Testing Techniques for Next Generation IP Networks

Agilent Technologies Broadband Series Test System Application Note

Introduction

The long-term vision for ATM was that it would become a universal end-to-end networking technology, used in the core, enterprise, and desktop to carry multimedia services. Now, it seems more likely that IP will adopt this role, and ATM will become a strategic technology used for applications such as the high-speed backbone in core networks. ATM is also likely to remain the technology of choice for implementing virtual LANs (VLANs) in the enterprise, using LANE and MPOA.

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Innovating the HP Way

IP is emerging as *the* universal end-to-end layer-3 protocol, operating over a range of layer-2 technologies such as ATM, Gigabit Ethernet, and SONET/SDH. IP is starting to adopt some ATM-like characteristics such as wire-speed (hardware) routing and Class of Service (CoS) management. Advances in architecture and features are creating new test challenges for designers of IP equipment and networks.

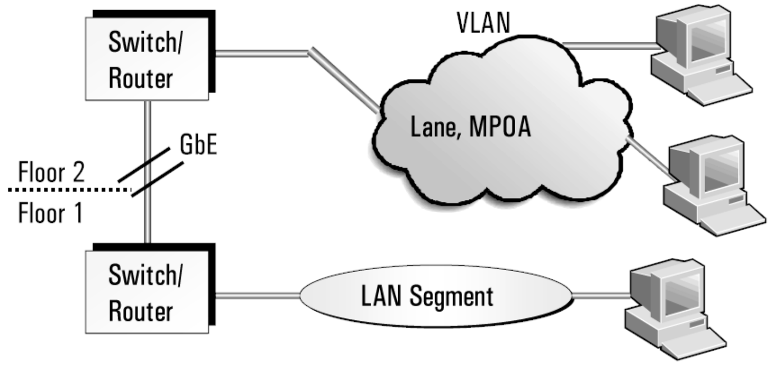
This application note discusses recent advances in IP standards and outlines the test techniques required for three different applications:

- functional testing of a layer-2/layer-3 switching device
- CoS contract verification in an IP network
- interworking testing of an IP/ATM access device

IP meets ATM in the enterprise network

In the enterprise, Gigabit Ethernet (GbE) offers a simple migration path that helps eliminate bandwidth bottlenecks. However, ATM is being deployed in the enterprise because of its guaranteed QoS capability and the ability to create remotely managed VLANs, using LANE and MPOA.

An example of IP adopting ATM-like capabilities is the RSVP (resource reservation) protocol, where the IP source specifies its traffic requirements and the network reserves capacity for the traffic flow in order to guarantee throughput. So far, RSVP has only been successful for small campus LANs and does not scale up for use in the larger networks. An interesting variation on this approach is to map RSVP reservations to ATM VCCs in order to take advantage of ATM QoS management.

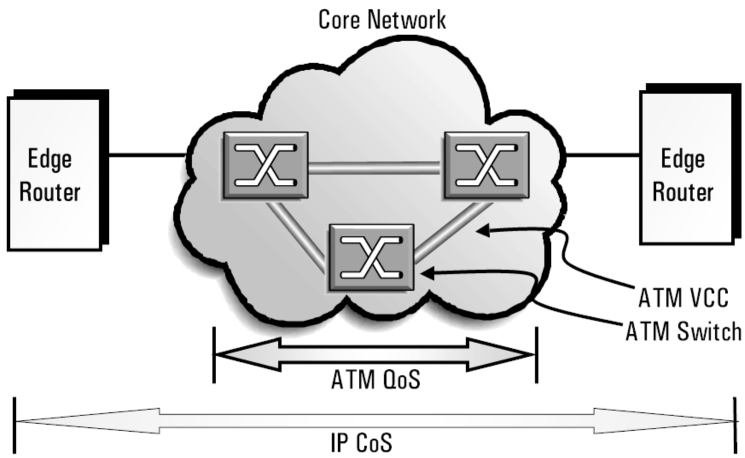


Gigabit Ethernet removes bandwidth bottlenecks, while ATM enables configuration of virtual workgroups (VLANs).

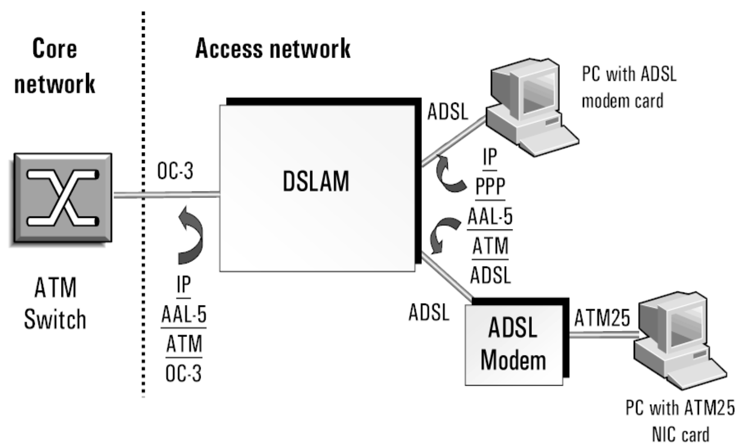
Another example of *IP meeting ATM* is MPLS (Multi-Protocol Label Switching), which is currently being defined by the IETF and is based on Cisco's tag switching. MPLS combines the circuit switching characteristics of ATM with the packet switching characteristics of traditional IP routers to increase throughput and reduce latency. In MPLS, all packets within an IP session can be *tagged* and treated as a single flow that is switched by hardware through each router hop. This contrasts with packet-by-packet routing which is often performed by software.

IP meets ATM in the core network

Due to its scalable nature and traffic management capability, ATM is being widely deployed in public data networks and in the backbones of ISPs (Internet Service Providers). IP has emerged as the predominant protocol carried by these networks. As a result of this trend, there are proposals to carry IP directly over SONET/SDH. This would avoid the overhead (sometimes referred to as the *cell tax*) associated with small, fixed-size ATM cells. In effect, this philosophy takes the switching function out of the core network and replaces it with routing at the edge of the network, using native IP routing protocols instead of ATM signalling.



