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SERIES I: INTEGRATED SERVICES DIGITAL NETWORK

Overall network aspects and functions – General network requirements and functions

ATM Adaptation Layer (ALL) performance

ITU-T Recommendation I.381

(Formerly CCITT Recommendation)

ITU-T I-SERIES RECOMMENDATIONS

INTEGRATED SERVICES DIGITAL NETWORK

GENERAL STRUCTURE	
Terminology	I.110–I.119
Description of ISDNs	I.120–I.129
General modelling methods	I.130–I.139
Telecommunication network and service attributes	I.140–I.149
General description of asynchronous transfer mode	I.150–I.199
SERVICE CAPABILITIES	
Scope	I.200–I.209
General aspects of services in ISDN	I.210–I.219
Common aspects of services in the ISDN	I.220–I.229
Bearer services supported by an ISDN	I.230–I.239
Teleservices supported by an ISDN	I.240–I.249
Supplementary services in ISDN	I.250–I.299
OVERALL NETWORK ASPECTS AND FUNCTIONS	
Network functional principles	I.310–I.319
Reference models	I.320–I.329
Numbering, addressing and routing	I.330–I.339
Connection types	I.340–I.349
Performance objectives	I.350–I.359
Protocol layer requirements	I.360–I.369
General network requirements and functions	**I.370–I.399**
ISDN USER-NETWORK INTERFACES	
Application of I-series Recommendations to ISDN user-network interfaces	I.420–I.429
Layer 1 Recommendations	I.430–I.439
Layer 2 Recommendations	I.440–I.449
Layer 3 Recommendations	I.450–I.459
Multiplexing, rate adaption and support of existing interfaces	I.460–I.469
Aspects of ISDN affecting terminal requirements	I.470–I.499
INTERNETWORK INTERFACES	I.500–I.599
MAINTENANCE PRINCIPLES	I.600–I.699
B-ISDN EQUIPMENT ASPECTS	
ATM equipment	I.730–I.739
Transport functions	I.740–I.749
Management of ATM equipment	I.750–I.759
Multiplexing aspects	I.760–I.769

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation I.381

ATM Adaptation Layer (AAL) performance

Summary

This Recommendation describes an approach for the performance description of AAL processes. It is motivated by the need, based on field experiences, to examine more carefully the performance aspects of some specific applications of ATM network technology. The approach presented here provides a unified framework for describing the performance of processes that depend upon AAL Type 1 (AAL-1), AAL Type 2 (AAL-2), AAL Type 3/4 (AAL-3/4), AAL Type 5 (AAL-5), or potentially other types of AAL. For each AAL, parameters that describe loss and delay performance are for further study. These parameters are related to relevant ATM cell transfer performance parameters from ITU-T I.356.

Source

ITU-T Recommendation I.381 was prepared by ITU-T Study Group 13 (2001-2004) and approved under the WTSA Resolution 1 procedure on 1 March 2001.

Keywords

AAL PDU transfer outcomes, ATM Adaptation Layer (AAL), circuit emulation, constant bit rate (CBR) service, internal reference event (IRE), measurement point (MP), PDU reference event (PRE), quality of service (QoS), reference event.

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.

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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

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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

		Page
1	Scope	1
2	References	1
3	Abbreviations and acronyms	1
4	Introduction	2
5	General aspects of performance description for AAL processes	3
5.1	General considerations for internal reference event definitions for all AAL types	7
5.2	Internal reference events for AAL Type 1	10
	5.2.1 Unstructured circuit emulation applications	10
	5.2.2 Structured circuit emulation applications	13
5.3	Internal Reference Events for AAL Type 2	14
	5.3.1 Applications where the service specific convergence sublayer is null	14
	5.3.2 Applications where the service specific convergence sublayer is not null	14
5.4	Internal Reference Events for AAL Type 3/4	14
5.5	Internal Reference Events for AAL Type 5	14
6	AAL PDU transfer outcomes	14
6.1	PDU transfer outcomes for AAL Type 1	15
	6.1.1 Unstructured circuit emulation applications	15
	6.1.2 Structured circuit emulation applications	15
6.2	PDU transfer outcomes for AAL Type 2	15
	6.2.1 Applications where the service specific convergence sublayer is null	15
	6.2.2 Applications where the service specific convergence sublayer is not null	15
6.3	PDU transfer outcomes for AAL Type 3/4	15
6.4	PDU transfer outcomes for AAL Type 5	15
7	AAL performance parameters	18
7.1	Performance parameters for AAL Type 1	18
	7.1.1 Circuit emulation applications	18
7.2	Performance parameters for AAL Type 2	18
	7.2.1 Applications where the service specific convergence sublayer is null	18
	7.2.2 Applications where the service specific convergence sublayer is not null	18
7.3	Performance parameters for AAL Type 3/4	18
7.4	Performance parameters for AAL Type 5	18
	7.4.1 Information loss parameter for AAL Type 5	18
	7.4.2 Information delay parameter for AAL Type 5	21
8	AAL performance objectives	21
9	Allocation of the performance objectives	21

ITU-T Recommendation I.381

ATM Adaptation Layer (AAL) performance

1 Scope

This Recommendation specifies an approach for the performance description of AAL processes [1]. It is motivated by the need, based on field experiences, to examine more carefully the performance aspects of some specific applications of ATM network technology. The approach provides a unified framework for describing the performance of a process that depends upon AAL Type 1 (AAL-1) [2], AAL Type 2 (AAL-2) [3], AAL Type 3/4 (AAL-3/4) [4], AAL Type 5 (AAL-5) [5], or potentially other types of AAL. The Recommendation defines measurement points and reference events for all AAL types, and uses these to define PDU transfer outcomes and AAL performance parameters for AAL Type 5 (PDU transfer outcomes and AAL performance parameters for other AAL Types are FFS).

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.363 (1993), *B-ISDN ATM Adaptation Layer specification*.

[2] ITU-T I.363.1 (1996), *B-ISDN ATM Adaptation Layer specification: Type 1 AAL*.

[3] ITU-T I.363.2 (2000), *B-ISDN ATM Adaptation Layer specification: Type 2 AAL*.

[4] ITU-T I.363.3 (1996), *B-ISDN ATM Adaptation Layer specification: Type 3/4 AAL*.

[5] ITU-T I.363.5 (1996), *B-ISDN ATM Adaptation Layer specification: Type 5 AAL*.

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

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

[8] ITU-T I.350 (1993), *General aspects of quality of service and network performance in digital networks, including ISDNs*.

[9] ITU-T I.353 (1996), *Reference events for defining ISDN and B-ISDN performance parameters*.

[10] ITU-T G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[11] ITU-T G.824 (2000), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy*.

3 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

AAL ATM Adaptation Layer

ATM Asynchronous Transfer Mode

CBR	Constant Bit Rate
CDV	Cell Delay Variation
CER	Cell Error Ratio
CLR	Cell Loss Ratio
CMR	Cell Misinsertion Rate
CPCS	Common Part Convergence Sublayer
CPS	Common Part Sublayer
CS	Convergence Sublayer
MP	Measurement Point
PCI	Protocol Control Information
PDU	Protocol Data Unit
PRE	PDU Reference Event
SAP	Service Access Point
SAR	Segmentation and Reassembly Sublayer
SDU	Service Data Unit
SECBR	Severely Errored Cell Block Ratio
SRE	SDU Reference Event
SSCS	Service Specific Convergence Sublayer
VBR	Variable Bit Rate
VC	Virtual Channel
VP	Virtual Path

4 Introduction

This Recommendation specifies an approach for the performance description of AAL processes [1]. It is motivated by the need, based on field experiences, to examine more carefully the performance aspects of some specific applications of ATM network technology. A means for describing, in a standardized manner, the performance aspects of particular ATM Adaptation Layer (AAL) processes is needed. The approach provides a unified framework for describing the performance of a process that depends upon AAL Type 1 (AAL-1) [2], AAL Type 2 (AAL-2) [3], AAL Type 3/4 (AAL-3/4) [4], AAL Type 5 (AAL-5) [5], or potentially other types of AAL.

The description of performance provided by specific AAL types is important for characterizing and measuring the performance of specific telecommunications applications or services that are supported in whole or in part by ATM-based telecommunications technology. As such applications can be quite diverse in nature, specific performance analysis for each such application is generally needed. While a standardized means for performance description at the ATM layer is available [6], performance analysis for a specific ATM-based application must currently invoke specialized methods to account for relevant aspects of the particular AAL used by that application. This Recommendation provides a unified framework for the performance description of any ATM-based application in terms of an approach that uses standardized methods up to the point at which AAL layer actions have been completed.

