



MPLS
Ready To Serve The Enterprise

SUPERCOMM CHICAGO 2004
PUBLIC INTEROPERABILITY EVENT

Introduction

The SUPERDEMO 2004 interoperability event has been organized by the MPLS & Frame Relay Alliance in partnership with the Multiservice Switching Forum (MSF), and facilitated by the University of New Hampshire InterOperability Lab (UNH-IOL) and the European Advanced Networking Test Center (EANTC).

The interoperability tests detailed in this document were conducted using MPLS routers and switches, as well as emulators, from various vendors, during a *hot stage* event. Through several rounds of testing and refining the methodology, a final network of interoperable devices was successfully constructed. This network and the test results were demonstrated at SUPERCMM 2004 in Chicago, June 22–24, 2004.



**Hot-staging at UNH-IOL
(Durham, NH)**

The test scenarios designed specifically for this showcase were based upon the experiences of previous interoperability test events:

- The test event covered new MPLS capabilities which have not been shown before. The tests demonstrated interoperability of hierarchical Virtual Private LAN Service (H-VPLS) and Label Switched Path (LSP) ping and traceroute. A key feature tested was PNNI-MPLS interworking. Other than these, multi-vendor MPLS/BGP VPNs and Layer 2 Ethernet pseudowires were configured to prove that multiple services could use the MPLS backbone in parallel.
- Test engineers installed a Voice over IP (VoIP) proof-of-concept demonstration on top of a separate MPLS network. Engineers then used the MPLS capabilities to allow Voice over IP switches, media gateways and telephones to connect over the backbone. This was one of the

first complete public demonstrations of Voice over IP running over an MPLS backbone.

To ensure the event's success, a one week hot-staging event with all the participating vendors was conducted before SUPERCMM. The MPLS hot-stage took place at the UNH-IOL (University of New Hampshire InterOperability Lab), the Voice over IP *proof-of-concept* hot-stage took place at Cisco labs in San Jose, CA. VoIP over MPLS will also be demonstrated at SUPERCMM 2004 along with the MPLS interoperability showcase.

The Interoperability Working Group of the MPLS & Frame Relay Alliance, including EANTC and UNH-IOL, defined the MPLS test plans.

Participants and Devices

The following companies and devices demonstrated their interoperability in the test event:

MPLS Demo	Agilent Technologies	N2X
	Alcatel	7670 RSP 7750 SR
	Native Networks	EMX 3706
	CIENA	DN 7050 DN 7100
	MRV	OSM-800
	Nortel Networks	SER 5500
	Tellabs	8820
	World Wide Packets	LE311 LE54
VoIP Demo	Cisco Systems	GSR 12008 GSR 12406 BTS 10200 CA MGX 8880 MGW 3745 VG 7960 SIP IP Phone
	Spirent Communications	Abacus 5000 SmartBits 600
	Navtel	Interwatch 95000

Test Areas and Test Plan

The interoperability evaluation focused on Ethernet and ATM pseudowires (layer 2 point-to-point service), BGP/MPLS VPNs (layer 3 service), MPLS flat and hierarchical Virtual Private LAN Service (H-VPLS) and enhanced management support for MPLS networks via recently proposed LSP Ping facilities.

The Voice over IP demo, installed at the edge of the MPLS network, used MPLS traffic engineering tunnels to prove that MPLS can carry guaranteed voice and video over IP traffic and provide resilient network service.

MPLS Protocol Support	RSVP-TE Signalling	L2 Ethernet Pseudowires	L2 ATM Pseudowires	Flat VPLS	Hierarchical VPLS	LSP Ping	BGP/MPLS VPNs	ATM/MPLS Interworking
Agilent Technologies	•	•	•	•		•	•	•
Alcatel 7670 RSP	•	•	•				•	•
Alcatel 7750 SR	•	•		•	•	•	•	
CIENA	•	•	•			•		•
MRV	•	•		•				
Native Networks	•	•			•			
Nortel Networks	•		•			•	•	
Tellabs	•	•	•	•			•	
World Wide Packets		•			•			

The following section describes the test plan in detail. Results are documented on page 5.

MPLS Signalling and Routing

Test engineers first constructed the backbone network. All test cases required RSVP-TE or LDP signalling for MPLS transport and dynamic routing in the backbone using OSPF with traffic engineering extensions.

