacity between the VCCs it contains is implementation specific. In particular, for an ABR VPC carrying ABR VCCs, the method used to couple control for the VCCs to bandwidth availability at the VPC end-point is implementation specific. Figure 5-6 illustrates an ABR VPC.

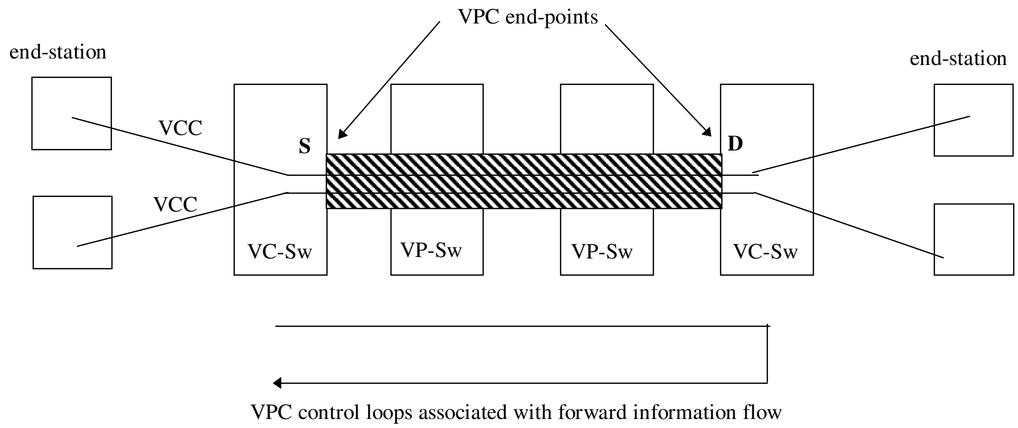


Figure 5-6: Example of an ABR VPC

3. Allocation of bandwidth between ABR VPCs and ABR VCCs on the same link

In the case where link capacity must be shared between both ABR-VPCs and ABR-VCCs the method used to allocate the bandwidth is implementation specific.

6. References

1. ITU-T Recommendation G.822, "Controlled slip rate objectives on an international digital connection," ITU-T Study Group 13, Geneva, 1990.
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8. ITU-T Recommendation I.610, "B-ISDN operation and maintenance principles and functions," ITU-T Study Group 13, Geneva, 1994.
9. ITU-T Recommendation Q.2931, "Broadband integrated services digital network (B-ISDN) - Digital subscriber signalling No. 2 (DSS 2) - User network interface layer 3 specification for basic call/connection control," ITU Study Group 11, Geneva, expected in 1996.
10. The ATM Forum, Interim Local Management Interface (ILMI) Specification (Draft), February 1996.
11. The ATM Forum, User-Network Interface (UNI) Signalling Specification (Draft), February 1996.
12. The ATM Forum, Private Network-Node Interface (PNNI) Signalling Specfication (Draft), February 1996.

Normative Annex A: Glossary of Acronyms and Terms

AAL	ATM Adaptation Layer
ABR	Available Bit Rate
ABT	ATM Block Transfer
ACR	Allowed Cell Rate
RIF	Rate Increase Factor
ATM	Asynchronous Transfer Mode
BICI	Broadband Inter-Carrier Interface
B-ISDN	Broadband ISDN
BECN	Backward Explicit Congestion Notification
BT	Burst Tolerance
BN	BECN (bit in RM-cell)
BRM	Backward RM-cell
CAC	Connection Admission Control
CAPC	Congestion Avoidance with Proportional Control
CBR	Constant Bit Rate
CCR	Current Cell Rate
CDF	See Table 5-2
CDV	Cell Delay Variation
CDVT	CDV Tolerance
CER	Cell Error Ratio
CI	Congestion Indication (bit in RM-cell)
CLP	Cell Loss Priority
CLR	Cell Loss Ratio
CMR	Cell Misinsertion Rate
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
CRF	Cell Relay Function or Connection Related Functions
CRM	See Table 5-2
CTD	Cell Transfer Delay
DES	Destination End-System
RM-cell	Resource Management Cell
DGCRA	Dynamic GCRA
DIR	Direction (bit in RM-cell)
EFCI	Explicit Forward Congestion Indication
EPRCA	Enhanced Proportional Rate Control Algorithm
ER	Explicit Rate
FECN	Forward Explicit Congestion Notification
FIFO	First In First Out queue service discipline
FRM	Forward RM-cell
FRS	Frame Relay Service
GCRA	Generic Cell Rate Algorithm
GFC	Generic Flow Control
IBT	Intrinsic Burst Tolerance
ICR	Initial Cell Rate
IE	Information Element
ILMI	Interim Local Management Interface
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ITT	Ideal Transmission Time
ITU	International Telecommunications Union
LAN	Local Area Network
LANE	LAN Emulation

LCT	Last Conformance Time
MACR	Mean Allowed Cell Rate
maxCTD	Maximum Cell Transfer Delay
Mrm	Minimum number of cells between RM-cell generation
MBS	Maximum Burst Size
MCR	Minimum Cell Rate
MCRmin	Minimum acceptable MCR
MIB	Management Information Base
MP	Measurement Point
Multiprotocol	Referring to internetworking layer protocols (including e.g., IP, DECNet, IPX, SNA, Apple Talk)
NFS	Network File Service
NI	No Increase (bit in RM-cell)
NMS	Network Management System
NNI	Network to node interface
NPC	Network Parameter Control
Nrm	Maximum number of cells between RM-cell generation
nrt-VBR	Non-Real-Time VBR
NT	Network Termination
OAM	Operations, Administration and Maintenance
PCR	Peak Cell Rate
PDU	Protocol Data Unit
peak-to-peak CDV	Peak-to-peak Cell Delay Variation
PHY	Physical Layer
PNNI	Private Network Node Interface
PTI	Payload Type Indicator
PVC	Permanent Virtual Connection
QL	Queue Length (field in RM-cell)
QoS	Quality of Service
RA	Resource Allocation (bit in RM-cell)
RDF	Rate Decrease Factor
RDFF	RDF Factor
RM-cell	Resource Management Cell
rt-VBR	Real-Time VBR
FRTT	Fixed Round-trip Time
SAA WG	ATM Forum Services Aspects and Applications Working Group
SAP	Service Access Point
SCR	Sustainable Cell Rate
SDU	Service Data Unit
SECBR	Severely Errored Cell Block Ratio
SES	Source End-System
SIG WG	ATM Forum Signaling Working Group
SMDS	Switched Multi-megabit Data Service
SN	Sequence Number (field in RM-cell)
STD	Source Traffic Descriptor
SVC	Switched Virtual Connection
SW	Switch
TAT	Theoretical Arrival Time
TCP	Transmission Control Protocol
TCR	See Table 5-2
TM	Traffic Management
ADTF	See Table 5-2
Trm	See Table 5-2
UBR	Unspecified Bit Rate

UDP	User Datagram Protocol
UNI	User Network Interface
UPC	Usage Parameter Control
VBR	Variable Bit Rate
VC	Virtual Connection
VCC	Virtual Channel Connection
VCI	Virtual Channel Identifier
VC-SW	Virtual Channel Switching Function
VPC	Virtual Path Connection
VPI	Virtual Path Identifier
VP-SW	Virtual Path Switching Function
VS/VD	Virtual Source/Virtual Destination
WAN	Wide Area Network
τ_1, τ_2, τ_3	See Section 4.5.5

Normative Annex B: Measurement & Analysis of QoS Parameters

B.1 Measurement Methods

In this section at least one method to measure each QoS parameter in either an in-service or out-of-service mode is defined. Other alternative measurement methods or estimates are possible.

Either in-service or out-of-service methods may be used to estimate values for the ATM cell transfer performance parameters. In-service methods are based on performance monitoring OAM flows which may be introduced into the user cell stream at any VPC or VCC termination or connecting point, and may then be copied or extracted at any similar point downstream. Details of OAM functions supporting performance measurement are provided in ITU-T Recommendation I.610. Out-of-service methods consist of establishing a test connection at an appropriate measurement point, introducing a cell stream of known content and timing at that point, and then observing the cell stream at a remote measurement point.

B.1.1 Cell Error Parameters

B.1.1.1 Cell Error Ratio

A method using test stream for out-of-service measurement is described in Annex C of ITU-T Recommendation I.356. It basically involves transferring a known data stream into the network at the source measurement point and comparing the received data stream with the known data stream at the destination measurement point.

An in-service measurement is desirable. Annex C of ITU-T Recommendation I.356 suggests a BIP-16 indicator to estimate the cell error ratio over a block of N cells.

B.1.1.2 Severely Errored Cell Block Ratio

Severely errored cell block ratio can be estimated in service for a set of S consecutive or non consecutive cell blocks by computing the number of lost cell or mis-inserted cell outcomes in each cell block, identifying cell blocks with more than M lost cell or mis-inserted cell outcomes as severely errored cell blocks, and dividing the total number of such severely errored cell blocks by S. This in-service measurement method will undercount severely errored cell blocks to some degree, since it does not include delivered errored cells in the estimation of M. A more accurate estimate of severely errored cell block ratio can be obtained by comparing transmitted and received data in an out-of-service measurement.

B.1.2 Cell Loss Ratio

A method using OAM cells for in-service measurement is described in Annex C of ITU-T Recommendation I.356. The transmitter inserts OAM cells into a transmitted user information cell stream at suitable intervals. Each OAM cell contains a count of the number of user information cells transmitted since the last OAM cell. The receiver keeps a running count of the number of user information cells transmitted (N_t) and received (N_r). Cell loss ratio can then be calculated as $(N_t - N_r) / N_t$ if $N_t - N_r$ is positive. This method will under-count cell loss events if misinsertion occurs during the measurement period. It will over count loss if SECB events are not excluded.

B.1.3 Cell Misinsertion Rate

A method using OAM cells for in-service measurement is described in Annex C of ITU-T Recommendation I.356. Counts, Nr and Nt, of the received and transmitted cells are obtained during a measurement period Tm (excluding cells in Severely Errored Cell Blocks), and the Cell Misinsertion Rate (CMR) is calculated by dividing the positive difference (Nr-Nt) by Tm. Cell misinsertion events will be under-counted if cell loss events occur.

An out-of-service measurement method is described in Annex C of ITU-T Recommendation I.356. Basically a VP or VC is maintained for a known period of time, however, no cells are transmitted on it. Any cells received on this VP or VC are mis-inserted cells.

B.1.4 Cell Transfer Delay

A method using OAM cells for in-service measurement is described in Annex C of ITU-T Recommendation I.356. Time stamped OAM cells are transmitted through the network on an established connection. The transmitted OAM cell payload contains the time stamp of the cell exit event. The receiver subtracts the received time stamp from the time stamp of the cell entry event to obtain the delay for that cell on that connection. Individual cell transfer delay observations may be combined to calculate statistics of the cell transfer delay distribution. This method requires synchronized clocks at the two measurement points, or a suitable reporting mechanism at the receiver, for example a loopback at the receiver.

B.1.5 Measuring Cell Non-Conformance Ratio

For the case of a connection described only by PCR and for a single cell flow (such as the aggregate CLP=0+1 cell flow), consider negotiated values for peak emission interval T and CDVT τ. Consider the variables c_k and y_k which are defined as follows:

$$c_0 = a_0$$

$$c_{k+1} = \begin{cases} c_k & \text{if } c_k > a_k + \tau \\ a_k + T & \text{if } c_k \le a_k \\ c_k + T & \text{otherwise} \end{cases}$$

$$y_k = c_k - a_k$$

where a_k is the observed arrival time of cell k at the measurement point. Figure B-1 of ITU-T Recommendation I.356 illustrates a measurement method that calculates, for a cell stream received at a measurement point, the number of cells that do not comply with a specified peak emission interval and a CDVT. The virtual scheduling algorithm and continuous-state leaky bucket described in Section 4.4.2 as equivalent versions of the GCRA may be used to measure the cell non-conformance ratio. The mapping between the variables of the two equivalent algorithms are summarized in table B-1 of ITU-T Recommendation I.356.

B.1.6 Measuring of Range of Cell Transfer Delay

Buffering procedures to implement AAL1 at the receiving side to compensate for cell delay variation are based on the expected maximum range of cell transfer delay. The actual range of cell transfer delay observed in a set of consecutive cells may be measured using the one-point CDV parameter y_k which is defined in ITU-T Recommendation I.356. This parameter describes the variability in the pattern of cell arrival events at a MP with reference to the negotiated peak emission interval T. The one-point CDV y_k for cell k at a MP is the difference between the cell's reference arrival time c_k and the actual arrival time a_k : $y_k = c_k - a_k$. The reference arrival pattern is defined as follows:

$$c_0 = a_0$$

$$c_{k+1} = \begin{cases} a_k + T & \text{if } c_k \le a_k \\ c_k + T & \text{otherwise} \end{cases}$$

A positive value for y_k corresponds to a cell which experienced a smaller delay than the maximum delay experienced up to cell (k-1). A negative value for y_k corresponds to a cell which experienced the largest delay experienced by cells up to cell k. The following figure provides a method of estimating the range of cell transfer delay for a succession of transferred cells. This method assumes that cells are input uniformly at the PCR.

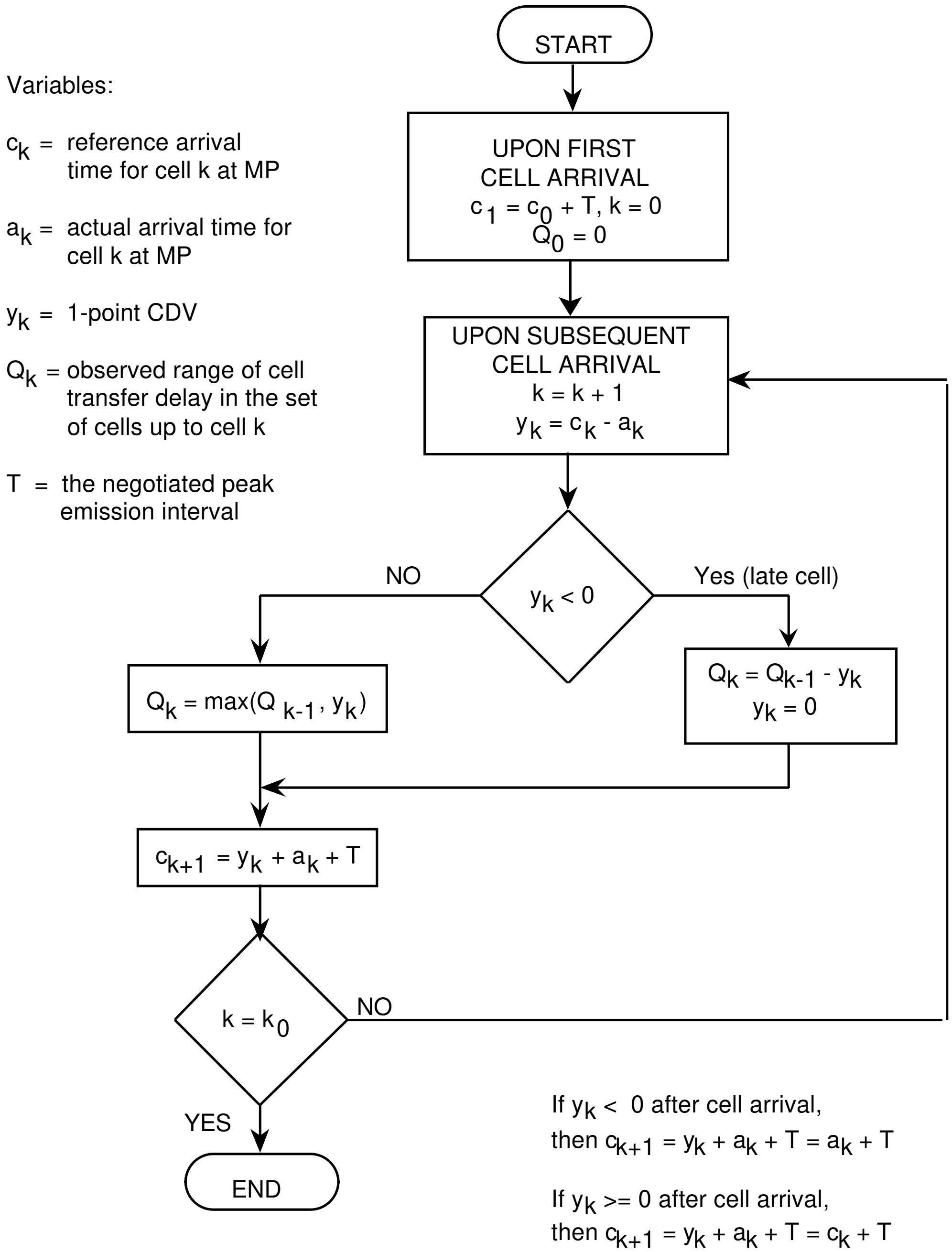


Figure B-1: Estimation of the range of two-point CDV from one-point CDV for connections providing CBR service

B.2 Factors Affecting ATM QoS Parameters

This section provides a list of items to be considered in setting QoS parameter objectives dependent upon characteristics that can exist in either private or public networks, or combinations thereof as indicated in Figure 3-1. The objective is to have maximum commonality between public and private networks.

This section summarizes the set of ATM cell transfer performance parameters defined in ITU-T Recommendation I.356. The cell events and cell transfer outcomes defined in Section 3.4 of this document are used in defining these performance parameters. This set of ATM cell transfer performance parameters correspond to the generic criteria of the assessment (shown in parentheses) of the QoS (see ITU-T Recommendation I.356), as follows:

Cell Error Ratio	(Accuracy)
Severely-Errored Cell Block Ratio	(Accuracy)
Cell Loss Ratio	(Dependability)
Cell Misinsertion Rate	(Accuracy)
Cell Transfer Delay (mean and max)	(Speed)
Cell Delay Variation	(Speed)

B.2.1 Sources of QoS Degradation

B.2.1.1 Propagation Delay

This is the delay caused by the Physical media which transports the bits comprising ATM cells between UNIs and between ATM switches. This equally impacts public and private networks, dependent upon distance only. Private networks may extend from the desktop to international distances, while public networks generally extend from metropolitan to international distances.

B.2.1.2 Media Error Statistics

This is the random and/or bursty bit errors that are introduced on the physical media.

B.2.1.3 Switch Architecture

The overall architecture of the switch can have significant impacts on performance. Some aspects to consider are the switch matrix design, buffering strategy and the switch characteristics under load. The switch matrix design may range from blocking to non-blocking. The strategy in which the buffer capacity of a port supporting the UNI on an ATM switch is managed may differ significantly across switch architectures. The buffer capacity may be dedicated to a single port, it may be shared between multiple ports, or some combination thereof. The management of this buffer capacity may range from a single First In First Out (FIFO) queue to a more complex, multiple queue system with an algorithmically defined service rule, that could operate based upon priorities. The switch matrix design may introduce some loss under heavy load conditions.

B.2.1.4 Buffer Capacity

This is the actual capacity of the buffer in units of cells at a port supporting the UNI, within an ATM matrix, or in other elements of an ATM switch.

B.2.1.5 Traffic Load

This is the load offered by the set of ATM connections on the same route as the connection under consideration.

B.2.1.6 Number of Nodes in Tandem

This is the number of ATM switching nodes that a particular connection traverses.

