Advanced Testing Techniques for ATM Service Level Agreements

Agilent Technologies Broadband Series Test System Application Note

Introduction

Many enterprises rely on public communication networks for their day-to-day business operations. With increasing telecommunications competition and deregulation, enterprise network operators are increasingly demanding Service Level Agreements (SLAs) from their service providers to guarantee the Quality of Service (QoS) of the network services to which they subscribe.

At the same time, service providers are competing by offering differentiated services with different levels of QoS. ATM is still the "layer 2 of choice" for applications that require a guaranteed level of service because ATM can deliver voice, video, and IP traffic with guarantee throughput or delay characteristics. So it is no surprise that service providers are using ATM and ATM traffic contracts to meet Service Level Agreements.

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Testing ATM traffic contracts (and therefore testing SLAs) is not as straightforward as it may sound. Service providers must test that their ATM networks are able to meet multiple traffic contracts simultaneously so that they can be confident that multiple SLAs can be honored. At the same time, network equipment manufacturers must be confident that their ATM switches have the functionality, accuracy, and performance to meet the needs of service providers.

This paper discusses advanced techniques for testing Service Level Agreements. Specifically it introduces advances in traffic generation technologies that allow engineers to generated compliant streams of traffic more accurately and realistically than ever before. It then discusses new technologies that allow test engineers to measure QoS and Traffic Policing in real time, the ATM Forum 0.191 test cell, extensions to that test cell, and how that extended cell can be used to test the new Guaranteed Frame Rate (GFR) ATM Service Category specified in TM4.1.

Service Level Agreements (SLAs)

An ATM Traffic Contract, which may be used to meet a Service Level Agreement, is an agreement between a network user and a network operator. The user agrees to generate traffic within a specific set of traffic characteristics, and the network must transport that traffic within specified Quality of Service (QoS) parameters.

Traffic characteristics are defined by Traffic Parameters. These describe the traffic profile of the source. For example, is the traffic distribution constant or bursty? Does it consist of long frames? In essence, the user agrees to send traffic within the bounds of these parameters. Traffic within these bounds is called "conformant".

ATM Layer Service Category

Attribute	CBR	rt-VBR	nrt-VBR	UBR	ABR	GFR
Traffic Parameters:						
PCR and CDVT$_{4,5}$	Specified			Specified$_{2}$	Specified$_{3}$	Specified
SCR, MBS, CDVT$_{4,5}$	n/a	Specified		n/a		
MCR$_{4}$	n/a				Specified	n/a
MCR, MBS, MFS, CDVT$_{4,5}$	n/a					Specified
QoS Parameters:						
Peak-to-Peak CDV	Specified		Unspecified			
MaxCTD	Specified		Unspecified			
CLR$_{4}$	Specified			Unspecified	See Note 1	See Note 7
Other Attributes:						
Feedback	Unspecified				Specified$_{6}$	Unspecified

Figure 1: ATM Service Categories. Source: ATM Forum.

Conformance Definitions	PCR Flow	SCR Flow	Tagging option active	MCR	CLR ON
CBR.1	0+1	ns$_{1}$	n/a$_{2}$	ns	0+1
VBR.1	0+1	0+1	n/a	ns	0+1
VBR.2	0+1	0	No	ns	0
VBR.3	0+1	0	Yes	ns	0
ABR	0	ns	n/a	Yes	0$_{6}$
GFR.1	0+1	ns	No	Yes	0$_{7}$
GFR.2	0+1	ns	Yes$_{5}$	Yes	0$_{7}$
UBR.1	0+1	ns	No	ns	U$_{3}$
UBR.2	0+1	ns	Yes$_{4}$	ns	U

Figure 2: Conformance Definitions. Source: ATM Forum.

QoS requirements are defined by QoS Parameters, such as Cell Loss Ratio, and (for delay-sensitive applications) Cell Delay and Cell Delay Variation. QoS Parameters describe the guarantees made by the network for traffic that is conformant.

ATM Service Categories

An ATM Service Category relates traffic characteristics and QoS requirements to network behavior. There is a range of behaviors used by the ATM network to enable it to meet the traffic contract - behaviors such as Connection Admission Control (CAC), routing, and network resource allocation. Functions such as scheduling and congestion control in the network elements can also contribute to fairness and isolation amongst multiple traffic sources.

