INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

I.371.1

(11/2000)

SERIES I: INTEGRATED SERVICES DIGITAL NETWORK

Overall network aspects and functions – General network requirements and functions

Guaranteed frame rate ATM transfer capability

ITU-T Recommendation I.371.1

(Formerly CCITT Recommendation)

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ITU-T Recommendation I.371.1

Guaranteed frame rate ATM transfer capability

Summary

This Recommendation specifies the Guaranteed Frame Rate ATM Transfer Capability as an extension to the ATCs specified in ITU-T I.371.

Source

ITU-T Recommendation I.371.1 was prepared by ITU-T Study Group 13 (2001-2004) and approved under the WTSA Resolution 1 procedure on 24 November 2000.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

ITU-T Recommendation I.371.1

Guaranteed frame rate ATM transfer capability

1 Scope

This Recommendation extends the specification of ATM Transfer Capabilities provided in ITU-T I.371 with the specification of the Guaranteed Frame Rate ATC. It provides a general description, the definition and service model, the source traffic descriptor and the conformance definition and QoS commitments for GFR. Appendices I to IV contain additional material related to the F-GCRA (used in the GFR conformance definition).

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[1] ITU-T I.371 (2000), *Traffic control and congestion control in B-ISDN*.

[2] ITU-T I.356 (2000), *B-ISDN ATM layer cell transfer performance*.

3 Abbreviations and terminology

3.1 Abbreviations

This Recommendation uses the following abbreviations.

ATC	ATM Transfer Capability
ATM	Asynchronous Transfer Mode
AUU	ATM user to ATM user indication (ITU-T I.361)
B-ISDN	Broadband ISDN
CDV	Cell Delay Variation
CF-GCRA	Conforming Cell F-GCRA (Appendix II)
CLP	Cell Loss Priority (bit)
CLR	Cell Loss Ratio
F-GCRA	Frame based Generic Cell Rate Algorithm
GCRA	Generic Cell Rate Algorithm
GFR	Guaranteed Frame Rate
LIT	Last Increment Time
MBS	Maximum Burst Size
MCR	Minimum Cell Rate
MFS	Maximum Frame Size

NPC	Network Parameter Control
OAM	Operation And Maintenance
PCR	Peak Cell Rate
QoS	Quality of Service
RM	Resource Management
UPC	Usage Parameter Control
VCC	Virtual Channel Connection

3.2 Terminology

For the purpose of this Recommendation, the terminology as used in ITU-T I.371 applies.

3.3 External terminology

Term	**Acronym**	**Reference**
Cell delay variation	CDV	ITU-T I.356
Cell loss ratio	CLR	ITU-T I.356
Cell loss priority	CLP	ITU-T I.150

4 GFR traffic parameters and GFR traffic characteristics

This clause lists the additional GFR traffic parameters and the GFR traffic characteristics to extend the specification provided in 5.4.2.3/I.371 and 5.4.4/I.371.

4.1 Specification of other traffic parameters

The following traffic parameters are specified to extend the list provided in 5.4.2.3/I.371.

– Minimum Cell Rate (MCR): For a GFR connection it is used (in conjunction with other parameters) to quantify the lower bound on the number of cells to which the committed QoS applies. It is specified on a per-connection basis.

– Maximum Frame Size (MFS): The maximum number of user generated cells in a frame that may be sent on a GFR connection.

4.2 Traffic characteristics relevant to ATCs

The following traffic characteristics apply to GFR and extend Table 1/I.371.

Table 1/I.371.1 – Traffic characteristics relevant to GFR

	Parameter reference	GFR
PCR(0+1)	5.4.1/I.371	X
τ_{PCR}(0+1)	5.4.1/I.371	X
τ_{IBT}(0)	5.4.2/I.371	X (Note 1)
MCR(0)	5.4.3/I.371, 6.7.2/I.371, 6.2	X
τ_{MCR}(0)	6.2	X
Frame tagging	6	(Note 2)
MFS	6.2	X
NOTE 1 – The value of τ_{IBT} is derived from the parameters MBS, PCR and MCR (see 6.3.3). NOTE 2 – Frame tagging applies to GFR2 only.		