B.2.1.7 Resource Allocation

This is the capacity allocated to a connection or to a set of connections, such as the set of connections on a given route that are assigned a given QoS class.

B.2.1.8 Failures

These are events that impact availability, such as port failures, switch failures or link failures. Switch overs between failing equipment or circuits may introduce cell loss.

B.2.2 Impact of QoS Degradation on Performance Parameters

In this section the impact of each of the sources of QoS degradation on each of the Performance Parameters of Section 3 is analyzed in a subjective manner as a guideline for what degradations and factors should be considered in determining a value for the performance parameter. Note that the scope of QoS is from UNI to UNI as defined in Section 3.

B.2.2.1 Cell Error Ratio and Severely Errored Cell Block Ratio

The cell error ratio is expected to be primarily influenced by the error characteristics of the physical media. The severely errored cell block ratio is also expected to be influenced by the error characteristics of the physical media and by buffer overflows.

Error characteristics may also be a function of the physical distance and the characteristics of the media. Operational effects such as transmission protection switching and rearrangements may also introduce errors.

B.2.2.2 Cell Loss Ratio

The Cell Loss Ratio is expected to be influenced by errors in the cell header, buffer overflows, and the non-ideal UPC actions. Loss due to the noncompliance of a connection should be excluded when network caused losses are to be estimated.

Errors detected in the cell header at the physical layer affect the Cell Loss Ratio. Cells may also be lost due to failures, protection switching and path reconfiguration.

Different buffering and resource allocation strategies may cause buffer overflow characteristics to differ.

Queuing implementations in some networks may not provide large buffers, or multiple levels of priority since transmission capacity and resources will be relatively inexpensive. Therefore, cell loss ratios may be higher than in a more complicated network. A lost higher level PDU can be detected in a much shorter period of time in a local area than in a wide area, so that higher layer protocol re-transmissions can be initiated sooner and thus will have less impact on higher layer application throughput in local area networks than in wide area networks.

Buffering strategies in wider area or lower speed networks may be much more complex than that in local, high speed networks. Transmission capacity resources will be relatively more expensive. Multiple levels of delay priority, and possibly relatively large buffers, may be implemented. Within a delay-priority level the CLP bit may also be used to indicate two levels of loss priority. High delay-priority levels will likely have low loss ratios, while lower delay-priority levels may have higher loss ratios during periods of buffer congestion.

The number of nodes in tandem may also impact the CLR due to the possibility of overflow in any buffer between the source and destination.

Path reconfiguration from a long to a shorter route is also a possible cause of cell losses, due to the difference in propagation delay. Path reconfiguration is a process at the physical layer used when a path needs to be taken out-of-service to perform maintenance. A possible cause is as follows, after a new path is set up, traffic is transmitted on both paths until it can be verified (at the physical layer) that the new path is operating properly. At this time, a physical layer switch is made at the receiving end of the path. This process is intended to minimize the interruption to the customer service.

B.2.2.3 Cell Misinsertion Rate

The cell misinsertion rate is expected to be primarily influenced by undetected/miscorrected errors in the cell header, which in turn is primarily influenced by the transmission error rate. The likelihood that an undetected/miscorrected cell header error maps into a valid VPI/VCI is also dependent upon the number of VPI/VCI values that are assigned and being actively used.

The cell error ratio will be dependent upon the factors defined in Section B.2.2.1. The number of active ATM sources is likely to be less for a private network than for a public network. This should decrease the likelihood of an undetected/miscorrected cell header error resulting in a cell which is incorrectly mis-inserted into some other VPI/VCI cell stream at the destination UNI.

The number of sources which can be mapped into another cell address will likely be much larger in a public network than in a private network.

B.2.2.4 Cell Transfer Delay

Cell transfer delay is affected by propagation, queuing, routing and switching delays, which are likely to differ for local and wide-area networks.

B.2.2.5 Cell Delay Variation (CDV)

Specification of CDV is essential for Constant Bit Rate (CBR) connection performance. Its value is necessary for the dimensioning of the elastic buffer required at the terminating end of the connection for absorbing the accumulated CDV, regardless of whether the network is public or private.

A common, maximum cell delay variation value for private, public and hybrid private/public networks is essential. As an implementation guideline the receiver CDVT should be designed to handle the case where a connection traverses three networks, each having three switches in tandem.

B.2.2.6 Degradation of QoS Parameters Summary

Table B-1 summarizes how various sources of degradation can impact the QoS parameters.

Attribute	CER	SECBR	CLR	CMR	CTD	CDV
Propagation Delay					X	
Media Error Statistics	X	X	X	X		
Switch Architecture			X		X	X
Buffer Capacity		X	X		X	X
Number of Tandem Nodes	X	X	X	X	X	X
Traffic Load			X	X	X	X
Failures	X	X	X			
Resource Allocation			X		X	X

Table B-1: Degradation of QoS Parameters

CER = Cell Error Ratio

SECBR = Severely Errored Cell Block Ratio

CLR = Cell Loss Ratio

CMR = Cell Misinsertion Rate

CTD = Cell Transfer Delay

CDV = Cell Delay Variation

B.3 QoS Classes

A user of an ATM connection (a VCC or a VPC) is provided with one of a number of QoS classes supported by the network. It should be noted that a VPC may carry VC links of various QoS classes. The QoS of the VPC must meet the most demanding QoS of the VC links carried as defined in ITU-T Recommendation I.150. The QoS class associated with a given ATM connection is indicated to the network at the time of connection establishment and will not change for the duration of that ATM connection.

A Quality of Service (QoS) class can have specified performance parameters (Specified QoS class) or no specified performance parameters (Unspecified QoS class). QoS classes are inherently associated with a connection. A Specified QoS class specifies a set of performance parameters and the objective values for each performance parameter identified. Examples of performance parameters that could be in a QoS class are: cell transfer delay, cell delay variation, and cell loss ratio, as currently mentioned in ITU-T recommendations I.371-draft and Q.2931.

Within a specified QoS class, at most two cell loss ratio parameters may be specified. If a specified QoS class does contain two cell loss ratio parameters, then one parameter is for all CLP=0 cells and the other parameter is for all CLP=1 cells of the ATM connection. As presently foreseen, other performance parameters besides the cell loss ratio would apply to the aggregate cell flow of the ATM connection. A QoS class could contain, for example, the following performance parameters: maximum cell transfer delay, a cell delay variation, and a cell loss ratio on CLP=0 cells.

The network may support several QoS classes. At most one (1) unspecified QoS class can be supported. The performance provided by the network should meet (or exceed) performance parameter objectives of the QoS class requested by the ATM end-point. ATM connections shall indicate the requested QoS by a particular class specification. For PVCs the management system can be used by the network to report the QoS classes across the UNI. For SVCs, a signaling protocol’s information elements can be used to communicate the QoS class across the UNI.

B.3.1 Specified QoS Classes

A Specified QoS class provides a quality of service to an ATM connection in terms of a subset of the ATM performance parameters defined in Section B.2. For each Specified QoS class, there is one specified objective value for each performance parameter identified as defined in Section B.2. Initially, each network should define objective values for a subset of the ATM performance parameters of Section B.2 for at least one of the following Service Classes from ITU-T Recommendation I.362 in a reference configuration that may depend on propagation delay and other factors:

Service Class A: Circuit Emulation, Constant Bit Rate Video

Service Class B: Variable Bit Rate Audio and Video

Service Class C: Connection-Oriented Data Transfer

Service Class D: Connectionless Data Transfer

In the future, more "QoS Classes" may be defined for a given "Service Class" described above. The following Specified QoS Classes are currently defined:

Specified QoS Class 1: support a QoS that will meet Service Class A performance requirements

Specified QoS Class 2: support a QoS that will meet Service Class B performance requirements

Specified QoS Class 3: support a QoS that will meet Service Class C performance requirements

Specified QoS Class 4: support a QoS that will meet Service Class D performance requirements

Specified QoS Class 1 should yield performance comparable to current digital private line performance.

Specified QoS Class 2 is intended for packetized video and audio in teleconferencing and multi-media applications.

Specified QoS Class 3 is intended for interoperation of connection oriented protocols, such as Frame Relay.

Specified QoS Class 4 is intended for interoperation of connectionless protocols, such as IP, or SMDS.

A network may provide the same performance for all or a subset of Specified QoS Classes, subject to the constraint that the requirements of the most stringent Service Class are met.

B.3.2 Unspecified QoS Class

In the Unspecified QoS class, no objective is specified for the performance parameters. However, the network may determine a set of internal objectives for the performance parameters. In fact, these internal performance parameter objectives need not be constant during the duration of a call. Thus, for the Unspecified QoS class there is no explicitly specified QoS commitment on either the CLP=0 or the CLP=1 cell flow. Services using the Unspecified QoS class may have explicitly specified traffic parameters.

An example application of the Unspecified QoS class is the support of "best effort" service (i.e., UBR). For this type of service, the user selects the Best-Effort Capability, the Unspecified QoS class, and only the traffic parameter for the PCR on CLP=0+1. This capability can be used to support users that are capable of regulating the traffic flow into the network and to adapt to time-variable available resources.
The Unspecified QoS class is identified by the integer zero (0) in the ILMI MIB or a code point in a signaling message for the requested QoS class.

Normative Annex C: Traffic Contract Related Algorithms and Procedures

C.1 Equivalence of Virtual Scheduling and Continuous Leaky Bucket Algorithms

The virtual scheduling algorithm updates a Theoretical Arrival Time (TAT), which is the "nominal" arrival time of the cell assuming that the active source sends equally spaced cells. If the actual arrival time of a cell is not "too" early relative to the TAT, in particular if the actual arrival time is after TAT - L, then the cell is conforming, otherwise the cell is non-conforming.

Tracing the steps of the virtual scheduling algorithm in Figure C-1, at the arrival time of the first cell $t_a(1)$, the theoretical arrival time TAT is initialized to the current time, $t_a(1)$. For subsequent cells, if the arrival time of the k^{th} cell, $t_a(k)$, is actually after the current value of the TAT then the cell is conforming and TAT is updated to the current time $t_a(k)$, plus the increment I. If the arrival time of the k^{th} cell is greater than or equal to TAT - L but less than TAT (i.e., as expressed in Figure C-1, if TAT is less than or equal to $t_a(k) + L$), then again the cell is conforming, and the TAT is increased by the increment I. Lastly, if the arrival time of the k^{th} cell is less than TAT-L (i.e., if TAT is greater than $t_a(k) + L$), then the cell is non-conforming and the TAT is unchanged.

The continuous-state leaky bucket algorithm can be viewed as a finite-capacity bucket whose real-valued content drains out at a continuous rate of 1 unit of content per time-unit and whose content is increased by the increment I for each conforming cell. Equivalently, it can be viewed as the work load in a finite-capacity queue or as a real-valued counter. If, at a cell arrival, the content of the bucket is less than or equal to the limit value, L, then the cell is conforming, otherwise the cell is non-conforming. The capacity of the bucket (the upper bound on the counter) is L + I.

Tracing the steps of the continuous-state leaky bucket algorithm in Figure C-1 at the arrival time of the first cell $t_a(1)$, the content of bucket, X, is set to zero and the last conformance time (LCT) is set to $t_a(1)$. At the arrival time of the k^{th} cell, $t_a(k)$, first the content of the bucket is provisionally updated to the value X', which equals the content of the bucket, X, after the arrival of the last conforming cell minus the amount the bucket has drained since that arrival, where the content of the bucket is constrained to be non-negative. Second, if X' is less than or equal to the limit value L, then the cell is conforming, and the bucket content X is set to X' plus the increment I for the current cell, and the last conformance time LCT, is set to the current time $t_a(k)$. If, on the other hand, X' is greater than the limit value L, then the cell is non-conforming and the values of X and LCT are not changed.

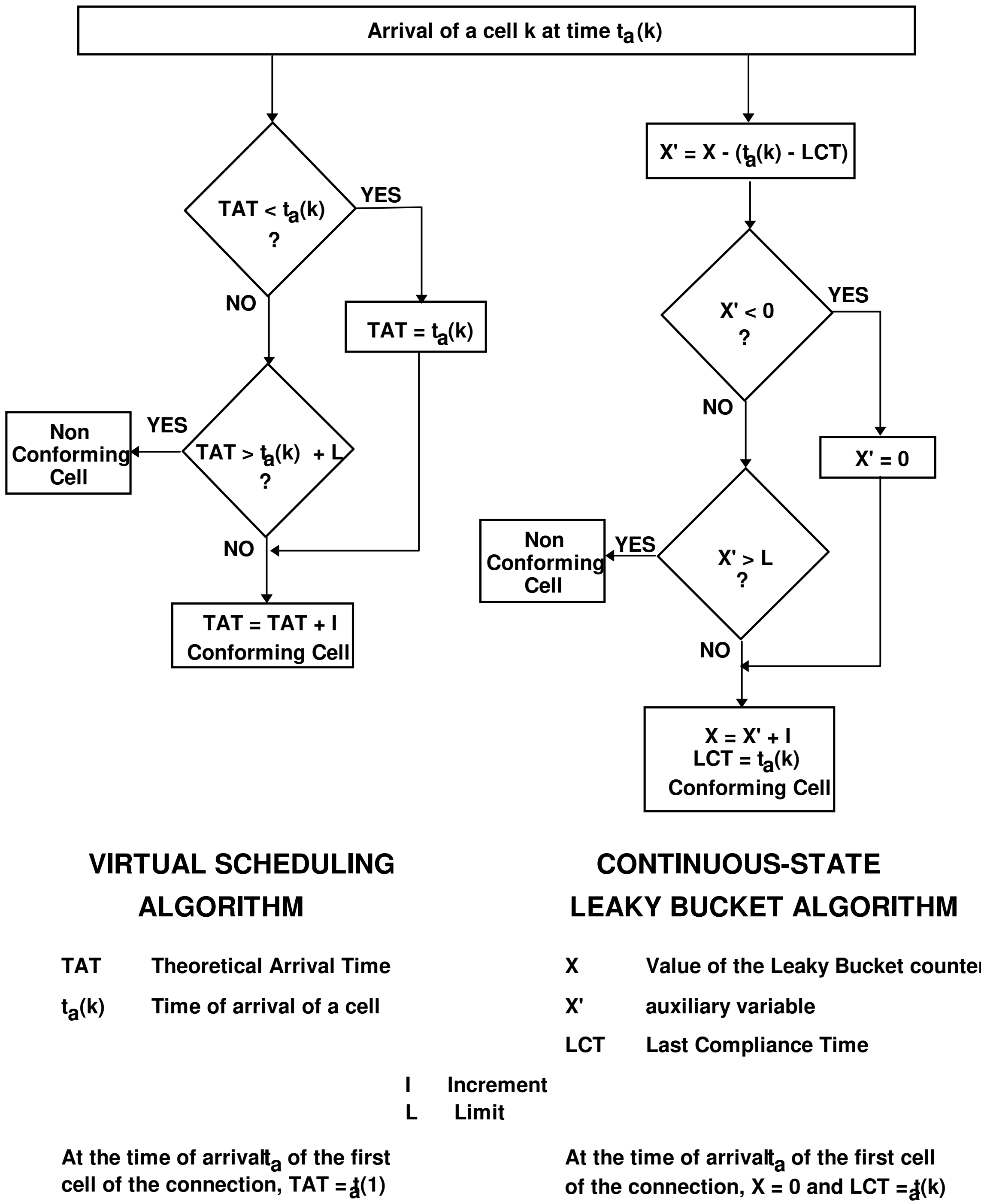


Figure C-1: Equivalent versions of the Generic Cell Rate Algorithm (same as Figure 4-1)

C.2 Interpretation of the Definition of PCR and Equivalent-Terminal

A “natural” or “intuitive” definition for PCR is the reciprocal of the minimum spacing of cells of an ATM connection on a transmission link. This intuitive definition is a rough approximation of the definition given in the previous section; however, this intuitive definition has technical flaws. These flaws are resolved by the Equivalent-Terminal definition of Section 4.4.2.1, at the possible expense of some obtuseness.

A simple technical flaw of the “intuitive” definition is that for a slotted transmission medium, it constrains the possible values of PCR to be the reciprocal of an integral number of cell slot times. For example and using round numbers, if 150Mbits/second is provided to the ATM layer, then the next possible peak rate below 150Mbits/sec is 75Mbits/sec and the next possible one below that is 50Mbits/sec, and so on. This granularity is too coarse.

Note that the equivalent-terminal is a conceptual model (or reference configuration). The definition does not imply that the real Customer Premises Equipment must do the shaping. The shaping by the Equivalent-Terminal may be viewed as a “thought experiment”. The fact that the source may not have shaped the traffic does not imply that the traffic is non-conforming since the criterion for conformance is at the UNI and is defined in terms of the GCRA.

Lastly, note that a definition of PCR does not tell the end-system the proper choice for the rate that meets the specific needs of the end-system. In particular, for VBR traffic sources, the equivalent-terminal model does not uniquely determine the value the end-system should pick for T. In the equivalent-terminal, T must be chosen so that the queue in the buffer (“mux”) behind the shaper is stable. This allows T to be chosen so that its reciprocal is any value greater than the sustainable rate, up to the link rate.

C.3 Examples of Cell Clumping

Figure C-2 through Figure C-5 show a few examples that illustrate the potential cell clumping allowed at the UNI for a given value of τ and for a given value of T (the inverse of the contracted PCR) of an ATM connection according to the *GCRA*(T, τ). In all these examples, it is assumed that T = 4.5δ, where δ is the time required to send 53 octets at the ATM layer data rate of 150 Mbits/sec (i.e., a peak bit rate of 33.3 Mbits/sec, including the cell header, is assumed). The notation in figures 3-3 through 3-6 is defined in Section 4.4.1, where it is noted that “X + LCT” equals the “TAT” at each cell arrival time and after the *GCRA* has been executed.

From Figure C-2 it can be observed that the minimum value of τ to be accommodated at the UNI is 0.5δ. From Figures C-3 to C-5, we observe that as τ increases, the minimum inter-arrival time between conforming cells decreases. When τ is greater than or equal to T - δ, the maximum number N of conforming back-to-back cells, i.e., at the full link rate, equals:

$N = \left\lfloor 1 + \frac{\tau}{T - \delta} \right\rfloor$ For T > δ where $\lfloor x \rfloor$ stands for the integer part of x.

This result of back-to-back cell clumping is illustrated in Figure C-4 and Figure C-5.

