Dynamic Terabit Testing up to OC-192c/STM-64c (10 Gb/s)

Agilent Technologies RouterTester
Application Note

Introduction

Carrier-class routers are being deployed by service providers on selected segments of their backbone and access IP networks. The industry’s leading equipment manufactures are already delivering carrier-class gigabit/terabit routers with 2.4 Gb/s (OC-48c/STM-16c) Packet over SONET/SDH (POS) interfaces. Now they are racing to develop 10 Gb/s (OC-192c/STM-64c) capability for interconnection of high-speed routers within the edge and core network.

This application note provides background information about the role of OC-192c/STM-64c POS in carrier networks, before taking an in-depth look at the functional and performance testing methodology for gigabit/terabit routers with OC-192c/STM-64c POS interfaces. Specific recommendations are provided for verifying the line card behavior and obtaining true Internet-scale router performance measurements.

The concept of Dynamic Terabit Testing (DTT), and its application to performance testing under dynamic routing conditions is explained. DTT methodology is available exclusively on the Agilent Technologies RouterTester.
Industry Overview

Advances in the Core Network: Gigabit/Terabit Routing Meets Optical Switching

A number of key factors are driving development and deployment of the new generation of terabit switch-routers:

- the emergence of IP as the preferred end-to-end Layer 3 protocol between the end user and access/edge/core networks,
- the explosive growth of services based on IP packet traffic, and
- the huge expansion of bandwidth capacity in the core transmission network due to the emergence of DWDM technology and other advances in optical fiber transmission.

The last factor in particular is driving the need for higher-speed interfaces such as OC-192c/STM-64c. In the near future, terabit routers will interwork with advanced optical switches to provide the next revolution in Internet scalability and manageability. As optical core capacity expands, there will be a corresponding need for even higher-speed interfaces in terabit routers.

Advances in optical switching will result in “lambda-intelligence” in the optical core network that will provide benefits such as rapid provisioning of optical circuits and efficient protection switching using optical mesh topologies. At the same time, terabit routers will provide the “IP-intelligence” required in the edge and core network to provide benefits such as differentiated IP service level agreements (SLAs) and managed IP quality of service (QoS).

The Role of Packet over SONET/SDH (POS) in the Core Network

Since its definition in 1986, SONET/SDH has clearly established itself as the primary Layer 1/2 transport mechanism for broadband carrier networks operating at speeds up to OC-192c/STM-64c (10Gb/s). POS uses HDLC-like framing to delineate packets and simple, point-to-point link access protocols such as PPP and Cisco-HDLC to configure the link.

POS is most appropriate for specific types of users, such as high-volume ISPs or large-scale corporate intranet operators, particularly at the higher rates such as OC-192c/STM-64c. Other potential users include carriers looking to connect regional, high-speed points of presence or aggregate high volumes of traffic from multiple edge routers.

POS supports “native” transmission of IP traffic by taking advantage of the advanced hardware-based routing and buffering capabilities within the terabit router to map IP packet streams into SONET/SDH frames. At the same time, POS is compatible with emerging intelligent optical networking equipment.

The next-generation core network provides advanced IP management and wavelength (lambda) management capabilities. OC-192c/STM-64c (10 Gb/s) POS connects terabit routers and optical switches.
Dynamic Terabit Testing (DTT)

The Agilent Technologies RouterTester is designed specifically to perform true Internet-scale simulation of gigabit/terabit routers and IP networks. It achieves this by incorporating multiple wire-speed (full line rate) POS interfaces and integrated support for the BGP-4, OSPF, and IS-IS routing protocols for every test port, required for development and performance testing of high-speed routers. Dynamic Terabit Testing (DTT) adds complete network realism to router performance testing by simulating the continuous control protocol fluctuations inherent within the Internet.

Routing protocols continuously carry information on the locations of networks throughout the Internet. Routers use this information to send data packets to the proper destination. However, due to the nature of the Internet, routing protocol messages are continuously flooded through the Internet, sometimes at rates of up to hundreds, or thousands, of messages per second. RouterTester DTT simulates the dynamic nature of routing protocol messages by subjecting a router to continuous routing protocol updates, while continuing to measure the data packet forwarding performance of a router.

OC-192c/STM-64c Test Methodology Overview

We will discuss the OC-192c/STM-16c functional and performance testing methodology in detail, explaining how DTT capability is applied to dynamic Internet-scale performance testing. The test requirements will be examined in two stages:

Stage 1: POS Line Card Functional and Performance Testing

This testing stage verifies the POS line card hardware functions and packet-handling performance. The testing requirements include full-rate traffic generation, stressing capability, and measurements.