Examples of the diverse nature of applications supported by specific AAL types are as follows. AAL-1 supports Deterministic Bit Rate applications that generally have sensitivity to Cell Delay

Variation, AAL-2 is intended to support bandwidth-efficient transmission for low-rate, short length packet applications that are delay sensitive [3], and has the potential for supporting significant emerging uses such as wireless in combination with ATM. AAL-5 processes are significant for popular and emerging ATM applications, which include Transmission Control Protocol/Internet Protocol (TCP/IP) services supported over ATM-based network equipment and the ATM-based Available Bit Rate (ABR) transfer capability [7].

This Recommendation first reviews some general aspects of performance description as they apply to AAL processes. The establishment of reference events that are suitable for measuring the performance of an AAL process is addressed from the viewpoints of both the AAL Service Access Point (SAP) and currently established Measurement Points within telecommunications networks. The Recommendation then proposes an approach for the performance description of AAL processes that is consistent with the general structure provided in ITU-T I.350 [8] and with the use of the reference events specified in ITU-T I.353 [9].

The remainder of this Recommendation is organized as follows. Clause 5 gives a general discussion of performance description for the AAL. This section includes definitions of appropriate Measurement Points, PDU Reference Events, and Internal Reference Events for each AAL type. This is followed by a discussion of the various AAL PDU transfer outcomes in clause 6. Clause 7 describes the performance parameters for each AAL type.

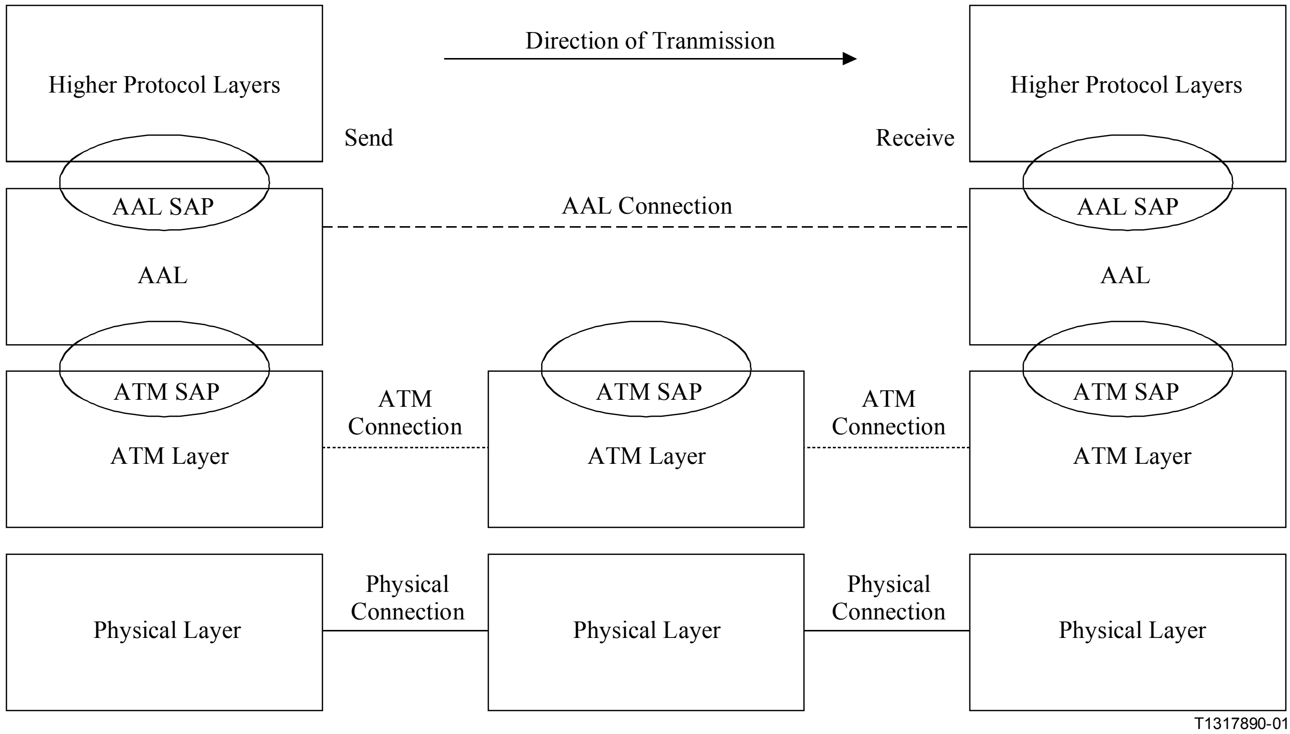
5 General aspects of performance description for AAL processes

This clause gives a general description of Measurement Points (MPs), Internal Reference Events (IREs), and PDU Reference Events (PREs) for all AAL types. Then, specific definitions of IREs are given for each AAL type.

An AAL provides functionality to facilitate the use of ATM layer cell transfer capabilities by higher layer processes, and a specific AAL type is selected to meet the needs of the particular higher layer process associated with a given application. Figure 1 shows the relations between relevant protocol layers and their associated Service Access Points (SAPs). Figure 1 is consistent with ITU-T I.363 [1] and is applicable to all of the currently defined AAL types.

To describe the performance of an AAL process consistent with the general structure provided in ITU-T I.350, it is necessary to define appropriate AAL Protocol Data Unit (PDU) Reference Events, and to then define relevant performance parameters based on these Reference Events. Consistent with ITU-T I.353, the PDU Reference Events are defined at observable MPs, i.e. at physical locations. Each PRE approximates an Internal Reference Event defined within the protocol stack. The IREs are ideally the reference events one would like to measure to determine the AAL performance. However, since the IREs are referred to interfaces within the protocol stack, they are generally not physically accessible with test sets. Each PRE is defined to approximate a respective IRE, and is observable at an MP with a suitable test set, i.e. the PRE is defined based on physical layer test access.

The IRE for each AAL is defined in terms of a specific interface and the respective PDU that crosses that interface. The interfaces and PDUs may be different for different AALs and applications; they are defined to facilitate the definitions of performance measures that are important for the respective application. (In the most general case, an IRE may be defined for each application that uses each AAL). Figure 2a shows all the sublayers and interfaces that are present in any of the currently-defined AALs.