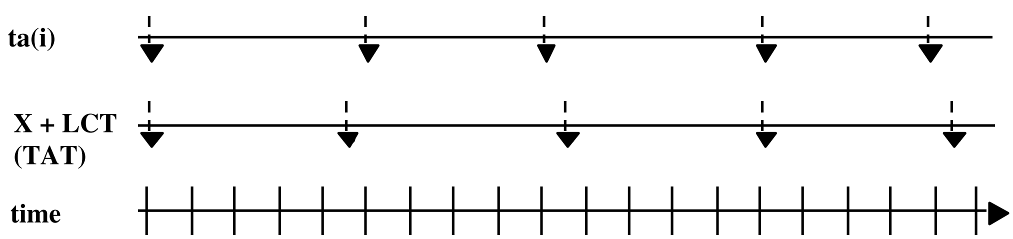


Figure C-2: Ideal Cell Arrival at the Public UNI (τ = 0.5δ)

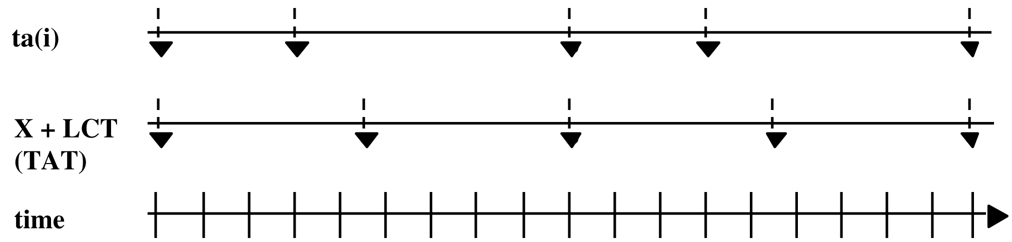


Figure C-3: Possible Cell Arrival at the Public UNI (τ = 1.5δ)

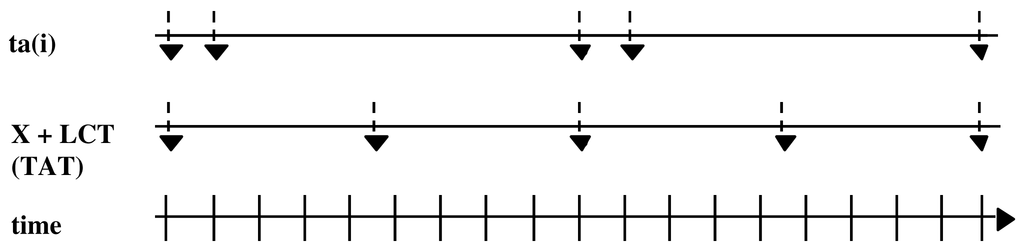


Figure C-4: Possible Cell Arrival at the Public UNI (τ = 3.5δ)

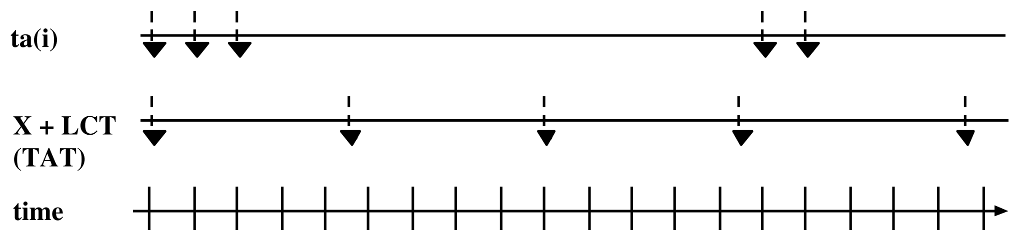


Figure C-5: Possible Cell Arrival at the Public UNI (τ = 7δ)

C.4 Interpretation of SCR and BT in Conjunction with PCR

The SCR is an upper bound on the possible conforming “average rate” of an ATM connection, where “average rate” is the number of cells transmitted divided by the “duration of the connection”; where in this case, the “duration of the connection” is the time from the emission of the first cell until the state of the GCRA for the SCR returns to zero after the emission of the last cell of the connection. Relative to the PCR parameter, T_s is greater than T.

The SCR and BT traffic parameters enable the end-system to describe the future cell flow of an ATM connection in greater detail than just the PCR. If an end-system is able to specify the future cell flow in greater detail than just the PCR, then the network may be able to more efficiently utilize the network resources.

If the source wants to submit traffic that conforms to the SCR ($R_s = 1/T_s$) and the BT (τ_s) and the PCR (1/T) at the PHY-SAP of the equivalent-terminal, then it offers traffic that is conforming to the GCRA(T_s, τ_s) and the peak emission interval T (i.e., GCRA(T, 0)).

The BT together with the SCR and the GCRA determine the MBS that may be transmitted at the peak rate and still be in conformance with the GCRA(T_s, τ_s). The MBS in number of cells is given by

$$MBS = \left\lfloor 1 + \frac{\tau_s}{T_s - T} \right\rfloor$$

where $\lfloor x \rfloor$ stands for the integer part of x.

In the signaling message, the BT is conveyed through the MBS which is coded as a number of cells. The granularity supported by the signaling message is 1 cell. The MBS is used to derive the value of τ_s. The MBS and τ_s apply at the PHY_SAP of the equivalent-terminal. Note that in order to determine τ_s from the MBS, the PCR also needs to be specified. By convention, the peak rate used in the calculation of τ_s is the PCR of the CLP=0+1 cell flow. This convention holds whether τ_s is associated with the SCR for the CLP=0, or the CLP=1, or the CLP=0+1 cell flow of the connection. Also, given the MBS, T, and T_s, then τ_s is not uniquely determined, but can be any value in the half-closed interval:
$[(MBS - 1)(T_s - T), MBS(T_s - T))$.

Hence, in order for all parties to derive a common value for τ_s, by convention, the minimum possible value is used. Thus, given the MBS, T, and T_s, then τ_s is set equal to:

$\tau_s = (MBS - 1)(T_s - T)$

Note that over any closed time interval of length t, the number of cells, N(t), that can be emitted with spacing no less than T and still be in conformance with GCRA(T_s, τ_s) is bounded by:

$$N(t) \le \min\left(\left\lfloor 1 + \frac{t + \tau_s}{T_s} \right\rfloor, \left\lfloor 1 + \frac{t}{T} \right\rfloor\right)$$

Observe that if t is greater than or equal to the MBS * T, then the first term of the above equation applies; otherwise, the second term applies.
Note that the maximum conforming burst size, defined above, does not imply that bursts of this size with arbitrary spacing between the bursts would be conforming with the GCRA(T_s, τ_s). Rather, in order for a burst this large to be conforming, the cell stream needs to be idle long enough for the state of the GCRA associated with SCR to become zero (i.e., long enough for the continuous-state leaky bucket to become empty) prior to the burst.
If an end-system chooses to specify a value for the SCR and BT traffic parameters and wishes to emit conforming bursts at the peak rate, then the appropriate choice of T_s and τ_s depends on the minimum spacing between bursts as well as the burst size. For a cell flow of an ATM connection, if the minimum spacing between bursts at the equivalent-terminal is T_I and if the MBS (with inter-cell spacing T) is B, then the cell flow is conforming with GCRA(T_s, τ_s), if T_s, τ_s are chosen at least large enough to satisfy the following equation:

$$B = 1 + \left\lfloor \frac{\min(T_I - T_S, \tau_S)}{T_S - T} \right\rfloor$$

where $\lfloor x \rfloor$ stands for the integer part of x.

The traffic pattern conforming with the GCRA(T_s, τ_s) is in general not unique. Two traffic patterns are equivalent in relationship with the GCRA(T_s, τ_s) if they both conform at the PHY_SAP with the GCRA(T_s, τ_s) within the equivalent-terminal. Therefore, any cell stream that complies with the GCRA(T, 0) and GCRA(T_s, τ_s) at the PHY_SAP has a PCR = 1/T, a mean cell rate which is bounded by $1/T_s$ and a burst length which is bounded by B. Note that the bounds 1/Ts and B are achievable. For example, a periodic cell stream with period B * T_s which transmits B cells at the peak rate with inter burst spacing T_I = B * (T_s - T) + T has PCR= 1/T, mean cell rate SCR=1/Ts and burst length B, and is compliant with both GCRAs.

C.4.1 Relationship of CDVT, SCR and BT

ATM layer functions (e.g., cell multiplexing) may alter the characteristics of a connection's cell flow between the equivalent-terminal and the public or private UNI. Thus, as with the PCR, some tolerance for CDV may need to be considered in order that cells conforming to the GCRA(T_s, τ_s) at the equivalent-terminal are also conforming at the public UNI.

It can be shown that if an end-system emits cells such that the emission epochs are conforming with GCRA(T_s, τ_s) and if the cells pass through a customer premises ATM network that introduces a random delay, but which is within the interval [d_{min}, d_{max}], then all cells arriving at the public UNI are conforming with GCRA(T_s, $\tau_s + d_{max} - d_{min}$). Thus if τ, the CDVT parameter for the PCR is chosen to be $d_{max} - d_{min}$ (or is chosen to be a small quantile, e.g., 10^{-9}, of the possible delay variation), then τ could be used for the CDVT for the SCR as well. Note that although an end-system may choose to select the CDVT from the set of values supported by the network to be greater than or equal to $d_{max} - d_{min}$, there is no requirement to do so.

In analogy with the PCR, the criterion for conformance to the SCR and the BT is specified at the UNI (both public and private). At the public UNI, the criterion for conformance is specified in terms of GCRA with the arguments T_s and $\tau_s + \tau$, GCRA(T_s, $\tau_s + \tau$).

With regard to conformance to the SCR at the public UNI, note that conformance depends on τ_s and on τ only via their sum. Thus, the constraint of a common CDVT τ for both PCR and SCR is not unduly restrictive as an end-system still has freedom in the choice of τ_s (by the choice of MBS), and thus can choose τ_s so that $\tau_s + \tau$ has the desired value. However, note that a negative consequence of choosing τ_s dependent on τ is that it violates the modeling principle that traffic parameters in the source traffic descriptor are chosen based solely on the characteristics of the source and do not consider the equipment and traffic between the source and the UNI. For example, PCR is a traffic parameter, but CDVT is not a traffic parameter. Thus, although BT is defined herein as a traffic parameter, if the end-system chooses its value based on factors besides the source traffic, then the modeling principle for source traffic descriptors is violated.

Also note that to apply the equations for "MBS", "N(t)" and "B" in the previous section to burst sizes at the public UNI, as opposed to at the equivalent-terminal, one simply needs to replace the "τ_s" with "$\tau_s + \tau$."

The text in this section is also applicable to the private UNI, one simply needs to replace τ with τ^*.

Informative Appendix I: Implementation Examples on ABR Service Category

I.1 Example End-System Pseudocode

The following pseudocode provides an example of conforming behavior for the source end system (SES) and destination end system (DES). It represents a minimal but complete implementation of the specified end system behavior. This pseudocode also applies to the virtual source and virtual destination behaviors, as when segmented rate control is used by an intermediate network. This pseudocode example is provided for a single source connection. It assumes, but does not detail, a cell scheduler mechanism that controls the cell emissions from the SES. For simplicity of example, it also assumes that only out-of-rate forward RM-cells will be sent when ACR < TCR.

The behavior of the SES is controlled by the values assigned to a set of parameters. PCR, MCR, and ICR, are in units of cells per unit time, and RIF is dimensionless. RDF, CDF and Nrm are dimensionless. PCR and MCR are agreed upon at connection setup time. ICR, RIF, RDF, CDF and Nrm are established by the network(s) at connection setup time, with values that are determined to best optimize performance over various network trade-offs. Values for these parameters observe the following constraints:

```
MCR <= ICR <= PCR
MCR <= ACR <= PCR
0 <= CCR <= min(ACR, LCR)
```

where CCR is the current cell rate, reflecting the user's offered traffic. Generally, but not necessarily, CCR will equal either ACR or 0, as the source either has or doesn't have traffic to send. LCR is the cell rate due to the physical line limitation. In this pseudocode the parameter "MCR" may be utilized to represent:

a) A NIC implementation limit, due to a lower bound on the integer precision, e.g., 1 cell/second,
b) A (low) value gratuitously offered by the network to provide improved performance, or
c) A means to support a contracted or guaranteed "MCR".

Each of the following parameters is assigned a value as a result of connection setup:

ICR, PCR, MCR, RIF, RDF, Nrm, Mrm, CRM, CDF, Trm, TCR, and ADTF.

In this section a "!" to the right of a pseudocode statement is the start of a comment. In the comments, "Sn" refers to source behavior #n, and "Dm" refers to destination behavior #m. Each connection has a few variables for its operation:

<u>SES Variables (Per connection)</u>

ACR	Allowed Cell Rate
count	Number of cells sent (all kinds) since the last forward RM-cell
unack	Number of forward RM-cells sent without an RM received
time-to-send	The time scheduled to send the next cell (in-rate)
last-RM	The time that the most recent RM was sent
turn-around	A flag indicating there is an RM-cell to turn-around
first-turn	A flag indicating the (first) turn-around RM has priority over data cells
CI-VC	A flag indicating the EFCI bit was set on the previous data cell

Per-connection Initialization

```
   ACR =            ICR
   count =          Nrm
   CI-VC =          unack = 0
   last-RM =        now - Nrm/ICR
   turn-around =    false
   first-turn =         true
   TDF =            TDFF/RDF * 2^Round-up[log2(PCR)]
```

End-System Pseudocode - Send

```
if cell-enters-empty-queue-event                        ! external event
   if time-to-send not scheduled
      schedule:  time-to-send = now                     ! activate scheduler


if now >= time-to-send  and                             ! scheduled event
      (data-in-queue or turn-around)                    ! something to send?
   if ACR < TCR        ! ACR is low:  send only FRMs out-of-rate at TCR
      send RM(DIR=forward, CCR=ACR, ER=PCR, CI=0, NI=0, CLP=1)         ! S13
      schedule:  time-to-send = now + 1/TCR              ! S11 (out-of-rate)

   else {              ! ACR >= TCR:  send  RM/data  cells in-rate
      if (count >= Nrm) or ((count > Mrm) and (now >= last-RM + Trm))  ! S3a
          time = now - last-RM
          if time > ADTF and ACR > ICR                   ! ACR is too high
              ACR = ICR                                  ! S5a: idle adjust
          if (unack >= CRM)
              ACR =  ACR - ACR*CDF                       ! S6
              ACR = max(ACR, MCR)
          send RM(DIR=forward,CCR=ACR,ER=PCR,CI=0,NI=0, CLP=0)   ! S4,S7,S10
          count = 0
          last-RM = now
          first-turn = true                              ! S3bi
          unack = unack + 1
      elseif turn-around and (first-turn or not data-in-queue) ! in-rate RMs
          CI-TA =  CI-TA or CI-VC
          send RM(DIR=backward,CCR-TA,ER-TA,MCR-TA,CI-TA,NI-TA,CLP=0)   ! D2
          CI-VC = 0
          turn-around = first-turn = false
      else
          send data cell (CLP=0, EFCI=0)                 ! S3c,S4,S14

      count = count + 1
      schedule:  time-to-send = now + 1/ACR              ! S1,S7 (in-rate)
      }
```

End-System Pseudocode - Receive

```
if receive data cell                                          ! D1
       CI-VC = EFCI state of cell


if receive RM(DIR=backward, CCR, ER, CI, NI, BN)              ! S8:  adjust ACR
       if  CI=1
           ACR = ACR - ACR*RDF                                ! do MD
       else if NI=0                                           ! S5b
           ACR = ACR + RIF*PCR                                ! do AI
           ACR = min(ACR, PCR)
       ACR = min(ACR, ER)                                     ! S9
       ACR = max(ACR, MCR)                                    ! S9
       if BN=0 then unack = 0                                 ! S6
       if time-to-send > (now + 1/ACR) then                   ! see Note 1
          reschedule:  time-to-send = now + 1/ACR             ! see Note 1


if receive RM(DIR=forward, CCR, ER, MCR, CI, NI)             ! D2: turn it around
       if turn-around                                      !S12(optional behavior)
              CI-TA =  CI-TA or CI-VC
              send RM(DIR=backward, CCR-TA, ER-TA, MCR-TA, CI-TA, NI-TA, CLP=1)
              CI-VC =  0
       CCR-TA= CCR;  ER-TA= ER;  MCR-TA= MCR;  CI-TA= CI;  NI-TA= NI     ! D3
       turn-around = true
       if time-to-send not scheduled                    ! D2 (required behavior)
              schedule: time-to-send = now              ! activate scheduler
```

Note 1: These two code lines represent optional behavior wherein a scheduled cell may be rescheduled to take advantage of an increase in ACR.

The ABR conformance definition in Section 4.5.5 includes tolerances τ_1, τ_2, and τ_3 to departures from the idealized ABR behavior in which successive cells from a connection are always spaced at intervals 1/ACR and the forward cell flow is instantaneously affected by backward feedback. Below is an example of the first stage of a two-stage scheduler, where the first stage determines the earliest cell compliance time at the interface to the ABR source/destination that is consistent with a tolerance of TOL and the second stage resolves local congestion due to contention for bandwidth at this interface. It is consistent with the ABR conformance definition from Section 4.5.5 when the parameter τ_1 for the interface to the ABR source destination exceeds the sum of TOL and the variable delay (if any) at the second stage of the scheduler for the forward connection. The parameter TOL is implementation specific but should not exceed TBE/PCR.

