                      Terminology for ATM Benchmarking

Status of this Memo

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Abstract

   This memo discusses and defines terms associated with performance
   benchmarking tests and the results of these tests in the context of
   Asynchronous Transfer Mode (ATM) based switching devices. The terms
   defined in this memo will be used in addition to terms defined in
   RFCs 1242, 2285, and 2544. This memo is a product of the Benchmarking
   Methodology Working Group (BMWG) of the Internet Engineering Task
   Force (IETF).

Introduction

   This document provides terminology for benchmarking ATM based
   switching devices. It extends terminology already defined for
   benchmarking network interconnect devices in RFCs 1242, 2285, and
   2544. Although some of the definitions in this memo may be applicable
   to a broader group of network interconnect devices, the primary focus
   of the terminology in this memo is on ATM cell relay and signaling.

   This memo contains two major sections: Background and Definitions.
   Within the definitions section is a formal definitions subsection,
   provided as a courtesy to the reader, and a measurement definitions
   sub-section, that contains performance metrics with inherent units.
   The divisions of the measurement sub-section follow the BISDN model.

The BISDN model comprises four layers and two planes. This document
addresses the interactions between these layers and how they effect
IP and TCP throughput. A schematic of the B-ISDN model follows:

```
---------|------------------------|-----------------------------
         |        User Plane       |         Control Plane
---------|------------------------|-----------------------------
Services |          IP            | ILMI    |        UNI, PNNI
---------|------------------------|---------|-------------------
AAL      | AAL1, AAL2, AAL3/4, AAL5| AAL5    |        SAAL
---------|------------------------|---------|-------------------
ATM      |       Cell Relay       |      OAM, RM
---------|------------------------|-----------------------------
         |       Convergence      |
Physical |------------------------|-----------------------------
         |         Media          |
---------|------------------------|-----------------------------
```

This document assumes that necessary services are available and
active.  For example, IP connectivity requires SSCOP connectivity
between signaling entities.  Further, it is assumed that the SUT has
the ability to configure ATM addresses (via hard coded addresses,
ILMI or PNNI neighbor discovery), has the ability to run SSCOP, and
has the ability to perform signaled call setups (via UNI or PNNI
signaling).  This document covers only CBR, VBR and UBR traffic
types.  ABR will be handled in a separate document.  Finally, this
document presents only the terminology associated with benchmarking
IP performance over ATM; therefore, it does not represent a total
compilation of ATM test terminology.

The BMWG produces two major classes of documents: Benchmarking
Terminology documents and Benchmarking Methodology documents. The
Terminology documents present the benchmarks and other related terms.
The Methodology documents define the procedures required to collect
the benchmarks cited in the corresponding Terminology documents.

Existing Definitions

   RFC 1242, "Benchmarking Terminology for Network Interconnect Devices"
   should be consulted before attempting to make use of this document.
   RFC 2544, "Benchmarking Methodology for Network Interconnect Devices"
   contains discussions of a number of terms relevant to the
   benchmarking of switching devices and should be consulted.  RFC 2285,
   "Benchmarking Terminology for LAN Switching Devices" contains a
   number of terms pertaining to traffic distributions and datagram
   interarrival.  For the sake of clarity and continuity, this RFC
   adopts the template for definitions set out in Section 2 of RFC 1242.
   Definitions are indexed and grouped together in sections for ease of

reference.  The key words "MUST", "MUST NOT", "REQUIRED", "SHALL",
"SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and
"OPTIONAL" go in this document are to be interpreted as described in
RFC 2119.

Definitions

   The definitions presented in this section have been divided into two
   groups.  The first group is formal definitions, which are required in
   the definitions of the performance metrics but are not themselves
   strictly metrics.  These definitions are subsumed from other work
   done in other working groups both inside and outside the IETF.  They
   are provided as a courtesy to the reader.

1. Formal Definitions

1.1. Definition Format (from RFC 1242)

   Term to be defined.

   Definition: The specific definition for the term.

   Discussion: A brief discussion of the term, its application and any
   restrictions on measurement procedures.  These discussions pertain
   solely to the impact of a particular ATM parameter on IP or TCP;
   therefore, definitions which contain no configurable components or
   whose components will have the discussion: None.

   Specification: The working group and document in which the terms are
   specified and are listed in the references section.

1.2.  Related Definitions

1.2.1. ATM Adaptation Layer (AAL)

   Definition: The layer in the B-ISDN reference model (see B-ISDN)
   which adapts higher layer PDUs into the ATM layer.

   Discussion: There are four types of adaptation layers: AAL 1: used
   for circuit qemulation, voice over ATM AAL2: used for sub-rated voice
   over ATM AAL3/4: used for data over noisy ATM lines AAL5: used for
   data over ATM, most widely used AAL type

   These AAL types are not measurements, but it is possible to measure
   the time required for Segmentation and Reassembly (SAR).

   Specification: I.363

1.2.2. ATM Adaptation Layer Type 5 (AAL5)

   Definition: AAL5 adapts multi-cell higher layer PDUs into ATM with
   minimal error checking and no error detection.  The AAL5 CPCS (Common
   Paer Convergence Sub-layer) PDU is defined as follows:

```
|--------------------------|--------------------------|--------------|
|     Higher Layer PDU     |    Padding (If needed)    |   Trailer    |
|--------------------------|--------------------------|--------------|
```

   Where the padding is used to ensure that the trailer occupies the
   final 8 octets of the last cell.