ATM QoS in the core network helps guarantee end-to-end IP Class of Service (CoS).



IP over ADSL in the access network: the DSLAM uses ATM to multiplex low-speed traffic.

The success of this approach will depend on the development of Gigabit and Terabit IP routers with CoS management capability. There are also proposals to map IP traffic flows at the edge of the network to ATM VCCs, using the MPLS routing mechanism. This approach could offer guaranteed QoS through the core network.

IP meets ATM in the access network

xDSL technology, particularly ADSL, is emerging as a cost-effective method of providing high-speed Internet access to the home or business, using the existing copper wire infrastructure. There is currently a lot of debate about how best to carry IP over ADSL. The use of PPP over AAL-5 (defined in RFC2364) to carry IP traffic is one proposal that appears to have a lot of support from equipment manufacturers. The large-scale adoption of this approach could bring ATM to the desktop, in the form of either ADSL modem cards or ATM25 NIC cards, installed in the home or office PC.

An alternative solution is to connect to the ADLS modem via 10/100 Mb/s Ethernet. In this case, the IP/MAC frames would be mapped into AAL-5 (as defined in RFC1483) without using PPP.

Major IP developments - new test challenges!

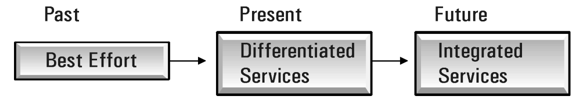
Best effort model

In the past, IP networks only offered a *best effort* class of service. This was satisfactory for most data transfer applications. Today, IP networks are facing two complicating factors: rapidly increasing demand for bandwidth; and the proliferation of web-based and multimedia applications running over the Internet. These are the same factors that ATM was intended to address. However, with IP emerging as the universal end-to-end protocol, it is now being recognized that it must provide similar traffic management capabilities to ATM.

Differentiated services model (DiffServ)

Today, IP networks are migrating towards a provisioning-based Differentiated Services (DiffServ) model. Routers at the edge of the network classify all packets within a flow by setting the Type of Service (TOS) or Differentiated Services (DS) field in the IP header. Routers within the core network interpret these fields in order to manage CoS. Queuing strategies such as class-based queuing (CBQ) and per-flow queuing (PFQ) can be used to manage traffic throughput.

Whereas ATM specifies five service classes (CBR, VBR-rt, VBR-nrt, UBR, and ABR), the DiffServ model is likely to offer only two or three IP classes of service (CoS): for example, *best effort*, *controlled load*, and *guaranteed throughput*. It is expected that IP CoS management will ensure satisfactory throughput for many applications, but will not guarantee end-to-end delay. CoS management is examined in more detail in test scenario #2.



Traffic management	None	Provisioning-based	Reservation-based
Guaranteed throughput	No	Yes	Yes
Guaranteed delay	No	No	Yes
Queuing strategy	FIFO	CBQ, PFQ	WFQ, RVSP

Increasing bandwidth, service integration

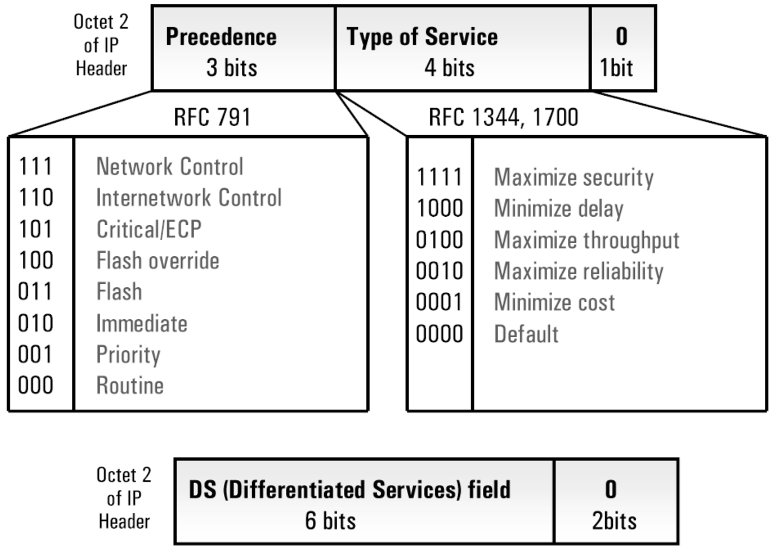
Major IP developments: IP is adopting ATM-like throughput and delay management capabilities.

Integrated services model (IntServ)

The longer-term vision for large-scale IP networks is to adopt a reservation-based Integrated Services (IntServ) model. This may require routing equipment to use more advanced traffic management strategies such as WFQ (Weighted Fair Queuing), operating in conjunction with the RSVP reservation protocol. WFQ employs a scheduler within each switching device in the core network. The WFQ scheduler controls packet departure times based on *weights* signalled into the network from the source.

Other measures could involve traffic shaping and admission control at the edge of the network. The token bucket algorithm (defined in RFC2215) is an example of a traffic shaping method. The token bucket TSpec parameter is described in more detail in test scenario #2.

The aim of the IntServ IP network model is to manage both throughput and end-to-end delay for a range of service classes.



The second octet of the IPv4 header is currently occupied by the TOS and Precedence fields. The IETF may replace them by a 6-bit DS field.

New RFCs

There are so many new RFCs being produced by the IETF that it is difficult to keep up! A few are discussed here.

Differentiated services model: TOS and precedence

IETF RFCs 791, 1349, and 1700 specify the assignment of TOS (Type of Service) bits and Precedence (priority) bits in the IP header. TOS specifies what quality parameters are important (for example throughput or delay). Precedence specifies the relative priority of traffic streams when congestion occurs. Work is in progress at the IETF that may replace TOS and Precedence fields by a 6-bit DS field. This is currently documented in an Internet-Draft by the Transport (DiffServ) working group.

Integrated services model

RFC1633 provides an overview of the IETF's Integrated Services model. RFCs 2205-2216 deal with specific aspects of RSVP and guaranteed quality of service. The IntServ model is particularly concerned with time-of-delivery of traffic. Additional work in progress is documented in several IETF Internet-Drafts by the Transport (IntServ) working group.