5 High level description of the GFR ATC

This clause contains the high level description of the Guaranteed Frame Rate ATM Transfer Capability, to extend the descriptions provided in 6.2/I.371.

The GFR transfer capability provides a minimum cell rate (MCR) for loss tolerant, non-real time applications with the expectation of transmitting data in excess of the MCR. It is assumed that the user generated data cells are organized in the form of frames that are delineated at the ATM layer. The network does not provide feedback to the user concerning instantaneous available network resources.

Traffic parameters are PCR(0+1), MCR(0), a maximum burst size MBS(0), a maximum frame size MFS(0+1) and tolerances associated with PCR(0+1) and MCR(0). A GFR cell is conforming if it conforms to the PCR(0+1), if it conforms to the maximum frame size and if it conforms to the homogeneous setting of the CLP bit of cells within the same frame. A GFR frame is conforming if all its cells are conforming and if the frame conforms to the Frame based GCRA, F-GCRA(T,τ), with parameters $T = 1/\text{MCR}$ and $\tau = \tau_{IBT} + \tau_{MCR}$, where $\tau_{IBT} = (\text{MBS} - 1) \times (1/\text{MCR} - 1/\text{PCR})$. By sending a frame with all CLP = 1 cells, the user indicates to the network that such a frame is of lesser importance than a frame with all CLP = 0 cells on the same GFR connection.

The GFR ATC allows the commitment to transmit the number of cells in conforming frames with the QoS corresponding to the associated QoS class. QoS commitments can only apply to cells in CLP = 0 frames of which all cells are conforming. Furthermore, with GFR the network attempts to deliver complete frames in excess of the minimum cell rate commitment, if all cells in the frame are conforming and provided that sufficient resources are available.

There are two variants of GFR: GFR1 and GFR2. In GFR1, tagging is not applicable. In GFR2, the network may apply frame tagging to non-conforming frames. Frame tagging means that the CLP bit of each cell of the frame is changed to 1. Frames tagged by the network and frames marked as CLP = 1 by the user are treated identically by the network.

For a complete specification of the GFR ATC, refer to clause 6.

6 Guaranteed Frame Rate transfer capability (GFR)

This clause contains the definition of the Guaranteed Frame Rate ATM Transfer Capability, to extend the definitions provided in 6.4-6.7/I.371.

Some users have traffic characteristics that make it difficult to determine traffic parameters required by existing ATM transfer capabilities. Often such users are also not able to react to explicit feedback from the ATM network. In addition, user data is often organized in frames and may tolerate loss. For sources of such user data it may be sufficient to get a low cell loss commitment that applies to a minimum cell rate and to expect that some of the frames in excess of the minimum cell rate are delivered. To support such traffic in an ATM network, an ATM transfer capability is defined which is termed Guaranteed Frame Rate (GFR).

6.1 Definition and service model

The Guaranteed Frame Rate (GFR) ATM transfer capability is intended to support non-real-time applications. The GFR ATC requires that the user data cells are organized in the form of frames that can be delineated at the ATM layer. The GFR applies to ATM connections that delineate frames using the AUU indication. Any other delineation method, e.g. the use of RM cells, is for further study. The GFR ATC only applies to VCCs, because the AUU indication is not a reliable frame delineation at the VP sublayer.

In the GFR ATC, the user can send a frame either unmarked or marked. By marking a frame the user indicates that the frame is of lesser importance than an unmarked frame on that particular GFR connection. An unmarked frame has all cells of the frame set to CLP = 0, a marked frame has all cells in the frame set to CLP = 1. Frames sent by the user should have all cells with the same setting of the CLP bit. QoS commitments do not apply to cells in frames with mixed setting of the CLP bit nor to cells in marked frames.