   The trailer is defined as follows:

```
   |--------------|--------------|--------------|--------------|
   |   CPCS-UU    |     CPI      |    Length    |    CRC-32    |
   |--------------|--------------|--------------|--------------|
```

   where:

   CPCS-UU is the 1 octet Common Part Convergence Sub-layer User to User
   Indication and may be used to communicate between two AAL5 entities.

   CPI is the 1 octet Common Part Indicator and must be set to 0.

   Length is the 2 octet length of the higher layer PDU.

   CRC-32 is a 32 bit (4 octet) cyclic redundancy check over the entire
   PDU.

   Discussion: AAL5 is the adaptation layer for UNI signaling, ILMI,
   PNNI signaling, and for IP PDUs. It is the most widely used AAL type
   to date.  AAL5 requires two distinct processes.  The first is the
   encapsulation, on the transmit side, and de-encapsulation, on the
   receive side, of the higher layer PDU into the AAL5 CPCS PDU which
   requires the computation of the length and the CRC-32.  The time
   required for this process depends on whether the CRC-32 computation
   is done on the interface (on-board) or in machine central memory (in
   core).  On-board computation should produce only a small, constant
   delay; however, in core computation will produce variable delay,
   which will negatively effect TCP RTT computations. The second process
   is segmentation and re-assembly (SAR) which is defined below (see

   SAR).

   Specification: I.363.5

1.2.3. Asynchronous Transfer Mode (ATM)

   Definition: A transfer mode in which the information is organized
   into 53 octet PDUs called cells. It is asynchronous in the sense that
   the recurrence of cells containing information from an individual
   user is not necessarily periodic.

   Discussion: ATM is based on the ISDN model; however, unlike ISDN, ATM
   uses fixed length (53 octet) cells. Because of the fixed length of
   ATM PDUs, higher layer PDUs must be adapted into ATM using one of the
   four ATM adaptation layers (see AAL).

   Specification: AF-UNI3.1

1.2.4. ATM Link

   Definition: A virtual path link (VPL) or a virtual channel link
   (VCL).

   Discussion: none.

   Specification: AF-UNI3.1

1.2.5. ATM Peer-to-Peer Connection

   Definition: A virtual channel connection (VCC) or a virtual path
   connection (VPC).

   Discussion: none.

   Specification: AF-UNI3.1

1.2.6. ATM Traffic Descriptor

   Definition: A generic list of traffic parameters, which specify the
   intrinsic traffic characteristics of a requested ATM connection (see
   GCRA), which must include PCR and QoS and may include BT, SCR and
   best effort (UBR) indicator.

Discussion: The effects of each traffic parameter will be discussed
individually.

Specification: AF-UNI3.1

1.2.7. ATM User-User Connection

Definition: An association established by the ATM Layer to support
communication between two or more ATM service users (i.e., between
two or more next higher entities or between two or more ATM-
entities).  The communications over an ATM Layer connection may be
either bi-directional or unidirectional. The same Virtual Channel
Identifier (VCI) is issued for both directions of a connection at an
interface.

Discussion: Because ATM is connection oriented, certain features of
IP (i.e. those which require multicast) are not available.

Specification: AF-UNI3.1

1.2.8. Broadband ISDN (B-ISDN) Model

Definition: A layered service model that specifies the mapping of
higher layer protocols onto ATM and its underlying physical layer.
The model is composed of four layers: Physical, ATM, AAL and Service.

Discussion: See discussion above.

Specification: I.321

1.2.9. Burst Tolerance (BT)

Definition: A traffic parameter, which, along with the Sustainable
Cell Rate (SCR), specifies the maximum number of cells which will be
accepted at the Peak Cell Rate (PCR) on an ATM connection.

Discussion: BT applies to ATM connections supporting VBR services and
is the limit parameter of the GCRA. BT will effect TCP and IP PDU
loss in that cells presented to an interface which violate the BT may
be dropped, which will cause AAL5 PDU corruption. BT will also effect
TCP RTT calculation.  BT=(MBS-1)*(1/SCR 1/PCR) (see MBS, PCR, SCR).

Specification: AF-TM4.0

1.2.10. Call

   Definition: A call is an association between two or more users or
   between a user and a network entity that is established by the use of
   network capabilities. This association may have zero or more
   connections.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.11. Cell

   Definition: A unit of transmission in ATM. A fixed-size frame
   consisting of a 5-octet header and a 48-octet payload.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.12. Call-based

   Definition: A transport requiring call setups - see CALL definition.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.13. Cell Delay Variation Tolerance (CDVT)

   Definition: ATM layer functions may alter the traffic characteristics
   of ATM connections by introducing Cell Delay Variation. When cells
   from two or more ATM connections are multiplexed, cells of a given
   ATM connection may be delayed while cells of another ATM connection
   are being inserted at the output of the multiplexer.  Similarly, some
   cells may be delayed while physical layer overhead or OAM cells are
   inserted.  Consequently, some randomness may affect the inter-arrival
   time between consecutive cells of a connection as monitored at the
   UNI.  The upper bound on the "clumping" measure is the CDVT.

   Discussion: CDVT effects TCP round trip time calculations.  Large
   values of CDVT will adversely effect TCP throughput and cause SAR
   timeout.  See discussion under SAR.

   Specification: AF-TM4.0

1.2.14. Cell Header

   Definition: ATM Layer protocol control information.

   Discussion: The ATM cell header is a 5-byte header that contains the
   following fields: Generic Flow Control (GFC) 4 bits Virtual Path
   Identifier (VPI) 8 bits Virtual Channel Identifier (VCI) 16 bits
   Payload Type (PT) 3 bits Cell Loss Priority (CLP) 1 bit Header Error
   Check (HEC) 8 bit CRC computed over the previous four octets

   Each field is discussed in this document.