Measuring performance in IP networks

Recommendations on how to measure performance in packet-based networks are provided by RFC1242 (by S. Bradner), RFC1944 (by S. Bradner and J. McQuaid) and RFC2285 (by R. Mandeville). RFC1944 suggests values to use for parameters such as frame size, burst size, and maximum frame rate. It also defines test frame formats and refers to terminology in RFC1242. RFC2285 also provides an extensive list of benchmarking parameter definitions.

RFC1944 performance measurements

RFC1944 describes the general test methodology for measuring throughput, latency, and frame loss rate in packet networks. Latency and throughput are the QoS parameters that are managed for different classes of service, depending on the value of the TOS field. Frame (or in this case, packet) loss rate is the QoS parameter that is managed under congested conditions, taking into account the value of the Precedence field for each traffic stream.

RFC1242 latency measurements

RFC1242 defines the latency measurement as either LIFO (Last-bit-In to First-bit-Out), for store-and-forward devices; or FIFO (First-bit-In to First-bit-Out), for bit-forwarding devices.

RFC2215 traffic characterization

RFC2215 defines general parameters required for the management of quality of service in IP networks. The traffic specification parameter (TSpec) can be used by a data sender to describe the parameters of traffic it expects to generate or by a QoS control service to describe the parameters of a traffic stream it is attempting manage. It is intended for use in the IntServ model of QoS management, but can also be used for characterizing traffic in the DiffServ model of CoS management.

The TSpec parameter (also denoted as TOKEN_BUCKET_TSPEC) defines traffic characteristics in terms of a token bucket algorithm. The leaky bucket traffic-shaping algorithm used in ATM tends to smooth out bursty traffic. By contrast, the token bucket algorithm allows traffic to continue transmitting at a specified peak burst rate for as long as there are sufficient tokens in the bucket. This is better suited to the characteristics of IP traffic.

An example of today's multi-service platform

Today, the distinction between a hub, router, switch, or access concentrator is blurring. Many vendors offer some type of *multi-services platform* for the enterprise network. Typical characteristics include:

- Support for multiple services
- Voice, data, video, leased line circuit emulation
- Support for multiple interfaces
- 10/100 Mb/s Ethernet, HSSI, ATM, IP over SONET, ISDN, N x 64 kb/s T1/E1

Increasingly, TCP/IP is being used to transport multimedia services over LAN, WAN, and ATM segments.

The Ethernet Test Solution for the HP BSTS

The three test scenarios in this application note use the HP E6282A 10/100 Mb/s Ethernet Frame Processor module. We will look at some aspects of testing IP functionality, class of service management, and interworking performance in next-generation IP equipment and networks.

Test scenario #1: Functional testing of a layer 2 or layer 3 switching device

In this scenario, the test equipment has two full-duplex 10/100 Mb/s Ethernet ports. Each port behaves as a different IP subnet connected to the router. After basic functions have been verified on two ports, testing can be expanded to generate traffic on multiple ports. (Performance testing is discussed in more detail in test scenario #2.)

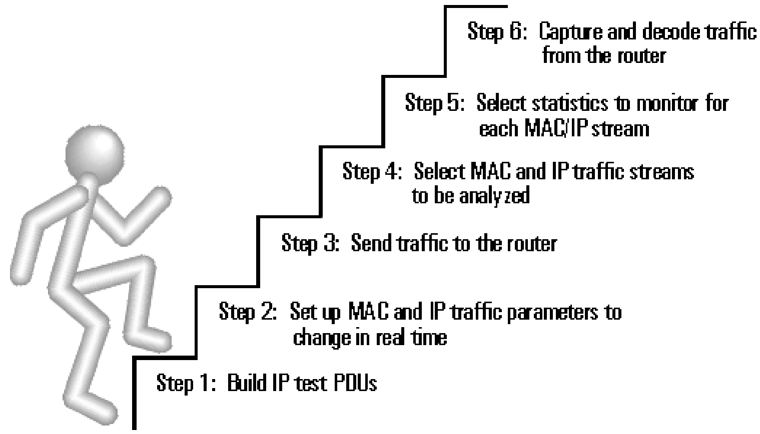
Router Test Issues

In this scenario, the aim of functional testing is to find problems in implementing features at the MAC and IP layers; for example, the ability to update MAC and IP address tables. Specific tests include:

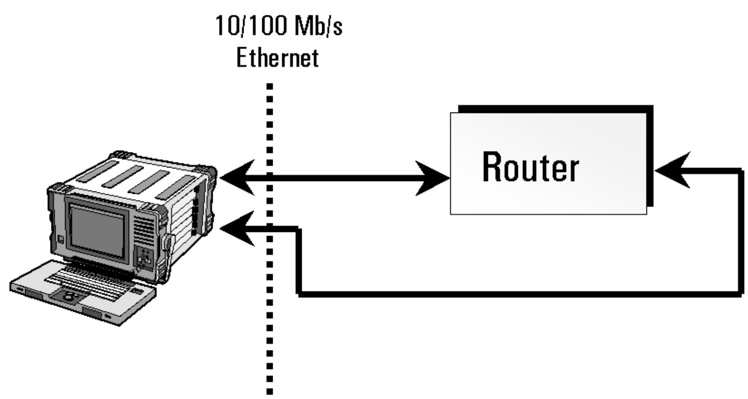
- MAC address learning table updates
- Ethernet (MAC)collision detection and jabber control
- Ethernet (MAC) inter-packet gap and inter-burst gap conformance with IEEE 802.3
- IP address registration and address table management
- error handling at the MAC, IP, and TCP layers

Test method

The test equipment generates IP traffic with various IP and MAC (Ethernet) parameters. Measurements can be made at the MAC layer to verify functions such as collision detection (detection of multiple sources transmitting at the same time) and jabber control (restriction on how long one source can transmit for). Measurements can be made at the IP layer to detect PDU errors, loss, duplication, or mis-sequencing.