ATM and Ethernet Point-to-Point VPNs (Pseudowires)

Virtual Private LAN Services over MPLS were tested according to *draft-ietf-l2vpn-vpls-ldp-01*, using the MPLS & Frame Relay Alliance test methodology defined in the test plans *mpls2003.091.00* and *mpls2003.092.02*. The tests covered:

- Label binding and distribution for Ethernet and ATM pseudowires via targeted LDP sessions between the provider edge routers
- Data encapsulation of ATM, Ethernet and tagged Ethernet frames
- Path tear down and withdraw between provider edge routers

Furthermore, interworking between ATM signalled permanent virtual connections (SPVCs) and ATM pseudowires was tested according to the ATM Forum standards *af-cs-0178.001* (user plane) and *af-cs-0197.000* (signaling). An MPLS & FR Alliance test plan, *mpls2004.092.00*, was designed for these tests covering:

- Label binding and distribution for ATM SPVCs

Virtual Private LAN Service (VPLS) and Hierarchical VPLS (H-VPLS)

Since VPLS is basically a multipoint extension of point-to-point Ethernet pseudowire links, point-to-point evaluation tests provided a prerequisite for the VPLS tests.

- VPLS service establishment by label exchange between provider edge routers
- Data forwarding to unknown and known Ethernet addresses

Regarding H-VPLS, the following features were included in the test plan:

- Hierarchical VPLS service establishment for provider edge (PE) VPLS switches
- Hierarchical VPLS configuration for multi-tenant unit (MTU) VPLS switches
- Per-port MPLS pseudowires with tunnel
- Per-port-per-VLAN MPLS pseudowires with tunnel
- Per-port MPLS pseudowires without tunnel
- Concurrent types of pseudowires

Vendors supporting H-VPLS could be either the provider edge (PE) or the multi-tenant unit (MTU) device while participating in the test.

BGP/MPLS VPNs

This portion of the testing used the MPLS & Frame Relay Alliance test plan *mpls2002.049.01*.

This test area determined the degree of interoperability possible between RFC2547bis implementations of the various vendors and involved:

- Full-mesh Multi Protocol BGP (MP-BGP) peering
- MPLS signalled tunnels between provider edge (PE) routers
- Dynamic route propagation using BGP or OSPF between customer edge routers (CE) and provider routers (PE).

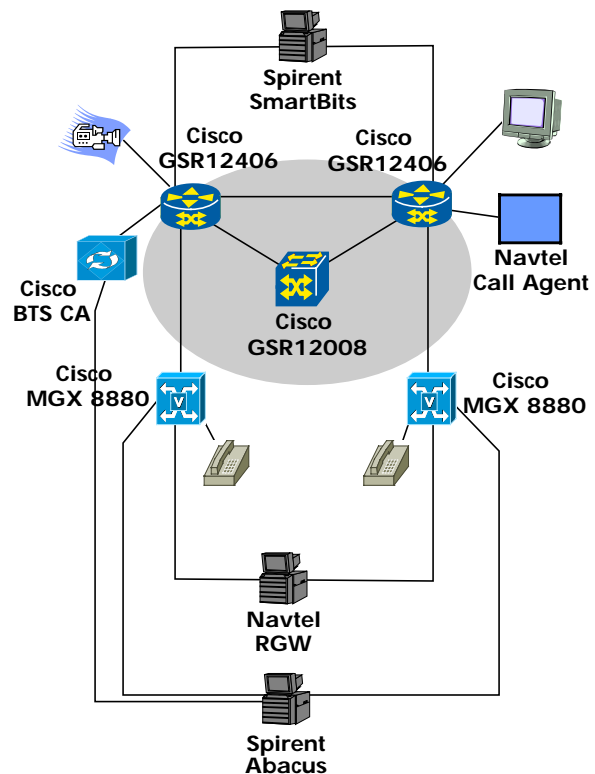
LSP Ping

LSP ping was tested according to draft-ietf-mpls-lsp-ping05.txt. Tests involved sending MPLS echo request packets from one label edge router to another, and receiving MPLS echo reply packets from the remote end. This verified connectivity as well as congruence between the data plane and the control plane.