Figure 1 depicts the Traffic Parameters and QoS Parameters for each of the ATM Service Categories.

Conformance Definitions

As discussed above, a user is obligated to insure traffic is Conformant under the parameters set out in the ATM traffic contract. Figure 2 explains the definitions of Conformant Traffic for the different service categories.

Note: The user may request cell tagging for unmarked (CLP=0) frames that are ineligible (exceed the MCR/MBS/MFS condition) - this option is known as the GFR.2 conformance definition and will be discussed in more detail later in this paper.

Testing Service Level Agreements

In order to test a SLA (Traffic Contract) it is necessary to verify both sides of the agreement are being upheld. Test engineers need to:

- Inject traffic that conforms to Traffic Parameters.
- Measure QoS, and compare the results with the QoS Parameters.

Additionally, to test the response of the network to non-compliant traffic, test engineers need to:

- Inject traffic that exceeds the Traffic Parameters by a deterministic amount.
- Measure the accuracy of the network's policing functionality.

The remainder of this paper will investigate the generation of compliant traffic and the measurement of QoS within the boundaries of ATM Traffic Contracts.

Figure 3: Verified Service Level Agreement.

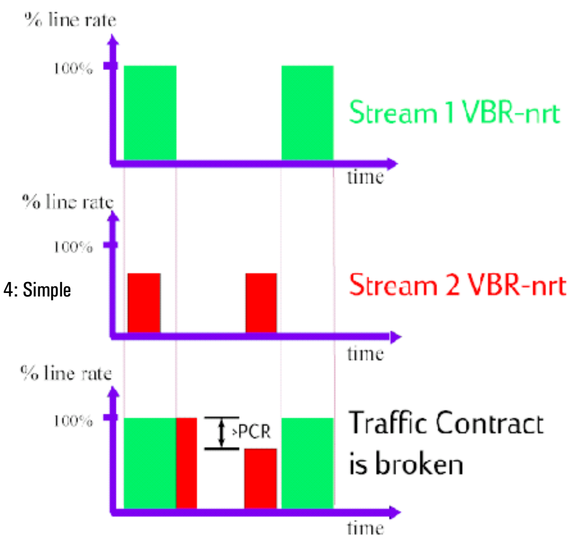


Figure 4: Simple

Generating Conformant Traffic

The test engineer must simulate compliant traffic from multiple network users in order to test the ability of the network or network device to meet SLAs. In this section we will look at advances in traffic generation techniques in broadband analyzers that allow test engineers to generate compliant streams of traffic more accurately and realistically than ever before.

Simple Priority Scheduling

Up until recently, all available test techniques have used simple priority scheduling to delay cells from low-priority streams. This introduces jitter, which can cause the traffic contract to be broken. Worse still, simple priority scheduling does not tell you when the test instrument is generating non-compliant traffic. If cells are dropped, you will not know whether the fault is in the network or in the test equipment. It is impossible to determine whether the ingress switch is policing a non-compliant stream, or whether the network is incorrectly discarding conformant cells.

Figure 4 illustrates how using a simple priority scheduling can distort traffic into non-conforming streams and break the SLA.

In this example, stream 1 of the analyzer's traffic generator is configured as a VBR-nrt (Variable Bit Rate, non-real-time) source. The traffic profile is configured to conform to the traffic contract parameters of this service category (PCR, SCR, MBS). The ingress switch should not discard or tag any cells, and the network should deliver the stream with the agreed QoS parameters (CLR).

To help simplify this example, stream 1 has a PCR of 100% of the ATM line rate.

Stream 2 is configured as a second VBR-nrt source with a different traffic contract, and therefore a different set of traffic parameters (PCR, SCR, MBS).

It is difficult to generate two or more compliant streams simultaneously on one port. When the streams are multiplexed together, it is possible that cells from more than one stream will compete for the same 'time slot'. In this simple but extreme example, every cell in the first burst of stream 2 competes with stream 1.