The GFR ATC uses a Minimum Cell Rate (MCR), in conjunction with a given Maximum Frame Size (MFS) and a given Maximum Burst Size (MBS). The MFS and MBS are both expressed in cells. QoS commitments apply only if MCR is greater than zero. It is a network option whether the GFR ATC supports MCRs greater than zero.

In addition to MCR, MBS and MFS, a PCR for the user generated CLP = 0 + 1 cells is defined for the GFR ATC. PCR is always larger than MCR.

The following two examples describe the commitment that the user of a GFR connection will receive:

– If MCR > 0 and if the user sends unmarked frames that do not exceed the Maximum Frame Size and the user sends them at a constant rate that is less than or equal to the MCR, then the commitment is that all these frames are delivered across the network according to the QoS class.

– If MCR > 0 and if the user sends unmarked frames that do not exceed the Maximum Frame Size and the user has not sent cells for a long time and the user sends them in a burst with a length that does not exceed the Maximum Burst Size and at a rate that does not exceed PCR, then the commitment is that all these frames are delivered across the network according to the QoS class.

The GFR ATC also allows the user to send in excess of the negotiated MCR, but traffic that exceeds MCR will only be delivered within the limits of available resources.

The GFR ATC does not provide explicit ATM layer feedback to the source regarding the current level of network congestion. Instead, the level of congestion is derived by the higher layer protocols from the delivery or discard of frames of the connection. VC RM cells on a VCC are not used to operate GFR; however, such cells that would still be present on the connection are considered as part of the user data cell flow. The present version of GFR does not support OAM cells for performance monitoring on a GFR connection.

The service model distinguishes between frames of which all cells are conforming and frames of which not all cells are conforming. GFR cell conformance is defined in 6.3.1.

– For a frame of which all cells are conforming, the network shall attempt to either deliver all the cells or deliver none of the frame's cells. However, if the network delivers only part of such a frame it shall attempt to deliver also the last cell of that frame. For the frames of which all cells are conforming, the ratio of the number of cells in partially delivered frames to the number of cells in all these frame should not be higher than the number of cells in MFS times the committed CLR of QoS class 2, irrespective of the QoS class with which the connection is associated.

  NOTE – Australia maintains its technical reservation on the GFR service model. The reservation reflects Australia's position that GFR delivers partial frames with a probability not higher than the CLR associated with QoS class 1.

– For a frame of which not all cells are conforming, there are no commitments or expectations on the network's delivery of the frame. However, if the network delivers part of such a frame, it should attempt to deliver also the last cell of that frame.

There are two versions of GFR, GFR1 and GFR2. They differ with respect to the treatment of the CLP bit of non-conforming frames:

– GFR1: The network conveys the CLP bit transparently. Tagging is not applicable.
– GFR2: The network may apply frame tagging, by tagging all cells of a frame that does not pass the F-GCRA frame test (see 6.3.2).

6.2 Source traffic descriptor and CDV tolerance

The user and the network agree upon a source traffic descriptor with the following traffic parameters:

– a Peak Cell Rate PCR(0+1) for the user generated CLP = 0 + 1 cells and the associated CDV tolerance $\tau_{PCR}(0+1)$;
– a Minimum Cell Rate MCR(0) for user generated CLP = 0 cells and the associated CDV tolerance $\tau_{MCR}(0)$. If MCR > 0, then it has location, basic events, and coding identical to the PCR (see 5.4.1/I.371);
– a Maximum Frame Size MFS(0+1) expressed in cells;
– a Maximum Burst Size MBS(0) for user generated CLP = 0 cells expressed in cells. MBS should be greater than or equal to MFS.

All the above values can either be conveyed via signalling or assigned on a per subscription basis.

When selecting values for the traffic descriptor and CDV tolerances, the phenomenon described in 6.3.3 under "Parameter selection for minimum throughput" is to be taken into account.