AAL SAP AAL Service Access Point
ATM SAP ATM Service Access Point

Figure 1/I.381 – AAL protocol reference model

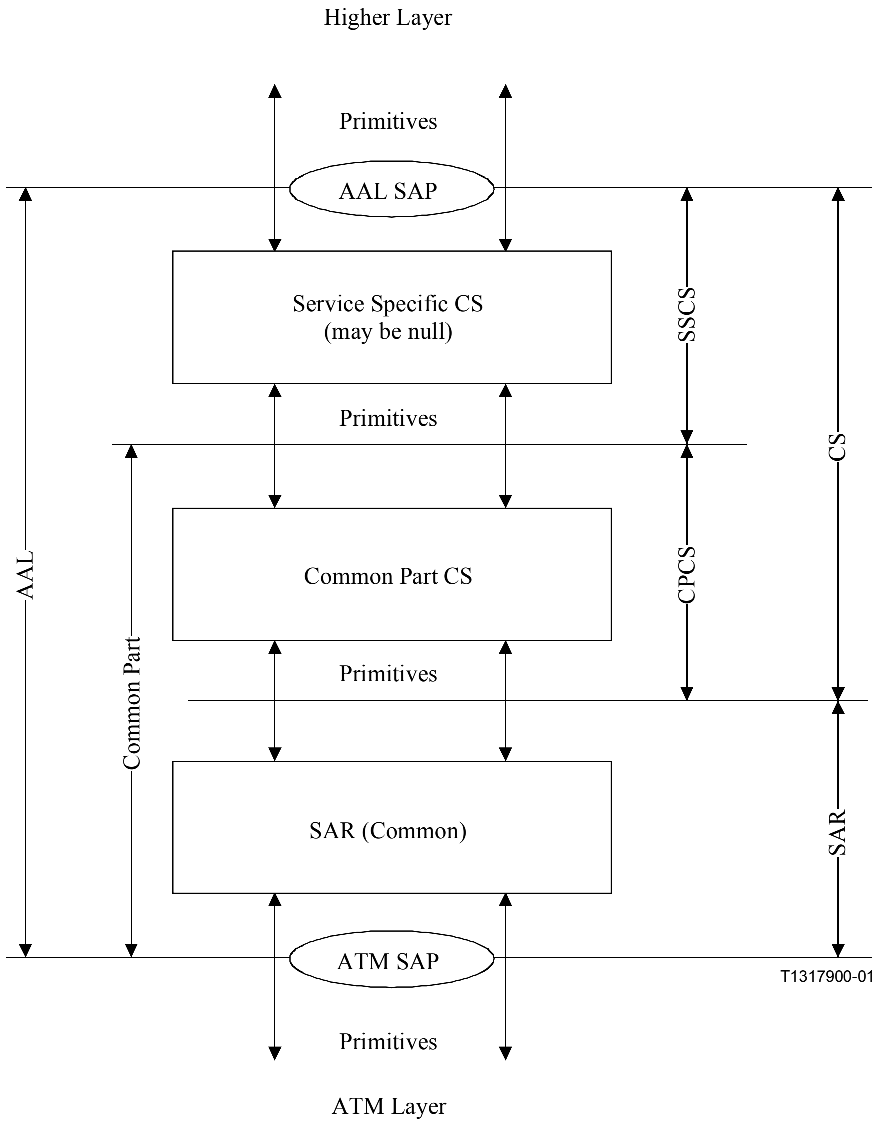


Figure 2a/I.381 – All the AAL sublayers and interfaces defined for any of the currently-defined AALs

Note that all these sublayers and interfaces are defined for AAL Types 3/4, and 5.

Note that not every sublayer and interface in Figure 2a is defined for every AAL (but, every sublayer and interface in Figure 2a is defined in at least one AAL). The figure shows the AAL SAP between the AAL and the next higher layer, and the ATM SAP between the AAL and ATM layer. The AAL is divided into a Convergence Sublayer (CS) and Segmentation and Reassembly Sublayer (SAR). The CS is further divided into a Common Part CS (CPCS) and Service Specific CS (SSCS). The SSCS may be null. Primitives are defined between the various sublayers, as will as between the AAL and ATM layer, and between the AAL and next higher layer. The SAR and CPCS are together referred to as the Common Part.

Figure 2b shows the sublayers that make up AAL Type 1. For AAL-1, only the CS and SAR are defined; the CS is not divided into a CPCS and SSCS.

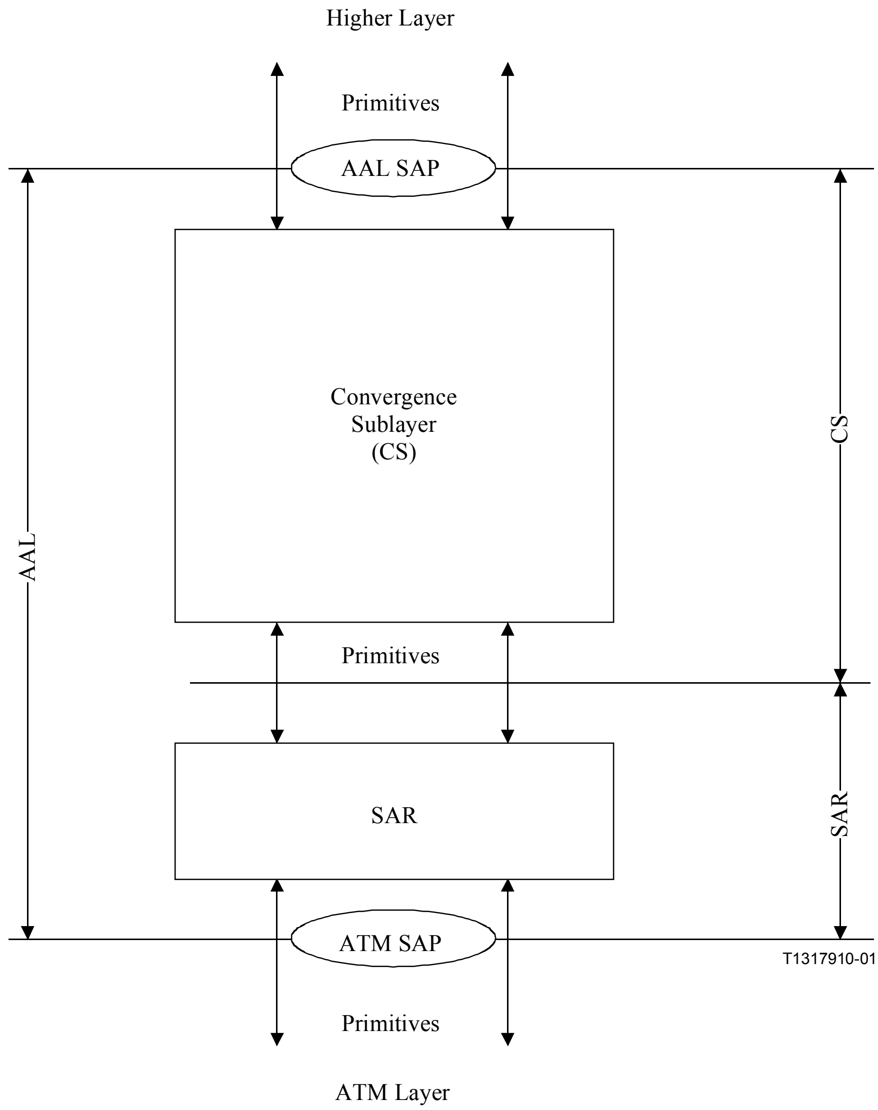


Figure 2b/I.381 – Sublayers and interfaces defined for AAL Type 1

Figure 2c shows the sublayers that make up AAL Type 2. For AAL-2, the SAR and CPCS are not defined separately; only a combined Common Part Sublayer (CPS) is defined (i.e. the SAR and CS are collapsed into a single sublayer).

For AAL Type 3/4 and AAL Type 5, all the sublayers shown in Figure 2a are defined (and, therefore, Figure 2a is not repeated for these AALs).

The PDUs and SDUs defined for the various sublayers are, in many cases, different for the different AAL types. These definitions reflect the applications that tend to use each AAL type. The PDU passed from the AAL to the ATM Layer (i.e. the SAR PDU for AAL Types 1, 3/4, and 5, and the CPS PDU for AAL Type 2 is always 48 octets (because the ATM cell payload is 48 octets).

The IREs, PREs, and MPs for each AAL type are used to describe the performance of that AAL as it transfers PDUs over an established ATM connection between the protocol layer interfaces where the respective IREs are defined. Consistent with the approach in ITU-T I.353, the IRE represents the transfer of a PDU across a desired interface that is defined within the protocol stack. The PRE represents the transfer of a PDU across a physical MP that is located on the network side of the IRE and is as close as practicable to it. Figure 3 is similar to Figure 1, except that it shows two respective IREs and PREs.

The PDU Reference Events are defined as follows, and are illustrated in Figure 4:

1) An AAL PDU Exit Event (shown as PRE_1 in Figures 3 and 4) is defined as occurring when the first bit of an AAL PDU moves across the Measurement Point MP1 near the transmitting equipment.

2) An AAL PDU Entry Event (shown as PRE_2 in Figures 3 and 4) is defined as occurring when the last bit of an AAL PDU moves across the Measurement Point MP2 near the receiving equipment.

Each MP is located near the respective IRE to permit the observation of these AAL PDU Reference Events. As illustrated in Figure 3, MP1 is located near the transmitting equipment, and MP2 is located near the receiving equipment. Test equipment at MP1 and at MP2 would be used to reconstruct the AAL PDUs.

Since each of these MPs is also located near an ATM SAP, the cell transfer reference events CRE_1 and CRE_2 as defined in ITU-T I.353 are also observable, and hence these MPs can also be used to measure ATM cell transfer performance parameters. This coincidence of MPs for AAL performance and for ATM cell transfer performance facilitates the identification of relations between these two types of performance parameters. Such relations for specific AAL types are given later in this Recommendation.

5.1 General considerations for internal reference event definitions for all AAL types

The AAL PDU Reference Events PRE_1 and PRE_2 are defined on the basis of observable events at physical Measurement Points MP1 and MP2, respectively. However, this construction also permits their interpretation from the perspective of the higher layer process supported over the AAL layer. As illustrated by Figure 3, an IRE_1 is associated with the movement of a PDU in the direction from the higher protocol layers, to the AAL layer, and then to the ATM and Physical layers. Similarly, an IRE_2 is associated with the movement of a PDU in the direction from the Physical and ATM layers, to the AAL layer, and then to the higher protocol layers.

