ZebOS™
Advanced Routing Suite

MPLS and Traffic Engineering: Testing & Interoperability

ipinfusion™

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Introduction

IP Infusion's ZebOS™ Advanced Routing Suite (ARS) is a platform-independent software package that supports IPv4, IPv6, and MPLS-based routing protocols for BGP, OSPF, IS-IS, and RIP. This report describes IP Infusion's MPLS testing and interoperability. For ZebOS core IPv4 and IPv6 product testing, please refer to the ZebOS IPv4 and IPv6Testing and Interoperability paper.

ZebOS supports multiprotocol label switching (MPLS) through the label distribution protocol (LDP), which provides a crucial platform for BGP-VPN (Virtual Private Network) and Traffic Engineering. Full Traffic Engineering support is by way of the OSPF-TE, RSVP-TE, CSPF, and CR-LDP modules. Also, please refer to our White Paper "MPLS-VPN: Application Note."

Because all ZebOS software is a critical component in routing and switching platforms, IP Infusion devotes a substantial amount of time and resources to the testing cycle of each development release, including full functional testing and extensive combinatorial testing in Multiple Instance environments, Redundancy environments, and Virtual Router operation. This paper discusses IP Infusion's MPLS/TE/VPN testing methodology and outlines in detail each phase of our test cycle.

Our aim is to provide the most complete performance, stress, interoperability, and reliability testing in the market. We welcome feedback and comments on this paper and encourage our customers to work with us to provide additional testing and performance metrics.

Please also refer to our family of Performance White Papers on BGP, OSPF, and RIP, especially relating to Memory Usage, Timings, and Scalability Parameters. The full Performance Test Methodology for these crucial performance issues are presented and summarized.

All the results for MPLS/TE/VPN tests described herein; our tests for our core products; and our tests for product performance are available. See your Sales Representative for instructions on how to obtain these test results.

MPLS/TE/VPN Testing Methodology

IP Infusion has defined a testing methodology to validate the high quality and reliability of our ZebOS MPLS/TE/VPN. This testing methodology starts from the moment we begin producing each new release, until it is finally shipped to market.

The four testing regimes are:

- MPLS Internal Testing
- Core Platform Q.A. and Interoperability Lab Testing
- Partner Testing for MPLS Interoperability, Japan
- Adoption of the MPLS Forum Interoperability and Conformance Tests

Planned for the Future are:

- 6-Bone (57 country) Deployment for MPLS - IPv6
- Adoption of the Network Processing Forum Testing and MPLS Initiatives

Our internal tests validate that the product design and functionality meet our specifications. Our Q.A. laboratory uses a variety of IXIA/Empirix/ANVL platforms and uses our own script suites to subject MPLS to a full set of rigorous tests. The ZebOS Core Platform of BGP, OSPF, and RIP is independently tested at the University of New Hampshire Interoperability Lab (UNH IOL). The tested packages are then forwarded to our Partner Test site at DML Networks in Japan, which has been working with IP Infusion for almost two years and verifies that each of the MPLS, TE, and RSVP protocols pass a detailed list of interoperability tests. IP Infusion confirms compliance with these tests before the product is released in the market. Additionally, the MPLS Forum Technical Committee meets on a regular basis and issues testing and conformance requirements documents.

Future MPLS testing will involve the MPLS-IPv6 testing. IP Infusion intends that ZebOS will be in full compliance with the Testing and Benchmarking of the Network Processing Forum (NPF). Currently IP Infusion holds two leadership roles in the NPF: Chair of the Software Working Group and Secretary of the Software Working Group.

Internal Testing

Our internal MPLS test suites are designed at the same time we develop the initial product specifications for each ZebOS release. This process certifies that testing is an integral part of the design of our product. While we implement the initial design, we continually perform a set of unit tests to ensure the reliability and functionality of the software. When the unit tests are complete, we go into a set of protocol module and routing services module tests to validate the performance, functionality, and reliability of each module in the ZebOS routing suite.

Of extreme importance to the testing cycle is the adoption of the Software Engineering Best Practices concepts embedded within the Rational Test RealTime testing and evaluation suites. This filtering process scans through and compiles the raw MPLS source code and scans for errors, redundancies, and in-efficiencies.

