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Detecting MPLS Data Plane Failures
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*** DRAFT ***

Status of this Memo

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Abstract

This document describes a simple and efficient mechanism that can be used to detect data plane failures in Multi-Protocol Label Switching (MPLS) Label Switched Paths (LSPs). There are two parts to this document: information carried in an MPLS "echo request" and "echo reply" for the purposes of fault detection and isolation; and mechanisms for reliably sending the echo reply.

Changes since last revision

(This section to be removed before publication.)

Added a new error code for Downstream Mapping Mismatch.

Split TLV space into "mandatory" and "optional"; updated IANA allocation policies to reflect this.

Added two new top-level TLVs for LSR Self Test.

Added a new optional top-level TLV for "Errored TLVs"

1. Introduction

This document describes a simple and efficient mechanism that can be used to detect data plane failures in MPLS LSPs. There are two parts to this document: information carried in an MPLS "echo request" and "echo reply"; and mechanisms for transporting the echo reply. The first part aims at providing enough information to check correct operation of the data plane, as well as a mechanism to verify the

data plane against the control plane, and thereby localize faults. The second part suggests two methods of reliable reply channels for the echo request message, for more robust fault isolation.

An important consideration in this design is that MPLS echo requests follow the same data path that normal MPLS packets would traverse. MPLS echo requests are meant primarily to validate the data plane, and secondarily to verify the data plane against the control plane.

Mechanisms to check the control plane are valuable, but are not covered in this document.

To avoid potential Denial of Service attacks, it is recommended to regulate the LSP ping traffic going to the control plane. A rate limiter should be applied to the well-known UDP port defined below.

1.1. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [KEYWORDS].

1.2. Structure of this document

The body of this memo contains four main parts: motivation, MPLS echo request/reply packet format, LSP ping operation, and a reliable return path. It is suggested that first-time readers skip the actual packet formats and read the Theory of Operation first; the document is structured the way it is to avoid forward references.

1.3. Contributors

The following made vital contributions to all aspects of this document, and much of the material came out of debate and discussion among this group.

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2. Motivation

When an LSP fails to deliver user traffic, the failure cannot always be detected by the MPLS control plane. There is a need to provide a tool that would enable users to detect such traffic "black holes" or

misrouting within a reasonable period of time; and a mechanism to isolate faults.

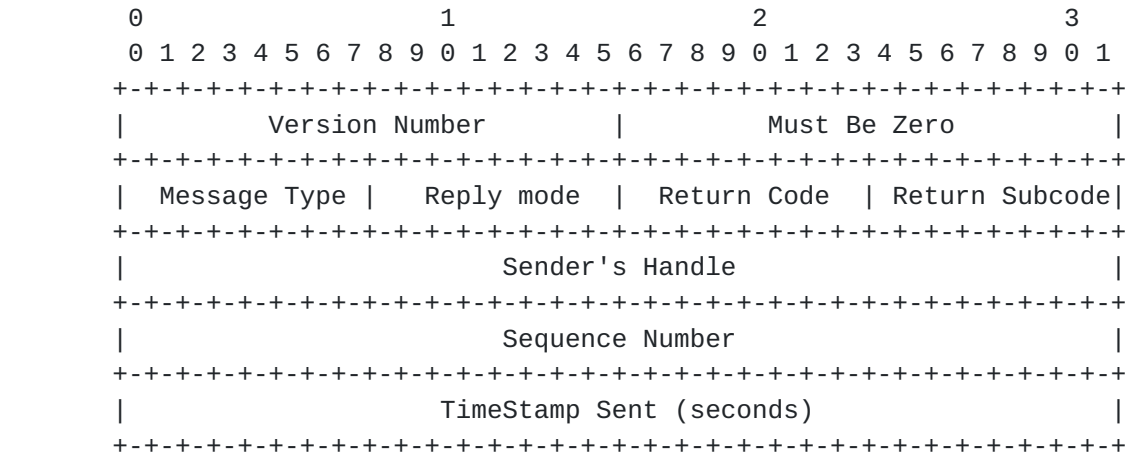
In this document, we describe a mechanism that accomplishes these goals. This mechanism is modeled after the ping/traceroute paradigm: ping (ICMP echo request [ICMP]) is used for connectivity checks, and traceroute is used for hop-by-hop fault localization as well as path tracing. This document specifies a "ping mode" and a "traceroute" mode for testing MPLS LSPs.

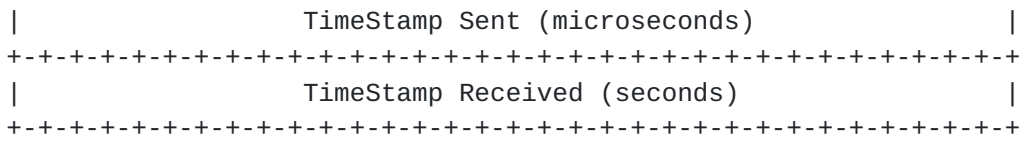
The basic idea is to verify that packets that belong to a particular Forwarding Equivalence Class (FEC) actually end their MPLS path on an LSR that is an egress for that FEC. This document proposes that this test be carried out by sending a packet (called an "MPLS echo request") along the same data path as other packets belonging to this FEC. An MPLS echo request also carries information about the FEC whose MPLS path is being verified. This echo request is forwarded just like any other packet belonging to that FEC. In "ping" mode (basic connectivity check), the packet should reach the end of the path, at which point it is sent to the control plane of the egress LSR, which then verifies whether it is indeed an egress for the FEC. In "traceroute" mode (fault isolation), the packet is sent to the control plane of each transit LSR, which performs various checks that it is indeed a transit LSR for this path; this LSR also returns further information that helps check the control plane against the data plane, i.e., that forwarding matches what the routing protocols determined as the path.

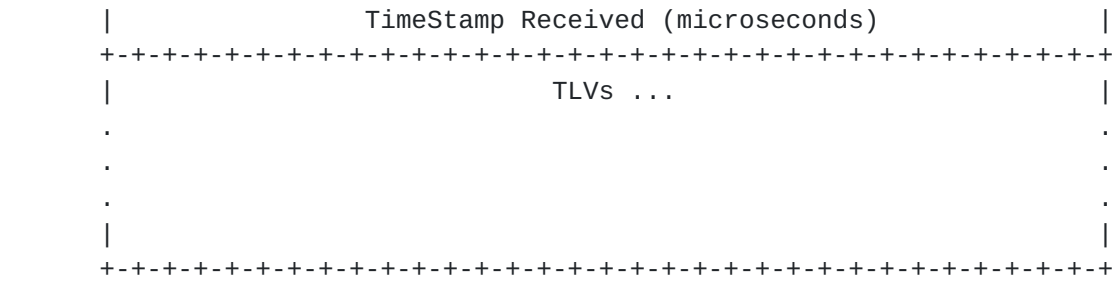
One way these tools can be used is to periodically ping a FEC to ensure connectivity. If the ping fails, one can then initiate a traceroute to determine where the fault lies. One can also periodically traceroute FECs to verify that forwarding matches the control plane; however, this places a greater burden on transit LSRs and thus should be used with caution.

3. Packet Format

An MPLS echo request is a (possibly labelled) IPv4 or IPv6 UDP packet; the contents of the UDP packet have the following format:




TimeStamp Sent (microseconds)
TimeStamp Received (seconds)



The Version Number is currently 1. (Note: the Version Number is to be incremented whenever a change is made that affects the ability of an implementation to correctly parse or process an MPLS echo request/reply. These changes include any syntactic or semantic changes made to any of the fixed fields, or to any TLV or sub-TLV assignment or format that is defined at a certain version number. The Version Number may not need to be changed if an optional TLV or sub-TLV is added.)

The Message Type is one of the following:

Value	Meaning
1	MPLS Echo Request
2	MPLS Echo Reply

The Reply Mode can take one of the following values:

Value	Meaning
1	Do not reply
2	Reply via an IPv4/IPv6 UDP packet
3	Reply via an IPv4/IPv6 UDP packet with Router Alert
4	Reply via application level control channel

An MPLS echo request with "Do not reply" may be used for one-way connectivity tests; the receiving router may log gaps in the sequence numbers and/or maintain delay/jitter statistics. An MPLS echo request would normally have "Reply via an IPv4/IPv6 UDP packet"; if the normal IP return path is deemed unreliable, one may use "Reply via an IPv4/IPv6 UDP packet with Router Alert" (note that this requires that all intermediate routers understand and know how to forward MPLS echo replies). The echo reply uses the same IP version

number as the received echo request, i.e., an IPv4 encapsulated echo reply is sent in response to an IPv4 encapsulated echo request.