A tutorial on POS technology and examples of typical stress tests are provided later in this application note.

Stage 2: Router Performance Testing under Dynamic Internet-Scale Conditions

This testing stage evaluates throughput capacity of the router's switching fabric. True Internet-scale performance measurements require the ability to simulate realistic routing configurations, traffic characteristics, and IP address distributions across advertised routes. The effect of dynamic routing conditions also needs to be verified.

A tutorial on Internet-scale traffic and routing parameters, and the application of the Dynamic Terabit Testing methodology are discussed later in this application note.

DTT enables the IP packet forwarding performance of a router to be evaluated under dynamic routing conditions.
POS is a Layer-2 protocol that maps IP packets into SONET/SDH frames. It can be thought of as a replacement of the AAL-5 adaptation layer, with the advantage that it avoids the inefficient process of ATM segmentation and reassembly. There are three main elements to POS:

- a link access protocol such as PPP (not required for Cisco-HDLC format)
- octet-synchronous HDLC-like framing (typically either Cisco-HDLC format, or IETF RFC1662: PPP in HDLC-like framing, and
- payload scrambling (RFC1619: PPP over SONET/SDH) prior to insertion into the SONET/SDH payload.

**PPP**

Point-to-point Protocol (PPP) establishes the link; exchanges IP addresses; and negotiates link parameters, such as the Frame Check Sequence (FCS) size. The link-establishment procedure must be successfully completed before the router will forward any user data across the link. Because PPP is handled by software, it can generally be disabled at the hardware testing stage, but it is required at the router performance testing stage.

**HDLC Framing**

HDLC framing delineates packet boundaries so that the receiver can extract them from the SONET/SDH frames. The HDLC frame includes address, control, and protocol fields, followed by the encapsulated packet. A 16 or 32-bit FCS protects the entire frame.

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The POS protocol stack, showing how IP packets are mapped into SONET/SDH frames.

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The PPP link establishment procedure must complete successfully before the router will forward data.

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The PPP and Cisco-HDLC frame formats are similar, but they use different header field values. The routers on each end of the POS link need to be configured for the same frame format.

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How POS Works: Technology Tutorial

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RFC1619, RFC1662

HDLC-like framing

Payload Scrambling: $SSS (1 + x^{43})$

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Layer 3 (Network)

IP

LCP

IPCP RFC1332

PPP RFC1661

Layer 2 (Data Link)

RFC1619, RFC1662

HDLC-like framing

Layer 1 (Physical)

SONET/SDH

Payload Scrambling

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IPCP Configure-Ack

1. IPCP Configure-Request

2. IPCP Configure-Ack

3. IPCP Configure-Request

4. IPCP Configure-Ack

Each side of the connection configures independently

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Flag (0x7E) Address (8 bits) Control (8 bits) Protocol (16 bits)

Payload | FCS (16 or 32 bits) | Flag (0x7E)

| PPP (IETF) Address (0xFF) Control (0x03) Protocol (16 bits) | 0021 (IP) C021 (LCP) 8021 (IPCP) |

| Cisco HDLC Address (0x0F) Control (0x00) Protocol (16 bits) | 0800 (IP) |

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The octet value 7E is used between frames to indicate the end of one frame and the start of the next. This means that the user data cannot contain the 7E-octet value. This is resolved by using an escape sequence, where 7E is converted to 7D-5E. The 7D octet is interpreted as the “escape” character. If present in the user data, it must itself be escaped by converting 7D to 7D-5D. This process, called octet stuffing, is reversed at the receiver.

Payload Scrambling

Payload scrambling prevents the occurrence of SONET/SDH framing patterns in the user data (possibly due to malicious intent) that could cause loss of SONET/SDH signal at the receiver. After the HDLC frame has been assembled, it is passed through a 1+x43 scrambler. The same algorithm is used in ATM interfaces up to OC-48c/STM-16c line rates. However, OC-192c/STM-64c presents new hardware design challenges.

OC-192c/STM-64c POS Hardware Design Challenges

POS line cards are generally designed using either Field Programmable Gate Arrays (FPGAs) or Application Specific Integrated Circuits (ASICs). For 10 Gb/s rates, the hardware architecture requires a data bus-width/clock speed of 128 bits at 80 MHz or 64 bits at 160 MHz, using the latest integrated circuit technology. The hardware design becomes very challenging when you consider that the payload scrambler design involves implementing a 43-bit serial shift register across a 64 or 128-bit parallel data bus (i.e. the parallel data bus is wider than the serial shift register)!
Stage 1: POS Line Card Functional and Performance Testing

The key issue in any POS implementation is wire-speed Layer-2 processing capacity. Octet-oriented processes such as octet stuffing, packing and rotating become more complex to perform in hardware as the clock speed and bus width increase. However, with a careful design that anticipates worst-case traffic patterns, POS line cards can be implemented at speeds of up to 10Gb/s using current FPGA technology.

