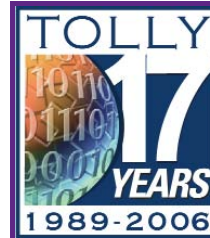


Nortel, Inc.

Ethernet Routing Switch 5000 Series

Competitive Performance Evaluation versus Cisco Catalyst 3750G and HP ProCurve 3400cl



Test Summary

Premise: When considering the purchase of stackable switches, network managers need to know the performance characteristics of the available products. Buyers need to know the bidirectional performance characteristic in the multiple switch stack configuration, plus what impact, if any, a device outage will have on the overall performance of the switching stack.

Nortel commissioned The Tolly Group to evaluate the Layer 2 switching performance, resiliency and ease of use delivered by the company's stackable Ethernet Routing Switch 5000 series of switches. The Nortel Ethernet Routing Switch 5000 series of stackable switches tested include 24- and 48-port versions of 5510, 5520 and 5530 models – single rack-unit stackable Gigabit Ethernet (GbE) Layer 3 routing switches designed to provide high-density GbE desktop connectivity to mid and large enterprise customers' wiring closets.

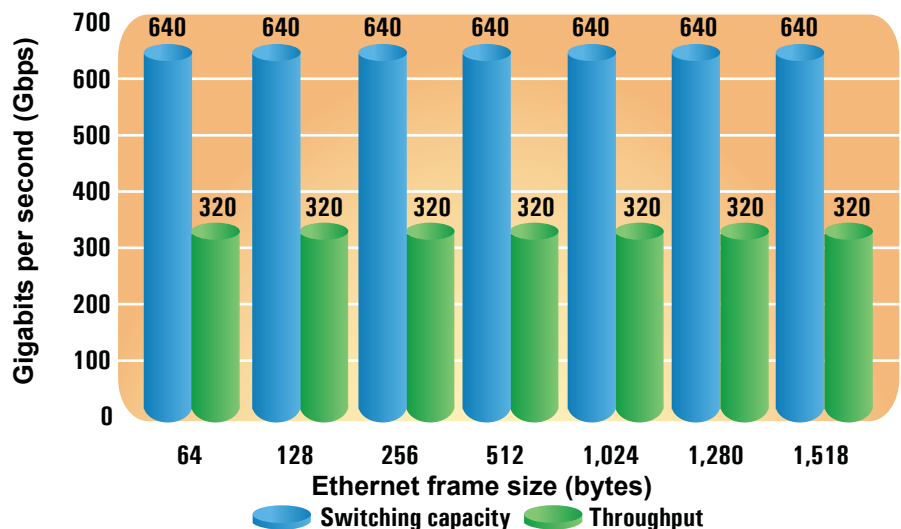
Engineers measured the performance and resiliency characteristics of the Ethernet Routing Switch 5000 series switches against Cisco Systems, Inc. Catalyst 3750G switches and Hewlett-Packard Co. ProCurve 3400cl switches.

Tolly Group engineers measured the frame forwarding rate, latency and standard deviation of latency (jitter) characteristics of an eight-switch stack of Nortel switches against similarly configured stacks of Cisco Catalyst 3750G and HP ProCurve 3400cl switches. The engineers also examined the resiliency of an eight-

Test Highlights

- Delivers superior stacking performance of up to 640 Gbps of switching capacity in an eight-unit stack of Nortel 5500 switches
- Achieves line-rate performance of 202 Gbps frame-forwarding in an eight-unit stack, while Cisco and HP switches support only 25.7 Gbps and 114.7 Gbps respectively
- Demonstrates 36% to 44% less average latency, when compared to Cisco and HP devices tested
- Recovers from link and switch outages almost 10X faster using Nortel's SMLT implementation than the RSTP implementation in the Cisco Catalyst and HP ProCurve solutions tested
- Offers the lowest cost per megabit of throughput among the switches tested at just below \$90 versus almost \$100 HP and over \$300 for Cisco

Zero-loss ($\leq 0.001\%$) Aggregate Layer 2 Throughput of Ethernet Routing Switch 5510-48T in an Eight-switch Stack Configuration (320 GbE ports) as Reported by SmartBits SmartFlow 4.60