   Specification: AF-UNI3.1

1.2.15. Cell Loss Priority (CLP)

   Definition: This bit in the ATM cell header indicates two levels of
   priority for ATM cells. CLP=0 cells are higher priority than CLP=1
   cells.  CLP=1 cells may be discarded during periods of congestion to
   preserve the CLR of CLP=0 cells.

   Discussion: The CLP bit is used to determine GCRA contract
   compliance.  Specifically, two traffic contracts may apply to a
   single connection:  CLP=0, meaning only cells with CLP=0, and
   CLP=0+1, meaning cells with CLP=0 or CLP=1.

   Specification: AF-UNI3.1

1.2.16. Connection

   Definition: An ATM connection consists of concatenation of ATM Layer
   links in order to provide an end-to-end information transfer
   capability to access points.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.17. Connection Admission Control (CAC)

   Definition: Connection Admission Control is defined as the set of
   actions taken by the network during the call set-up phase (or during
   call re-negotiation phase) in order to determine whether a connection
   request can be accepted or should be rejected (or whether a request
   for re-allocation can be accommodated).

   Discussion: CAC is based on the ATM traffic descriptor (see ATM
   traffic descriptor) associated with the call as well as the presented
   and existing load.  It may also be based on administrative policies
   such as calling party number required or access limitations. The
   effect on performance of these policies is beyond the scope of this
   document and will be handled in the BMWG document: Benchmarking
   Terminology for Firewall Performance.

      Specification: AF-UNI3.1

1.2.18. Constant Bit Rate (CBR)

   Definition: An ATM service category which supports a constant and
   guaranteed rate to transport services such as video or voice as well
   as circuit emulation which requires rigorous timing control and
   performance parameters.  CBR requires the specification of PCR and
   QoS (see PCR and QoS).

   Discussion: Because CBR provides minimal cell delay variation (see
   CDV), it should improve TCP throughput by stabilizing the RTT
   calculation.  Further, as CBR generally provides a high priority
   service, meaning that cells with a CBR traffic contract usually take
   priority over other cells during congestion, TCP segment and IP
   packet loss should be minimized.  The cost associated with using CBR
   is the loss of statistical multiplexing.  Since CBR guarantees both
   throughput and CDV control, the connections must be subscribed at
   PCR.  This is extremely wasteful as most protocols, e.g., TCP, only
   utilize full bandwidth on one half of a bi-directional connection.

      Specification: AF-UNI3.1

1.2.19. Cyclic Redundancy Check (CRC)

   Definition: A mathematical algorithm that computes a numerical value
   based on the bits in a block of data. This number is transmitted with
   the data, the receiver uses this information and the same algorithm
   to insure the accurate delivery of data by comparing the results of
   algorithm, and the number received.  If a mismatch occurs, an error
   in transmission is presumed.

   Discussion: CRC is not a measurement, but it is possible to measure
   the amount of time to perform a CRC on a string of bits. This
   measurement will not be addressed in this document. See discussion
   under AAL5.

      Specification: AF-UNI3.1

1.2.20. End System (ES)

   Definition: A system where an ATM connection is terminated or
   initiated.  An originating end system initiates the ATM connection,
   and terminating end system terminates the ATM connection.  OAM cells
   may be generated and received.

   Discussion: An ES can be the user side of a UNI signaling interface.

   Specification: AF-TEST-0022

1.2.21. Explicit Forward Congestion Indication (EFCI)

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

   Discussion: EFCI may be used to prevent congestion by alerting a
   positive acknowledgement protocol and causing action to be taken.  In
   the case of TCP, when EFCI cells are received the driver software
   could alert the TCP software of impending congestion.  The TCP
   receiver would then acknowledge the current segment and set the
   window size to some very small number.

   Specification: AF-TM4.0

1.2.22. Generic Cell Rate Algorithm (GCRA)

   Definition: The GCRA is used to define conformance with respect to
   the traffic contract of the connection.  For each cell arrival, the
   GCRA determines whether the cell conforms to the traffic contract.
   The UPC function may implement the GCRA, or one or more equivalent
   algorithms to enforce conformance. The GCRA is defined with two
   parameters: the Increment (I) and the Limit (L).

   Discussion: The GCRA increment and limit parameters are mapped to CBR
   and VBR in the following fashion.  For CBR, I=1/PCR and L=CDVT (CDV
   tolerance).  For VBR, there are two GCRA algorithms running (dual
   leaky bucket).  The first functions in the same fashion .bp as CBR,
   I=1/PCR and L=CDVT.  The second, which polices cells which are in
   conformance with the first GCRA uses I=1/SCR and L=BT (see BT, CDV,

   MBS, PCR and SCR).

   Specification: AF-TM4.0

1.2.23. Generic Flow Control (GFC)

   Definition: GFC is a field in the ATM header, which can be used to
   provide local functions (e.g., flow control). It has local
   significance only and the value encoded in the field is not carried
   end-to-end.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.24. Guaranteed Frame Rate (GFR)

   Definition: The GFR service provides the user with a Minimum Cell
   Rate (MCR) guarantee under the assumption of a given maximum frame
   size (MFS) and a given Maximum Burst Size (MBS).  The MFS and MBS are
   both expressed in units of cells.  GFR only applies to virtual
   channel connections (VCCs).

   Discussion: GFR is intended for users who are either not able to
   specify the range of traffic parameters needed to request most ATM
   services, or are not equipped to comply with the (source) behavior
   rules required by existing ATM services.  Specifically, GFR provides
   the user with the following minimum service guarantee: When the
   network is congested, all frames whose length is less than MFS and
   presented to the ATM interface in bursts less than MBS and at a rate
   less than PCR will be handled with minimum frame loss.  When the
   network is not congested, the user can burst at higher rates.