6.3 Conformance definition and QoS commitments

6.3.1 Cell conformance

A GFR user generated cell is conforming if all of the following three conditions are met:

– The cell conforms to the GCRA(1/PCR, τ_{PCR}) test for CLP = 0 + 1 cells.
– The cell is either the last cell of the frame or the number of cells in this frame up to and including this cell is less than MFS.
– The CLP bit of the cell has the same value as the CLP bit of the first cell of the frame.

The GCRA test is applied to every cell and the GCRA is updated (incrementing by $T = 1/\text{PCR}$) when the cell conforms to the GCRA(1/PCR, τ_{PCR}) test.

See 6.3.4 regarding UPC/NPC actions.

6.3.2 Frame conformance and F-GCRA(T,τ)

This clause defines frame conformance for GFR1 and GFR2. A frame is conforming if all cells of the frame are conforming (see 6.3.1) and if the frame passes the Frame based Generic Cell Rate Algorithm F-GCRA as described below.

The F-GCRA uses the negotiated value of a cell rate $1/T$, assuming that a tolerance τ is allowed.

The variables of the F-GCRA are as follows:

– t_a denotes the arrival time of the latest cell at a standardized interface;

– X denotes the value of the Leaky Bucket counter, as in the continuous-state leaky bucket algorithm;

– *LIT* denotes the Last Incrementing Time;

– *X_1* and *LIT_1* denote the values of the parameters *X* and *LIT* at the end of the last frame whose first cell was a CLP = 0 cell. The parameters *LIT_1* and *X_1* are used so that the F-GCRA is not updated for a CLP = 0 frame of which all cells are conforming but that did not pass the frame test. It is updated for all other frames that start with a CLP = 0 cell;

– *Frame_test_passed* denotes a connection specific variable that stores the frame test result;

– *Frame_tagging* denotes a connection specific variable that is only used in GFR2. It stores the frame tagging status. If frame tagging for GFR is implemented, then this status information could be used to change the CLP bit from 0 to 1;

– X' is an auxiliary variable.

Initialization of the F-GCRA variables:

– At the time of arrival t_a of the first cell of the connection to cross the given interface, $X = X\_1 = 0$ and $LIT = LIT\_1 = t_a$.

– The initial values of frame_test_passed and frame_tagging are irrelevant.

The F-GCRA is defined as follows:

The algorithm below has three parts. Part 1 is executed before part 2, and part 2 is executed before part 3.

Part 1: At the arrival of the *first* cell of a frame at a given interface T_B or inter-network interface, on the ATM connection.

GFR1

```
if (CLP = 1)
    then frame_test_passed = false
    else
        X' = X – (ta – LIT)
        if (X' > τ)
            then frame_test_passed = false
            else frame_test_passed = true
```

GFR2

```
if (CLP = 1)
    then frame_test_passed = false;
        frame_tagging = false
    else
        X' = X – (ta – LIT)
        if (X' > τ)
            then frame_test_passed = false;
                frame_tagging = true
            else frame_test_passed = true;
                frame_tagging = false
```

Part 2: At the arrival of *each* cell of a frame whose first cell was a CLP = 0 cell.

GFR1 and GFR2

X' = X – (t_a – LIT)
X = max(0, X') + T
LIT = t_a

Part 3: At the arrival of the *last* cell of a frame whose first cell was a CLP = 0 cell.

GFR1 and GFR2

if (frame contained a non-conforming cell) or (frame_test_passed = true)
then X_1 = X; LIT_1 = LIT
else X = X_1; LIT = LIT_1

NOTE – The reader is referred to Appendix II for an algorithm called CF-GCRA. This algorithm is less exact than F-GCRA in testing frame conformance, but could form the basis of simple implementations, provided tolerances are set to sufficiently large values.

6.3.3 QoS commitments

QoS commitments are the same for GFR1 and GFR2.

QoS commitments apply only to connections with MCR greater than zero. Therefore it is assumed that MCR is greater than zero in the following. There are no commitments on CDV or cell transfer delay.