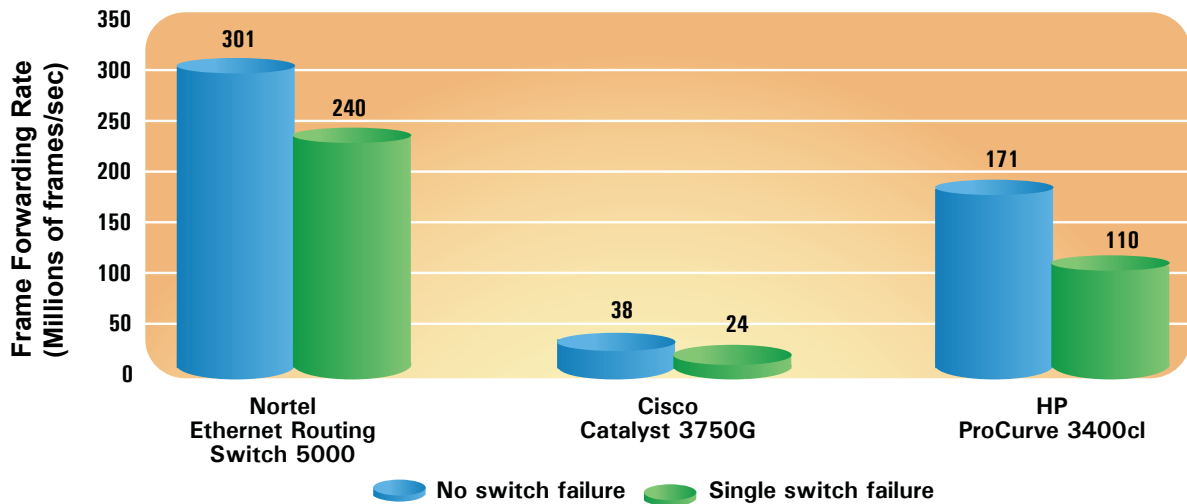
Note: A custom port-pairing scheme was used. See the "Test Configuration and Methodology" section.

Source: The Tolly Group, September 2005

Figure 1

Layer 2 Stack Resiliency Comparison Impact of Stacked Switch Failures on Frame Forwarding Rate

202 GbE ports in an 8-switch stack with 64-byte frames at 100% line-rate load as Reported by Spirent SmartFlow 4.60



Note: No connection between top and bottom switches of the stack for HP ProCurve 3400cl since one 10-GbE link has to be reserved as an uplink.

No Switch Failure: All 202 GbE ports across the 8-switch stack are in the same VLAN. Frames transmitted at 100% line-rate or approximately 301 million frames/sec.

Single Switch Failure: The 202 GbE ports across the 8-switch stack are divided into two VLANs - 162 GbE ports in VLAN1 and 40 GbE ports in VLAN2. Switch failure is introduced in VLAN2, and the resultant frame-forwarding rate in VLAN1 is reported. Traffic input to switch ports in VLAN1 is at 100% line-rate or approximately 240 million frames/sec.

Source: The Tolly Group, September 2005

Figure 2

switch stack by examining the impact of a single unit failure in a VLAN on the frame forwarding rate in a different VLAN in the stack.

In addition, engineers also measured the amount of usable Layer 2, zero-loss throughput and latency as experienced by users in a standalone switch. Engineers also measured the failover times of the Rapid Spanning Tree Protocol (RSTP) and Nortel's Split Multi-Link Trunking (SMLT) technologies. Finally, engineers evaluated the ease of use of Nortel's implementation of "Intelligent Auto Unit Replacement" feature and the number of commands required to configure Nortel's SMLT versus the RSTP implementation of Cisco and HP switches.

All tests were conducted in September 2005 at Nortel facilities in Santa Clara, Calif. and audited by Tolly Group personnel.

RESULTS AND ANALYSIS

STACK PERFORMANCE: FRAME FORWARDING RATE AND LATENCY

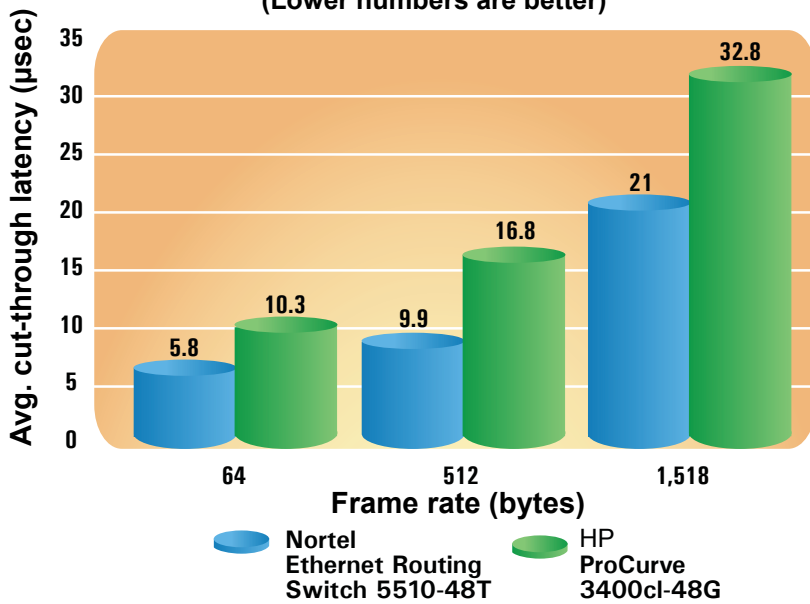
Layer 2 performance tests on the DUTs in an eight-switch stack revealed that the Nortel switches consistently outperformed the Cisco Catalyst 3750G and HP ProCurve 3400cl switches while handling line-rate traffic of 64-, 512- and 1,518-byte frames across the 202 GbE ports in the stack. Nortel's switch stack achieved frame forwarding rates in excess of 300 million frames per second (fps) for 64-byte frames. In the same test, HP's ProCurve 3400cl maxed out at 171 million fps while Cisco's Catalyst 3750G performed the worst — maxing out at 38 million fps. The Tolly Group also verified that Nortel 5500 switches provided 320 Gbps (640 Gbps full duplex) of zero-loss aggregate Layer

2 throughput using 320 GbE ports. The stackable switching capacity was 640 Gbps. For details, refer to Tolly Group document No. 205137. (See Figures 1 and 2.)