   The effect of GFR on performance is somewhat problematic as the
   policing algorithm associated with GFR depends on the network load;
   however, under congested condition and assuming a user who is
   following the GFR service agreement, it should improve performance.

   Specification: AF-TM4.1

1.2.25. Header Error Control (HEC)

   Definition: A check character calculated using an 8 bit CRC computed
   over the first 4 octets of the ATM cell header. This allows for
   single bit error correction or multiple bit error detection.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.26. Integrated Local Management Interface

   Definition: A management protocol which uses SNMPv1 carried on AAL5
   to provide ATM network devices with status and configuration
   information concerning VPCs, VCCs, registered ATM addresses and the
   capabilities of ATM interfaces.

   Discussion: ILMI is a conditionally required portion of UNI3.1;
   however, ILMI 4.0 has been issued as a separate specification.  This
   document will refer to ILMI 4.0.

   Specification: AF-ILMI4.0

1.2.27. Intermediate System (IS)

   Definition: A system that provides forwarding functions or relaying
   functions or both for a specific ATM connection. OAM cells may be
   generated and received.

   Discussion: An IS can be either the user or network side of a UNI
   signaling interface, or the network side of a PNNI signaling
   interface.

   Specification: AF-TEST-0022

1.2.28. Leaky Bucket (LB)

   Definition: Leaky Bucket is the term used as an analogous description
   of the algorithm used for conformance checking of cell flows from a
   user or network. See GCRA and UPC.  The "leaking hole in the bucket"
   applies to the sustained rate at which cells can be accommodated,
   while the "bucket depth" applies to the tolerance to cell bursting
   over a given time period.

   Discussion: There are two types of LB algorithms - single and dual.
   Single LB is used in CBR; dual LB is used in VBR (see CBR and VBR).

   Specification: AF-TM4.0

1.2.29. Maximum Burst Size (MBS)

   Definition: In the signaling message, the Burst Tolerance (BT) is
   conveyed through the MBS that is coded as a number of cells. The BT
   together with the SCR and the PCR determine the MBS that may be
   transmitted at the peak rate and still is in conformance with the
   GCRA.

   Discussion: See the discussion under BT.

   Specification: AF-TM4.0

1.2.30. Maximum Frame Size (MFS)

   Definition: The MFS is the maximum length of a frame, expressed in
   units of cells, which in interface implementing GFR will accept
   during congested conditions (see GFR).

   Discussion: During congestion, frames whose size is in excess of the
   MFS may be dropped or tagged.  Assuming that the user is adhering to
   the MFS limit, this behavior should improve performance by improving
   congestion.

   Specification: AF-TM4.1

1.2.31. Operations, Administration, and Maintenance (OAM)

   Definition: A group of network management functions that provide
   network fault indication, performance information, and data and
   diagnosis functions.

   Discussion: There are four types of ATM OAM flows: segment or end-
   to-end VP termination management (i.e. F4 segment, F4 E2E) and
   segment or end-to-end VC termination management (i.e. F5 segment, F5
   E2E). These OAM cells can be used to identify fault management,
   connection verification, and loop back measurements.

   Specification: AF-UNI3.1

1.2.32. Payload Type Indicator (PTI)

   Definition: Payload Type Indicator is the Payload Type field value
   distinguishing the various management cells and user cells as well as
   conveying explicit forward congestion indication (see EFCI).
   Example:  Resource Management cell is indicated as PTI=110, End-to-
   end OAM F5 Flow cell is indicated as PTI=101.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.33. Peak Cell Rate (PCR)

   Definition: A traffic parameter, which specifies the upper bound on
   the rate at which ATM cells can be submitted to an ATM connection.
   This parameter is used by the GCRA.

   Discussion: PCR directly limits the maximum data rate on an ATM
   connection.  If a user violates the PCR, cells may be dropped
   resulting in Cell Loss.  This in turn will negatively impact AAL5
   PDUs, which may be carrying IP datagrams.  See the discussion under
   SAR.

   Specification: AF-TM4.0

1.2.34. Permanent Virtual Circuit (PVC)

   Definition: This is a link with static route(s) defined in advance,
   usually by manual setup.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.35. Permanent Virtual Channel Connection (PVCC)

   Definition: A Virtual Channel Connection (VCC) is an ATM connection
   where switching is performed on the VPI/VCI fields of each cell. A
   permanent VCC is one that is provisioned through some network
   management function and left up indefinitely.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.36. Permanent Virtual Path Connection: (PVPC)

   Definition: A Virtual Path Connection (VPC) is an ATM connection
   where switching is performed on the VPI field only of each cell. A
   permanent VPC is one that is provisioned through some network
   management function and left up indefinitely.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.37. Private Network-Network Interface (PNNI)

   Definition: A routing information protocol that enables extremely,
   scalable, full function, dynamic multi-vendor ATM switches to be
   integrated in the same network.

   Discussion: PNNI consists of signaling and routing between ATM
   network devices.  PNNI signaling is based on UNI 4.0 signaling
   between two network side interfaces, while PNNI routing provides a
   mechanism to route ATM cells between two separate, autonomous ATM
   networks.

   Specification: AF-PNNI1.0

1.2.38. Protocol Data Unit (PDU)

   Definition: A PDU is a message of a given protocol comprising payload
   and protocol-specific control information, typically contained in a
   header.  PDUs pass over the protocol interfaces that exist between
   the layers of protocols (per OSI model).