This approach for the performance description of AAL processes permits, within the constraints imposed by the placement of physical Measurement Points, interpretation in terms of the transfer of user information between two AALs that communicate over an established ATM connection. As indicated above, the definition of the IRE depends on the AAL type and application (and the specific definitions of the IREs for each AAL and application are given in the following subclauses). However, regardless of AAL type and application, the information content of PRE_1 is, for practical purposes, the same as that of the corresponding IRE_1 that generated it. The time of occurrence of PRE_1, T_1, lags behind the time of IRE_1 by a small and quantifiable amount. The same considerations apply to PRE_2, IRE_2, and T_2.

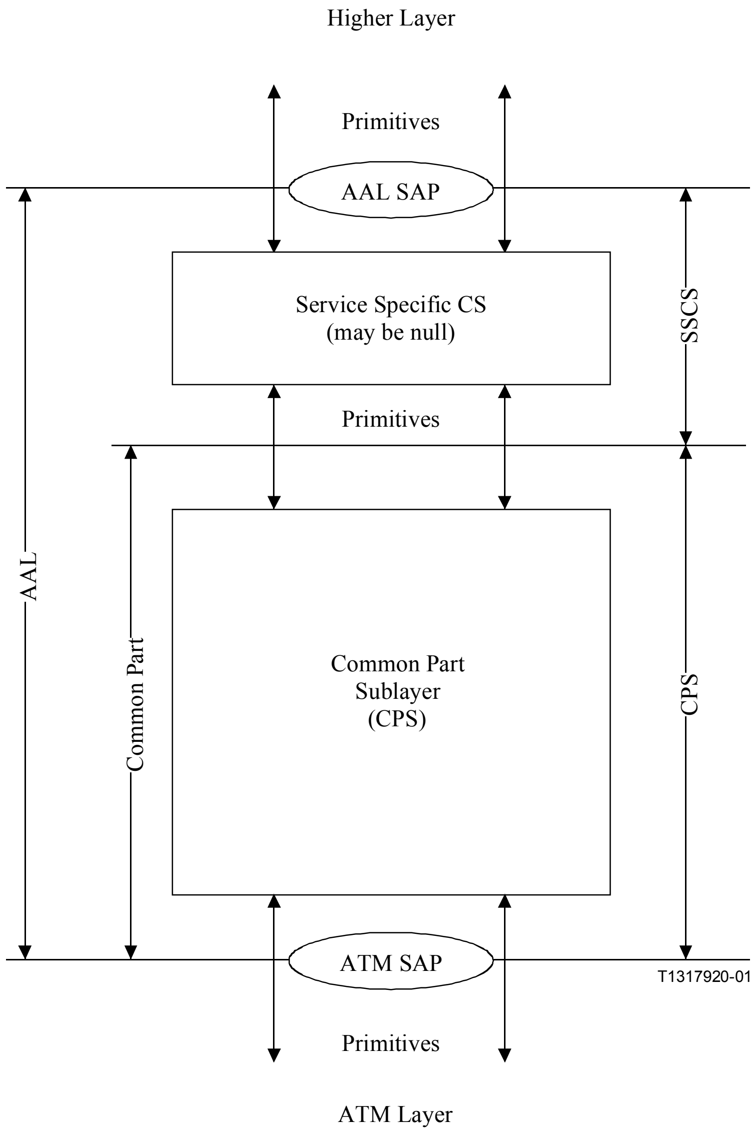
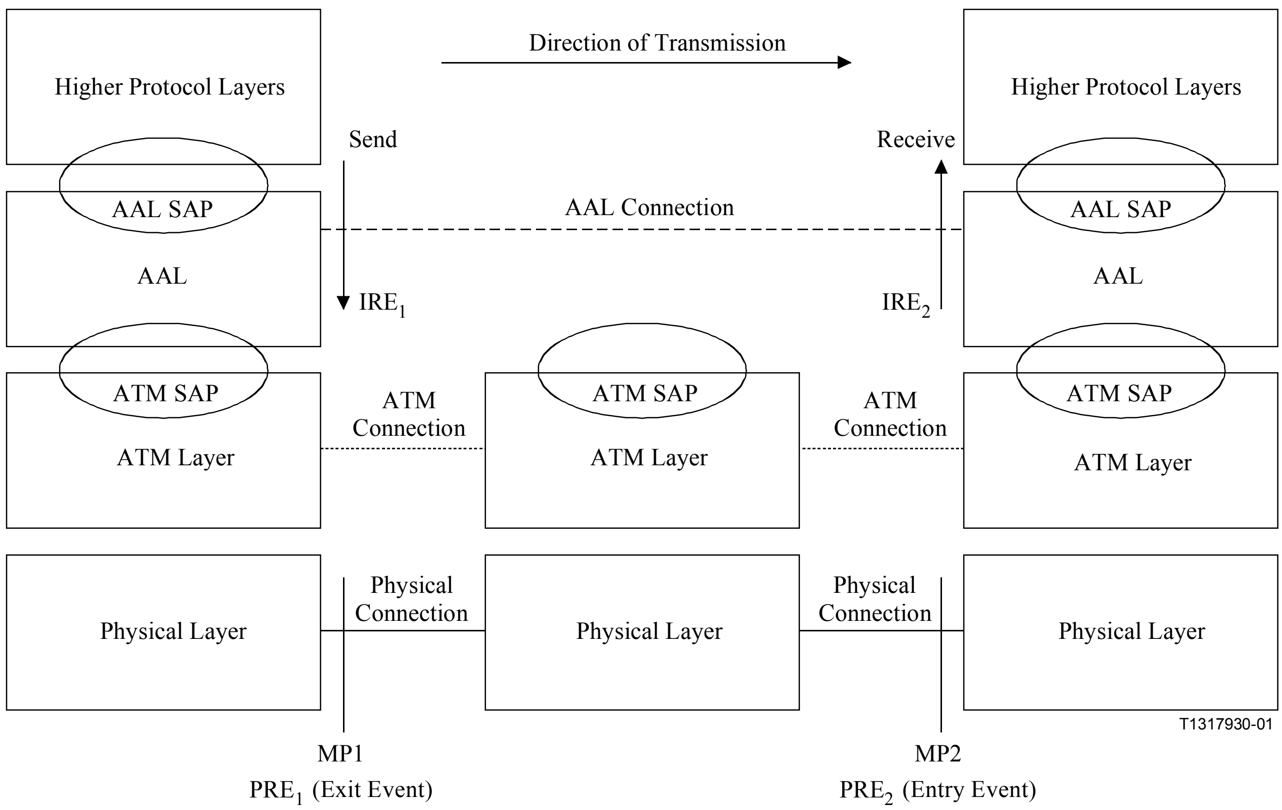


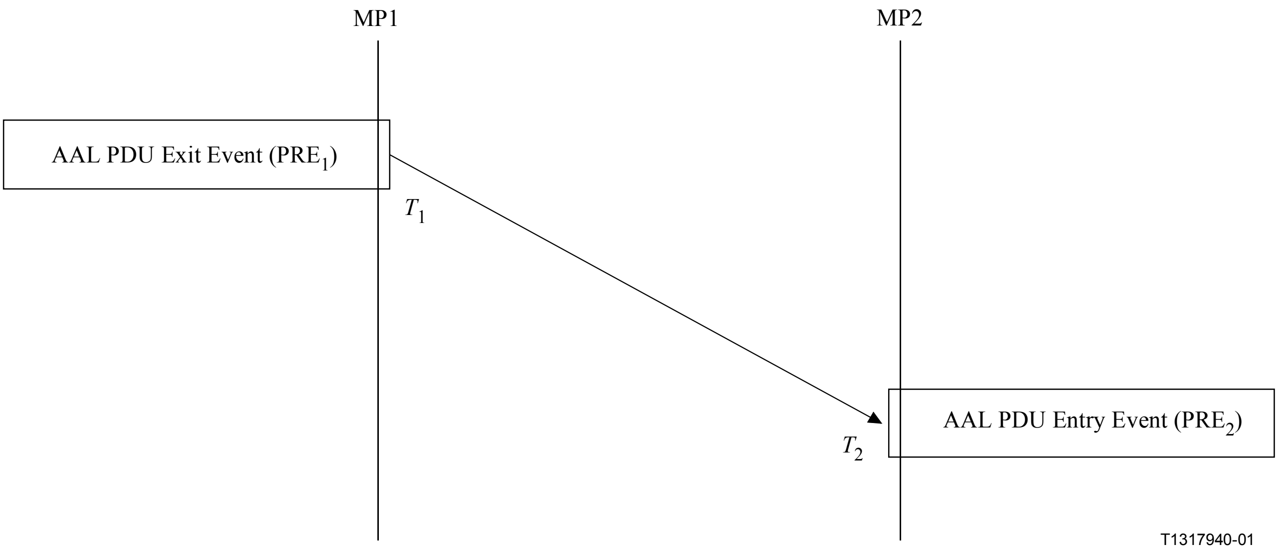
Figure 2c/I.381 – Sublayers and interfaces defined for AAL Type 2



AAL SAP AAL Service Access Point
ATM SAP ATM Service Access Point
MP1 y PM2 Measurement Points located within telecommunications networks

PRE_1 and PRE_2 are AAL PDU Reference Events external to the indicated protocol stacks, and which are observable at the indicated measurement points.

