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Loa Andersson
Nortel Networks Inc.

Paul Doolan
Ennovate Networks

Nancy Feldman
IBM Corp

Andre Fredette
Nortel Networks Inc.

Bob Thomas
Cisco Systems, Inc.

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# LDP Specification

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## Status of this Memo



## Abstract

An overview of Multi Protocol Label Switching (MPLS) is provided in [FRAMEWORK] and a proposed architecture in [ARCH]. A fundamental concept in MPLS is that two Label Switching Routers (LSRs) must agree on the meaning of the labels used to forward traffic between and

through them. This common understanding is achieved by using the Label Distribution Protocol (LDP) referenced in [ARCH]. This document defines the LDP protocol.

## Changes from Previous Draft

- This draft removes the explicit path setup mechanism from the spec.

- This draft removes loop prevention from the spec. The MPLS working group will continue to evaluate and compare the two leading contenders for loop prevention: loop prevention via path vectors and draft-ohba-mpls-loop-prevention-01.txt. We expect that one of these methods will be selected and added to a later version of LDP.

- This draft retains and refines the path vector mechanism for optional loop detection. In addition, it introduces an upper limit on the size of path vectors.

- This draft specifies parameters for the exponential backup used to throttle session setup retry attempts. It also specifies a mechanism for resetting the backoff parameters in response to LSR configuration changes by adding an optional parameter to the Hello message.

- This draft adds Appendix "LDP Label Distribution Procedures".

- This draft adds rules for resolving differences in the Label Distribution Discipline and Merge session parameters exchanged in the Initialization message.

- This draft modifies message and TLV encodings slightly by adding explicit specification of LSR behavior when an LSR does not recognize the message or TLV.

- This draft modifies the encodings for the Initialization and Hello messages to group parameters likely to be used together and to reduce message sizes. It defines some new TLVs for use with these messages and eliminates some previously defined TLVs.

- This draft specifies a procedure for negotiating the maximum PDU length to be used for a session.

- This draft simplifies the encodings for the Label Mapping, Label Request, Label Withdraw and Label Release messages by eliminating the FEC-Label Mapping, FEC-Request, and FEC-Withdraw-Release TLVs.

- This draft modifies the CoS TLV by specifying that its detailed definition is a subject for further study.

- This draft adds a Return Message Id optional parameter to the Label Request message and a Label Request Message Id parameter to the Label Mapping message to enable an LSR to match received Label Mapping messages with outstanding Label Request messages.

- This draft refines support for vendor-private protocol extensions and specifies support for experimental protocol extensions.

- This draft specifies optional use of the TCP MD5 Signature Option to protect against the introduction of spoofed TCP segments into LDP session connection streams.

## Open Issues

The following LDP issues are left unresolved with this version of the spec:

- LDP support for CoS is not completely specified in this version. Cos support will be more fully addressed in a future version.

- LDP support for multicast is not specified in this version. Multicast support will be addressed in a future version.

- LDP support for multipath label switching is not specified in this version. Multipath support will be addressed in a future version.

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## 1. LDP Overview

LDP is the set of procedures and messages by which Label Switched Routers (LSRs) establish Label Switched Paths (LSPs) through a network by mapping network-layer routing information directly to data-link layer switched paths. These LSPs may have an endpoint at a directly attached neighbor (comparable to IP hop-by-hop forwarding), or may have an endpoint at a network egress node, enabling switching via all intermediary nodes.

LDP associates a Forwarding Equivalence Class (FEC) [ARCH] with each LSP it creates. The FEC associated with an LSP specifies which packets are "mapped" to that LSP. LSPs are extended through a network as each LSR "splices" incoming labels for a FEC to the outgoing label assigned to the next hop for the given FEC.

Note that this document is written with respect to unicast routing only. Multicast will be addressed in a future revision.

### 1.1. LDP Peers

Two LSRs which use LDP to exchange label/stream mapping information are known as "LDP Peers" with respect to that information and we speak of there being an "LDP Session" between them. A single LDP session allows each peer to learn the other's label mappings; i.e., the protocol is bi-directional.

### 1.2. LDP Message Exchange

There are four categories of LDP messages:

1. Discovery messages, used to announce and maintain the presence of an LSR in a network.

2. Session messages, used to establish, maintain, and terminate sessions between LDP peers.

3. Advertisement messages, used to create, change, and delete label mappings for FECs.

4. Notification messages, used to provide advisory information and to signal error information.

Discovery messages provide a mechanism whereby LSRs indicate their presence in a network by sending the Hello message periodically. This is transmitted as a UDP packet to the LDP port at the `all

routers' group multicast address. When an LSR chooses to establish a session with another LSR learned via the Hello message, it uses the LDP initialization procedure over TCP transport. Upon successful completion of the initialization procedure, the two LSRs are LDP peers, and may exchange advertisement messages.

When to request a label or advertise a label mapping to a peer is largely a local decision made by an LSR. In general, the LSR requests a label mapping from a neighboring LSR when it needs one, and advertises a label mapping to a neighboring LSR when it wishes the neighbor to use a label.

Correct operation of LDP requires reliable and in order delivery of messages. To satisfy these requirements LDP uses the TCP transport for session, advertisement and notification messages; i.e., for everything but the UDP-based discovery mechanism.

## 1.3. LDP Message Structure

All LDP messages have a common structure that uses a Type-Length_Value (TLV) encoding scheme; see Section "Type-Length-Value" encoding. The Value part of a TLV-encoded object, or TLV for short, may itself contain one or more TLVs.

## 1.4. LDP Error Handling

LDP errors and other events of interest are signaled to an LDP peer by notification messages.

There are two kinds of LDP notification messages:

1. Error notifications, used to signal fatal errors. If an LSR receives an error notification from a peer for an LDP session, it terminates the LDP session by closing the TCP transport connection for the session and discarding all label mappings learned via the session.

2. Advisory notifications, used to pass an LSR information about the LDP session or the status of some previous message received from the peer.

### 1.5. LDP Extensibility and Future Compatibility

Functionality may be added to LDP in the future. It is likely that future functionality will utilize new messages and object types (TLVs). It may be desirable to employ such new messages and TLVs within a network using older implementations that do not recognize them. While it is not possible to make every future enhancement backwards compatible, some prior planning can ease the introduction of new capabilities. This specification defines rules for handling unknown message types and unknown TLVs for this purpose.

## 2. LDP Operation

### 2.1. FECs

It is necessary to precisely specify which IP packets may be mapped to each LSP. This is done by providing a FEC specification for each LSP. The FEC identifies the set of IP packets which may be mapped to that LSP.

Each FEC is specified as a set of one or more FEC elements. Each FEC element identifies a set of IP packets which may be mapped to the corresponding LSP. When an LSP is shared by multiple FEC elements, that LSP is terminated at (or before) the node where the FEC elements can no longer share the same path.

Following are the currently defined types of FEC elements. New element types may be added as needed:

1. IP Address Prefix. This element is an IP address prefix of any length from 0 to 32 bits, inclusive.

2. Host Address. This element is a 32-bit IP address.

We say that a particular IP address "matches" a particular IP address prefix if and only if that address begins with that prefix. We also say that a particular packet matches a particular LSP if and only if that LSP has an IP Address Prefix FEC element which matches the packet's IP destination address. With respect to a particular packet and a particular LSP, we refer to any IP Address Prefix FEC element which matches the packet as the "matching prefix".

The procedure for mapping a particular packet to a particular LSP uses the following rules. Each rule is applied in turn until the packet can be mapped to an LSP.

- If there is exactly one LSP which has a Host Address FEC element that is identical to the packet's IP destination address, then the packet is mapped to that LSP.

- If there multiple LSPs, each containing a Host Address FEC element that is identical to the packet's IP destination address, then the packet is mapped to one of those LSPs. The procedure for selecting one of those LSPs is beyond the scope of this document.

- If a packet matches exactly one LSP, the packet is mapped to that LSP.

- If a packet matches multiple LSPs, it is mapped to the LSP whose matching prefix is the longest. If there is no one LSP whose matching prefix is longest, the packet is mapped to one of those LSPs. The procedure for selecting one of those LSPs is beyond the scope of this document.

- If it is known that a packet must traverse a particular egress router, and there is an LSP which has an IP Address Prefix FEC element (of length 32 bits) which is an address of that router, then the packet is mapped to that LSP. The procedure for obtaining this knowledge is beyond the scope of this document.

## 2.2. Label Spaces, Identifiers, Sessions and Transport

### 2.2.1. Label Spaces

The notion of "label space" is useful for discussing the assignment and distribution of labels. There are two types of label spaces:

- Per interface label space. Interface-specific incoming labels are used for interfaces that use interface resources for labels. An example of such an interface is a label-controlled ATM interface that uses VCIs as labels, or a Frame Relay interface that uses DLCIs as labels.

  Note that the use of a per interface label space only makes sense when the LDP peers are "directly connected" over an interface, and the label is only going to be used for traffic sent over that interface.

- Per platform label space. Platform-wide incoming labels are used for interfaces that can share the same labels.

### 2.2.2. LDP Identifiers

An LDP identifier is a six octet quantity used to identify an LSR label space. The first four octets encode an IP address assigned to the LSR, and the last two octets identify a specific label space within the LSR. The last two octets of LDP Identifiers for platform-wide label spaces are always both zero. This document uses the following print representation for LDP Identifiers:

<IP address> : <label space id>

e.g., 171.32.27.28:0, 192.0.3.5:2.

Note that an LSR that manages and advertises multiple label spaces uses a different LDP Identifier for each such label space.

A situation where an LSR would need to advertise more than one label space to a peer and hence use more than one LDP Identifier occurs when the LSR has two links to the peer and both are ATM (and use per interface labels). Another situation would be where the LSR had two links to the peer, one of which is ethernet (and uses per platform labels) and the other of which is ATM.

### 2.2.3. LDP Sessions

LDP sessions exist between LSRs to support label exchange between them.

When an LSR uses LDP to advertise more than one label space to another LSR it uses a separate LDP session for each label space.

### 2.2.4. LDP Transport

LDP uses TCP as a reliable transport for sessions.

When multiple LDP sessions are required between two LSRs there is one TCP session for each LDP session.

### 2.3. LDP Sessions between non-Directly Connected LSRs

LDP sessions between LSRs that are not directly connected at the link level may be desirable in some situations.

For example, consider a "traffic engineering" application where LSRa sends traffic matching some criteria via an LSP to non-directly connected LSRb rather than forwarding the traffic along its normally routed path.

The path between LSRa and LSRb would include one or more intermediate LSRs (LSR1,...LSRn). An LDP session between LSRa and LSRb would enable LSRb to label switch traffic arriving on the LSP from LSRa by providing LSRb means to advertise labels for this purpose to LSRa.

In this situation LSRa would apply two labels to traffic it forwards on the LSP to LSRb: a label learned from LSR1 to forward traffic along the LSP path from LSRa to LSRb; and a label learned from LSRb to enable LSRb to label switch traffic arriving on the LSP.

LSRa first adds the label learned via its LDP session with LSRb to the packet label stack (either by replacing the label on top of the packet label stack with it if the packet arrives labeled or by pushing it if the packet arrives unlabeled). Next, it pushes the label for the LSP learned from LSR1 onto the label stack.

### 2.4. LDP Discovery

LDP discovery is a mechanism that enables an LSR to discover potential LDP peers. Discovery makes it unnecessary to explicitly configure an LSR's label switching peers.

There are two variants of the discovery mechanism:

- A basic discovery mechanism used to discover LSR neighbors that are directly connected at the link level.

- An extended discovery mechanism used to locate LSRs that are not directly connected at the link level.

#### 2.4.1. Basic Discovery Mechanism

To engage in LDP Basic Discovery on an interface an LSR periodically sends LDP Link Hellos out the interface. LDP Link Hellos are sent as UDP packets addressed to the well-known LDP discovery port for the "all routers" group multicast address.

An LDP Link Hello sent by an LSR carries the LDP Identifier for the label space the LSR intends to use for the interface and possibly additional information.

Receipt of an LDP Link Hello on an interface identifies a "Hello adjacency" with a potential LDP peer reachable at the link level on the interface as well as the label space the peer intends to use for the interface.

### 2.4.2. Extended Discovery Mechanism

LDP sessions between non-directly connected LSRs are supported by LDP Extended Discovery.

To engage in LDP Extended Discovery an LSR periodically sends LDP Targeted Hellos to a specific IP address. LDP Targeted Hellos are sent as UDP packets addressed to the well-known LDP discovery port at the specific address.

An LDP Targeted Hello sent by an LSR carries the LDP Identifier for the label space the LSR intends to use and possibly additional optional information.

Extended Discovery differs from Basic Discovery in the following ways:

- A Targeted Hello is sent to a specific IP address rather than to the "all routers" group multicast address for the outgoing interface.

- Unlike Basic Discovery, which is symmetric, Extended Discovery is asymmetric.

  One LSR initiates Extended Discovery with another targeted LSR, and the targeted LSR decides whether to respond to or ignore the Targeted Hello. A targeted LSR that chooses to respond does so by periodically sending Targeted Hellos to the initiating LSR.

Receipt of an LDP Targeted Hello identifies a "Hello adjacency" with a potential LDP peer reachable at the network level and the label space the peer intends to use.

## 2.5. Establishing and Maintaining LDP Sessions

### 2.5.1. LDP Session Establishment

The exchange of LDP Discovery Hellos between two LSRs triggers LDP session establishment. Session establishment is a two step process:

- Transport connection establishment.
- Session initialization

The following describes establishment of an LDP session between LSRs LSR1 and LSR2 from LSR1's point of view. It assumes the exchange of Hellos specifying label space LSR1:a for LSR1 and label space LSR2:b for LSR2.

### 2.5.2. Transport Connection Establishment

The exchange of Hellos results in the creation of a Hello adjacency at LSR1 that serves to bind the link (L) and the label spaces LSR1:a and LSR2:b.

1. If LSR1 does not already have an LDP session for the exchange of label spaces LSR1:a and LSR2:b it attempts to open a TCP connection for a new LDP session with LSR2.

   LSR1 determines the transport addresses to be used at its end (A1) and LSR2's end (A2) of the LDP TCP connection. Address A1 is determined as follows:

   a. If LSR1 uses the Transport Address optional object (TLV) in Hello's it sends to LSR2 to advertise an address, A1 is the address LSR1 advertises via the optional object;

   b. If LSR1 does not use the Transport Address optional object, A1 is the source IP address used in Hellos it sends to LSR2.

   Similarly, address A2 is determined as follows:

   a. If LSR2 uses the Transport Address optional object, A2 is the address LSR2 advertises via the optional object;

   b. If LSR2 does not use the Transport Address optional object, A2 is the source IP address in Hellos received from LSR2.

2. LSR1 determines whether it will play the active or passive role in session establishment by comparing addresses A1 and A2 as

unsigned integers. If A1 > A2, LSR1 plays the active role; otherwise it is passive.

3. If LSR1 is active, it attempts to establish the LDP TCP connection by connecting to the well-known LDP port at address A2. If LSR1 is passive, it waits for LSR2 to establish the LDP TCP connection to its well-known LDP port.

### 2.5.3. Session Initialization

After LSR1 and LSR2 establish a transport connection they negotiate session parameters by exchanging LDP Initialization messages. The parameters negotiated include LDP protocol version, label distribution method, timer values, VPI/VCI ranges for label controlled ATM, DLCI ranges for label controlled Frame Relay, etc.

Successful negotiation completes establishment of an LDP session between LSR1 and LSR2 for the advertisement of label spaces LSR1:a and LSR2:b.

The following describes the session initialization from LSR1's point of view.

After the connection is established, if LSR1 is playing the active role, it initiates negotiation of session parameters by sending an Initialization message to LSR2. If LSR1 is passive, it waits for LSR2 to initiate the parameter negotiation.

In general when there are multiple links between LSR1 and LSR2 and multiple label spaces to be advertised by each, the passive LSR cannot know which label space to advertise over a newly established TCP connection until it receives the first LDP PDU on the connection.

By waiting for the Initialization message from its peer the passive LSR can match the label space to be advertised by the peer (as determined from the LDP Identifier in the PDU header for the Initialization message) with a Hello adjacency previously created when Hellos were exchanged.

1. When LSR1 plays the passive role:

   a. If LSR1 receives an Initialization message it attempts to match the LDP Identifier carried by the message PDU with a Hello adjacency.

   b. If there is a matching Hello adjacency, the adjacency specifies the local label space for the session.

Next LSR1 checks whether the session parameters proposed in the message are acceptable. If they are, LSR1 replies with an Initialization message of its own to propose the parameters it wishes to use and a KeepAlive message to signal acceptance of LSR2's parameters. If the parameters are not acceptable, LSR1 responds by sending a Session Rejected/Parameters Error Notification message and closing the TCP connection.

c. If LSR1 cannot find a matching Hello adjacency it sends a Session Rejected/No Hello Error Notification message and closes the TCP connection.

d. If LSR1 receives a KeepAlive in response to its Initialization message, the session is operational from LSR1's point of view.

e. If LSR1 receives an Error Notification message, LSR2 has rejected its proposed session and LSR1 closes the TCP connection.

2. When LSR1 plays the active role:

a. If LSR1 receives an Error Notification message, LSR2 has rejected its proposed session and LSR1 closes the TCP connection.

b. If LSR1 receives an Initialization message, it checks whether the session parameters are acceptable. If so, it replies with a KeepAlive message. If the session parameters are unacceptable, LSR1 sends a Session Rejected/Parameters Error Notification message and closes the connection.

c. If LSR1 receives a KeepAlive message, LSR2 has accepted its proposed session parameters.

d. When LSR1 has received both an acceptable Initialization message and a KeepAlive message the session is operational from LSR1's point of view.

It is possible for a pair of incompatibly configured LSRs that disagree on session parameters to engage in an endless sequence of messages as each NAKs the other's Initialization messages with Error Notification messages.

An LSR must throttle its session setup retry attempts with an exponential backoff in situations where Initialization messages

are being NAK'd. It is also recommended that an LSR detecting such a situation take action to notify an operator.

The session establishment setup attempt following a NAK'd Initialization message must be delayed no less than 15 seconds, and subsequent delays must grow to a maximum delay of no less than 2 minutes. The specific session establishment action that must be delayed is the attempt to open the session transport connection by the LSR playing the active role.

The throttled sequence of Initialization NAKs is unlikely to cease until operator intervention reconfigures one of the LSRs. After such a configuration action there is no further need to throttle subsequent session establishment attempts (until their initialization messages are NAK'd).

Due to the asymmetric nature of session establishment, reconfiguration of the passive LSR will go unnoticed by the active LSR without some further action. Section "Hello Message" describes an optional mechanism an LSR can use to signal potential LDP peers that it has been reconfigured.