The GFR ATC provides a QoS commitment in terms of a cell loss ratio according to the associated QoS class for the number of cells in conforming frames (see 6.3.2), where at a standardized interface the F-GCRA(T,τ) is applied with the parameters $T = 1/\text{MCR}$ and $\tau = \tau_{IBT} + \tau_{MCR}$, and where $\tau_{IBT} = (\text{MBS} - 1)\cdot(1/\text{MCR} - 1/\text{PCR})$.

Additional procedural commitments

In addition to the QoS commitments, the GFR ATC includes the procedural commitment that, when there are sufficient resources available, some CLP = 0 frames of which all cells are conforming yet are failing the F-GCRA test and some CLP = 1 frames of which all cells are conforming will be delivered. To deliver these frames in excess of the QoS commitments, a network-specific policy is applied to allocate a share of the available resources to each GFR connection involved. Network-specific policies are not subject to standardization. In such a network policy, the network could, for example, take the CLP status of the frames into account by discarding CLP = 1 frames in preference to CLP = 0 frames on that particular GFR connection.

There are no commitments for frames of which not all cells are conforming and the network is allowed to discard any cell of these frames. However, if the network delivers part of such a frame, it should attempt to deliver also the last cell of that frame. If some cells on a GFR connection are non-conforming, then the network may consider the GFR connection as non-compliant, see 5.3.2/I.371.

Parameter selection for minimum throughput

The F-GCRA may show a phenomenon similar to the phenomenon for the GCRA as described in Appendix III/I.371. Under certain conditions, and when CLP = 0 frames of which all cells are conforming, arrive at the F-GCRA(1/MCR, $\tau_{IBT} + \tau_{MCR}$) with a cell rate greater than MCR, the cell rate of *conforming frames* can be less than MCR. It can be shown that this phenomenon is not present if $\tau_{IBT} + \tau_{MCR} \geq \text{MFS/MCR}$.

6.3.4 UPC/NPC actions

During the connection lifetime, cell conformance may be continuously checked within the network by static UPC/NPC mechanisms, given such UPC/NPC mechanisms are present (see 7.2.3/I.371). The conformance definition does not imply any particular implementation of the UPC/NPC.

For a frame of which not all cells are conforming, the network is allowed to discard any cell of the frame, e.g. to discard isolated cells or to perform frame tail discard. For a frame of which all cells except the last one are conforming, it may be desirable to retain that last cell and to update the GCRA, even if that cell did not pass the GCRA(1/PCR,τ_{PCR}) test.

APPENDIX I

Additional material related to the F-GCRA

The following is a list of additional comments on the F-GCRA which are added to aid the reader's understanding of the behaviour of F-GCRA.

I.1 The support of QoS commitments through F-GCRA

For deriving the QoS commitments, the GFR ATC uses the Frame based Generic Cell Rate Algorithm F-GCRA(T,τ) defined in 6.3.2. The GFR ATC provides a QoS commitment in terms of a low cell loss ratio for at least the number of cells in conforming frames.

One expects that if the tolerance of the F-GCRA increases, that the total number of cells in conforming frames will not decrease. However, this is not always true when the frames have different lengths. This will be shown by way of an example. Results will be stated under which conditions this unexpected phenomenon disappears.

Example

The following example shows that an increase of the tolerance of the F-GCRA may reduce the total number of cells in conforming frames if frames have different lengths. In the following we will assume that all cells in CLP = 0 frames are conforming.

In the first part of the example assume that the tolerance of the F-GCRA is $\tau = \tau_{IBT} + \tau_{MCR}$ and in the second part of the example assume that the tolerance is $\tau' = \tau_{IBT} + \tau'_{MCR}$ where τ'_{MCR} is larger than τ_{MCR}. For both parts of the example $T = 1/\text{MCR}$.