Figure 3/I.381 – Relation of reference events to measurement points (this figure applies to all AAL types)



MP Measurement Point
PRE AAL PDU Reference Event
T_1 and T_2 are times at which PRE_1 and PRE_2 , respectively, occur.

Figure 4/I.381 – PDU reference events

As will be seen in the following subclauses (and as documented in References [1]-[5]), the relative sizes of the SDUs and PDUs for the various sublayers can be quite different for the different AAL types. This is because the different AALs may carry different types of applications. In addition to the different PDU and SDU sizes, the timing of the PDUs at the various interfaces may be different for different applications and AAL types. For example, if an application is expecting bits to be delivered by the AAL at a constant rate, the CS will have to buffer the received bits and recover the appropriate clock. The timing of the PDUs received by the CS will not be the same as the timing of the PDUs delivered to the higher layer. This consideration is relevant mainly for AAL Type 1 because CBR applications are mainly carried by AAL-1; however, it is true in principle for any AAL that would carry CBR applications. Alternatively, if a sublayer is expected to deliver PDUs to the higher layer as fast as it receives them from the next lower sublayer, the timing at the interfaces above and below the sublayer is likely to be similar (unless there is some delay in traversing the sublayer). Finally, performance at the interfaces above and below a null sublayer should be the same.

The discussion here indicates that AAL performance parameter definitions can depend on the interfaces that the respective IREs are defined relative to. The IRE definition determines the PDU or SDU whose performance is measured. The delay parameters will be impacted because the timing may be different at the different interfaces. The IRE are chosen appropriately for each AAL and application, and need not be the same for all AALs.

5.2 Internal reference events for AAL Type 1

5.2.1 Unstructured circuit emulation applications

A circuit emulation application involves the transport of a constant bit rate (CBR) service. The Convergence Sublayer (CS) is responsible for reconstructing (i.e. recovering) the CBR service clock. For such applications, the CS SDU is one bit, i.e. the bits are passed to the AAL from the higher layer or delivered by the AAL to the higher layer one bit at a time.[1] At the transmitter, 376 bits (47 octets) are accumulated in the CS buffer; the octets are then passed to the SAR. The SAR SDU is therefore 47 octets; one may also define the CS PDU to be 47 octets (with no overhead added by the CS). The SAR adds a single octet of overhead (the AAL-1 overhead) to produce the 48-octet SAR PDU.

At the receiver, the CS is responsible for recovering the CBR service clock and delivering the bits to the higher layer application at the proper rate. By "delivering the bits to the higher layer application at the proper rate", it is meant that the timing of the bits delivered to the higher layer must meet the appropriate jitter and wander requirements. These requirements are given in ITU-T G.823 [10] for CBR PDH payloads of the 2048 kbit/s hierarchy and ITU-T G.824 [11] for CBR PDH payloads of the 1544 kbit/s hierarchy.

The CBR service bits are available for delivery to the higher layer when the last bit of the SAR SDU, or CS PDU, is delivered to the CS, i.e. placed in the CS receiver buffer *and CS error control and handling of lost and misinserted cells are completed*. Thus, the function within the CS (at the receive end) that performs the clock recovery receives the bits as a batch of 376 bits, and they are received (i.e. available for delivery to the higher layer) after CS error control and handling of lost and misinserted cells have been completed. This clock recovery function must generate a clock such that the bits can be delivered to the higher layer one at a time at such a rate that the respective jitter and wander requirements are met.

The CS error control and sequence count (handling of lost and misinserted cells) functions that must be completed prior to the delivery of the received bits to the higher layer are one source of PDU delay variation added by AAL Type 1. ITU-T I.363.1 [2] states that the processing of sequence count to detect cell loss and misinsertion, and the further handling of lost and misinserted cells, are performed by the CS. For circuit emulation, detected misinserted cells are discarded and lost cells can be compensated for by inserting the appropriate number of dummy SAR-PDU payloads (the SAR-PDU payload is the CS PDU). The actual sequence count operations at the AAL Type 1 transmitter and receiver are described in 2.5.2.1.1 and 2.5.2.1.2 of ITU-T I.363.1, respectively. Two informative examples of algorithms for the sequence count processing at the receiver are given in Appendix III/I.363.1. In the first algorithm, referred to as a *robust* algorithm, the decision to accept a cell (actually, CS PDU, since this is occurring in the CS) is made after the arrival of the next cell. This waiting for the next cell enables the robust algorithm to distinguish between lost and misinserted cells. In the second algorithm, referred to as a *fast* algorithm, the decision to accept a cell is made immediately after the arrival of a cell. A finite state machine for both algorithms is given in Figure III.1/I.363.1. Both algorithms introduce additional delay variability over and above that due to ATM network CDV. In the case of the fast algorithm, the additional delay variability is due to the fact that a dummy CS PDU that is inserted when a cell is lost will generally not be inserted at the same time instant that the cell would have arrived had it not been lost. In the case of the robust algorithm the additional delay variability is due to the fact that the acceptance of a CS PDU that is invalid or out of sequence is held up until subsequent PDUs (cells) are received. Once the subsequent PDUs are received, an appropriate decision is made whether to accept the PDU, discard the PDU, or insert a dummy PDU (note that, as is the case for the fast algorithm, the time instant of insertion of a dummy PDU is generally not the same as the time instant that the cell would have arrived had it not been lost).

Note that the jitter and wander requirements of ITU-T G.823 and ITU-T G.824 apply at a network interface, i.e. they are *network limits*. Any jitter and wander added to a CBR signal by a single AAL Type 1 receiver must be sufficiently below these limits to allow for other sources of jitter and

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[1] ITU-T I.363.1 [2] states (in 2.5.1.1 a)) that the length of the AAL-SDU is one bit when the Synchronous Residual Time Stamp (SRTS) method is used. Here, this statement is considered to be true for circuit emulation applications in general; i.e. the use of an adaptive clock recovery method is not precluded.

wander. For example, a PDH signal might traverse more than one ATM island, i.e. might go through more than one AAL-1 mapping/demapping operation. In addition, the same PDH signal, might traverse a number of SDH islands and PDH multiplex/demultiplex operations. All of these operations add some amount of jitter and wander. Typically, the network limits and jitter and wander hypothetical reference models for the various CBR services are used to derive jitter and wander budgets. The budgets include all sources of jitter and wander, and are used to derive equipment requirements.

ITU-T I.363.1 identifies two principal methods that can be used for CBR clock recovery:

- Synchronous Residual Time Stamp Method (SRTS);
- Adaptive Clock Methods.

The SRTS method makes use of synchronized network timing signals that are assumed to be available at the AAL Type 1 transmitter and receiver (i.e. available to the clock recovery functions within the CS at the transmitter and CS at the receiver, respectively). In contrast, adaptive clock methods do not depend on having available synchronized network timing signals; instead, they use the statistics of the AAL Type 1 CS receive buffer fill variations and/or the statistics of the inter-arrival times between successive CS PDUs to reconstruct the CBR service clock. Essentially, an adaptive clock algorithm filters the CS receive buffer fill variation and/or the sequence of CS PDU arrival times. Therefore, the jitter and wander at the output of the adaptive clock algorithm (i.e. the recovered CBR service clock) depends on the sequence of time instants when successive CS PDUs have been received by the CS and error checking and sequence count handling have been completed. When the adaptive algorithm is designed, it must be known how severe the input CS PDU delay variation that it must filter will be in order to ensure that the output will be within desired limits. Conversely, for a given adaptive algorithm design, keeping the input delay variation within respective limits will ensure that the output meets appropriate equipment requirements (and thus that the G.823 or G.824 network limits are met) provided that the connection does not exceed the hypothetical reference model. This is the basis for choosing the IRE for AAL Type 1 circuit emulation applications as described above, with the internal measurement point within the CS just above the CS error control function. Note that it would not be adequate to constrain only the CDV seen at the top of the ATM layer, because any delay variation due to the AAL Type 1 (e.g. error handling and sequence count operations, which are stochastic effects) would not be accounted for.