Any application which supports an IP control channel between its control entities may set the Reply Mode to 4 to ensure that replies use that same channel. Further definition of this codepoint is

application specific and thus beyond the scope of this docuemnt.

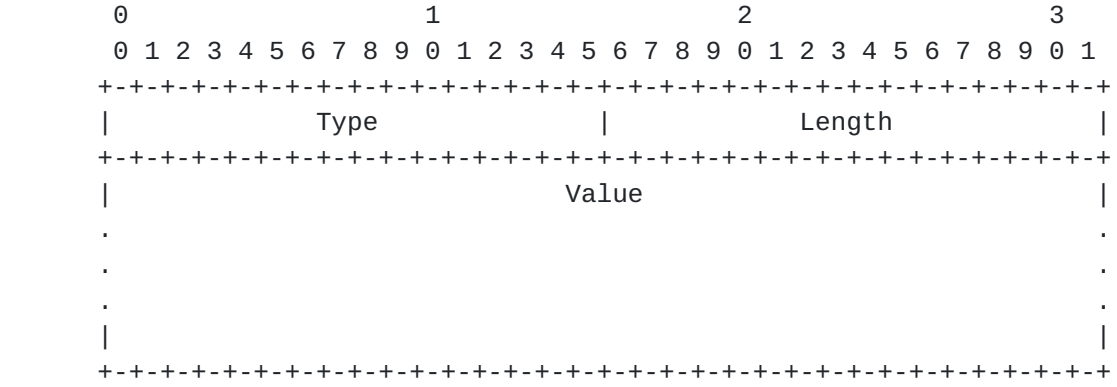
Return Codes and Subcodes are described in the next section.

The Sender's Handle is filled in by the sender, and returned unchanged by the receiver in the echo reply (if any). There are no semantics associated with this handle, although a sender may find this useful for matching up requests with replies.

The Sequence Number is assigned by the sender of the MPLS echo request, and can be (for example) used to detect missed replies.

The TimeStamp Sent is the time-of-day (in seconds and microseconds, wrt the sender's clock) when the MPLS echo request is sent. The TimeStamp Received in an echo reply is the time-of-day (wrt the receiver's clock) that the corresponding echo request was received.

TLVs (Type-Length-Value tuples) have the following format:



Types are defined below; Length is the length of the Value field in octets. The Value field depends on the Type; it is zero padded to align to a four-octet boundary.

Type #	Value Field
1	Target FEC Stack
2	Downstream Mapping
3	Pad

4	Error Code
5	Vendor Enterprise Code
6	TBD
7	IPv4 Interface and Label Stack Object
8	IPv6 Interface and Label Stack Object
9	Errored TLVs

Types with the high order bit not set (i.e., 1) are mandatory TLVs

that MUST either be supported by an implementation or result in the return code of 2 ("One or more of the TLVs was not understood") being sent in the echo response.

Types with the high order bit not set (i.e., 0) are optional TLVs that MUST be ignored if the implementation does not support or understand them.

3.1. Return Codes

The Return Code is set to zero by the sender. The receiver can set it to one of the values listed below. The notation <RSC> refers to the Return Subcode. This field is filled in with the stack-depth for those codes which specify that. For all other codes the Return Subcode MUST be set to zero.

Value	Meaning
0	No return code or return code contained in the Error Code TLV
1	Malformed echo request received
2	One or more of the TLVs was not understood
3	Replying router is an egress for the FEC at stack depth <RSC>
4	Replying router has no mapping for the FEC at stack depth <RSC>
5	Downstream Mapping Mismatch (See Note 1)
6	Reserved
7	Reserved

8 Label switched at stack-depth <RSC>

9 Label switched but no MPLS forwarding at stack-depth <RSC>

10 Mapping for this FEC is not the given label at stack depth <RSC>

11 No label entry at stack-depth <RSC>

12 Protocol not associated with interface at FEC stack depth <RSC>

13 Premature termination of ping due to label stack shrinking to a single label

Note 1. The Return Subcode contains the point in the label stack where processing was terminated. If the RSC is 0, no labels were processed. Otherwise the packet would have been label switched at depth RSC.

3.2. Target FEC Stack

A Target FEC Stack is a list of sub-TLVs. The number of elements is determined by the looking at the sub-TLV length fields.

Sub-Type #	Length	Value Field
1	5	LDP IPv4 prefix
2	17	LDP IPv6 prefix
3	20	RSVP IPv4 Session Query
4	56	RSVP IPv6 Session Query
5		Reserved; see Appendix
6	13	VPN IPv4 prefix
7	25	VPN IPv6 prefix
8	14	L2 VPN endpoint
9	10	"FEC 128" Pseudowire (old)
10	14	"FEC 128" Pseudowire (new)
11	13+	"FEC 129" Pseudowire
12	10	BGP labeled IPv4 prefix

Other FEC Types will be defined as needed.

Note that this TLV defines a stack of FECs, the first FEC element corresponding to the top of the label stack, etc.

An MPLS echo request MUST have a Target FEC Stack that describes the FEC stack being tested. For example, if an LSR X has an LDP mapping for 192.168.1.1 (say label 1001), then to verify that label 1001 does indeed reach an egress LSR that announced this prefix via LDP, X can

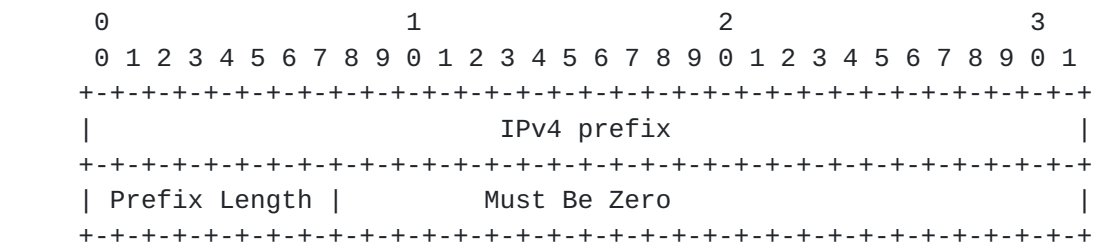
send an MPLS echo request with a FEC Stack TLV with one FEC in it, namely of type LDP IPv4 prefix, with prefix 192.168.1.1/32, and send the echo request with a label of 1001.

Say LSR X wanted to verify that a label stack of <1001, 23456> is the right label stack to use to reach a VPN IPv4 prefix of 10/8 in VPN foo. Say further that LSR Y with loopback address 192.168.1.1 announced prefix 10/8 with Route Distinguisher RD-foo-Y (which may in

general be different from the Route Distinguisher that LSR X uses in its own advertisements for VPN foo), label 23456 and BGP nexthop 192.168.1.1. Finally, suppose that LSR X receives a label binding of 1001 for 192.168.1.1 via LDP. X has two choices in sending an MPLS echo request: X can send an MPLS echo request with a FEC Stack TLV with a single FEC of type VPN IPv4 prefix with a prefix of 10/8 and a Route Distinguisher of RD-foo-Y. Alternatively, X can send a FEC Stack TLV with two FECs, the first of type LDP IPv4 with a prefix of 192.168.1.1/32 and the second of type of IP VPN with a prefix 10/8 with Route Distinguisher of RD-foo-Y. In either case, the MPLS echo request would have a label stack of <1001, 23456>. (Note: in this example, 1001 is the "outer" label and 23456 is the "inner" label.)

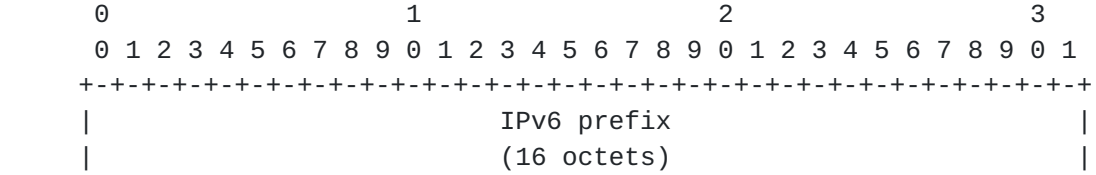
3.2.1. LDP IPv4 Prefix

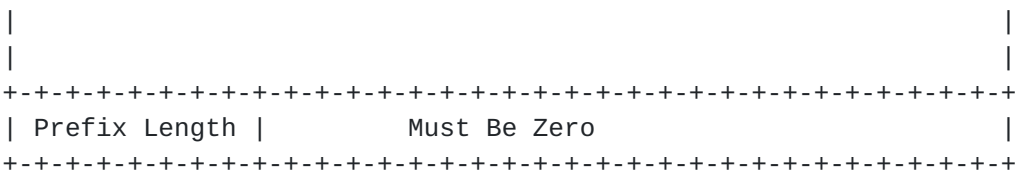
The value consists of four octets of an IPv4 prefix followed by one octet of prefix length in bits; the format is given below. The IPv4 prefix is in network byte order; if the prefix is shorter than 32 bits, trailing bits SHOULD be set to zero. See [LDP] for an example of a Mapping for an IPv4 FEC.