When the MPLS (LDP) module tests are complete, we run a set of system tests to determine the functionality of the entire system. This includes the Network Services Module (NSM) and the protocol modules for OSPF-TE, CSPF, BGP-VPN, and RSVP/TE. This process validates the communication, configuration, and functionality for each of the protocol modules and the routing services module. This process includes route conversion, command line interface functionality, management, logging, and event handling.

We use a variety of internal test suites to validate the functionality and performance of ZebOS-MPLS. These include:

- Rational Test Real-Time

- IP Infusion MPLS Test Suite for LDP, Forwarder, and BGP-VPN
- Empirix ANVL testing for RSVP-TE
- IP Infusion testing for CR-LDP
- IP Infusion CSPF Test Suite

Internal Rational Test RealTime

The Rational Test RealTime software suite provides key elements to determine source code integrity for IP Infusion's MPLS Suite on Linux. The code is subjected to various levels of analysis throughout its compilation and link stages. Code under execution is scrutinized for possible memory leaks and a variety of erroneous operating conditions.

Internal MPLS Test Suite for LDP, FWDr, BGP-VPN

Table of LDP Testing (58 tests)

1. Periodic LDP Hello
2. Proper LDP Version
3. Hello upstream / downstream
4. Targeted Hello upstream
5. TCP connection from TLV
6. TCP connection well known
7. LDP alive Init / Keepalive
8. Closes TCP upon error
9. Delayed Session after error
10. Hold Timer Expiration
11. *(Session rejected)*
12. *Keepalive before expiration*
13. *Loop Detection, Label Req*
14. *Upstream to Downstream Req*
15. *Label Map to Upstream LSR*
16. *Hop Count Increment*
17. *Independent Control Mode*
18. *Unknown Hop Count Msg*
19. *Path Vector Downstream*
20. *Self Path vector*
21. *Ordered Control Self Path*
22. *Independent Control path*
23. *Path Vector upstream*
24. *Appending self to Path*
25. *Notification w/ F-bit*
26. *Notification Rejection*
27. *Upstream Advertisement*
28. *Label Request Downstream*
29. *Retransmit Downstream*
30. Loop Detection Notification
31. No Label Resource notify
32. retransmit Label Request
33. Unmatched Prefix Response
34. Hop Count exceeded max
35. Label Request out of range
36. Label Request downstream
37. *Mapping for FEC from FIB*
38. *Mapping DOD label adv*
39. *Mapping on new FEC N-Hop*
40. *Using Label from Neighbor*
41. *Upstream Label w/no map*
42. *Upstream Label w/Indep.*
43. *Upstream Label w/egress*
44. *Ordered control mode*
45. *Upstream Label w/loop det.*
46. *Label Map with own LSR ID*
47. *Upstream Label w/ord. Ctrl*
48. *Upstream Label w/ord. Ctrl*
49. *Downstream Label, new FEC*
50. *Label Req Abort Notification*
51. *Ignoring Label Abort Msg*
52. *Label Withdraw Messages*
53. *Fwd Label Withdraw Msg*
54. *Response to Label Release*
55. *Transmit Label Release Msg*
56. *label Release not Next Hop*
57. *Response, Label Withdraw*
58. *Interface Status*

List of MPLS-VPN Testing (30 tests)

	1. Basic VRF function Testing .	draft-ietf-ppvpn-rfc2547bis-00.txt page5 1.3 page8 3 page 14 4.3.2
	Purpose: Testing VPN route distribution among PE routers by BGP and MPLS.	

1	1.1 MPLS and LDP Testing	
	Purpose: MPLS-VPN completely depends on MPLS packet switching. So we should make sure that MPLS and LDP work first.	

2	1.2 Basic VRF Function Testing	
	Purpose: For same VPN, two site attached to different PE router should communicate with each other.	

3	1.3 Basic VRF Function Testing	
	Purpose: For same VPN, two site attached to the same PE router can communicate with each other	

4	1.4 Basic VRF Function Testing	
	Purpose: If remove one site from VPN, it should not communicate to that site anymore.	

5	1.5 Basic VRF Function Testing	
	Purpose: Two sites, which belong to different VPNs, attached to different PE router should not communicate.	

6	1.6 Basic VRF Function Testing	
	Purpose: If a new import Route Target is later added to one of the PE's VRF, it must then acquire the routes that it may previously have discarded.	