While the above discussion might seem to indicate that the AAL-1 IREs and MPs are mainly relevant for adaptive clock algorithms, they are relevant for SRTS in certain cases as well. While the SRTS algorithm does not depend on the sequence of CS PDU arrival times at the receiver, its performance does depend on the timing signals at the transmitter and receiver AAL-1 meeting appropriate synchronization requirements. However, the case where the AAL Type 1 transmitter and/or receiver timing signals lose synchronization must also be considered. This might happen, for example, if clocks at the transmitter or receiver or clocks that either of these two clocks are traceable to enter holdover. In this case, the performance of SRTS depends on the quality of the holdover, the length of time the clock is left in holdover, and the CS receive buffer size. For a given buffer size, if the frequency offset and/or drift rate of the clock in holdover are too large and/or the clock is left in holdover for too long, the CS buffer will overflow or underflow, which results in a misframe at the CBR service layer and a severely errored second (SES). After the first misframe, the rate at which subsequent misframes occur also depends on, in addition to the above factors, whether and how the CS receive buffer is recentered. One can ensure acceptable performance with SRTS when clocks enter holdover by always using clocks of sufficiently good quality and not letting them remain in holdover longer than some maximum length of time. However, this may not always be possible or practical for all applications. Therefore, in at least some cases it may be desirable to have a backup mode that uses an adaptive clock algorithm even when relying primarily on SRTS. The AAL Type 1 IREs and MPs are needed for consideration of the performance of backup adaptive clock algorithms. Note that, while it is desirable that clocks enter holdover as infrequently as possible, in practice this can happen frequently enough that the effect of clocks in holdover on jitter and wander performance cannot be ignored.

The above discussion indicates that, from the standpoint of designing the clock recovery scheme, it is the arrival of the CS PDU at the CS buffer that is important. Therefore, the IREs for AAL Type 1 circuit emulation applications are defined with respect to the interface between the SAR and CS. The approach used in ITU-T I.353 for defining the VP and VC layer MPs (MP(VP) and MP(VC), respectively) for ATM cell transfer performance is followed here. ITU-T I.353 defines the locations of the MP(VP) and MP(VC) interfaces by specifying the protocol functions that are above and below each MP. Using this approach, Internal Reference Events for AAL Type 1 circuit emulation applications are defined as:

1) An AAL Internal Reference Exit Event (shown as IRE_1 in Figure 3) is defined as occurring when the first bit of an AAL CS PDU moves across the protocol layer interface between the AAL CS and the AAL SAR of the transmitting equipment.

2) An AAL Internal Reference Entry Event (shown as IRE_2 in Figure 3) is defined as occurring when the last bit of an AAL CS PDU moves across the protocol layer interface between the AAL CS and the AAL SAR of the receiving equipment.

For purposes of this definition, the interface between the AAL CS and AAL SAR is above the SAR functions specified in 2.4.1/I.363.1 [2] and below the CS functions specified in 2.5.1/I.363.1. The SAR functions include:

a) adding the 1 octet of AAL overhead on the transmitting end, and removing the 1 octet of AAL overhead on the receiving end;

b) processing the 3-bit CRC in the 4-bit Sequence Number Protection (SNP) field of the AAL overhead;

c) processing the single parity bit in the 4-bit SNP field of the AAL overhead; and

d) indication of the existence of a CS above the SAR (via the CSI bit of the 1-octet AAL overhead; note that the SAR receives this indication from the CS).

The CS functions include:

a) blocking of user information to form a 47-octet SAR PDU (CS SDU);

b) buffering of received information to handle cell delay variation;

c) handling of SAR PDU payload assembly delay by partially filling the SAR PDU payload;

d) processing the sequence number (SN) count, including detecting lost and misinserted cells, and stuffing dummy bits (at the receiver) when a lost cell detected;

e) use of the CS indication provided by the SAR sublayer to support CS functions for some AAL users;

f) source clock timing recovery at the receiver (e.g., using SRTS, and adaptive method, etc.);

g) transfer of structure information between source and destination;

h) forward error correction; and

i) generation of reports of end-to-end AAL performance.

Note that not all the above functions are necessarily implemented in every AAL-1. Additional description of these functions is given in ITU-T I.363.1.

5.2.2 Structured circuit emulation applications

For future study.

5.3 Internal Reference Events for AAL Type 2

5.3.1 Applications where the service specific convergence sublayer is null

For the case of AAL Type 2 with a null Service Specific Convergence Sublayer, the SSCS SDU, SSCS PDU, and Common Part Sublayer SDU are the same. The CPS SDU is an integral number of octets up to 45, and in some cases up to 64. A 3-octet packet header is added to the CPS SDU to make a CPS packet. CPS packets are then placed into the payload portion of the CPS PDU, which is 47 octets. Since the CPS packets may be much smaller than 47 octets, a CPS PDU may contain more than one packet; in addition, portions of a single packet may be in different CPS PDUs. Finally, a single octet of CPS overhead is added to make the 48-octet CPS PDU. The details of this are described in [3].

For AAL Type 2 applications, the performance of interest is at the AAL SAP. For the case of a null SSCS, this is the same as the performance at the interface between the SSCS and CPS. The PDU of interest is the SSCS PDU, which corresponds to one CPS packet.

As stated above, a CPS PDU (and an ATM cell) may contain multiple CPS packets (SSCS PDUs); in addition, the first or last bit of a packet may be in the middle of an ATM cell. This bit will not be directly accessible at the physical layer measurement point. Therefore, the PDU Reference Event (PRE) should be defined (i.e. should approximate the associated IRE) with respect to the first or last bit of the ATM cell that contains the first or last bit of the respective packet (SSCS PDU).

5.3.2 Applications where the service specific convergence sublayer is not null

For future study.

5.4 Internal Reference Events for AAL Type 3/4

For AAL Type 3/4, the SSCS SDU and CPCS SDU (these are the same if the SSCS is null) can be as large as 65 535 octets. Therefore, for this AAL type a single AAL SDU may extend over many ATM cells.

5.5 Internal Reference Events for AAL Type 5

Internal Reference Events for AAL Type 5 are defined as:

1) An AAL Internal Reference Exit Event (shown as IRE_1 in Figure 3) is defined as occurring when the first bit of an AAL CS PDU moves across the protocol layer interface between the AAL CS and the AAL SAR of the transmitting equipment.

2) An AAL Internal Reference Entry Event (shown as IRE_2 in Figure 3) is defined as occurring when the last bit of an AAL CS PDU moves across the protocol layer interface between the AAL CS and the AAL SAR of the receiving equipment.

For AAL Type 5, the SSCS SDU and CPCS SDU (these are the same if the SSCS is null) can be as large as 65 535 octets. Therefore, for this AAL Type a single AAL SDU may extend over many ATM cells.

6 AAL PDU transfer outcomes

AAL performance can be described with performance parameters whose definitions are based on these AAL PDU Reference Events. Following the approach used in ITU-T I.356, appropriate AAL PDU transfer outcomes are defined based on the occurrence of appropriate AAL PDU Entry Events (PRE_2) at an MP2 near receiving equipment that correspond to AAL PDU Exit Events (PRE_1) at an MP1 near transmitting equipment. Two AAL PDU Reference Events are said to be *corresponding* if they are created by the same PDU.

Also in parallel with the approach in ITU-T I.356, an *AAL PDU transfer outcome* can be defined as the occurrence at an MP2 of a PRE_2 corresponding to the occurrence at an MP1 of a PRE_1, within a specified time T_{AAL}. The AAL PDU transfer outcome is further classified by certain criteria, such as whether the user information bits in the PRE_2 are identical to the user information bits in the corresponding PRE_1.

6.1 PDU transfer outcomes for AAL Type 1

6.1.1 Unstructured circuit emulation applications

For unstructured circuit emulation applications, the CS SDU (and therefore AAL-1 SDU) is one bit. The AAL PDU transfer outcomes are defined in a manner similar to those for Unrestricted Digital Bearer Services in 5.10/I.353 [9]; for these services, the relevant unit of user information is one bit.

6.1.2 Structured circuit emulation applications

For future study.

6.2 PDU transfer outcomes for AAL Type 2

For future study.

