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Foreword

This Interim European Telecommunication Standard (I-ETS) has been produced by the Network Aspects (NA) Technical Committee of the European Telecommunications Standards Institute (ETSI).

An ETSI standard may be given I-ETS status either because it is regarded as a provisional solution ahead of a more advanced standard, or because it is immature and requires a "trial period". The life of an I-ETS is limited to three years after which it can be converted into an ETS, have it's life extended for a further two years, be replaced by a new version, or be withdrawn.

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1 Scope

This Interim European Telecommunication Standard (I-ETS) defines speed and accuracy performance parameters and values for cell transfer in the Asynchronous Transfer Mode (ATM) layer of a Broadband Integrated Services Digital Network (B-ISDN). The defined parameters and values apply to end-to-end ATM connections and to specified portions of such connections. The parameters are defined on the basis of ATM cell transfer reference events which may be observed at physical interfaces between ATM networks and associated customer equipment, and at physical interfaces between ATM networks. The values characterize the ATM layer performance for B-ISDN connection types.

NOTE: The parameters defined in this I-ETS may be augmented or modified based upon further study of the requirements of the services to be supported on B-ISDNs.

The defined parameters apply to compliant connections or connection portions. The criteria for deciding a connection or a connection portion as compliant or not need to be defined. These criteria such as the ratio of non conforming cells may be operator specific.

It is intended that one or more ATM connection performance objectives will be specified for each of the defined parameters.

Each value applies to ATM connections in their available state. Dependability aspects will be considered in separate standards.

This I-ETS provides a theoretical framework for the measurement of the performance parameter values. In some instances they may not be directly applied for real network measurements, and need to be approximated.

2 Normative references

This I-ETS incorporates by dated and undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this I-ETS only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

[1] ITU-T Recommendation G.826 (1994): "Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate".

[2] ITU-T Recommendation I.150 (1993): "B-ISDN asynchronous transfer mode functional characteristics".

[3] ITU-T Recommendation I.353 (1993): "Reference events for defining".

[4] ITU-T Recommendation I.363 (1993): "B-ISDN ATM adaptation layer (AAL) specification".

[5] ITU-T Recommendation I.371 (1993): "Traffic control and congestion control in B-ISDN".

[6] ITU-T Recommendation I.610 (1993): "B-ISDN operation and maintenance principles and functions".

3 Symbols and abbreviations

For the purposes of this I-ETS, the following abbreviations apply:

AAL	ATM Adaptation Layer
ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
BIP	Bit Interleave Parity
CBR	Constant Bit Rate
CDV	Cell Delay Variation
CEQ	Customer Equipment
CER	Cell Error Ratio
CLR	Cell Loss Ratio
CMR	Cell Misinsertion Rate
CRE	Cell Reference Event
CTD	Cell Transfer Delay
FS	Frontier Station
HEC	Header Error Control
ISC	International Switching Center
ISDN	Integrated Services Digital Network
MP	Measurement Point
MPI	International Measurement Point
MPT	Measurement Point, located at the T_B reference point
NCCR	Non Conforming Cell Ratio
NNI	Network Node Interface
NP	Network Performance
NPC	Network Parameter Control
NT	Network Termination
OAM	Operation Administration and Maintenance
PDH	Plesiochronous Digital Hierarchy
PL	Physical Layer
SDH	Synchronous Digital Hierarchy
SDU	Service Data Unit
SECBR	Severely Errored Cell Block Ratio
SN	Sequence Number
SSN	Signalling Switching Node
STM	Synchronous Transfer Mode
TE	Terminal Equipment
UNI	User Network Interface
UPC	Usage Parameter Control
VBR	Variable Bit Rate
VC	Virtual Channel
VCC	Virtual Channel Connection
VP	Virtual Path
VPC	Virtual Path Connection

4 Performance model

ITU-T Recommendation I.353 [3] defines Measurement Points (MPs) and associated reference events that provide a basis for ISDN performance description. ATM cell transfer performance is measured by observing the reference events created as ATM cells cross MPs.

For B-ISDN, the MPs are ideally located at interfaces where the ATM layer is accessible. For broadband ISDN two types of MP are defined:

- an ingress MP is located at the input of the first equipment which accesses the ATM layer in a network operator domain;

- an egress MP is located at the output of the last equipment which accesses the ATM layer in a network operator domain.

For B-ISDN, the location of the MPI is on the international side of the International Switching Center (ISC) (or Frontier Station (FS), if the FS accesses the ATM layer) at:

- the last egress MP in a given country; and

- the first ingress MP in a given country.

For B-ISDN, the Measurement Point, located at the T_B reference point (MPT) is conceptually located at the interface (the T_B reference point) that separates the network operator domain and the customer equipment or private network domain. Since a given ATM layer connection (VPC or VCC) is likely to terminate within the Customer Equipment (CEQ), the ATM reference events detailed is this I-ETS may not be directly observable at the MPT. Practical guidance on measurement at the MPT are under study.

Two possible methods are :

- locating a physical test set at the UNI; and

- approximation by measuring within the network at the nearest point to the MPT at which the ATM layer is observable.

Figure 1 illustrates the layered nature of B-ISDN performance issues. The Network Performance (NP) provided to B-ISDN users depends on the performance of three layers:

- the physical layer, which may be based on Plesiochronous Digital Hierarchy (PDH), Synchronous Digital Hierarchy (SDH), or cell-based transmission systems. This layer is terminated at points where a virtual channel or virtual path is switched by equipment using the ATM technique, and thus has no end-to-end significance when such switching occurs;

- the ATM layer, which is cell-based. The ATM is physical media and application independent and has end-to-end MPT significance;

- the ATM adaptation layer (AAL), which may enhance the performance provided by the ATM layer to meet the needs of higher layers. The AAL supports multiple protocol types, each providing different functions and different performance.

Qualitative relationships between ATM layer NP and the NP provided by the Type 1 AAL are described in annex A. It is intended that quantitative relationships between ATM layer network performance and the performance of the physical layer and AAL will be developed.

In the context of ITU-T Recommendation I.353 [3] and of this I-ETS:

- a cell exit event occurs when an ATM cell crosses an MP out of a TE, or crosses an MP out of an SSN;

- a cell entry event occurs when an ATM cell crosses an MP into a TE or crosses an MP into a SSN.

NOTE: For practical measurement purposes, reference events can be observed at a physical location that differs from the actual MP. In cases where reference events are monitored at a physical interface, the time of occurrence of an actual exit can best be approximated by the observation of the first bit of the unit of control or user information out of the SSN or CEQ. The time of occurrence of an entry event can best be approximated by the observation of the last bit of the unit of control or user information into the SSN or CEQ.