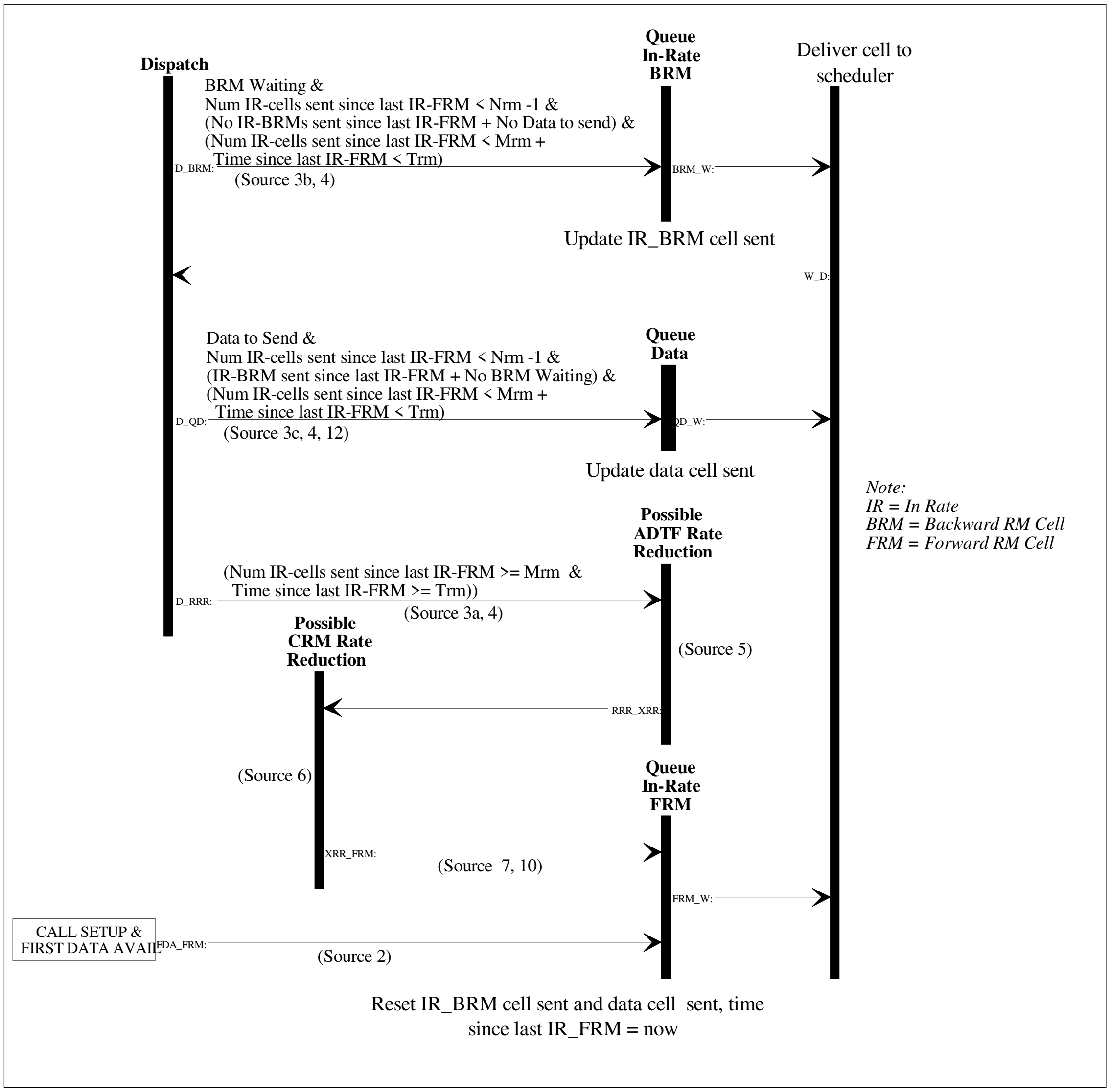
```
(begin pseudocode)
TAT=now                    !initialize Theoretical Arrival Time
last_rm=now-Nrm/ICR

if cell_enters_empty_queue_event  !data cell or turned-around RM
                                                  !presented to the ABR source
    enqueue cell
    schedule: time_to_send=max(TAT, now)

if now >= time_to_send
    while (cell_in_queue and now >= TAT - TOL)
        (A) set virtual_time = max (TAT, now)
        (B) determine the type of cell to be sent (forward RM, backward RM,
             or data) by applying source behavior #3 as if the current
            time were equal to virtual_time and the time when the previous
            forward RM-cell was sent were equal to last_RM.
         (C) if the cell to be sent is a forward RM-cell,
                 (i) determine whether a decrease in the ACR is required
```

```
                by applying source behaviors #5 and #6 as if the current
                time were equal to virtual_time and the time when the
                previous forward RM-cell was sent were equalto last_rm.
           (ii) set last_rm=virtual_time
    (D) update ACR if necessary as specified by source behavior #7
        and send the cell as specified by source behaviors #4, #7,
        #10, and #12 to the second stage of the scheduler.
    (E) TAT =virtual_time + 1/ACR
            if (cell_in_queue)
                   schedule: time_to_send= TAT
            else
                   schedule: time_to_send=INFINITY

        if receive RM(DIR=backward, CCR, ER, CI, NI, BN)
                   update ACR following source behaviors #8 and #9.

(end pseudocode)
```

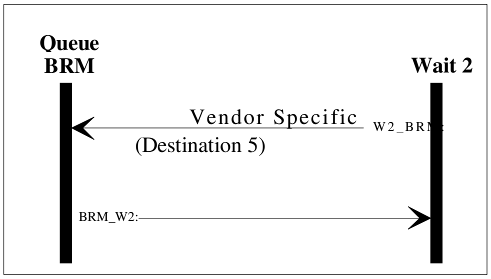
When TOL=0, the above is equivalent to the ideal source behavior in Section 5.10.4 for sending in-rate cells. If TOL>0, then the "while" loop in the above is entered at most once every TOL units of time, as long as cells are in queue. The while loop thus schedules cells in batches, where these batches are separated by a time TOL as long as there are cells to send. One result is that backward RM-cells will change the ACR only during the intervals between these batches. This introduces a lag of up to TOL from when a backward RM-cell is received by the source/destination to when the information in this backward RM-cells affects the scheduling. This lag is consistent with having τ_2 > TOL.

I.2 State Machine

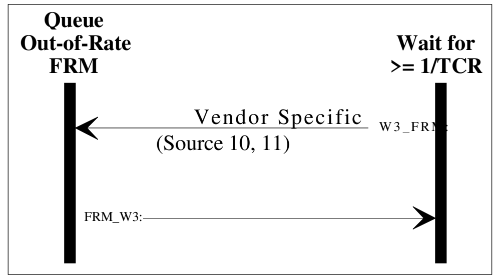
The four ABR service model State Machines are shown below. State Machine 1 controls the generation of Data cells as well as in-rate forward and backward RM-cells. This State Machine follows all of the behaviors specified in Sections 5.10.4 and 5.10.5. State machines 2 and 3 show the non-standard generation of RM-cells. The exact implementation of these state machines is implementation specific. Forward out-of-rate RM-cells are limited only by TCR. Backward RM-cells are limited by Destination behavior #5 (10 cells/seconds) and the number of forward RM-cells received. State machine 4 controls operation during reception of backward RM-cells. It should be noted that the Source and Destination textual behavior descriptions should take precedence in case of discrepancy.



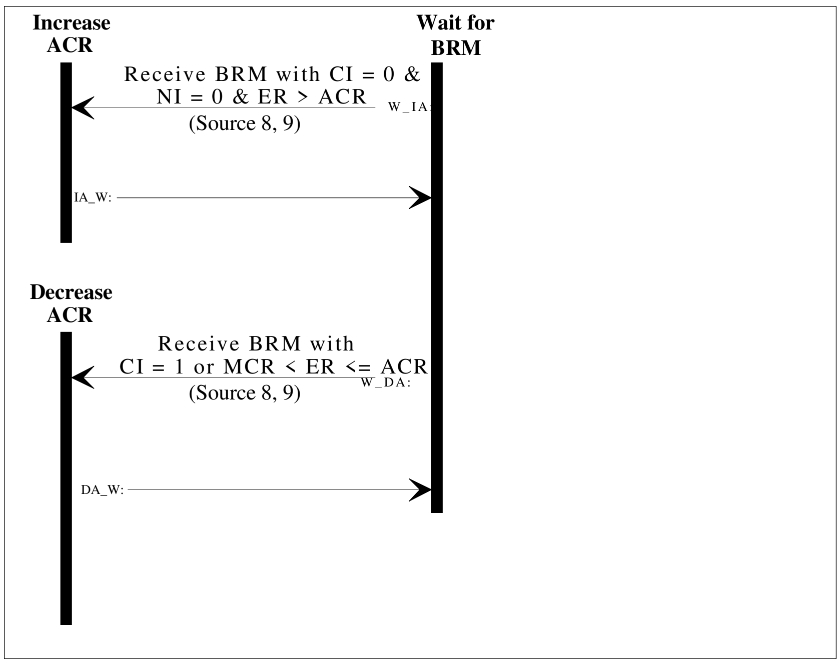
Generation of In-Rate Cells (Data, Forward and Backward RM-
(State Machine #1)



Destination Generated Backward RM (BN=1) (State Machine #2)



Source Out-of-Rate Forward RM Generatic (State Machine #3)



Backward RM Reception (State Machine #4)

I.3 Example Fairness Criteria

Define the following parameters:

A =	Total available bandwidth for all ABR connections on a given link.
U =	Sum of bandwidth of connections bottlenecked elsewhere (including those limited by PCR).
B =	A-U, bandwidth to be shared by connections bottlenecked on this link.
N =	Total number of active connections.
N' =	Number of active connections bottlenecked elsewhere.
n =	N-N', number of active connections bottlenecked on this link.
M =	Sum of MCRs of active connections within **n**.
B(i) =	Fair allocation for connection **i**.
MCR(i) =	MCR of connection **i**.

The following are the example fairness criteria for the given link.

1. Max-Min
   The available bandwidth B is equally shared among n connections which are bottlenecked at the link.

B(i)=B/n.
Comments: This criterion only applies to the case where all connections are unweighted (or equally weighted) and with zero-MCR.

2. MCR plus equal share
The bandwidth allocation for a connection is its MCR plus equal share of the bandwidth B with used MCR removed.
B(i)=MCR(i)+(B-M)/n.
Comments: The criterion converges to Max-Min criteria as all MCRs approach zero. To achieve this criterion, the switch may need to use ACR-MCR to compute the fair share.
3. Maximum of MCR or Max-Min share
The bandwidth allocation for a connection is its MCR or Max-Min share, which ever is larger.
B(i)=max(MCR(i), Max-Min share).
Comments: This criterion also converges to Max-Min criterion as all MCRs approach zero. The bandwidth allocation according to this criterion may need long iteration time to converge to the equilibrium point.
4. Allocation proportional to MCR
The bandwidth allocation for a connection is weighted proportional to its MCR.
B(i)=B*(MCR(i)/M).
Comments: This criterion does not apply if there are connections with zero MCR.
5. Weighted allocation
The bandwidth allocation for connection i is proportional to its pre-determined weight, w(i).
B(i)=B*(w(i)/sum w(j)).
Comments: The Max-Min criterion is a special case with all connections having equal weight. The weight may be defined independent of MCR or dependent on MCR (e.g., option 4 is with weight proportional to MCR).

I.4 MCR characteristics

This appendix provides a rationale for MCR, and explains its implications on networks and applications. Also see the pseudocode (Appendix I.1, above) for an implementation example.

Field of application

In the ABR service category, the ACR available to the application varies with network load. There may be some value of ACR below which the performance of the application degenerates. For example,

- protocol liveness may require that protocol control information be sent at some minimum rate;
- some applications may become intolerable to users if they are unable to send at least at some minimum rate;
- applications that need to run to completion within a period of time (e.g., an overnight disk backup that has to be completed by morning), will miss their deadline if they cannot transmit at least at some minimum rate.

For such applications, the concept of MCR is defined.

Some applications will have no way to determine an appropriate value of MCR, and MCR will not always be needed or wanted by applications or users. In particular, networks may have economic, administrative or other disincentives to specifying an MCR greater than 0.

The Internet concept of an elastic service does not include a MCR. The ABR service category is intended to meet the requirements of the elastic service definition when MCR=0.

In some applications, it may be possible for users to control MCR, even if an MCR is not inherent in the design of the application.

Definition of MCR

Minimum Cell Rate (MCR) is a rate negotiated between the end-systems and the network(s), such that the actual cell rate sent by the end-system on the ABR connection need never be less than MCR. MCR is negotiated independently for both directions of transfer on a bidirectional ATM connection.

MCR is negotiated between the end-systems and the network(s) using the connection control signaling procedures. The MCR agreed between the end-systems and the network(s) carrying the connection may range from 0 to the maximum value supported by the network(s). This maximum may be 0. If the calling end-system does not indicate a requested MCR, the default value of MCR is 0.

In the negotiation procedures specified in the signaling protocol, the calling end-system specifies a “requested MCR” and a “smallest acceptable MCR” (MCRmin of Section 5.10.2.2). The MCR value indicated when the connection is offered to the called end-system(s) will be either the “requested MCR”, or, if that value is not available, a value between the “requested MCR” and the “smallest acceptable MCR”. If the network(s) cannot offer at least the “smallest acceptable MCR”, the connection attempt is blocked. Thus, by specifying a “smallest acceptable MCR” greater than 0 (i.e., a “floor” on the negotiation), the calling end-system accepts a risk that the connection will be blocked. Blocking in preference to unacceptable performance may be preferred by some applications and/or users.

The option of negotiating an MCR does not imply that ABR is intended to be a real-time service.

If an MCR > 0 is negotiated for the connection, the end-systems may transmit at any rate up to the greater of MCR and ACR. There is no obligation that end-systems transmit at a rate of at least MCR.

Implications for network resource allocation

Policy for resource allocation within networks and network elements is implementation specific subject to the constraint that these policies not preclude the network from meeting the ABR service objectives. Specifically, end-systems are not to be expected to reduce their ACR to less than MCR in order to meet the cell loss ratio objective.

Implications on connection admission control (CAC) and routing

Networks and network elements which offer MCR>0 need to incorporate reservation of MCR resources into their CAC functions in order to meet ABR service objectives. This implies blocking of connection attempts when the “smallest acceptable MCR” is greater than the resources that the network or network element can reserve for MCR.

During a connection establishment attempt for a connection that does not request MCR, or for which “smallest acceptable MCR” = 0, the CAC function will not block the connection attempt because of bandwidth (including MCR) allocated to other connections. Blocking due to CAC for other reasons is not precluded.

I.5 Example Switch Mechanisms

The following is a high level description of the switch mechanisms that were considered and in some cases simulated by various members of the traffic management working group. While general comments can be made about the relative merits of these various mechanisms detailed performance characteristics depend on the exact source and destination behavior used. The various switch mechanisms can be classified broadly depending on the congestion monitoring criteria used and the feedback mechanism employed. The feedback mechanisms have been typically either binary or calculating the explicit rate and sending this information to the source through the RM-cell.

I.5.1 Binary Feedback Schemes

The switches perform two important functions: a) Detect incipient congestion and b) provide binary feedback to the source. The simplest example of a binary feedback mechanism is based on the old DECbit scheme and was described as part of the original proposal for an end-to-end rate based traffic control scheme. In this scheme all the VCs share a common FIFO and the queue length is monitored by setting a threshold T. When the queue length exceeds the threshold congestion is declared and the cells passing through the queue have their EFCI bit set. When the queue length falls below the threshold the cells are passed without their EFCI bits set. In variations of this mechanism two thresholds can be used, a high threshold THigh, and a low threshold TLow. Typically as the queue increases past the low threshold and crosses the high threshold, THigh, congestion is declared and the cells passing through the queue have their EFCI bits set. When the queue starts emptying, the condition of congestion is not removed until the queue falls below the low threshold.

Binary feedback schemes where all the connections may share a common FIFO may sometimes suffer from unfairness problems depending on the network topology and the source and destination behavior employed. Given the same level of congestion at all the switches connections traveling more hops have a higher probability of having their EFCI bits set than those traveling a smaller number of hops. Depending on the source and destination behavior employed these long hop connections get very few opportunities to increase their rate and consequently their throughputs are starved giving rise to what has been called the “beat down problem”.

Potential unfairness problems in binary feedback schemes where all the VCs share a common FIFO can be alleviated by some enhancements to the basic scheme. The simplest enhancement is to provide separate FIFOs for each VC or groups of VCs. This generally results in ensuring fairness among different VCs. Another enhancement is to provide selective feedback or intelligent marking. In this scheme a switch computes a “fair share” and if congested sets EFCI bits in cells belonging to only those VCs whose current rates are above the fair share. Examples of ways that a switch can compute the “fair share” are presented in the following sections on explicit rate feedback.

I.5.2 Explicit Rate Feedback Schemes

The switches perform three important functions:

1. Compute the fair share of the bandwidth for a VC that can be supported.
2. Determine the load. (e.g., This can be done by either monitoring the queue length or the queue growth rate).
3. Determine the actual explicit rate and send this information to the source.

Examples of explicit rate switch mechanisms are the Enhanced Proportional Rate Control Algorithm (EPRCA) and two congestion avoidance algorithms.

Note: some of the following ER switch mechanisms assume that the information in the forward RM-cell is correct. If the sources are not well behaving (e.g., they insert incorrect information) or the flow has been reshaped when passing through a switch then switches using these methods base their feedback on uncertain information. This may lead to a decrease in fairness and even to increased cell loss.

I.5.2.1 EPRCA

This scheme was considered as an enhancement to the Proportional Rate Control Algorithm where the source sends RM-cells at a rate proportional to its current rate. The RM-cells sent by the source contain a desired explicit rate (ER), the current cell rate usually set to the allowed cell rate (ACR) and the congestion indication bit CI set to zero. The switch computes a mean allowed cell rate for all VCs (MACR) using a running exponential weighted average. MACR is computed by MACR = $(1-\alpha)$ MACR + α CCR, where α is generally chosen to be 1/16, weights the MACR more than the current CCR. The switch monitors its load by keeping track of the queue length. When the RM-cell returns from the destination the switch reduces the ER field if it is in a state of congestion. In this scheme the fair share was computed to be a fraction 7/8 of the MACR. If the value in the ER field is less than the fair share no adjustments are made. On the other hand if the value is higher and the switch is in a congested state the value is lowered to its fair share.

I.5.2.2 Congestion Avoidance Schemes

In this scheme the rate of change of queue length is used as a load indicator. The load factor is defined as z = Input rate/Target rate. The input rate is measured over a fixed averaging interval and the target rate is set slightly below the link bandwidth, e.g., 85-90%. There are two variations of this scheme that differ in the algorithm used to compute the fair share or explicit rate based on the load factor.

I.5.2.3 ERICA

ERICA (Explicit Rate Indication for Congestion Avoidance) tries to maintain the network at a load z close to one. In its simplest form, it calculates two quantities: fairshare, and this VC's share:

Fairshare = Target capacity / Number of active connections

VCshare = CCR / z.

Here CCR is the current cell rate field in the RM-cell which contains ACR declared by the source (or as measured by the switch). This scheme achieves fairness concurrently with efficiency by using the following formula to compute the explicit rate (ER):

ER = Max (Fairshare, VCshare).

The above quantities are measured periodically using information from the forward RM-cells, and the feedback is given in the backward RM-cells. This ensures that the most current information is used to provide fastest feedback. The measurement interval is independent of the rate at which the sources send RM-cells. For each interval, no more than one new explicit rate value is advertised per VC. This avoids conflicting feedback to sources due to stale information at the switches. The scheme has few parameters which can be easily tuned. There are a few other variations of this scheme.

I.5.2.4 Congestion Avoidance using Proportional Control (CAPC)

Again as in the previous scheme the target utilization is set to be slightly less than one, and the load factor is computed. The load factor is used to update the fair share which is computed differently depending on whether z<1 or z>1. During underload, the fair share is increased by the formula Fair share = Fair share * Min(ERU, 1+(1-z)*Rup). Rup is a slope parameter between 0.025 and 0.1 and ERU determines the maximum increase allowed in the allotment of fair share. When z>1, the fair share is decreased according to Fair share = Fair share * Max(ERF, 1- (z-1)*Rdn) where Rdn is between 0.2 and 0.8 and ERF set to 0.5 determines the maximum decrease in the fair share.

I.5.2.5 ER based on bandwidth Demand Estimate Algorithm

The Mean Allowed Cell Rate (MACR) computed at the switch is based on a running exponential average of the ACR value read from each VC's forward RM-cells. MACR is given by MACR = MACR + (ACR - MACR) * AVF (e.g., AVF = 1/16). If the load factor (LF = Input Rate/Target Rate) is < 1, the leftover bandwidth is reallocated according to MACR = MACR + MAIR, where MAIR is the MACR Additive Increase Rate (e.g., MAIR = .5 Mbps). A positive queue derivative indicates an increasing bandwidth demand that causes the switch to enter a congestion state, The ER value computed is then ER = MACR * MRF (e.g., MRF = .95), if the switch has detected congestion. Otherwise, ER = MACR.

I.5.3 Reactive Switch Behavior

A reactive switch can be used to partially segment an ABR control loop. It assumes an ER mode of switch operation. The objective of using reactive switches is to take advantage of short control loops to reduce reaction time to congestion and limit buffer requirements, without implementing full VSVD behavior. It requires dynamic shaping of traffic on a per-connection basis.

The rules of RS operation are:

- An RS assumes the behaviors of an ABR switch as specified in Section 5.10.6
- An RS monitors backward RM-cells in order to extract the content of the ER field
- An RS may never transmit cells of a particular connection at a rate greater than that specified in the ER field of the last received backward RM-cell for that connection.