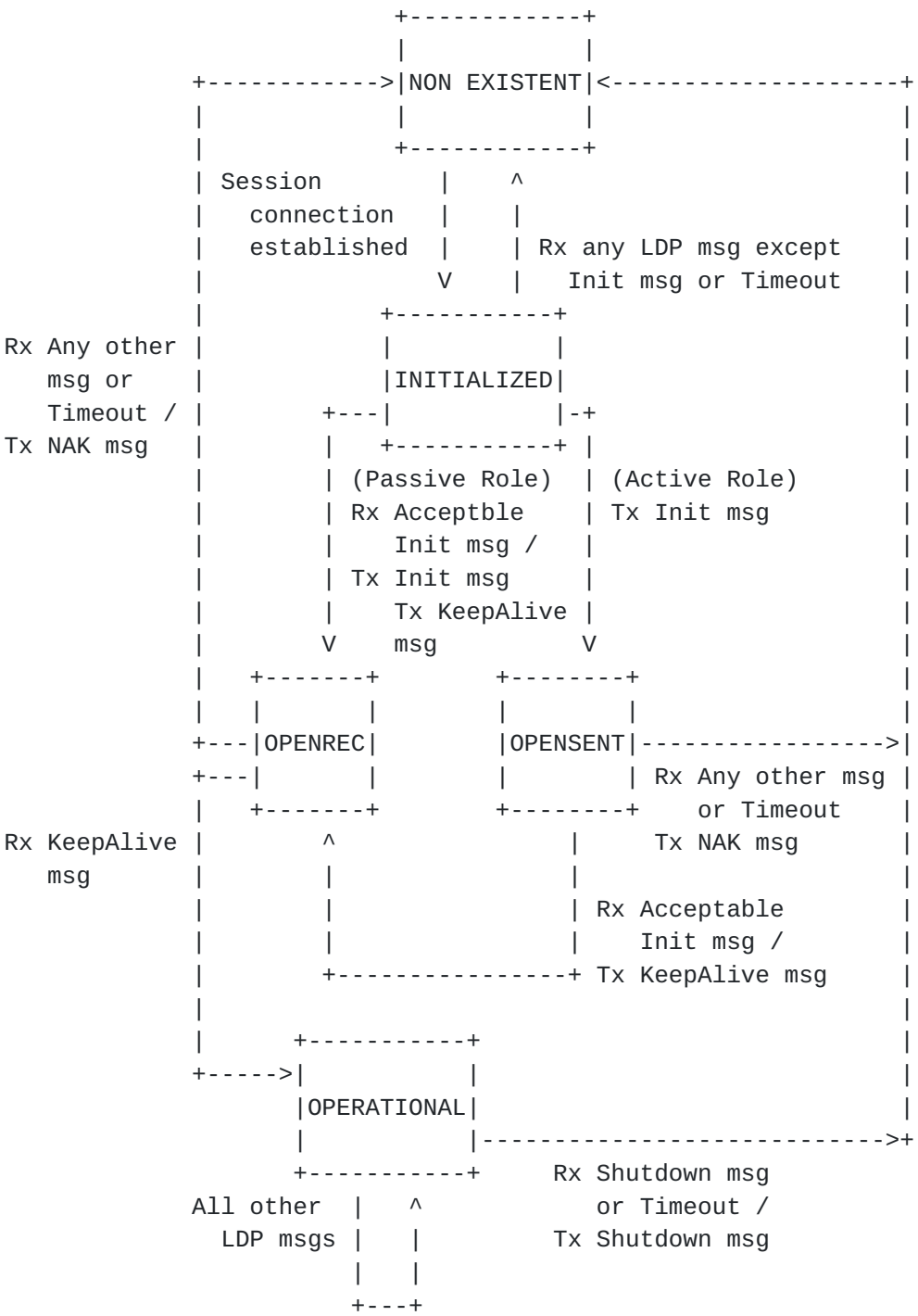
### 2.5.4. Initialization State Machine

It is convenient to describe LDP session negotiation behavior in terms of a state machine. We define the LDP state machine to have five possible states and present the behavior as a state transition table and as a state transition diagram.

Session Initialization State Transition Table

| STATE | EVENT | NEW STATE |
|---|---|---|
| NON EXISTENT | Session TCP connection established established | INITIALIZED |
| INITIALIZED | Transmit Initialization msg (Active Role) | OPENSENT |
| | Receive acceptable Initialization msg (Passive Role ) Action: Transmit Initialization msg and KeepAlive msg | OPENREC |
| | Receive Any other LDP msg Action: Transmit Error Notification msg (NAK) and close transport connection | NON EXISTENT |
| OPENREC | Receive KeepAlive msg | OPERATIONAL |
| | Receive Any other LDP msg Action: Transmit Error Notification msg (NAK) and close transport connection | NON EXISTENT |
| OPENSENT | Receive acceptable Initialization msg Action: Transmit KeepAlive msg | OPENREC |
| | Receive Any other LDP msg Action: Transmit Error Notification msg (NAK) and close transport connection | NON EXISTENT |
| OPERATIONAL | Receive Shutdown msg Action: Transmit Shutdown msg and close transport connection | NON EXISTENT |
| | Receive other LDP msgs | OPERATIONAL |
| | Timeout Action: Transmit Shutdown msg and close transport connection | NON EXISTENT |

Session Initialization State Transition Diagram



### 2.5.5. Maintaining Hello Adjacencies

An LDP session with a peer has one or more Hello adjacencies.

An LDP session has multiple Hello adjacencies when a pair of LSRs is connected by multiple links that share the same label space; for example, multiple PPP links between a pair of routers. In this situation the Hellos an LSR sends on each such link carry the same LDP Identifier.

LDP includes mechanisms to monitor the necessity of an LDP session and its Hello adjacencies.

LDP uses the regular receipt of LDP Discovery Hellos to indicate a peer's intent to use the label space identified by the Hello. An LSR maintains a hold timer with each Hello adjacency which it restarts when it receives a Hello that matches the adjacency. If the timer expires without receipt of a matching Hello from the peer, LDP concludes that the peer no longer wishes to label switch using that label space for that link (or target, in the case of Targeted Hellos) or that the peer has failed. The LSR then deletes the Hello adjacency. When the last Hello adjacency for a LDP session is deleted, the LSR terminates the LDP session by closing the transport connection.

### 2.5.6. Maintaining LDP Sessions

LDP includes mechanisms to monitor the integrity of the LDP session.

LDP uses the regular receipt of LDP PDUs on the session transport connection to monitor the integrity of the session. An LSR maintains a KeepAlive timer for each peer session which it resets whenever it receives an LDP PDU from the session peer. If the KeepAlive timer expires without receipt of an LDP PDU from the peer the LSR concludes that the transport connection is bad or that the peer has failed, and it terminates the LDP session by closing the transport connection.

After an LDP session has been established, an LSR must arrange that its peer receive an LDP PDU from it at least every KeepAlive time period to ensure the peer restarts the session KeepAlive timer. The LSR may send any protocol message to meet this requirement. In circumstances where an LSR has no other information to communicate to its peer, it sends a KeepAlive message.

An LSR may choose to terminate an LDP session with a peer at any time. Should it choose to do so, it informs the peer with a Shutdown message.

### 2.6. Label Distribution and Management

The MPLS architecture [ARCH] allows an LSR to distribute a FEC label binding in response to an explicit request from another LSR. This is known as Downstream On Demand label distribution. It also allows an LSR to distribute label bindings to LSRs that have not explicitly requested them. This is known as Downstream Unsolicited label distribution.

Both of these label distribution techniques may be used in the same network at the same time. However, for any given LDP session, each LSR must be aware of the label distribution method used by its peer in order to avoid situations where one peer using Downstream Unsolicted label distribution assumes its peer is also. See Section "Downstream-on-Demand label Advertisement".

#### 2.6.1. Label Distribution Control Mode

The behavior of the initial setup of LSPs is determined by whether the LSR is operating with independent or ordered LSP control. An LSR may support both types of control as a configurable option.

##### 2.6.1.1. Independent Label Distribution Control

When using independent LSP control, each LSR may advertise label mappings to its neighbors at any time it desires. For example, when operating in independent Downstream-on-Demand mode, an LSR may answer requests for label mappings immediately, without waiting for a label mapping from the next hop. When operating in independent Downstream Unsolicited mode, an LSR may advertise a label mapping for a FEC to its neighbors whenever it is prepared to label-switch that FEC.

A consequence of using independent mode is that an upstream label can be advertised before a downstream label is received. This can result in unlabeled packets being sent to the downstream LSR.

##### 2.6.1.2. Ordered Label Distribution Control

When using LSP ordered control, an LSR may initiate the transmission of a label mapping only for a FEC for which it has a label mapping for the FEC next hop, or for which the LSR is the egress. For each FEC for which the LSR is not the egress and no mapping exists, the LSR MUST wait until a label from a downstream LSR is received before mapping the FEC and passing corresponding labels to upstream LSRs.

An LSR may be an egress for some FECs and a non-egress for others. An LSR may act as an egress LSR, with respect to a particular FEC, under any of the following conditions:

1. The FEC refers to the LSR itself (including one of its directly attached interfaces).

2. The next hop router for the FEC is outside of the Label Switching Network.

3 FEC elements are reachable by crossing a routing domain boundary, such as another area for OSPF summary networks, or another autonomous system for OSPF AS externals and BGP routes [rfc1583] [rfc1771].

### 2.6.2. Label Retention Mode

#### 2.6.2.1. Conservative Label Retention Mode

In Downstream Unsolicited advertisement mode, label mapping advertisements for all routes may be received from all peer LSRs. When using conservative label retention, advertised label mappings are retained only if they will be used to forward packets (i.e., if they are received from a valid next hop according to routing). If operating in Downstream-on-Demand mode, an LSR will request label mappings only from the next hop LSR according to routing. Since Downstream-on-Demand mode is primarily used when label conservation is desired (e.g., an ATM switch with limited cross connect space), it is typically used with the conservative label retention mode.

The main advantage of the conservative mode is that only the labels that are required for the forwarding of data are allocated and maintained. This is particularly important in LSRs where the label space is inherently limited, such as in an ATM switch. A disadvantage of the conservative mode is that if routing changes the next hop for a given destination, a new label must be obtained from the new next hop before labeled packets can be forwarded.

#### 2.6.2.2. Liberal Label Retention Mode

In Downstream Unsolicited advertisement mode, label mapping advertisements for all routes may be received from all LDP peers. When using liberal label retention, every label mappings received from a peer LSR is retained regardless of whether the LSR is the next hop for the advertised mapping. When operating in Downstream-on-Demand mode with liberal label retention, an LSR might choose to request

label mappings for all known prefixes from all peer LSRs. Note, however, that Downstream-on-Demand mode is typically used by devices such as ATM switch-based LSRs for which the conservative approach is recommended.

The main advantage of the liberal label retention mode is that reaction to routing changes can be quick because labels already exist. The main disadvantage of the liberal mode is that unneeded label mappings are distributed and maintained.

### 2.6.3. Label Advertisement Mode

Each interface on an LSR is configured to operate in either Downstream Unsolicited or Downstream-on-Demand advertisement mode. LSRs exchange advertisement modes during initialization. The major difference between Downstream Unsolicited and Downstream-on-Demand modes is in which LSR takes responsibility for initiating mapping requests and mapping advertisements.

## 2.7. LDP Identifiers and Next Hop Addresses

An LSR maintains learned labels in a Label Information Base (LIB). When operating in Downstream Unsolicited mode, the LIB entry for an address prefix associates a collection of (LDP Identifier, label) pairs with the prefix, one such pair for each peer advertising a label for the prefix.

When the next hop for a prefix changes the LSR must retrieve the label advertised by the new next hop from the LIB for use in forwarding. To retrieve the label the LSR must be able to map the next hop address for the prefix to an LDP Identifier.

Similarly, when the LSR learns a label for a prefix from an LDP peer, it must be able to determine whether that peer is currently a next hop for the prefix to determine whether it needs to start using the newly learned label when forwarding packets that match the prefix. To make that decision the LSR must be able to map an LDP Identifier to the peer's addresses to check whether any are a next hop for the prefix.

To enable LSRs to map between a peer LDP identifier and the peer's addresses, LSRs advertise their addresses using LDP Address and Withdraw Address messages.

An LSR sends an Address message to advertise its addresses to a peer. An LSR sends a Withdraw Address message to withdraw previously

advertised addresses from a peer

## 2.8. Loop Detection

Loop detection is a configurable option which provides a mechanism for finding looping LSPs and for preventing Label Request messages from looping in the presence of non-merge capable LSRs.

The mechanism makes use of Path Vector and Hop Count TLVs carried by Label Request and Label Mapping messages. It builds on the following basic properties of these TLVs:

- A Path Vector TLV contains a list of the LSRs that its containing message has traversed. An LSR is identified in a Path Vector list by its unique LSR Identifier (Id), which is the IP address component of its LDP Identifier. When an LSR propagates a message containing a Path Vector TLV it adds its LSR Id to the Path Vector list. An LSR that receives a message with a Path Vector that contains its LSR Id detects that the message has traversed a loop. LDP supports the notion of a maximum allowable Path Vector length; an LSR that detects a Path Vector has reached the maximum length behaves as if the containing message has traversed a loop.

- A Hop Count TLV contains a count of the LSRS that the containing message has traversed. When an LSR propagates a message containing a Hop Count TLV it increments the count. An LSR that detects a Hop Count has reached a configured maximum value behaves as if the containing message has traversed a loop. By convention a count of 0 is interpreted to mean the hop count is unknown. Incrementing an unknown hop count value results in an unknown hop count value (0).

The following paragraphs describes LDP loop detection procedures. In these paragraphs, "MUST" means "MUST if configured for loop detection". The paragraphs specify messages that must carry Path Vector and Hop Count TLVs. Note that the Hop Count TLV and its procedures are used without the Path Vector TLV in situations when loop detection is not configured (see [ATM]).

### 2.8.1. Label Request Message

The use of the Path Vector TLV and Hop Count TLV prevent Label Request messages from looping in environments that include non-merge capable LSRs.

The rules that govern use of the Hop Count TLV in Label Request

messages by LSR R when Loop Detection is enabled are the following:

- The Label Request message MUST include a Hop Count TLV.

- If R is sending the Label Request because it is a FEC ingress, it MUST include a Hop Count TLV with hop count value 1.

- If R is sending the Label Request as a result of having received a Label Request from an upstream LSR, and if the received Label Request contains a Hop Count TLV, R MUST increment the received hop count value by 1 and MUST pass the resulting value in a Hop Count TLV to its next hop along with the Label Request message;

The rules that govern use of the Path Vector TLV in Label Request messages by LSR R when Loop Detection is enabled are the following:

- If R is sending the Label Request because it is a FEC ingress, then if R is non-merge capable, it MUST include a Path Vector TLV of length 1 containing its own LSR Id.

- If R is sending the Label Request as a result of having received a Label Request from an upstream LSR, then if the received Label Request contains a Path Vector TLV or if R is non-merge capable:

    R MUST add its own LSR Id to the Path Vector, and MUST pass the resulting Path Vector to its next hop along with the Label Request message. If the Label Request contains no Path Vector TLV, R MUST include a Path Vector TLV of length 1 containing its own LSR Id.

Note that if R receives a Label Request message for a particular FEC, and R has previously sent a Label Request message for that FEC to its next hop and has not yet received a reply, and if R intends to merge the newly received Label Request with the existing outstanding Label Request, then R does not propagate the Label Request to the next hop.

If R receives a Label Request message from its next hop with a Hop Count TLV which exceeds the configured maximum value, or with a Path Vector TLV containing its own LSR Id or which exceeds the maximum allowable length, then R detects that the Label Reqeust message has traveled in a loop.

When R detects a loop, it MUST send a Loop Detected Notification message to the source of the Label Request message and drop the Label Request message.

### 2.8.2. Label Mapping Message

The use of the Path Vector TLV and Hop Count TLV in the Label Mapping message provide a mechanism to find and terminate looping LSPs. When an LSR receives a Label Mapping message from a next hop, the message is propagated upstream as specified below until an a ingress LSR is reached or a loop is found.

The rules that govern the use of the Hop Count TLV in Label Mapping messages sent by an LSR R when Loop Detection is enabled are the following:

- R MUST include a Hop Count TLV.

- If R is the egress, the hop count value MUST be 1.

- If the Label Mapping message is being sent to propagate a Label Mapping message received from the next hop to an upstream peer, the hop count value MUST be the result of incrementing the hop count value received from the next hop.

- If the Label Mapping message is not being sent to propagate a Label Mapping message, the hop count value MUST be the result of incrementing R's current knowledge of the hop count to the egress. Note that the hop count to the egress will be unknown if R has not received a Label Mapping message from the next hop.

Any Label Mapping message MAY contain a Path Vector TLV. The rules that govern the mandatory use of the Path Vector TLV in Label Mapping messages sent by LSR R when Loop Detection is enabled are the following:

- If R is the egress, the Label Mapping message need not include a Path Vector TLV.

- If R is sending the Label Mapping message to propagate a Label Mapping message received from the next hop to an upstream peer, then:

    o If R is merge capable and if R has not previously sent a Label Mapping message to the upstream peer, then it MUST include a Path Vector TLV.

    o If the received message contains an unknown hop count, then R MUST include a Path Vector TLV.

    o If R has previously sent a Label Mapping message to the upstream peer, then it MUST include a Path Vector TLV if the received message reports an LSP hop count increase, a change in

hop count from unknown to known, or a change from known to unknown.

If the above rules require R include a Path Vector TLV in the Label Mapping message, R computes it as follows:

- o If the received Label Mapping message included a Path Vector, the Path Vector sent upstream MUST be the result of adding R's LSR Id to the received Path Vector.

- o If the received message had no Path Vector, the Path Vector sent upstream MUST be a path vector of length 1 containing R's LSR Id.

- If the Label Mapping message is not being sent to propagate a received message upstream, the Label Mapping message MUST include a Path Vector of length 1 containing R's LSR Id.

If R receives a Label Mapping message from its next hop with a Hop Count TLV which exceeds the configured maximum value, or with a Path Vector TLV containing its own LSR Id or which exceeds the maximum allowable length, then R detects that the corresponding LSP contains a loop.

When R detects a loop, it MUST stop using the label for forwarding, drop the Label Mapping message. and send a Loop Detected Notification message to the source of the Label Mapping message.

### 2.8.3. Discussion

LSRs which are configured for loop detection are NOT expected to store the path vectors as part of the LSP state.

Note that in a network where only non-merge capable LSRs are present, Path Vectors are passed downstream from ingress to egress, and are not passed upstream. Even when merge is supported, Path Vectors need not be passed upstream along an LSP which is known to reach the egress. When an LSR experiences a change of next hop, it need pass Path Vectors upstream only when it cannot tell from the hop count that the change of next hop does not result in a loop.

In the case of ordered label distribution, Label Mapping messages are propagated from egress toward ingress, naturally creating the Path Vector along the way. In the case of independent label distribution, an LSR may originate a Label Mapping message for an FEC before receiving a Label Mapping message from its downstream peer for that FEC. In this case, the subsequent Label Mapping message for the FEC

received from the downstream peer is treated as an update to LSP attributes, and the Label Mapping message must be propagated upstream. Thus, it is recommended that loop detection be configured in conjunction with ordered label distribution, to minimize the number of Label Mapping update messages.

If loop detection is desired in some portion of the network, then it should be turned on in ALL LSRs within that portion of the network, else loop detection will not operate properly.

## 3. Protocol Specification

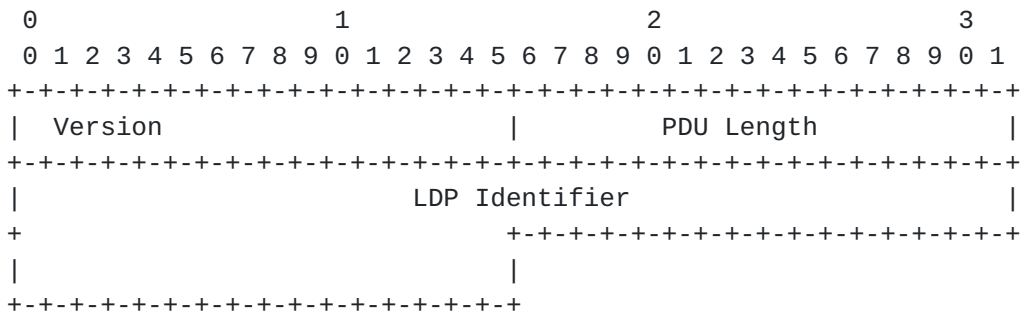
Previous sections that describe LDP operation have discussed scenarios that involve the exchange of messages among LDP peers. This section specifies the message encodings and procedures for processing the messages.