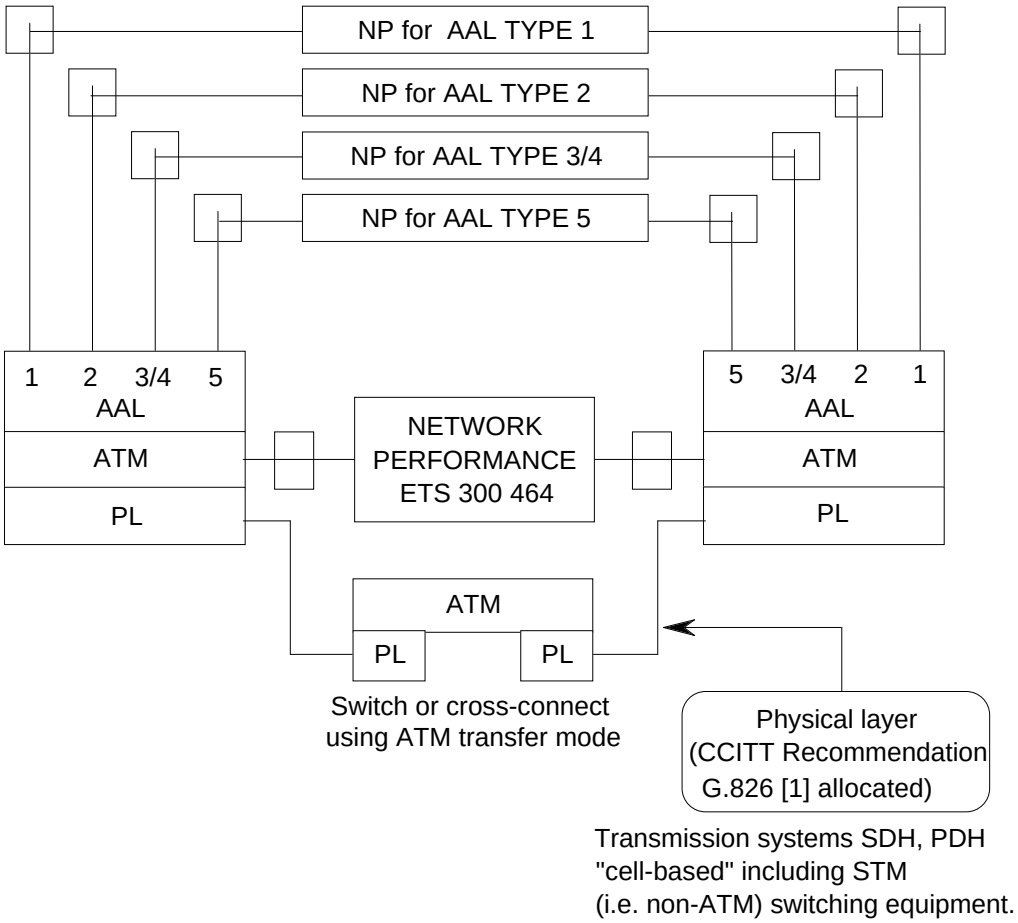
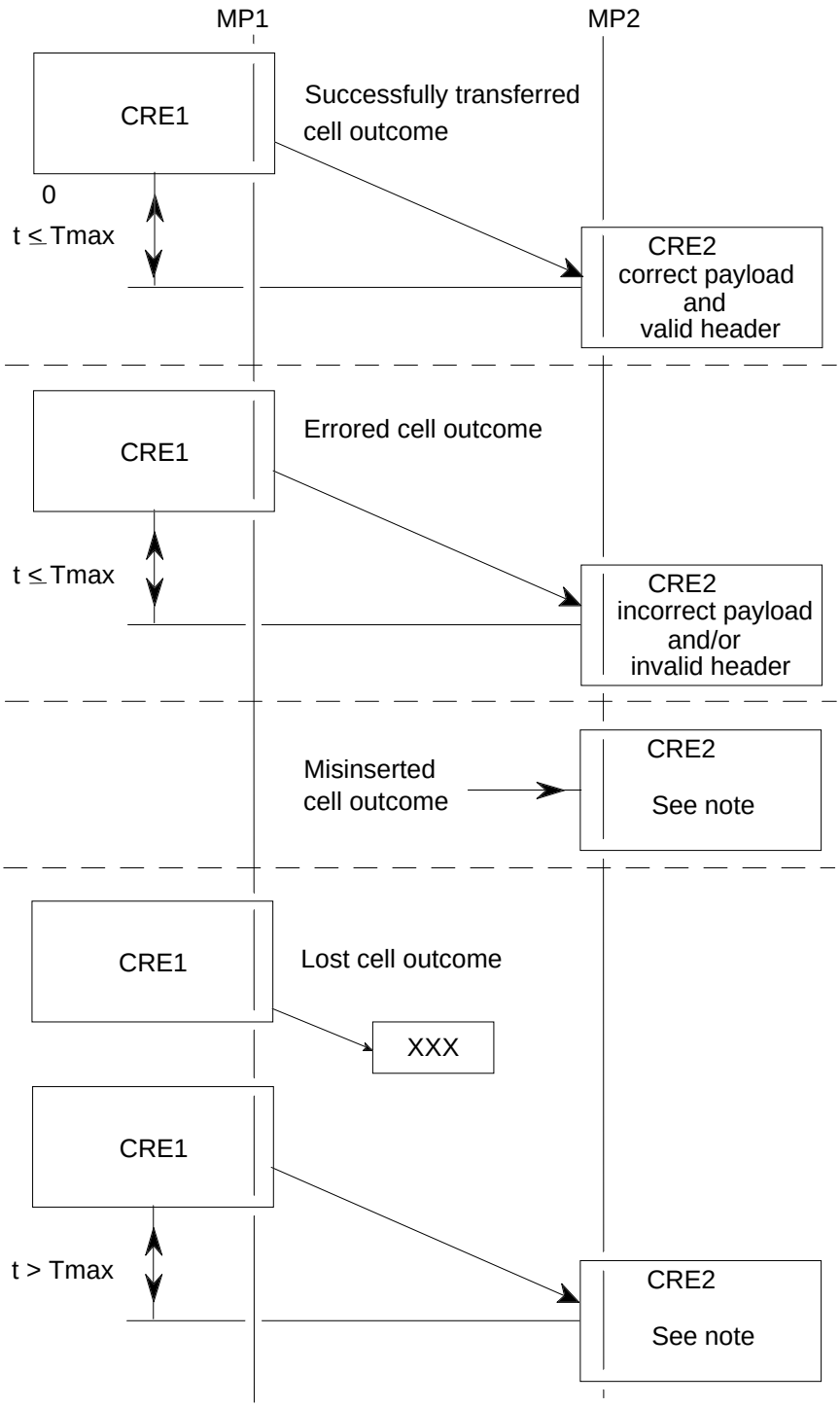


Figure 1: Layered model of performance for B-ISDN

5 ATM cell transfer outcomes

In the following, it is assumed that the sequence of ATM cells on a Virtual Channel Connection (VCC) or Virtual Path Connection (VPC) is preserved (see ITU-T Recommendation I.150 [2]). Two events are said to be corresponding if they occur on a predefined connection and at a pair of predefined boundaries.

By considering two cell transfer reference events, CRE_1 and CRE_2 at MP_1 and MP_2 respectively, a number of possible cell transfer outcomes may be defined. A transmitted cell is either successfully transferred, errored, or lost. A received cell for which no corresponding transmitted cell exists is said to be misinserted. Cell misinsertion can occur as a result of errors in the cell header. Figure 2 illustrates the cell transfer outcome definitions.



NOTE: Outcome occurs independent of cell content.

Figure 2: Cell transfer outcomes

Methods for estimating cell transfer outcomes either in service or out of service are provided in annex C.