In low-speed WAN interfaces, HDLC framing is performed by software, but at SONET/SDH line rates, it must be performed by hardware. FCS calculation, octet stuffing and de-stuffing, and payload scrambling are the major sources of complexity in implementing POS, particularly in high-speed, wide-bus architectures. The design challenges faced by developers are best illustrated by considering some typical traffic patterns with which the line card must deal. What follows is an examination of three typical cases, each with a different type of packet data that acts as a corner case.

Case One: Traffic that Causes the Maximum Stuffing Ratio

An IP/PPP packet that contains all 7D or 7E octet values will result in a doubling of the payload size after insertion into the HDLC frame. A sequence of such packets will cause maximum stress on the stuffing and de-stuffing circuits. This payload pattern also fully exercises the transmit-direction flow-control mechanism between the POS line card and the router’s egress buffer.

Case Two: Traffic with Variable Inter-frame Gaps

HDLC framing can have variable-length strings of 7E-octets between frames, acting as an idle pattern. This effectively introduces a “phase shift” of the HDLC frame as it is presented to the wide-bus architecture and can cause problems in the pack-and-rotate circuit. For example, a POS line card with a 64-bit architecture must handle 8 different octet phases; a line card with a 128-bit architecture must handle 16.

Case Three: Traffic Consisting of Minimum-size Packets at Full Rate

To handle this kind of traffic, a line card must perform the maximum rate of FCS calculations. The traffic also causes maximum stress to the overall HDLC frame-handling circuit in the POS line card.

An example of OC-192c/STM-64c POS line card hardware architecture, showing the 64-bit wide data bus. In this case, the hardware clock rate is approximately 160 MHz.
Dynamic Terabit Testing: Technology Tutorial

Internet-Scale Testing

The following factors should be considered when setting up the test:

- Scale up the test throughput by testing over multiple OC-192c/STM-64c test ports per router.
- Set up routing tables with a realistic mix of network prefixes, with lengths ranging from \( /16 \) to \( /24 \).
- Send traffic with a realistic mix of packet sizes: 40/44/552/576/1504 octets.
- Send traffic with IP addresses corresponding to all the network prefixes in the router table.

Dynamic Routing Performance

Terabit routers must not only receive, process and forward billions of packets per second; they must also be capable of maintaining this performance in the face of a dynamically changing Internet environment, where thousands of new packet destinations are added, deleted or changed each second.

A major challenge to equipment performance is ‘route flapping’, which requires routers, guided by routing protocols such as the Border Gateway Protocol (BGP) or Open Shortest Path First (OSPF), to simultaneously update their internal address tables and reroute packet streams, while continuing to forward packets at terabit rates.

Typical dynamic performance tests include:

- **Convergence**: measure maximum convergence time as active routes are withdrawn and reinserted, forcing redirection of traffic to a different port on the router.
- **Stability**: continuously monitor traffic on all router ports, while inactive routes modified in the routing table.
Stage 2: Router Performance Testing under Dynamic Internet-Scale Conditions

This stage of testing needs to ensure that gigabit/terabit routers can perform under realistic Internet-scale conditions. This includes high packet throughputs on multiple ports, complex routing table configurations, and realistic traffic content. By simulating Internet conditions as closely as possible, an Internet-scale benchmark of the router performance can be obtained.

Throughput Capacity (Test Ports)

An Internet-scale test will surround the router with a large number of test ports, with rates up to OC-192c/STM-64c. The test can be scaled up to verify the maximum packet-handling capacity of the router’s switching fabric. Typical test configurations include:

- A single router with multiple OC-192c/STM-64c ports (n x 10 Gb/s throughput).
- A number of fully-meshed routers, each with multiple OC-192c/STM-64c ports. If required, the routers can be meshed with even higher-speed links such as 40 Gb/s (OC-768c/STM-256c). This configuration is illustrated below.

Routing Table Configuration (Network Prefixes)

The Internet consists of different sized networks (called autonomous systems), with prefix lengths ranging from /16 to /24. In fact, over half the autonomous systems in the Internet are small networks (/24 prefix). A realistic test will use the ratio of network prefix lengths typically found in the Internet. The router under test will appear to be connected to many autonomous systems of various sizes.