3.2.2. LDP IPv6 Prefix

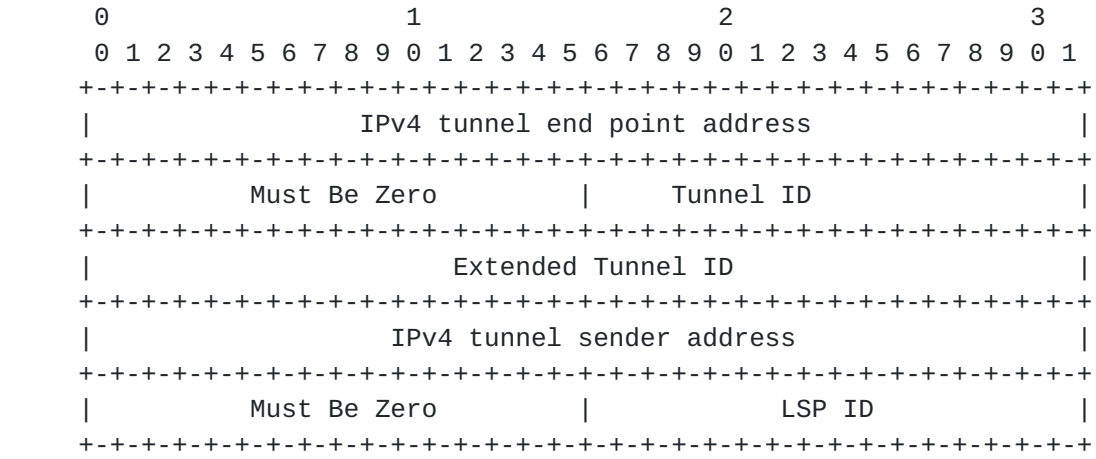
The value consists of sixteen octets of an IPv6 prefix followed by one octet of prefix length in bits; the format is given below. The IPv6 prefix is in network byte order; if the prefix is shorter than 128 bits, the trailing bits SHOULD be set to zero. See [LDP] for an example of a Mapping for an IPv6 FEC.




| Prefix Length | Must Be Zero |

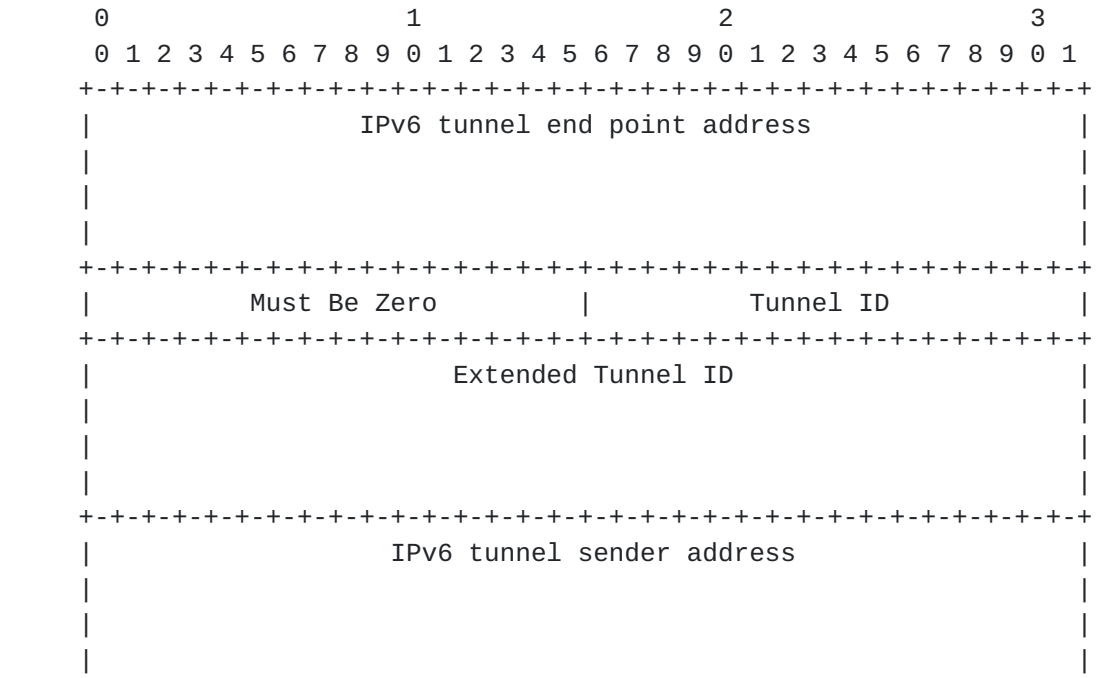
3.2.3. RSVP IPv4 Session

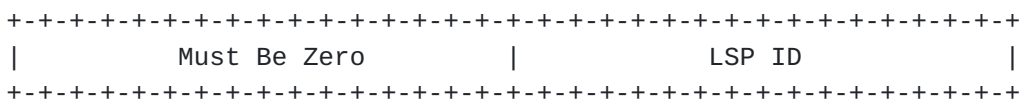
The value has the format below. The value fields are taken from [RFC3209, sections 4.6.1.1 and 4.6.2.1].



3.2.4. RSVP IPv6 Session

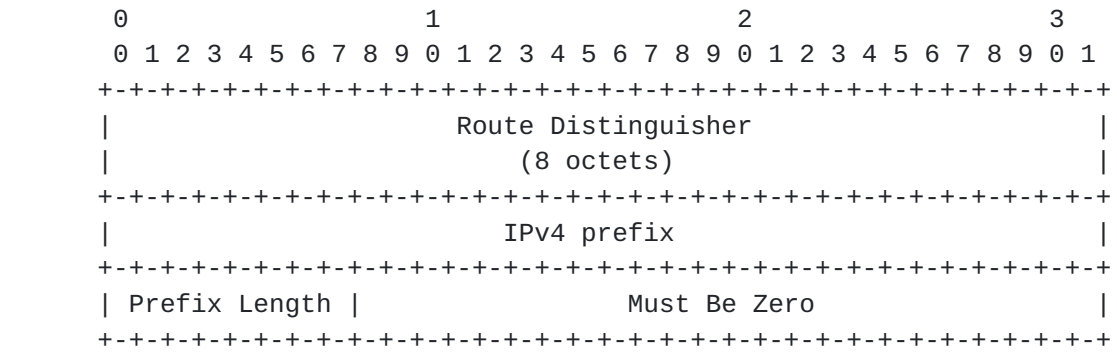
The value has the format below. The value fields are taken from [RFC3209, sections 4.6.1.2 and 4.6.2.2].




Must Be Zero
LSP ID

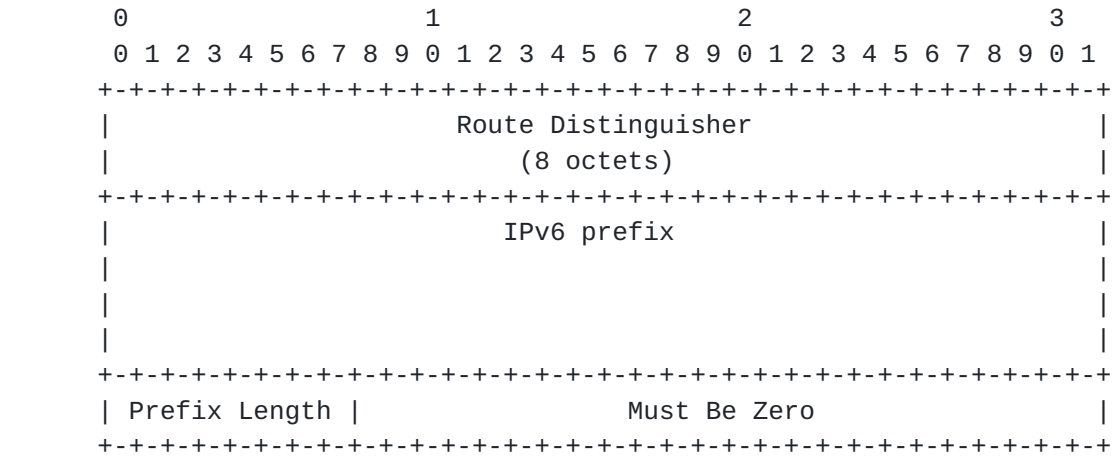
3.2.5. VPN IPv4 Prefix

The value field consists of the Route Distinguisher advertised with the VPN IPv4 prefix, the IPv4 prefix (with trailing 0 bits to make 32 bits in all) and a prefix length, as follows:



3.2.6. VPN IPv6 Prefix

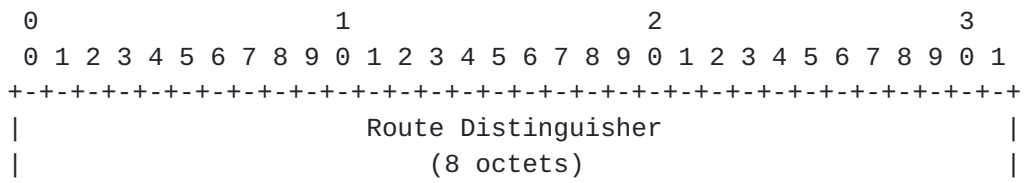
The value field consists of the Route Distinguisher advertised with the VPN IPv6 prefix, the IPv6 prefix (with trailing 0 bits to make 128 bits in all) and a prefix length, as follows:

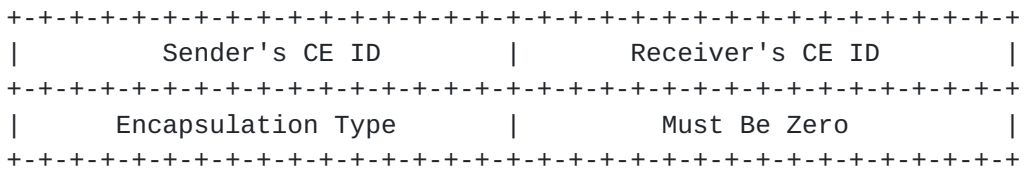


3.2.7. L2 VPN Endpoint

The value field consists of a Route Distinguisher (8 octets), the sender (of the ping)'s CE ID (2 octets), the receiver's CE ID (2

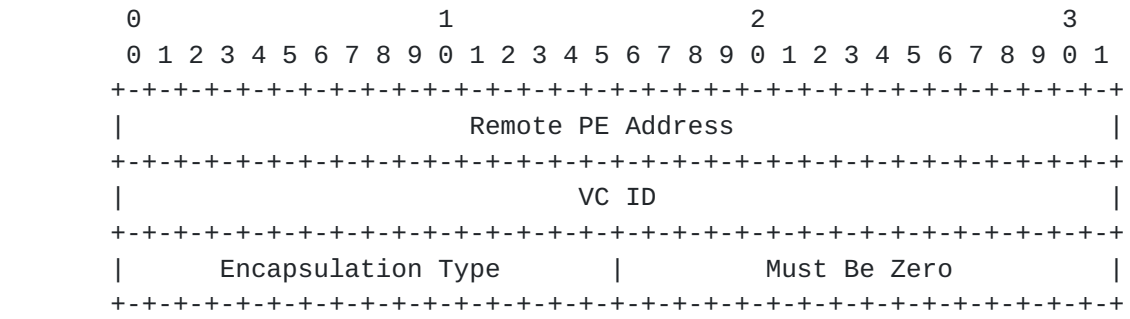
octets), and an encapsulation type (2 octets), formatted as follows:





3.2.8. FEC 128 Pseudowire (Deprecated)

The value field consists of the remote PE address (the destination address of the targetted LDP session), a VC ID and an encapsulation type, as follows:

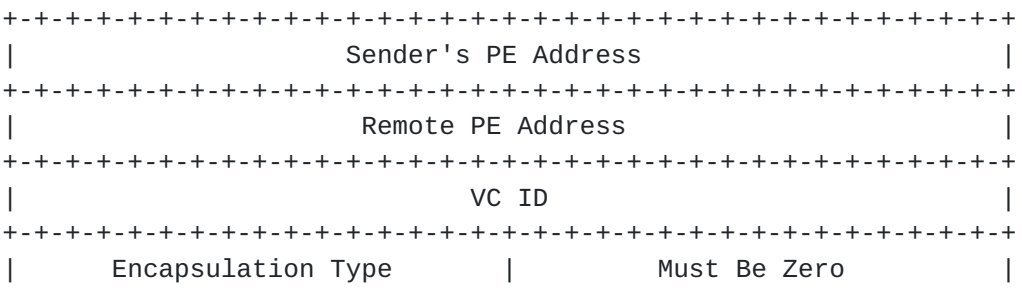


This FEC will be deprecated, and is retained only for backward compatibility. Implementations of LSP ping SHOULD accept and process this TLV, but SHOULD send LSP ping echo requests with the new TLV (see next section), unless explicitly asked by configuration to use the old TLV.

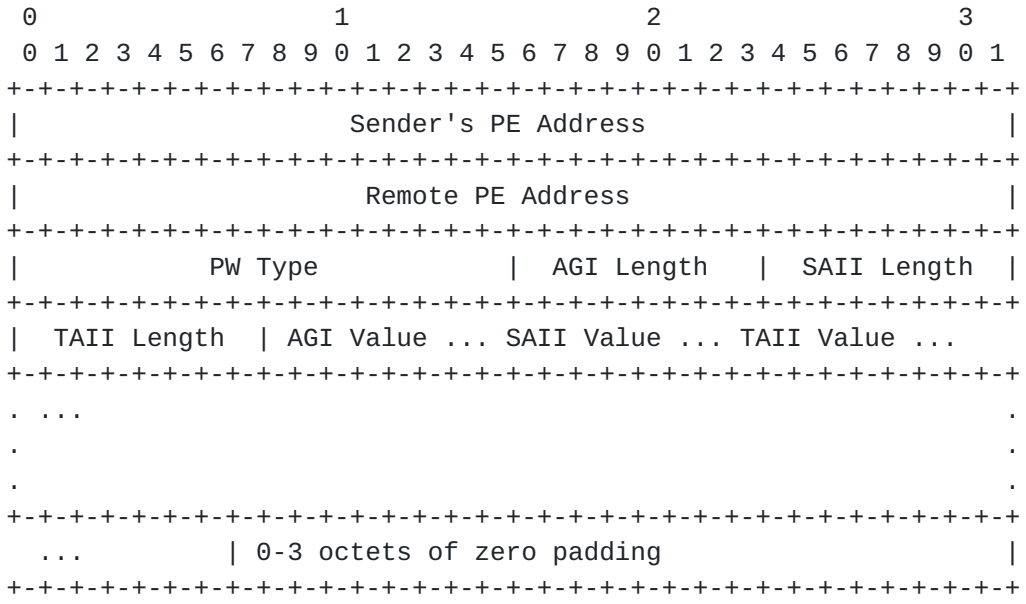
An LSR receiving this TLV SHOULD use the source IP address of the LSP echo request to infer the Sender's PE Address.

3.2.9. FEC 128 Pseudowire (Current)

The value field consists of the sender's PE address (the source address of the targetted LDP session), the remote PE address (the destination address of the targetted LDP session), a VC ID and an encapsulation type, as follows:


Sender's PE Address
Remote PE Address
VC ID
Encapsulation Type
Must Be Zero

3.2.10. FEC 129 Pseudowire



The Length of this TLV is 13 + AGI length + SAII length + TAII length. Padding is used to make the total length a multiple of 4; the length of the padding is not included in the Length field.