Assume that before the arrival of the first cell of a frame, X' was always less than or equal to τ for the previous cells. This means that the values of X' in both parts of the example were the same until now. Assume that for a GFR connection, a short frame (frame length = 1) arrives that is followed by a long frame with length MFS >> 1. Assume that the F-GCRA parameter X' at the arrival of the first cell of the short frame is just slightly above τ but still below τ'.

Therefore, in the first part of the example the short frame would not pass the F-GCRA frame test. In that case it may happen that the subsequent long frame would pass.

On the other hand, in the second part of the example the short frame passes the F-GCRA frame test, but it may happen that the subsequent long frame would not pass.

As a result, out of the MFS + 1 arriving cells there are MFS cells in frames that passed in the first part of the example and there is one cell in frames that passed in the second part of the example. Therefore, the case of increased tolerance produced less cells in frames that passed. This is not what one expects.

Result

The following result shows that this unexpected phenomenon disappears if the increase in tolerance is "sufficiently" large. The proof of the result can be found in I.4.

The number of cells in conforming frames is determined with two F-GCRAs on the same cell flow: a reference F-GCRA(T,τ) and a second F-GCRA(T',τ'). Define the capacity of the reference F-GCRA as $C = 1 + \tau/T$ and the capacity of the second F-GCRA as $C' = 1 + \tau'/T'$.

If $T' \leq T$ and $C' \geq C + \text{MFS}$ then the total number of cells in conforming frames as determined by the second F-GCRA is at least as large as the total number of cells in conforming frames as determined by the reference F-GCRA.

Consequences of the result

If the F-GCRA is not implemented with the exact parameters (T,τ) but with the parameters (T′,τ') then the undesirable phenomenon described above will not arise if the parameters T' and τ' are chosen so that $T' \leq T$ and $\tau'/T' \geq \tau/T + \text{MFS}$. Using such parameters (T',τ') may result in an increase by MFS cells of the buffer space to be reserved in a network element for the connection.

I.2 Example implementation illustrating how F-GCRA may be used to support QoS commitments

In this example a possible GFR implementation is described to show the relationship between F-GCRA and cell forwarding decisions taken in the implementation.

- A QoS reference counter is used per GFR connection. It is set to zero at the arrival of the first cell of the connection.
- At the arrival of the last cell of a conforming frame, the QoS reference counter is increased by the number of cells of the frame.
- When the last cell of a CLP = 0 frame of which all cells are conforming leaves the implementation, the QoS reference counter is decreased by the number of cells of the frame, but it is never decreased below zero.
- It is anticipated that the QoS reference counter returns to zero very often. This would mean that the implementation would provide at least the committed QoS for the GFR connection.
- It is anticipated that even when the QoS reference counter is zero that frames may leave the implementation if excess resources are available.

I.3 Implementation limits for the case of many non-conforming frames

The variables X' and X may grow beyond any limit in the case that many non-conforming frames are sent. In an implementation of the F-GCRA, X' and X have to be limited so they will not exceed a network specific value. For any connection, to have committed QoS in the network, its $\tau + T \times \text{MFS}$ should not exceed that network specific value.

I.4 Proof of a result related to F-GCRA

The following result and its proof were mentioned in I.1.

QoS result

Assume that QoS is determined by two frame-based GCRAs on the same cell flow. A reference F-GCRA(T,τ) and a second F-GCRA(T',τ'). Define the capacity of the reference F-GCRA as $C = 1+\tau/T$ and the capacity of the second F-GCRA as $C' = 1 + \tau'/T'$. If $T' \leq T$ and $C' \geq C + \text{MFS}$ then $\text{QoS\_count}_n \leq \text{QoS\_count}_n'$ if the cell n is the last cell of a frame. Here QoS_count_n is the number of cells in conforming frames that passed the reference F-GCRA out of the first n cells. QoS_count_n' is defined similarly for the second F-GCRA.

Proof

The proof is by induction on m where $n = n_m$ is the number of cells at the end of the frame m. For $n = n_1$, $QoS\_count_n \le QoS\_count_n'$ is trivial since the first frame receives QoS by both the F-GCRAs or by none.