   Discussion: In ATM networks, a PDU can refer to an ATM cell, multiple
   ATM cells, an AAL segment, an IP datagram and others.

   Specification: Common Usage

1.2.39. Segmentation and Reassembly (SAR)

   Definition: The process used by the AAL in the B-ISDN reference model
   (see B-ISDN) which fragments higher layer PDUs into ATM cells.

   Discussion: SAR is not a measurement, but the speed in which SAR can
   be completed on a bit stream can be measured. Although this
   measurement is not included in this document, it should be noted that
   the manner in which SAR is performed will greatly effect performance.
   SAR can be performed either on the interface card (on board) or in
   machine central memory (in core).  On-board computation should

produce only a small, constant delay; however, in core computation
will produce variable delay, which will negatively effect TCP RTT
computations.  This situation is further complicated by the location
of the CRC-32 calculation.  Given an in core CRC-32 calculation, bus
contention may cause on board SAR to be slower than in core SAR.
Clearly, on board CRC-32 calculation and SAR will produce the most
favorable performance results.

SAR performance will also be effected by ATM layer impairments.  Cell
error (CE), cell loss(CL), cell mis-insertion (CM) and cell delay
variation (CDV) will all negatively effect SAR.  CE will cause an
AAL5 PDU to fail the CRC-32 check and be discarded, thus discarding
the packet which the PDU contained.  CL and CM will both cause an
AAL5 PDU to fail the length check and be discarded.  CL can have
other effects depending on whether the cell which was lost is the
final cell (PTI=1) of the AAL5 PDU.  The following discussion
enumerates the possibilities.

1. PTI=0 cell is lost.  In this case, re-assembly registers a length
discrepancy and discards the PDU.

2. PTI=1 cell is lost.

2.  A.  The AAL5 re-assembly timer expires before the first cell,
PTI=0, of the next AAL5 PDU arrives.  The AAL5 PDU with the missing
PTI=1 cell is discarded due to re-assembly timeout and one packet is
lost.

2.  B.  The first cell of the next AAL5 PDU arrives before the re-
assembly timer expires.  The AAL5 with the missing PTI=1 cell is
prepended to the next AAL5 PDU in the SAR engine.  This yields two
possibilities:

2. B. i. The AAL5 re-assembly timer expires before the last cell,
PTI=1, of the next AAL5 PDU arrives.  The AAL5 PDU with the missing
PTI=1 cell and the next AAL5 PDU are discarded due to re-assembly
timeout and two packets are lost.

2. B. ii. The last cell of the next AAL5 PDU arrives before the re-
assembly timer expires.  In this case, AAL5 registers a length
discrepancy and discards the PDU; therefore, the AAL5 PDU with the
missing PTI=1 cell and the next AAL5 PDU are discarded due to their
concatenation and two packets are lost.

   2. C. Coupled with re-assembly, there exists some mechanism for
   identifying the start of a higher layer PDU, e.g., IP, and the cells
   associated with the first incomplete AAL5 PDU are discarded,
   resulting in the loss of one packet.

      Specification: AF-UNI3.1

1.2.40. Sustainable Cell Rate (SCR)

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

   Discussion: SCR limits the average data rate on an ATM connection.
   If a user violates the SCR, cells may be dropped resulting in Cell
   Loss.  This in turn will negatively impact AAL5 PDUs, which may be
   carrying IP datagrams.  See the discussion under SAR.

      Specification: AF-TM4.0

1.2.41. Switched Connection

   Definition: A connection established via signaling.

   Discussion: none.

      Specification: AF-UNI3.1

1.2.42. Switched Virtual Channel Connection (SVCC)

   Definition: A Switched VCC is one that is established and taken down
   dynamically through control signaling. A Virtual Channel Connection
   (VCC) is an ATM connection where switching is performed on the
   VPI/VCI fields of each cell.

   Discussion: none.

      Specification: AF-UNI3.1

1.2.43. Switched Virtual Circuit (SVC)

   Definition: A connection established via signaling. The user defines
   the endpoints when the call is initiated.

   Discussion: SVCs are established using either UNI signaling or PNNI
   signaling.  The signaling state machine implements several timers,
   which can effect the time required for call establishment.  This will
   effect TCP round trip time calculation, effecting TCP throughput.
   Specifically, there are two possibilities.  In the case where Call
   Proceeding is not implemented, there is only one timer, T310, with a
   value of 10 seconds.  In the case where Call Proceeding is
   implemented, there are two timers, T303 and T310, with the values 4
   and 10 seconds, respectively.  In either case, if a timer, either
   T303 or T310, expires after a Setup message is send, the calling
   party has the option of re-transmitting the Setup.  In the T303 case,
   this yields a maximum setup time of 18 seconds and, In the T310 case,
   a maximum setup time of 20 seconds.  Thus, the initial TCP RTT
   calculation will be on he order of 20 seconds.

   Specification: AF-UNI3.1, AF-UNI4.0, AF-PNNI1.0

1.2.44. Switched Virtual Path Connection (SVPC)

   Definition: A Switched Virtual Path Connection is one that is
   established and taken down dynamically through control signaling.  A
   Virtual Path Connection (VPC) is an ATM connection where switching is
   performed on the VPI field only of each cell.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.45. Traffic Contract

   Definition: A specification of the negotiated traffic characteristics
   of an ATM connection.

   Discussion: See discussions under BT, CAC, CDV, GCRA, PCR and SCR.