6.2.1 Applications where the service specific convergence sublayer is null

For future study.

6.2.2 Applications where the service specific convergence sublayer is not null

For future study.

6.3 PDU transfer outcomes for AAL Type 3/4

For future study.

6.4 PDU transfer outcomes for AAL Type 5

AAL-5 PDU transfer outcomes should be defined so that they are simple as well as well-defined. The following principles are used:

1) AAL-5 performance parameters should reflect the phenomenon at AAL-5 level, which is independent on the underlying layers such as ATM layer and physical layer, because the only phenomenon at AAL-5 level has the influence on AAL-5 users.
2) An AAL-5 PDU transfer outcome should correspond to each AAL-5 PDU which traverses MP_1 and/or MP_2 as a cell transfer outcome corresponds to each cell which traverses MP_1 and/or MP_2 in ITU-T I.356. This correspondence may make it easy to well define the outcomes.
3) The cell transfer outcome of the last cell of AAL-5 PDU, however, should be taken into account because the last cell loss raises the two impaired AAL-5 PDU transfer outcomes. If the last cell loss was not taken into account, the next AAL-5 PDU would be successful. But, in fact, the next AAL-5 PDU cannot be correctly reassembled by the receiver. For example, the last cell loss raises the two impaired AAL-5 PDUs.

Based on the above principles, AAL-5 PDU transfer outcomes are defined using the two AAL-5 PDU reference events, PRE_1 at MP_1 and PRE_2 at MP_2, respectively. Figure 5 illustrates the possible AAL-5 PDU transfer outcome definitions.

a) **Successful AAL-5 PDU transfer outcome**

A successful cell transfer outcome occurs when a PRE_2 corresponding to PRE_1 happens within a specified time T_{AAL-5} of PRE_1, and the binary content of the received AAL-5 PDU conforms exactly with that of the corresponding transmitted AAL-5 PDU.

b) **Impaired AAL-5 PDU outcome**

An impaired AAL-5 PDU outcome occurs when a PRE_2 corresponding to PRE_1 happens within a specified time T_{AAL-5} of PRE_1, but

1) the binary content of the received AAL-5 PDU differs from that of the corresponding transmitted AAL-5 PDU; and
2) the last cell of the AAL-5 PDU is not lost.

NOTE 1 – Lost cell outcome, errored cell outcome, or misinserted cell outcome may invoke this outcome.

Use of a limit, T_{AAL-5}, on the maximum permissible PDU transfer time classifies unduly delayed PDUs as Impaired PDU Transfer Outcomes. The possible occurrence of a "lost" PDU is included in the above definition as an Impaired PDU Transfer Outcome. The possible occurrence of a "misinserted" PDU is included in the above definition as an Impaired PDU Transfer Outcome.

It is observed that this definition of an Impaired PDU Transfer Outcome does not distinguish between the failure of a PRE_2 to match bit-for-bit with the user information in the corresponding PRE_1 due to the supporting ATM connection's experiencing a lost cell, errored cell, or misinserted cell. Regardless of the underlying impairment cause at the supporting ATM layer, this resulting AAL PDU is unlikely to be usable by most higher layer applications, and therefore contributes to information loss for this AAL process.

c) **Tail lost AAL-5 PDU outcome**

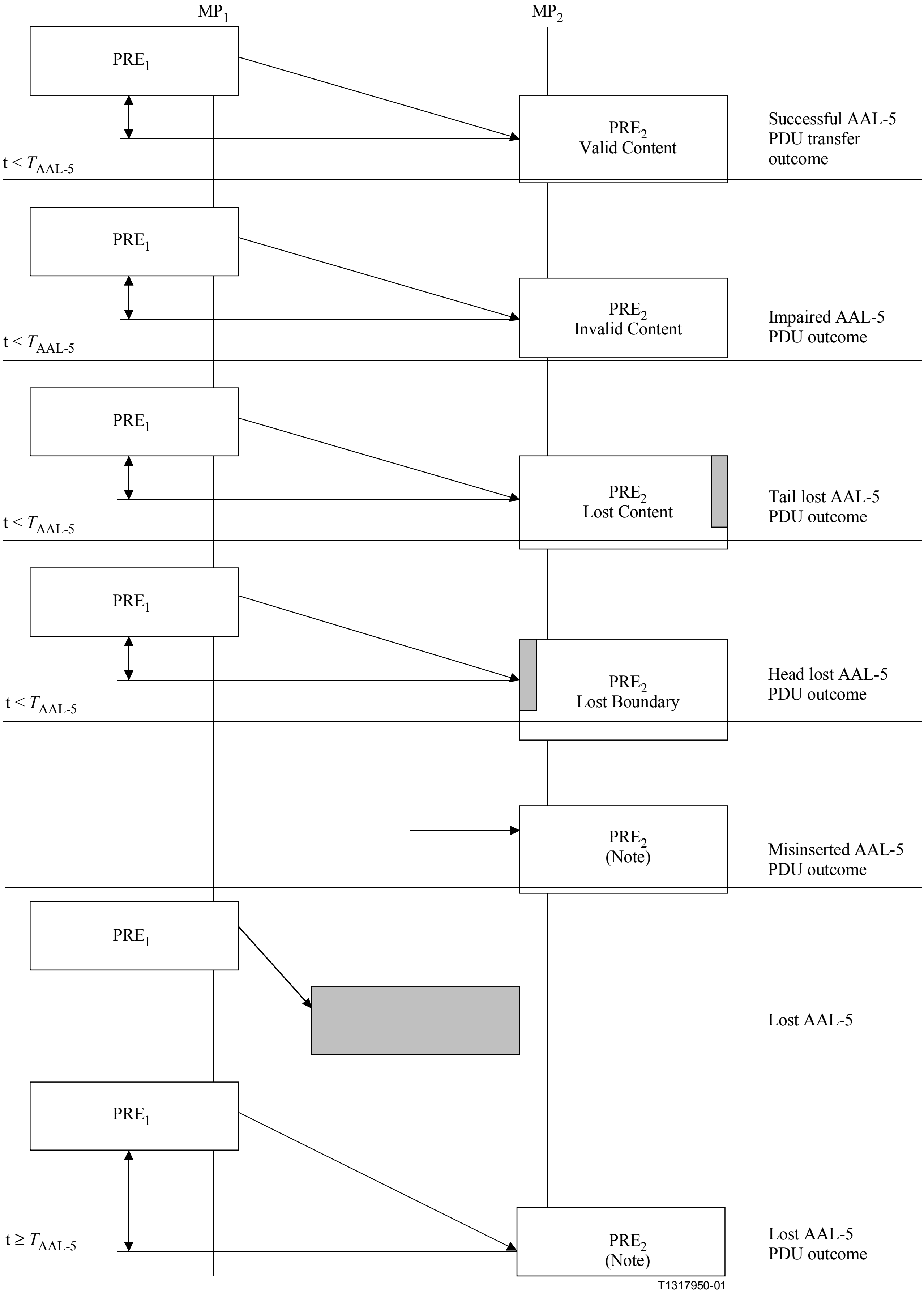
A tail lost AAL-5 PDU outcome occurs when a PRE_2 corresponding to PRE_1 happens within a specified time T_{AAL-5} of PRE_1, but the last cell of the AAL-5 PDU is lost.

NOTE 2 – Lost cell outcome in the last cell of the AAL-5 PDU must invoke this outcome.

NOTE 3 – Head lost AAL-5 PDU outcome is always triggered by this outcome.

NOTE 4 – Tail lost AAL-5 PDU outcome can be considered a subset of Impaired AAL-5 PDU outcome.

NOTE 5 – The need for a separate Tail lost AAL PDU outcome is under study.



NOTE – Outcome occurs independent of AAL-5 PDU content.

Figure 5/I.381 – AAL Type 5 PDU transfer outcomes – Shading (hatch marks) denote lost PDU or lost cell within a PDU

d) Head lost AAL-5 PDU outcome

A head lost AAL-5 PDU outcome occurs when a PRE_2 corresponding to PRE_1 happens within a specified time $T_{AAL\text{-}5}$ of PRE_1, but the received cell just before the arrival of the AAL-5 PDU does not indicate the last cell of the corresponding AAL-5 PDU.

NOTE 6 – Tail lost AAL-5 PDU outcome always precedes this outcome.

NOTE 7 – Head lost AAL-5 PDU outcome can be considered a subset of Impaired AAL-5 PDU outcome.