I.6 Generic Negotiating Behavior

This informative appendix describes how signaling negotiates traffic contract and QoS parameters. Requirements on ABR control parameters are different, and are described in Section 5.10.2.1. It is intended to provide an overview of the negotiation process for the user of this specification, and only generic behaviors are provided. Specific procedures and encodings are provided in the UNI signaling and PNNI signaling specifications; the BICI 2.0 specification does not include negotiation, which is planned to be included in future versions.

I.6.1 Overview of Generic Negotiating Behavior

The purpose of the negotiation is to select a value of each parameter that can both be provided by the network and meets the needs of both end-systems. Since call establishment is accomplished in one round trip (two relevant messages), negotiation must be tied to a single round trip exchange. At the highest level, the calling end-system proposes a requested value and an acceptable value. The network tries to meet the requested value, or at least some value between the requested and acceptable value, and if it can't meet the acceptable value, it clears the call. Otherwise, it offers the call to the called end-system with the better of the requested value and the best value it can support. In some cases, the signaling protocol does not explicitly support signaling for a desired value.

I.6.2 Details of Generic Negotiating Behavior

The protocol specifies a range of values for the parameter. Typically, the range is integer valued (although real or enumerated types are possible). In some cases, the range may be a choice of two (or more) discrete values. One end of the range is designated as the “most desirable” value, and the other is the “least desirable” value. If the most desirable value is greater than the least desirable, the negotiation proceeds downwards, i.e., decreases in value. Otherwise, negotiation is upwards, i.e., increases in value. For example, a high cell rate is considered more desirable than a lower one, and negotiation proceeds downwards, while a low CTD is more desirable than a higher one, so CTD negotiation proceeds upwards. The protocol also determines whether the objective of the negotiation is to "meet" or to "meet or exceed" the parameter value indicated by the calling end-system. If the objective is to meet the value, it is usually because the parameter relates to a resource (e.g., bandwidth) that can be divided with relatively fine granularity among calls, with a penalty to the network attached to giving a greater value to the connection than that indicated. If the objective is to meet or exceed, the network may have alternative values available not necessarily over a continuous range, and can't benefit from giving the connection exactly the value indicated rather than the next most desirable value. For example, peak cell rate is a "meet" parameter, since it can be divided fairly precisely among connections; if there is 10 Mbit/s of capacity available, and the connection needs 3 Mbit/s, then that quantity will be assigned (ignoring for the present imprecision and "fudge factors" present in real implementations), and the remainder will be available for other connections. Delay is a "meet or exceed" parameter; if a connection needs 50 ms, and routes are available that offer 20, 40 and 60 ms, respectively, then the 20 ms or the 40 ms route will be selected (all other things being equal), and there will be no reason to pad the delay out to 50 ms.

A parameter is characterized as either a "metric" or an "attribute". A metric is a parameter that requires the contribution of each topological component (i.e., link or node) to be accumulated to determine the value of the parameter for the connection. An attribute considers each topological component individually, such that the least desirable contribution of one or more links constitutes the parameter value for the connection. For example, delay is a metric, while peak cell rate is an attribute. In general, path calculation is facilitated by minimizing the number of metrics that can apply to the connection.

Note that these definitions are consistent with, but not identical to, those in the PNNI specification.

Behavior	CLR	maxCTD	CDV
Direction	Up (Note 1)	Up	Up
Meet/Meet or Exceed	Meet/Exceed	Meet/Exceed	Meet/Exceed
Attribute or Metric	Attribute	Metric	Metric
Accumulation Algorithm	N/A	see Section 3.6.2	see Section 3.6.2
Called end-system may select less desirable value	no	no	no

Note 1: The negotiation refers to the actual value of the parameter, and not to its encoding. For example, if CLR = 10^{-x}, the value of the CLR parameter may be represented as x. Therefore negotiating the CLR upwards implies that the actual value of x decreases

Table I-1: Application of generic negotiating procedures to QoS parameters

I.6.3 Description of Generic Negotiation Algorithm

This section provides a high level description of the procedures for generic negotiation. Specific, detailed procedures and message formats are described in the signalling and PNNI specifications. These procedures are not supported in BICI 2.0, but are expected to be in future versions of the BICI specification.

The negotiation for each parameter operates as follows:

1. In the initial call establishment message, the calling end-system may indicates a "requested" value, which is the value of the parameter that it would like to have, and also indicates either a "highest acceptable value" (for upward negotiation) or a "lowest acceptable value" (for downward negotiation). The latter value is, respectively, the highest or lowest value of the parameter that the calling end-system is willing to accept; that is, it would rather the call be rejected than to have it completed with a higher or lower value, respectively. If the requested value is not specified (either because the calling end system chooses not to include it, or because it is not supported in the signaling protocol), it is assumed to be the same as the highest or lowest acceptable value.
2. The switch serving the calling end-system makes a preliminary determination as to whether it can meet the requested, or at least the highest or lowest acceptable value for the parameter. This might, for example, involve 'sanity checking', tests against administrative limits or path computation. If the network cannot satisfy at least the highest or lowest acceptable value, it rejects the call. These

determinations may also be made at administrative boundaries between networks (e.g., at BICI interfaces, interfaces between public and private networks or PNNI border nodes).

3. If the parameter is an attribute, the network node interface carries an “indicated” value of the parameter, in addition to the requested and lowest or highest acceptable value. If the parameter is a metric, the network node interface carries a “cumulative” value of the parameter, in addition to the requested and lowest or highest acceptable value. The accumulation function is part of the specific negotiating behavior for the parameter, and also applies to path computation.
4. Each successive switching system determines an outgoing link over which it will progress the call, and determines the value of each parameter that applies to that link. For “meet” parameters, it selects the appropriate value for the parameter. For 'meet or exceed' parameters, it might or might not have a choice among several values, and if so, it selects one according to implementation specific criteria.
   a) If the parameter is an attribute, the value of the parameter that applies to the outgoing link is compared with the lowest or highest acceptable value in the initial call establishment message.
      i) If it is less desirable than highest or lowest acceptable value (i.e., higher than the highest acceptable value or lower than the lowest acceptable value, whichever applies), the call is cleared (or crankback occurs).
      ii) If it is less desirable than the indicated value carried in the incoming initial call establishment message received from a preceeding switching system, or if the initial call establishment message was received from an end-system, then the indicated value carried in the outgoing initial call establishment is set to the value that applies to the outgoing link.
   b) If the parameter is a metric, the accumulation function is applied to value of the parameter that applies to the outgoing link and the cumulative parameter value in the incoming initial call establishment message, resulting in the new cumulative value. If the new cumulative value is less desirable than highest or lowest acceptable value (whichever applies), the call is rejected (or crankback occurs). The new cumulative value is carried in the outgoing initial call establishment message.
   c) The call is progressed to the next switching system or the called end-system.
5. When the initial call establishment message is received at the called end-system, it contains the requested, either highest or lowest acceptable, and either indicated or cumulative values of the parameter. The called end-system determines whether or not the value is acceptable, and either accepts or rejects the call. For some negotiations (e.g., PCR), where the parameter value affects resources in the called end- system, called end-system may select a less desirable value for the parameter, as long as it is not less desirable than the highest or lowest acceptable value. In this case, the call connected message sent by the called end-system contains the agreed value, which is always between the indicated or cumulative value and the highest or lowest acceptable value contained in the received initial call establishment message.
6. The call connected message progressed through the network, and the call connected message sent to the calling end-system contains the agreed value, which applies for the duration of the call (absent protocol specifications for renegotiation).

I.7 Turning RM-Cells Around

I.7.1 Introduction

The purpose of this section is to explain the behavior of the various allowed possibilities of turning around received forward RM-cells as specified in destination behavior #3.

Destination Behavior #3 states:

If a forward RM-cell is received by the destination while another turned-around RM-cell (on the same VC) 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 overwritten) 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

Given that behavior #3b specifies 3 options of what to do with the old waiting cell, and behavior #3a specifies 2 options of what the contents of the old waiting cell can be, there are a total of 6 possibilities represented by destination behavior #3.

However, if the old cell is discarded (the second option of #3b), it makes no difference whether its contents were overwritten or not. As a result, there are really only 5 possibilities for the relationship between newly received forward RM-cells and previously received forward RM-cells that are awaiting in-rate transmission.

These 5 possibilities are:

1. The newly arrived cell's contents are sent as an out-of-rate backward RM-cell in addition to being scheduled for in-rate transmission. (This follows recommendations of behaviors #3a and #3b.)
2. The old cell's contents are sent as an out-of-rate backward RM-cell and the newly arrived cell is scheduled for in-rate transmission. (This follows the recommendation of #3b but does not follow the recommendation of behavior #3a.)
3. The newly arrived cell is scheduled for in-rate transmission and the old cell is dropped. (This follows the discard alternative of #3b. It makes no difference whether the recommendation of #3a was followed or not.)
4. Two copies of the newly arrived cell are scheduled for in-rate transmission. (This follows the recommendation of #3a and follows the "remain scheduled" alternative of behavior #3b.)
5. Both the old cell and the newly arrived cell are scheduled for in-rate transmission. (This does not follow the recommendation of behavior #3a and follows the "remain scheduled" alternative of behavior #3b.)

These 5 possibilities will be referred to as options 1 - 5 throughout the rest of this section.

The first part of this section discusses options 1, 2, and 3. Options 4 and 5 are "queuing" options and will be discussed later in the section.

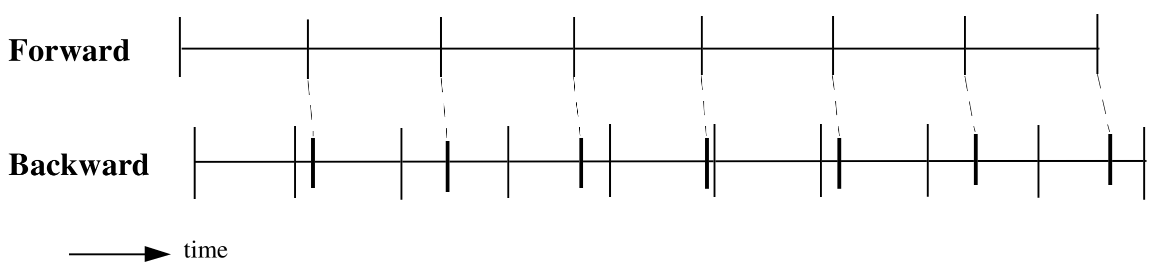
I.7.2 Behavior of the Non-Queuing Options

This section discusses and compares the behavior of options 1, 2, and 3. The behaviors are explored over the range of forward bandwidth (ACRfwd) and backward bandwidth (ACRbck). The specific cases discussed are ACRbck > ACRfwd, ACRfwd > ACRbck, ACRfwd >> ACRbck, and ACRbck= 0.

I.7.2.1 ACRbck > ACRfwd

A diagram showing the case where the backward ACR is greater than the forward ACR is shown in the following figure:

All Options



Vertical lines represent RM-cells. Longest lines are forward RM-cells. Middle length lines are in rate backward RM-cells. Shortest lines are out of rate backward RM-cells. All vertical lines on the forward links represent forward RM-cells.

In this illustration, RM-cell flow in both the forward and backward direction is illustrated. Time flows from left to right. Vertical lines represent RM-cells (data cells are not represented). The length of the vertical lines determines the type of RM-cell. Longest lines are the forward RM-cells, middle length lines are the in-rate backward RM-cells, and the shortest vertical lines are the out-of-rate backward RM-cells. Note that only forward RM-cells are shown in the forward cell flow but both forward and backward RM-cells are shown in the backward cell flow. The above illustration contains only forward RM-cells and in-rate backward RM-cells. Out-of-rate backward RM-cells are represented in later illustrations.

In addition, dotted and dashed lines are used to show which received forward RM-cell's contents became which backward RM-cell. To help differentiate (in the absence of color) between in-rate and out-of-rate backward RM-cells, dashed lines are used to show a forward RM-cell's contents that became an in-rate backward RM-cell and dotted lines are used to show a forward RM-cell's contents that became an out-of-rate backward RM-cell.

In this specific case where the ACR of the backward direction is greater than the ACR of the forward direction, it is obvious that all backward RM-cells will be sent in-rate with all three options. Source Behavior #3 will allow for the backward RM-cell to be sent at the next available cell time in the backward direction with all three options, and, therefore, the behavior of all three options will be the same.

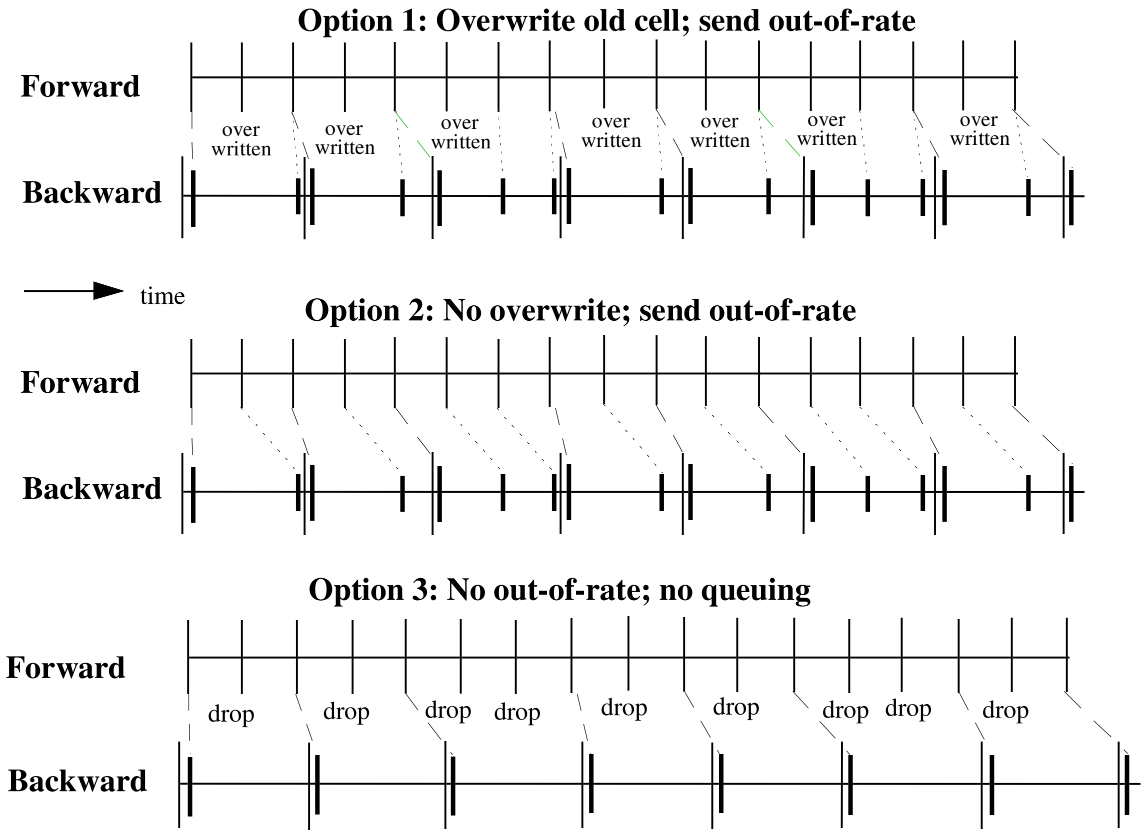
The case where ACRbck > ACRfwd is the ideal case for in-rate backward RM-cells.

I.7.2.2 ACRfwd > ACRbck

As the backward ACR becomes lower than the forward ACR, differences begin to emerge in the operation of the different optional behaviors. The following diagram shows the behavior of each of the option combinations when the backward ACR is less than the forward ACR (but not tremendously less).

Before contrasting the differences in the 3 options, it is important to discuss their similarities. One of the most important properties of destination Behavior #3 is the assurance that in-rate backward RM-cells will be transmitted as often as possible given the frequency of received forward RM-cells and source behavior #3. When the ACR in the forward direction is greater than the ACR in the backward direction, every possible chance to send in-rate backward RM-cells should be taken. The requirement of destination behavior #3c insures that this will be true. All 3 of the options above reflect the fact that an in-rate backward RM-cell is sent at every opportunity (according to source behavior #3).

Now, contrast the operation of options 1 and 2 above. The difference between the two options is that option 1 overwrites the old cell before transmitting it out-of-rate (therefore transmitting the newly arrived cell's contents out-of-rate) and option 2 does not. Both options schedule the newly arrived cell for in-rate backward RM-cell transmission.



Vertical lines represent RM-cells. Longest lines are forward RM-cells. Middle length lines represent in-rate backward RM-cells. Shortest lines are out-of-rate backward RM-cells. All vertical lines on the forward links represent forward RM-cells.

The frequency and spacing of both in-rate and out-of-rate backward RM-cells are the same with both options. The difference is that option 1 always transmits the latest information in out-of-rate backward RM-cells and option 2 does not.

The ramifications of old vs. new information in backward RM-cells will now be further explored.

It is advantageous to transmit the latest RM-cell data in the presence of explicit rate switches that modify the explicit rate field in the forward direction or that monitor the CCR field of the RM-cell (in either the forward or the backward direction). Also, out-of-rate backward RM-cells may not be able to be transmitted immediately because of higher priority traffic (CBR or VBR). If the out-of-rate backward RM-cell is different than the awaiting in-rate backward RM-cell, there will need to be storage capability for 2 backward RM-cells per VC. These are some of the reasons behind the recommendation of behavior #3a which leads to option 1.

However, option 1 has a characteristic that needs to be examined. Option 1 has the possibility of duplicating the contents between an out-of-rate backward RM-cell and the next in-rate backward RM-cell. In fact, whenever there are out-of-rate backward RM-cells with option 1, the next in-rate backward RM-cell will be a duplicate (except for the CI bit) of the last out-of-rate backward RM-cell. This duplication is illustrated in the above figure.

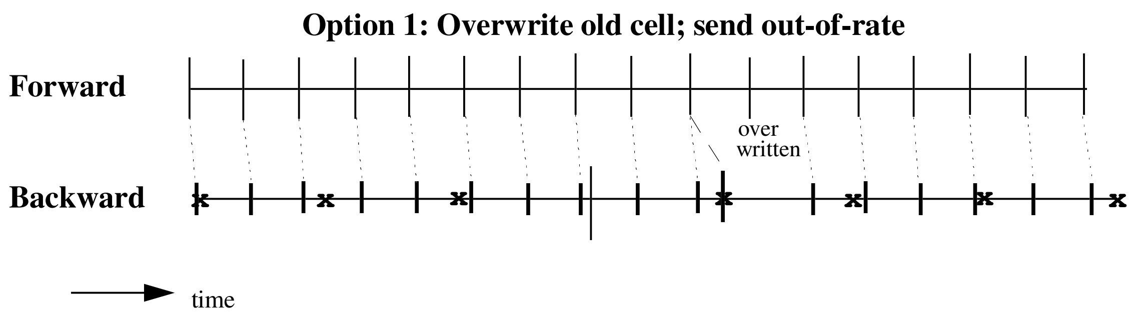
The reality is that this duplication has no adverse effect on ABR operation. In the case of explicit rate switches, it simply means that the explicit rate and the current cell rates of backward RM-cells will always be the latest that are available. In the case of binary mode switches, if the CI bit is set as the backward RM-cell is being transmitted (as preferred from destination behavior #2b), then the backward RM-cell always carries the latest EFCI state.