3.2.11. BGP Labeled IPv4 Prefix

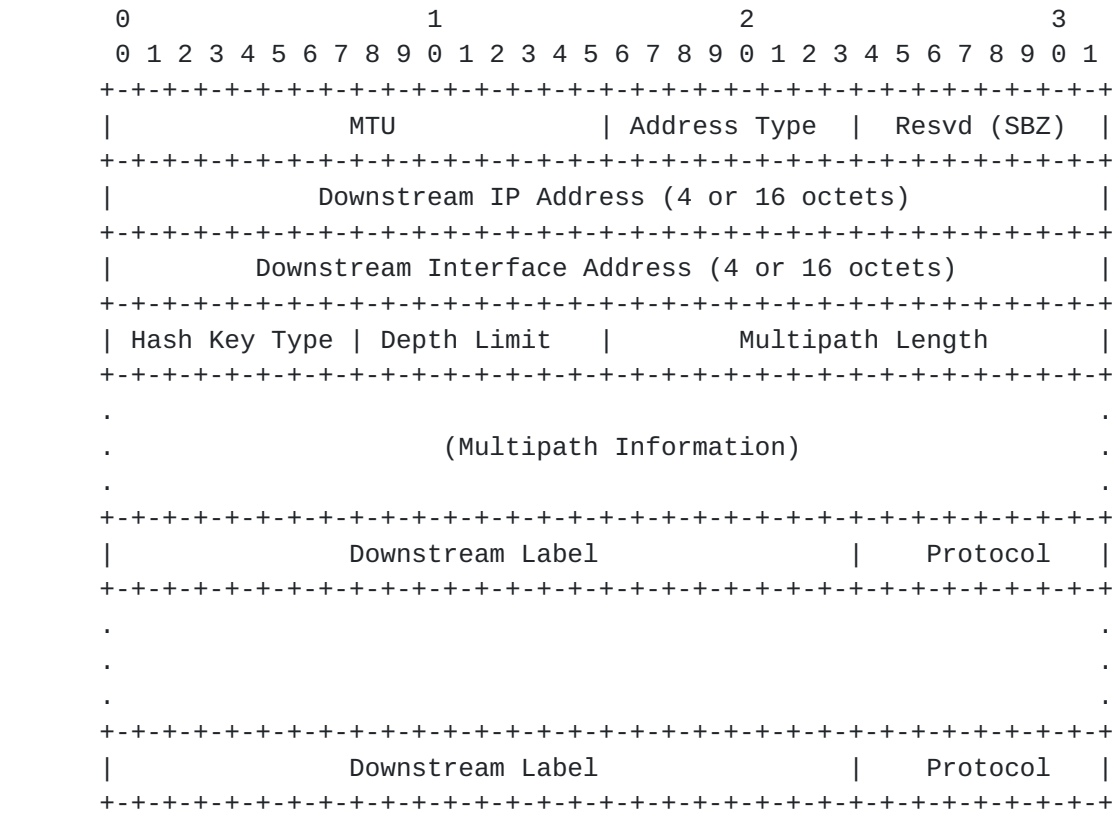
The value field consists of the BGP Next Hop associated with the NLRI advertising the prefix and label, the IPv4 prefix (with trailing 0 bits to make 32 bits in all), and the prefix length, as follows:

3.3. Downstream Mapping

The Downstream Mapping object is an optional TLV. Only one Downstream Mapping request may appear in and echo request. The presence of a Downstream Mapping object is a request that Downstream Mapping objects be included in the echo reply. If the replying

router is the destination of the FEC, then a Downstream Mapping TLV SHOULD NOT be included in the echo reply. Otherwise Downstream Mapping objects SHOULD include a Downstream Mapping object for each interface over which this FEC could be forwarded. For a more precise definition of the notion of "downstream", see the section named "Downstream".

The Length is 16 + M + 4*N octets, where M is the Multipath Length, and N is the number of Downstream Labels. The Value field of a Downstream Mapping has the following format:



Maximum Transmission Unit (MTU)

The MTU is the largest MPLS frame (including label stack) that fits on the interface to the Downstream LSR.

Address Type

The Address Type indicates if the interface is numbered or unnumbered and is set to one of the following values:

Type #	Address Type
1	IPv4

2	Unnumbered
3	IPv6

Reserved

The field marked SBZ SHOULD be set to zero when sending and SHOULD be ignored on receipt.

Downstream IP Address and Downstream Interface Address

If the interface to the downstream LSR is numbered, then the Address Type MUST be set to IPv4 or IPv6, the Downstream IP Address MUST be set to either the downstream LSR's Router ID or the interface address of the downstream LSR, and the Downstream Interface Address MUST be set to the downstream LSR's interface address.

If the interface to the downstream LSR is unnumbered, the Address Type MUST be Unnumbered, the Downstream IP Address MUST be the downstream LSR's Router ID (4 octets), and the Downstream Interface Address MUST be set to the index assigned by the upstream LSR to the interface.

Multipath Length

The length in octets of the Multipath Information.

Downstream Label(s)

The set of labels in the label stack as it would have appeared if this router were forwarding the packet through this interface. Any Implicit Null labels are explicitly inluded. Labels are treated as numbers, i.e. they are right justified in the field.

A Downstream Label is 24 bits, in the same format as an MPLS label minus the TTL field, i.e., the MSBit of the label is bit 0, the LSbit is bit 19, the EXP bits are bits 20-22, and bit 23 is the S bit. The replying router SHOULD fill in the EXP and S bits; the LSR receiving the echo reply MAY choose to ignore these

bits.

Protocol

The Protocol is taken from the following table:

Protocol #	Signaling Protocol
0	Unknown

1	Static
2	BGP
3	LDP
4	RSVP-TE
5	Reserved; see Appendix

Depth Limit

The Depth Limit is applicable only to a label stack, and is the maximum number of labels considered in the hash; this SHOULD be set to zero if unspecified or unlimited.

Multipath Information

The multipath information encodes labels or addresses which will exercise this path. The multipath informaiton depends on the hash key type. The contents of the field are shown in the table above. IP addresses are drawn from the range 127/8. Labels are treated as numbers, i.e. they are right justified in the field. Label and Address pairs MUST NOT overlap and MUST be in ascending sequence.

Hash key 8 allows a denser encoding of IP address. The IPv4 prefix is formatted as a base IPv4 address with the non-prefix low order bits set to zero. The maximum prefix length is 27. Following the prefix is a mask of length 2^(32-prefix length) bits. Each bit set to one represents a valid address. The address is the base IPv4 address plus the position of the bit in the mask where the bits are numbered left to right begining with zero.

Hash key 9 allows a denser encoding of Labels. The label prefix is formatted as a base label value with the non-prefix low order bits set to zero. The maximum prefix (including leading zeros due to encoding) length is 27. Following the prefix is a mask of length 2^(32-prefix length) bits. Each bit set to one represents a valid Label. The label is the base label plus the position of the bit in the mask where the bits are numbered left to right begining with zero.

If the received multipath information is non-null, the labels and

IP addresses MUST be picked from the set provided or the Hash Key Type MUST be set to 7. If the received multipath information is null, the receiver simply returns null.

For example, suppose LSR X at hop 10 has two downstream LSRs Y and Z for the FEC in question. X could return Hash Key Type 4, with low/high IP addresses of 1.1.1.1->1.1.1.255 for downstream

LSR Y and 2.1.1.1->2.1.1.255 for downstream LSR Z. The head end reflects this information to LSR Y. Y, which has three downstream LSRs U, V and W, computes that 1.1.1.1->1.1.1.127 would go to U and 1.1.1.128-> 1.1.1.255 would go to V. Y would then respond with 3 Downstream Mappings: to U, with Hash Key Type 4 (1.1.1.1->1.1.1.127); to V, with Hash Key Type 4 (1.1.1.127->1.1.1.255); and to W, with Hash Key Type 7.

3.3.1. "Downstream"

The notion of "downstream router" and "downstream interface" should be explained. Consider an LSR X. If a packet that was originated with TTL n>1 arrived with outermost label L at LSR X, X must be able to compute which LSRs could receive the packet if it was originated with TTL=n+1, over which interface the request would arrive and what label stack those LSRs would see. (It is outside the scope of this document to specify how this computation is done.) The set of these LSRs/interfaces are the downstream routers/interfaces (and their corresponding labels) for X with respect to L. Each pair of downstream router and interface requires a separate Downstream Mapping to be added to the reply. (Note that there are multiple Downstream Label fields in each TLV as the incoming label L may be swapped with a label stack.)

The case where X is the LSR originating the echo request is a special case. X needs to figure out what LSRs would receive the MPLS echo request for a given FEC Stack that X originates with TTL=1.

The set of downstream routers at X may be alternative paths (see the discussion below on ECMP) or simultaneous paths (e.g., for MPLS multicast). In the former case, the Multipath sub-field is used as a hint to the sender as to how it may influence the choice of these alternatives. The "No of Multipaths" is the number of IP Address/Next Label fields. The Hash Key Type is taken from the following table:

Key	Type	Multipath Information
0	no multipath	(empty; M = 0)
1	label	labels
2	IP address	IP addresses
3	label range	low/high label pairs
4	IP address range	low/high address pairs

5	no more labels	(empty; M = 0)
6	All IP addresses	(empty; M = 0)
7	no match	(empty; M = 0)
8	Bit-masked IPv4 address set	IP address prefix and bit mask

9	Bit-masked label set	Label prefix and bit mask

Type 0 indicates that all packets will be forwarded out this one interface.

Types 1, 2, 3, 4, 8 and 9 specify that the supplied Multipath Information will serve to execise this path.

Types 5 and 6 are TBD.

Type 7 indicates that no matches are possible given the Multipath Information in the received DS mapping information.

3.4. Pad TLV

The value part of the Pad TLV contains a variable number (>= 1) of octets. The first octet takes values from the following table; all the other octets (if any) are ignored. The receiver SHOULD verify that the TLV is received in its entirety, but otherwise ignores the contents of this TLV, apart from the first octet.

Value	Meaning
1	Drop Pad TLV from reply
2	Copy Pad TLV to reply
3-255	Reserved for future use

3.5. Error Code

The Error Code TLV is currently not defined; its purpose is to provide a mechanism for a more elaborate error reporting structure, should the reason arise.