LDP message exchanges are accomplished by sending LDP protocol data units (PDUs) over LDP session TCP connections.

Each LDP PDU can carry one or more LDP messages. Note that the messages in an LDP PDU need not be related to one another. For example, a single PDU could carry a message advertising FEC-label bindings for several FECs, another message requesting label bindings for several other FECs, and a third notification message signaling some event.

### 3.1. LDP PDUs

Each LDP PDU is an LDP header followed by one or more LDP messages. The LDP header is:




Version
Two octet unsigned integer containing the version number of the protocol. This version of the specification specifies LDP protocol version 1.

PDU Length
Two octet integer specifying the total length of this PDU in octets, excluding the Version and PDU Length fields.

The maximum allowable PDU Length is negotiable when an LDP session is initialized. Prior to completion of the negotiation the maximum allowable length is 4096 bytes.

LDP Identifier
Six octet field that uniquely identifies the label space for which this PDU applies. The first four octets encode an IP address assigned to the LSR. This address should be the router-id, also used to identify the LSR in loop detection Path Vectors. The last two octets identify a label space within the LSR. For a platform-wide label space, these should both be zero.

Note that there is no alignment requirement for the first octet of an LDP PDU.

## 3.2. LDP Procedures

LDP defines messages, TLVs and procedures in the following areas:

- Peer discovery;
- Session management;
- Label distribution;
- Notification of errors and advisory information.

The sections that follow describe the message and TLV encodings for these areas and the procedures that apply to them.

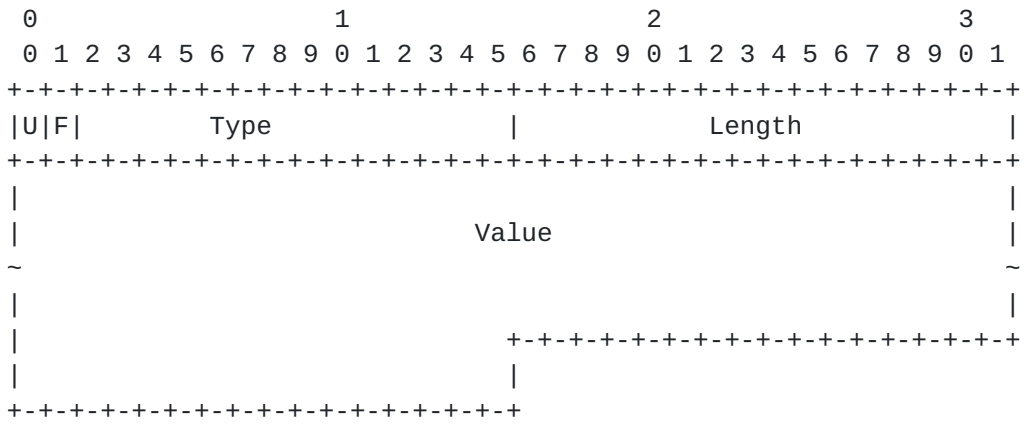
The label distribution procedures are complex and are difficult to describe fully, coherently and unambiguously as a collection of separate message and TLV specifications.

Appendix A, "LDP Label Distribution Procedures", describes the label distribution procedures in terms of label distribution events that may occur at an LSR and how the LSR must respond. Appendix A is the specification of LDP label distribution procedures. If a procedure described elsewhere in this document conflicts with Appendix A, Appendix A specifies LDP behavior.

### 3.3. Type-Length-Value Encoding

LDP uses a Type-Length-Value (TLV) encoding scheme to encode much of the information carried in LDP messages.

An LDP TLV is encoded as a 2 octet field that uses 14 bits to specify a Type and 2 bits to specify behavior when an LSR doesn't recognize the Type, followed by a 2 octet Length Field, followed by a variable length Value field.




U bit
Unknown TLV bit. Upon receipt of an unknown TLV, if U is clear (=0), a notification must be returned to the message originator and the entire message must be ignored; if U is set (=1), the unknown TLV is silently ignored and the rest of the message is processed as if the unknown TLV did not exist.

F bit
Forward unknown TLV bit. This bit applies only when the U bit is set and the LDP message containing the unknown TLV is to be forwarded. If F is clear (=0), the unknown TLV is not forwarded with the containing message; if F is set (=1), the unknown TLV is forwarded with the containing message.

Type
Encodes how the Value field is to be interpreted.

Length
Specifies the length of the Value field in octets.

Value
Octet string of Length octets that encodes information to be interpreted as specified by the Type field.

Note that there is no alignment requirement for the first octect of a TLV.

Note that the Value field itself may contain TLV encodings. That is, TLVs may be nested.

The TLV encoding scheme is very general. In principle, everything appearing in an LDP PDU could be encoded as a TLV. This specification does not use the TLV scheme to its full generality. It is not used where its generality is unnecessary and its use would waste space unnecessarily. These are usually places where the type of a value to be encoded is known, for example by its position in a message or an enclosing TLV, and the length of the value is fixed or readily derivable from the value encoding itself.

Some of the TLVs defined for LDP are similar to one another. For example, there is a Generic Label TLV, an ATM Label TLV, and a Frame Relay TLV; see Sections "Generic Label TLV", "ATM Label TLV", and "Frame Relay TLV".

While it is possible to think about TLVs related in this way in terms of a TLV type that specifies a TLV class and a TLV subtype that specifies a particular kind of TLV within that class, this specification does not formalize the notion of a TLV subtype.

The specification assigns type values for related TLVs, such as the label TLVs, from of a contiguous block in the 16-bit TLV type number space.

Section "TLV Summary" lists the TLVs defined in this version of the protocol and the section in this document that describes each.

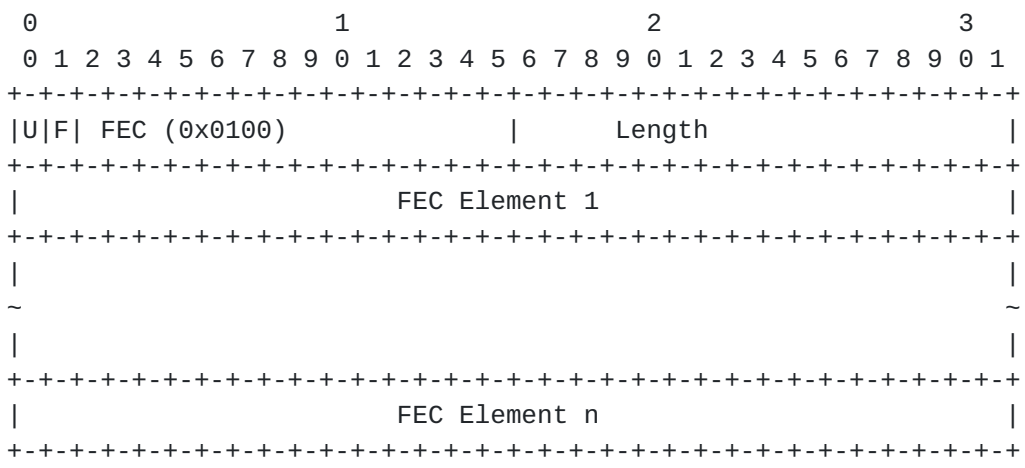
### 3.4. TLV Encodings for Commonly Used Parameters

There are several parameters used by more than one LDP message. The TLV encodings for these commonly used parameters are specified in this section.

#### 3.4.1. FEC TLV

Labels are bound to Forwarding Equivalence Classes (FECs). a FEC is a list of one or more FEC elements. The FEC TLV encodes FEC items.

Its encoding is:




FEC Element 1 to FEC Element n

There are several types of FEC elements; see Section "FECs". The FEC element encoding depends on the type of FEC element.

A FEC Element value is encoded as a 1 octet field that specifies the element type, and a variable length field that is the type-dependent element value. Note that while the representation of the FEC element value is type-dependent, the FEC element encoding itself is one where standard LDP TLV encoding is not used.

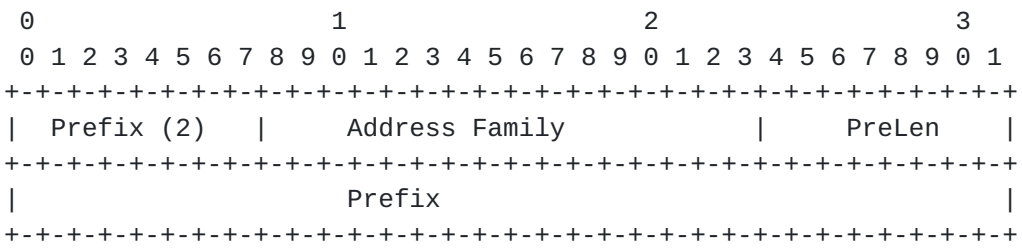
The FEC Element value encoding is:

| FEC Element type name | Type | Value |
|---|---|---|
| Wildcard | 0x01 | No value; i.e., 0 value octets; see below. |
| Prefix | 0x02 | See below. |
| Host Address | 0x03 | 4 octet full IP address; see below. |

Wildcard FEC Element

To be used only in the Label Withdraw and Label Release Messages. Indicates the withdraw/release is to be applied to all FECs associated with the label within the following label TLV. Must be the only FEC Element in the FEC TLV.

Prefix FEC Element value encoding:

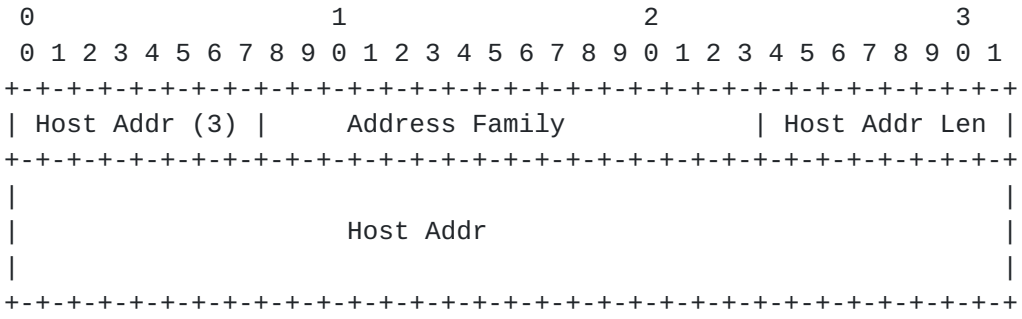



Address Family
Two octet quantity containing a value from ADDRESS FAMILY NUMBERS in [rfc1700] that encodes the address family for the address prefix in the Prefix field.

PreLen
One octet unsigned integer containing the length in bits of the address prefix that follows.

Prefix
An address prefix encoded according to the Address Family field, whose length, in bits, was specified in the PreLen field, padded to a byte boundary.

Host Address FEC Element encoding:




Address Family
Two octet quantity containing a value from ADDRESS FAMILY NUMBERS in [rfc1700] that encodes the address family for the address prefix in the Prefix field.

Host Addr Len
Length of the Host address in octets.

Host Addr
An address encoded according to the Address Family field.

#### 3.4.1.1. FEC Procedures

If in decoding a FEC TLV an LSR encounters a FEC Element type it cannot decode, it should stop decoding the FEC TLV, abort processing the message containing the TLV, and send an Notification message to its LDP peer signaling an error.

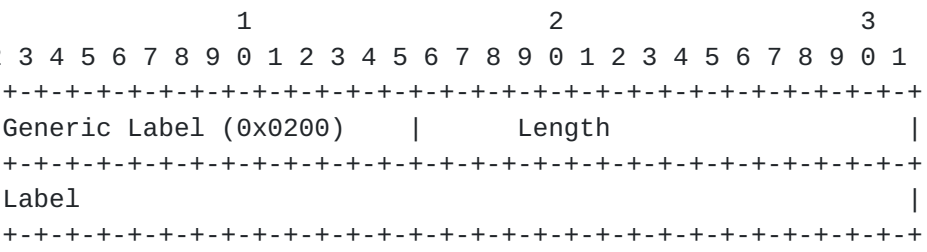
### 3.4.2. Label TLVs

Label TLVs encode labels. Label TLVs are carried by the messages used to advertise, request, release and withdraw label mappings.

There are several different kinds of Label TLVs which can appear in situations that require a Label TLV.

#### 3.4.2.1. Generic Label TLV

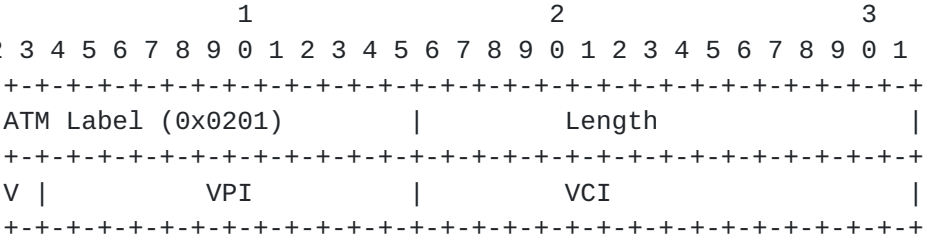
An LSR uses Generic Label TLVs to encode labels for use on links for which label values are independent of the underlying link technology. Examples of such links are PPP and Ethernet.




Label
This is a 20-bit label value as specified in [ENCAP] represented as a 20-bit number in a 4 octet field.

#### 3.4.2.2. ATM Label TLV

An LSR uses ATM Label TLVs to encode labels for use on ATM links.



Res
This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

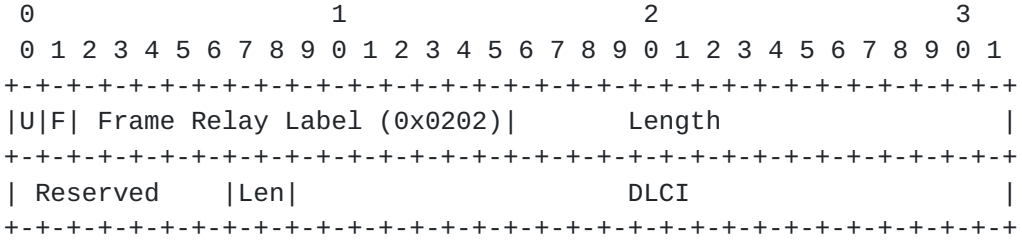
V-bits
Two-bit switching indicator. If V-bits is 00, both the VPI and VCI are significant. If V-bits is 01, only the VPI field is significant. If V-bit is 10, only the VCI is significant.

VPI
Virtual Path Identifier. If VPI is less than 12-bits it should be right justified in this field and preceding bits should be set to 0.

VCI
Virtual Channel Identifier. If the VCI is less than 16- bits, it should be right justified in the field and the preceding bits must be set to 0. If Virtual Path switching is indicated in the V-bits field, then this field must be ignored by the receiver and set to 0 by the sender.

### 3.4.2.3. Frame Relay Label TLV

An LSR uses Frame Relay Label TLVs to encode labels for use on Frame Relay links.




Res
This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

Len
This field specifies the number of bits of the DLCI. The following values are supported:

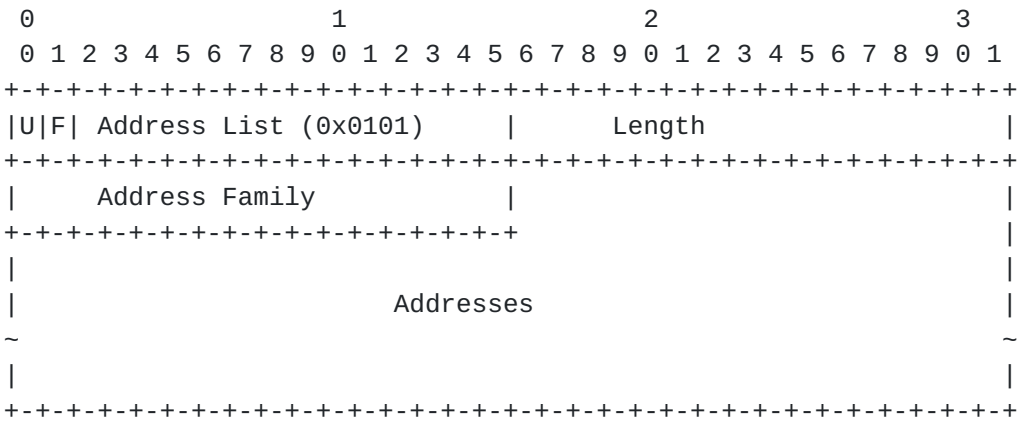
0 = 10 bits DLCI
1 = 17 bits DLCI
2 = 23 bits DLCI

DLCI
The Data Link Connection Identifier. Refer to [FR] for the label values and formats.

### 3.4.3. Address List TLV

The Address List TLV appears in Address and Address Withdraw messages.

Its encoding is:




Address Family
Two octet quantity containing a value from ADDRESS FAMILY NUMBERS in [rfc1700] that encodes the addresses contained in the Addresses field.

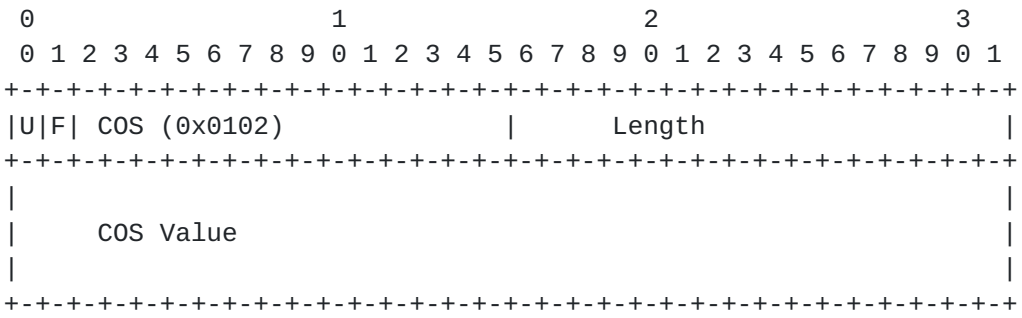
Addresses
A list of addresses from the specified Address Family. The encoding of the individual addresses depends on the Address Family.

The following address encodings are defined by this version of the protocol:

| Address Family | Address Encoding |
|---|---|
| IPv4 | 4 octet full IPv4 address |

### 3.4.4. COS TLV

The COS (Class of Service) TLV may appear as an optional field in messages that request and carry label mappings. It is used to request and advertise (Label, FEC, class of service) bindings. Its encoding is:



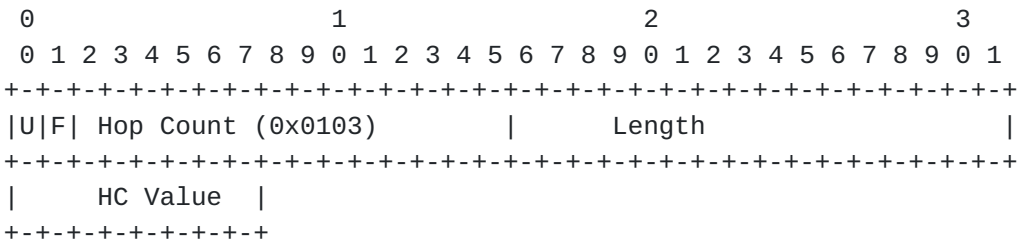

COS Value
The value field for this TLV is a subject for further study.

One possibility is to define a set of CoS values that map to Differentiated Services [DIFFSERV] code points. Other CoS values could be supported in addition to or in place of the Differentiated Services code points.

### 3.4.5. Hop Count TLV

The Hop Count TLV appears as an optional field in messages that set up LSPs. It calculates the number of LSR hops along an LSP as the LSP is being setup.

Note that setup procedures for LSPs that traverse ATM links require use of the Hop Count TLV (see [ATM]).




HC Value
1 octet unsigned integer hop count value.