Traffic Characteristics (Packet Sizes and Types)

Monitoring of Internet traffic patterns shows that the most common packet-sizes are 40/44/552/576/1504 octets. The router is likely to have more packet loss with minimum-size packets. Considering that about half of all packets on the Internet are 40-octet TCP acknowledgments, this is a significant issue to consider when evaluating router performance. A realistic test requires a mix of the packet sizes, in the ratios typically found in the Internet.
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**IP Address Distribution across Advertised Routes**

By combining routing and traffic in the one tester, it is possible to configure realistic mix of prefixes lengths (ranging from /16 to /24), and generate a wide range of IP addresses (for example 64,000 unique IP addresses) across these advertised routes. The carrier-class router test will simulate many networks of various sizes, and many traffic sources with various packet lengths, while measuring router performance.

In effect, the router under test behaves as though it is connected to many different-size networks, and is required to forward IP packets from many different sources. With this type of test, it is possible to evaluate how the router will actually perform when it is connected into the real Internet.

**Dynamic Routing Conditions**

Route-flapping performance can be measured by withdrawing and reinserting routes. Forwarding performance is monitored on a steady-state stream of fixed-length IP packets. This provides a fairly basic indication of route-flapping capability.

By combining routing and traffic in the one tester, it is possible to make more specific route-flapping measurements. For example, convergence time, which is a measure of the delay between a new route being advertised and the first packet arriving at the new destination, can be measured.

This type of measurement requires exchange of information between the route generator and the traffic source.
RouterTester

The Agilent Technologies RouterTester, which incorporates multiple POS interfaces and integrated support for the BGP-4 routing protocol, is the industry’s only test system capable of performing true Internet-scale simulation and Dynamic Terabit Testing, required for development and performance testing of high-speed routers.

The system’s BGP-4 routing protocol implementation allows users to establish large, complex routing tables rapidly in systems under test. This enables the product to simulate traffic delivered to many thousands of networks of varying sizes, creating traffic with realistic distributions of IP source and destination addresses to stress router performance. Traffic that is characteristic of data, voice or video streams can be generated automatically between all combinations of these networks.

RouterTester’s Internet-Scale OC-192c/STM-64c Test Solution

RouterTester P192/1 test module is capable of simultaneously transmitting and receiving up to 24 million IP packets per second. A complete RouterTester system can support 20 synchronized OC-192c/STM-64c POS test ports.

The system generates multiple streams of IP packets that simulate realistic traffic from many different-sized networks and creates real-world Internet traffic conditions for testing under real-world conditions. Simple, partial and full-mesh traffic patterns can be configured to fully stress the router switching fabric under test.

Agilent Technologies Dynamic Terabit Testing (DTT)

With the addition of Dynamic Terabit Testing (DTT) capabilities on RouterTester, developers of next-generation terabit routers now have the ability to test, evaluate and benchmark all aspects of the performance of their equipment, including both protocol and packet forwarding performance, under the rapidly changing conditions of the Internet.

RouterTester DTT allows developers to create simulated, real-world test networks within their labs, define and insert events such as route flaps while routers are running at maximum speed, and evaluate the equipment’s response and subsequent performance, all in real time. By integrating Internet-scale performance and routing protocol testing in one wire-speed, easy-to-use solution, RouterTester helps accelerate the delivery of routers that can meet the escalating, real-world demands of next-generation networks.

RouterTester has an easy-to-use graphical interface that lets you set up multiple test ports, configure realistic traffic and routing parameters, and monitor performance statistics in real time, under dynamic routing conditions.
For More Information

Other application notes in this series cover individual topics in more detail, such as terabit router architectures, Internet-scale performance testing, routing instability, and route flap convergence.

For more information about the Agilent Technologies RouterTester refer to the web site at:
www.agilent.com/comms/RouterTester

Summary

In this application note, we have examined some of the industry drivers behind the deployment of OC-192c/STM-64c POS in the core network.

At 10 Gb/s line rates, the hardware design of the POS line card becomes very challenging. We have examined some of the POS technology issues, and looked at typical test cases to stress test the hardware design.

When the router is deployed in the Internet, it needs to cope with a wide range of traffic and routing conditions. In this application note, we have examined some of the parameters that make up true Internet-scale testing.

Finally, the routing conditions in the Internet are not static. We have taken a brief look at conditions such as route flapping, and seen how Dynamic Terabit Testing can be used to evaluate the ability of the router to handle these conditions.
Agilent Technologies Router Tester

Router Tester provides true Internet-scale testing through realistic routing protocol support, multi-stream wire-speed traffic generation and real-time analysis, and multi-port scalability. Router Tester is set to grow as the testing needs of the carrier class router industry evolve to meet the challenges of scale and Quality of Service within the Internet.

www.Agilent.com/comms/RouterTester