3.6. Vendor Enterprise Code

The Length is always 4; the value is the SMI Enterprise code, in network octet order, of the vendor with a Vendor Private extension to any of the fields in the fixed part of the message, in which case

this TLV MUST be present. If none of the fields in the fixed part of the message have vendor private extensions, this TLV is OPTIONAL.

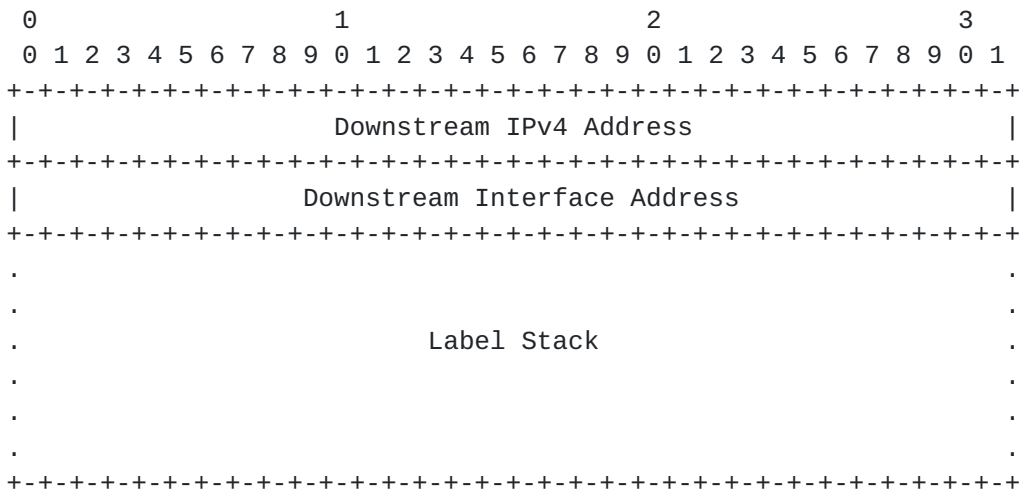
3.7. Interface and Label Stack Object

The Interface and Label Stack Object is an optional TLV. It is used in a Reply message to report the interface on which the Request Message was received and the label stack which was on the packet when it was received. Only one such object may appear. The purpose of the object is to allow the upstream router to obtain the exact

interface and label stack information as it appears at the replying LSR. It has two formats, type 7 for IPv4 and type 8 for IPv6 (to be assigned by IANA).

3.8. IPv4 Interface and Label Stack Object

The Length is 8 + 4*N octets, N is the number of Downstream Labels. The value field of a Interface and Label Stack TLV has the following format:



Downstream IPv4 Address

If the address type is 'No Address', the address field MUST be set to zero and ignored on receipt.

If the address type is 'IPv4', the address field MUST either be set to the downstream LSR's Router ID or the downstream LSR's interface address.

If the address type is 'unnumbered', the address field MUST be set to the downstream LSR's Router ID.

Downstream Interface Address

If the address type is 'IPv4', the interface address field MUST

MUST be set to the downstream LSR's interface address.

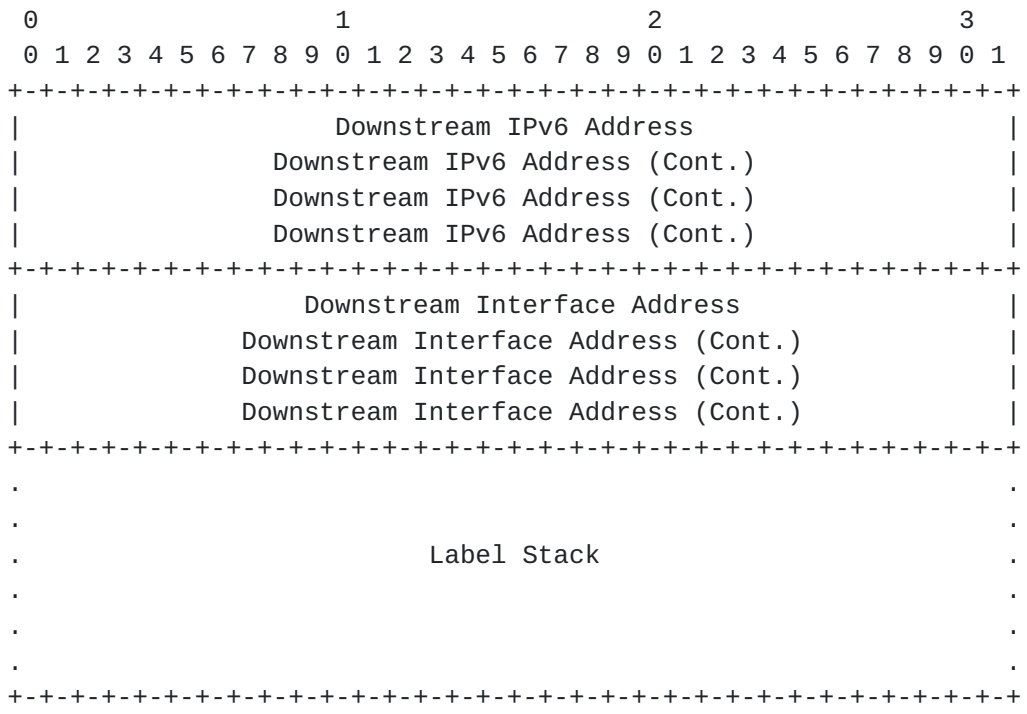
If the address type is 'unnumbered', interface address field MUST be set to the index assigned by the downstream LSR to the interface.

Label Stack

The label stack of the received echo request message. If any TTL values have been changed by this router, they SHOULD be restored.

3.9. IPv6 Interface and Label Stack Object

The Length is 32 + 4*N octets, N is the number of Downstream Labels. The value field of a Interface and Label Stack TLV has the following format:



Downstream IPv6 Address

If the address type is 'No Address', the address field MUST be set to zero and ignored on receipt.

If the address type is 'IPv6', the address field MUST either be set to the downstream LSR's Router ID or the downstream LSR's interface address.

If the address type is 'unnumbered', the address field MUST be

set to the downstream LSR's Router ID.

Downstream Interface Address

If the address type is 'IPv6', the interface address field MUST MUST be set to the downstream LSR's interface address.

If the address type is 'unnumbered', first four octets of interface address field MUST be set to the index assigned by the downstream LSR to the interface. The remaining 12 octets MUST be set to zero.

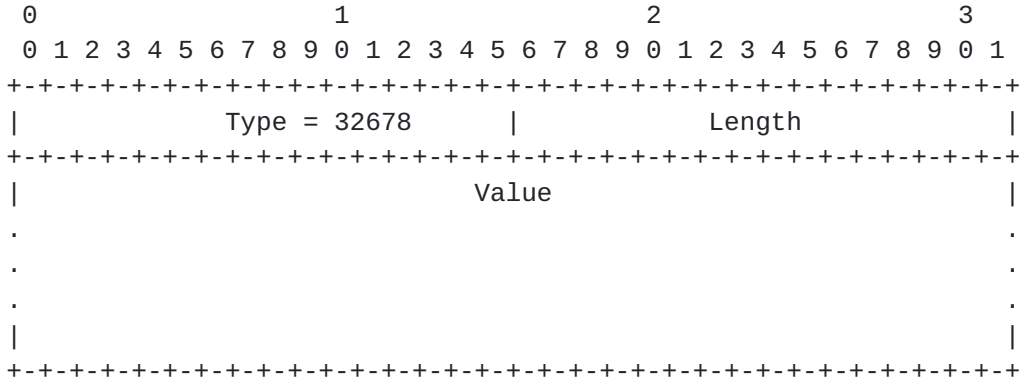
Label Stack

The label stack of the received echo request message. If any TTL values have been changed by this router, they SHOULD be restored.

3.10. Errored TLVs

The following TLV is an optional TLV defined to be sent back to the sender of an Echo Request to inform it of Mandatory TLVs either not supported by an implementation, or parsed and found to be in error.

The Value field contains the TLVs not understood encoded as subtlvs.



4. Theory of Operation

An MPLS echo request is used to test a particular LSP. The LSP to be tested is identified by the "FEC Stack"; for example, if the LSP was set up via LDP, and is to an egress IP address of 10.1.1.1, the FEC stack contains a single element, namely, an LDP IPv4 prefix sub-TLV with value 10.1.1.1/32. If the LSP being tested is an RSVP LSP, the FEC stack consists of a single element that captures the RSVP Session

and Sender Template which uniquely identifies the LSP.