5.1 Successful cell transfer outcome

A successful cell transfer outcome occurs when a CRE_2 corresponding to CRE_1 happens within a specified time Tmax of CRE_1, and (1) the binary content of the received cell information field conforms exactly with that of the corresponding transmitted cell and (2) the cell is received with a valid header field.

5.2 Errored cell outcome

An errored cell outcome occurs when a CRE_2 corresponding to CRE_1 happens within a specified time Tmax of CRE_1, but (1) the binary content of the received cell information field differs from that of the corresponding transmitted cell (i.e., one or more bit errors exist in the received cell information field) or (2) the cell is received with an invalid header field after Header Error Control (HEC) procedures are completed.

Most cells with header errors that are undetected or miscorrected by the HEC will be misdirected by the ATM layer procedures with the result that no CRE_2 occurs.

These cell transfer attempts will be classified as lost cell outcomes.

5.3 Lost cell outcome

A lost cell outcome occurs when a CRE_2 fails to happen within time Tmax of the corresponding CRE_1.

NOTE: The characteristics of the connections are negotiated in the traffic contract (see ITU-T Recommendation I.371 [5]). Cell losses attributable to cells non conforming to the negotiated traffic contract shall be excluded in assessing the performance of the network.

Cell losses attributable to customer equipment shall also be excluded in assessing the performance of the network. Estimation of cell losses occurring in customer equipment due to network causes is for further study.

5.4 Misinserted cell outcome

Misinserted cell outcome occurs when a CRE_2 happens without a corresponding CRE_1.

5.5 Severely errored cell block outcome

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 cell, lost cell, or misinserted cell outcomes are observed in a received cell block.

This definition applies to the case when all cells are conforming to the traffic contract (see ITU-T Recommendation I.371 [5]). The definition of severely errored cell block outcome in case when some cells are non conforming to the traffic contract is for further study.

For practical measurement purposes, a cell block will normally correspond to the number of user information cells transmitted between successive OAM cells. The size N of a cell block and the value of M are to be specified in a later version of this I-ETS.

6 ATM performance parameters

This clause defines a set of ATM cell transfer performance parameters using the cell transfer outcomes defined in clause 5 (see also annex B). All parameters may be estimated on the basis of observations at the MPs. Cell transfer performance measurement methods are described in annex C.

6.1 Severely errored cell block ratio

Severely Errored Cell Block Ratio (SECBR) is the ratio of total severely errored cell blocks to total cell blocks in a population of interest.

NOTE: The severely errored cell block outcome and parameter provide a means of preventing bursts of cell transfer failures from inappropriately influencing the observed values for cell error ratio, cell loss ratio, cell misinsertion rate, and the associated availability parameters.

6.2 Cell error ratio

Cell Error Ratio (CER) is the ratio of total errored cells to total successfully transferred cells plus errored cells in a population of interest. 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 (see subclause 6.1).

6.3 Cell loss ratio

Cell Loss Ratio (CLR) is the ratio of total lost cells to total transmitted cells in a population of interest. The total number of lost cells is computed as the total number of cells which are lost in excess of the total number of non conforming cells to the negotiated traffic contract. The total number of transmitted cells is computed as the number of cells which are conforming to the negotiated traffic contract.

Lost cells and transmitted cells in cell blocks counted as severely errored cell blocks should be excluded from the population used in calculating cell loss ratio (see subclause 6.1).

6.4 Cell misinsertion rate

Cell Misinsertion Rate (CMR) is the total number of misinserted cells observed during a specified time interval divided by the duration of the time interval (i.e. the number of misinserted cells per unit of time)[1)]. Misinserted cells and time intervals associated with cell blocks counted as severely errored cell blocks should be excluded from the population used in calculating cell misinsertion rate (see subclause 6.1).

6.5 Cell transfer delay

Cell Transfer Delay (CTD) is the time, $t_2 - t_1$, between the occurrence of two corresponding cell transfer events, CRE_1 at time t_1. and CRE_2 at time t_2,where $t_2 > t_1$ and $t_2 - t_1 \leq Tmax$.

NOTE 1: The value of Tmax is for further study.

NOTE 2: t_1 and t_2 are measured with the same reference time.

6.5.1 Mean cell transfer delay

Mean cell transfer delay is the arithmetic mean of a specified number of cell transfer delays.

6.5.2 Cell Delay Variation (CDV)

Two cell transfer performance parameters associated with Cell Delay Variation (CDV) are defined. The first parameter, 1-point cell delay variation, is defined on the basis of observation of a sequence of consecutive cell arrivals at a single MP. The second parameter, 2-point cell delay variation, is defined on the basis of observations of corresponding cell arrivals at two MPs that delimit a virtual connection portion. The 1-point CDV parameter describes variability in the pattern of cell arrival (entry or exit) events at an MP with reference to the negotiated peak cell rate 1/T (see ITU-T Recommendation I.371 [5]), it includes variability present at the cell source (customer equipment) and the cumulative effects of variability introduced (or removed) in all connection portions between the cell source and the specified MP. It is related to cell conformance at the MP, and to network queues. It is also related to the buffering procedures used in AAL 1 of the receiving side to compensate for cell delay variation. The 2-point CDV parameter describes variability in the pattern of cell arrival events at the output of a connection portion (e.g. measurement point MP2) with reference to the pattern of corresponding events at the input to the portion (e.g. measurement point MP1): it includes only variability introduced within the connection portion. It provides a direct measure of portion performance and an indication of the maximum (aggregate) length of cell queues that may exist within the portion. Additional information on relationships of these CDV related parameters to cell queues and their application in ATM network performance specification is provided in annex B.

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1) By definition, a misinserted cell is a received cell that has no corresponding transmitted cell. 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. Since the mechanism that most often causes misinserted cells is independent of the number of cells transmitted on the observed connection, this performance parameter cannot be expressed as a ratio, only as a rate.

6.5.2.1 1-point CDV at an MP

The 1-point CDV (y_k) for cell k at an MP is the difference between the cell's reference arrival time (c_k) and actual arrival time (a_k) at the MP (figure 3) : $y_k = c_k - a_k$. The reference arrival time pattern (c_k) is defined as follows:

$$c_0 = a_0 = 0$$

$$c_{k+1} = c_k + T \quad \text{when } c_k \geq a_k,$$

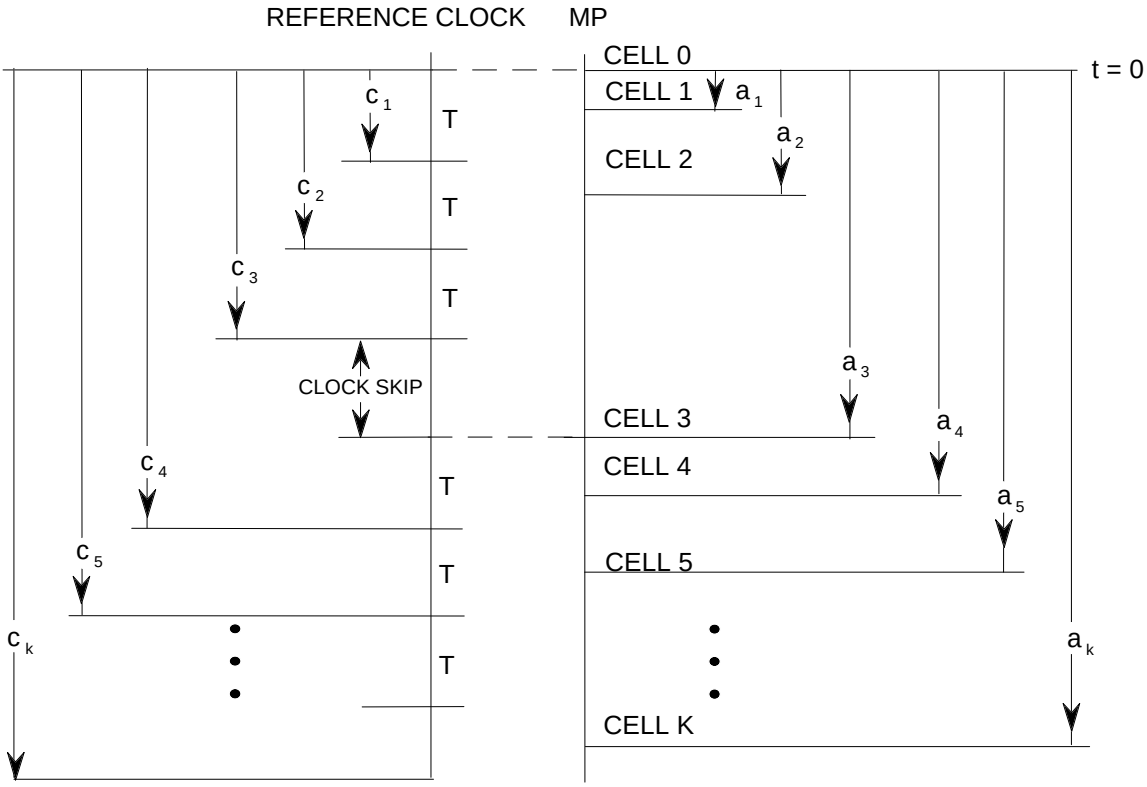
$$a_k + T \quad \text{otherwise.}$$

Positive values of 1-point CDV ("early" cell arrivals) correspond to cell clumping: negative values of 1-point CDV ("late" cell arrivals) correspond to gaps in the cell stream. The reference pattern defined above eliminates the effect of gaps in the specification and measurement of cell clumping[2)] or more.

Annex C illustrates one measurement method that calculates, for a cell stream received at an MP, the number of cells that do not conform with a specified peak cell rate at a specified CDV tolerance.

It is anticipated that one or more values for maximum CDV tolerance (τ) will be specified.

NOTE: The reference instant c_0 is defined as the arrival time of the first cell recognized by the 1 point CDV mechanism.



Variables:

a_k = cell k actual arrival time at MP

c_k = cell k reference arrival time at MP

y_k = 1-point CDV

$y_k = c_k - a_k$

Figure 3: Cell delay variation - 1-point definition

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2) The reference clock "skips" by an amount equal to the difference between the actual and expected arrival times immediately after each "late" cell arrival.

6.5.2.2 Cell delay variation between two MPs (2-point CDV)

The 2-point CDV (v_k) for cell k between MP_1 and MP_2 is the difference between the absolute cell transfer delay (x_k) or cell k between the two MPs and a defined reference cell transfer delay ($d_{1.2}$) between the same two MPs (figure 4) : $v_k = x_k - d_{1.2}$.

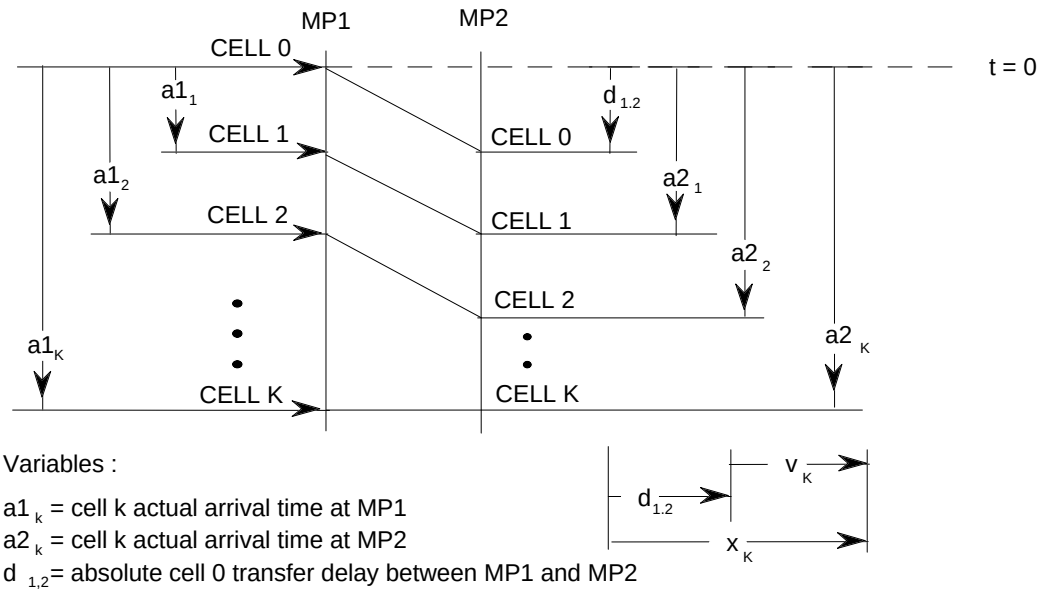
The reference time at the locations of MP_1 and MP_2 is the same.

The absolute cell transfer delay [3] (x_k) of cell k between MP_1 and the MP_2 is the difference between the cell's actual arrival time at MP_2 ($a2_k$) and the cell's actual arrival time at MP_1 ($a1_k$) : $x_k = a2_k - a1_k$. The reference cell transfer delay ($d_{1.2}$) between MP_1 and MP_2 is the absolute cell transfer delay experienced by cell 0 between the two MPs.

Positive values of 2-point CDV correspond to cell transfer delays greater than that experienced by the reference cell; negative values of 2-point CDV correspond to cell transfer delays less than that experienced by the reference cell. The distribution of 2-point CDV is identical to the distribution of absolute cell transfer delay for any specified population of transferred cells. It is anticipated that the specification of 2-point CDV objectives will be in terms of upper and lower quantiles. The specified upper and lower quantile values may depend on the negotiated peak cell rate.

Annex C illustrates one method of estimating the range of the 2-point CDV distribution for a succession of transferred cells on the basis of observations of 1-point CDV values (y_k) for connections providing CBR services. Annex B relates an upper quantile of the probability distribution for 2-point cell delay variation to the cell loss ratio.

NOTE: Cell zero is specified as the first cell which is recognized by the 2 points CDV measurement mechanism.



Variables :

$a1_k$ = cell k actual arrival time at MP1
$a2_k$ = cell k actual arrival time at MP2
$d_{1,2}$ = absolute cell 0 transfer delay between MP1 and MP2
x_k = absolute cell k transfer delay between MP1 and MP2
v_k = 2-point CDV value between MP1 and MP2

$$x_k = a2_k - a1_k \qquad \boxed{v_k = x_k - d_{1.2}}$$

Figure 4: Cell delay variation - 2 - point definition

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[3] It is defined for all corresponding cell transfer reference event pairs (CRE_1, CRE_2) ; cell transfer delay as defined in subclause 6.5 applies only to successful cell transfer outcomes. Variables $a2_k$ and $a1_k$ are measured with reference to the same reference time in calculating absolute cell transfer delay.