Only one cell can be generated in each 'time slot'. First-generation test equipment traffic schedulers use a simple 'prioritizer' to give preference to stream 1, or use 'round robin' scheduling to rotate the priority of streams. This is useful in test scenarios that need a high background load with a known average bandwidth. However, it is NOT useful for traffic contract verification, QoS measurement, or policing testing.

In this example, simple priority scheduling delays the first burst of stream 2 until the end of the first burst of stream 1, and reshapes it into a short burst at 100% line rate. The first two bursts of stream 2 are also much closer together. The traffic contract is broken! (Both the PCR and SCR 'leaky buckets' overflow).

The test is not valid, and most test equipment would fail to inform the user that they are generating non-conformant traffic.

Multi-User Compliant Scheduling (MUCS)

In order to overcome this problem, recent developments have seen the introduction of Multi-User Compliant Scheduling (MUCS). Using MUCS, an engineer can be sure that the traffic the test equipment is generating is compliant to the SLA parameters. You can be confident that any faults the test identifies belong to the switch, not the means by which the traffic is being generated.

Figure 5 depicts the concept behind MUCS. In this example, the first burst of stream 2 is still delayed, but is not reshaped. (This is achieved by maintaining the scheduled cell inter-departure gaps as minimum gaps). The traffic generator also dynamically reschedules the second and subsequent bursts of stream 2. The result is that ALL streams conform to their traffic parameters and the test is valid. QoS and policing can be accurately tested.

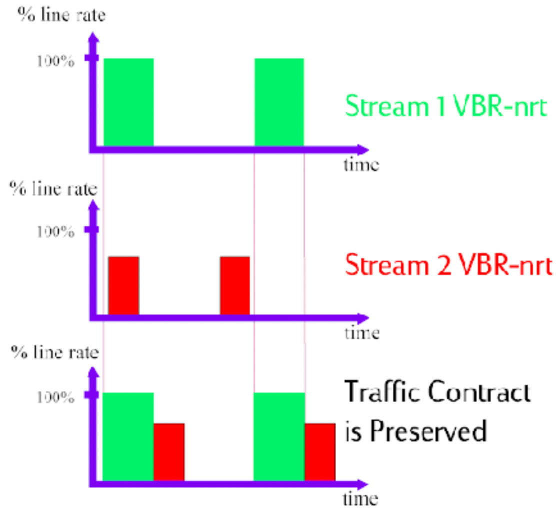


Figure 5: Multi-User Compliant Scheduling.

Static Load Variation

Now that we have analyzed conformant traffic under a static load, we should look at how the network behaves when we increase the load or introduce non-conforming streams.

All broadband analyzers let you generate a static traffic load or a load with a particular profile or pattern. However, the ability to manually create a disturbance or "step change" in the traffic source can be very useful. For example, you may want to introduce a few additional traffic streams, one by one, to bring the network to the point of congestion and then beyond. You are not just interested in how the switch performs under congestion. You are interested in the dynamic behavior of the switch as it reaches and passes through this state. Are there any glitches? How quickly does the switch respond? Does it "over-shoot"?

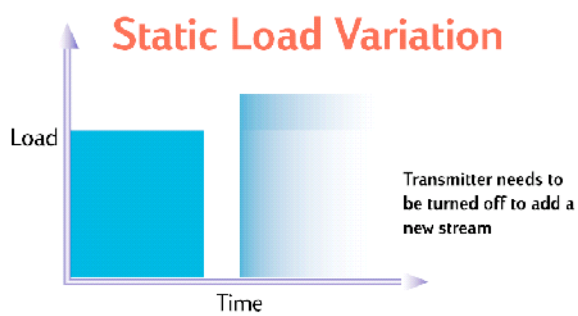
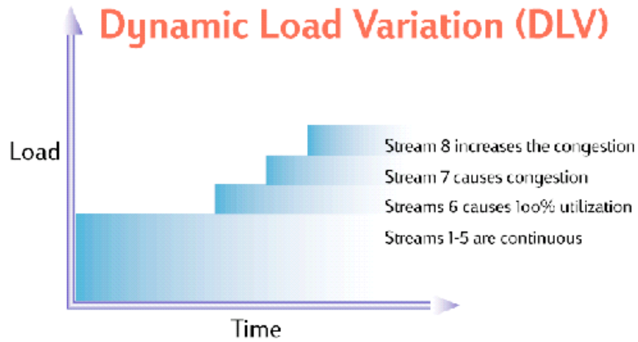


Figure 6: Static Load Variation.