Voice over IP

The Voice over IP proof of concept demonstration had the following goals:

- An MPLS-TE network can integrate with VoIP Call Agents, Media Gateways, IP phones, and Call Generators running MGCP, H.248/Megaco, or SIP to provide end-to-end high quality voice and video service.
- An MPLS-TE network can guarantee VoIP QoS even under congestion. QoS means no voice packet loss, minimum delay, minimum jitter, and near zero call completion rate change.
- An MPLS-TE network can recover itself in milliseconds when network resources (i.e. nodes and links) failed. Voice and video services are not impacted by network recovery.



VoIP-over-MPLS Topology

The prestaging tests covered:

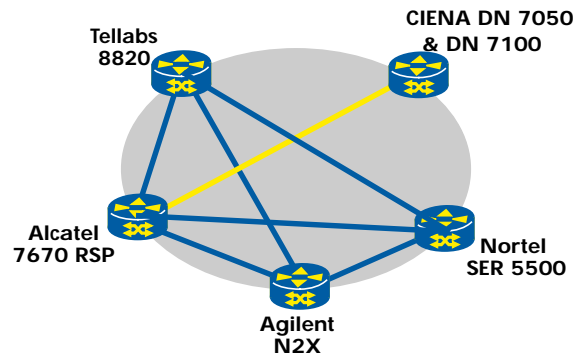
- Establishing basic VoIP calls over the MPLS network
- VoIP quality of service test, adding video and best effort traffic to generate congestion
- MPLS fast reroute test to verify uninterrupted service in the event of a node or link failure.

Interoperability Test Results

The goal of this event was two-fold. First, as in most interoperability test events, the test event sought to verify and improve the interworking of vendors' implementations, and second, it sought to prove that service providers may confidently deploy voice services over MPLS networks knowing that the network will carry these services with the required levels of resilience and availability.

Today, this means more than just finding bugs and correcting them to advance standards compliance. In many cases, implementations rely on draft standards — vendors need to adapt their features to customers' requirements so quickly that they cannot wait until the final standard is adopted. Thus, the test served secondarily to verify clarity of the current standards.

pseudowires were successfully tested among Agilent N2X, Alcatel 7750 SR, Alcatel 7670 RSP, CIENA DN 7050 & DN 7100, MRV OSM-800, Native Networks EMX 3706, Tellabs 8820 and World Wide Packets. ATM pseudowires were tested successfully between Agilent N2X, Alcatel 7670 RSP, CIENA DN 7050 & DN 7100, Nortel SER 5500 and Tellabs 8820.



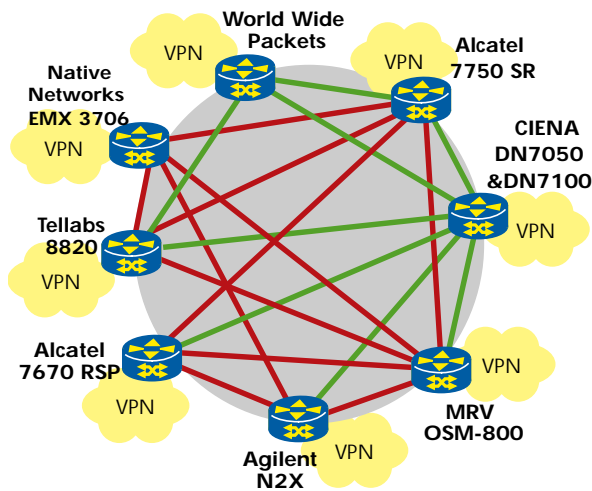
	Provider Edge (PE) Router
	ATM Pseudowire carrying an ATM PVC
	ATM Pseudowire carrying an ATM SPVC

ATM Point-to-Point Tunnels

Also, ATM signalled permanent virtual connection (SPVC) interworking with ATM pseudowires for user-plane and for signaling were successfully tested between Alcatel 7670 RSP and CIENA DN 7050 & DN 7100.

The majority of vendors now use RSVP-TE for VPN transport labels. Only one participant did not support RSVP-TE for VPLS / Ethernet pseudowires; label-switched paths were established using static labels with this device. However, static label support is not widely available in the industry, so it is recommended for all MPLS vendors to support an MPLS transport signalling protocol.