In terms of frame loss percentage, this equaled to zero frame loss for Nortel for all frame sizes tested. In contrast, Cisco's Catalyst 3750G switch exhibited the worst performance with a frame loss as high as 87% for 64-byte frames. The HP Procurve 3400cl exhibited frame loss ranging from 43% for 64-byte frames to 45% for 1,518-byte frames.

In the same test scenario, Nortel's Ethernet Routing Switch 5500 series switch stack also exhibited considerably less latency with low standard deviation of latency compared to the HP ProCurve 3400cl switch stack. Latency values for the Cisco Catalyst 3750G stack were not recorded due to significant frame loss. Latency was measured as the

Layer 2 Stack Performance Average Cut-Through Latency (µsec) at 90% Line-Rate Load across 202 GbE Ports in a Stack as Reported by Spirent SmartFlow 4.60 (Lower numbers are better)



Note: Latency of the Cisco switch was not measured due to excessive frame loss.
Source: The Tolly Group, September 2005 Figure 3

average cut-through latency. The Nortel Ethernet Routing Switch 5500 demonstrated at least 1.5X less average cut-through latency for all frame sizes tested. In terms of standard deviation of latency, Nortel demonstrated almost 7X less standard deviation compared to the HP ProCurve 3400cl for 64-byte frames, while the Nortel switch demonstrated 1.4X less standard deviation with 1,518-byte frames. The latency results show that the Nortel Ethernet Routing Switch 5500 offered superior performance in terms of latency and standard deviation of latency compared to the HP ProCurve 3400cl and Cisco Catalyst 3750G.

STACK RESILIENCY: SINGLE UNIT FAILURE

The resiliency of an eight-unit Nortel switch stack was compared to the Cisco Catalyst 3750G and the HP ProCurve 3400cl switches in a similar resilient stacking network configuration. The 202 GbE switch ports in the stack were distributed as 162 GbE ports in VLAN 1 and 40 GbE ports in

VLAN 2, and the corresponding input traffic consisted of 64-byte frames at approximately 240 million fps into VLAN 1 and 46 million fps into

Nortel

Ethernet Routing Switch 5000 Series

Zero-Loss Throughput, Resiliency and Ease of Management

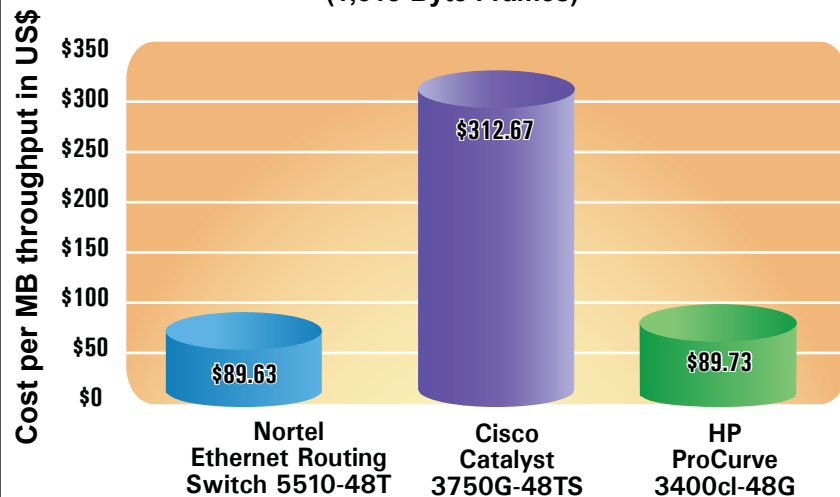


VLAN 2. Switch failure was introduced in VLAN 2. Test results show that Nortel exhibited 2X to 10X the maximum frame forwarding rate compared to similarly configured Cisco and HP stacks. Nortel achieved a frame forwarding rate as high as 240 million fps, while HP achieved 110 million fps and Cisco fared the worst achieving a frame forwarding rate of just 24 million fps. (See Figure 3.)

STANDALONE SWITCH PERFORMANCE

The Nortel Ethernet Routing Switch 5510-48T was compared with Cisco Catalyst 3750G-48TS and HP

Cost per Megabit of Throughput in a Standalone Switch Configuration (1,518-Byte Frames)



Note: The cost per megabit/throughput metric is derived from U.S. retail prices gathered from Unistar-Sparco Computers, Inc., a Cisco Systems certified reseller. Prices were gathered the week of 02 January 2006 and represent hardware prices only, not including support costs. The metric was obtained by dividing the cost of each switch by the throughput achieved in a standalone switch configuration with 1,518-byte packets.
Source: The Tolly Group, September 2005 Figure 4

ProCurve 3400cl-48G switches in terms of Layer 2 zero-loss ($\leq 0.001\%$ acceptable frame loss) throughput, average cut-through latency and standard deviation of latency.