FEC stacks can be more complex. For example, one may wish to test a VPN IPv4 prefix of 10.1/8 that is tunneled over an LDP LSP with egress 10.10.1.1. The FEC stack would then contain two sub-TLVs, the first being a VPN IPv4 prefix, and the second being an LDP IPv4 prefix. If the underlying (LDP) tunnel were not known, or was considered irrelevant, the FEC stack could be a single element with

just the VPN IPv4 sub-TLV.

When an MPLS echo request is received, the receiver is expected to do a number of tests that verify that the control plane and data plane are both healthy (for the FEC stack being pinged), and that the two planes are in sync.

4.1. Dealing with Equal-Cost Multi-Path (ECMP)

LSPs need not be simple point-to-point tunnels. Frequently, a single LSP may originate at several ingresses, and terminate at several egresses; this is very common with LDP LSPs. LSPs for a given FEC may also have multiple "next hops" at transit LSRs. At an ingress, there may also be several different LSPs to choose from to get to the desired endpoint. Finally, LSPs may have backup paths, detour paths and other alternative paths to take should the primary LSP go down.

To deal with the last two first: it is assumed that the LSR sourcing MPLS echo requests can force the echo request into any desired LSP, so choosing among multiple LSPs at the ingress is not an issue. The problem of probing the various flavors of backup paths that will typically not be used for forwarding data unless the primary LSP is down will not be addressed here.

Since the actual LSP and path that a given packet may take may not be known a priori, it is useful if MPLS echo requests can exercise all possible paths. This, while desirable, may not be practical, because the algorithms that a given LSR uses to distribute packets over alternative paths may be proprietary.

To achieve some degree of coverage of alternate paths, there is a certain lattitude in choosing the destination IP address and source UDP port for an MPLS echo request. This is clearly not sufficient; in the case of traceroute, more lattitude is offered by means of the "Multipath Exercise" sub-TLV of the Downstream Mapping TLV. This is used as follows. An ingress LSR periodically sends an MPLS traceroute message to determine whether there are multipaths for a given LSP. If so, each hop will provide some information how each of its downstreams can be exercised. The ingress can then send MPLS echo requests that exercise these paths. If several transit LSRs have ECMP, the ingress may attempt to compose these to exercise all possible paths. However, full coverage may not be possible.

4.2. Sending an MPLS Echo Request

An MPLS echo request is a (possibly) labelled UDP packet. The IP header is set as follows: the source IP address is a routable address of the sender; the destination IP address is a (randomly chosen) address from 127/8; the IP TTL is set to 1. The source UDP port is chosen by the sender; the destination UDP port is set to 3503 (assigned by IANA for MPLS echo requests). The Router Alert option is set in the IP header.

If the echo request is labelled, one may (depending on what is being pinged) set the TTL of the innermost label to 1, to prevent the ping request going farther than it should. Examples of this include pinging a VPN IPv4 or IPv6 prefix, an L2 VPN end point or a pseudowire. This can also be accomplished by inserting a router alert label above this label; however, this may lead to the undesired side effect that MPLS echo requests take a different data path than actual data.

In "ping" mode (end-to-end connectivity check), the TTL in the outermost label is set to 255. In "traceroute" mode (fault isolation mode), the TTL is set successively to 1, 2, ...

The sender chooses a Sender's Handle, and a Sequence Number. When sending subsequent MPLS echo requests, the sender SHOULD increment the sequence number by 1. However, a sender MAY choose to send a group of echo requests with the same sequence number to improve the chance of arrival of at least one packet with that sequence number.

The TimeStamp Sent is set to the time-of-day (in seconds and microseconds) that the echo request is sent. The TimeStamp Received is set to zero.

An MPLS echo request MUST have a FEC Stack TLV. Also, the Reply Mode must be set to the desired reply mode; the Return Code and Subcode are set to zero.

In the "traceroute" mode, the echo request SHOULD contain one or more Downstream Mapping TLVs. For TTL=1, all the downstream routers (and corresponding labels) for the sender with respect to the FEC Stack being pinged SHOULD be sent in the echo request. For n>1, the

Downstream Mapping TLVs from the echo reply for TTL=(n-1) are copied to the echo request with TTL=n; the sender MAY choose to reduce the size of a "Downstream Multipath Mapping TLV" when copying into the next echo request as long as the Hash Key Type matching the label or IP address used to exercise the current MP is still present.

4.3. Receiving an MPLS Echo Request

An LSR X that receives an MPLS echo request first parses the packet to ensure that it is a well-formed packet, and that the TLVs that are not marked "Ignore" are understood. If not, X SHOULD send an MPLS echo reply with the Return Code set to "Malformed echo request received" or "TLV not understood" (as appropriate), and the Subcode set to zero. In the latter case, the misunderstood TLVs (only) are included in the reply.

If the echo request is good, X notes the interface I over which the echo was received, and the label stack with which it came.

X matches up the labels in the received label stack with the FECs contained in the FEC stack. The matching is done beginning at the bottom of both stacks, and working up. For reporting purposes the bottom of stack is consided to be stack-depth of 1. This is to establish an absolute reference for the case where the stack may have more labels than are in the FEC stack.

If there are more FECs than labels, the extra FECs are assumed to correspond to Implicit Null Labels. That is, extra Implicit Null Labels are added to the top of the received label stack and the stack depth is set to the depth of the FEC stack. Thus for the processing below, there is never the case where there is a FEC with no corresponding label. Further, the label operation associated with an assumed Null Label is 'pop and continue processing'.

Note: in all the error codes listed in this draft a stack-depth of 0 means "no value specified". This allows compatibility with existing implementations which do not use the Return Subcode field.

X sets a variable, call it current-stack-depth, to the number of labels in the received label stack. Processing now continues with the following steps:

1. Check if there is a FEC corresponding to the current-stack-depth. If there is, go to step 2. If not, check if the label is valid on interface I. If it is, continue with step 4. Otherwise X MUST send an MPLS echo reply with a Return Code 11, "No label entry at stack-depth" and a Return Subcode set to current-stack-

depth.

2. Check the FEC at the current-stack-depth to determine what protocol would be used to advertise it. If it can determine that no protocol associated with interface I, would have advertised a FEC of that FEC-Type, X MUST send an MPLS echo reply with a Return Code 12, "Protocol not associated with interface at FEC

stack-depth" and a Return Subcode set to current-stack-depth.

3. Check that the mapping for the FEC at the current-stack-depth is the corresponding label.

   If no mapping for the FEC exists, X MUST send an MPLS echo reply with a Return Code 4, "Replying router has no mapping for the FEC at stack-depth" and a Return Subcode set to current- stack-depth.

   If a mapping is found, but the mapping is not the corresponding label, X MUST send an MPLS echo reply with a Return Code 10, "Mapping for this FEC is not the given label at stack-depth" and a Return Subcode set to current-stack-depth.

4. X determines the label operation. If the operation is to pop and continue processing, X checks the current-stack-depth. If it is one, X MUST send an MPLS echo reply with a Return Code 3, "Replying router is an egress for the FEC at stack depth" and a Return Subcode set to one. Otherwise, X decrements current-stack-depth and goes back to step 1.

   If the label operation is pop and switch based on the popped label, X then checks if it is valid to forward a labelled packet. If it is, X MUST send an MPLS echo reply with a Return Code 8, "Label switched at stack-depth" and a Return Subcode set to current-stack-depth. If it is not valid to forward a labelled packet, X MUST send an MPLS echo reply with a Return Code 9, "Label switched but no MPLS forwarding at stack-depth" and a Return Subcode set to current-stack-depth. This return code is sent even if current-stack-depth is one.

   If the label operation is swap, X MUST send an MPLS echo reply with a Return Code 8, "Label switched at stack-depth" and a Return Subcode set to current-stack-depth.

If the MPLS echo request contains a downstream mapping TLV, and the MPLS echo reply has either a Return Code of 8, or a Return Code of 9 with a Return Subcode of 1 then Downstream mapping TLVs SHOULD be included for each multipath.

X uses the procedure in the next subsection to send the echo reply.

4.4. Sending an MPLS Echo Reply

An MPLS echo reply is a UDP packet. It MUST ONLY be sent in response to an MPLS echo request. The source IP address is a routable address of the replier; the source port is the well-known UDP port for LSP ping. The destination IP address and UDP port are copied from the

source IP address and UDP port of the echo request. The IP TTL is set to 255. If the Reply Mode in the echo request is "Reply via an IPv4 UDP packet with Router Alert", then the IP header MUST contain the Router Alert IP option. If the reply is sent over an LSP, the topmost label MUST in this case be the Router Alert label (1) (see [LABEL-STACK]).

The format of the echo reply is the same as the echo request. The Sender's Handle, the Sequence Number and TimeStamp Sent are copied from the echo request; the TimeStamp Received is set to the time-of-day that the echo request is received (note that this information is most useful if the time-of-day clocks on the requestor and the replier are synchronized). The FEC Stack TLV from the echo request MAY be copied to the reply.