Results: Ethernet and ATM Point-to-Point Pseudowire Tests



	Provider Edge (PE) Router
	Logical link, static VC label
	Logical link, VC label exchanged via targeted LDP

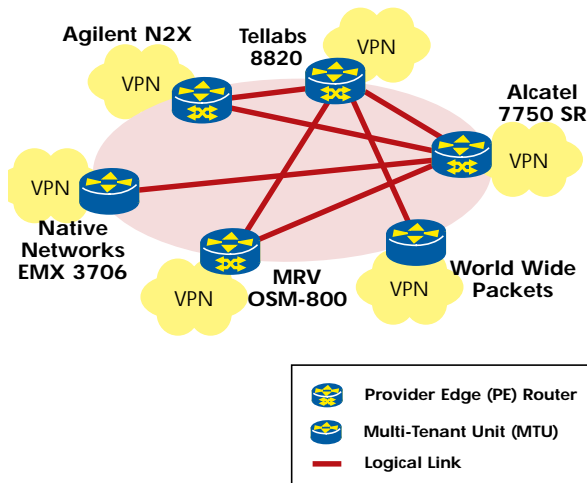
Ethernet Point-to-Point Tunnels

Point-to-point Ethernet over MPLS tunnels («pseudowires») were tested according to the Martini draft. In the hot-staging, almost all tested point-to-point connections interoperated as expected. Ethernet

Results: VPLS and H-VPLS Tests

During the hot-staging, most of the VPLS interoperability testing had positive outcome. As illustrated in the diagram above, the majority of vendors were able to interoperate successfully. Only a few vendors already implemented hierarchical VPLS in time for the hot-staging. Vendors supporting only

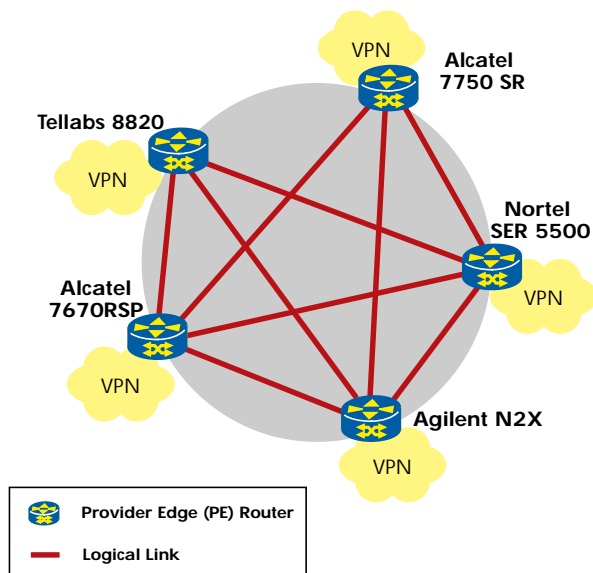
static LSPs further restricted the number of potential test combinations.



VPLS Test Network

Results: BGP/MPLS VPN Tests

The industry has used BGP/MPLS VPNs for several years. The test session did not focus testing this area in detail again; BGP/MPLS VPNs were merely used to demonstrate VPN realization.

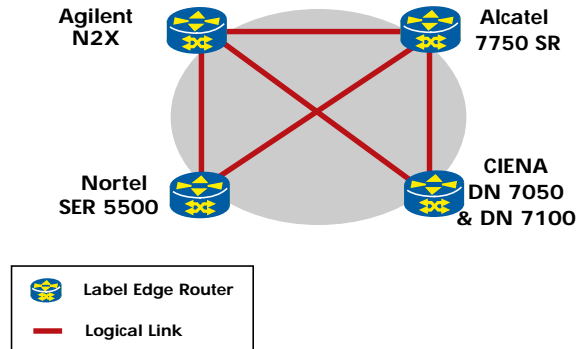


BGP/MPLS VPN Connections

There were no issues encountered while testing MPLS/BGP VPNs. The vendors involved in these tests were Alcatel 7750 SR, Alcatel 7670 RSP,

Agilent N2X, Nortel SER 5500 and Tellabs 8820.

Results: LSP Ping Tests



LSP Ping Connections

LSP ping was tested successfully without any issues between the vendors that implemented it already. The test included Agilent N2X, Alcatel 7750 SR, Nortel SER 5500 and CIENA DN 7050 & DN 7100.