NOTE 8 – The need for a separate Head lost AAL-5 PDU outcome is under study.

e) Lost AAL-5 PDU outcome

A lost AAL-5 PDU outcome occurs when a PRE_2 fails to happen within time $T_{AAL\text{-}5}$ of the corresponding PRE_1.

f) Misinserted AAL-5 PDU outcome

A misinserted AAL-5 PDU outcome occurs when a PRE_2 happens without a corresponding PRE_1.

7 AAL performance parameters

7.1 Performance parameters for AAL Type 1

For future study.

7.1.1 Circuit emulation applications

For future study.

7.2 Performance parameters for AAL Type 2

7.2.1 Applications where the service specific convergence sublayer is null

For future study.

7.2.2 Applications where the service specific convergence sublayer is not null

For future study.

7.3 Performance parameters for AAL Type 3/4

For future study.

7.4 Performance parameters for AAL Type 5

7.4.1 Information loss parameter for AAL Type 5

The Impaired PDU Ratio (IPR) is defined as:

$$\text{IPR} = \frac{N_t(\text{Impaired})}{N_t(\text{Successful}) + N_t(\text{Impaired})}$$

where:

N_t(Impaired) = Number of Impaired PDU Transfer Outcomes

N_t(Successful) = Number of Successful PDU Transfer Outcomes

The Successful PDU Transfer Outcomes and Impaired PDU Transfer Outcomes belong to some population of interest. This population of interest could, for example, contain all such PDU Transfer Outcomes that occur between a specific pair of MPs during a stipulated time interval.

A relation between the IPR performance parameter and the relevant ATM layer cell transfer performance parameters may now be developed. As a consequence of its definition in clause 6, an Impaired PDU Transfer Outcome will occur as the result of any of the following mechanisms:

1) ATM-level burst impairment events involving multiple errored cells, lost cells, and/or misinserted cells.
2) ATM-level random independent (background) impairments involving errored cells.
3) ATM-level random independent (background) impairments involving lost cells.
4) ATM-level random independent (background) impairments involving misinserted cells.
5) AAL-level network processing impairments when such network processing exists for a specific application.

Mechanism 1 accounts for the impact of all burst impairments that are visible at the ATM level, while mechanisms 2, 3 and 4 account for the independently occurring background impairment types that are visible at the ATM level and that remain after burst impairments are counted and removed. Mechanism 5 accounts for impairments (of both burst and background types) that are caused strictly at the AAL level. The presence or absence of AAL-level network processing must be determined on an application-specific basis. Take these five mechanisms to be independent. Then applying the approach just cited, the IPR for a specific AAL Type 5 process during a specific time period can be represented by

$$IPR = IPR_{SECBR} + IPR_{CER} + IPR_{CLR} + IPR_{CMR} \qquad (7.4\text{-}1)$$

where IPR_{SECBR} is the IPR due to ATM-level burst impairment events, IPR_{CER} is the IPR due to independent errored cells, IPR_{CLR} is the IPR due to independent lost cells, and IPR_{CMR} is the IPR due to independent misinserted cells. The component due to mechanism 5 is not considered here. The individual IPR components due to mechanisms 1-4 are now considered in detail.

1) ATM-level burst-type impairments

Consider first the IPR component due to ATM-level burst-type impairments. The Severely Errored Cell Block Ratio (SECBR), as defined in ITU-T I.356 and measured over a time period of interest on the ATM connection supporting a specific AAL Type 5 process, can be used to estimate this component of the IPR. It is necessary to relate the length (in cells) of a PDU, denoted by P_{cells} to the length of a cell block (in cells), denoted by B_{cells}. Three cases are considered:

$$P_{cells} << B_{cells}$$

$$P_{cells} >> B_{cells}$$

$$P_{cells} = B_{cells}$$

If $P_{cells} << B_{cells}$, then[2] the fraction of PDUs that are impacted by these burst-type impairments is approximated by the fraction of cell blocks that are severely errored, i.e. the SECBR. Hence

$$IPR_{SECBR} = SECBR \qquad (7.4\text{-}2a)$$

[2] This case where $P_{cells} << B_{cells}$ can be further subdivided by comparing P_{cells} with the threshold $M = B_{cells}/32$ used for determining whether or not a cell block is severely errored. Such considerations show that equation (7.4-2) holds for $P_{cells} \geq 32$ cells, and that a somewhat smaller estimate for this IPR component may hold for smaller values of P_{cells}.

If $P_{cells} >> B_{cells}$, then any one of P_{cells}/B_{cells} cell blocks[3] would, if severely errored, impair such a PDU. The probability that a PDU is not so impaired is given by

$$(1-\text{SECBR})^{\frac{P_{cells}}{B_{cells}}}$$

The desired IPR component is the logical complement of this (i.e., the probability that a PDU of this length does not experience one or more Severely Errored Cell Blocks), which is

$$\text{IPR}_{\text{SECBR}} = 1-(1-\text{SECBR})^{\frac{P_{cells}}{B_{cells}}} \qquad (7.4\text{-}2b)$$

If P_{cells} and B_{cells} are about equal, then a single Severely Errored Cell Block would usually impact two PDUs, and so

$$\text{IPR}_{\text{SECBR}} = 2\,\text{SECBR} \qquad (7.4\text{-}2c)$$

Note that B_{cells} is given in ITU-T I.356 as a function of the capacity of the supporting ATM connection, and therefore the relation between $\text{IPR}_{\text{SECBR}}$ and the SECBR value depends on the capacity of the ATM connection.

2) ATM-level random impairments involving errored cells

Consider next the IPR component due to independently-occurring errored cells. Let the probability of such an errored cell's occurrence be given by the Cell Error Ratio (CER) as defined in ITU-T I.356. The probability that a PDU of length P_{cells} does not contain an errored cell is given by

$$(1-\text{CER})^{P_{cells}}$$

The desired IPR component due to this mechanism is its logical complement, and so

$$\text{IPR}_{\text{CER}} = 1-(1-\text{CER})^{P_{cells}} \qquad (7.4\text{-}3)$$

3) ATM-level random impairments involving lost cells

Consider the IPR component due to independently occurring lost cells. Take the probability of a single cell's loss to be given by the Cell Loss Ratio (CLR) as defined in ITU-T I.356. The probability that a PDU of length P_{cells} does not experience a lost cell is given by

$$(1-\text{CLR})^{P_{cells}}$$

The desired IPR component is the logical complement of this, and so

$$\text{IPR}_{\text{CLR}} = 1-(1-\text{CLR})^{P_{cells}} \qquad (7.4\text{-}4)$$

4) ATM-level random impairments involving misinserted cells

Consider the IPR component due to independently occurring misinserted cells. If the Cell Misinsertion Rate (CMR) and the Peak Cell Rate (PCR) of the supporting ATM connection are known, then the fraction of received cells that are misinserted is CMR/PCR. Take this fraction to be the probability that a single cell is misinserted. Then the probability that a PDU of length P_{cells} does not experience a misinserted cell is given by

$$\left(1-\frac{\text{CMR}}{\text{PCR}}\right)^{P_{cells}}$$

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[3] Or, more precisely, $\lceil P_{cells}/B_{cells} \rceil$, where $\lceil x \rceil$ denotes the smallest integer which is greater than or equal to x.

The desired IPR component due to this mechanism is the logical complement of this, and so

$$\mathrm{IPR_{CMR}} = 1 - \left(1 - \frac{\mathrm{CMR}}{\mathrm{PCR}}\right)^{P_{\mathrm{cells}}} \tag{7.4-5}$$

Summary of IPR component analysis

The resulting IPR due to lower layer performance impairments can be estimated by substituting into Equation (7.4-1) the results of Equations (7.4-2), (7.4-3), (7.4-4) and (7.4-5).

7.4.2 Information delay parameter for AAL Type 5

The previously defined AAL PDU Reference Events PRE_1 and PRE_2 and Successful PDU Transfer Outcome can be used to define a performance parameter for characterizing the information delay of an AAL Type 5 process.

The AAL PDU Delay (PD) parameter is defined as the time T_2 of a PRE_2 at MP2 minus the time T_1 of a corresponding PRE_1 at MP1, where PRE_2 and PRE_1 are related as a Successful PDU Transfer Outcome. (The times T_1 and T_2 are illustrated in Figure 4.)

This definition excludes from consideration those PRE_1 and PRE_2 events that are associated with Impaired PDU Transfer Outcomes because such outcomes can be less reflective of the user information delays experienced in normal operation.

8 AAL performance objectives

For future study.

9 Allocation of the performance objectives

For future study.

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