#### 3.4.5.1. Hop Count Procedures

During setup of an LSP an LSR may receive a Label Mapping or Label Request message for the LSP that contains the Hop Count TLV. If it does, it should record the hop count value. If the LSR then propagates the Label Mapping message for the LSP to an upstream peer or the Label Request message to a downstream peer to continue the LSP setup, it must increment the recorded hop count value and include it in a Hop Count TLV in the message. The first LSR in the LSP should set the hop count value to 1.

By convention a value of 0 indicates an unknown hop count. The result of incrementing an unknown hop count is itself an unknown hop count (0).

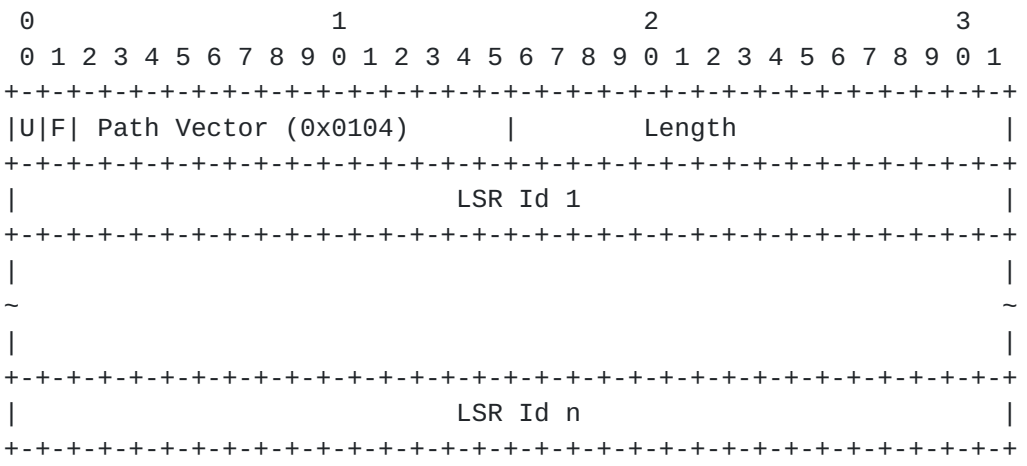
If an LSR receives a message containing a Hop Count TLV, it must check the hop count value to determine whether the hop count has exceeded its configured maximum allowable value. If so, it must behave as if the containing message has traversed a loop by sending a Notification message signaling Loop Detected in reply to the sender of the message.

If Loop Detection is configured, the LSR must follow the procedures specified in Section "Loop Detection".

### 3.4.6. Path Vector TLV

The Path Vector TLV is used with the Hop Count TLV in Label Request and Label Mapping messages to implement the optional LDP loop detection mechanism. See Section "Loop Detection". Its use in the Label Request message records the path of LSRs the request has traversed. Its use in the Label Mapping message records the path of LSRs a label advertisement has traversed to setup an LSP.

Its encoding is:




One or more LSR Ids
A list of router-ids indicating the path of LSRs the message has traversed. Each LSR Id is the IP address (router-id) component of the LDP identifier for the corresponding LSR. This ensures it is unique within the LSR network.

#### 3.4.6.1. Path Vector Procedures

The Path Vector TLV is carried in Label Mapping and Label Request messages when loop detection is configured.

##### 3.4.6.1.1. Label Request Path Vector

Section "Loop Detection" specifies situations when an LSR must include a Path Vector TLV in a Label Request message.

An LSR that receives a Path Vector in a Label Request message must perform the procedures described in Section "Loop Detection".

If the LSR detects a loop, it must reject the Label Request message. The LSR must:

1. Transmit a Notification message to the sending LSR signaling "Loop Detected".

2. Not propagate the Label Reqeust message further.

Note that a Label Request message with Path Vector TLV is forwarded until:

1. A loop is found,

2. The LSP egress is reached,

3. The maximum Path Vector limit or maximum Hop Count limit is reached. This is treated as if a loop had been detected.

#### 3.4.6.1.2. Label Mapping Path Vector

Section "Loop Detection" specifies the situations when an LSR must include a Path Vector TLV in a Label Mapping message.

An LSR that receives a Path Vector in a Label Mapping message must perform the procedures described in Section "Loop Detection".

If the LSR detects a loop, it must reject the Label Mapping message in order to prevent a forwarding loop. The LSR must:

1. Transmit a Notification message to the sending LSR signaling "Loop Detected".

2. Not propagate the message further.

3. Check whether the Label Mapping message is for an existing LSP. If so, the LSR must unsplice any upstream labels which are spliced to the downstream label for the FEC.

Note that a Label Mapping message with a Path Vector TLV is forwarded until:

1. A loop is found,

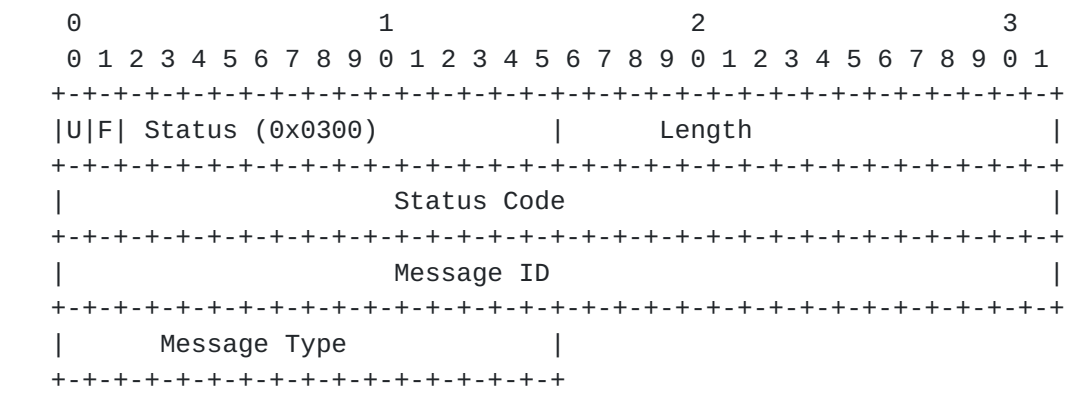
2. An LSP ingress is reached, or

3. The maximum Path Vector or maximum Hop Count limit is reached. This is treated as if a loop had been detected.

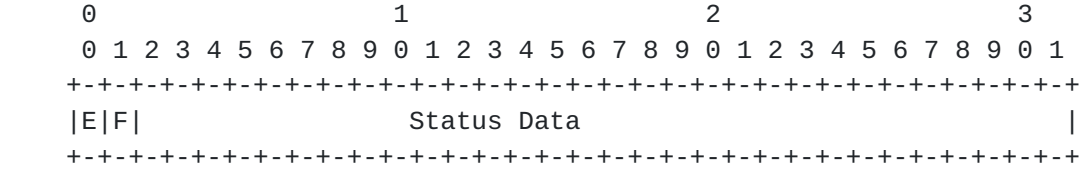
### 3.4.7. Status TLV

Notification messages carry Status TLVs to specify events being signaled.

The encoding for the Status TLV is:




Status Code
32-bit unsigned integer encoding the event being signaled. The structure of a Status Code is:




E bit
Fatal error bit. If set (=1), this is a fatal error notification. If clear (=0), this is an advisory notification.

F bit
Forward bit. If set (=1), the notification should be forwarded to the LSR for the next-hop or previous-hop for the LSP, if any, associated with the event being signaled. If clear (=0), the notification should not be forwarded.

Status Data
30-bit unsigned integer which specifies the status information.

This specification defines Status Codes (32-bit unsigned integers with the above encoding).

A Status Code of 0 signals success.

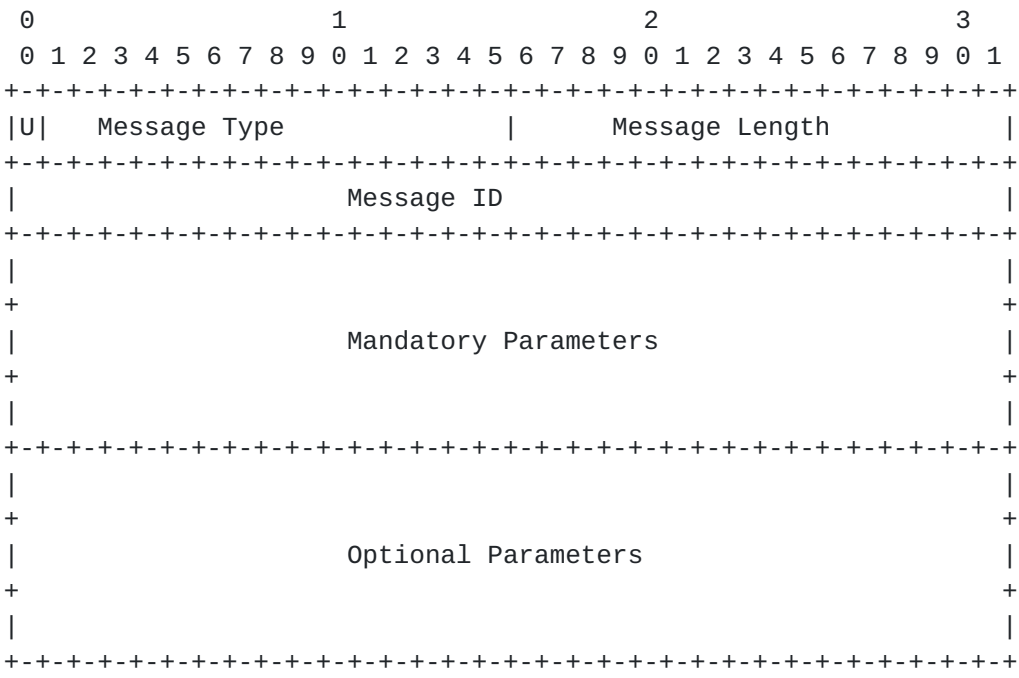
Message ID
If non-zero, 32-bit value that identifies the peer message to which the Status TLV refers. If zero, no specific peer message is being identified.

Message Type
If non-zero, the type of the peer message to which the Status TLV

refers. If zero, the Status TLV does not refer to any specific peer message.

## 3.5. LDP Messages

All LDP messages have the following format:




U bit
Unknown message bit. Upon receipt of an unknown message, if U is clear (=0), a notification is returned to the message originator; if U is set (=1), the unknown message is silently ignored.

Message Type
Identifies the type of message

Message Length
Specifies the cumulative length in octets of the Message ID, Mandatory Parameters, and Optional Parameters.

Message Id
32-bit value used to identify this message. Used by the sending LSR to facilitate identifying notification messages that may apply to this message. An LSR sending a notification message in response to this message should include this Message Id in the notification message; see Section "Notification Message".

Mandatory Parameters
Variable length set of required message parameters. Some messages have no required parameters.

For messages that have required parameters, the required parameters MUST appear in the order specified by the individual message specifications in the sections that follow.

Optional Parameters
Variable length set of optional message parameters. Many messages have no optional parameters.

For messages that have optional parameters, the optional parameters may appear in any order.

Note that there is no alignment requirement for the first octet of an LDP message.

The following message types are defined in this version of LDP:

| Message Name | Section Title |
|---|---|
| Notification | "Notification Message" |
| Hello | "Hello Message" |
| Initialization | "Initialization Message" |
| KeepAlive | "KeepAlive Message" |
| Address | "Address Message" |
| Address Withdraw | "Address Withdraw Message" |
| Label Mapping | "Label Mapping Message" |
| Label Request | "Label Request Message" |
| Label Withdraw | "Label Withdraw Message" |
| Label Release | "Label Release Message" |

The sections that follow specify the encodings and procedures for these messages.

Some of the above messages are related to one another, for example the Label Mapping, Label Request, Label Withdraw, and Label Release messages.

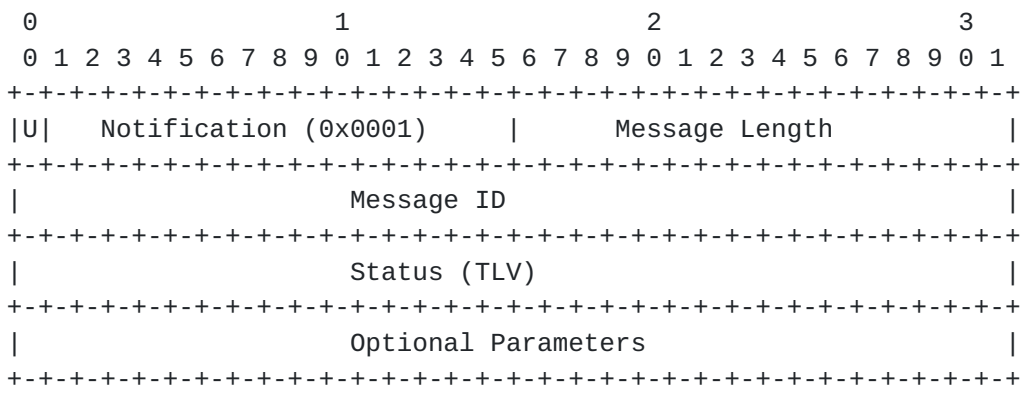
While is possible to think about messages related in this way in terms of a message type that specifies a message class and a message subtype that specifies a particular kind of message within that class, this specification does not formalize the notion of a message subtype.

The specification assigns type values for related messages, such as the label messages, from of a contiguous block in the 16-bit message type number space.

### 3.5.1. Notification Message

An LSR sends a Notification message to inform an LDP peer of a significant event. A Notification message signals a fatal error or provides advisory information such as the outcome of processing an LDP message or the state of the LDP session.

The encoding for the Notification Message is:




Message Id
32-bit value used to identify this message.

Status TLV
Indicates the event being signaled. The encoding for the Status TLV is specified in Section "Status TLV".

Optional Parameters
This variable length field contains 0 or more parameters, each encoded as a TLV. The following Optional Parameters are generic and may appear in any Notification Message:

| Optional Parameter | Type | Length | Value |
|---|---|---|---|
| Extended Status | 0x0301 | 4 | See below |
| Returned PDU | 0x0302 | var | See below |
| Returned Message | 0x0303 | var | See below |

Other Optional Parameters, specific to the particular event being signaled by the Notification Messages may appear. These are

described elsewhere.

Extended Status
The 4 octet value is an Extended Status Code that encodes additional information that supplements the status information contained in the Notification Status Code.

Returned PDU
An LSR uses this parameter to return part of an LDP PDU to the LSR that sent it. The value of this TLV is the PDU header and as much PDU data following the header as appropriate for the condition being signalled by the Notification message.

Returned Message
An LSR uses this parameter to return part of an LDP message to the LSR that sent it. The value of this TLV is the message type and length fields and as much message data following the type and length fields as appropriate for the condition being signalled by the Notification message.

#### 3.5.1.1. Notification Message Procedures

If an LSR encounters a condition requiring it to notify its peer with advisory or error information it sends the peer a Notification message containing a Status TLV that encodes the information and optionally additional TLVs that provide more information about the event.

If the condition is one that is a fatal error the Status Code carried in the notification will indicate that. In this case, after sending the Notification message the LSR should terminate the LDP session by closing the session TCP connection and discard all state associated with the session, including all label-FEC bindings learned via the session.

When an LSR receives a Notification message that carries a Status Code that indicates a fatal error, it should terminate the LDP session immediately by closing the session TCP connection and discard all state associated with the session, including all label-FEC bindings learned via the session.

#### 3.5.1.2. Events Signaled by Notification Messages

It is useful for descriptive purpose to classify events signaled by Notification Messages into the following categories.

#### 3.5.1.2.1. Malformed PDU or Message

Malformed LDP PDUs or Messages that are part of the LDP Discovery mechanism are handled by silently discarding them.

An LDP PDU received on a TCP connection for an LDP session is malformed if:

- The LDP Identifier in the PDU header is unknown to the receiver, or it is known but is not the LDP Identifier associated by the receiver with the LDP session. This is a fatal error signaled by the Bad LDP Identifier Status Code.

- The LDP protocol version is not supported by the receiver, or it is supported but is not the version negotiated for the session during session establishment. This is a fatal error signaled by the Bad Protocol Version Status Code.

- The PDU Length field is too short (< 20) or too long (> maximum PDU length). This is a fatal error signaled by the Bad PDU Length Status Code. Section "Initialization Message" describes how the maximum PDU length for a session is determined.

An LDP Message is malformed if:

- The Message Type is unknown.

  If the Message Type is < 0x8000 (high order bit = 0) it is a fatal error signaled by the Unknown Message Type Status Code.

  If the Message Type is >= 0x8000 (high order bit = 1) it is silently discarded.

- The Message Length is too large, that is, indicates that the message extends beyond the end of the containing LDP PDU. This is a fatal error signaled by the Bad Message Length Status Code.

#### 3.5.1.2.2. Unknown or Malformed TLV

Malformed TLVs contained in LDP messages that are part of the LDP Discovery mechanism are handled by silently discarding the containing message.

A TLV contained in an LDP message received on a TCP connection of an LDP is malformed if:

- The TLV Length is too large, that is, indicates that the TLV extends beyond the end of the containing message. This is a fatal error signaled by the Bad TLV Length Status Code.

- The TLV type is unknown.

  If the TLV type is < 0x8000 (high order bit 0) it is a fatal error signaled by the Unknown TLV Status Code.

  If the TLV type is >= 08000 (high order bit 1) the TLV is silently dropped. Section "Unknown TLV in Known Message Type" elaborates on this behavior.

- The TLV Value is malformed. This occurs when the receiver handles the TLV but cannot decode the TLV Value. This is interpreted as indicative of a bug in either the sending or receiving LSR. It is a fatal error signaled by the Malformed TLV Value Status Code.

#### 3.5.1.2.3. Session Hold Timer Expiration

This is a fatal error signaled by the Hold Timer Expired Status Code.

#### 3.5.1.2.4. Unilateral Session Shutdown

This is a fatal event signaled by the Shutdown Status Code. The Notification Message may optionally include an Extended Status TLV to provide a reason for the Shutdown. The sending LSR terminates the session immediately after sending the Notification.

#### 3.5.1.2.5. Initialization Message Events

The session initialization negotiation (see Section "Session Initialization") may fail if the session parameters received in the Initialization Message are unacceptable. This is a fatal error. The specific Status Code depends on the parameter deemed unacceptable, and is defined in Sections "Initialization Message".

#### 3.5.1.2.6. Events Resulting From Other Messages

Messages other than the Initialization message may result in events that must be signaled to LDP peers via Notification Messages. These events and the Status Codes used in the Notification Messages to signal them are described in the sections that describe these messages.

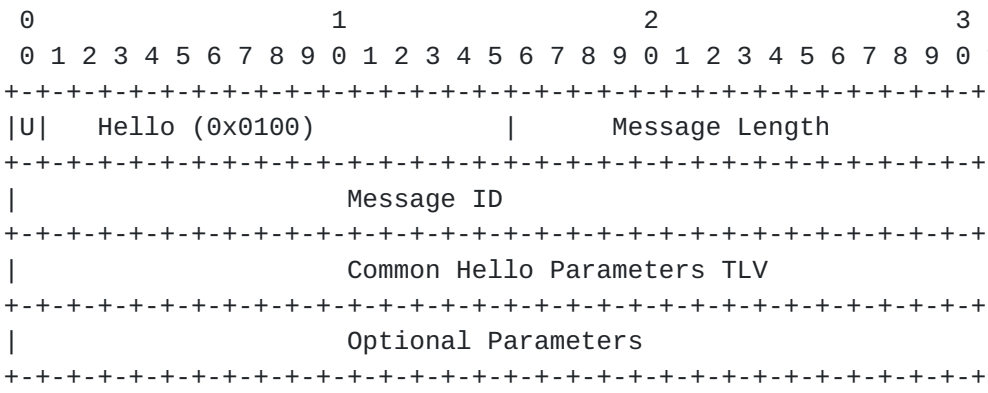
#### 3.5.1.2.7. Miscellaneous Events

These are events that fall into none of the categories above. There are no miscellaneous events defined in this version of the protocol.