The replier MUST fill in the Return Code and Subcode, as determined in the previous subsection.

If the echo request contains a Pad TLV, the replier MUST interpret the first octet for instructions regarding how to reply.

If the echo request contains a Downstream Mapping TLV, the replier SHOULD compute its downstream routers and corresponding labels for the incoming label, and add Downstream Mapping TLVs for each one to the echo reply it sends back.

4.5. Receiving an MPLS Echo Reply

An LSR X should only receive an MPLS Echo Reply in response to an MPLS Echo Request that it sent. Thus, on receipt of an MPLS Echo Reply, X should parse the packet to assure that it is well-formed, then attempt to match up the Echo Reply with an Echo Request that it had previously sent, using the destination UDP port and the Sender's Handle. If no match is found, then X jettisons the Echo Reply; otherwise, it checks the Sequence Number to see if it matches. Gaps in the Sequence Number MAY be logged and SHOULD be counted. Once an Echo Reply is received for a given Sequence Number (for a given UDP port and Handle), the Sequence Number for subsequent Echo Requests for that UDP port and Handle SHOULD be incremented.

If the Echo Reply contains Downstream Mappings, and X wishes to

traceroute further, it SHOULD copy the Downstream Mappings into its next Echo Request (with TTL incremented by one).

4.6. Issue with VPN IPv4 and IPv6 Prefixes

Typically, a LSP ping for a VPN IPv4 or IPv6 prefix is sent with a label stack of depth greater than 1, with the innermost label having a TTL of 1. This is to terminate the ping at the egress PE, before it gets sent to the customer device. However, under certain circumstances, the label stack can shrink to a single label before the ping hits the egress PE; this will result in the ping terminating prematurely. One such scenario is a multi-AS Carrier's Carrier VPN.

To get around this problem, one approach is for the LSR that receives such a ping to realize that the ping terminated prematurely, and send back error code 13. In that case, the initiating LSR can retry the ping after incrementing the TTL on the VPN label. In this fashion, the ingress LSR will sequentially try TTL values until it finds one that allows the VPN ping to reach the egress PE.

4.7. Non-compliant Routers

If the egress for the FEC Stack being pinged does not support MPLS ping, then no reply will be sent, resulting in possible "false negatives". If in "traceroute" mode, a transit LSR does not support LSP ping, then no reply will be forthcoming from that LSR for some TTL, say n. The LSR originating the echo request SHOULD try sending the echo request with TTL=n+1, n+2, ..., n+k in the hope that some transit LSR further downstream may support MPLS echo requests and reply. In such a case, the echo request for TTL>n MUST NOT have Downstream Mapping TLVs, until a reply is received with a Downstream Mapping.

Normative References

[IANA] Narten, T. and H. Alvestrand, "Guidelines for IANA Considerations", BCP 26, RFC 2434, October 1998.

[KEYWORDS] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[LABEL-STACK] Rosen, E., et al, "MPLS Label Stack Encoding", RFC

3032, January 2001.

[RSVP] Braden, R. (Editor), et al, "Resource ReSerVation protocol (RSVP) -- Version 1 Functional Specification," RFC 2205, September 1997.

[RSVP-REFRESH] Berger, L., et al, "RSVP Refresh Overhead Reduction Extensions", RFC 2961, April 2001.

[RSVP-TE] Awduche, D., et al, "RSVP-TE: Extensions to RSVP for LSP tunnels", RFC 3209, December 2001.

Informative References

[ICMP] Postel, J., "Internet Control Message Protocol", RFC 792.

[LDP] Andersson, L., et al, "LDP Specification", RFC 3036, January 2001.

Security Considerations

There are at least two approaches to attacking LSRs using the mechanisms defined here. One is a Denial of Service attack, by sending MPLS echo requests/replies to LSRs and thereby increasing their workload. The other is obfuscating the state of the MPLS data plane liveness by spoofing, hijacking, replaying or otherwise tampering with MPLS echo requests and replies.

Authentication will help reduce the number of seemingly valid MPLS echo requests, and thus cut down the Denial of Service attacks; beyond that, each LSR must protect itself.

Authentication sufficiently addresses spoofing, replay and most tampering attacks; one hopes to use some mechanism devised or suggested by the RPSec WG. It is not clear how to prevent hijacking (non-delivery) of echo requests or replies; however, if these messages are indeed hijacked, LSP ping will report that the data plane isn't working as it should.

It doesn't seem vital (at this point) to secure the data carried in MPLS echo requests and replies, although knowledge of the state of the MPLS data plane may be considered confidential by some.

5. IANA Considerations

The TCP and UDP port number 3503 has been allocated by IANA for LSP echo requests and replies.

The following sections detail the new name spaces to be managed by IANA. For each of these name spaces, the space is divided into assignment ranges; the following terms are used in describing the procedures by which IANA allocates values: "Standards Action" (as defined in [IANA]); "Expert Review" and "Vendor Private Use".

Values from "Expert Review" ranges MUST be registered with IANA, and MUST be accompanied by an Experimental RFC that describes the format and procedures for using the code point; the actual assignment is made during the IANA actions for the RFC.

Values from "Vendor Private" ranges MUST NOT be registered with IANA; however, the message MUST contain an enterprise code as registered with the IANA SMI Network Management Private Enterprise Codes. For each name space that has a Vendor Private range, it must be specified where exactly the SMI Enterprise Code resides; see below for examples. In this way, several enterprises (vendors) can use the same code point without fear of collision.

5.1. Message Types, Reply Modes, Return Codes

It is requested that IANA maintain registries for Message Types, Reply Modes, Return Codes and Return Subcodes. Each of these can take values in the range 0-255. Assignments in the range 0-191 are via Standards Action; assignments in the range 192-251 are made via Expert Review; values in the range 252-255 are for Vendor Private Use, and MUST NOT be allocated.

If any of these fields fall in the Vendor Private range, a top-level Vendor Enterprise Code TLV MUST be present in the message.

5.2. TLVs

It is requested that IANA maintain registries for the Type field of top-level TLVs as well as for sub-TLVs. The valid range for each of

these is 0-65535. Assignments in the range 0-16383 and 32768-49161 are made via Standards Action as defined in [IANA]; assignments in the range 16384-31743 and 49162-64511 are made via Expert Review (see below); values in the range 31744-32746 and 64512-65535 are for Vendor Private Use, and MUST NOT be allocated.

If a TLV or sub-TLV has a Type that falls in the range for Vendor Private Use, the Length MUST be at least 4, and the first four octets

MUST be that vendor's SMI Enterprise Code, in network octet order. The rest of the Value field is private to the vendor.

Acknowledgments

This document is the outcome of many discussions among many people, that include Manoj Leelanivas, Paul Traina, Yakov Rekhter, Der-Hwa Gan, Brook Bailey, Eric Rosen, Ina Minei, Shivani Aggarwal and Vansom Lim.

The description of the Multipath Information sub-field of the Downstream Mapping TLV was adapted from text suggested by Curtis Villamizar.

Appendix

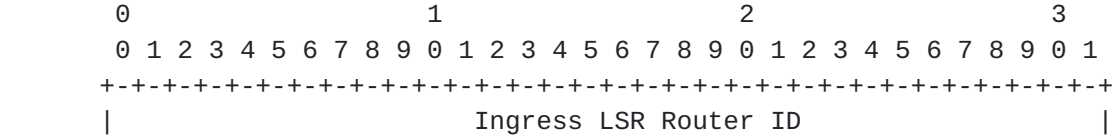
This appendix specifies non-normative aspects of detecting MPLS data plane liveness.

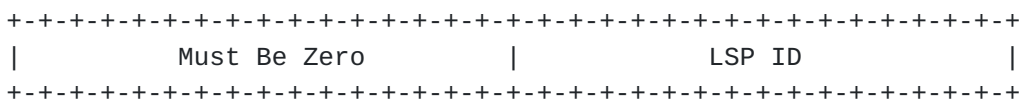
5.1. CR-LDP FEC

This section describes how a CR-LDP FEC can be included in an Echo Request using the following FEC subtype:

Sub-Type #	Length	Value Field
5	6	CR-LDP LSP ID

The value consists of the LSPID of the LSP being pinged. An LSPID is a four octet IPv4 address (a local address on the ingress LSR, for example, the Router ID) plus a two octet identifier that is unique per LSP on a given ingress LSR.




Must Be Zero
LSP ID

5.2. Downstream Mapping for CR-LDP

If a label in a Downstream Mapping was learned via CR-LDP, the Protocol field in the Mapping TLV can use the following entry:

Protocol #	Signaling Protocol
5	CR-LDP

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