7	1.7 Basic VRF Function Testing	
	Purpose: If a previously imported Route-Target to one of the PE's VRF is discarded, it must then discard the routes associated with that Router-Target.	

8	1.8 Basic VRF Function Testing	
	Purpose: Test VPN with overlapping address space.	

9	1.9 Basic VRF Function Testing	
	Purpose: Test VPN with overlapping address space.	

10	1.10 Basic VRF Function Testing	
	Purpose: If the BGP peers between PE and CE is shutdown, CE should discard all entries learned from that PE and PE should discard all entries learned form that CE.	

11	1.11 Basic VRF Function Testing	
	Purpose: If the BGP peering between PE and CE is re-enable, CE and PE should acquire route from each other.	

12	1.12 Basic VRF Function Testing	
	Purpose: If the BGP peers between PE12 and PE are shutdown, then both PEs should discard entries learned from each other.	

13	1.13 Basic VRF Function Testing	
	Purpose: If the BGP peering between PE1 and PE2 is re-enabling, both PEs should acquire routes from each other.	

14	1.14 Basic VRF Function Testing	
	Purpose: Testing delete vrf function.	

15	1.15 Basic VRF Function Testing	
	Purpose: Testing delete vrf function.	

16-29	2.1 Route-Reflector Function Testing	
	Purpose: Testing route distribution by Route-Reflector.	

30	3.1 Site Origin and import-map Testing	
	Purpose: Testing Site Origin attribute and import map feather.	

Internal Empirix ANVL testing for RSVP-TE

Empirix ANVL testing continues with the authoring of an array of test suites to specifically test a rich variety of traffic engineering router functionalities. Each release is subjected to this stream of testing. OSPF-TE is specifically tested during the core testing of the OSPF Extensions.

TE Tests for RSVP-TE, 2.1 thru 9.17

General Traffic Engineering Tests and RSVP-Traffic Engineering tests are based on the IETF Internet draft “draft-ietf-mpls-rsvp-lsp-tunnel-07.txt” and on the “RSVP-TE: Extensions to RSVP for LSP Tunnels”, (Swallow et al. August 2000)

The suite expects to be running against an RSVP-TE implementation wherein a few of the tests can be run against a single interface, but more thorough testing requires that the host machine for ANVL is connected to 2 interfaces that are connected to the device under test. The ANVL configuration file must contain at least one IP interface.
To run all tests in this suite three IP interfaces must be configured.

Table of TE Tests for RSVP-TE, 2.1 thru 9.17 (91 tests)

2.1 - MTU (DF bit not set)
2.2 - MTU (DF bit set)
3.1 - LABEL_REQUEST
3.2 - LABEL FILTER_SPEC
3.3 - RECORD_ROUTE FILTER_spec
3.4 - EXPLICIT_route label_request
4.1 - Label follows FILTER_SPEC
4.2 - Labels received in Resv
4.3 - Label MUST be drawn from range
4.4 - Senders m-bit
4.5 - Same label to two senders
4.6 - Implicit null label
4.7 - Label is outside requested range
4.8 - Label object without label_request
4.9 - Reserved field set to zero
4.10 - Reserved field ignored
4.11 - Reserved field Label Range
4.12 - Reserved Label Range ignored
4.13 - Minimum VPI field
4.14 - Maximum VPI field
4.15 - Minimum VCI field
4.16 - Maximum VCI field
5.1 - Label range was specified
5.2 - LABEL object in Resv
5.3 - LABEL_REQUEST not present
5.4 - Node sends LABEL_REQUEST
5.5 - Recognizing a LABEL_REQUEST
5.6 - Copy the L3PID
5.7 - Send a PathErr
5.8 - RSVP, no LABEL_REQUEST
5.9 - An RSVP w/ LABEL_REQUEST
5.10 - No RSVP no LABEL_REQUEST
5.11 - No RSVP send PathErr
5.12 - No RSVP, label…send PathErr
6.1 - EXPLICIT_ROUTE ignored
6.2 - Length field EXPLICIT_ROUTE
6.3 - Length field of IPv4 prefix
7.2 - The address to be added
7.3 - Label_Recording flag is set
7.4 - Setting the Global Label flag
7.5 - Pushing Label Record subobject
7.6 - Include label in next Path refresh
7.7 - RRO to be too big to fit
7.8 - PathErr to sender
7.9 - Receiving a ResvErr
7.10 - 'RRO too large for MTU'
7.11 - Resending PathErr or ResvErr
7.12 - Receiving Path message w/ RRO
7.13 - Subsequent Resv not have RRO
7.14 - RRO, unrecognized subobjects
7.15 - Send PathTear msg for old route
7.16 - A tunnel egress node
7.17 - SE style when responding
8.1 - Setup and holding priorities
8.2 - Requested bandwidth not available
8.3 - The support of local-protection
8.4 - Contents of the Session Name
8.5 - Multiple SESSION_ATTRIBUTE
8.6 - All RSVP routers
8.7 - Resources not allocated to LSP
8.8 - Reserved field of SENDER_TSPEC
8.9 - SENDER_TSPEC object ignored
8.10 -Reserv. field of FLOW_SPEC to zero
8.11 - Reserv. field of FLOW_SPEC ignored
9.1 - Verify fields of HELLO REQUEST
9.2 - Verify fields of HELLO ACK
9.3 - IP TTL field HELLO set to 1
9.4 - The Src_Instance NOT be set to zero
9.5 - Src_Instance field MUST NOT change
9.6 - Hello message should be suppressed
9.7 - Hello msg containing HELLO ACK
9.8 - Verify that neighbor has not reset
9.9 - Value differs or the Src_Instance field
9.10 - Neighbor reflects receivers