Results show that both Nortel and HP switches achieved 100% of the maximum theoretical throughput while handling Layer 2 test traffic consisting of 64-, 512- and 1,518-byte frames transmitted across 48 ports in a port-to-port configuration. Cisco could only achieve throughput of 55% of the theoretical maximum for 64-byte frames, 61% for 512-byte frames and 62% for 1,518-byte frames.

The Tolly Group also used the throughput results to calculate a cost-per-megabit of throughput for the three switches. This is done by

dividing the switch price by the zero-loss throughput achieved. The Nortel switch offered the lowest cost/MB of throughput at just under \$90, while Cisco offered the highest with a cost/MB of throughput exceeding \$300. (See Figure 4.)

RSTP vs SMLT PERFORMANCE

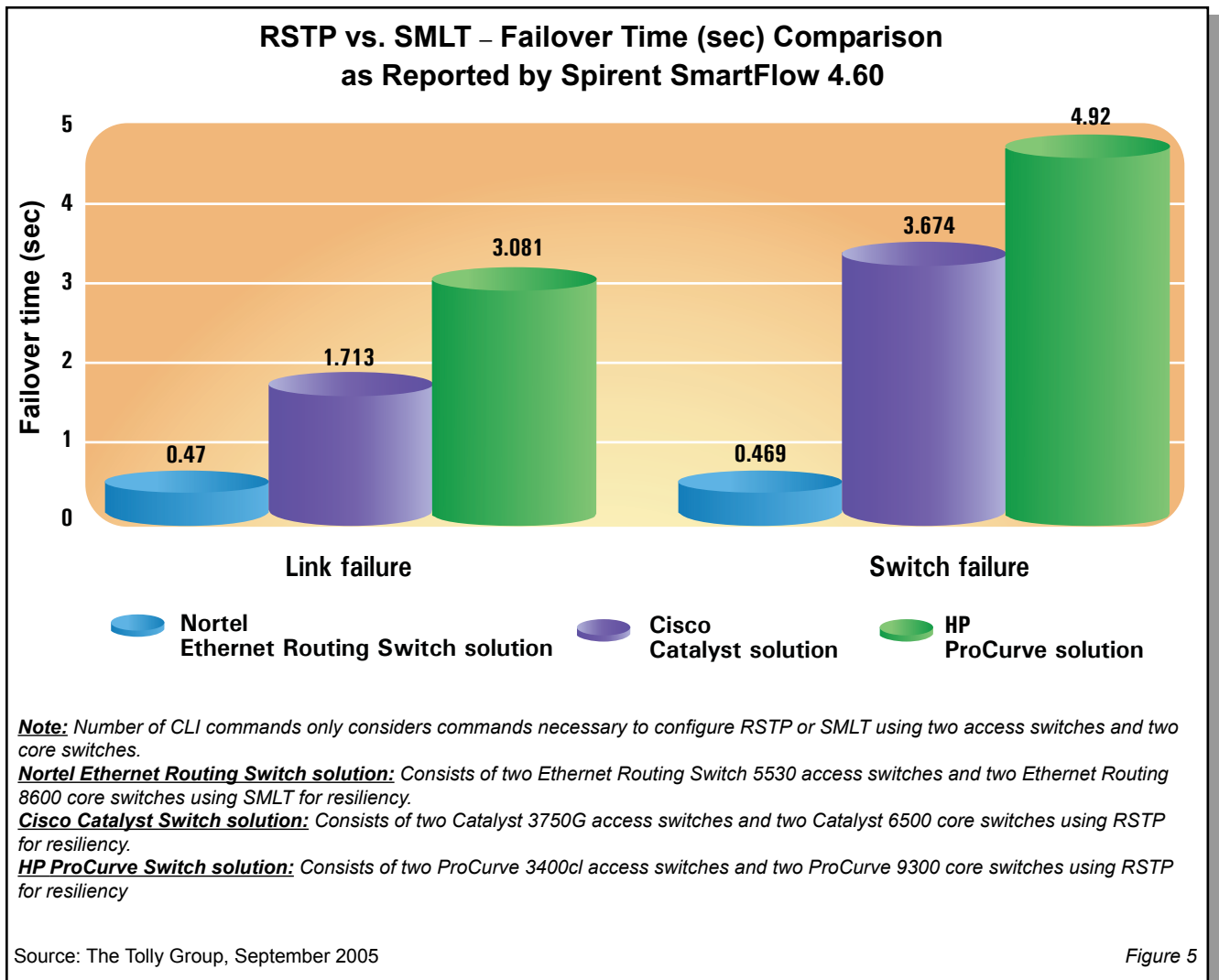
Tolly Group engineers tested the failover times of the Rapid Spanning Tree Protocol (RSTP) and Nortel's Split Multi-Link Trunking (SMLT) technologies in the event of a link failure and a switch failure. Nortel's solution consisted of Ethernet Routing Switch 5530 and 8600 switches implementing SMLT, while Cisco's solution of Catalyst 3750G and 6513 switches, and HP's solution

using ProCurve 3400cl and 9403 switches, both implemented RSTP.