   Specification: AF-TM4.0

1.2.46. Traffic Management (TM)

   Definition: Traffic Management is the aspect of the traffic control
   and congestion control procedures for ATM. ATM layer traffic control
   refers to the set of actions taken by the network to avoid congestion
   conditions.  ATM layer congestion control refers to the set of

   actions taken by the network to minimize the intensity, spread and
   duration of congestion. The following functions form a framework for
   managing and controlling traffic and congestion in ATM networks and
   may be used in appropriate combinations.

      Connection Admission Control
      Feedback Control
      Usage Parameter Control
      Priority Control
      Traffic Shaping
      Network Resource Management
      Frame Discard
      ABR Flow Control

   Discussion: See CAC and traffic shaping.

   Specification: AF-TM4.0

1.2.47. Traffic Shaping (TS)

   Definition: Traffic Shaping is a mechanism that alters the traffic
   characteristics of a stream of cells on a connection to achieve
   better network efficiency, while meeting the QoS objectives, or to
   ensure conformance at a subsequent interface. Traffic shaping must
   maintain cell sequence integrity on a connection.  Shaping modifies
   traffic characteristics of a cell flow with the consequence of
   increasing the mean Cell Transfer Delay.

   Discussion: TS should improve TCP throughput by reducing RTT
   variations.  As a result, TCP RTT calculations should be more stable.

   Specification: AF-UNI3.1

1.2.48. Transmission Convergence (TC)

   Definition: A sub-layer of the physical layer of the B-ISDN model
   transforms the flow of cells into a steady flow of bits and bytes for
   transmission over the physical medium. On transmit the TC sublayer
   maps the cells to the frame format, generates the Header Error Check
   (HEC), and sends idle cells when the ATM layer has none. to send. On
   reception, the TC sublayer delineates individual cells in the
   received bit stream, and uses the HEC to detect and correct received
   errors.

   Discussion: TC is not a measurement, but the speed in which TC can
   occur on a bit stream can be measured. This measurement will not be
   discussed in this document; however, its value should be constant and
   small with respect to cell inter-arrival at the maximum data rate.

   Specification: AF-UNI3.1

1.2.49. Unspecified Bit Rate (UBR)

   Definition: UBR is an ATM service category, which does not specify
   traffic related service guarantees. Specifically, UBR does not
   include the notion of a per-connection-negotiated bandwidth.  No
   commitments are made with respect to the cell loss ratio experienced
   by a UBR connection, or as to the cell transfer delay experienced by
   cells on the connection.

   Discussion: RFC 2331 specifies UBR service class for IP over ATM.
   UBR service models the "best effort" service type specified in RFC
   791; however, UBR has specific drawbacks with respect to TCP service.
   Since UBR makes no guarantee with respect to cell loss (CL), cell
   delay variation (CDV) or cell mis-insertion(CM), TCP RTT estimates
   will be highly variable.  Further, all negatively impact AAL5 re-
   assembly, which in turn may cause packet loss.  See discussions under
   CDV and SAR.

   Specification: AF-TM4.0

1.2.50. Usage Parameter Control (UPC)

   Definition: Usage Parameter Control is defined as the set of actions
   taken by the network to monitor and control traffic, in terms of
   traffic offered and validity of the ATM connection, at the end-system
   access.  Its main purpose is to protect network resources from
   malicious as well as unintentional misbehavior, which can affect the
   QoS of established connections, by detecting violations of negotiated
   parameters and taking appropriate actions.

   Discussion: See discussions under BT, CAC, CDV, GCRA, PCR and SCR.

   Specification: AF-TM4.0

1.2.51. User-Network Interface (UNI)

   Definition: An interface point between ATM end users and a private
   ATM switch, or between a private ATM switch and the public carrier
   ATM network; defined by physical and protocol specifications per ATM
   Forum UNI documents.  The standard adopted by the ATM Forum to define
   connections between users or end stations and a local switch.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.52. Variable Bit Rate (VBR)

   Definition: An ATM Forum defined service category which supports
   variable bit rate data traffic with average and peak traffic
   parameters.

   Discussion: VBR may potentially adversely effect TCP throughput due
   to large RTT variations.  This in turn will cause the TCP RTT
   estimates to be unstable.

   Specification: AF-TM4.0

1.2.53.  Virtual  Channel  (VC)

   Definition: A communications channel that provides for the sequential
   unidirectional transport of ATM cells.

   Discussion: none.

   Specification: AF-TM3.1

1.2.54. Virtual Channel Connection (VCC)

   Definition: A concatenation of VCIs that extends between the points
   where the ATM service users access the ATM layer. The points at which
   the ATM cell payload is passed to, or received from, the users of the
   ATM Layer (i.e., a higher layer or ATM-entity) for processing signify
   the endpoints of a VCC. VCCs are unidirectional.

   Discussion: none.

   Specification: AF-TM3.1

1.2.55. Virtual Channel Identifier (VCI)

   Definition: A unique numerical tag as defined by a 16 bit field in
   the ATM cell header that identifies a virtual channel, over which the
   cell is to travel.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.56. Virtual Path (VP)

   Definition: A unidirectional logical association or bundle of VCs.

   Discussion: none.

   Specification: AF-UNI3.1

1.2.57. Virtual Path Connection (VPC)

   Definition: A concatenation of VPIs between Virtual Path Terminators
   (VPTs). VPCs are unidirectional

   Discussion: none.

   Specification: AF-TM3.1

1.2.58. Virtual Path Identifier (VPI)

   Definition: An eight-bit field in the ATM cell header that indicates
   the virtual path over which the cell should be routed.

   Discussion: none.