### 3.5.2. Hello Message

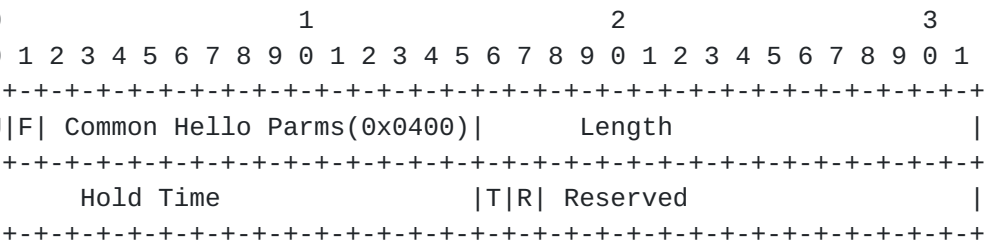
LDP Hello Messages are exchanged as part of the LDP Discovery Mechanism; see Section "LDP Discovery".

The encoding for the Hello Message is:




Message Id
32-bit value used to identify this message.

Common Hello Parameters TLV
Specifies parameters common to all Hello messages. The encoding for the Common Hello Parameters TLV is:




Hold Time,
Hello hold time in seconds. An LSR maintains a record of Hellos received from potential peers (see Section "Hello Message Procedures"). Hello Hold Time specifies the time the sending LSR will maintain its record of Hellos from the receiving LSR without receipt of another Hello.

A pair of LSRs negotiates the hold times they use for Hellos from each other. Each proposes a hold time. The hold time used is the minimum of the hold times proposed in their Hellos.

A value of 0 means use the default. There are interface type specific defaults for Link Hellos as well as a default for Targeted Hellos. A value of 0xfffff means infinite.

T, Targeted Hello
A value of 1 specifies that this Hello is a Targeted Hello. A value of 0 specifies that this Hello is a Link Hello.

R, Request Send Targeted Hellos
A value of 1 requests the receiver to send periodic Targeted Hellos to the source of this Hello. A value of 0 makes no request.

An LSR initiating Extended Discovery sets R to 1. If R is 1, the receiving LSR checks whether it has been configured to send Targeted Hellos to the Hello source in response to Hellos with this request. If not, it ignores the request. If so, it initiates periodic transmission of Targeted Hellos to the Hello source.

Reserved
This field is reserved. It must be set to zero on transmission and ignored on receipt.

Optional Parameters
This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters defined by this version of the protocol are

| Optional Parameter | Type | Length | Value |
|---|---|---|---|
| Transport Address | 0x0401 | 4 | See below |
| Configuration Sequence Number | 0x0402 | 4 | See below |

Transport Address
Specifies the IPv4 address to be used for the sending LSR when opening the LDP session TCP connection. If this optional TLV is not present the IPv4 source address for the UDP packet carrying the Hello should be used.

Configuration Sequence Number
Specifies a 4 octet unsigned configuration sequence number that identifies the configuration state of the sending LSR. Used by the receiving LSR to detect configuration changes on the

sending LSR.

#### 3.5.2.1. Hello Message Procedures

An LSR receiving Hellos from another LSR maintains a Hello adjacency corresponding to the Hellos. The LSR maintains a hold timer with the Hello adjacency which it restarts whenever it receives a Hello that matches the Hello adjacency. If the hold timer for a Hello adjacency expires the LSR discards the Hello adjacency: see sections "Maintaining Hello Adjacencies" and "Maintaining LDP Sessions".

We recommend that the interval between Hello transmissions be at most one third of the Hello hold time.

An LSR processes a received LDP Hello as follows:

1. The LSR checks whether the Hello is acceptable. The criteria for determining whether a Hello is acceptable are implementation dependent (see below for example criteria).

2. If the Hello is not acceptable, the LSR ignores it.

3. If the Hello is acceptable, the LSR checks whether it has a Hello adjacency for the Hello source. If so, it restarts the hold timer for the Hello adjacency. If not it creates a Hello adjacency for the Hello source and starts its hold timer.

4. If the Hello carries any optional TLVs the LSR processes them (see below).

5. Finally, if the LSR has no LDP session for the label space specified by the LDP identifier in the PDU header for the Hello, it follows the procedures of Section "LDP Session Establishment".

The following are examples of acceptability criteria for Link and Targeted Hellos:

A Link Hello is acceptable if the interface on which it was received has been configured for label switching.

A Targeted Hello from IP source address a.b.c.d is acceptable if either:

- The LSR has been configured to accept Targeted Hellos, or

- The LSR has been configured to send Targeted Hellos to a.b.c.d.

The following describes how an LSR processes Hello optional TLVs:

Transport Address
The LSR associates the specified transport address with the Hello adjacency.

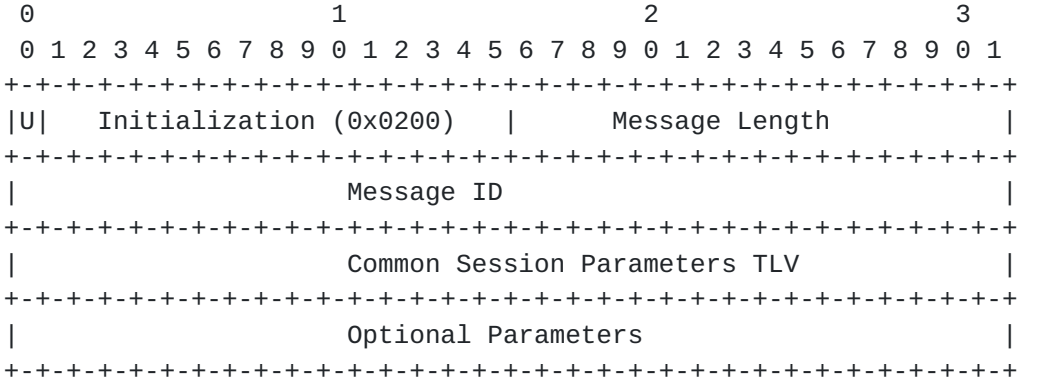
Configuration Sequence Number
The Configuration Sequence Number optional parameter is used by the sending LSR to signal configuration changes to the receiving LSR. When a receiving LSR playing the active role in LDP session establishment detects a change in the sending LSR configuration, it may clear the session setup backoff delay, if any, associated with the sending LSR (see Section "Session Initialization").

A sending LSR using this optional parameter is responsible for maintaining the configuration sequence number it transmits in Hello messages. Whenever there is a configuration change on the sending LSR, it increments the configuration sequence number.

### 3.5.3. Initialization Message

The LDP Initialization Message is exchanged as part of the LDP session establishment procedure; see Section "LDP Session Establishment".

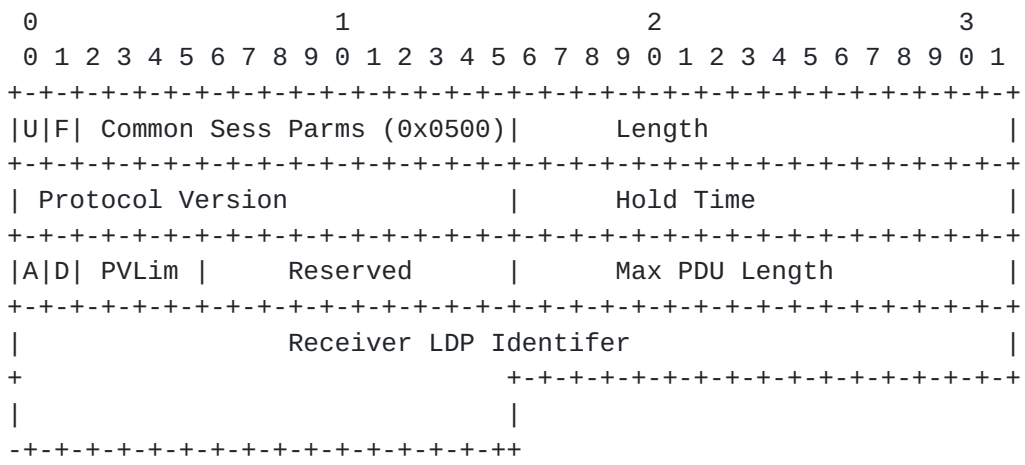
The encoding for the Initialization Message is:



Message Id
32-bit value used to identify this message.

Common Session Parameters TLV
Specifies values proposed by the sending LSR for parameters common to all LDP sessions.

The encoding for the Common Session Parameters TLV is:




Protocol Version
Two octet unsigned integer containing the version number of the protocol. This version of the specification specifies LDP protocol version 1.

Hold Time
Two octet unsigned non zero integer that indicates the number of seconds that the sending LSR proposes for the value of the KeepAlive Interval. The receiving LSR MUST calculate the value of the KeepAlive Timer by using the smaller of its proposed Hold Time and the Hold Time received in the PDU. The value chosen for Hold Time indicates the maximum number of seconds that may elapse between the receipt of successive PDUs from the LDP peer. The KeepAlive Timer is reset each time a PDU arrives.

A, Label Advertisement Discipline
Indicates the type of Label advertisement. A value of 0 means Downstream Unsolicited advertisement; a value of 1 means Downstream On Demand.

If one LSR proposes Downstream Unsolicted and the other proposes Downstream on Demand, the rules for resolving this difference is:

- If the session is for a label-controlled ATM link or a label-controlled Frame Relay link, then Downstream on Demand must be used.

- Otherwise, Downstream Unsolicted must be used.

If the label advertisement discipline determined in this way is unacceptable to an LSR, it must send a Session Rejected/Parameters Advertisement Mode Notification message in response to the Initialization message and not establish the session.

D, Loop Detection
Indicates whether loop detection based on path vectors is enabled. A value of 0 means loop detection is disabled; a value of 1 means that loop detection is enabled.

PVLim, Path Vector Limit
The configured maximum path vector length. Must be 0 if loop detection is disabled (D = 0). If the loop detection procedures would require the LSR to send a path vector that exceeds this limit, the LSR will behave as if a loop had been detected for the FEC in question.

When Loop Detection is enabled in a portion of a network, it is recommended that all LSRs in that portion of the network be configured with the same path vector limit. Although knowledege of a peer's path vector limit will not change an LSR's behavior, it does enable the LSR to alert an operator to a possible misconfiguration.

Reserved
This field is reserved. It must be set to zero on transmission and ignored on receipt.

Max PDU Length
Two octet unsigned integer that proposes the maximum allowable length for LDP PDUs for the session. A value of 255 or less specifies the default maximum length of 4096 octets.

The receiving LSR MUST calculate the maximum PDU length for the session by using the smaller of its and its peer's proposals for Max PDU Length. The default maximum PDU length applies before session initialization completes.

If the maximum PDU length determined this way is unacceptable to an LSR, it must send a Session Rejected/Parameters Max PDU Length Notification message in response to the Initialization

message and not establish the session.

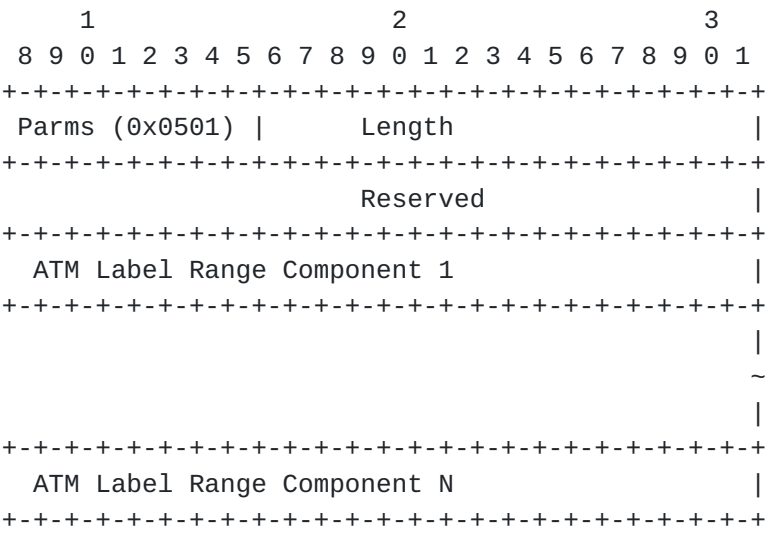
Receiver LDP Identifer
Identifies the receiver's label space. This LDP Identifier, together with the sender's LDP Identifier in the PDU header enables the receiver to match the Initialization message with one of its Hello adjacencies; see Section "Hello Message Procedures".

If there is no matching Hello adjacency, the LSR must send a Session Rejected/No Hello Notification message in response to the Initialization message and not establish the session.

Optional Parameters
This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters are:

| Optional Parameter | Type | Length | Value |
|---|---|---|---|
| ATM Session Parameters | 0x0501 | var | See below |
| Frame Relay Session Parameters | 0x0502 | var | See below |

ATM Session Parameters
Used when an LDP session manages label exchange for an ATM link to specify ATM-specific session parameters.




M, ATM Merge Capabilities
Specifies the merge capabilities of an ATM switch. The following values are supported in this version of the specification:

| Value | Meaning |
|---|---|
| 0 | Merge not supported |
| 1 | VP Merge supported |
| 2 | VC Merge supported |
| 3 | VP & VC Merge supported |

If the merge capabilities of the LSRs differ, then:

- Non-merge and VC-merge LSRs may freely interoperate.

- The interoperability of VP-merge-capable switches with non-VPN-merge-capable switches is a subject for future study.

Note that if VP merge is used, it is the responsibility of the ingress node to ensure that the chosen VCI is unique within the LSR domain.

N, Number of label range components
Specifies the number of ATM Label Range Components included in the TLV.

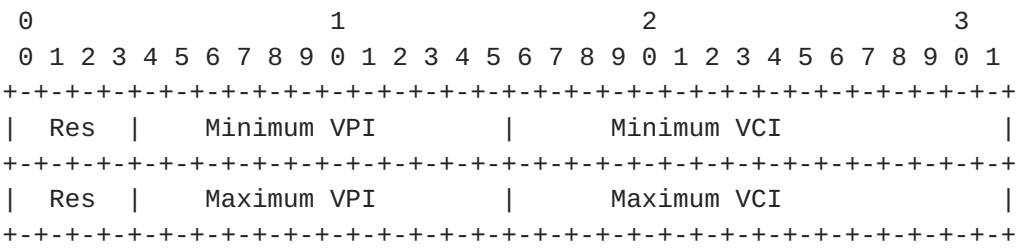
E, ATM Null Encapsulation
A value of 1 specifies specifies that the LSR supports the null encapsulation of [rfc1483] for its data VCs on the ATM link managed by the LDP session. In this case IP packets are carried directly inside AAL5 frames. A value of 0 specifies that the null encapsulation is not supported.

Reserved
This field is reserved. It must be set to zero on transmission and ignored on receipt.

One or more ATM Label Range Components
A list of ATM Label Range Components which together specify the Label range supported by the transmitting LSR.

A receiving LSR MUST calculate the intersection between the received range and its own supported label range. The intersection is the range in which the LSR may allocate and accept labels. LSRs MUST NOT establish a session with neighbors for which the intersection of ranges is NULL. In this case, the LSR must send a Session Rejected/Parameters Label Range Notification message in response to the Initialization message and not establish the session.

The encoding for an ATM Label Range Component is:




Res
This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

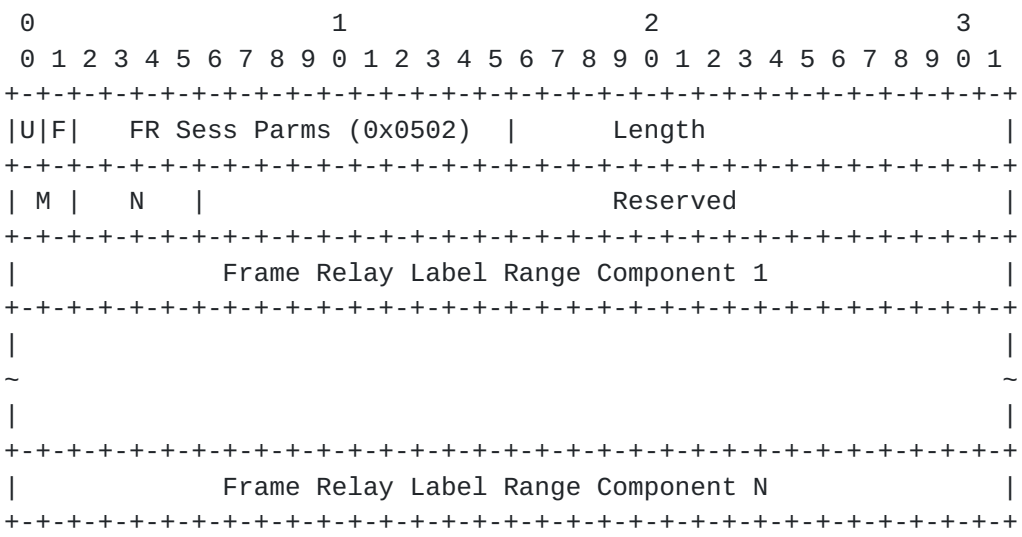
Minimum VPI (12 bits)
This 12 bit field specifies the lower bound of a block of Virtual Path Identifiers that is supported on the originating switch. If the VPI is less than 12-bits it should be right justified in this field and preceding bits should be set to 0.

Minimum VCI (16 bits)
This 16 bit field specifies the lower bound of a block of Virtual Connection Identifiers that is supported on the originating switch. If the VCI is less than 16-bits it should be right justified in this field and preceding bits should be set to 0.

Maximum VPI (12 bits)
This 12 bit field specifies the upper bound of a block of Virtual Path Identifiers that is supported on the originating switch. If the VPI is less than 12-bits it should be right justified in this field and preceding bits should be set to 0.

Maximum VCI (16 bits)
This 16 bit field specifies the upper bound of a block of Virtual Connection Identifiers that is supported on the originating switch. If the VCI is less than 16-bits it should be right justified in this field and preceding bits should be set to 0.

Frame Relay Session Parameters
Used when an LDP session manages label exchange for a Frame Relay link to specify Frame Relay-specific session parameters.




M, Frame Relay Merge Capabilities
Specifies the merge capabilities of a Frame Relay switch. The following values are supported in this version of the specification:

| Value | Meaning |
|---|---|
| 0 | Merge not supported |
| 1 | Merge supported |

Non-merge and merge Frame Relay LSRs may freely interoperate.

N, Number of label range components
Specifies the number of Frame Relay Label Range Components included in the TLV.

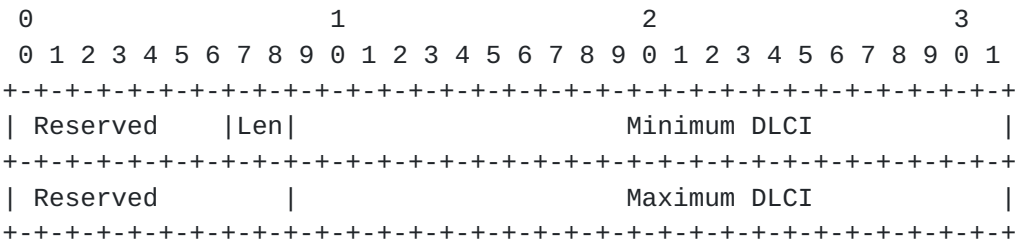
Reserved
This field is reserved. It must be set to zero on transmission and ignored on receipt.

One or more Frame Relay Label Range Components
A list of Frame Relay Label Range Components which together specify the Label range supported by the transmitting LSR.