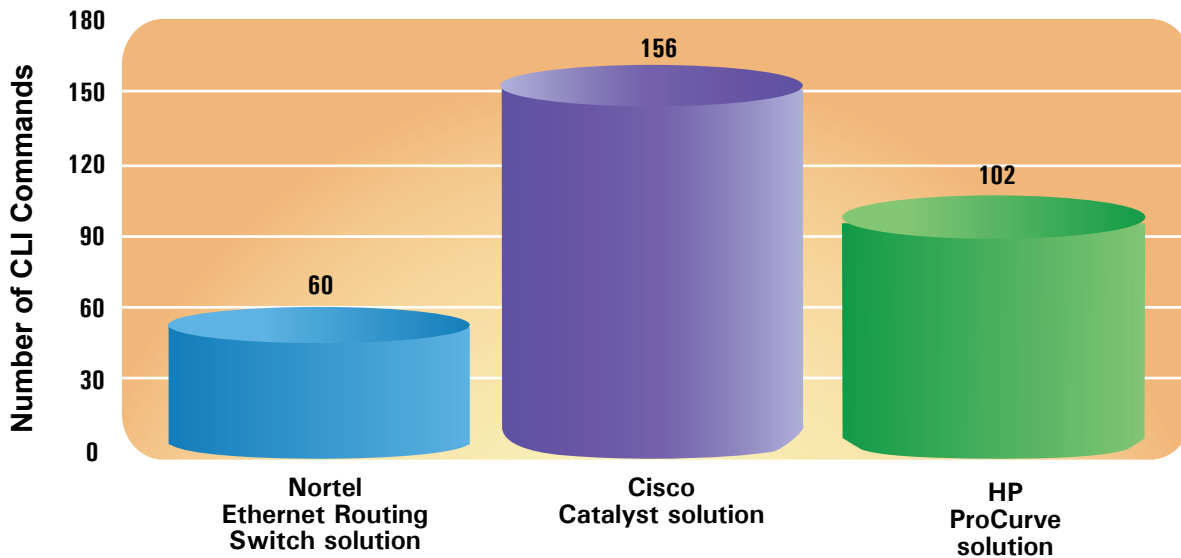
Tests show that Nortel's Ethernet Routing Switch 8600 and 5530 solution using SMLT demonstrated the fastest network failover time in the event of a link or switch failure. In the event of a link failure, Nortel's solution using SMLT failed-over in 0.5 seconds while Cisco's solution took 1.7 seconds and HP's solution took 3.1 seconds. (See Figure 5.)

In the event of a switch failure, Nortel's solution using SMLT again failed-over in 0.5 seconds, while Cisco's solution using RSTP failed-over in 3.7 seconds, and HP's solution using RSTP failed-over in 4.9 seconds.

This shows that even with the same network topology, the Nortel SMLT



Ease of Configuration Comparison - SMLT vs. RSTP Number of CLI Commands Required to Configure The Test Bed



Note: Number of CLI commands only considers commands necessary to configure RSTP or SMLT using two access switches and two core switches.

Nortel Ethernet Routing Switch solution: Consists of two Ethernet Routing Switch 5530 access switches and two Ethernet Routing 8600 core switches using SMLT for resiliency.

Cisco Catalyst Switch solution: Consists of two Catalyst 3750G access switches and two Catalyst 6500 core switches using RSTP for resiliency.

HP ProCurve Switch solution: Consists of two ProCurve 3400cl access switches and two ProCurve 9300 core switches using RSTP for resiliency.

Source: The Tolly Group, September 2005

Figure 6

implementation achieved significantly faster fail-over times compared to the RSTP implementations offered by Cisco and HP.

EASE OF USE - NUMBER OF COMMANDS TO CONFIGURE RSTP vs. SMLT

The engineers counted the number of CLI commands required to configure the switches in the test bed for SMLT versus RSTP. The result showed that Nortel's test bed consisting of two Ethernet Routing Switch 5530 access switches and two Ethernet Routing Switch 8600 core switches required a total of 60 commands to configure SMLT. (See Figure 6.) In comparison, HP's test bed consisting of two ProCurve 3400cl access switches and two ProCurve 9300 core switches needed 102 commands to configure RSTP. Cisco's test bed consisting of two Catalyst 3750G access switches

and two Catalyst 6500 core switches needed 156 commands to configure RSTP.

This shows that Nortel's SMLT implementation requires less number of CLI commands to configure the test bed compared to HP and Cisco's implementation of RSTP.