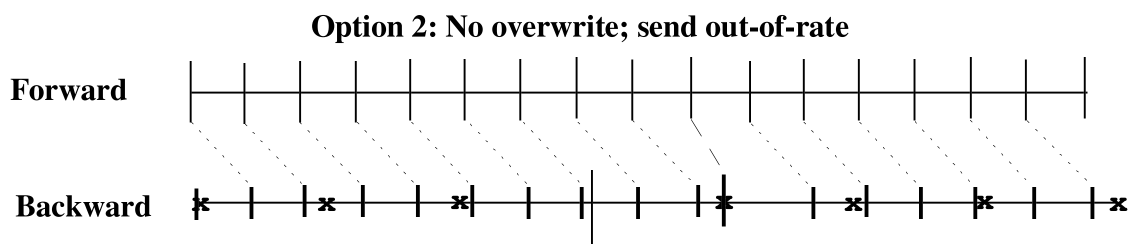
Since the duplication has no effects on either explicit mode or binary mode networks, since there are definite advantages to carrying the latest information in backward RM-cells, and since there are implementation advantages in the end stations if only a single RM-cell's contents needs to be saved, option 1 is recommended over option 2.

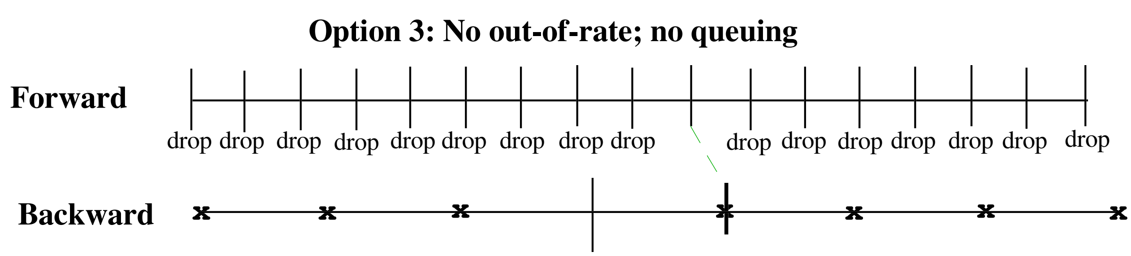
Option 3 does not support out-of-rate backward RM-cells at all. It can be seen in the figure that, as the backward ACR falls below the forward ACR, received forward RM-cells begin to be dropped and the number of backward RM-cells begins to drop well below the number of received forward RM-cells. The responsiveness of the forward ACR control loop will be lessened by the decrease in frequency of backward RM-cells.

I.7.2.3 ACRfwd >> ACRbck

Now, the behavior when the forward ACR is much larger than the backward ACR is explored. The following diagram illustrates the different option combinations under this condition.







Vertical lines represent RM-cells. Longest lines are forward RM-cells. Middle length lines represent in-rate backward RM-cells. Shortest lines are out-of-rate backward RM-cells. All vertical lines on the forward links represent forward RM-cells.

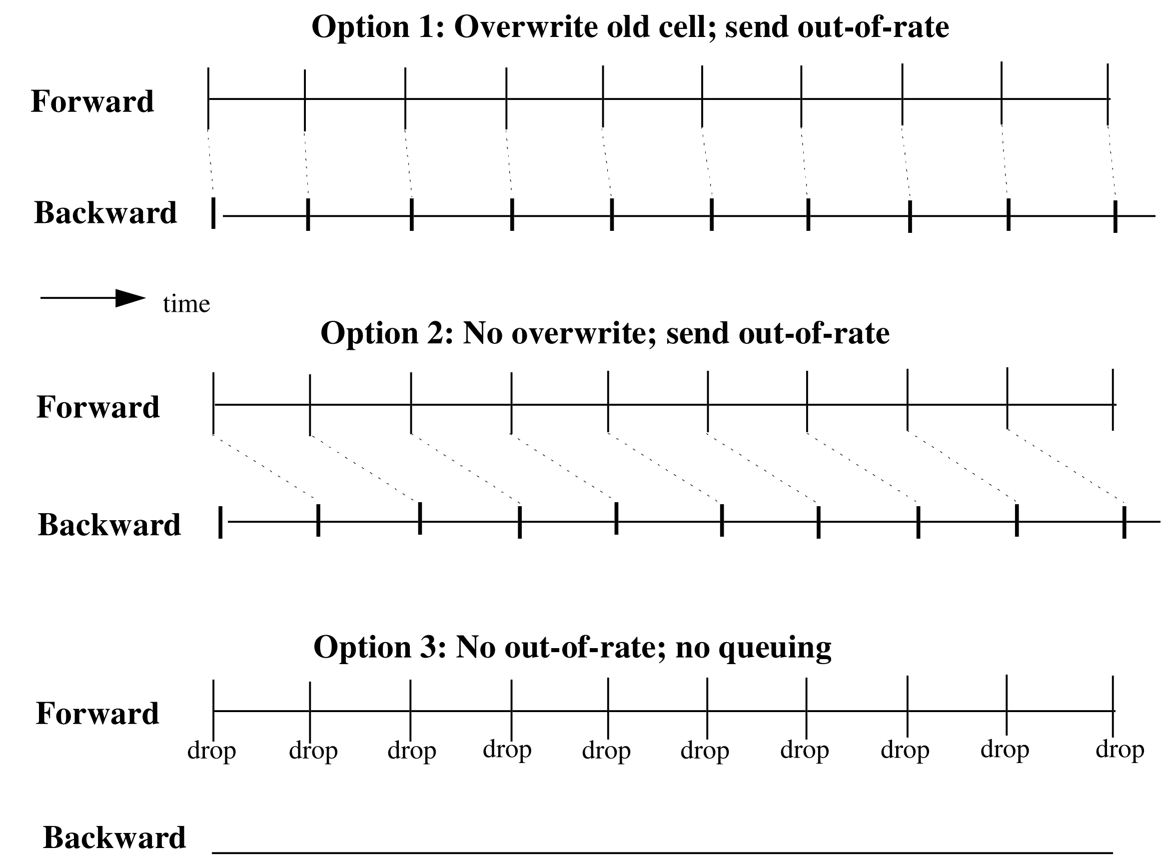
In this case, the rate of forward RM-cells is greater than the cell rate in the backward direction. Notice now that individual in-rate cell opportunities are shown in the backward channel representations. In-rate cell opportunities are represented as x's.

Once again, options 1 and 2 produce the same frequency and spacing of both in-rate and out-of-rate backward RM-cells. Again, with both options, the total number of backward RM-cells (both in-rate and out-of-rate) equals the number of received forward RM-cells.

Option 3 drops most of the received forward RM-cells. With the very limited number of in-rate backward RM-cells in this case, the responsiveness of the forward direction ACR control loop may be very limited.

I.7.3 ACRbck = 0

The analysis continues with the backward ACR dropping all the way to zero. The following diagram shows the behavior of all option combinations with this case.



In this case, since there are no in-rate slots in the backward direction, both option 1 and option 2 send nothing but out-of-rate backward RM-cells. The only difference between these two options is in the latency of the out-of-rate backward RM-cell's contents. Option 1 transmits the newly arrived forward RM-cell's contents as the out-of-rate backward RM-cell and option 2 transmits the old forward RM-cell's contents as the out-of-rate backward RM-cell.

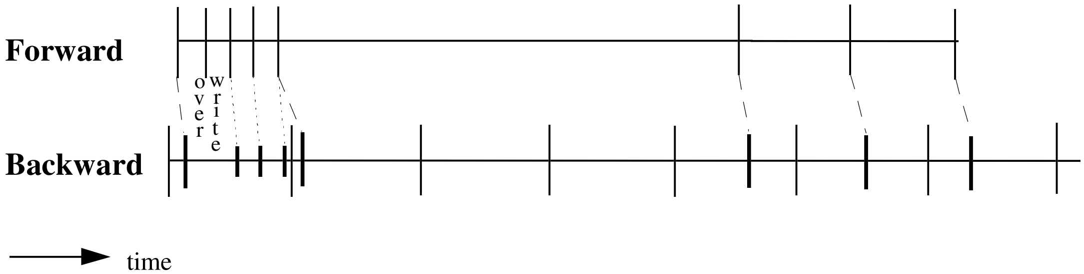
Notice that there are no backward RM-cells at all in option 3. There are no in-rate cell slots and option 3 does not implement out-of-rate backward RM-cells. Any end station implementing option 3 for backward RM-cell handling cannot operate in a situation where the backward ACR is 0. There must be sufficient MCR in the backward direction to allow for enough in-rate backward RM-cells to effectively implement the forward ACR control loop.

I.7.4 Behavior of the Queuing Options

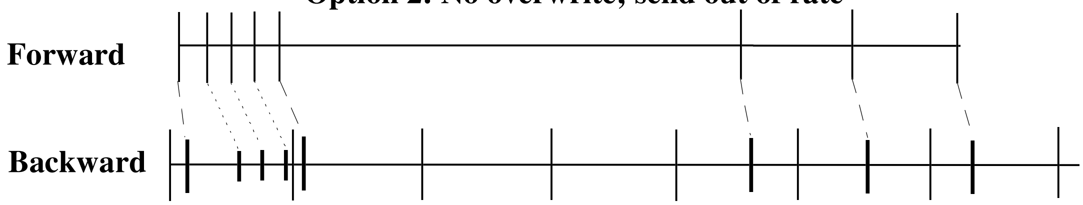
Options 4 and 5 from Section I.7.1 represent queuing options for in-rate backward RM-cells.

A queue for in-rate backward RM-cells is in order if there is a desire to handle a situation where clumping of forward RM-cells occurs. A queue allows for the received clumped RM-cells to be sent in successive in-rate backward RM-cell slots. Without a queue, much of the clump of received RM-cells will be transmitted as out-of-rate backward RM-cells. An illustration of a case where the forward and backward ACRs are equal and a clump of forward RM-cells is received is shown in the following figure.

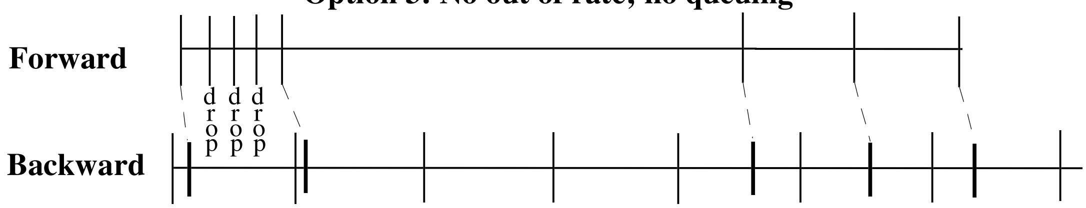
Option 1: Overwrite old cell; send out-of-rate



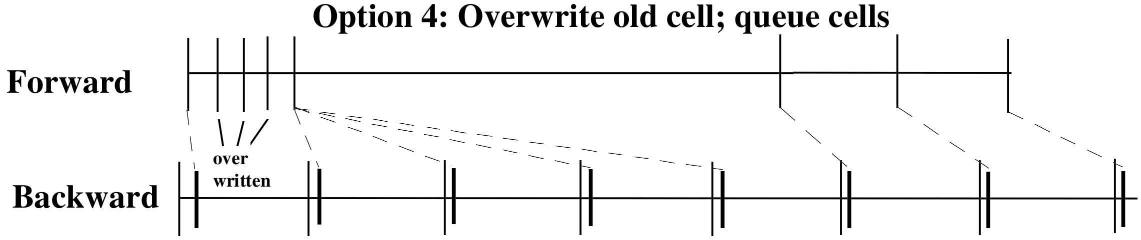
Option 2: No overwrite; send out of rate



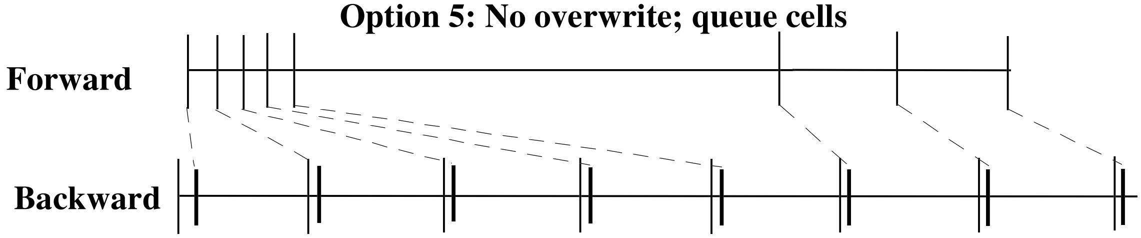
Option 3: No out of rate; no queuing



Option 4: Overwrite old cell; queue cells



Option 5: No overwrite; queue cells



Notice that the difference between options 4 and option 5 is that option 4 always uses the latest received forward RM-cell's contents while option 5 keeps the older RM-cells' contents in the queue. The queue of option 4 could be implemented with a counter along with a single RM-cell storage area. Option 5 requires a storage area for each of the queued RM-cells.

It is also important to discuss what will happen in a queued backward RM-cell implementation when the queue fills. Recall that a queue may be desired to handle the situation where clumping of forward RM-cells has occurred in the network. However, a queue does nothing to handle the situation where the forward ACR is larger than the backward ACR. In this case, the queue will fill.

When the queue fills, the implementation can use either option 1, option 2, or option 3 to handle subsequently received forward RM-cells.

Using option 3 to handle queue overflow is simple to comprehend. When a forward RM-cell is received and the queue is full, the head of the queue will be discarded and the newly received forward RM-cell will be added to the tail of the queue. This works whether the queue was implemented with option 4 or option 5.

Using option 2 to handle queue overflow is also simple to comprehend. When a forward RM-cell is received and the queue is full, the head of the queue will be sent as an out-of-rate backward RM-cell and the newly received forward RM-cell will be added to the tail of the queue. Again, this works whether the queue was implemented with option 4 or option 5.

A little care must be taken in using option 1 to handle queue overflow. Recall that option 1 sends the contents of the newly arrived forward RM-cell as an out-of-rate backward RM-cell in addition to queuing it for in-rate backward RM-cell transmission. If the backward RM-cell queue is implemented using option 5 (where old cells are not overwritten with the contents of the newly arrived cell), then all cells in the queue would need to be flushed if the newest forward RM-cell was sent as an in-rate backward RM-cell (see destination behavior #4). If the backward RM-cell queue is implemented using option 4, then there is no problem.

I.7.5 Summary

The advantage of using one of the queuing options (option 4 or option 5) is that network clumping of forward RM-cells can be handled more elegantly. The disadvantage to using one of the queuing options (besides the increase in complexity) is that there will be a longer time before an out-of-rate backward RM-cell is transmitted when the backward ACR becomes smaller than the forward ACR. The queue must fill before an out-of-rate backward RM-cell will be sent. (If the destination does not wait for the queue to fill, there is the possibility of transmitting more backward RM-cells than received forward RM-cells.)

If a non-queued turn-around RM-cell implementation is desired, the recommendations of destination behavior #3 imply that option 1 of this section is the desired mode of operation in turning around received forward RM-cells. It has the properties of always transmitting the latest RM data, always using available in-rate backward RM-cell slots, making full use of allowed out-of-rate backward RM-cell possibilities, and allowing for only one set of backward RM-cell contents to be stored awaiting transmission by the destination.

Option 2 is the second more desirable of the non-queued options since it implements the recommendation of behavior #3b but not of behavior #3a. Option 3 is the least desirable of the 3 non-queued options.

Of the queued RM-cell implementations, option 4 is the most desired mode of operation. It implements the recommendation of behavior #3a which allows for only the latest RM-cell information to be transmitted. It can also be simpler to implement than option 5. If the queue implemented in option 4 overflows, the recommended procedure is to follow the recommendations of behavior #3a and #3b and send the contents of the newly arrived RM-cell as an out-of-rate backward RM-cell while keeping it scheduled for in-rate transmission.

I.8 End-System Congestion and Optional Use-it-or-lose-it Behavior

Situations will arise where an ABR end-system will not be able to send cells as fast as the ACR allows. This could be due to application or end-system architecture constraints, such as contention for access to a disk. Another possible cause is local scheduler congestion, which occurs when the sum of ACRs to be scheduled exceeds the link rate. Use-it-or-lose-it behavior reduces the ACR assigned to a connection if that connection is transmitting significantly below its ACR. The objective of use-it-or-lose-it behavior is to ensure that ACR is maintained reasonably close to the real cell transmission rate.

Although the source may choose to support use-it-or-lose-it behavior to help protect the switches, it is the responsibility of the switches to support QoS objectives for ABR connections that conform to the mandatory ABR behaviors.

Use-it-or-lose-it behavior may be beneficial in the following circumstances:

- Temporarily rate limited sources may jump to their acquired ACR at any time, causing an unexpected step increase in the arrival rate at switches on its path. These kind of jumps occur as contention for application or scheduler resources fluctuates. Use-it-or-lose-it behavior can reduce these transient fluctuations in traffic load. For networks with binary switches it can reduce the control lag experienced after transitions from underload to overload. Keeping ACR close to the real rate reduces the number of CI=1 RM-cells required to reduce ACR by an amount sufficient enough to control the actual cell transmission rate.

Note however, that by reducing ACR, use-it-or-lose-it behavior can reduce the performance of request response applications. In addition, sources implementing use-it-or-lose-it behavior may be at a fairness disadvantage with respect to sources that do not implement use-it-or-lose-it behavior.

The means by which use-it-or-lose-it behavior is achieved is implementation specific. Some example methods include:

- End-system method 1: forward RM-cell triggered
  When an in-rate forward RM-cell is sent, if the ACR exceeds the recent transmission rate plus a fixed bound, the ACR is reduced by a multiplicative factor and the next increase inhibited. Specifically the recent rate R, could be estimated by Nrm divided by the time since the last in-rate forward RM-cell was sent. If ACR exceeds R+ICR, the ACR could be set to the higher of ACR*15/16 and R+ICR, and the next increase inhibited.
- End-system method 2: backward RM triggered
  When a backward RM is received, the ACR increases are limited such that the resulting ACR it is not significantly greater than the recent transmission rate R. Specifically the received ER could be reduced to R+ICR.
- End-system method 3: Internal congestion algorithm
  The end-system might run an implementation specific switch algorithm internal to the end-system that reacts to internal scheduler congestion. To work effectively the scheduler must be able to schedule cells faster than the outgoing link rate. This kind of method does not respond to application level congestion, but does respond to scheduler congestion.
- Switch based:
  The use-it-or-lose-it can also be implemented in a switch which monitors each connections cell transmission rate and sends explicit rate messages to hold ACR within some implementation specific bound.

Informative Appendix II: Conformance Examples in a Traffic Contract

II.1 Introduction

In the traffic contract, the Cell Delay Variation tolerance specified at the UNI is defined in relation to the PCR by the GCRA and the BT specified at the UNI is defined in relation to the SCR also by the GCRA. Additionally, a conformance definition that defines the combination of GCRAs in relation to the different cell streams and cell rates of a connection at the UNI is also specified in the traffic contract. Depending upon the services provided, different conformance definitions could be specified. In this appendix, a few examples are given for information purposes.