6.4 - Bits beyond prefix are ignored
6.5 - Bits beyond the prefix set to zero
6.6 - 'BAD initial subobject' error
6.7 - 'Bad EXPLCIT_ROUTE OBJECT'
6.8 - EXPLCIT_ROUTE removed
6.9 - RROs not propagated
6.10 - Each subobject own length field
6.11 - Length field of the IPv4
7.1 - Newly added subobject of RRO

Instance
9.11 - Continuing to adv. wrong non-zero
9.12 - Message containing a HELLO ACK
9.13 - Value differs or the Src_Instance field
9.14 - Verify that the neighbor is reflecting
9.15 - Use a different Src_Instance value
9.16 - Continue advertised new value
9.17 - New instance value not received

IP Infusion Testing for CR-LDP

RA, RB and DUT are connected to each other on an isolated network because of the sensitivity of the tests to the traffic analyzer's captured packets. All tests require that an IGP (RIP/OSPF) be running and connectivity between routers be established by IGP. Packets are captured using ethereal Protocol analyzer on DUT and Test Machine.

Table of IP Infusion Testing for CR-LDP (24 tests)

1.1 DOD Ordered Control
1.2: Sending label map msg to upstream LSR
1.3: Sending traffic parameters unavailable to downstream LSR
1.4: Label Request Aborted label relse. msg
1.5: Negotiation flag set in traffic parameters
1.6: Unchanged traffic parameters TLV
2.1: Recognizing a new FEC
2.2: Request message with ER and ER-HOP
2.3 Incorrectly encoded traffic parameter
2.4 : Label request with negotiable flag set
2.5: Not part of abstract node in first ER-Hop
2.6: Upstream LSR with no First ER-Hop
2.7: Second ER-Hop as strict
2.8: Second loose ER-Hop
3.1: Propagate notification to upstream LSR
3.2: Label request msg with Traffic parameters
3.3: Forward the Label Request with ER-TLV
3.4: Label Request message with Pinning-TLV
3.5: Label Request msg. with Resource Class
3.6: Label Request msg. with PreemptionTLV
3.7: Label Request with Mandatory LSPID TLV
4.1: Label mapping from Downstream LSR
4.2: Label with LSPID TLV from Downstream
4.3: LSP configured for an administrative group

NOTE: repeat test for

1) Include-all: More than one admin-group should be defined for each interface but each interface should have some uncommon admin groups. Trunk should request all admin groups on any 1 interface.

2) Exclude-any: LSP should choose the interface on which specified admin group is not configured.

3) Exclude-all: More than one admin-group should be defined for each interface but each interface should have some uncommon admin groups. Trunk should exclude all admin groups on any 1 interface.