Unfortunately, with most test equipment, you need to turn off the whole traffic generator just to be able to add or delete a single stream, or to change the parameters of a stream. As a result, the transmitted bandwidth temporarily reduces to zero, as shown graphically in Figure 6.

This is an unrealistic methodology and does not simulate what happens in a real network. Before the traffic generator is turned back on, all of the switch buffers will quickly empty, and the switch or network under test will reallocate resources. This invalidates the test.



Dynamic Load Variation

In contrast, Dynamic Load Variation (DLV) can manually introduce step changes to the traffic source like the network would, without turning off the transmitter!

You can add, remove, or re-order traffic streams without interrupting existing traffic streams. This provides valid incremental traffic streams for analyzing the dynamic behavior of ATM switches, networks, and conformance to Service Level Agreements under realistic traffic conditions. The concept of DLV is represented graphically in Figure 7.

Measuring QoS

Having discussed recent advances that allow more accurate and realistic traffic generation to simulate multiple compliant traffic streams, let us now focus our attention on the other side of the SLA - the Network. This section discusses advances in testing technologies that allow engineers to measure QoS and Traffic Policing in real time. It discusses the ATM Forum 0.191 test cell, extensions to that test cell, and methods that can be used to test the GFR service category as specified in TM4.1.

The ITU-T / ATM Forum 0.191 Test Cell

The 0.191 test cell is an ITU-T standard that has the endorsement of the ATM Forum. The use of industry-accepted test cells provides a common yardstick on which Carriers, Service Providers and Network Equipment Manufacturers can measure performance against ATM QoS parameters. The 0.191 test cell format is explained in the Figure 8.

Constant cell payloads and simple repeating patterns provide insufficient stress for testing an ATM switch. The 0.191 Test Cell’s unique scrambling guarantees that every payload bit changes frequently and in a pseudo-random way. This better stresses switch hardware and uncovers "stuck bit" faults - in the same way that computer RAM is best tested by applying a rapidly-changing, pseudo-random sequence.

A PRBS-23 cell sequence achieves a similar purpose - however, a PRBS sequence cannot be used to accurately measure cell loss, cell errors, or cell delay. Therefore, the O.191 test cell replaces the need for separate QoS and PRBS testing, and can reduce system test / QA test time.

Note that other ATM test cells do not offer payload scrambling and are therefore inferior to the O.191 test cell for hardware design, system test, or QA test applications.

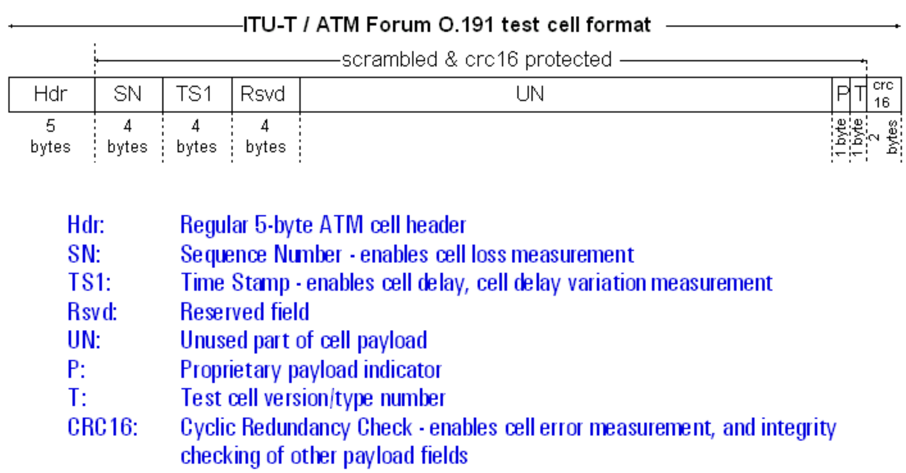
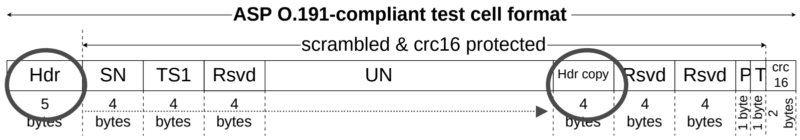


Figure 8: ITU-T/ATM Forum 0.191 Test Cell. Source: ATM Forum.