For each example described herein, the service needs are summarized and then followed with a conformance definition that *could* be used to accommodate the service needs. Specifically, the examples illustrate how one can emulate the traffic definitions of various services by appropriately mapping them into parameters of various GCRAs. The specific conformance definition used is for illustrative purposes. Figures are also provided in the form of block diagrams to depict how various GCRAs interact with each other. Two functional blocks are used to represent the high level flowchart of a GCRA(I, L) algorithm and are labeled by C(I) and U(I):

1. Conformance Checking Functional Block:

$$\boxed{C(I)}$$

2. Update Functional Block:

$$\boxed{U(I)}$$

The conformance checking functional block represents functions performed in order to determine whether a cell is conforming or not. The update functional block represents the update function performed if a cell is identified as conforming. Note that the only purpose of the block diagrams are to test conformance to the traffic descriptors as defined by the conformance definition. The conformance definitions indicated in these examples should not be interpreted as the UPC algorithms. Hence, non-conformance does not imply a discard or tagging decision.

II.2 Example 1: Switched Multi-megabit Data Service (SMDS)

SMDS allows customers to send bursts at the full access link rate (e.g., DS3 PLCP). To control the sustainable information rate, an I_{inc}, a N_{inc}, and a C_{max} are specified. I_{inc} is the interval (in 53-octet slot times) between increments to the credit. N_{inc} is the number of credits (in user information octets) increase per increment. I_{inc} and N_{inc} together determine a maximum sustainable information rate. C_{max} is the maximum credits that can be accrued. C_{max} is 9188 octets for all access classes. An arriving message will be discarded, if the current accrued credits are less than the estimated user information length.

For an ATM connection supporting the above SMDS application, the following conformance definition (VBR.1, see Section 4.5.2.1) in relation to a source traffic descriptor that specifies the PCR for the CLP=0 cell stream and SCR for the CLP=0+1 cell stream *could* be specified in the traffic contract *if a proper minimum user information length that the SMDS user could submit is imposed*:

For an ATM connection supporting the above SMDS application, the following conformance definition (VBR.1) *could* be specified in the traffic contract:

1. One GCRA(T_{0+1}, CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream.

2. One GCRA(T_{S0+1}, BT_{0+1}+ CDVT) defining the sum of the BT and CDVT in relation to the SCR of the CLP=0 cell stream.

A cell that is conforming to both GCRAs (1) and (2) above is said to be conforming to the connection traffic descriptor. The tagging option is not applicable to this conformance definition.

PCR could be chosen to emulate the original SMDS access line rate. The values of PCR and SCR should be chosen to include the extra margin required to accommodate the overhead introduced in transferring the user information via an ATM network in order to deliver an equivalent maximum sustainable information rate to the user. This overhead is closely related to the SMDS message length distribution.

The BT_{0+1} should be set to allow the maximum burst accepted in SMDS to be passed at the PCR.

Figure II-1 depicts this conformance definition in terms of the GCRA functional block diagrams.

Although traffic conformance at the UNI is defined by this definition, the network may use any UPC mechanism as long as the QoS objectives are met for compliant connections.

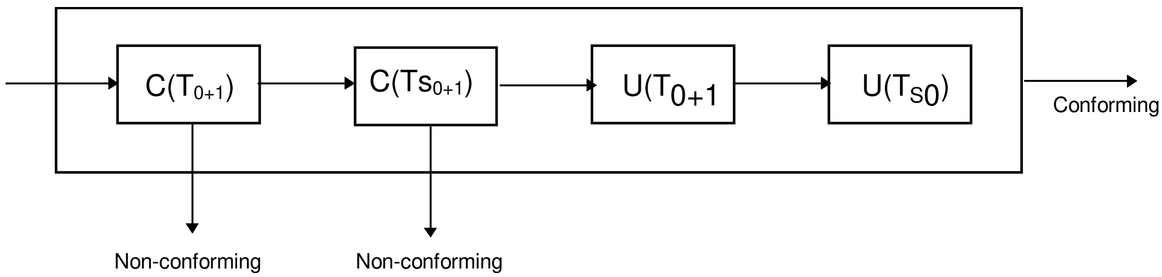


Figure II-1: Example 1

II.3 Example 2: Frame Relay Service (FRS)

FRS allows customers to send bursts at the full access link rate (e.g., DS1). To control the sustainable information rate, a B_c, a B_e, and a *CIR* are specified. The measurement interval *T* is derived and is equal to B_c/CIR. The excessive information rate (*EIR*) is also derived and is equal to B_e/T.

- When a frame with discard eligibility indication not set arrives,
    - a. if the current accrued credits for *CIR* is greater than or equal to the frame length, send the frame;
    - b. if the current accrued credits for *CIR* is less than the frame length, but the current accrued credits for *EIR* is greater than or equal to the frame length, the frame is sent with discard eligibility indication set;
    - c. if the current accrued credits for *CIR* is less than the frame length and the current accrued credits for *EIR* is also less than the frame length, the frame is discarded.
- When a frame with discard eligibility indication set arrives and,
    - a. if the current accrued credits for *EIR* is greater than or equal to the frame length, send the frame,
    - b. if the current accrued credits for *EIR* is less than the frame length, discard the frame.

The maximum number of credits that can be accrued for *CIR* is B_c. The maximum number of credits that can be accrued for *EIR* is B_e.

The intent of this section is to provide an example of the interworking of ATM and Frame Relay where the ATM connection is described by two GCRAs. The restriction to two GCRAs leads to a limitation in matching the ATM parameter to the *EIR* or the Frame Relay access line rate.

For an ATM connection supporting the above FRS application, the following conformance definition (VBR.3, see Section 4.5.2.3) in relation to a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream, SCR for the CLP=0 cell stream *could* be specified in the traffic contract *if a proper minimum frame length that the FRS user could submit is imposed.*

1. One GCRA(T_{0+1},CDVT) defining the CDVT in relation to the PCR of the aggregate CLP=0+1 cell stream.
2. One GCRA(T_{S0}, BT_0+CDVT) defining sum of the BT and CDVT in relation to the SCR of the CLP=0 cell stream.

A CLP=0 cell that is conforming to both GCRAs (1) and (2) above is said to be conforming to the connection traffic descriptor. A CLP=1 cell that is conforming to GCRA (1) above is said to be conforming to the connection traffic descriptor. A CLP=0 cell that is not conforming to GRCA (2) above but is conforming to GCRA (1) above is considered to have the CLP bit changed to 1 and said to be conforming to the connection traffic descriptor.

The values of PCR and SCRs should be chosen to include the extra margin required to accommodate the overhead introduced in transferring the FRS frames via an ATM network. When the PCR is chosen to emulate the FRS access line rate, the *EIR* that is allowed is the difference between the access line rate and the *CIR*. Therefore, the *EIR* that is allowed possibly exceeds the *EIR* negotiated for the FRS. However, using traffic shaping, the PCR may be chosen to be the higher of either the required value to achieve the Transfer Delay objectives, or the required value to achieve the sum of *CIR* and *EIR* to the user. The BT_0 should be set to allow the maximum committed burst accepted in FRS to be passed at the PCR.

Figure II-2 depicts this conformance definition in terms of the GCRA functional block diagrams. Although traffic conformance at the UNI is defined by this definition, the network may use any UPC mechanism as long as the QoS objectives are met for compliant connections.

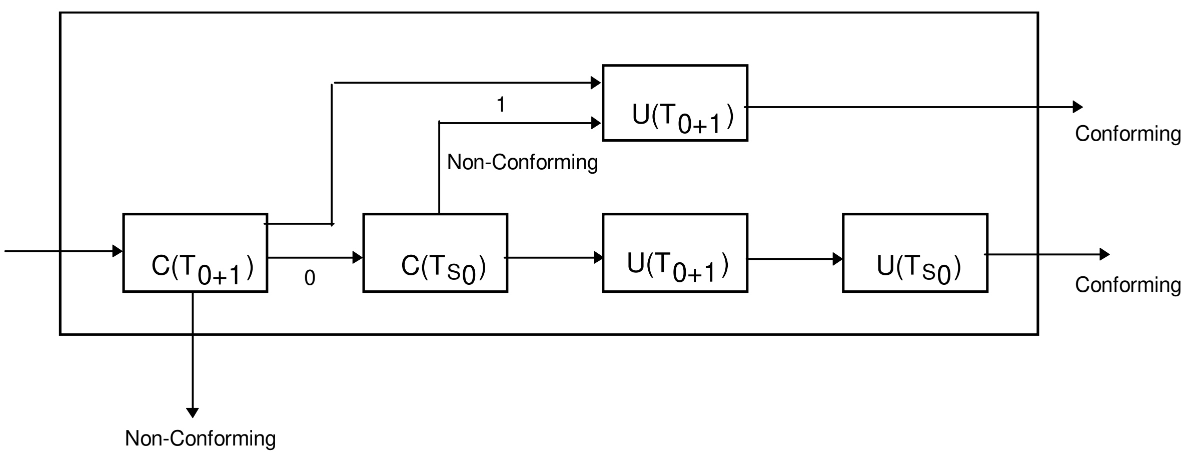


Figure II-2: Example 2

The conformance definition that defines the traffic descriptor can be such that cells that are not conforming with the CLP=0 SCR parameter set may or may not be submitted as CLP=1 cells through marking at the source. In this case the single CLP bit in the ATM header carries two meanings; one for user marked CLP=1 cells and the other for the tagged cells. The network (i.e., the switches) cannot distinguish between the two meanings. Therefore, the same QoS objectives are supported for both the user marked CLP=1 cells and the network tagged CLP=1 cells.

II.4 Example 3: Constant Bit Rate Services

For an ATM connection supporting a Constant Bit Rate service, the following definition (see Section 4.5.1)in relation to a source traffic descriptor that specifies PCR for the CLP=0+1 cell stream *could* be specified in the traffic contract:

1. One GCRA(T_{0+1},CDVT) defining the CDVT in relation to the PCR of the CLP=0+1 cell stream.

A cell that is conforming to this GCRA is said to be conforming to the connection traffic descriptor. PCR is chosen to emulate the constant bit rate of the service.
Figure II-3 depicts this conformance definition in terms of the GCRA functional block diagrams. Although traffic conformance at the UNI is defined by this definition, the network may use any UPC mechanism as long as the QoS objectives are met for compliant connections.

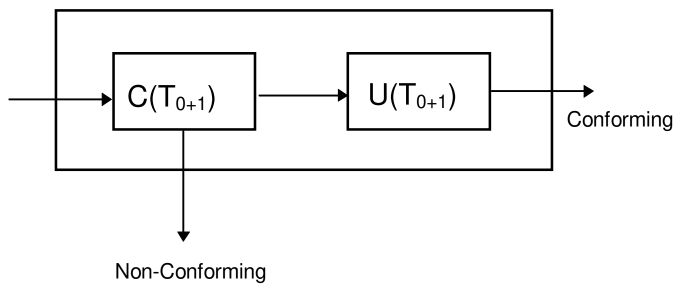


Figure II-3: Example 3

II.5 Example 4: LAN Interconnection

In applications such as LAN interconnection, multiple workstations on a LAN can send data over a public or private ATM WAN to other workstations in other LANs. These LANs can be interconnected through VPCs across the ATM backbone. In this example it is assumed that a VBR.3 VPC is used (see Section 4.5.2.3). In such applications, the user's packets typically have the same level of importance and therefore are submitted to the ATM network as CLP=0 cells (after being processed at the AAL). Since traffic from multiple workstations are multiplexed on a given VP, there may not be a traffic shaper on the user side of the UNI (this may particularly be the case at the private-UNI). In such applications, it is desirable for the network to tolerate some amount of non-conformance of the CLP=0 stream by tagging these non-conforming cells as CLP=1 cells. This allows the users not to be very pessimistic in their traffic description and therefore may avoid excessive "over-allocation" for bursty data applications.

Informative Appendix III: Examples of ABR conformance and compliance definitions

III.1 Dynamic GCRA: An Example of a Conformance Definition

The Dynamic GCRA (DGCRA), an extension of the GCRA algorithm, may be used to specify conformance to Explicit-Rate (ER) feedback at the public or private UNI, the Private NNI, or the BICI for the cell flow of an ABR connection. The DGCRA objectively defines ER-conformance on a cell-by-cell basis and thus establishes the number of ER-conforming cells on the connection over any specified interval. If ER-conformance is used by the network as the definition of conformance more generally, then the number of ER-conforming cells on a compliant connection is a lower bound on the number of cells for which QoS objectives should apply. In this way, the definition of ER-conformance can serve as a constraint on the design of UPC algorithms. It is not necessarily intended as a UPC algorithm itself.

The DGCRA differs from the GCRA defined in Section 4.4.2 primarily in that the increment I changes with time, as determined by ABR feedback information conveyed on the corresponding backward connection. The DGCRA checks the conformance of all CLP=0 cells on the ABR connection. The increment I may change on the arrival of any CLP=0 cell on the connection, and the increment calculated on the arrival of the k^{th} CLP=0 cell on the connection is denoted by $I(k)$. At the arrival time $t_a(k)$ of this k^{th} cell, the DGCRA algorithm first calculates $I(k)$ and then checks the cell's conformance and updates its own Last Virtual Scheduling Time *(LVST)* as follows:

Initialize: $LVST=t_a(1)$, $Iold=I(1)$.

At each arrival time $t_a(k)$ of a CLP=0 cell for $k \geq 2$,

- if $t_a(k) \geq LVST + \min(I(k),Iold) - \tau_1$, /*cell is conforming*/
  then set $LVST = \max(t_a(k), LVST + \min(I(k),Iold))$ and
  $Iold = I(k)$;
- otherwise /* cell is nonconforming*/
  do not update algorithm state.

The tolerance τ_1, which accommodates jitter or bursts, is a constant that does not depend on k. In the special case where $I(k)=I$ (a constant) for all k, the above algorithm is equivalent to GCRA(I, τ_1). The DGCRA accounts for the option of the source to reschedule the next cell transmitted on a connection when new feedback is received.

The selection of $I(k)$ depends on two additional delay parameters τ_2 and τ_3 for the connection. The interval $I(k)$ must satisfy the constraints that $I(0) = 1/ICR$ and that $1/PCR <= I(k) <= 1/MCR$ for $k \geq 1$, where MCR is the Minimum Cell Rate and PCR is the Peak Cell Rate for the connection. The DGCRA algorithm, with the parameters PCR, MCR, ICR, τ_1, τ_2, and τ_3, and is denoted by $DGCRA(MCR^{-1}, PCR^{-1}, ICR^{-1}, \tau_1, \tau_2, \tau_3)$.

The sequence $\{I(k), k \geq 1\}$ of increments, which are successively used at arrival times $\{t_a(k), k \geq 1\}$of CLP=0 cells at the interface, depends on the sequence $\{ER(j), j \geq 1\}$ of explicit rates sent across the interface at departure times $\{t_b(j), j \geq 1\}$of CLP=0 backward RM-cells on the backward connection. The DGCRA defers mapping increases in the sequence $\{ER(j)\}$ of explicit rates into the increments $\{I(k)\}$ until after a lag τ_3, and defers mapping decreases in $\{ER(j)\}$ into $\{I(k)\}$ until after a lag τ_2. This accommodates the behavior of a connection that requires at least a time τ_3 and at most a time $\tau_2 > \tau_3$ to affect the instructed changes in the rate at which cells arrive at the interface. In addition to checking the use by the source of explicit-rate feedback, the DGCRA also checks for consistency with the specified ABR source behavior under RM-return-failure conditions.

Two algorithms A and B for determining the increment I(k) are presented below. Algorithm A results in a tighter conformance test, but does so at the expense of needing to keep track (possibly via a linked list) of a potentially large number of scheduled changes to these increments over a moving interval of length τ_2 minus τ_3. Algorithm B is a simpler test where at most two scheduled changes need to be stored.

III.2 Algorithm A to Determine I(k)

Algorithm A uses the following algorithm to define the potential allowed cell rate $\{PACR(k),\ k \geq 1\}$ from which the increment $\{I(k),\ k \geq 1\}$ is derived by taking the inverse:

Initialize: $t_a(0) = 0$, *Ccount = 0*, $t_{ICR} = 0$, t_f = INFINITY

At each arrival time $t_a(k)$ of a CLP=0 cell for $k \geq 1$,

- if cell k is a forward RM-cell
    - if the previous arrival time t_f of a CLP=0 forward RM-cell satisfies

      $t_a(k) - t_f > ADTF + \tau_1$

        - set $t_{ICR} = t_a(k)$
    - set $t_f = t_a(k)$

- if the set of indices j of CLP=0 backward RM-cells such that $0 < t_b(j) \leq t_a(k) - \tau_2$ is non-empty with largest element j_{max}, then
    - if $t_b(j_{max}) < t_{ICR} - \tau_2$
        - set $PACR(k) = min\ (ER\ (j_{max}), \mathrm{ICR})$

      otherwise
        - set $PACR(k) = ER\ (j_{max})$,
    - if $t_b(j_{\max}) > t_a(k-1) - \tau_3$
        - *Ccount* = 0

  otherwise
    - set $PACR(k) = ICR$.

- if the set of indices j of CLP=0 backward RM-cells such that $t_a(k) - \tau_2 < t_b(j) \leq t_a(k) - \tau_3$ is non-empty, then
    - set $PACR(k) = max\ (PACR(k),\ ER_{max})$, where ER_{max} is the largest explicit rate $ER(j)$ for j in the set.
    - set *Ccount* = 0.

  otherwise, if cell k is a CLP=0 forward RM-cell, then
    - set *Ccount* = *Ccount* + 1.

- if *Ccount* > *Crm*, then
    - if cell k is a forward RM-cell,

      $PACR(k) = min(PACR(k-1)*(1-CDF), PACR(k)*(1-CDF))$

  otherwise

      $PACR(k) = PACR(k-1)$
- PACR(k) = min(PCR, max(MCR, PACR(k))).
- I(k) = 1 / PACR(k)

Remark: The following text motivates the above definitions of the DGCRA. For this text we assume that no cells are lost and that the source behaves according to the ABR source reference behavior.