Now let $QoS\_count_n \le QoS\_count_n'$ for $n = n_m$. Since CLP = 1 frames bypass the F-GCRA one may assume that all frames arriving at the Frame based GCRA start with CLP = 0 cells. Then, once the last cell of frame m+1 has been processed by the F-GCRAs, there is only something to show if the frame m+1 is conforming to the reference F-GCRA and not conforming to the second F-GCRA. Let the first cell of this frame be the cell $j = n_m+1$. At the arrival of cell j, for the variable X'_j for the reference F-GCRA the following relationship holds: $X'_j \le \tau$. For the corresponding variable X''_j for the second F-GCRA the following relationship holds: $X''_j > \tau'$.

For $k = 1, 2, \ldots n$, let t_k be the arrival time of the cell k. Define X'_k and for all cells up to cell n, even for cells in frames that did not pass the frame test. For all the cells up to cell n, the last cell of the frame has arrived so that the cell conformance information about the cells in the frame is available. For the reference F-GCRA, set $X'_k = X - (t_k - LIT\_1)$ for frames where the incrementing is undone and for frames where no incrementing takes place. Similarly, define X''_k for the second F-GCRA. In addition, define $Y'_k = \max(X'_k, 0)$ and $Y''_k = \max(X''_k, 0)$.

For a cell $k \le n$, the QoS_count_k can be defined naturally as follows: if the corresponding frame contains one or more non-conforming cells or is not conforming, the value QoS_count_k is the same as at the end of the previous frame. Otherwise it increases by one for every cell of the frame. Similarly for QoS_count_k'. With this definition one also gets that $QoS\_count_k \le QoS\_count_k'$ for $k = 1, \ldots, n$.

Note that $Y''_j/T' = X''_j/T' > \tau'/T' = C'-1 \ge C-1 + \text{MFS} = \tau/T + \text{MFS} \ge Y'_j/T + \text{MFS}$ and thus:

$$Y''_j/T' - Y'_j/T > \text{MFS} \qquad \text{(I.1)}$$

Let the cell i be the last cell arriving before cell j such that $Y''_i = 0$. Then $1 \le i < j$. Then:

$$Y''_i/T' - Y'_i/T \le 0 \qquad \text{(I.2)}$$

One then gets the following:

– For every cell of a conforming frame according to the second F-GCRA and not to the reference F-GCRA, the incrementing will result in an increase of the difference $Y''/T' - Y'/T$ by one.

– For every cell of a conforming frame according to the reference F-GCRA and not to the second F-GCRA, the incrementing will result in a decrease of the difference $Y''/T' - Y'/T$ by one.

– For all other cells of frames of which all cells are conforming, the incrementing will not change the difference $Y''/T' - Y'/T$.

– For every cell of a frame of which not all cells are conforming, the incrementing will result in an increase of Y'/T by one and in an increase of Y''/T by one. This will not result in an increase of $Y''/T' - Y'/T$.

Also since $Y'' > 0$ from cell i+1 to j, and since $T \ge T'$, Y''/T' is decremented from cell to cell at most as much as Y'/T. This means that the decrementing does not increase the difference $Y''/T' - Y'/T$.

Therefore inequalities (I.1) and (I.2) show that of the cells i up to $j-1$, the second F-GCRA has found at least MFS cells more in conforming unmarked frames that passed the frame test than the reference F-GCRA. Therefore $QoS\_count_{j-1} + MFS \leq QoS\_count_{j-1}'$ or $QoS\_countn_m + MFS \leq QoS\_countn_m'$. Since the frame $m+1$ is conforming, it has a size of at most MFS cells and one gets $QoS\_count_n \leq QoS\_count'$ for $n = n_{m+1}$ which finishes the proof.