HIGHEST AVAILABLE UPLINK BANDWIDTH

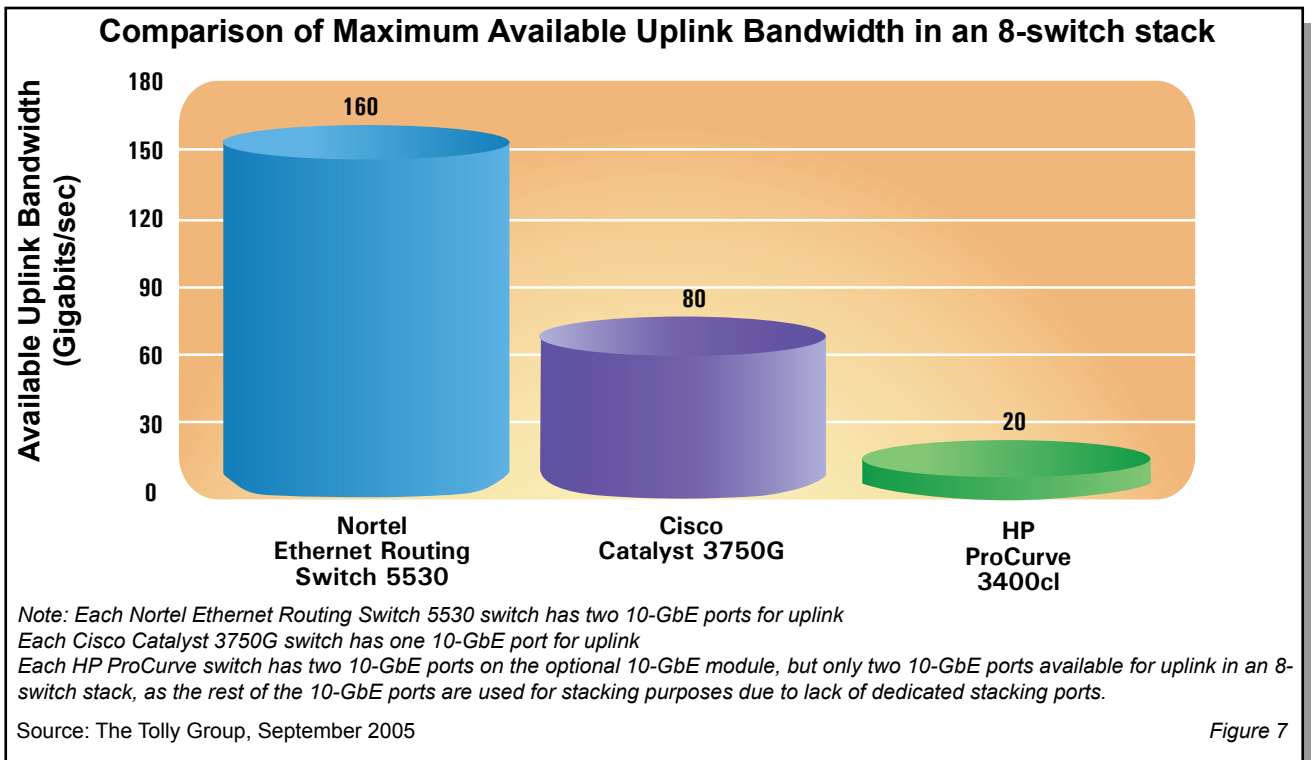
Nortel Ethernet Routing Switch 5530 and Cisco Catalyst 3750G switches support dedicated uplink connections in addition to dedicated stacking connections, where as the HP ProCurve 3400cl does not have dedicated stacking ports. This necessitates using an optional 10-GbE module with two 10-GbE ports for stacking connections on the HP ProCurve 3400cl. In an eight switch stack configuration, the Ethernet Routing Switch 5530 solution has 16

10-GbE links available for uplink connections, the Cisco Catalyst 3750G solution has eight 10-GbE links available for uplink, while the HP ProCurve 3400cl solution only has two 10-GbE links available for uplink. This means that in an eight switch stack, the Nortel switch has 160 Gbps of maximum available uplink bandwidth compared to 80 Gbps for the Cisco and 20 Gbps for the HP devices. (See Figure 7.)

This shows that Nortel's Ethernet Routing Switch 5530 solution offers the highest uplink bandwidth among the devices tested.

TEST CONFIGURATION AND METHODOLOGY

For performance tests, The Tolly Group tested Nortel Ethernet Routing Switch 5000 series stackable switches (models 5510, 5520



and 5530) against Cisco Catalyst 3750G series switches and HP ProCurve 3400cl series switches. According to Nortel, all the switches were tested with production software generally available to the customer base. (See Project Profile for switch model details.)

For evaluating the Layer 2 stack performance of the DUTs in an eight-unit high stack, engineers tested the frame forwarding rate, average cut-through latency and standard deviation of latency. The eight-unit stack of each vendor consisted of a mix of 24 and 48-port Gigabit Ethernet switches with the switch at the top of the stack configured with a 10-GbE port that normally acts as an uplink to a core switch. For this testing, the 10-GbE uplink port did not carry traffic as the testing focused on the performance of the switch stack alone. Nortel's switch stack consisted of five 5510-24T switches, one 5520-48T-PWR switch and one 5530-24TFD switch. Cisco's Catalyst switch stack consisted of one Catalyst 3750G-48TS switch, one 3750G-48PS switch, five 3750G-24TS switches and one 3750G-16TD