   Specification: AF-UNI3.1

2. Performance Metrics

2.1. Definition Format (from RFC 1242)

   Metric to be defined.

   Definition: The specific definition for the metric.

   Discussion: A brief discussion of the metric, its application and any
   restrictions on measurement procedures.

   Measurement units: Intrinsic units used to quantify this metric. This
   includes subsidiary units; e.g., microseconds are acceptable if the
   intrinsic unit is seconds.

2.2. Definitions

2.2.1. Physical Layer - SONET

2.2.1.1. Pointer Movements

   Definition: Pointer Movements is the number of changes in a SONET
   pointer due to clock synchronization slips.

   Discussion: SONET Pointer Movements can cause loss of information in
   the SONET payload envelop (SPE) which contains IP datagrams, either
   in the form of ATM cells or as PPP delimited PDUs.

   Measurement Units: Per second.

2.2.1.2. Transport Overhead Error Count

   Definition: SONET Transport Overhead Error Count is the number of
   SONET transport overhead errors detected.

   Discussion: SONET Transport Overhead Errors SONET Transport Overhead
   Errors cause SONET frames to be lost.  These frames may contain IP
   datagrams; either in the form of cells or as PPP delimited PDUs.

   Measurement Units: Positive integer

2.2.1.3. Path Overhead Error Count

   Definition: SONET Path Overhead Error Count is the number of SONET
   path overhead errors detected.

   Discussion: SONET Path Overhead Errors cause SONET frames to be lost.
   These frames may contain IP datagrams; either in the form of cells or
   as PPP delimited PDUs.

   Measurement Units: Positive integer

2.2.2. ATM Layer

2.2.2.1. Cell Delay Variation (CDV)

   Definition: The variation in cell transfer delay (CTD) associated
   with a given traffic load, orientation and distribution, as well as
   an integration period. CDV = max (CTD) - min (CTD) where max and min
   indicate the maximum and minimum over the integration period,
   respectively.

   Discussion: CDV is a component of cell transfer delay, induced by
   buffering and cell scheduling. Peak-to-peak CDV is a QoS delay
   parameter associated with CBR and VBR services. The peak-to-peak CDV
   is the ((1-a) quantile of the CTD) minus the fixed CTD that could be
   experienced by any delivered cell on a connection during the entire
   connection holding time.  The parameter "a" is the probability of a
   cell arriving late.

   CDV effects TCP round trip time calculations.  Large values of CDV
   will adversely effect TCP throughput and cause SAR timeout.  See
   discussion under SAR.

   Measurement Units: seconds

2.2.2.2. Cell Error Ratio (CER)

   Definition: The ratio of cells with payload errors in a transmission
   in relation to the total number of cells sent in a transmission
   associated with a given traffic load, orientation and distribution,
   as well as an integration period.  Note that errors occurring in the
   cell header will cause cell loss at the ATM layer.  Note further that
   multiple errors in a payload will only be counted as one cell payload
   error.

        CER = Cells with payload errors / Total Cells Transmitted.

   Discussion: The measurement is taken over a time interval and is
   desirable to be measured on an in-service circuit.  CER is closely
   related to the number of corrupted AAL5 PDUs; however, there is not a
   direct numerical correlation between the number of errored cells and
   the number of corrupted AAL5 PDUs.  There are two cases described
   below.

   1. Only one cell in an AAL5 PDU contains payload errors.  In this
   case, there is a one-to-one correspondence between cell payload
   errors and the number of corrupted AAL5 PDUs.

2. Multiple cells in the AAL5 PDU contain payload errors. In this
case, there is not a one-to-one correspondence between cell payload
errors and the number of corrupted AAL5 PDUs.

Measurement Units: dimensionless.

2.2.2.3. Cell Loss Ratio (CLR)

Definition: The ratio of lost cells in a transmission in relation to
the total cells sent in a transmission associated with a given
traffic load, orientation and distribution, as well as an integration
period.

     CLR = Lost Cells / Total Cells Transmitted.

Discussion: CLR is a negotiated QoS parameter and acceptable values
are network specific. The objective is to minimize CLR provided the
end-system adapts the traffic to the changing ATM layer transfer
characteristics. The CLR parameter is the value of CLR that the
network agrees to offer as an objective over the lifetime of the
connection. It is expressed as an order of magnitude, having a range
of $10^{-1}$ to $10^{-15}$ and unspecified.

CLR indicates the number of ATM cells lost in relation to the total
number of cells sent. CLR is closely related to the number of
corrupted AAL5 PDUs; however, there is not a direct numerical
correlation between the number of cells lost and the number of
corrupted AAL5 PDUs.  See the discussion under SAR.

Measurement Units: dimensionless.

2.2.2.4. Cell Misinsertion Ratio (CMR)

Definition: The ratio of cells received at an endpoint that were not
originally transmitted by the source end in relation to the total
number of cells properly transmitted associated with a given traffic
load, orientation and distribution, as well as an integration period.

     CMR = Misinserted Cells / Total Cells Transmitted.

Discussion: The measurement is taken over a time interval and is
desirable to be measured on an in-service circuit.  CMR is closely
related to the number of corrupted AAL5 PDUs; however, there is not a
direct numerical correlation between the number of mis-inserted cells
and the number of corrupted AAL5 PDUs.  There are two cases described
below.

1.  Only one cell is mis-inserted into an AAL5 PDU.  In this case,
there is a one-to-one correspondence between cell mis-insertion and
the number of corrupted AAL5 PDUs.

2.  Multiple cells are mis-inserted into an AAL5. In this case, there
is not a one-to-one correspondence between cell mis-insertion and the
number of corrupted AAL5 PDUs.