6.6 Cell flow related parameters

The need for network performance parameters describing the actual flow of cells in an ATM connection is for further study. Such parameters will be needed if flow control mechanisms are implemented in ATM networks. One useful parameter could be the (positive) difference between the negotiated peak cell rate and the actual cell transfer rate. The difference between the requested peak cell transfer rate and the negotiated peak cell transfer rate could also be useful. Measures of specific flow control mechanisms may also be of value.

7 Performance objectives

The performance objectives will be defined in a later version of this I-ETS.

Annex A (normative): Relationship between ATM layer NP and the NP of AAL type 1 for CBR services

This annex describes qualitative relationships between ATM layer network performance and the NP provided by the type 1 AAL.

A.1 Possible AAL functions and their effects

Examples of adaptation layer functions which may compensate for specific performance impairments introduced in ATM cell transfer are provided below.

A.1.1 Lost and misinserted AAL SDUs

A Sequence Number (SN) in the AAL header can be used to detect lost and misinserted AAL SDUs due to lost cells and misinserted cell outcomes. Detection mechanisms are for further study.

If lost AAL SDUs are detected, replacement AAL SDUs may be substituted to compensate for the lost AAL SDUs in order to maintain bit count integrity. However, if there is no error correction in the AAL this substitution will result in user information bit errors in the AAL SDU. The contents of such dummy AAL SDUs (e.g. all "1", all "0", repeat the previous cell, etc.) require further study (see ITU-T Recommendation I.363 [4]).

If misinserted AAL SDUs are detected, they may be discarded, restoring the delivered user information content to that transmitted. If lost and misinserted AAL SDUs are not detected, they may cause a loss of frame alignment in the delivered user information stream.

A.1.2 Errored AAL SDUs

Error control mechanisms have been identified for some signals transported by AAL type 1. In the absence of such error control, bit errors will be transferred to the AAL user.

A.1.3 AAL SDUs Cell transfer delay

To compensate for cell delay variation, arriving AAL SDUs are buffered in the AAL at the receiving side of a connection. This buffering increases the user information transfer delay. Error control and lost AAL SDUs detection mechanisms may introduce additional delay.

Excessive cell delay variation that cannot be compensated or excessive delay due to the lost AAL type 1 SDUs detection mechanism can cause the substitution of dummy AAL SDUs for valid AAL SDUs, resulting in bit errors in user information.

A.2 Relationships between NP parameters and binary errors

In the absence of error control covering the cell information field:

- the expected number of binary errors associated with each lost cell is 188 (assuming 47 octets of AAL user information in the ATM cell payload and a BER of 0,5) if dummy AAL SDUs are inserted;

- an errored cell can theoretically produce any number of errored bits from 1 to 376 (assuming 47 octets of AAL user information in the ATM layer cell payload), with a distribution skewed towards the low end of the theoretical range;

- each misinserted cell delivered to the AAL user, i.e. not dropped by the AAL, results in binary errors. Furthermore, an undetected misinsertion could cause a loss of frame alignment.

Annex B (normative): Cell transfer delay, 1-point CDV, and 2-point CDV characteristics

B.1 Components of delay associated with ATM-based user information transfer

The overall delay perceived by an end-user of AAL service can be divided into the following three components:

a) T1 coding and decoding delay (see note 1);

b) T2 segmentation and reassembly delay (see note 1).

The segmentation and reassembly delay can be further sub-divided into three:

1) T21 segmentation delay in the AAL of the sending side;

2) T22 buffering delay in the AAL of the receiving side to compensate the cell delay variation (see note 2);

3) T23 reassembly delay in the AAL of the receiving side;

c) T3 cell transfer delay (MPT - MPT).

This delay is the sum of the following:

1) T31 total inter-ATM node transmission delay (see note 3);

2) T32 total ATM node processing (queuing, switching and routing etc.) delay (see notes 4 and 5).

NOTE 1: Coding and data segmentation may or may not be performed in the same equipment. Similarly, decoding and reassembly may or may not be performed in the same equipment.

NOTE 2: The amount of buffering delay consumed in AAL handling equipment will depend on the amount of cell delay variation for which the ATM network is responsible.

NOTE 3: Delay caused by transmission related equipment between two adjacent ATM nodes, e.g. SDH cross-connect systems, is considered to be part of this component.

NOTE 4: ATM nodes may perform both Virtual Channel (VC) and Virtual Path (VP) switching.

NOTE 5: Due to queuing in ATM nodes, this component is variable on a cell-by-cell basis within one ATM connection.

B.2 Relationship between cell clumping and distributed cell queues

With respect to a particular MP, define a **clump** as a sequence of early cell arrivals between two successive reference clock skips. The corresponding time interval is a **positive queue interval**. Clumps can be considered to increase the aggregate length of cell queues downstream of the MP. If each 1-point CDV value in a particular clump is rounded to the next more positive T integer, the rounded values and the aggregate cell queue deviation from the expected level in the corresponding positive queue interval are identically distributed. Within a clump, each (rounded) 1-point CDV value is equal to the aggregated cell queue deviation from the expected level at the corresponding cell arrival time. This relationship can be useful in associating (positive) 1-point CDV values with UPC and NPC mechanisms.

B.3 Relationship between 2-point CDV and cell loss in a shared buffer

Consider the operation of one of the physical links which support a specific ATM connection. All of the cells that are intended to pass through this physical link would be held in a buffer that absorbs momentary surpluses of cells until they are either transmitted over the link, or until this buffer overflows with the resultant loss of some cells. The cells that are intended to pass through this physical link are provided by both the specific ATM connection under consideration and other ATM connections which share this link. These cells contribute to the link's offered load, which may be characterized by a utilization factor ρ offered. Any cell arriving at this buffer experiences a random waiting time W before it reaches the link and is transmitted. Figure B.1 illustrates this situation, together with some representative probability density functions for W, P(w).

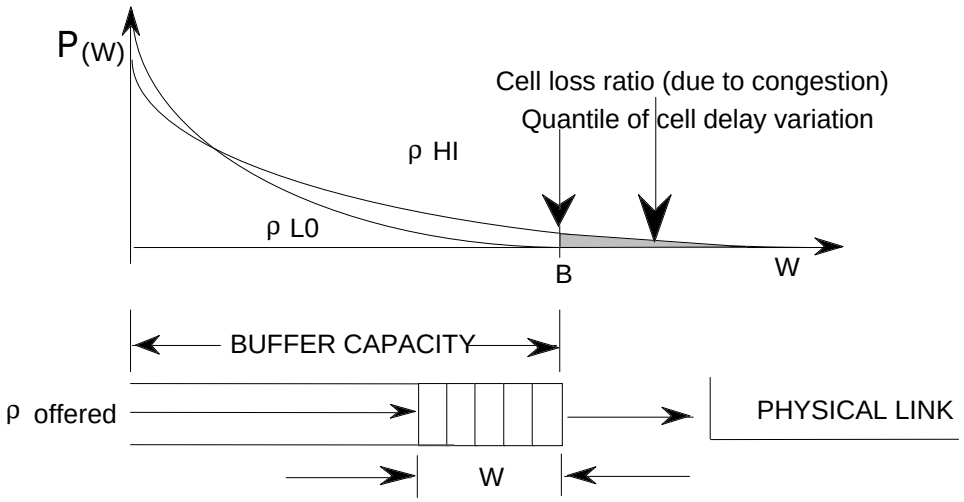

Figure B.1: Relationship between 2-point CDV and cell loss

In an infinite FIFO queue with a sufficiently high value of offered load, characterized in figure B.1 by ρHI, the tail of the probability density function will place a significant amount of weight beyond the buffer level B, as measured in cell emission times[4)]. As a practical approximation of a finite FIFO queue of capacity B, which is valid if the volume of lost cells is small enough, B represents a quantile of cell delay and the shaded area can be interpreted as the cell loss ratio (due to congestion).