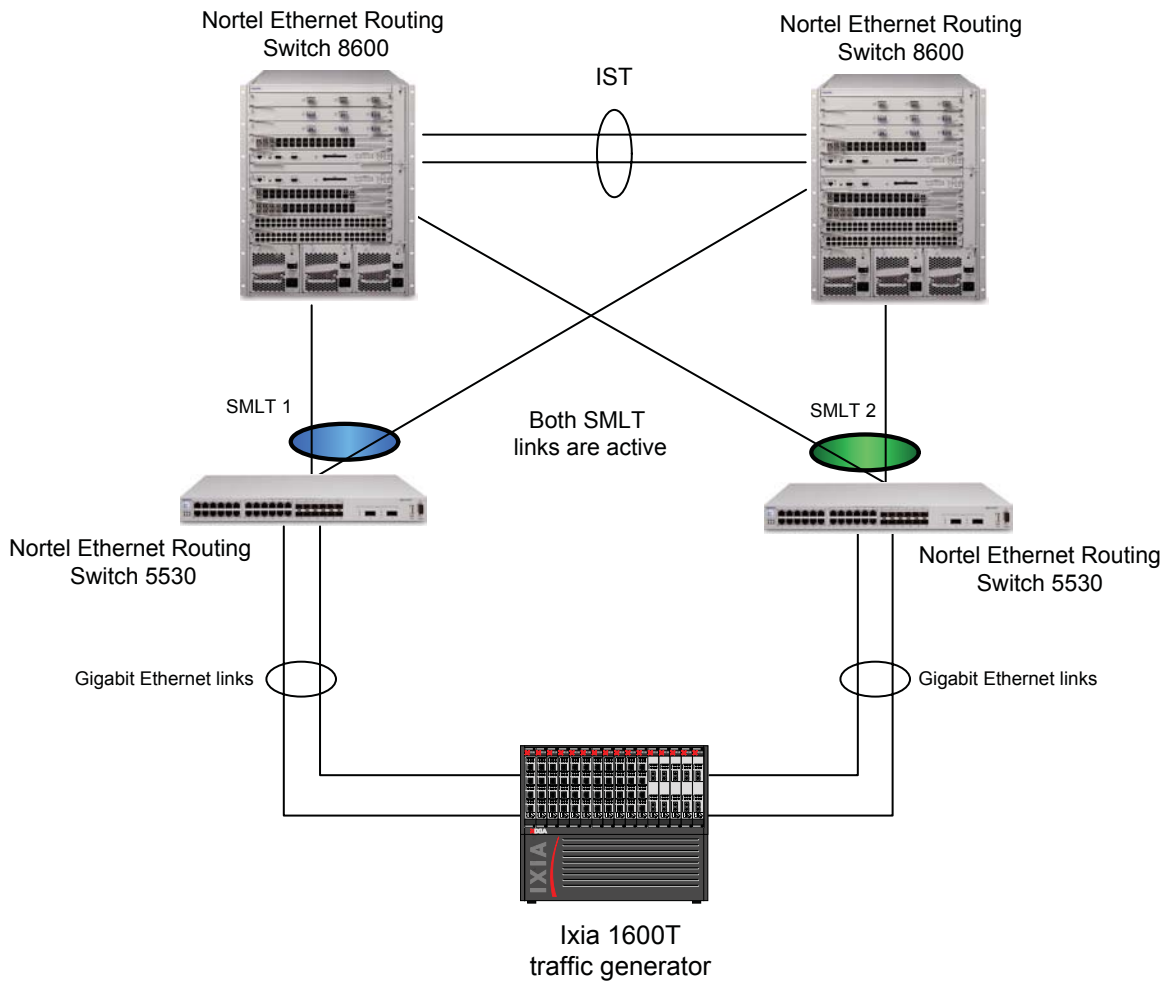
switch. HP's ProCurve switch stack consisted of two 3400cl-48G switches and six 3400cl-24G switches.

The switches in the stack were connected using the appropriate stacking cables for Nortel and Cisco products. Since HP did not support dedicated stacking ports, the switches were stacked using 10-GbE modules with one 10-GbE module on the top-of-the-stack switch reserved for an uplink to a core switch. Nortel and Cisco switch stacks were connected in a fully resilient network with a connection between the top and bottom units of the stack. 202 GbE ports from Spirent SmartBits were connected to the eight-switch stack in a port-to-port configuration. 202 GbE ports in the stack connected to the same number of SmartBits ports. In the SmartBits SmartFlow test setup, port-pairing scheme was configured as: Port #1 of the switch was destined for Port #2, and Port #3 for Port#4 and so on. The traffic consisted of 64-, 512- and 1,518-byte frames, transmitted for 60 seconds. For measuring the zero-loss throughput of the DUT, the acceptable frame loss percentage was set at less than

or equal to 0.001%. For measuring the frame forwarding rate of the DUT, the test traffic was sent at 100% of line-rate for 60 seconds, and the "Frame Loss" test of SmartFlow was used to find the frame forwarding rate. For measuring the latency characteristics of the devices under test, the "Latency" and "Latency distribution" tests of SmartFlow were used, with the test traffic sent at 90% of line-rate.