Hdr: 5-byte ATM cell header
- includes 1-byte Header Error Control (HEC)
- includes Cell Loss Priority (CLP) bit

Hdr copy: Copy of cell header including CLP, without HEC

Figure 9: Extended 0.191 Test Cell.

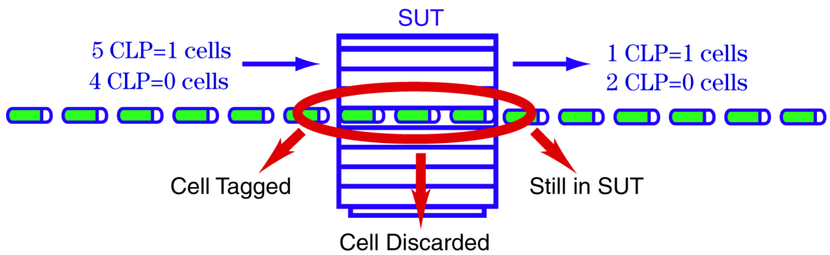


Figure 10: Measuring Cell Tagging.

The Extended 0.191 Test Cell

The 0.191 Test Cell can be extended to include a "Header Copy". This extension enables tagging measurements to be made in real time. The structure of the extended cell is depicted in Fig 9.

Testing methodologies that do not incorporate the Extended 0.191 Test Cell simply count CLP=0 and CLP=1 cells at the input and output of the system under test (SUT). While the test is running, there will always be cells in the SUT - for example, within input and output switch buffers. So it is not possible to accurately count tagged or discarded cells during such a test. The generator must be turned off to "clear" the cells from the SUT. This action would destroy any value the test might have. So cell tagging CANNOT be measured in real-time during the test with this type of technique. When using this methodology during long tests, it is impossible to know when a cell has been tagged. So cell tagging cannot be correlated with other events! Furthermore, if a cell is tagged or discarded during the test, it is not possible to know which cell was tagged or discarded. What did the traffic look like when it happened? Were the switch buffers full? These issues are illustrated in Figure 10.

The Extended 0.191 Test Cell overcomes these issues. A switch tags a cell at the point of entry by changing its CLP bit from 0 to 1 (high to low priority). The Extended 0.191 Test Cell can be used to compare the tagged CLP bit (in the header) with the original CLP bit value (in the header copy) to measure cell tagging in real time. These measurements can be made without turning off the transmitter and disrupting the test. Cell tagging statistics can be correlated with other events or measurements and used to diagnose the time, location, and cause of unexpected problems.

TM 4.1 & TCP/IP Traffic over ATM

The ATM Forum's Traffic Management specification, and its ITU-T equivalent (including recommendation I.356), are considered to be the most important standards for ATM systems and networks. Traffic Management specification version 4.0, or "TM4.0" as it is often called, was completed in April 1996. Together with an ABR Addendum completed in January 1997, TM4.0 describes the first five ATM Forum traffic categories -- CBR, real-time VBR, non-real-time VBR, UBR, and ABR -- and the behavior of compliant systems that must transport and switch ATM traffic.

In this discussion, I will assume that you are reasonably familiar with the first five ATM Forum traffic categories, and with the concepts of traffic policing and Quality of Service that are the building blocks of ATM Service Level Agreements.

Broadband Series Test System

Although the ABR (Available Bit Rate) service category has already been implemented in many ATM switches and deployed in some ATM networks, ABR is not as popular as first expected. For applications that use ATM from end-to-end, ABR is efficient and can maximize the use of available network resources. However, few of today's applications can take full advantage of ABR flow control. Most applications use IP end-to-end over a variety of layer-2 transport protocols. Worse still, the flow control mechanisms of ABR and TCP sometimes interact rather badly. There are many papers that demonstrate this, and new layer-4 transport protocols that are more "ABR-friendly" have been proposed.