With a lower value of offered load, characterized in figure B.1 by ρ LO, the tail of the probability density function will place less weight beyond B, thereby reducing the resulting value of cell loss ratio.

These effects should be considered in the selection of cell transfer delay timeout Tmax in the specification of 2-point CDV and cell loss ratio values.

B.4 Allocation of 2-point CDV values

The maximum 2-point CDV V(p, q) between two non adjacent MPs (p, q) is related to the 2-point CDVs of the portions between those MPs by the inequality:

$$V(p,q) \leq \sum_{i=p}^{q-1} V(i,i+1)$$

This inequality could be useful in allocating end-to-end values for 2-point CDV among connection portions.

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4) One cell emission time on an STM-1 link is 2,73 μs. If, for example, a buffer has 100 cells and feeds an STM-1 link, B would be 273 μs.

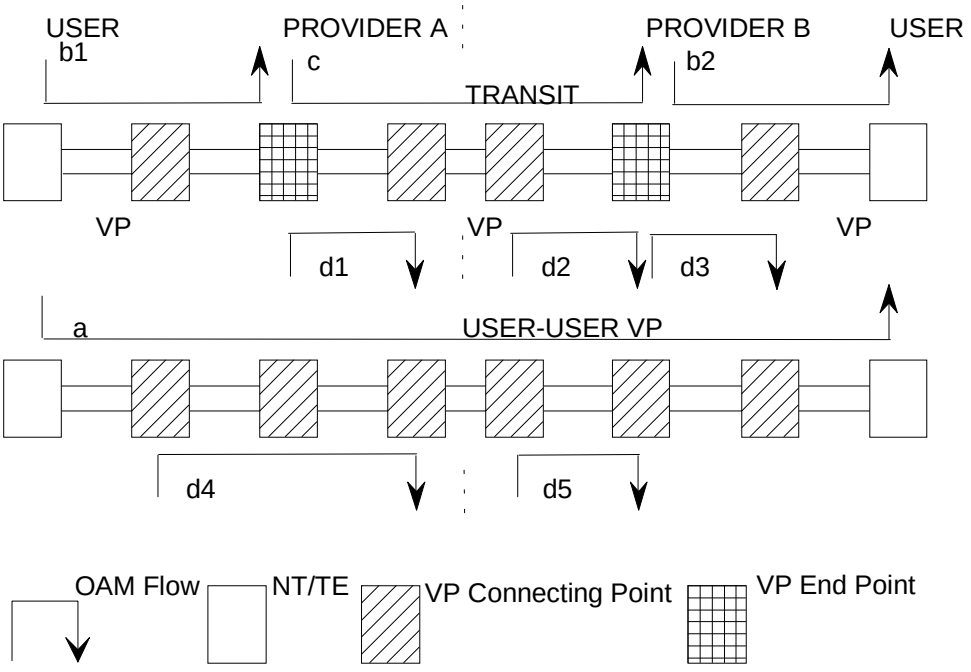
Annex C (normative): Cell transfer performance measurement methods

This annex describes measurement methods which may be used to estimate values for the ATM cell transfer performance parameters defined in this I-ETS. The described methods include in-service methods, which introduce OAM cells into the transmitted user information cell stream, and out-of-service methods, which perform measures on a test connection dedicated to measurement. The in-service methods include direct methods, which make use of information derived from the user cell stream (e.g. cell counts), and indirect methods, which rely on the correlation between user and OAM cells. The in-service methods allow continued use of the channel under measurement; the out-of-service methods allow greater control of the measurement process and can generally provide better measurement precision.

NOTE: The accuracy of measurement of these events may only be about plus or minus 200 μs at SDH interfaces if the event times for cells embedded in SDH frames are approximated by the frame event times.

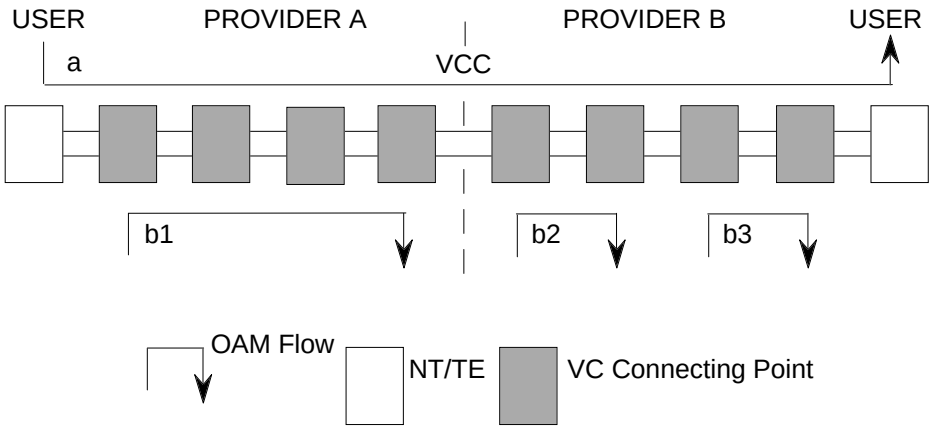
Figures C.1 and C.2 illustrate the general approach envisioned for use of OAM cells in performance monitoring. Performance monitoring OAM cells may be introduced into the cell stream at any VP or VC termination or connecting point, and may then be copied or extracted at any similar point downstream. The corresponding approach for out-of-service monitoring is to establish a virtual path or connection at an appropriate measurement point, introduce a cell stream of known content and timing at that point, and then observe the cell stream at a remote measurement point.

Measurement methods are described below for cell error ratio, cell loss ratio, cell misinsertion rate, severely errored cell block ratio, cell transfer delay, and cell delay variation. A method is also provided for measuring the number of non conforming cells Details of OAM functions supporting performance measurement are provided in ITU-T Recommendation I.610 [6]. In-service performance monitoring will likely be performed only on a selected number of Virtual Path Connections/Virtual Channel Connections (VPCs/VCCs) on an on-demand basis.



a = end-to-end performance monitoring flow
b, c, d = VP segment performance monitoring flow

Figure C.1: OAM cell flows for VP performance monitoring



a = end-to-end performance monitoring flow
b = VC segment performance monitoring flow

NOTE: An end-to-end performance monitoring flow and a network maintenance flow can be provided at any VC cross section.

Figure C.2: OAM cell flow for VC performance monitoring

C.1 Cell error ratio

Cell error ratio can be measured out-of-service by 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 MP.