A receiving LSR MUST calculate the intersection between the received range and its own supported label range. The intersection is the range in which the LSR may allocate and accept labels. LSRs MUST NOT establish a session with neighbors for which the intersection of ranges is NULL. In this case, the LSR must send a Session Rejected/Parameters Label Range Notification message in response to the Initialization message and

not establish the session.

The encoding for a Frame Relay Label Range Component is:




Reserved
This field is reserved. It must be set to zero on transmission and ignored on receipt.

Len
This field specifies the number of bits of the DLCI. The following values are supported:

| Len | DLCI bits |
|---|---|
| 0 | 10 |
| 1 | 17 |
| 2 | 23 |

Minimum DLCI
This 23-bit vield specifies the lower bound of a block of Data Link Connection Identifiers (DLCIs) that is supported on the originating switch. The DLCI should be right justified in this field and unused bits should be set to 0.

Maximum DLCI
This 23-bit vield specifies the upper bound of a block of Data Link Connection Identifiers (DLCIs) that is supported on the originating switch. The DLCI should be right justified in this field and unused bits should be set to 0.

Note that there is no Generic Session Parameters TLV for sessions which advertise Generic Labels.

#### 3.5.3.1. Initialization Message Procedures

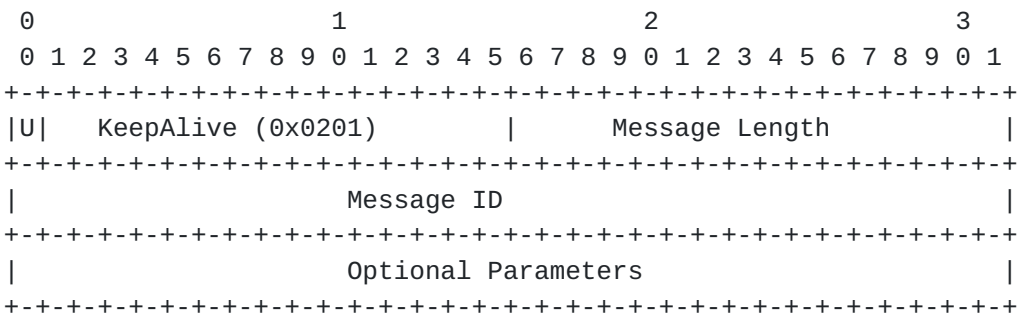
See Section "LDP Session Establishment" and particularly Section "Session Initialization" for general procedures for handling the

Initialization Message.

### 3.5.4. KeepAlive Message

An LSR sends KeepAlive Messages as part of a mechanism that monitors the integrity of the LDP session transport connection.

The encoding for the KeepAlive Message is:




Message Id
32-bit value used to identify this message.

Optional Parameters
No optional parameters are defined for the KeepAlive message.

#### 3.5.4.1. KeepAlive Message Procedures

The Hold Timer mechanism described in Section "Maintaining LDP Sessions" resets a session hold timer every time an LDP PDU is received. The KeepAlive Message is provided to allow reset of the Hold Timer in circumstances where an LSR has no other information to communicate to an LDP peer.

An LSR must arrange that its peer receive an LDP Message from it at least every Hold Time period. Any LDP protocol message will do but, in circumstances where no other LDP protocol messages have been sent within the period, a KeepAlive message must be sent.

### 3.5.5. Address Message

An LSR sends the Address Message to an LDP peer to advertise its interface addresses.

The encoding for the Address Message is:


Message Id
  32-bit value used to identify this message.

Address List TLV
  The list of interface addresses being advertised by the sending LSR. The encoding for the Address List TLV is specified in Section "Address List TLV".

Optional Parameters
  No optional parameters are defined for the Address message.

#### 3.5.5.1. Address Message Procedures

An LSR that receives an Address Message message uses the addresses it learns to maintain a database for mapping between peer LDP Identifiers and next hop addresses; see Section "LDP Identifiers and Next Hop Addresses".

When a new LDP session is initialized and before sending Label Mapping or Label Request messages an LSR should advertise its interface addresses with one or more Address messages.

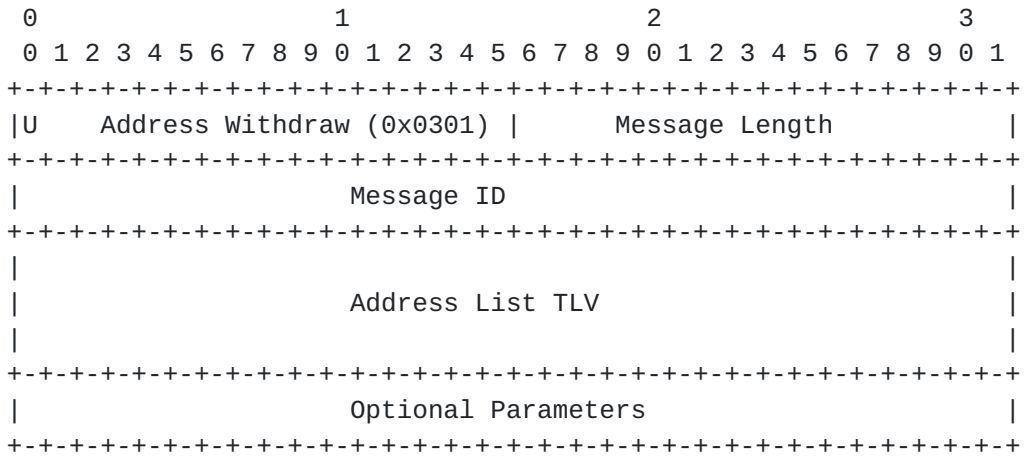
Whenever an LSR "activates" a new interface address, it should advertise the new address with an Address message.

Whenever an LSR "de-activates" a previously advertised address, it should withdraw the address with an Address Withdraw message; see Section "Address Withdraw Message".

### 3.5.6. Address Withdraw Message

An LSR sends the Address Message to an LDP peer to withdraw previously advertised interface addresses.

The encoding for the Address Withdraw Message is:




Message Id
32-bit value used to identify this message.

Address list TLV
The list of interface addresses being withdrawn by the sending LSR. The encoding for the Address list TLV is specified in Section "Address List TLV".

Optional Parameters
No optional parameters are defined for the Address Withdraw message.

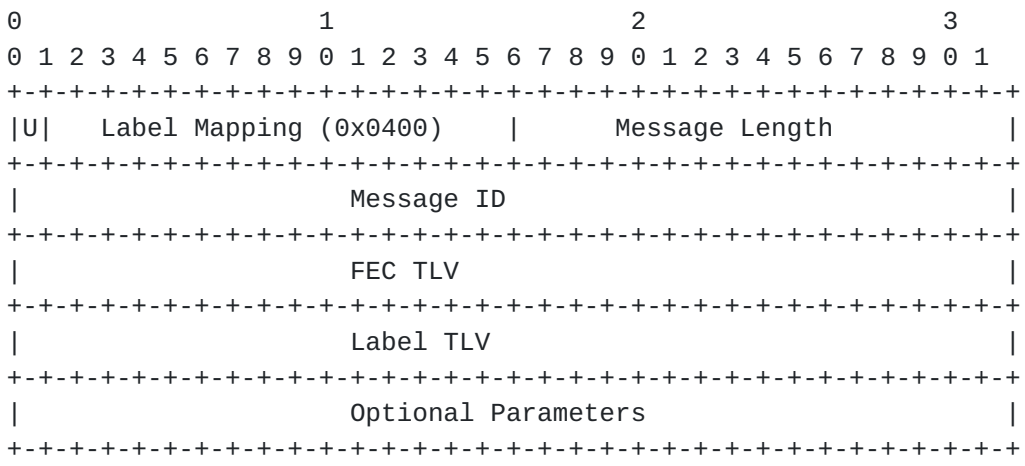
#### 3.5.6.1. Address Withdraw Message Procedures

See Section "Address Message Procedures"

### 3.5.7. Label Mapping Message

An LSR sends a Label Mapping message to an LDP peer to advertise FEC-label bindings to the peer.

The encoding for the Label Mapping Message is:




Message Id
  32-bit value used to identify this message.

FEC TLV
  Specifies the FEC component of the FEC-Label mapping being advertised. See Section "FEC TLV" for encoding.

Label TLV
  Specifies the Label component of the FEC-Label mapping. See Section "Label TLV" for encoding.

Optional Parameters
  This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters are:

| Optional Parameter | Length | Value |
|---|---|---|
| Label Request Message Id | 4 | See below |
| COS TLV | 1 | See below |
| Hop Count TLV | 1 | See below |
| Path Vector TLV | variable | See below |

  The encodings for the COS, Hop Count, and Path Vector TLVs can be found in Section "TLV Encodings for Commonly Used Parameters".

    Label Request Message Id
      If this Label Mapping message is a response to a Label Request message that carried the Return Message Id optional parameter (see Section "Label Request Message") the Label Mapping message must include the Request Message Id optional parameter. The value of this optional parameter is the Message Id of the corresponding Label Request Message.

COS
Specifies the Class of Service (COS) to be associated with the FEC-Label mapping. If not present, the LSR should use its default COS for IP packets as the COS.

Hop Count
Specifies the running total of the number of LSR hops along the LSP being setup by the Label Message. Section "Hop Count Procedures" describes how to handle this TLV.

Path Vector
Specifies the LSRs along the LSP being setup by the Label Message. Section "Path Vector Procedures" describes how to handle this TLV.

#### 3.5.7.1. Label Mapping Message Procedures

The Mapping message is used by an LSR to distribute a label mapping for a FEC to an LDP peer. If an LSR distributes a mapping for a FEC to multiple LDP peers, it is a local matter whether it maps a single label to the FEC, and distributes that mapping to all its peers, or whether it uses a different mapping for each of its peers.

An LSR is responsible for the consistency of the label map- pings it has distributed, and that its peers have these mappings.

See Appendx A "LDP Label Distribution Procedures" for more details.

##### 3.5.7.1.1. Independent Control Mapping

If an LSR is configured for independent control, a mapping message is transmitted by the LSR upon any of the following conditions:

1. The LSR recognizes a new FEC via the forwarding table, and the label advertisement mode is Downstream Unsolicited advertisement.

2. The LSR receives a Request message from an upstream peer for a FEC present in the LSR's forwarding table.

3. The next hop for a FEC changes to another LDP peer, and loop detection is configured.

4. The attributes of a mapping change.

5. The receipt of a mapping from the downstream next hop AND
   a) no upstream mapping has been created OR
   b) loop detection is configured OR
   c) the attributes of the mapping have changed.

#### 3.5.7.1.2. Ordered Control Mapping

If an LSR is doing ordered control, a Mapping message is transmitted by downstream LSRs upon any of the following conditions:

1. The LSR recognizes a new FEC via the forwarding table, and is the egress for that FEC.

2. The LSR receives a Request message from an upstream peer for a FEC present in the LSR's forwarding table, and the LSR is the egress for that FEC OR has a downstream mapping for that FEC.

3. The next hop for a FEC changes to another LDP peer, and loop detection is configured.

4. The attributes of a mapping change.

5. The receipt of a mapping from the downstream next hop AND
   a) no upstream mapping has been created OR
   b) loop detection is configured OR
   c) the attributes of the mapping have changed.

#### 3.5.7.1.3. Downstream-on-Demand Label Advertisement

In general, the upstream LSR is responsible for requesting label mappings when operating in Downstream-on-Demand mode. However, unless some rules are followed, it is possible for neighboring LSRs with different advertisement modes to get into a livelock situation where everything is functioning properly, but no labels are distributed. For example, consider two LSRs Ru and Rd where Ru is the upstream LSR and Rd is the downstream LSR for a particular FEC. In this example, Ru is using Downstream Unsolicited advertisement mode and Rd is using Downstream-on-Demand mode. In this case, Rd may assume that Ru will request a label mapping when it wants one and Ru may assume that Rd will advertise a label if it wants Ru to use one. If Rd and Ru operate as suggested, no labels will be distributed from Rd to Ru.

This livelock situation can be avoided if the following rule is observed: an LSR operating in Downstream-on-Demand mode should not be

expected to send unsolicited mapping advertisements. Therefore, if the downstream LSR is operating in Downstream-on-Demand mode, the upstream LSR is responsible for requesting label mappings as needed.

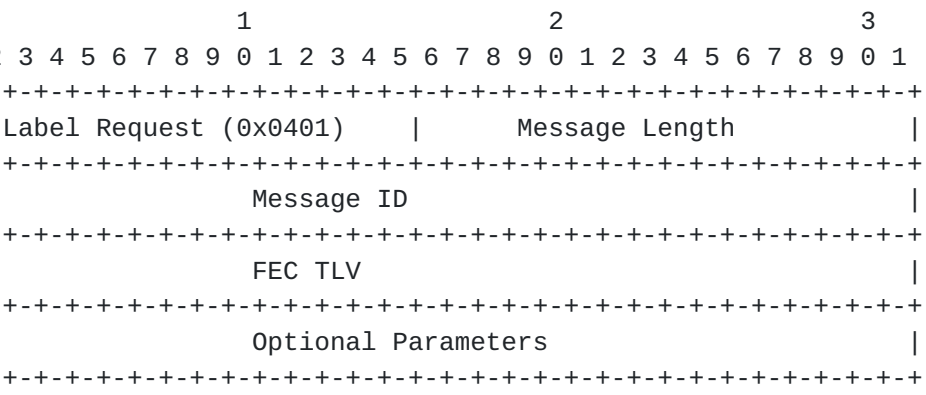
#### 3.5.7.1.4. Downstream Unsolicited Label Advertisement

In general, the downstream LSR is responsible for advertising a label mapping when it wants an upstream LSR to use the label. An upstream LSR may issue a mapping request if it so desires.

### 3.5.8. Label Request Message

An LSR sends the Label Request Message to an LDP peer to request a binding (mapping) for a FEC.

The encoding for the Label Request Message is:




Message Id
32-bit value used to identify this message.

FEC TLV
The FEC for which a label is being requested. See Section "FEC TLV" for encoding.

Optional Parameters
This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters are:

| Optional Parameter | Length | Value |
|---|---|---|
| Return Message Id | 0 | See below |
| COS TLV | 1 | See below |
| Hop Count TLV | 1 | See below |

| | | |
|---|---|---|
| Path Vector TLV | variable | See below |

The encodings for the COS, Hop Count, and Path Vector TLVs can be found in Section "TLV Encodings for Commonly Used Parameters".

Return Message Id
Requests the LDP peer include the Message Id of this Label Request message in its Label Mapping message response. If an LDP peer receives a Label Request message with the Return Message Id optional parameter, its Label Mapping message response must contain a Label Request Message Id optional parameter with the Message Id of the Label Request message. See Section "Label Mapping Message".

COS
Specifies the Class of Service (COS) to be associated with the requested FEC-Label mapping. If not present, the LSR should use its default COS for IP packets as the COS.

Hop Count
Specifies the running total of the number of LSR hops along the LSP being setup by the Label Request Message. Section "Hop Count Procedures" describes how to handle this TLV.

Path Vector
Specifies the LSRs along the LSR being setup by the Label Request Message. Section "Path Vector Procedures" describes how to handle this TLV.

#### 3.5.8.1. Label Request Message Procedures

The Request message is used by an upstream LSR to explicitly request that the downstream LSR assign and advertise a label for a FEC.

An LSR may transmit a Request message under any of the following conditions:

1. The LSR recognizes a new FEC via the forwarding table, and the next hop is an LDP peer, and the LSR doesn't already have a mapping from the next hop for the given FEC.

2. The next hop to the FEC changes, and the LSR doesn't already have a mapping from that next hop for the given FEC.

3. The LSR receives a Label Request for a FEC from an upstream LDP peer, the FEC next hop is an LDP peer, and the LSR doesn't already have a mapping from the next hop.

The receiving LSR should respond to a Label Request message with a Label Mapping for the requested label or with a Notification message indicating why it cannot satisfy the request.

This version of the protocol defines the following Status Codes for the Notification message that signals a request cannot be satisfied:

No Route
The FEC for which a label was requested is for a Prefix FEC Element, and the LSR does not have a route for that prefix.

No Label Resources
The LSR cannot provide a label because of resource limitations. When resources become available the LSR must notify the requesting LSR by sending a Notification message with the Label Resources Available Status Code.

An LSR that receives a No Label Resources response to a Label Request message must not issue further Label Request messages until it receives a Notification message with the Label Resources Available Status code.

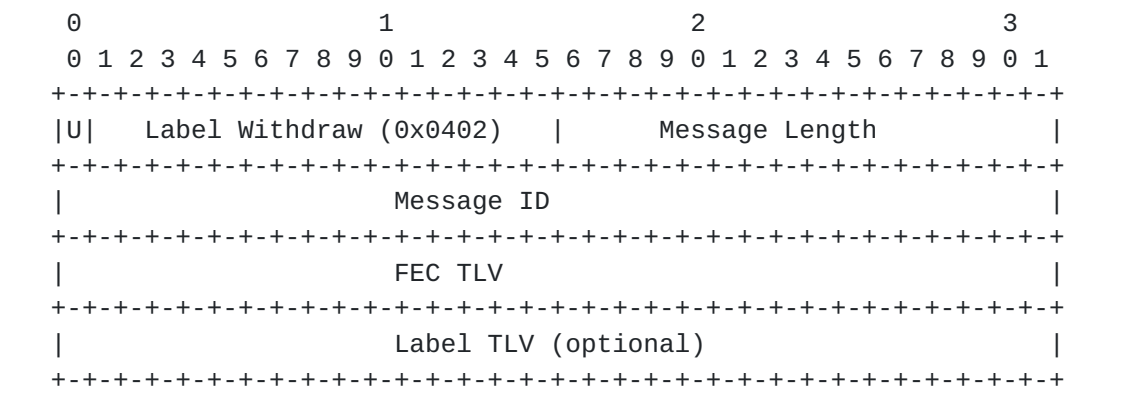
Loop Detected
The LSR has detected a looping Label Requst message.

See Appendx A "LDP Label Distribution Procedures" for more details.

### 3.5.9. Label Withdraw Message

An LSR sends a Label Withdraw Message to an LDP peer to signal the peer that the peer may not continue to use specific FEC-label mappings the LSR had previously advertised. This breaks the mapping between the FECs and the labels.

The encoding for the Label Withdraw Message is:




Message Id
  32-bit value used to identify this message.

FEC TLV
  Identifies the FEC for which the FEC-label mapping is being withdrawn.

Optional Parameters
  This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters are:

| Optional Parameter | Length | Value |
|---|---|---|
| Label TLV | variable | See below |

  The encoding for Label TLVs are found in Section "Label TLVs".

  Label
    If present, specifies the label being withdrawn (see procedures below).

### 3.5.9.1. Label Withdraw Message Procedures

An LSR transmits a Label Withdraw message under the following conditions:

1. The LSR no longer recognizes a previously known FEC.

2. The LSR has decided unilaterally (e.g., via configuration) to no longer label switch a FEC (or FECs) with the label mapping being withdrawn.

The FEC TLV specifies the FEC for which labels are to be withdrawn. If no Label TLV follows the FEC, all labels associated with the FEC

are to be withdrawn; otherwise only the label specified in the optional Label TLV is to be withdrawn.