APPENDIX II

Providing GFR QoS with the CF-GCRA

This appendix contains an algorithm called the cell conforming F-GCRA (CF-GCRA). The CF-GCRA is equivalent to the F-GCRA algorithm for connections containing *only* frames of which all cells are conforming. It is simpler than the F-GCRA and can also be used to provide GFR QoS because of the following: under the condition that all cells are conforming, it can be shown (the proof is similar to the proof in Appendix I.4), that the number of cells in frames that pass the CF-GCRA is at least as large as the number of cells in frames that pass the F-GCRA. This assumes that the CF-GCRA is not implemented with the exact parameters (T,τ) but with the parameters (T',τ') where $T' \leq T$ and $\tau'/T' \geq \tau/T + \text{MFS}$. With these settings of T' and τ', the minimum QoS commitments based on F-GCRA are met.

In the CF-GCRA below:

– t_a denotes the arrival time of the latest cell at a standardized interface.
– X denotes the value of the Leaky Bucket counter, as in the continuous-state leaky bucket algorithm.
– *LIT* denotes the Last Incrementing Time.
– *Frame_test_passed* denotes a connection specific variable that stores the frame test result.
– *Frame_tagging* denotes a connection specific variable that is only used in GFR2. It stores the frame tagging status. If frame tagging for GFR is implemented, then this status information could be used to change the CLP bit from 0 to 1.
– X' is an auxiliary variable.

Initialization:

– At the time of arrival t_a of the first cell of the connection to cross the given interface, $X = 0$ and $LIT = t_a$.
– The initial values of *frame_test_passed* and *frame_tagging* are irrelevant.

At the arrival of the *first* cell of the frame at a given interface T_B or inter-network interface, on the ATM connection:

GFR1

```
if (CLP = 1)
    then frame_test_passed = false
    else
        X' = X – (ta – LIT)
        if (X' > τ)
            then frame_test_passed = false
            else frame_test_passed = true
            X = max(0,X') + T
                LIT = ta
```

GFR2

```
if (CLP = 1)
    then frame_test_passed = false;
        frame_tagging = false
    else
        X' = X – (ta – LIT)
        if (X' > τ)
            then frame_test_passed = false;
                frame_tagging = true
            else frame_test_passed = true;
                frame_tagging = false
            X = max(0,X') + T
                LIT = ta
```

At the arrival of *subsequent* cells of a frame at a given interface T_B or inter-network interface, on the ATM connection:

GFR1 and GFR2

```
if (frame_test_passed = true)
    then X' = X – (ta – LIT)
    X = max(0, X') + T
    LIT = ta
```

APPENDIX III

Expectations of a GFR network element behaviour

From clause 6.1 on the GFR service model, some minimal GFR implementation requirements may be derived. The following contains expectations on how a network element could support GFR in order to improve the GFR service.

– If the connection transmits a mixture of CLP = 0 and CLP = 1 frames at a constant overall cell rate which is below MCR and assuming that all cells are conforming, then the network element should deliver all of the connection's frames.

– If the connection transmits CLP = 0 frames at a cell rate lower than MCR and in addition CLP = 1 frames such that the overall cell rate is higher than the MCR and assuming that all cells are conforming, then the network element should deliver all the conforming frames (the CLP = 0 frames, as part of the commitments) and, in addition, deliver an overall rate of at least MCR for that connection.

APPENDIX IV

Applicability of GFR ATM Transfer Capability to applications

This appendix extends Table IX.1/I.371, which illustrates the applicability of ATCs and QoS classes through examples of applications, with an example application for the GFR ATC defined in this Recommendation. Where rate parameters are listed, their associated tolerances are also relevant. See Table IV.1.

Table IV.1/I.371.1 – Examples of applications, ATCs, parameters and QoS classes

Example application	ATM Transfer Capability	QoS class	Transfer Capability Parameters	Remarks
IP support (edge-to-edge router connection)	GFR	QoS class 3 for conforming frames	PCR, MCR/IBT, MFS	IP traffic between two routers is put into a GFR VCC. Minimum throughput and QoS support and frame discard.

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Geneva, 2001