In 1999, the ATM Forum completed Traffic Management specification version 4.1, known as "TM4.1". TM4.1 includes a new ATM service category, known as "Guaranteed Frame Rate", or "GFR". GFR was proposed as a more suitable service category for the transport of TCP/IP traffic over ATM.

TM4.1 also includes some clarifications that better explain the ABR and UBR service categories and Virtual Channel to Virtual Path multiplexing.

Guaranteed Frame Rate (GFR)

The concept of a "UBR+" service category has been discussed for some time. "UBR+" would be like the UBR service category (which offers only "best effort" service), but includes a service guarantee for traffic that falls within a Minimum Cell Rate. GFR is like UBR+ with a frame-based service guarantee. This makes it more useful for frame-based traffic, such as TCP/IP data. In fact the GFR Service Category is suitable for any application that can organize its data into frames that be delineated at the ATM layer using AAL-5. This includes IP traffic, which is generally encapsulated into AAL-5 PDUs.

The GFR service category is designed for non-real-time applications that

- Can be mapped onto AAL-5 frames
- Require a minimum rate guarantee
- Can benefit from additional available bandwidth, with "fair sharing" amongst users - "fair sharing" is implementation -specific.

GFR is a frame-aware service and applies only to VCCs (Virtual Channel Connections). Frame delineation is not visible at the VP (Virtual Path) level, so it would not make sense to apply GFR to VPCs (Virtual Path Connections). Unlike ABR, GFR does not require adherence to a flow control protocol. For TCP/IP this make very little difference, because it has its own flow control and does not need ABR.

Under congestion, the network should attempt to discard whole frames of GFR traffic. Partial frames should not be delivered. This is more formal than EPD (Early Packet Discard) and PPD (Partial Packet Discard) mechanisms, which are optional and not related to any service guarantee.

GFR Traffic Parameters

As with other ATM Traffic Categories, the GFR Traffic Parameters are negotiated at the connection establishment. The Traffic Parameters that define the characteristics of a GFR traffic source can be divided into two groups:

1. MCR, MBS, and associated MFS:

- MCR (Minimum Cell Rate); the unit for this parameter is "cells per second".
  Transfer of complete AAL-5 frames is guaranteed for traffic whose cell rate is less than or equal to the MCR. MCR can be zero.

- MBS (Maximum Burst Size); the unit for this parameter is "number of cells".
  MBS is the length of the maximum burst allowed at the Peak Cell Rate. This defines the Burst Tolerance parameter for the leaky bucket GCRA policing algorithm.
  In effect, this allows the traffic to exceed MCR for short bursts, as long as the average cell rate is not above MCR.
- MFS (Maximum Frame Size): the unit for this parameter is "number of cells".
  MFS is the length of the longest AAL-5 frame to be sent.
  Together, these 3 parameters help define traffic that is "eligible" for the service guarantee.

2. PCR and associated CDVT:

- PCR (Peak Cell Rate); the unit for this parameter is "cells per second".
  The user may send traffic above MCR, up to the PCR (Peak Cell Rate) to try to take advantage of available network bandwidth.
  There are no service guarantees for this "non-eligible" traffic -- it is delivered "best effort" only.
- CDVT (Cell Delay Variation Tolerance): CDVT is associated with the PCR parameter.
  CDVT effectively defines the size of the PCR "leaky bucket", allowing the traffic source some amount of jitter.
  CDVT is not signalled in UNI 4.0 SVCs (Switched Virtual Connections).

Together, these 2 parameters define traffic that is "conformant". Traffic that is non-conformant may be policed by the network.

GFR QoS Parameters

There is only one QoS parameter associated with GFR connections: CLR (Cell Loss Ratio). There are no delay or delay variation bounds. GFR is a non-real-time service category, like VBR-nrt, UBR, and ABR.CLR is not negotiated during connection establishment. So the user may have no say in the choice of the value of the CLR parameter. In fact, whether a quantitative value for CLR is specified is network specific; some network implementations may offer only qualitative CLR service guarantees for GFR traffic. This simply means that the network will offer a higher priority ("better than best effort") so that CLR is "low". This is quite different to other service categories, which only offer quantitative CLR service guarantees.