Test methodology for functional testing in order to find implementation problems at the MAC and IP layers.

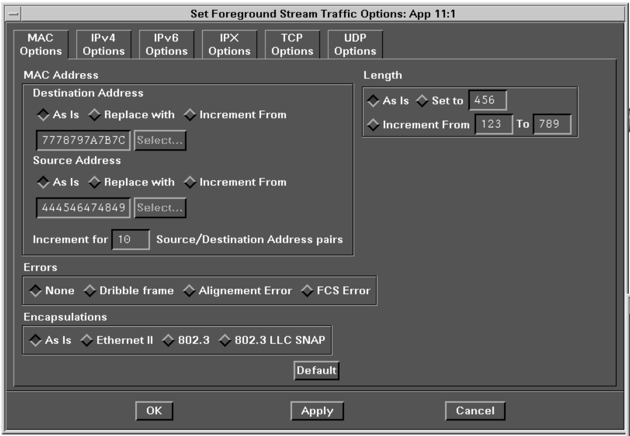


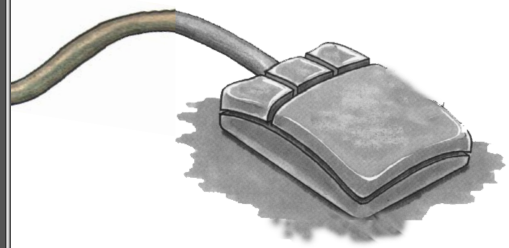
Test configuration #1: Dual-port 10/100 Mb/s Ethernet tester connected to a router.

Once a problem has been detected, you can capture and decode traffic to determine its cause. The definitions of PDU formats for the IP family of protocols are defined in various IETF documents.

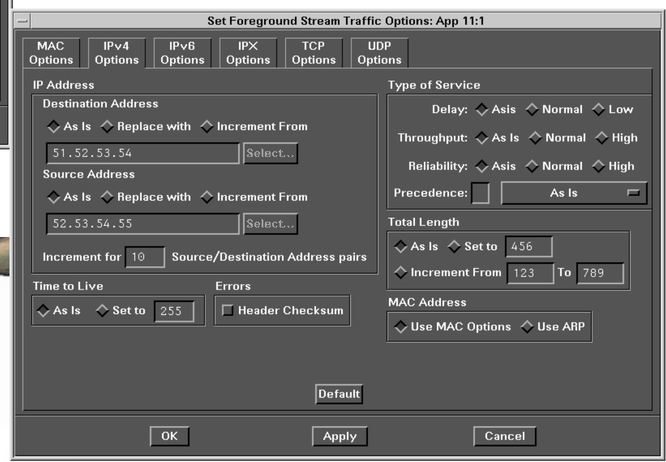
- RFC768 - User Datagram Protocol (UDP)
- RFC791 - Internet Protocol version 4 (IPv4)
- RFC792 - Internet Control Message Protocol (ICMP)
- RFC793 - Transmission Control Protocol (TCP)
- RFC1885 - Internet Protocol version 6 (IPv6)

Key test requirements for test scenario #1

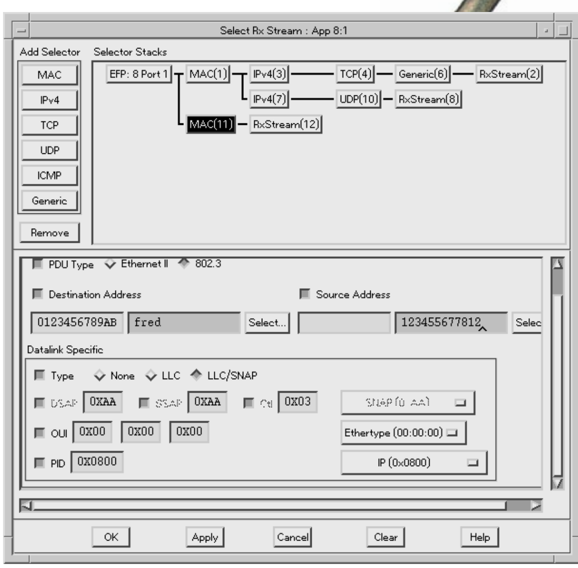




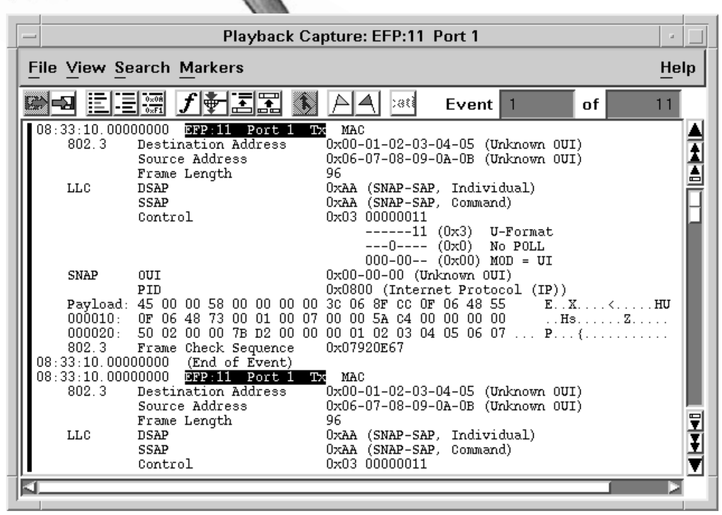
After building an IP packet or sequence of packets, configure the traffic parameters that are to be varied in real time. Configure MAC layer parameters such as source and destination address ranges, frame lengths, or induce various types of frame errors.



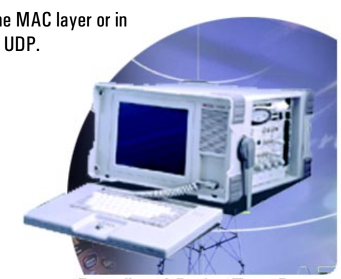
Configure IP PDU parameters to vary in real time, such as source and destination address ranges, frame lengths, time-to-live (maximum number of router hops), or induce header checksum errors.