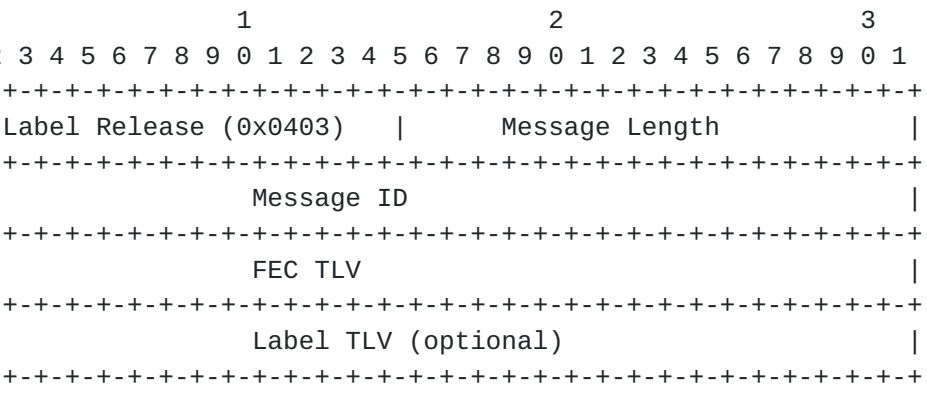
The FEC TLV may contain the Wildcard FEC Element; if so, it may contain no other FEC Elements. In this case, if the Label Withdraw message contains an optional Label TLV, then the label is to be withdrawn from all FECs to which it is bound. If there is not an optional Label TLV in the Label Withdraw message, then the sending LSR is withdrawing all label mappings previously advertised to the receiving LSR.

See Appendx A "LDP Label Distribution Procedures" for more details.

### 3.5.10. Label Release Message

An LSR sends a Label Release message to an LDP peer to signal the peer that the LSR no longer needs specific FEC-label mappings previously requested of and/or advertised by the peer.

The encoding for the Label Release Message is:




Message Id
32-bit value used to identify this message.

FEC TLV
Identifies the FEC for which the FEC-label mapping is being released.

Optional Parameters
This variable length field contains 0 or more parameters, each encoded as a TLV. The optional parameters are:

| Optional Parameter | Length | Value |
|---|---|---|

| | | |
|---|---|---|
| Label TLV | variable | See below |

The encodings for Label TLVs are found in Section "Label TLVs".

Label
If present, the label being released (see procedures below).

### 3.5.10.1. Label Release Message Procedures

An LSR transmits a Label Release message to a peer when it is no longer needs a label previously received from or requested of that peer.

An LSR must transmit a Label Release message under any of the following conditions:

1. The LSR which sent the label mapping is no longer the next hop for the mapped FEC, and the LSR is configured for conservative operation.

2. The LSR receives a label mapping from an LSR which is not the next hop for the FEC, and the LSR is configured for conservative operation.

3. The LSR has received a Label Withdraw message for a previously received label.

Note that if an LSR is configured for "liberal mode", a release message will never be transmitted in the case of conditions (1) and (2) as specified above. In this case, the upstream LSR keeps each unused label, so that it can immediately be used later if the downstream peer becomes the next hop for the FEC.

The FEC TLV specifies the FEC for which labels are to be released. If no Label TLV follows the FEC, all labels associated with the FEC are to be released; otherwise only the label specified in the optional Label TLV is to be released.

The FEC TLV may contain the Wildcard FEC Element; if so, it may contain no other FEC Elements. In this case, if the Label Release message contains an optional Label TLV, then the label is to be released for all FECs to which it is bound. If there is not an optional Label TLV in the Label Release message, then the sending LSR is releasing all label mappings previously learned from the receiving LSR.

See Appendx A "LDP Label Distribution Procedures" for more details.

### 3.6. Messages and TLVs for Extensibility

Support for LDP extensibility includes the rules for the U and F bits that specify how an LSR should handle unknown TLVs and messages.

This section specifies TLVs and messages for vendor-private and experimental use.

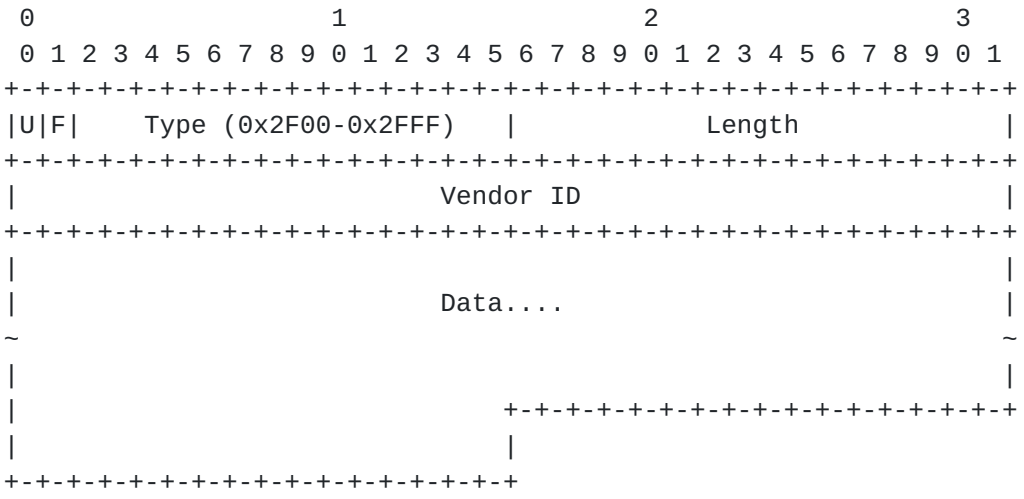
#### 3.6.1. LDP Vendor-private Extensions

Vendor-private TLVs and messages are used to convey vendor-private information between LSRs.

##### 3.6.1.1. LDP Vendor-private TLVs

The Type range 0x2F00 through 0x2FFF is reserved for vendor-private TLVs.

The encoding for a vendor-private TLV is:




U bit
Unknown TLV bit. Upon receipt of an unknown TLV, if U is clear (=0), a notification must be returned to the message originator and the entire message must be ignored; if U is set (=1), the unknown TLV is silently ignored and the rest of the message is processed as if the unknown TLV did not exist.

The determination as to whether a vendor-private message is understood is based on the Type and the mandatory Vendor ID field.

F bit
Forward unknown TLV bit. This bit only applies when the U bit is set and the LDP message containing the unknown TLF is is to be forwarded. If F is clear (=0), the unknown TLV is not forwarded with the containing message; if F is set (=1), the unknown TLV is forwarded with the containing message.

Type
Type value in the range 0x2F00 through 0x2FFF. Together, the Type and Vendor Id field specify how the Data field is to be interpreted.

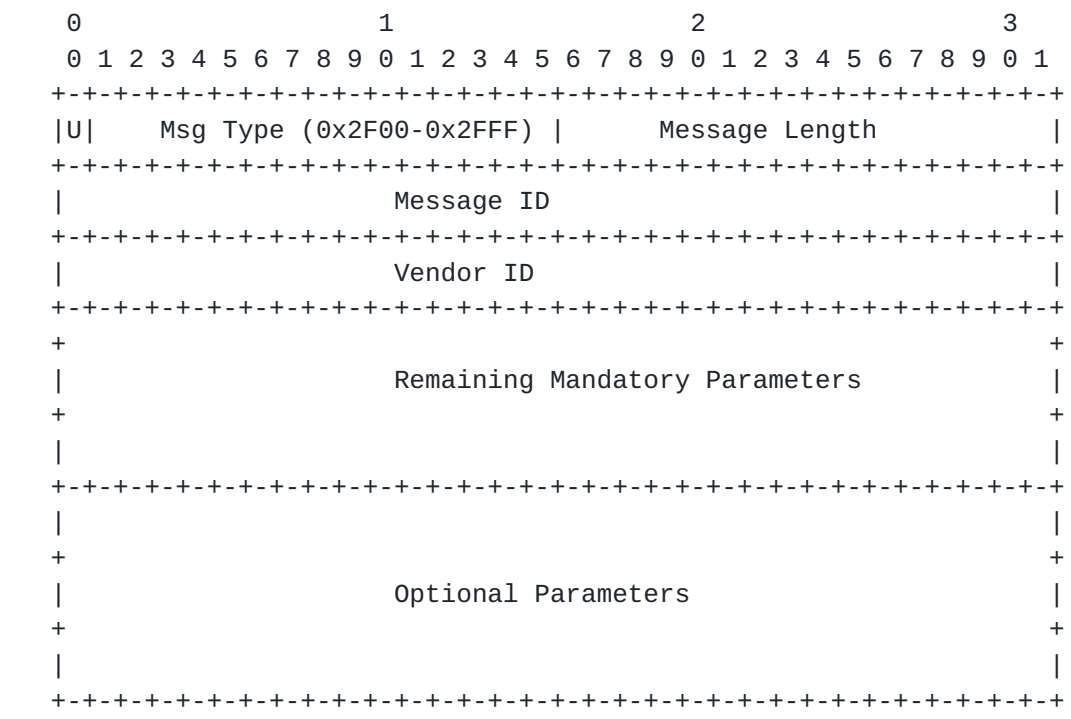
Length
Specifies the cumulative length in octets of the Vendor ID and Data fields.

Vendor Id
802 Vendor ID as assigned by the IEEE.

Data
The remaining octets after the Vendor ID in the Value field are optional vendor-dependent data.

#### 3.6.1.2. LDP Vendor-private Messages

The Message Type range 0x2F00 through 0x2FFF is reserved for vendor-private Messages.




U bit
  Unknown message bit. Upon receipt of an unknown message, if U is clear (=0), a notification is returned to the message originator; if U is set (=1), the unknown message is silently ignored.

  The determination as to whether a vendor-private message is understood is based on the Msg Type and the Vendor ID parameter.

Msg Type
  Message type value in the range 0x2F00 through 0x2FFF. Together, the Msg Type and the Vendor ID specify how the message is to be interpreted.

Message Length
  Specifies the cumulative length in octets of the Message ID, Vendor ID, Remaining Mandatory Parameters and Optional Parameters.

Message ID
  32-bit integer used to identify this message. Used by the sending LSR to facilitate identifying notification messages that may apply to this message. An LSR sending a notification message in response to this message will include this Message Id in the notification message; see Section "Notification Message".

Vendor ID
  802 Vendor ID as assigned by the IEEE.

Remaining Mandatory Parameters
Variable length set of remaining required message parameters.

Optional Parameters
Variable length set of optional message parameters.

### 3.6.2. LDP Experimental Extensions

LDP support for experimentation is similar to support for vendor-private extensions with the following differences:

- The Type range 0x3F00 through 0x3FFF is reserved for experimental TLVs.

- The Message Type range 0x3F00 through 0x3FFF is reserved for experimental messages.

- The encodings for experimental TLVs and messages are similar to the vendor-private encodings with the following difference.

  Experimental TLVs and messages use an Experiment ID field in place of a Vendor ID field. The Experiment ID field is used with the Type or Message Type field to specify the interpretation of the experimental TLV or Message.

  Administration of Experiment IDs is the responsiblity of the experimenters.

## 3.7. Message Summary

The following are the LDP messages defined in this version of the protocol.

| Message Name | Type | Section Title |
|---|---|---|
| Notification | 0x0001 | "Notification Message" |
| Hello | 0x0100 | "Hello Message" |
| Initialization | 0x0200 | "Initialization Message" |
| KeepAlive | 0x0201 | "KeepAlive Message" |
| Address | 0x0300 | "Address Message" |
| Address Withdraw | 0x0301 | "Address Withdraw Message" |
| Label Mapping | 0x0400 | "Label Mapping Message" |
| Label Request | 0x0401 | "Label Request Message" |
| Label Withdraw | 0x0402 | "Label Withdraw Message" |
| Label Release | 0x0403 | "Label Release Message" |
| Vendor-Private | 0x2F00-0x2FFF | |
| Experimental | 0x3F00-0x3FFF | |

### 3.8. TLV Summary

The following are the TLVs defined in this version of the protocol.

| TLV | Type | Section Title |
|---|---|---|
| FEC | 0x0100 | "FEC TLV" |
| Address List | 0x0101 | "Address List TLV" |
| COS | 0x0102 | "COS TLV" |
| Hop Count | 0x0103 | "Hop Count TLV" |
| Path Vector | 0x0104 | "Path Vector TLV" |
| Generic Label | 0x0200 | "Generic Label TLV" |
| ATM Label | 0x0201 | "ATM Label TLV" |
| Frame Relay Label | 0x0202 | "Frame Relay Label TLV" |
| Status | 0x0300 | "Status TLV" |
| Extended Status | 0x0301 | "Notification Message" |
| Returned PDU | 0x0302 | "Notification Message" |
| Returned Message | 0x0303 | "Notification Message" |
| Common Hello Parameters | 0x0400 | "Hello Message" |
| Transport Address | 0x0401 | "Hello Message" |
| Configuration Sequence Number | 0x0402 | "Hello Message" |
| Common Session Parameters | 0x0500 | "Initialization Message" |
| ATM Session Parameters | 0x0501 | "Initialization Message" |
| Frame Relay Session Parameters | 0x0502 | "Initialization Message" |
| Vendor-Private | 0x2F00-0x2FFF | |
| Experimental | 0x3F00-0x3FFF | |

### 3.9. Status Code Summary

The following are the Status Codes defined in this version of the protocol.

| Status Code | Type | Section Title |
|---|---|---|
| Success | 0x00000000 | "Status TLV" |
| Bad LDP Identifer | 0x80000001 | "Events Signaled by ..." |
| Bad Protocol Version | 0x80000002 | "Events Signaled by ..." |
| Bad PDU Length | 0x80000003 | "Events Signaled by ..." |
| Unknown Message Type | 0x80000004 | "Events Signaled by ..." |
| Bad Message Length | 0x80000005 | "Events Signaled by ..." |
| Unknown TLV | 0x80000006 | "Events Signaled by ..." |
| Bad TLV length | 0x80000007 | "Events Signaled by ..." |
| Malformed TLV Value | 0x80000008 | "Events Signaled by ..." |
| Hold Timer Expired | 0x80000009 | "Events Signaled by ..." |
| Shutdown | 0x8000000A | "Events Signaled by ..." |
| Loop Detected | 0x0000000B | "Loop Detection" |
| Unknown FEC | 0x0000000C | "FEC Procedures" |
| No Route | 0x0000000D | "Label Request Mess ..." |
| No Label Resources | 0x0000000E | "Label Request Mess ..." |
| Label Resources Available | 0x0000000F | "Label Request Mess ..." |
| Session Rejected/ No Hello | 0x80000010 | "Session Initialization" |
| Session Rejected/ Parameters Advertisement Mode | 0x80000011 | "Session Initialization" |
| Session Rejected/ Parameters Max PDU Length | 0x80000012 | "Session Initialization" |
| Session Rejected/ Parameters Label Range | 0x80000013 | "Session Initialization" |

### 3.10. UDP and TCP Ports

The UDP port for LDP Hello messages is 646.

The TCP port for establishing LDP session connections is 646.

## 4. Security

This section specifies an optional mechanism to protect against the introduction of spoofed TCP segments into LDP session connection streams.

It is based on use of the TCP MD5 Signature Option specified in [rfc2385] for use by BGP. See [rfc1321] for a specification of the MD5 hash function.

### 4.1. The TCP MD5 Signature Option

The following quotes from [rfc2385] outline the security properties achieved by using the TCP MD5 Signature Option and summarizes its operation:

"IESG Note

This document describes currrent existing practice for securing BGP against certain simple attacks. It is understood to have security weaknesses against concerted attacks."

"Abstract

This memo describes a TCP extension to enhance security for BGP. It defines a new TCP option for carrying an MD5 [RFC1321] digest in a TCP segment. This digest acts like a signature for that segment, incorporating information known only to the connection end points. Since BGP uses TCP as its transport, using this option in the way described in this paper significantly reduces the danger from certain security attacks on BGP."

"Introduction

The primary motivation for this option is to allow BGP to protect itself against the introduction of spoofed TCP segments into the connection stream. Of particular concern are TCP resets.

To spoof a connection using the scheme described in this paper, an attacker would not only have to guess TCP sequence numbers, but would also have had to obtain the password included in the MD5 digest. This password never appears in the connection stream, and the actual form of the password is up to the application. It could even change during the lifetime of a particular connection so long as this change was synchronized on both ends (although retransmission can become problematical in some

TCP implementations with changing passwords).

Finally, there is no negotiation for the use of this option in a connection, rather it is purely a matter of site policy whether or not its connections use the option."

"MD5 as a Hashing Algorithm

Since this memo was first issued (under a different title), the MD5 algorithm has been found to be vulnerable to collision search attacks [Dobb], and is considered by some to be insufficiently strong for this type of application.

This memo still specifies the MD5 algorithm, however, since the option has already been deployed operationally, and there was no "algorithm type" field defined to allow an upgrade using the same option number. The original document did not specify a type field since this would require at least one more byte, and it was felt at the time that taking 19 bytes for the complete option (which would probably be padded to 20 bytes in TCP implementations) would be too much of a waste of the already limited option space.

This does not prevent the deployment of another similar option which uses another hashing algorithm (like SHA-1). Also, if most implementations pad the 18 byte option as defined to 20 bytes anyway, it would be just as well to define a new option which contains an algorithm type field.

This would need to be addressed in another document, however."

End of quotes from [rfc2385].

## 4.2. LDP Use of the TCP MD5 Signature Option

LDP uses the TCP MD5 Signature Option as follows:

- Use of the MD5 Signature Option for LDP TCP connections is a configurable LSR option.

- An LSR that uses the MD5 Signature Option is configured with a password for each potential LDP peer.

- The LSR applies the MD5 algorithm as specified in [RFC2385] to compute the MD5 digest for a TCP segment to be sent to a peer. This computation makes use of the peer password as well as the TCP segment.

- When the LSR receives a TCP segment with an MD5 digest, it validates the segment by calculating the MD5 digest (using its own record of the password) and compares the computed digest with the received digest. If the comparison fails, the segment is dropped without any response to the sender.

- The LSR ignores LDP Hellos from any LSR for which a password has not been configured. This ensures that the LSR establishes LDP TCP connections only with LSRs for which a password has been configured.

## 5. Intellectual Property Considerations

The IETF has been notified of intellectual property rights claimed in regard to some or all of the specification contained in this document. For more information consult the online list of claimed rights.

## 6. Acknowledgments

The ideas and text in this document have been collected from a number of sources. We would like to thank Rick Boivie, Ross Callon, Alex Conta, Eric Gray, Yoshihiro Ohba, Eric Rosen, Bernard Suter, Yakov Rekhter, and Arun Viswanathan.

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## 8. Author Information

Loa Andersson
Nortel Networks Inc
Kungsgatan 34, PO Box 1788
111 97 Stockholm
Sweden
Phone: +46 8 441 78 34, Mobile: +46 70 522 78 34
email: loa_andersson@baynetworks.com

Paul Doolan
Ennovate Networks
330 Codman Hill Rd
Marlborough MA 01719
Phone: 978-263-2002
email: pdoolan@ennovatenetworks.com

Nancy Feldman
IBM Corp.
17 Skyline Drive
Hawthorne NY 10532
Phone: 914-784-3254
email: nkf@us.ibm.com

Andre Fredette
Nortel Networks Inc
3 Federal Street

Billerica, MA 01821
Phone: 978-916-8524
email: fredette@baynetworks.com

Bob Thomas
Cisco Systems, Inc.
250 Apollo Dr.
Chelmsford, MA 01824
Phone: 978-244-8078
email: rhthomas@cisco.com

## Appendix A. LDP Label Distribution Procedures

This section specifies label distribution behavior in terms of LSR response to the following events:

- Receive Label Request Message;
- Receive Label Mapping Message;
- Receive Label Release Message;
- Receive Label Withdraw Message;
- Recognize new FEC;
- Detect change in FEC next hop;
- Receive Notification Message / No Label Resources;
- Receive Notification Message / No Route;
- Receive Notification Message / Loop Detected;
- Receive Notification Message / Label Resources Available;
- Detect local label resources have become available;
- LSR decides to no longer label switch a FEC;
- Timeout of deferred label request.