CLR is guaranteed to be low for eligible frames. Eligible frames are frames that:

- conform to MCR, MBS, and MFS.
- that are complete and unmarked (CLP=0).

Frames that are non-eligible but conformant are transported with best effort. A frame is conformant if:

- it conforms to the leaky bucket with PCR/CDVT parameters.
- it is no larger than the MFS.
- it has consistent marking (all cells in the frame have CLP=0 or all cells in the frame have CLP=1).

For frames that are too large (longer than MFS), the last cell is not considered to be non-conformant. This effectively creates a partial packet discard; that is, the last cell of partially-discarded frames is forwarded rather than discarded to signal that a packet has been discarded and to mark the start of the next frame.

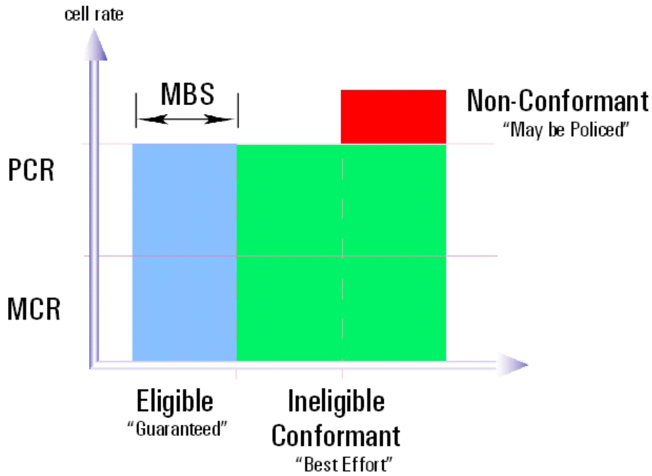


Figure 11: GFR Service Category Eligible and Conformant Traffic.

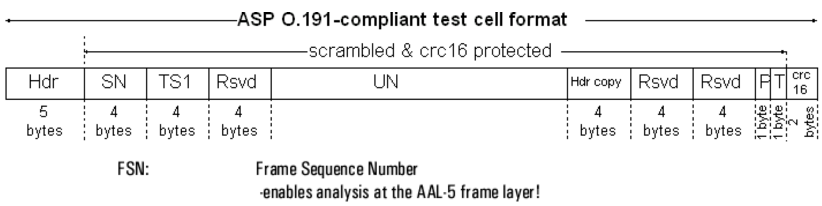


Figure 12: O.191-Based AAL-5 Test Frame.

GFR is a non-real-time category (like VBR-nrt, UBR, ABR) Non-conformant frames (e.g., cells in frames that overflow the PCR leaky-bucket) may be policed by the network using the Frame-based GCRA algorithm, also known as "F-GCRA".

GFR Eligibility and Conformance

Figure 11. Illustrates a GFR stream showing the difference between eligible traffic, ineligible but compliant traffic, and non-compliant traffic.

- The first burst of traffic (of length MBS at Peak Cell Rate PCR) is compliant. Its delivery is "guaranteed".
- The continuation of this PCR burst is ineligible because it exceeds the Maximum Burst Size (MBS). However, it is still compliant because it does not exceed PCR. Ineligible but conformant traffic is carried with "best effort".
- The upper-right portion of the diagram shows that if PCR is then exceeded, the stream will become non-conformant. Non-conformant traffic may be policed by the network (discarded or tagged).

O.191-based AAL-5 Test Frame

The ATM Forum recently accepted a proposal Agilent Technologies for an O.191-style AAL-5 test frame. Such a frame is useful for testing the cell-layer performance and frame-layer behavior of an ATM switch that offers Early Packet Discard, Partial Packet Discard, or the new Guaranteed Frame Rate (GFR) traffic category that has been introduced with the new ATM Forum Traffic Management specification version 4.1 (TM4.1).