For testing the stacking resiliency of the DUTs, the eight-switch stack was set up in two virtual LANs, with 162 GbE ports in VLAN 1, and the remaining 40 GbE ports in VLAN 2. The resiliency of the stack was measured in terms of the frame forwarding rate in VLAN 1 in the event of a single switch failure in VLAN 2. The test traffic consisted of 64-byte Ethernet frames transmitted at 100% of line-rate across the 202 GbE ports in the stack. The test duration was set at 60 seconds, and switch failure was introduced halfway through the test duration. The number of frames successfully forwarded per second in VLAN 1 during the entire 60-second period was recorded.

Test Bed for RSTP vs. SMLT Failover Time Comparison Showing Nortel Ethernet Routing Switch Solution Using SMLT



Source: The Tolly Group, September 2005

Figure 8

For comparing the failover times of Nortel's implementation of SMLT with Cisco and HP's implementation of RSTP, the test bed consisted of two access switches dual-homed to two core switches, with the access switches and the core switches of the same vendor. (See Figure 8.) Nortel's solution consisted of two Nortel Ethernet Routing Switch 5530-24TD switches, each dual-homed to two Nortel 8600 switches using two 10-GbE links. Cisco's solution under test consisted of two Cisco Catalyst 3750G-16TD access switches, each dual-homed to two Cisco Catalyst 6500 series core switches using two 10-GbE links. Similarly, HP's solution under test consisted of two ProCurve 3400cl-24G switches dual-homed to two ProCurve 9403m

switches using two 10-GbE links. An Ixia 1600T traffic generator was connected to the access switches to send test traffic. RSTP aims to eliminate network loops, and hence only one of the links from each access switch was active at a given time. In contrast, with Nortel's SMLT, both links are active at the same time. While the traffic was flowing at a steady state, the active link from each switch was failed, and engineers measured the time required for the network to reconverge and start transmitting the traffic on the other link. Also, while the traffic was flowing at a steady-state, the core switch forwarding the traffic was failed, and engineers measured the time required for the network to reconverge. The tests were done

three times to ensure repeatability of the results, and the results were averaged to obtain the final numbers.

For evaluating the standalone switch performance of the DUTs, engineers tested the zero-loss throughput, average cut-through latency and standard deviation of latency. The test bed consisted of the DUT as a standalone switch connected to 48 GbE ports on a Spirent SmartBits 6000C traffic generator. The test procedure and test setup to measure throughput, average cut-through latency and standard deviation of latency were similar to the eight-switch stack test described earlier.

VENDOR INTERACTION

The Tolly Group invited Cisco and HP to participate in the testing as per The Tolly Group's Fair Testing Charter (see <http://tollygroup.com/Corporate/FTC.aspx>).

Representatives from Cisco did not respond to the invitation while HP elected to participate.

As part of the competitive interaction, Tolly Group engineers shared test methodology with HP, and implemented HP's recommendations to ensure the testing of the HP switch was performed accurately. At the end of the testing, HP was provided with the opportunity to review the test results. While HP did not contest the validity of the test results as per the switch and stack configurations tested, representatives from

HP stated that the company's preferred approach to stacking switches differs from the implementation tested. However, the end user could choose either the implementation as tested, or could choose to implement HP's preferred method of using a top-of-the-stack aggregator switch with 10-GbE modules, or could upgrade to HP's chassis-based solutions.

The Tolly Group gratefully acknowledges the providers of test equipment used in this project.

Vendor	Product	Web address
Ixia	Ixia 1600T	http://www.ixiacom.com
Spirent Communications	SmartFlow ver 4.60	http://www.spirentcom.com
Spirent Communications	SmartBits 6000C ver 2.6	http://www.spirentcom.com

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PROJECT PROFILE

Sponsor: Nortel

Document number: 206106

Product Class: Stackable Gigabit Ethernet switch

Products under test:

- Nortel Ethernet Routing Switch 5510-48T (Running switch software version 4.2.0.004)
- Nortel Ethernet Routing Switch 5510-24T (Running switch software version 4.2.0.004)
- Nortel Ethernet Routing Switch 5520-48T-PWR (Running switch software version 4.2.0.004)
- Nortel Ethernet Routing Switch 5530-24TFD (Running switch software version 4.2.0.004)
- Nortel Ethernet Routing Switch 8600 (Running switch software version 4.0.1.0)
- Cisco Catalyst 3750G-48TS (running switch software version 12.2 (25) SEB1)
- Cisco Catalyst 3750G-48PS (running switch software version 12.2 (25) SEB1)

- Cisco Catalyst 3750G-24TS (running switch software version 12.2 (25) SEB1)
- Cisco Catalyst 3750G-16TD-S (running switch software version 12.2 (25) SEB1)
- Cisco Catalyst 6500 (running switch software version 12.2 (18) SXD5)
- HP ProCurve 3400cl-48G (running switch software version M.08.66)
- HP ProCurve 3400cl-24G (running switch software version M.08.66)
- HP ProCurve 9304M (running switch software version 07.8.00aT53)

Testing window: September 2005

Software status: Generally available

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