Simultaneous LDP and RSVP-TE Deployment

During the hotstaging simultaneous LDP and RSVP-TE label switched paths were deployed between provider edge routers, to differentiate between the premium traffic using RSVP-TE and best effort traffic using LDP. The tests were based on Multiservice Switching Forum contribution MSF2004.077.00. Agilent N2X, Alcatel 7670 RSP and Nortel SER 5500 participated in this architecture.

Results: VoIP over MPLS Proof-of-Concept Demonstration

Basic MGCP, H.248/Megaco and SIP calls were tested successfully between the Cisco MGX 8880 media gateways, Cisco 3745 voice gateways and a Cisco 10200 BTS CA. Also, MGCP and H.248/Megaco call generator tests with Cisco and Spirent equipment were passed. A SIP voice over IP network simulation over MPLS core using the Navtel SIP proxy server simulator and 2 x 1000 SIP UAs simulators was tested at SuperComm

booth and test was passed, too.

Voice over IP QoS tests involved the Cisco BTS 10200 CA, the two Cisco MGX 8880, the Spirent Abacus 5000 call generator and voice quality measurement equipment, the Spirent SmartBits, the Navtel RGW, the Navtel CA delay / voice quality measurement equipment, and the video end systems. Video and SmartBits were used to add congestion to voice traffic. Under network congestion, it was demonstrated that the voice traffic is properly prioritized in the MPLS backbone:

Traffic Load	Voice Delay (ms)	Voice Jitter (ms)	MOS ^a H.248 results	Call Completion Rate
Voice	43.4	1	4.26	100 %
Voice + Video	43.3	1	4.26	100 %
Voice + Video + 8 Gbps Data	43.3	1	4.26	100 %

- a. Mean Opinion Score; perceptual voice quality measured according to ITU-T P.862 (PESQ); toll quality >= 3.5; ISDN = 4.2; theoretical maximum = 4.5

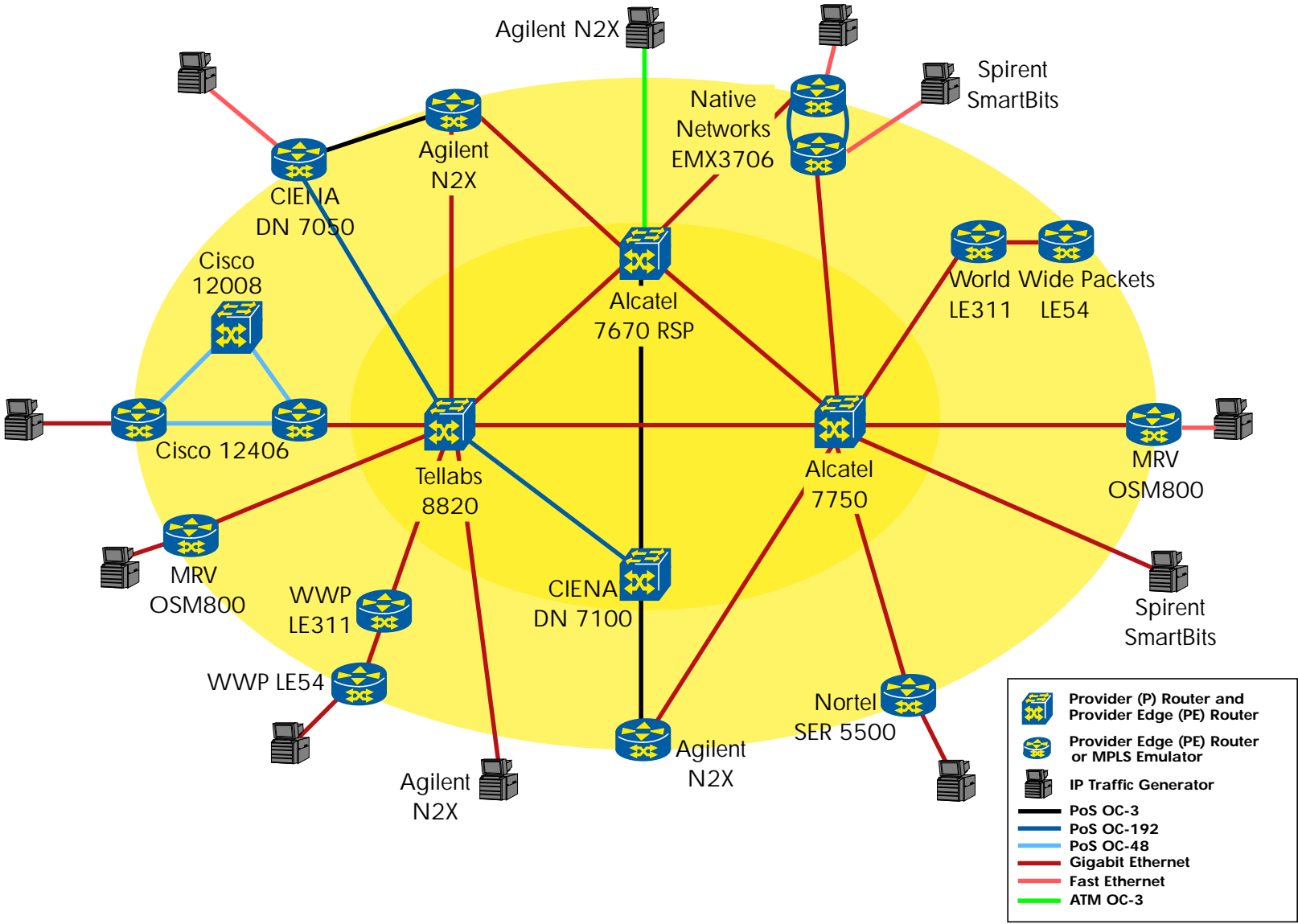
There was no measurable influence on the voice quality even when the network was congested with 8 Gbit/s background data.