In essence, the test frame consists of zero or more O.191 "frame-body" test cells, followed by a special "end-of-frame" test cell that makes room for the AAL-5 trailer.

An initiative driven by Agilent Technologies has seen the adding of a special Frame Sequence Number (FSN). The FSN counts the number of AAL-5 test frames, just as the cell SN within the O.191 cell payload counts the number of ATM test cells. This can be useful for testing AAL-5 Early Packet Discard and Partial Packet Discard, and for examining frame-layer impairments such as frame loss, repetition, mis-sequencing, misinsertion, frame latency, and frame latency variation.

Figure 12 illustrates Agilent's O.191-based AAL-5 test frame.

A regular O.191 test cell cannot be used at the end of an AAL-5 frame because the AAL-5 trailer would overwrite the last few fields of the test cells (including the CRC-16 field, which checks the integrity of the cell payload and protects the other fields such as the Sequence Number). The ASP end-of-frame test cell is very similar to the frame-body test cell, except that the trailing fields are shifted to the left by 8 bytes to make room for the AAL-5 trailer. Of course, the ASP receiver can detect and recognize the end-of-frame test cell, and is able to read the payload to make ATM cell-based measurements.

At the same time, the user can examine the Frame Sequence Number to look for impairments to frame-layer throughput, such as frame loss, frame repetition, frame mis-sequencing, and frame latency.

The AAL-5 CRC-32 field can be used to measure packet errors (frame loss). This can be correlated with the ATM cell loss measurement for more in-depth analysis.

Conclusion

ATM networks and ATM traffic contracts are used by network operators to meet Service Level Agreements. In this paper, we have introduced four advanced techniques for testing ATM Traffic Contracts:

- Multiple User Compliant Scheduling (MUCS) for accurately generating multiple traffic streams that comply to ATM traffic contracts.
- Dynamic Load Variation (DLV) for accurately testing the dynamic response of ATM switches and networks under a step change to the load
- Extended O.191 Test Cell with copied CLP bit for real-time measurement of cell tagging.
- O.191-based AAL-5 Test Frame for testing the new GFR service category, for testing EPD and PPD, and for correlating ATM cell QoS with AAL-5 frame performance.

Service providers use these techniques to test that their ATM networks are able to meet multiple traffic contracts simultaneously so that they can be confident that multiple SLAs can be honored.

ATM network equipment manufacturers also use these testing techniques to verify that their ATM switches and network devices have the functionality, accuracy, and performance to meet the needs of service providers.

Broadband Series Test System

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Acronyms

AAL-5	ATM Adaption Layer 5
ABR	Available Bit Rate
ASP	E1609A ATM Stream Processor
ATM	Asynchronous Transfer Mode
CAC	Connection Admission Control
CBR	Constant Bit Rate
CDV	Cell Delay Variation
CDVT	CDV Tolerance
CLP	Cell Loss Priority
CLR	Cell Loss Ratio
CRC	Cyclic Redundancy Check
CTD	Cell Transfer Delay
DLV	Dynamic Load Variation
EPD	Early Packet Discard
F-GCRA	Framed base Generic Cell Rate Algorithm
FSN	Frame Sequence Number
GFR	Guaranteed Frame Rate
Hdr	Header
IP	Internet Protocol
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
MBS	Maximum Burst Size
MCR	Minimum Cell Rate
MFS	Maximum Frame Size
MUCS	Multi-User Compliant Scheduling
nrt	non-real-time
O.191	ITU-T ATM Test Cell recommendation
PCR	Peak Cell Rate
PDU	Protocol Data Unit
PPD	Partial Packet Discard
PRBS	Pseudo Random Binary Sequence
QA	Quality Assurance
Qos	Quality of Service
Rsvd	Reserved
rt	real-time
SCR	Sustained Cell Rate
SLAs	Service Level Agreements
SN	Sequence Number
SUT	System Under Test
TCP	Transmission Control Protocol
TM	Traffic Management
TSE	Time Stamp
UBR	Unspecified Bit Rate
VBR	Variable Bit Rate
VCC	Virtual Channel Connections
VPC	Virtual Path Connections

Agilent Technologies Broadband Series Test System

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Specifications subject to change.

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