IP Infusion CSPF Test Suite

General CSPF Tests

The General CSPF Tests are tabulated below; they are then run against a CR-LDP configuration or run against the RSVP-TE configuration.

A C program "test_program.c" is used to test CSPF. The test program along with client APIs is configured as the client and the CSPF module is the server. The TE (traffic engineering) feature is enabled on all the routers. The administrative groups and bandwidths on the link can be set through ZebOS. CSPF is enabled by default.

Table of General CSPF Tests (25 tests)

1. Bandwidth less than the avail. bandwidth
2. Bandwidth greater than max. reserv. Bndw.
3. CSPF sends the route messge with ERO
4. The formed lsp satisfies the constraints
5. The formed lsp doesn’t satisfy constraints
6. Formed lsp satisfies multiple constarints
7. Excluding all of the administrative groups.
8. Formed lsp satisfies strict path constraints.
9. Egress is given as the end-point
10. Formed lsp satisfies loose path constraints.
11. and the administrative group constraints
12. Both path constraints
13. Client-id is not either 0 or 1
14. Cspf module sends notification message
15. Egress is not reachable
16. Cspf module sends notification message
17. Strict path is given till egress
18. Two equal paths to egress
19. Random cspf-tie-break is used
20. Route to egress changes randomly
21. Te-metric is zero
22. Lowest cost(ospf) should be preferred
23. Colorless links, included as a constraint
24. Colorless links, excluded as a constraint
25. Route request is sent over Point-to-Point

CSPF-CR-LDP Tests (26+ tests)

The General CSPF tests, shown above, are run in the integrated CR-LDP configuration. Two sub-tests are included, as well as test number 26.

15a. RSVP-TE reserves the bandwidth correctly for multiple LSPs. If the set-up priority of the new, unestablished LSP is **greater** than the hold priority of the old, established LSPs, the old LSP will get pre-empted.

15b. RSVP-TE reserves the bandwidth correctly for multiple LSPs. If the set-up priority of the new, unestablished LSP is **less** than the hold priority of the old, established LSPs, the old LSP will get pre-empted.

26. Link Failure Test

CSPF-RSVP-TE Tests (33 tests)

The General CSPF tests (previous table) are run in the integrated RSVP-TE configuration.

FOR RSVP-TE TESTS: The following special tests are performed using RSVP-TE.

28. For the CSPF to compute the route, te (traffic engineering) feature should be enabled on all the routers except egress.

29.For the CSPF to compute the route, te (traffic engineering) feature should be enabled on all the routers except egress.

30. For the CSPF to compute the route, te (traffic engineering) feature should be enabled on all the routers except egress.

31. CSPF does not check the viability of the reverse link while computing the path.

32. CSPF finds the path if strict path constraint is given on a high metric link.

33. CSPF does not find the path if loose path constraint is given on a high metric link.

Internal Testing Conclusions

Advanced internal testing continues with several combinations of testing, including OSPF/BGP Multiple Instances, BGP/MPLS/VPN/TE over Ethernet, SNMP-API, full Command Line Interface-API, and Virtual Router Operation. At this point many configurations are tested for performance, consisting of memory usage, scalability, and timing parameters. For further details, please refer to our separate Performance Methodology White Papers.

Significant Performance Evaluation statistics are gathered using the IXIA traffic generator. Some tests have exceeded 1 Million installed routes and the testing focuses on building a database of Benchmarks, Memory Footprints, and Scalability. These tests are especially tailored to generate massive router traffic deployed with an extensive variety of parameters.

It is important to note that as ZebOS is ported and integrated into various customer configurations it is subjected to yet another level of rigorous testing and validation. These customer-run verifications of the product become an important ingredient to overall reliability of the ZebOS Advanced Routing Suite.