Define the streams (for example MAC and IP) that you want to analyze. Select MAC layer statistics such as throughput, errored frames, short/long/runt/jabber frames, single/multiple/late collisions. Select IP data stream statistics such as throughput, errored/lost/duplicated/mis-ordered PDUs.



Capture data and decode it to see problems at the MAC layer or in IP-family protocols such as IPv4, ICMP, TCP, or UDP.



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Test scenario #2: CoS contract verification in an IP network

In this scenario, the test equipment has two full-duplex 10/100 Mb/s Ethernet ports. Each port behaves as an IP end-station connected to the network.

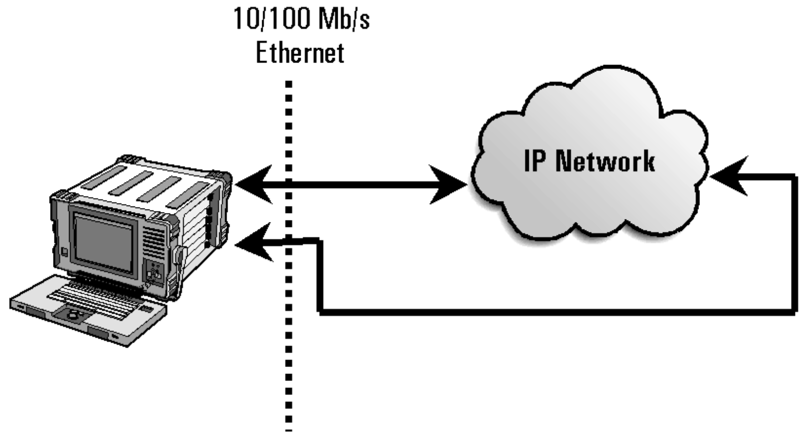
IPv4 TOS and Precedence fields

As discussed earlier, the class of service of a particular traffic stream is defined by setting the TOS/Precedence fields or DS field in the IP header. The aim of this test scenario is to generate several traffic streams with different classes of service, and evaluate how the network handles each stream under normal and congested conditions. After traffic management has been verified on two ports, testing can be expanded to generate traffic on multiple ports to simulate more realistic traffic conditions in the network.

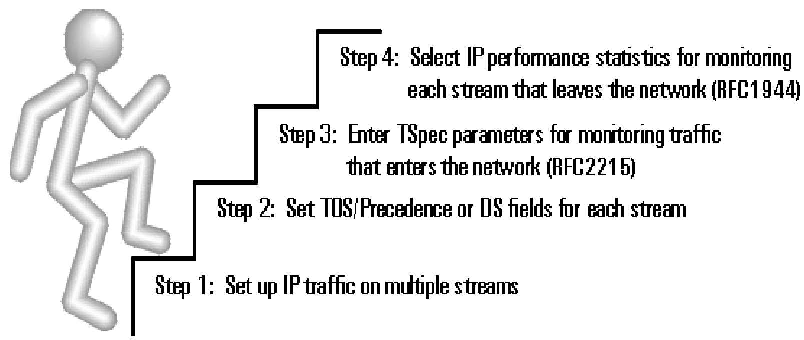
IP traffic management test issues

The major IP traffic management test issues are:

- handling of multiple IP traffic streams with different CoS requirements.
- effect of congestion on low and high priority traffic streams.
- IP performance measurements for each traffic stream (RFC1944).
- handling of conforming and non-conforming traffic streams (RFC2215).



Test configuration #2: Dual-port 10/100 Mb/s Ethernet tester connected to an IP network: This configuration can also be used to test ADSL modems that have Ethernet access ports.

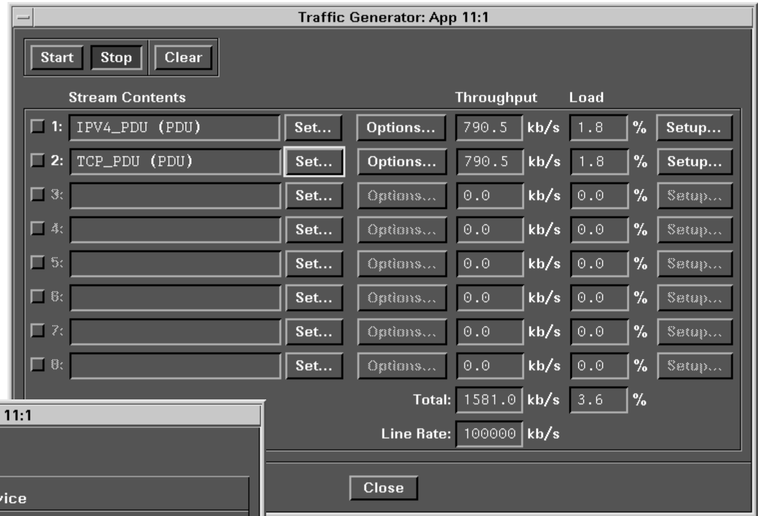


Test methodology for CoS contract verification in an IP network

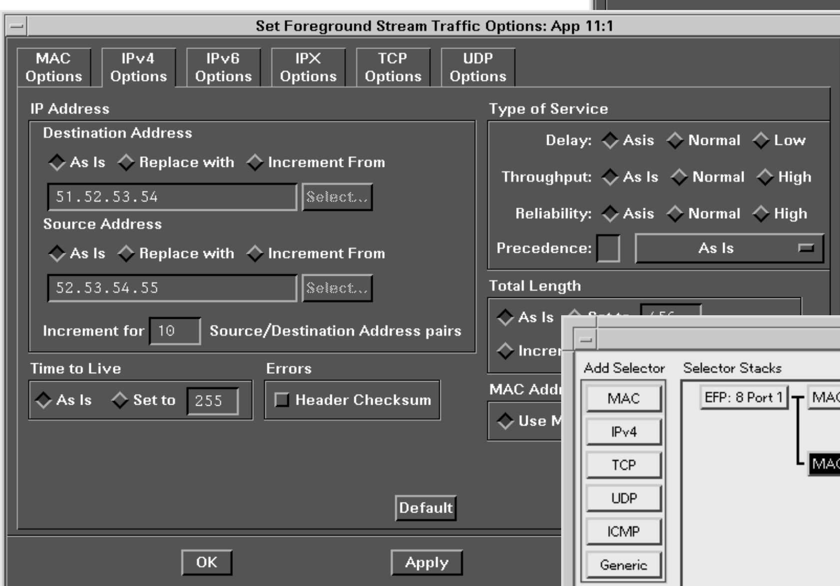
Test method

The test equipment generates several streams of IP traffic and measures the ability of the network to manage the CoS on each stream. If TSpec parameters have been specified, each traffic stream should be monitored for conformance at the entry to the network.