Estimation of cell error ratio by in-service measurement is desirable but difficult. A solutin may be that a BIP16 indicator could be used to estimate the cell error ratio over a block of N cells using the following algorithms:

- if "i" parity violations are observed ($0 \leq i \leq 2$) without any loss of cells, estimate the number of errored cells by i;

- if more than 2 parity violations are observed without any loss of cells, estimate the number of errored cells by N.

The method assumes that the number of cells within a block is not too large (e.g. less than 200 cells) and that the transmission medium is such that either very few errors are experienced or large bursts of errors occur. The feasibility and accuracy of this and other in-service CER estimation methods are for further study.

C.2 Cell loss ratio

Cell loss ratio can be estimated in-service as follows. The transmitter inserts OAM cells into a transmitted user information cell stream at suitable intervals. Each OAM cell contains the running count of the number of user information cells transmitted. The receiver keeps a running count of the number of user information cells transmitted (Nt) and received (Nr), excluding cells in severely errored blocks. Cell loss ratio can then be calculated by dividing the positive difference (Nt-Nr) by Nt i.e.: CLR=max {O,(Nt-Nr)/Nt}. The method will underestimate the number of cell loss events if cell misinsertion occurs during the measurement period.

This method applies to cell streams in which all cells are conforming to the negotiated traffic contract. For cell streams for which the number of non conforming cells (NNC) is available at the receiving end, the cell loss ratio could be calculated by dividing max (0,Nt-Nr-NNC) by (Nt-NNC).

C.3 Cell misinsertion rate

Cell misinsertion rate can be estimated in-service using a method similar to that described in annex C, clause C.2. Running counts Nt and Nr are obtained during a measurement period Tm (excluding cells in severely errored cell blocks), and the cell misinsertion rate is calculated by dividing the positive difference (Nr-Nt) by Tm, i.e.: max {O,(Nr-Nt)/Tm}. The method will underestimate the number of cell misinsertion events if cell loss occurs during the measurement period.

A more accurate out-of-service method of estimating cell misinsertion rate is to maintain a VP or VC for a known period of time but transmit no cells on it. Any cells received on the connection are then misinserted cells, and the cell misinsertion rate can be estimated by dividing the number of received cells by the observation time. The likelihood of observing misinserted cells can be increased by observing more idle connections.

C.4 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 outcomes in excess of the number of non conforming cells and the number of misinserted cell outcomes in each cell block (as described in annex C, clauses C.2 and C.3), identifying cell blocks with more than M lost cell or misinserted cell outcomes as severely errored cell blocks; and dividing the total number of such severely errored cell blocks by S.

C.5 Cell transfer delay

Cell transfer delay can be measured in-service by transmitting time-stamped OAM cells through the network on an established connection. The transmitted OAM cell payload contains the time t_1 at which the cell was transmitted. The receiver subtracts t_1 from the time t_2 at which the cell is received to determine the cell transfer delay for that cell. The method requires synchronized clocks at the two MPs or a suitable loopback mechanism at the receiver.

This traffic sampling method may give accurate results as long as the observed cell flow is ergodic and stationary during the observation interval.

Individual cell transfer delay observations may be combined to calculate statistics of the cell transfer delay distribution. Such statistics also characterize 2-point cell delay variation. The use of OAM cell measurements to develop cell transfer delay and 2-point CDV distributions is possible but may be limited by the OAM cell transmission frequency. This topic is for further study.

C.6 Cell delay variation

Figure C.3 provides a method of estimating the range of the 2-point CDV (i.e., the range of the absolute cell transfer delay) for a succession of transferred cells on the basis of observations of 1-point CDV values (y_k). The method assumes that cells are inserted at the peak cell rate and is applicable only to connections providing CBR service. At time a_k, when cell k is observed at the measurement point, the value of the 1-point CDV parameter $y_k = c_k - a_k$ is computed to obtain the current value of Q_k (the observed range of cell transfer delay, see annex C, figure C.3). Then:

- if y_k is non-negative, the next cell reference time c_{k+1} is computed and the value of Q_k is computed taking into account the observed positive difference between the theoretical emission time, and the actual arrival time;

- if y_k is negative, cell k is considered "late" compared to the theoretical time. The next cell reference time c_{k+1} is computed and the value for Q_k is computed taking into account the computed values for Q_{k-1} and y_k.

This method does not provide correct results when cell loss or misinsertion occurs. Methods capable of handling such outcomes are for further study. One such method would count the number of lost or misinserted cells and shift the expected arrival times for subsequent cells accordingly.

The method described above does not provide an estimate of the quantiles of the cell transfer delay distribution. Such quantiles could be estimated by measuring the 2-point CDV distribution. A more complete measurement process could be elaborated based on the process described here.

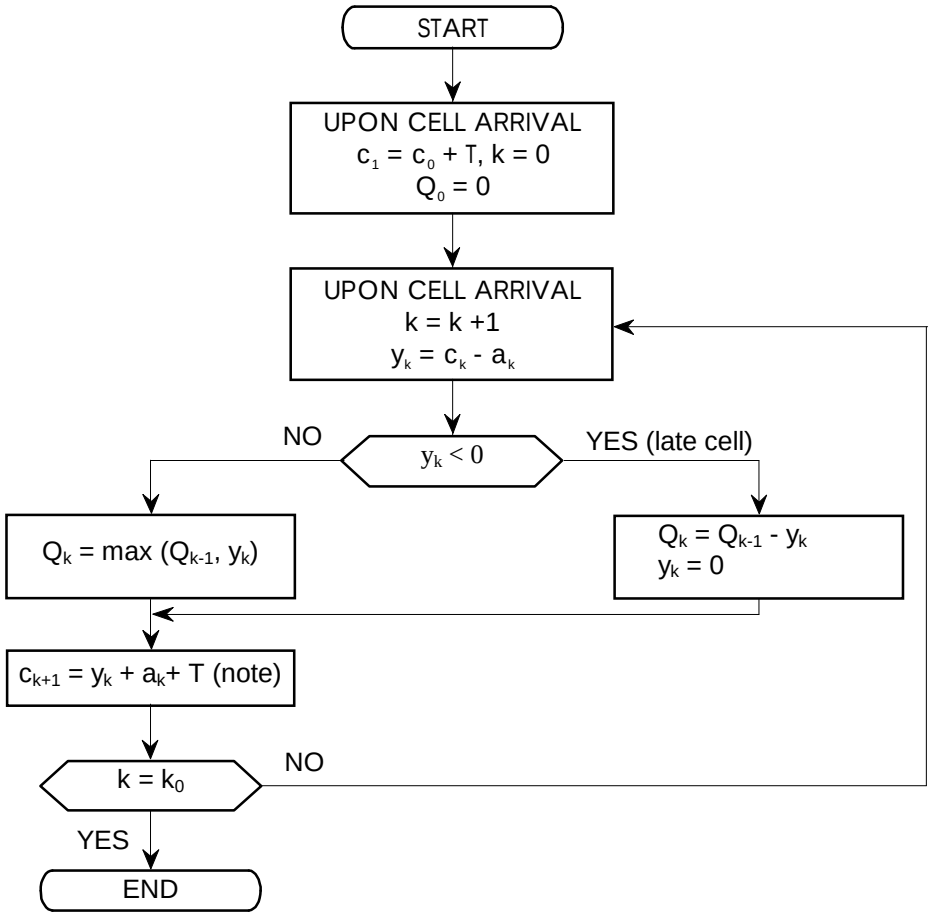
In the above method, when the modified reference arrival time pattern (c''_k) is defined as follows:

$$c_0 = a_0 = 0$$

$$c''_{k+1} = c''_k + T$$

and no lost or misinserted cell outcomes occur in the measured cell stream, the distribution of the values of $y''_k = c''_k - a_k$ can be used to estimate 2-point CDV distribution quantiles.