Measurement Units: dimensionless.

2.2.2.5. Cell Rate Margin (CRM)

Definition: This is a measure of the difference between the effective
bandwidth allocation and the allocation for sustainable rate in cells
per second.

Discussion: This measures the amount of provisioned bandwidth which
is not utilized.  This lack of utilization may be caused by
encapsulation overhead, e.g., AAL5 trailer and padding, or by the
protocol itself, e.g., TCP usually transmits in only one direction.

Measurement units: Cells per second

2.2.2.6. CRC Error Ratio

Definition: The ratio of PDUs received at an endpoint that which
contain an invalid CRC in relation to the total number of cells
properly transmitted associated with a given traffic load,
orientation and distribution, as well as an integration period.

Discussion: CRC errors cause ATM cells to be lost.  Although this
will appear as cell loss at the ATM layer, this measurement can be
made in-service using a test probe which measures CRC errors at the
TC layer.

Measurement Units: dimensionless

2.2.2.7. Cell Transfer Delay (CTD)

Definition: The elapsed time between a cell exit event at the
measurement point 1 (e.g., at the source UNI) and the corresponding
cell entry event at a measurement point 2 (e.g., the destination UNI)
for a particular connection.

   Discussion: The cell transfer delay between two measurement points is
   the sum of the total inter-ATM node transmission delay and the total
   ATM node processing delay.  While this number is a constant and
   should not adversely effect performance, it is a component in RTT.

   Measurement units: seconds

2.2.3. ATM Adaptation Layer (AAL) Type 5 (AAL5)

2.2.3.1. AAL5 Re-assembly Errors

   Definition: AAL5 Re-assembly Errors constitute any error, which
   causes the AAL5 PDU to be corrupted.

   Discussion: AAL5 Re-assembly errors cause AAL5 PDUs to be lost.
   These PDUs may contain IP datagrams.

   Measurement Units: Positive Integer

2.2.3.2. AAL5 Reassembly Time

   Definition: AAL5 Reassembly Time constitutes the time between the
   arrival of the final cell in the AAL5 PDU and the AAL5 PDUs payload
   being made available to the service layer.

   Discussion: AAL5 Reassembly time directly effects TCP round trip time
   calculations.

   Measurement Units: seconds

2.2.3.3. AAL5 CRC Error Ratio

   Definition: The ratio of PDUs received at an endpoint that which
   contain an invalid CRC in relation to the total number of cells
   properly transmitted associated with a given traffic load,
   orientation and distribution, as well as an integration period.

   Discussion: AAL5 CRC errors cause AAL5 re-assembly errors.  See
   discussion under AAL5 re-assembly errors.

   Measurement Units: dimensionless

2.2.4. ATM Service: Signaling

2.2.4.1. CAC Denial Time

   Definition: The amount of time required for CAC to determine that a
   call must be rejected.

   Discussion: In the case where Call Proceeding is implemented, this
   number will be less than 4 seconds. Otherwise, it will be less than
   10 seconds.  Large values of this measurement will adversely effect
   performance on systems where an alternate, non-NBMA, service is
   available.

   Measurement Units: seconds

2.2.4.2. Connection Establishment Time

   Definition: The amount of time between the first Setup message from
   the calling party and the Connect message to the calling party.

   Discussion:  See discussion under SVC.

   Measurement Units: seconds

2.2.4.3. Connection Teardown Time

   Definition: The amount of between the Release message being sent and
   the Release Complete message being received.

   Discussion: Large values of this measurement will adversely effect
   performance in systems where the total number of open calls or VCs is
   limited.  Specifically, a new VC cannot be instantiated with the same
   VPI/VCI before the old one is released.

   Measurement Units: seconds

2.2.4.4. Crankback Time

   Definition: The amount of time between the issuance of the first
   release or release complete message by the switch where the current
   Designated Transit List (DTL) is blocked and the receipt of the SETUP
   with the updated DTLs by the target switch.

   Discussion: This measurement does not take into account the amount of
   time associated with either the successful portion of the call setup
   transit or the time required for the calling party to receive .bp a
   response from the called party.  As a result, the call may still fail
   to complete if the call setup timer on the calling party expires.

   See discussion under SVC.

   Measurement Units: seconds

2.2.4.5. Route Update Response Time

   Definition: The amount of time between the receipt of a PNNI Topology
   State Element (PTSE), which is the PNNI routing PDU, containing a
   topology different from the current topology and the point at which
   the switch begins to generate DTLs reflecting the routing change.

   Discussion: This measurement provides a lower bound on the amount of
   time during which SETUP messages will be forwarded along a sub-
   optimal or blocked path.

   Measurement Units: seconds

2.2.5. ATM Service: ILMI

2.2.5.1. MIB Alignment Time

   Definition: The amount of time between the issuance of the final cold
   start message and the final get response associated with the exchange
   of static MIB information.

   Discussion: This measurement reflects the amount of time required by
   the switch and end system to exchange all information required to
   characterize and align the capabilities of both systems.  It does not
   include address registration.  It should also be noted that this
   measurement will depend on the number of MIB elements implemented by
   both systems.

   Measurement Units: seconds

2.2.5.2. Address Registration Time

   Definition: The amount of time between the initial set request issued
   by the switch and the final get response issued by the switch.

   Discussion: This measurement assumes that the switch has checked the
   network prefix status object and the end system has checked the ATM
   address status object.  In the case where the end system checks the
   ATM address status object only after the switch has issued a set
   request of the network prefix status object, this measurement will
   not reflect the actual time required to complete the address
   registration.

   Measurement Units: seconds

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