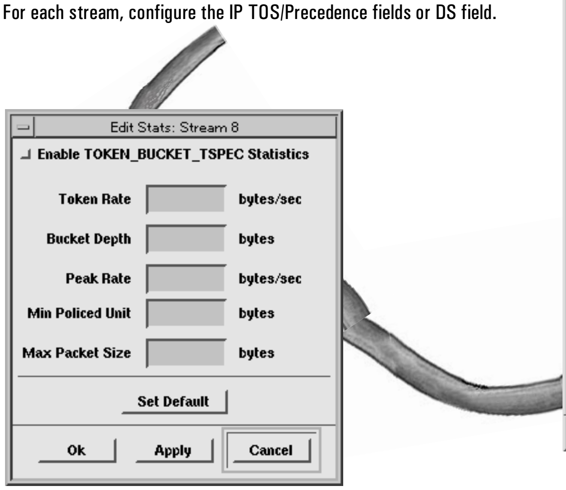
Key test requirements for test scenario #2

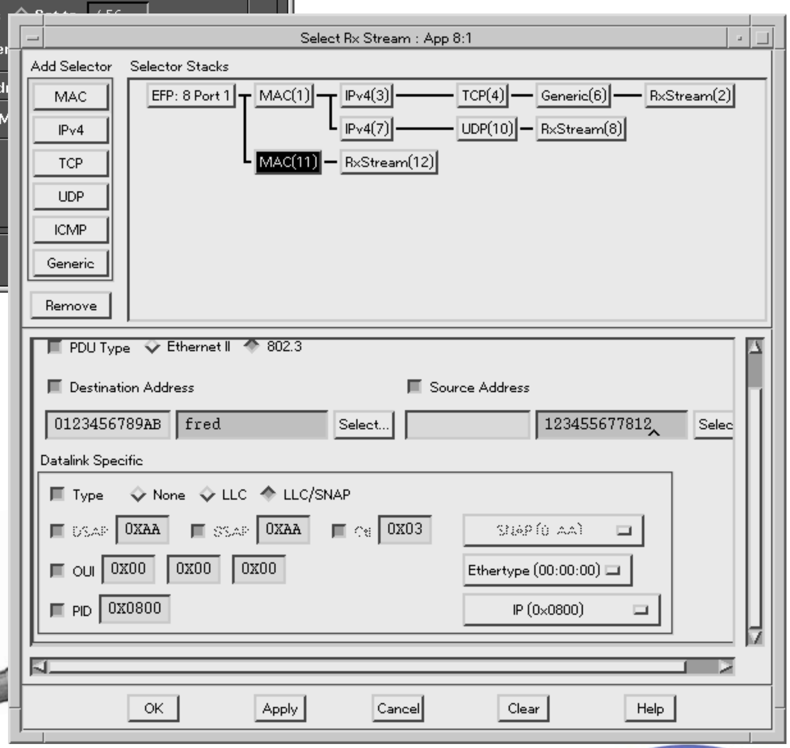


Define several IP traffic streams. The number of streams depends on the number of service classes the network is designed to manage. Repeat the tests for different bandwidths and traffic profiles.



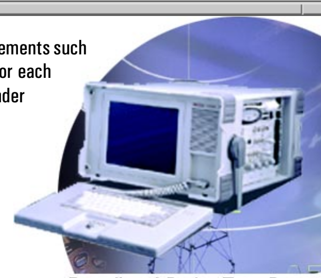
For each stream, configure the IP TOS/Precedence fields or DS field.





On traffic entering the network: Set RFC2215 TOKEN_BUCKET_TSPEC parameters for each traffic stream and monitor the network behavior under conforming and non-conforming traffic conditions.

On traffic leaving the network: Select IP performance measurements such as throughput and FIFO/LIFO latency (defined in RFC1242) for each traffic stream to determine how well the CoS is managed under various traffic conditions.



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Test scenario #3: Interworking testing of an IP/ATM access device

In this scenario, the test equipment has a full-duplex 10/100 Mb/s Ethernet port and a full-duplex ATM port (for example, OC-3). The Ethernet port behaves as an IP end-station and the ATM port acts as the ATM network connected to the access equipment.

This test setup could be applied to the ADSL example described previously, where the ADSL modem provides 10/100 Maps Ethernet access.

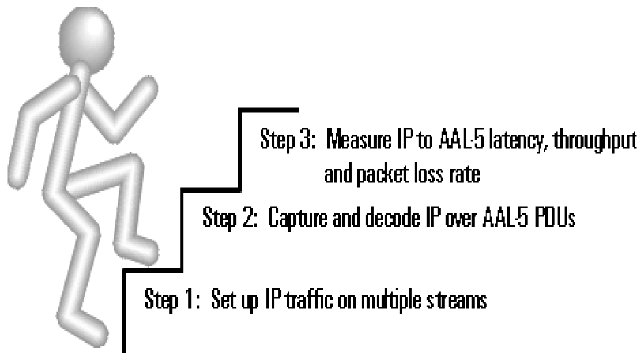
Test Issues

The major IP/ATM interworking test issues are:

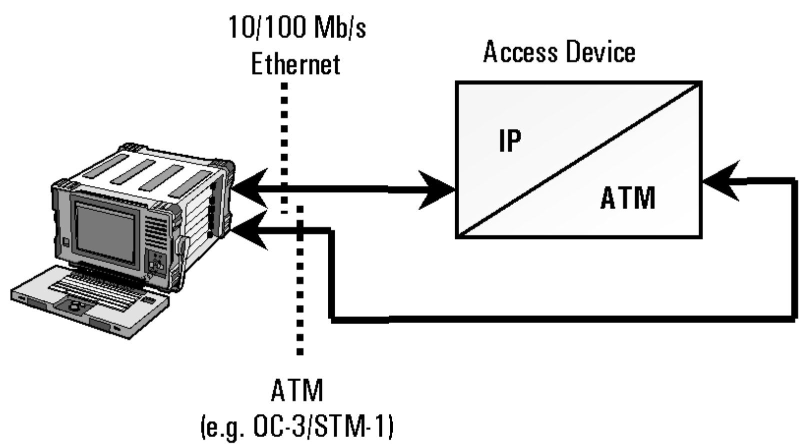
- correct IP to ATM encapsulation (RFC1483 and RFC2225)
- IP to ATM performance measurements for each traffic stream (RFC1944)
- handling of conforming and non-conforming traffic streams (RFC2215)

RFC1483 and RFC2225 define the *Classical IP* encapsulation of IP packets within AAL-5 PDUs. Other encapsulation methods are defined in the ATM Forum LANE and MPOA recommendations.

Because RFC1944 refers to any type of packet-based network, it can be applied to interworking performance measurements between IP and AAL-5 PDUs. Latency, throughput, and packet (or PDU) loss rate are the main parameters that describe interworking performance.



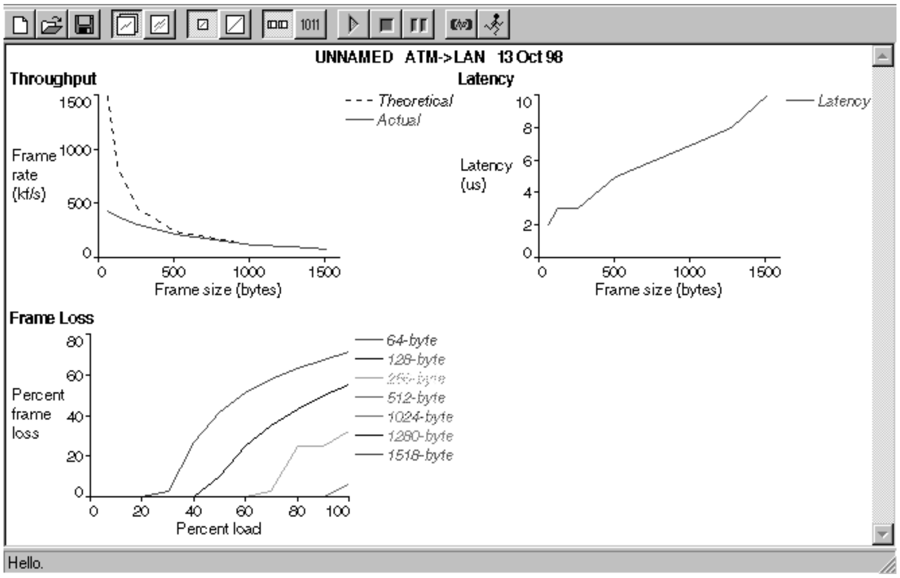
Test methodology for interworking testing of an IP/ATM access device



Test configuration #3: Test equipment with Ethernet and ATM ports connected to an interworking device.

Test method

The test equipment generates a known number of timestamped IP packets. On the ATM side, AAL-5 PDUs are captured and decoded. Latency is calculated by comparing departure and arrival timestamps. Throughput is counted as PDUs per second. Packet loss rate is calculated as (PDUs sent - PDUs received) / PDUs sent.



An example of how the results of your performance tests can be plotted graphically to discover performance trends.

Discovering performance trends

You can repeat the performance tests with different traffic parameters such as increasing frame size and bandwidth. By plotting the results graphically, performance trends can be analyzed for latency, throughput, and packet loss.

Summary

In summary, IP is emerging as the universal end-to-end protocol for multimedia applications. We have examined some examples of how IP interworks with ATM in enterprise, core, and access networks. As IP adopts ATM-like traffic management features it is becoming more complex. This application note has provided a brief overview of the DiffServ and IntServ traffic management models and some of the many new RFCs that they encompass.

The evolution of IP presents new test challenges. We have examined three different test scenarios in order to illustrate some of the test issues and test techniques that can be used to solve them.

IETF RFCs referred to in this paper

768	User Datagram Protocol (UDP)
791	Internet Protocol version 4 (IPv4)
792	Internet Control Message Protocol (ICMP)
793	Transmission Control Protocol (TCP)
1180	A TCP/IP Tutorial
1242	Benchmarking Terminology for Network Interconnection Devices
1349	Type of Service in the Internet Protocol Suite
1483	Multiprotocol Encapsulation over ATM Adaptation Layer 5
1633	Integrated Services in the Internet Architecture: an Overview (IntServ model)
1700	Assigned Numbers
1885	Internet Protocol version 6 (IPv6)
1944	Benchmarking Methodology for Network Interconnect Devices
2205-2210	Resource ReSerVation Protocol (RSVP) specifications
2211	Specification of Controlled-Load Network Elements (IntServ model)
2212	Specification of Guaranteed QoS (IntServ model)
2213-2214	IntServ MIB using SMIv2
2215	General Characterization Parameters for IntServ Network Elements
2216	Network Element Service Specification Template (IntServ model)
2225	Classical IP and ARP over ATM (Obsoletes RFC1626 and RFC1577)
2285	Benchmarking Terminology for LAN Switching Devices
2364	PPP over AAL-5

IETF work in progress referred to in this paper

Refer to the IETF web site at:

- www.ietf.org

Transport Area Internet-Drafts:

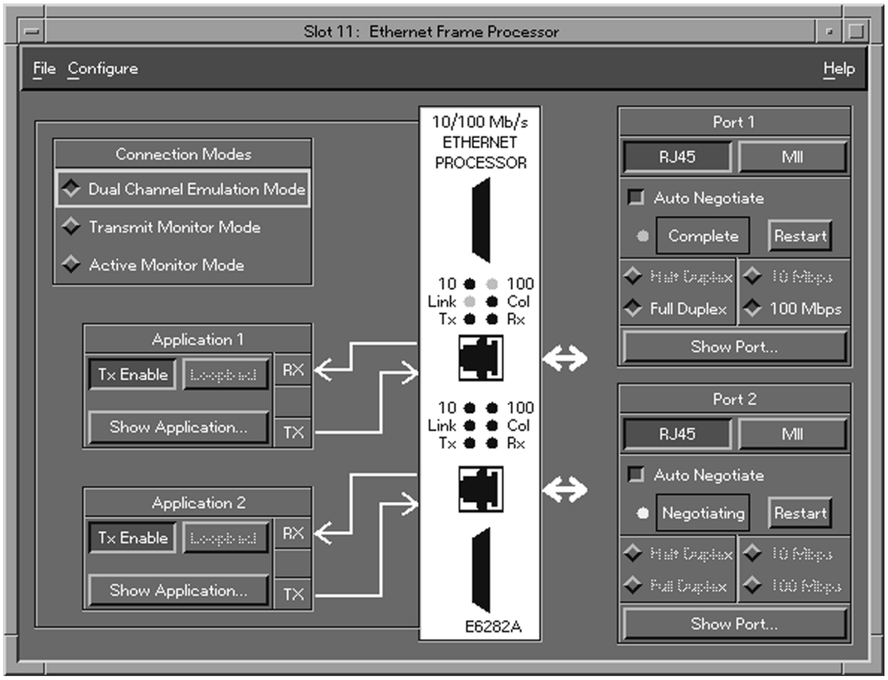
- Differentiated Services (DiffServ model)
- Replacement of Type of Service and Precedence fields with the DS field
- Integrated Services (IntServ model)

Routing Area Internet-Drafts:

- Multi-Protocol Label Switching (MPLS)

Acronyms

AAL-5	ATM Adaptation Layer 5
ADSL	Asymmetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
ATM25	ATM 25.6 Mb/s desktop line interface
CBQ	Class-Based Queuing
CoS	Class of Service
DiffServ	Differentiated Services IP model (IETF)
DS byte	Differentiated Services IP header field (replaces TOS)
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
FIFO	First-(bit)-In, First-(bit)-Out (latency parameter)
GbE	Gigabit Ethernet
ICMP	Internet Control Message Protocol (IETF)
IEEE	Institute of Electrical and Electronic Engineers (Ethernet standards)
IETF	Internet Engineering Task Force (IP protocol suite)
IntServ	Integrated Services IP model (IETF)
IP	Internet Protocol (layer 3 LAN protocol)
IPv4	Internet Protocol version 4 (IETF)
IPv6	Internet Protocol version 6 (IETF)
ISP	Internet Service Provider
LAN	Local Area Network
LANE	ATM Forum LAN Emulation
LIFO	Last-(bit)-In, First-(bit)-Out (latency parameter)
MAC	Media Access (layer 2 LAN protocol, for example Ethernet)
MPLS	Multi-Protocol Label Switching (IETF)
MPOA	ATM Forum Multi-Protocol Over ATM
NIC	Network Interface Card
PFQ	Per-Flow Queuing
PPP	Point-to-Point Protocol (IETF)
QoS	Quality of Service
RFC	Request for Comment (IETF document)
RSVP	Resource ReSerVation Protocol (IETF)
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network (transmission protocol)
TCP	Transmission Control Protocol (IETF)
TOS	Type of Service (IETF)
TSpec	Traffic Specification (RFC2215, token bucket algorithm)
UDP	User Datagram Protocol (IETF)
VCC	Virtual Circuit Connection (ATM)
VLAN	Virtual LAN
WFQ	Weighted Fair Queuing
xDSL	Family of DSL standards for carrying data over copper twisted-pair cables



Main control dialog for the dual port E6282A Ethernet Frame Processor showing key operational modes and interface type, duplex and rate.

E6282A Ethernet Frame Processor

The Agilent Technologies E6282A 10/100 Mb/s Ethernet Frame Processor brings LAN interworking and native Ethernet testing to the BSTS. As with all BSTS modules, the Ethernet Frame Processor has a rich set of test features tailored for equipment design and network test applications.

You can create LAN Protocol Data Units (PDUs) such as IP, send them individually or use the capabilities provided by the traffic generator to create complex traffic streams. On the receive side, you can filter out the LAN traffic of interest for further analysis. This analysis includes real-time statistical monitoring, multifunctioned triggers, and capture playback.

The playback viewer supports the decoding of over 100 LAN protocols.

This module works seamlessly with other BSTS ATM or frame relay modules to form the foundation of a functional interworking test.

Important test connection modes supported include:

- Dual Channel Emulation
- Transmit Monitor
- Active Monitor

Physical layer support includes a choice of RJ45 or Media Independent Interfaces (MII). Full or half duplex operation is available for either 10BaseT or 100BaseTX interface rates.

Product Features

- Dual port 10/100 Ethernet module for the BSTS
- Enables LAN-LAN and LAN-ATM interworking
- Comprehensive real-time analysis and filtering
- IP CoS stimulus/response testing
- Functional and performance IP testing
- More than 100 protocols supported
- Error injection and the ability to transmit non-conforming streams
- Over 200 real-time measurements
- Full and half duplex configuration support
- Network Services including RIP, PING and full ARP implementation

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Agilent Technologies Broadband Series Test System

The Agilent Technologies BSTS is the industry-standard ATM/BISDN test system for R&D engineering, product development, field trials and QA testing. The latest leading edge, innovative solutions help you lead the fast-packet revolution and reshape tomorrow's networks. It offers a wide range of applications:

- ATM traffic management and signalling
- Packet over SONET/SDH (POS)
- switch/router interworking and performance
- third generation wireless tesing
- complete, automated conformance testing

The BSTS is modular to grow with your testing needs. Because we build all BSTS products without shortcuts according to full specifications, you'll catch problems other test equipment may not detect.

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Specifications subject to change.

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