NOTE: The use of AAL protocol mechanisms in ATM layer performance measurement is for further study.



NOTE: If $y_k < 0$ upon cell arrival, then $c_{k+1} = y_k + a_k + T = a_k + T$.

If $y_k \geq 0$ upon cell arrival, then $c_{k+1} = y_k + a_k + T = c_k + T$.

Variables:

c_k reference arrival time for cell k at MP
a_k actual arrival time for cell k at MP
y_k 1-point CDV
Q_k observed range of cell transfer delay in the set of cells up to cell k

Figure C.3: Estimation of the range of 2-point CDV from 1-point CDV for connections providing CBR service

C.7 Number of non conforming cells

A virtual connection provides negotiated values for peak emission interval T (inverse of peak cell rate) and Cell Delay Variation (CDV) tolerance τ. As long as the y_k value computed as in subclause 6.5.2.1 is smaller than τ, cell k is observed as conforming with a specified peak cell rate (1/T) and a Cell Delay

Variation (CDV) tolerance τ. However, when some cells are observed as non-conforming (i.e. $y_k > \tau$) it is useful to measure the number of non-conforming cells in a given cell stream. Figure C.4 illustrates one measurement method that calculates, for a cell stream received at an MP, the number of cells (n) that do not conform with a specified peak cell rate (1/T) and Cell Delay Variation (CDV) tolerance τ. This number could be divided by the number of cells (ko) arriving at the MP during an observation period to calculate a cell non-conforming ratio (n/ko). The virtual scheduling and leaky bucket algorithms described in annex 1 of ITU-T Recommendation I.371 [5] as equivalent peak cell rate monitoring algorithms may be used to implement the measurement of nonconforming ratio. To facilitate comparison of such implementations, the mapping between the variables of the two equivalent algorithms are summarized in table C.1.

NOTE 1: The method modifies the values computed for (c_k) and (y_k) if non-conforming cells are observed. The set of variables (c'_k) and (y'_k) represent the theoretical arrival time and the one-point CDV, respectively, for a specific value of CDV tolerance (τ) of the kth cell. These variables are obtained as follows:

$c'_0 = a_0$

$c'_{k+1} = c'_k$ when $c'_k > a_k + \tau$

$= a_k + T$ when $c'_k \leq a_k$

$= c'_k + T$ otherwise;

$y_k = c'_k - a_k$

Note that $c_k = c'_k$ and $y_k = y'_k$ if only conforming cells are observed (up to cell k).

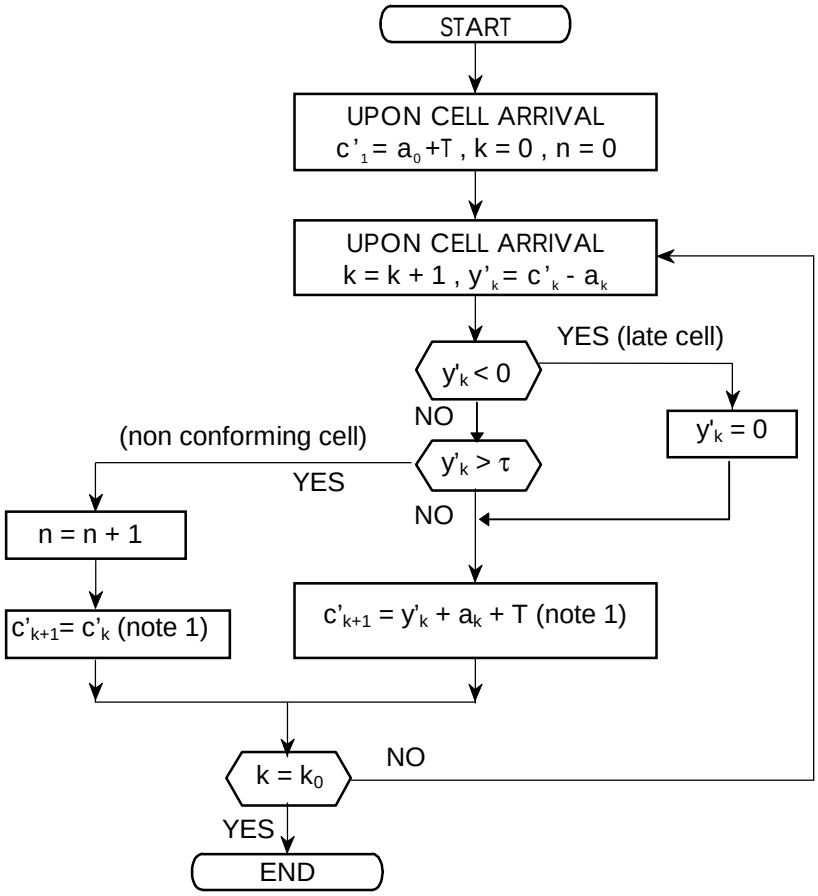
Other methods of calculating the total number of non-conforming cells are possible.

NOTE 2: During the life of the VCC, long silence periods may happen between two consecutive cells. This may lead to wrong decision on conforming cells due to the fact that real blocks have finite time cycles. Special care shall be taken in the implementation to minimize this phenomenon.

Mapping between the variables defined in clause C.7 and those of virtual scheduling and continuous state leaky bucket algorithms defined in annex 1 of ITU-T Recommendation I.371 [5].

Table C.1

Variable defined in various algorithms	Clause C.7	Virtual scheduling	Continuous state leaky bucket
Theoretical arrival time of cell k	c'_k	TAT	x+LCT
Actual arrival time	a_k	ta	ta
Modified one-point CDV parameter for cell k	y'_k	TAT - ta	x'
Parameter values at first observed arrival time	$c'_0 = a_0$	TAT = a_0	x = 0 LCT = a_0



NOTE 1: If $y'_k < 0$ upon cell arrival, then $c'_{k+1} = y'_k + a_k + T = a_k + T$.

If $0 \leq y'_k \leq \tau$ upon cell arrival, then $c'_{k+1} = y'_k + a_k + T = c_k + T$.

Variables:

c'_k	cell k reference arrival time at MP
a_k	cell k actual arrival time at MP
y'_k	cell clumping for cell k at MP ($c'_k - a_k$)
τ	CDV tolerance at MP
T	negotiated cell interarrival time
n	non-conforming cell count
k_0	measurement size

NOTE 2: Additional updating is required for the continuous state leaky bucket:

$$LCT_{k+1} = \begin{cases} a_k & \text{if kth cell is conforming} \\ LCT_k & \text{otherwise} \end{cases}$$

Figure C.4: One method of calculating the number of non conforming cells for a given CDV tolerance and peak cell rate

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