Finally, a link between two Cisco GSR 12406 was taken out of service to demonstrate MPLS fast reroute while voice and video connections were active. All voice calls remained established; the call completion rate of the call generator was not influenced and the video quality remained visually unchanged.

Results Summary

Key Features Tested		Results
L2 Pseudo-wires	Interoperability LDP, RSVP-TE	OK
	Data Transfer	OK
	Ethernet tunnels	OK
	ATM tunnels	OK
	Traffic Transfer Over RSVP-TE and LDP Tunnels	OK
	E1 (Data and Voice) Emulated Traffic Transfer	not tested
ATM-MPLS interworking	ATM signalled PVC (SPVC) interworking for data transfer and ATM signalling	OK
VPLS	Full-Mesh Establishment	OK
	Traffic Transfer Over RSVP-TE and LDP Tunnels	OK
	MAC Address Withdraw	not tested
	Hierarchical VPLS PE functionality	OK
	Hierarchical VPLS MTU functionality	OK
BGP/MPLS VPNs	Interoperability iBGP-MP	OK
	Data Transfer	OK
	Traffic Transfer Over RSVP-TE Tunnels	OK
LSP Ping	Generating MPLS Echo Request	OK
	Generating MPLS Echo Reply	OK

Final Integrated MPLS Test Network



Problem Summary

Problem Area	Description	Temporary Solution, if any	Recommendation
LDP	Some vendors do not support Targeted LDP	Static VC labels were used as a workaround	All implementations should support a signaling protocol for both transport and VC label exchange
	Some vendors only accept the interface address or the Router ID as the transport address	None	Switches should accept all interface addresses and the router ID for tunnel establishment
	A directly connected PE did not send the Label Mapping for the VC FEC	Put a P device in between	(bug will be fixed)
	Label withdraw procedure does not conform to the standard		(bug will be fixed)
	Lack of ability to view the Group ID used as a default, which resulted in a lot of time wasted for the debugging		
	Vendor-specific MTU size calculations do not always match		Implementations should be liberal in the MTU sizes accepted
PPP	One vendor only supports PPP MTU size set to 1500	Other vendors had to use the same PPP MTU size in order to establish a PPP session	
	PPP keepalive problem	One vendor had to disable PPP keepalive in order to establish a PPP session	(bug should be fixed)
RSVP-TE	Some vendors do not support pseudowires on RSVP-TE tunnels	None	To be most flexible for multi-vendor networks, it is recommended to support both RSVP-TE and LDP signaling protocols for tunnel transport
OSPF	Some vendors do not support OSPF	The Router ID had to be configured statically.	OSPF-TE support is recommended
H-VPLS	No widespread support in the industry yet	None	
VPLS	Some vendors do not accept VC type 11 for VPLS	Change the VC type to 5	

Conclusion

Since 2002, the MPLS and Frame Relay Alliance has tested and publicly demonstrated different aspects of MPLS interoperability. In a total of five large multi-vendor test events, the participating vendors verified many different MPLS protocols for multi-vendor interoperability — from basic signalling to different flavors of Layer 2 and Layer 3 VPN services as well as DiffServ traffic engineering.