Core Platform Q.A. and Interoperability Testing

A summary of the core product testing is itemized herein to show the necessary steps undertaken before MPLS system testing and interoperability begins. Please refer to the "ZebOS ARS IPv4 and IPv6 Testing and Interoperability" report for the full details of the core product testing

Summary of Core Testing at IP Infusion's Q.A. Lab

RIP Testing (54 Tests total)
OSPF Testing in 62 Categories (non-extended, 307 tests total)
Extended OSPF and TE Testing (46 tests total)
BGP Testing (48 tests total)

Summary of Core Testing at the Interoperability Lab

After completing both our MPLS and CORE internal tests, we send the core software to private entities that perform very detailed protocol functionality, reliability, stress, and interoperability testing. One of the key interoperability labs that we use is the University of New Hampshire Interoperability Laboratory (UNH IOL). The UNH IOL tests all of the protocols (OSPF, BGP, and RIP), and tests IPv6 for RIP. The UNH IOL tests perform multiple sets of tests for each protocol. The UNH IOL has a large list of consortium members that use their various testing services

The UNH IOL tests are extensive. The sections below summarize the specific tests run for each of the protocols that we support: RIP, OSPF, and BGP, as well as IPv6.

RIP TESTING
Processing Tests
Validation Tests
Forwarding Tests

OSPF TESTING
Hello Protocol
Flooding & Adjacency
Link State Advertisements
Route Calculation
Configuration & Formatting

BGP TESTING
Basic Processing
BGP Finite State Machine
Error Handling
Extensions

INTERNET PROTOCOL VERSION 6 (IPv6)
Basic IPv6 Packet Operation
IPv6 Neighbor Discovery

RIPng TESTING
Basic RIPng, IPv6 Packet Operation

As can be seen from the above test suites for RIP, OSPF, and BGP, the UNH IOL tests are very detailed test suites. IP Infusion feels that by successfully completing these tests, we have achieved a significant level of functionality, quality, reliability, and performance with our software. IP Infusion will continue to use the UNH IOL as an external core protocol test center.

Partner Testing for MPLS Interoperability- Japan

After the successful completion of the core product elements and the MPLS internal elements, the package is sent to Japan. The MPLS-TE testing at DML Networks in Japan proceeds through a suite of interoperability tests that include Cisco Routers, Juniper Routers, Riverstone Routers, Fujitsu Routers, Foundry Routers, and an assortment of Japanese Routers.

The IP Infusion Routers not only passed all tests, but also uncovered an assortment of compatibility issues that exist when some Vendors talk to the routers from other Vendors. The IP Infusion Routers have been confirmed to adjust to these areas of incompatibility as follows:

(1) Some vendors have implemented the “INTSRV” “Class-of-Service” in accordance with IETF drafts. The function has been removed in final IETF RFCs. IP Infusion does not specifically respond to these erroneous objects, and appropriately discards them.

(2) Some tested vendors do not fully support the QoS standards; (though they state that they will in the future). IP Infusion Routers do support QoS, and were attaining full performance when they peered with other full-function routers.

(3) Some tested vendors do not fully support the ERO object; Again, IP Infusion Routers were attaining full performance when they peered with ERO functioning routers.

Interoperability testing confirmed that the IP Infusion MPLS-TE is up-to-date and attains all the performance objectives defined by the IETF when peering with up-to-date routers. The testing also confirmed that the IP Infusion MPLS-TE is fully compatible with older generation routers.

Adoption of MPLS Forum Interoperability and Conformance

The MPLS Forum is engaged in the rapid definition and deployment of the crucial performance feature set grouped as MPLS.

The performance demand for MPLS has never been greater, and IP Infusion tests its MPLS and Traffic Engineering solutions to the fullest level possible. With the introduction of MPLS, IP Infusion offers its first Data Plane product called the MPLS Forwarder; the product undergoes significant testing for Packet Performance and Reliability for Ethernet data link layers.

The ZebOS-MPLS will undergo rigorous testing in full compliance with the MPLS Forum and its Interoperability and Conformance testing. The MPLS Forum Technical Committee meets on a regular basis, and the Interoperability Working Group of the MPLS forum focuses on Test Plans and Conformance Requirements documents for vendors and service providers.

Conclusions & Futures

By using in house tools & processes, external testing organizations, external partner organizations, and advanced-concepts test-sites, IP Infusion offers a complete MPLS testing program that focuses on the delivery of high-quality, reliable, high-performance routing software to the router/switch, network processor, wireless, and embedded device community. Our mission is to become the industry standard, platform-independent, routing protocol vendor. IP Infusion's focus on next generation Internet standards such as IPv6, MPLS, VPN, Traffic Engineering, the Network Processor, our rich feature set, and our complete testing program positions us well to achieve our mission.

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