The rate change induced by a backward RM-cell departing from the interface (on the backward connection) at time t_b should be observed on the forward connection at some later time t_a such that

$$t_b + \tau_3 \leq t_a \leq t_b + \tau_2$$

If a cell arrives on the forward connection at time t_a, one can conclude the following:

a) The rate change due to a backward cells that passed at times t_b such that

$$t_a \geq t_b + \tau_2$$

will have taken place at the interface by time t_a (second bullet item above). If there are such RM-cells, one takes the most recent one with the index j_{max} and uses the Explicit Rate (ER) contained in this cell as the rate to be controlled.

b) If a cell with index j_{max} has been identified, if the cell k is CLP=0 forward RM-cell, and if the previous forward CLP=0 RM-cell arrival time t_f satisfies $t_a(k) - t_f > ADTF + \tau_1$ one concludes that the reduction of ACR down to ICR (source behavior #5) has taken effect. If $t_b(j_{max}) < t_{ICR} - \tau_2$ then the decrease to ICR must have occurred at the source after backward RM-cell j_{max} reached the source. In that case, PACR(*k*) is possibly further reduced by replacing *ER* (j_{max}) with *min (ER* (j_{max})*, ICR)* (first and second bullet items above).
c) If no cell with index j_{max} can be identified, one takes ICR as the rate to be controlled.
d) At the arrival of a forward cell at time t_a, *Ccount* is a lower bound on the number of forward RM-cells that have left the source since the last backward RM-cell that it received (as in Source Behavior #6). Backward RM-cells transmitted from the interface to the source at time t_b such that

$$t_a < t_b + \tau_3$$

should not have been received by the source before it had transmitted the cell arriving at the interface at time t_a. Thus, if the forward cell *k-1* arrived at time t_a(k-1) such that

$$t_a(k-1) < t_b(j_{\max}) + \tau_3$$

then the forward cell *k-1* must have left the source before the backward RM-cell departing the interface at time $t_b(j_{max})$ arrived at the source. If forward cell *k* then arrives at the interface at time t_a(k) such that

$$t_a(k) \geq t_b(j_{\max}) + \tau_2$$

it is considered to be the first cell leaving the source after the arrival there of the RM-cell j_{max}, so that *Ccount* is set equal to zero in this case (second bullet from above).
e) Backward RM-cells that passed at times t_b such that

$$t_b + \tau_3 \leq t_a < t_b + \tau_2.$$

may also have an impact on the rate at time t_a. To be on the safe side, one takes the maximum of these rates. Then one takes the maximum of this rate and the rate derived from part a)-c) above as the rate to be controlled (second bullet item above).
f) If *Ccount > Crm* and cell *k* is a forward CLP=0 RM-cell, *PACR(k)* has to reduced by *CDF*PACR(k)* (source behavior #6). At the same time, *PACR(k)* should be at most equal to the PACR at the last forward RM-cell times *(1-CDF)*. But *PACR* at the last forward RM-cell is just *PACR(k-1)* since one sets *PACR(k)* to *PACR(k-1)* if the cell is not an RM-cell.

III.3 Algorithm B to Determine I(k)

Algorithm B, which follows, is a method to determine the increment I(k) for the DGCRA. The resulting conformance test is an approximation to the conformance test in Appendix III.2 in the following sense: At a forward CLP=0 cell arrival, the Potential Allowed Cell Rate (PACR) derived in the Algorithm B is greater than or equal to the PACR resulting from the conformance test in Appendix III.2. The proposed conformance algorithm meets the design constraints for an ABR conformance test stated in Section 4.5.5. Like Algorithm A, Algorithm B derives the PACR from the explicit rates ER(j) received in the backward RM-cells. A received backward RM-cell results in a delayed increase or a delayed decrease of PACR. Rate increases are scheduled with a delay of τ_3 or earlier. Rate decreases are scheduled with a delay of τ_2 or later.

For the sake of simplicity, at most two rate change events are scheduled: The first event is scheduled at time t_first with delayed explicit cell rate DER_first. The second (and last) event is scheduled at time t_last with DER_last. DER_last when scheduled is always a decrease in rate. Whether an explicit rate ER(j) results in a rate increase or rate decrease is determined by comparing ER(j) with DER_first and with PACR. If ER(j) is greater or equal to DER_first and PACR then a rate increase is scheduled. If ER(j) is smaller than DER_first then a rate decrease is scheduled.

If a rate increase has been scheduled for time t_first and this rate has not yet taken effect, then a further rate increase uses the same scheduled increase time t_first with a rate equal to the maximum of the old DER_first and ER(j). This further rate increase takes then effect with a delay less than τ_3 while the first increase scheduled for time t_first takes effect with delay τ_3. If the first rate change event is a rate decrease and this rate has not taken effect then a rate increase is scheduled for time t_first but not later than t_now

+ τ_3. If a decreased delayed cell rate has been scheduled, then a another further rate decrease is scheduled for time t_last = tb(j) + τ_2. Further rate decreases overwrite t_last until the first rate has taken effect.
The first part of the algorithm schedules rate increases or rate decreases after arrival of a backward RM-cell. The last part is used at the arrival of a CLP=0 cell in the forward direction to determine whether this cell is conforming. This is done by using an algorithm equivalent to the GCRA.
A return of the rate down to ICR is reflected in Algorithm B if the last CLP=0 backward RM-cell arrived at the source well before the return time to ICR (source behavior #5). In that case, the variable ICR_elegible is set equal to “TRUE” and only then can PACR be reduced down to ICR.
The following algorithm provides an approximate ABR conformance test:

```
Initialize:
   t_first = t_last = LVST = 0;
   t_f = INFINITY;
   ICR_elegible = FALSE;
   DER_first = DER_last = PACR = ICR;
   I_old = 1/ICR;

At each t_b(j) after a CLP=0 backward RM-cell departure with explicit rate
ER(j):
   ER(j)    = min(PCR, max(MCR, ER(j)));
   IF ER(j) ≥ DER_first     (* increase over first scheduled rate? *)
      THEN t_last     = 0;    (* un-schedule future decrease rate (if any))*)
           DER_first  = ER(j);    (* update scheduled rate *)
           DER_last   = ER(j);
           IF t_first < t_b(j)      (* no first rate scheduled? *)
              THEN t_first = t_b(j) + τ3;  (* schedule new increase *)
           IF ER(j)   ≥ PACR
              THEN t_first = min (t_first, t_b(j) + τ3);
                     (* reschedule if DER_first was decrease *)

   IF ER(j) < DER_first (* decrease over the current, first scheduled
                          increase? *)
      THEN t_last     = t_b(j) + τ2  (* schedule the time for the decrease *)
           DER_last   = ER(j)    (* schedule the decreased rate *)
           IF t_first < t_b(j) (* first event has taken place? *)
              THEN t_first = t_last;
                   DER_first = ER(j);
                            (*schedule first event like second event *)
   IF t_b(j) +τ2 < t_f + ADTF - τ1 (*cell arrives at source before a possible
                                     rate return down to ICR? *)
      THEN ICR_elegible = TRUE;
      ELSE ICR_elegible = FALSE;

When real time t reaches t_first:
   PACR      =  DER_first;
   t_first   =  t_last;
   DER_first = DER_last;

At arrival of a forward CLP=0 cell at time t_a(k):
   IF cell k is a CLP=0 forward RM-cell
      THEN IF t_a(k) - t_f > ADTF +τ1 and ICR_elegible=TRUE
              THEN PACR=min(PACR, ICR);
   t_f = t_a(k);
   ICR_elegible = FALSE;

   I(k) = 1/PACR

I' = min(I(k), I_old);      (* I' is an auxiliary increment variable *)
IF LVST + I' ≤ t_now + τ1    (* cell conforming? *)
THEN LVST = max (t_a(k), LVST + I');
```

```
     I_old = I(k);     (* cell conforming, update parameters *)
ELSE  ;                          (* cell not conforming *)
```

III.4 Measures of ABR RM-Cell Compliance: Examples

The source behavior in Section 5.10.4 and destination behavior in Section 5.10.5 state explicit conditions under which forward and backward RM-cells shall be sent with CLP=0. From the perspective of a source, these conditions result in a specific ordering of forward and backward RM-cells relative to other cells on the connection. Switch behavior #3, however, allows RM-cells to be served out of sequence with respect to data cells at switches. As a result, a specific ordering of forward and backward RM-cells and other cells cannot be expected at network interfaces. Nevertheless, the relative numbers of each type of cell received at an interface over sufficiently long intervals should observe certain constraints. The section provides examples of such constraints.

Source Behavior #3 in Section 5.10.4 results in three distinct regions for the generation of CLP=0 forward RM-cells. In the first region, one forward RM-cell is sent for every Nrm CLP=0 cells on the connection and at least at a rate of one per interval *Trm*. In the second region, one forward RM-cell is sent per interval *Trm*. Finally, in the third region, one forward RM-cell is sent per Mrm+1 cells on the connection but at a rate no greater than one per interval *Trm*. As a result, over any interval of length *L* (in seconds), the number $R^f_{CLP=0}$ of CLP=0 forward RM-cells received on the forward connection at the public or private UNI or BICI and the total number $R_{CLP=0}$ of CLP=0 cells received on the forward connection at the interface should satisfy

$$c \times \frac{R_{CLP=0}}{Nrm} - d \leq R^f_{CLP=0} \leq \max\left(a, b \times \min\left(\frac{R_{CLP=0}}{Nrm} + \frac{L}{Trm}, \frac{R_{CLP=0}}{Mrm+1}\right)\right) \qquad \textbf{(C1)}$$

where *a*, *b*, *c*, *d*, *Nrm*, *Mrm*, and *Trm* are constants common to all ABR connections at the interface. The units for *a* and *d* are cells and for *Trm* is seconds/cell. The constants $b > 1$ and $c < 1$, which describe the tolerance to deviations from ideal source behavior (as can occur if some cells are lost between the source and the interface in question) are dimensionless, as are *Nrm* and *Mrm*. The constants a and d account for deviations from ideal ratios that occur when a small total number of cells are received at the interface on the connection.

Likewise, over any interval of length $L > \tau_2$, the number $R^b_{CLP=0}$ of CLP=0 backward RM-cells received at the interface on the connection, the number $T^f_{CLP=0}$ of CLP=0 forward RM-cells transmitted at the interface on the corresponding backward connection, and the number $T^f_{CLP=1}$ of CLP=1 forward RM-cells transmitted at the interface on the backward connection should satisfy

$$g \times \min\left(T^f_{CLP=0}, R^f_{CLP=0}\right) - h \leq R^b_{CLP=0} \leq \max\left(e, f \times \left(T^f_{CLP=0} + T^f_{CLP=1} + 10L(S+1)\right)\right) \qquad \text{(C2)}$$

where S is the number of switches through which the received backward RM-cells pass between the source/destination and the interface in question, where *e*, *f*, *g*, and *h* are constants common to all ABR connection at the interface and where τ_2 is specified for the connection in question, as described earlier in Section 3.3.2. The constants *e* and *h* are in units of cells, and the constants $f > 1$ *and* $g < 1$, which describe the tolerance to deviations from the ideal source/destination behavior, are dimensionless.

An ABR connection that observes the reference behavior for an ABR source also should copy its most recently calculated Allowed Cell Rate (ACR) into the Current Cell Rate (CCR) field and its Minimum Cell Rate (MCR) into the MCR field of each forward RM-cell. When the forward RM-cell arrives at the private or public UNI or BICI, its CCR field should not exceed the inverse of the increment calculated by the algorithm $DGCRA(MCR^{-1}, PCR^{-1}, ICR^{-1}, \tau_1, \tau_2, \tau_3)$ at that time**,** and its MCR field should not exceed the negotiated MCR for the connection. Hence, the number R_V^f of forward RM-cells received at the interface with CCR field more than the inverse of the calculated DGCRA increment or with MCR field greater than the negotiated MCR should satisfy

$$R^f_V \leq \max\left(u, v \times \left(R^f_{CLP=0} + R^f_{CLP=1}\right)\right) \qquad \text{(C3)}$$

over any interval, where $R^f_{CLP=1}$ is the number of CLP=1 forward RM-cells received on the forward connection over the interval and *u* and *v* are constants common to all ABR connections at the interface. The constant *u* is in units of cells, and the constant *v* is dimensionless. Condition (C3) assures that the ratio of the number R_V^f of forward RM-cells with CCR or MCR field in violation to the total number $R^f_{CLP=0} + R^f_{CLP=1}$ of forward RM-cells is close to 0, except when $R^f_{CLP=0} + R^f_{CLP=1}$ is small (i.e., $R^f_{CLP=0} + R^f_{CLP=1} <$ u/v).

Informative Appendix IV: Application Examples for ATM Service Categories

This section identifies some example applications which are appropriate targets for each of the defined service categories. ITU-T Recommendation I.211 gives more examples and further details on some types of applications.

These example applications are provided to convey the original intention and focus of the service categories, which broadly relate application aspects to network functionality. However, an application is not constrained by this mapping, and may select any service category consistent with its needs.

Example applications for CBR:

- Interactive Video (e.g., videoconferencing)
- Interactive Audio (e.g., telephone)
- Video Distribution (e.g., television, distributed classroom)
- Audio Distribution (e.g., radio, audio feed)
- Video Retrieval (e.g., video on demand)
- Audio Retrieval (e.g., audio library)
- Any data/text/image transfer application which contains smooth enough traffic or for which the end-system's response time requirements justify occupying a fully reserved CBR channel.

Example applications for real-time VBR:

- A real-time application (including those listed above for CBR) for which the end-system can benefit from statistical multiplexing by sending at a variable rate, and can tolerate or recover from a small but non-zero cell loss ratio.
- A real-time application (including those listed above for CBR) for which variable rate transmission allows more efficient use of network resources.

Example applications for non-real-time VBR:

- Response time critical transaction processing (e.g., airline reservations, banking transactions, process monitoring)
- Frame Relay interworking

Example applications for UBR:

- Interactive Text/Data/Image Transfer (e.g., banking transaction, credit card verification)
- Text/Data/Image Messaging (e.g., email, telex, fax)
- Text/Data/Image Distribution (e.g., news feed, weather sat. pictures)
- Text/Data/Image Retrieval (e.g., file transfer, library browsing)
- Aggregate LAN (e.g., LAN interconnection or emulation)
- Remote Terminal (e.g., telecommuting, telnet)

Example types of applications for ABR:

- Any UBR application listed above that can take advantage of the ABR flow-control protocol in order to achieve a low cell loss ratio.
- Critical data transfer (e.g., defense information).
- Super computer applications.
- Data communications applications requiring better delay behavior, such as remote procedure call, distributed file service (e.g., NFS), or computer process swap/paging.

Informative Appendix V: Example of a Future CDV Accumulation Method

This appendix contains a method for peak-to-peak CDV accumulation called the asymptotic method. This method is an example of how the simple method for peak-to-peak CDV accumulation described in Section 3.6.2 could be enhanced in future versions of this specification.

V.1 Values Determined Directly from the Delay Density

To accomplish the accumulation, any switch must first be able to determine three parameters intrinsic to the switch, determined from the probability density function of the delay of Figure 3-2. This delay density function may be determined analytically or through measurements. If the delay density function is determined through measurements then the test cases should include a wide variety of background traffic patterns. The details of determining the density function are implementation specific, but it is expected that this density function will be determined based on the switch itself and will require no real-time computation. Of particular importance is the probabilistic queuing delay, which is given by the probability density translated to the left so that the fixed delay is 0. The three parameters precomputed from the probability density function are:

- The mean queuing delay, μ: Since the transfer delay is the fixed delay plus the queuing delay, we can also express μ as the mean transfer delay minus the fixed delay.
- The variance of the queuing delays σ^2 (or equivalently the standard deviation σ): Since variance is not sensitive to translation, this is the same as the variance of the cell transfer delay.
- The cell delay variation for the switch, CDV(α): This depends on the parameter α. It is expected that the switch will precompute a table of values for CDV(α) over a range of α.

V.2 Derived Values Precomputed at the Switch

Using these three parameters, the switch must compute a value called the discrepancy. The discrepancy can be thought of as a measure of how different the probability density function of the delay is from a Gaussian density of the same mean and variance: it measures the difference in values along the x-axis between the start of the α-tail of the switch queuing density and the start of the α-tail of the Gaussian density. Figure V-1 below illustrates the idea.

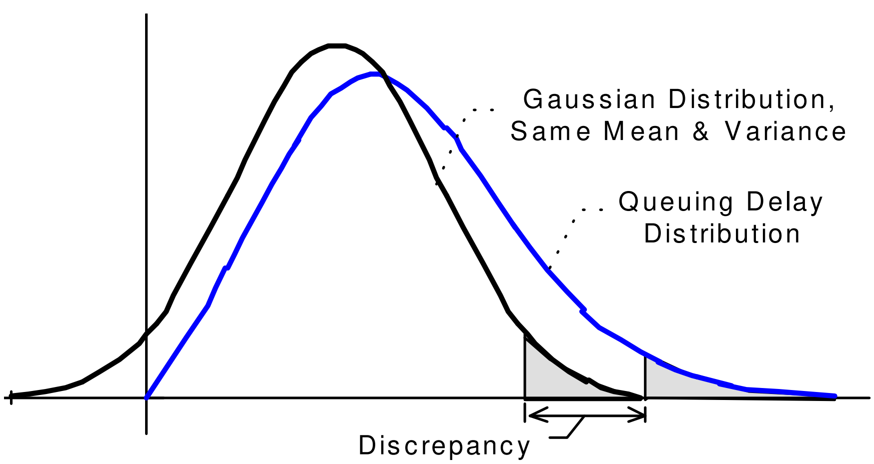


Figure V-1: The discrepancy of a queuing delay density

It is useful to have a table of the abscissas for which the standard normal density has tail size α. The table below gives, for some values of α, the value t(α), defined as the point on the x-axis where a Gaussian random variable with mean 0 and standard deviation 1 has right-hand tail area α. For convenience, u(α), the reciprocal of $t(\alpha)$ is also given. The precision of the values given is not meant to imply a precision of calculation required of the switch, nor are the values of α given here required to be those supported by a switch.

$-\log_{10} \alpha$	$t(\alpha)$	$u(\alpha)$
1	1.2815516	0.78030415
2	2.3263479	0.42985832
3	3.0902323	0.32360027
4	3.7190165	0.26888829
5	4.2648908	0.23447259
6	4.7534243	0.21037466
7	5.1993376	0.19233219
8	5.6120012	0.17818955
9	5.997807	0.16672761
10	6.3613409	0.15719956
11	6.7060232	0.14911968
12	7.0344838	0.14215684
13	7.3487961	0.13607671
14	7.6506281	0.13070822
15	7.9413453	0.12592325

Table V-1: Unit Gaussian right-hand tail areas

The definition of the discrepancy can now be given by converting the numbers for the mean 0, standard deviation 1 Gaussian density to those of the queuing density. The parameter of interest is:
The discrepancy $d(\alpha) = CDV(\alpha) - (\mu + \sigma * t(\alpha))$.

V.3 Parameters used in Accumulation Algorithms

The previous two sections introduced four parameters that can be determined prior to any signaling. Only three of these are used in the accumulation algorithm. The fourth parameter, the fixed delay, which is intrinsic to the switch, is also needed. Thus for the accumulations, the following parameters are used:

- The mean queuing delay μ;
- The variance of queuing delays σ^2;
- The discrepancy $d(\alpha)$;
- The fixed delay f.

V.4 Accumulation Algorithms

The accumulation of peak-to-peak CDV and max CTD require signaling of a total of four accumulation parameters: M, V, D, F. Each of these is initialized to the value of 0 at the source. Parameters M, V and F are increased additively: at each switch, M is replaced by $M+\mu$, V is replaced by $V+\sigma^2$, and F is replaced by F+f. The parameter D is a maximum of the discrepancies along the path, and so D is replaced by max{d, D}.

The estimated cumulative peak-to-peak CDV is $M + t(\alpha) * V^{1/2} + D$. This needs to be no more than the requested peak-to-peak CDV for the call to be accepted. This test can be algebraically rewritten as

$$((\text{Requested peak-to-peak CDV} - M - D) * u(\alpha))^2 \geq V,$$

to avoid computation of a square root, if desired.

The estimated max CTD is the estimated peak-to-peak CDV plus the sum of the fixed delays F.

The mean CTD can be estimated as the sum of F+M, and does not require use of the parameters V or D.

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