The interoperability event of summer 2004 showed that MPLS is ready for the Enterprise, as all services and network features have reached a good level of maturity, enabling service providers to offer BGP-MPLS VPNs, Ethernet, Frame Relay and ATM point-to-point pseudowires as well as multipoint Ethernet services with Virtual Private LAN Service (VPLS). All these together can make use of advanced MPLS network features like fast reroute, tunnel bandwidth management and Diff-Serv prioritization.

A lot has been achieved in the past five years since MPLS standardization began. Naturally, a number of technology areas are still under development, like the much requested MPLS Operation, Administration and Maintenance (OAM) protocols that were only supported by a small subset of participating vendors. VPLS support is seen from a growing number of vendors although hierarchical VPLS is still at its early stages.

Also, all MPLS users would benefit (and MPLS product support would become less expensive) if the industry had a better formulation of the use cases under which different protocols are utilized that could potentially be used for the same function. For example, both RSVP-TE and LDP are available as MPLS signaling protocols, and in some situations either one could be used. Thus, new switch vendors sometimes do not support them both, creating interoperability issues. A clearer specification of the use cases under which each is applicable would be helpful for vendors and network operators. Similarly, a better formulation of where the two solutions for fast reroute (detour and facility backup) are used would be beneficial in eliminating interoperability problems. We hope to see more guidance from the Internet Engineering Task Force (IETF) in these cases in the future.

Despite of these small issues, Multi-Protocol Label Switching has grown to support a full set of standardized and interoperable VPN types — making MPLS way more flexible than network technologies of the past. A vast number of vendors implement MPLS by now, and the majority of carriers worldwide uses MPLS as the foundation for their IP and layer 2 service backbones.

The MPLS & Frame Relay Alliance and the supporting test labs, UNH-IOL and EANTC, are proud that the series of interoperability test events conducted since 2001 have been able to improve interoperability dramatically.

The VoIP over MPLS test demonstrated that service providers can seamlessly integrate their voice, video and data traffic in one network with MPLS-TE and Fast Reroute and maintain toll quality voice and good quality video service even under congestion or link failure.

Acknowledgements

We would like to thank the following individuals who helped develop the test plans for this event: Peter Chang, Matt Erich, Gilad Goren, Michael Gorokhovsky, Sergej Kaelberer, Vishal Sharma, Mathieu Tallega and Serena Yu. The white paper was authored by Ananda Sen Gupta, Ankur V. Chadda, Chris Volpe, Michael Pergament and Carsten Rossenhoevel.

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 - RFC2205 — Resource ReSerVation Protocol (RSVP)
 - RFC3209 — RSVP-TE: Extensions to RSVP for LSP Tunnels
 - RFC3630 — Traffic Engineering (TE) Extensions to OSPF Version 2
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 - MSF-TR-ARCH-001-FINAL: Next-Generation VoIP Network Architecture
 - MSF-TR-QoS-001-FINAL: Quality of Service for Next Generation Voice over IP Networks
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 - MSF-IA-SIP.001-FINAL: Implementation Agreement for SIP Profile, for Voice over IP, Between a Line-Side Media Gateway Controller and a Trunks Media Gateway Controller
- Generic
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MPLS & Frame Relay Alliance

Tel: +1.510.608.5910
Fax: +1.510.608.5917
amorris@mplsforum.org
www.mplsforum.org

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Multiservice Switching Forum

Tel: +1.510.608.5922
Fax: +1.510.608.5917
info@msforum.org
www.msforum.org

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University of New Hampshire Interoperability Lab

Tel: +1.603.862.4212
Fax: +1.603.862.0898
avchadda@iol.unh.edu (Ankur Chadda)
www.iol.unh.edu



EANTC AG European Advanced Networking Test Center

Tel: +49 30 3180595-0
Fax: +49 30 3180595-10
info@eantc.de
www.eantc.com

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