The specification of LSR behavior in response to an event has three parts:

1. Summary. Prose that describes LSR response to the event in overview.

2. Context. A list of elements referred to by the Algorithm part of the specification. (See 3.)

3. Algorithm. An algorithm for LSR response to the event.

The Summary may omit details of the LSR response, such as bookkeeping action or behavior dependent on the LSR label advertisement mode, control mode, or label retention mode in use. The intent is that the Algorithm fully and unambiguously specify the LSR response.

The algorithms in this section use procedures defined in the MPLS architecture specification [ARCH] for hop-by-hop routed traffic. These procedures are:

- Label Distribution procedure, which is performed by a downstream LSR to determine when to distribute a label for a FEC to LDP peers. The architecture defines four Label Distribution procedures:

  . Downstream Unsolicited Independent Control, called PushUnconditional in [ARCH].

  . Downstream Unsolicited Ordered Control, called PushConditional in [ARCH].

  . Downstream On Demand Independent Control, called PulledUnconditional in [ARCH].

  . Downstream On Demand Ordered Control, called PulledConditional in [ARCH].

- Label Withdrawal procedure, which is performed by a downstream LSR to determine when to withdraw a FEC label mapping previously distributed to LDP peers. The architecture defines a single Label Withdrawal procedure. Whenever an LSR breaks the binding between a label and a FEC, it must withdraw the FEC label mapping from all LDP peers to which it has previously sent the mapping.

- Label Request procedure, which is performed by an upstream LSR to determine when to explicitly request that a downstrem LSR bind a label to a FEC and send it the corresponding label mapping. The architecture defines three Label Request procedures:

  . Request Never. The LSR never requests a label.

  . Request When Needed. The LSR requests a label whenever it needs one.

  . Request On Request. This procedure is used by non-label merging LSRs. The LSR requests a label when it receives a request for one, in addition to whenever it needs one.

- Label Release procedure, which is performed by an upstream LSR to determine when to release a previously received label mapping for a FEC. The architecture defines two Label Release procedures:

  . Conservative label retention, called Release On Change in [ARCH].

  . Liberal label retention, called No Release On Change in [ARCH].

- Label Use procedure, which is performed by an LSR to determine when to start using a FEC label for forwarding/switching. The architecture defines three Label Use procedures:

  . Use Immediate. The LSR immediately uses a label received from a FEC next hop for forwarding/switching.

. Use If Loop Free. The LSR uses a FEC label received from a FEC next hop for forwarding/switching only if it has determined that by doing so it will not cause a forwarding loop.

. Use If Loop Not Detected. This procedure is the same as Use Immediate unless the LSR has detected a loop in the FEC LSP. Use of the FEC label for forwarding/switching will continue until the next hop for the FEC changes or the loop is no longer detected.

This version of LDP does not include a loop prevention mechanism; therefore, the procedures below do not make use of the Use If Loop Free procedure.

- Label No Route procedure (called Label Not Available procedure in [ARCH]), which is performed by an upstream LSR to determine how to respond to a No Route notification from a downstream LSR in response to a request for a FEC label mapping. The architecture specification defines two Label No Route procedures:

  . Request Retry. The LSR should issue the label request at a later time.

  . No Request Retry. The LSR should assume the downstream LSR will provide a label mapping when the downstream LSR has a next hop and it should not reissue the request.

## A.1. Handling Label Distribution Events

The algorithms for handling label distribution events share common actions. The specifications below package these common actions into procedure units. Specifications for these common procedures are in their own section "Common Label Distribution Procedures", which follows this.

An implementation would use data structures to store information about protocol activity. This appendix specifies the information to be stored in sufficient detail to describe the algorithms, and assumes the ability to retrieve the information as needed. It does not specify the details of the data structures.

### A.1.1. Receive Label Request

Summary:

The response by an LSR to receipt of a FEC label request from an LDP peer may involve one or more of the following actions:

- Transmission of a notification message to the requesting LSR indicating why a label mapping for the FEC cannot be provided;
- Transmission of a FEC label mapping to the requesting LSR;
- Transmission of a FEC label request to the FEC next hop;
- Installation of labels for forwarding/switching use by the LSR.

Context:

- LSR. The LSR handling the event.
- MsgSource. The LDP peer that sent the message.
- FEC. The FEC specified in the message.
- RAttributes. Attributes received with the message. E.g., CoS, Hop Count Path Vector.
- SAttributes. Attributes to be included in Label Request message, if any, propagated to FEC Next Hop.
- StoredHopCount. The hop count, if any, previously recorded for the FEC.

Algorithm:

LRq.1 Execute procedure Check_Received_Attributes (MsgSource, RAttributes).
If Loop Detected, goto LRq.11.

LRq.2 Is there a Next Hop for FEC?
If so, goto LRq.4.

LRq.3 Execute procedure Send_Notification (MsgSource, No Route).
Goto LRq.11.

LRq.4 Has LSR previously received a label request for FEC from MsgSource?
If not, goto LRq.6. (See Note 1.)

LRq.5 Is the label request a duplicate request?
If so, Goto LRq.11. (See Note 2.)

LRq.6 Record label request for FEC received from MsgSource and mark it pending.

LRq.7 Perform LSR Label Distribution procedure:

For Downstream Unsolicited Independent Control OR
For Downstream On Demand Independent Control

1. Has LSR previously received and retained a label mapping for FEC from Next Hop?.
   Is so, set Propagating to IsPropagating.
   If not, set Propagating to NotPropagating.

2. Execute procedure
   Prepare_Label_Mapping_Attributes(MsgSource, FEC, RAttributes, SAttributes, Propagating, StoredHopCount).

3. Execute procedure Send_Label (MsgSource, FEC, SAttributes).

4. Is LSR egress for FEC? OR
   Has LSR previously received and retained a label mapping for FEC from Next Hop?
   If so, goto LRq.9. If not, goto LRq.8.

For Downstream Unsolicited Ordered Control OR
For Downstream On Demand Ordered Control

1. Is LSR egress for FEC? OR
   Has LSR previously received and retained a label mapping for FEC from Next Hop?
   If not, goto LRq.8.

2. Execute procedure
   Prepare_Label_Mapping_Attributes(MsgSource, FEC, RAttributes, SAttributes, IsPropagating, StoredHopCount)

3. Execute procedure Send_Label (MsgSource, FEC, SAttributes).
   Goto LRq.9.

LRq.8 Perform LSR Label Request procedure:

For Request Never

1. Goto LRq.11.

For Request When Needed OR
For Request On Request

1. Execute procedure Prepare_Label_Request_Attributes (Next Hop, FEC, RAttributes, SAttributes);

2. Execute procedure Send_Label_Request (Next Hop, FEC, SAttributes).
   Goto LRq.11.

LRq.9 Has LSR successfully sent a label for FEC to MsgSource?
If not, goto LRq.11. (See Note 3.)

LRq.10 Perform LSR Label Use procedure.

For Use Immediate OR
For Use If Loop Not Detected

1. Install label sent to MsgSource and label from Next Hop (if LSR is not egress) for forwarding/switching use.

LRq.11 DONE

Notes:

1. In the case where MsgSource is a non-label merging LSR it will send a label request for each upstream LDP peer that has requested a label for FEC from it. The LSR must be able to distinguish such requests from a non-label merging MsgSource from duplicate label requests.

2. When an LSR sends a label request to a peer it records that the request has been sent and marks it as outstanding. As long as the request is marked outstanding the LSR should not send another request for the same label to the peer. Such a second request would be a duplicate. The Send_Label_Request procedure described below obeys this rule.

   A duplicate label request is considered a protocol error and should be dropped by the receiving LSR (perhaps with a suitable notification returned to MsgSource).

3. The Send_Label procedure may fail due to lack of label resources, in which case the LSR should not perform the Label Use procedure.

### A.1.2. Receive Label Mapping

Summary:

The response by an LSR to receipt of a FEC label mapping from an LDP peer may involve one or more of the following actions:

- Transmission of a label release message for the FEC label to the LDP peer;

- Transmission of label mapping messages for the FEC to one or more LDP peers,

- Installation of the newly learned label for forwarding/switching use by the LSR.

Context:

- LSR. The LSR handling the event.

- MsgSource. The LDP peer that sent the message.

- FEC. The FEC specified in the message.

- Label. The label specified in the message.

- PrevAdvLabel. The label for FEC, if any, previously advertised to an upstream peer.

- StoredHopCount. The hop count previously recorded for the FEC.

- RAttributes. Attributes received with the message. E.g., CoS, Hop Count, Path Vector.

- SAttributes to be included in Label Mapping message, if any, propagated to upstream peers.

Algorithm:

LMp.1 Does the received label mapping match an outstanding label request for FEC previously sent to MsgSource.
If not, goto LMp.9.

LMp.2 Delete record of outstanding FEC label request.

LMp.3 Execute procedure Check_Received_Attributes (MsgSource, RAttributes).
If No Loop Detected, goto LMp.9.

LMp.4 Does the LSR have a previously received label mapping for FEC from MsgSource?
If not, goto LMp.8. (See Note 1.).

LMp.5 Does the label previously received from MsgSource match Label (i.e., the label received in the message)?
If not, goto LMp.8. (See Note 2.)

LMp.6 Delete matching label mapping for FEC previously received from MsgSource.

LMp.7 Remove Label from forwarding/switching use. (See Note 3.).

LMp.8 Execute procedure Send_Message (MsgSource, Label Release, FEC, Label). Goto LMp.26.

LMp.9 Determine the Next Hop for FEC.

LMp.10 Is MsgSource the Next Hop for FEC?
If so, goto LMp.12.

LMp.11 Perform LSR Label Release procedure:

For Conservative Label retention:

1. Execute procedure Send_Message (MsgSource, Label Release, FEC, Label).
Goto LMp.26.

For Liberal Label retention:

1. Record label mapping for FEC with Label and RAttributes has been received from MsgSource.
Goto LMp.26.

LMp.12 Does LSR have a previously received label mapping for FEC from MsgSource?
If not, goto LMp.14

LMp.13 Does the label previously received from MsgSource match Label (i.e., the label received in the message)?
If not, goto LMp.8. (See Note 2.)

LMp.14 Is LSR an ingress for FEC?
If not, goto LMp.16.

LMp.15 Install Label for forwarding/switching use.

LMp.16 Record label mapping for FEC with Label and RAttributes has been received from MsgSource.

LMp.17 Iterate through for LMp.25 for each Peer, other than MsgSource.

LMp.18 Has LSR previously sent a label mapping for FEC to Peer?
If not, goto LMp.23.

LMp.19 Are RAttributes in the received label mapping consistent with those previously sent to Peer?
If so, goto LMp.24. (See Note 4.)

LMp.20 Execute procedure Prepare_Label_Mapping_Attributes(Peer, FEC, RAttributes, SAttributes, IsPropagating, StoredHopCount).

LMp.21 Execute procedure Send_Message (Peer, Label Mapping, FEC, PrevAdvLabel, SAttributes). (See Note 5.)

LMp.22 Update record of label mapping for FEC previously sent to Peer to include the new attributes sent.
Goto LMp.24.

LMp.23 Perform LSR Label Distribution procedure:

For Downstream Unsolicited Independent Control OR
For Downstream Unsolicited Ordered Control

1. Execute procedure Prepare_Label_Mapping_Attributes(Peer, FEC, RAttributes, SAttributes, IsPropagating, UnknownHopCount).

2. Execute procedure Send_Label (Peer, FEC, SAttributes).
If the procedure fails, continue iteration for next Peer at LMp.17.

3. Goto LMp.24.

For Downstream On Demand Independent Control OR
For Downstream On Demand Ordered Control

1. Does LSR have a label request for FEC from Peer

marked as pending?
If not, continue iteration for next Peer at LMp.17.

2. Execute procedure
Prepare_Label_Mapping_Attributes(Peer, FEC, RAttributes, SAttributes, IsPropagating, UnknownHopCount)

3. Execute procedure Send_Label (Peer, FEC, SAttributes).
If the procedure fails, continue iteration for next Peer at LMp.17.

4. Goto LMp.24.

LMp.24 Perform LSR Label Use procedure:

For Use Immediate OR
For Use If Loop Not Detected

1. Install label received and label sent to Peer for forwarding/switching use.
Goto LMp.25.

LMp.25 End iteration from LMp.17.

LMp.26 DONE.

Notes:

1. If LSR has detected a loop and it has not previously received a label mapping from MsgSource for the FEC, it simply releases the label.

2. A mapping with a different label from the same peer would be an attempt to establish multipath label switching, which is not supported in this version of LDP.

3. If Label is not in forwarding/switching use, LMp.7 has no effect.

4. The loop detection Path Vector attribute is considered in this check. If the received RAttributes include a Path Vector and no Path Vector had been previously sent to the Peer, or if the received Path Vector is inconsistent with the Path Vector previously sent to the Peer, then the attributes are considered to be inconsistent. Note that an LSR is not required to store a received Path Vector after it propagates the Path Vector in a mapping message. If an LSR does not store the Path Vector, it

has no way to check the consistency of a newly received Path Vector. This means that whenever such an LSR receives a mapping message carrying a Path Vector it must always propagate the Path Vector.

5. LMp.19 through LMp.21 deal with a situation that can arise when the LSR is using independent control and it receives a mapping from the downstream peer after it has sent a mapping to an upstream peer. In this situation the LSR needs to propagate any changed attributes, such as Hop Count, upstream. If Loop Detection is configured on, the propagated attributes must include the Path Vector

### A.1.3. Receive Label Release

Summary:

When an LSR receives a label release message for a FEC from a peer, it checks whether other peers hold the released label. If none do, the LSR removes the label from forwarding/switching use, if it has not already done so, and if the LSR holds a label mapping from the FEC next hop, it releases the label mapping.

Context:

- LSR. The LSR handling the event.

- MsgSource. The LDP peer that sent the message.

- Label. The label specified in the message.

- FEC. The FEC specified in the message.

Algorithm:

LRl.1 Remove MsgSource from record of peers that hold Label for FEC. (See Note 1.)

LRl.2 Does message match an outstanding label withdraw for FEC previously sent to MsgSource?
If not, goto LRl.4

LRl.3 Delete record of outstanding label withdraw for FEC previously sent to MsgSource.

LRl.4 Is LSR merging labels for this FEC?
If not, goto LRl.6. (See Note 2.)

LRl.5 Has LSR previously advertised a label for this FEC to other peers?
If so, goto LRl.10.

LRl.6 Is LSR egress for the FEC?
If so, goto LRl.10

LRl.7 Is there a Next Hop for FEC? AND
Does LSR have a previously received label mapping for FEC from Next Hop?
If not, goto LRl.10.

LRl.8 Is LSR configured to propagate releases?
If so, goto LRl.10. (See Note 3.)

LRl.9 Execute procedure Send_Message (Next Hop, Label Release, FEC, Label from Next Hop).

LRl.10 Remove Label from forwarding/switching use for traffic from MsgSource.

LRl.11 Do any peers still hold Label for FEC?
If so, goto LRl.13.

LRl.12 Free the Label.

LRl.13 DONE.

Notes:

1. If LSR is using Downstream Unsolicted label distribution, it should not re-advertise a label mapping for FEC to MsgSource until MsgSource requests it.

2. LRl.4 through LRl.8 deal with determining whether where the LSR should propagate the label release to a downstream peer (LRl.9).

3. If LRl.8 is reached, no upstream LSR holds a label for the FEC, and the LSR holds a label for the FEC from the FEC Next Hop. The LSR could propagate the Label Release to the Next Hop. By propagating the Label Release the LSR releases a potentially scarce label resource. In doing so, it also increases the latency for re-establishing the LSP should MsgSource or some other upstream LSR send it a new Label Request for FEC.

   Whether or not to propagate the release is not a protocol issue. Label distribution will operate properly whether or not

the release is propagated. The decision to propagate or not should take into consideration factors such as: whether labels are a scarce resource in the operating environment; the importance of keeping LSP setup latency low by keeping the amount of signalling required small; whether LSP setup is ingress-controlled or egress-controlled in the operating environment.

### A.1.4. Receive Label Withdraw

Summary:

When an LSR receives a label withdraw message for a FEC from an LDP peer, it responds with a label release message and it removes the label from any forwarding/switching use. If ordered control is in use, the LSR sends a label withdraw message to each LDP peer to which it had previously sent a label mapping for the FEC. If the LSR is using Downstream on Demand label advertisement with independent control, it then acts as if it had just recognized the FEC.

Context:

- LSR. The LSR handling the event.

- MsgSource. The LDP peer that sent the message.

- Label. The label specified in the message.

- FEC. The FEC specified in the message.

Algorithm:

LWd.1 Remove Label from forwarding/switching use. (See Note 1.)

LWd.2 Execute procedure Send_Message (MsgSource, Label Release, FEC, Label)

LWd.3 Has LSR previously received and retained a matching label mapping for FEC from MsgSource?
If not, goto LWd.13.

LWd.4 Delete matching label mapping for FEC previously received from MsgSource.

LWd.5 Is LSR using ordered control?
If so, goto LWd.8.

LWd.6 Is MsgSource using Downstream On Demand label advertisement?

If not, goto LWd.13.

LWd.7 Generate Event: Recognize New FEC for FEC.
Goto LWd.13. (See Note 2.)

LWd.8 Iterate through LWd.12 for each Peer, other than MsgSource.

LWd.9 Has LSR previously sent a label mapping for FEC to Peer?
If not, continue interation for next Peer at LWd.8.

LWd.10 Does the label previously sent to Peer "map" to the withdrawn Label?
If not, continue iteration for next Peer at LWd.8. (See Note 3.)

LWd.11 Execute procedure Send_Label_Withdraw (Peer, FEC, Label previously sent to Peer).

LWd.12 End iteration from LWd.8.

LWd.13 DONE

Notes:

1. If Label is not in forwarding/switching use, LWd.1 has no effect.

2. LWd.7 handles the case where the LSR is using Downstream On Demand label distribution with independent control. In this situation the LSR should send a label request to the FEC next hop as if it had just recognized the FEC.

3. LWd.10 handles both label merging (one or more incoming labels map to the same outgoing label) and no label merging (one label maps to the outgoing label) cases.

### A.1.5. Recognize New FEC

Summary:

The response by an LSR to learning a new FEC may involve one or more of the following actions:

- Transmission of label mappings for the FEC to one or more LDP peers;

- Transmission of a label request for the FEC to the FEC next hop;

- Any of the actions that can occur when the LSR receives a label mapping for the FEC from the FEC next hop.

Context:

- LSR. The LSR handling the event.

- FEC. The newly recognized FEC.

- Next Hop. The next hop for the FEC.

- InitAttributes. Attributes to be associated with the new FEC. (See Note 1.)

- SAttributes. Attributes to be included in Label Mapping or Label Request messages, if any, sent to peers.

- StoredHopCount. Hop count associated with FEC label mapping , if any, previously received from Next Hop.

Algorithm:

FEC.1 Perform LSR Label Distribution procedure:

For Downstream Unsolicited Independent Control

1. Iterate through 5 for each Peer.

2. Has LSR previously received and retained a label mapping for FEC from Next Hop?
   If so, set Propagating to IsPropagating.
   If not, set Propagating to NotPropagating.

3. Execute procedure Prepare_Label_Mapping_Attributes (Peer, FEC, InitAttributes, SAttributes, Propagating, Unknown hop count(0)).

4. Execute procedure Send_Label (Peer, FEC, SAttributes)

5. End iteration from 1.
   Goto FEC.2.

For Downstream Unsolicited Ordered Control

1. Iterate through 5 for each Peer.

2. Is LSR egress for the FEC? OR
   Has LSR previously received and retained a label mapping for FEC from Next Hop?
   If not, continue iteration for next Peer.

3. xecute procedure Prepare_Label_Mapping_Attributes (Peer, FEC, InitAttributes, SAttributes, Propagating, StoredHopCount).

4. Execute procedure Send_Label (Peer, FEC, SAttributes)

5. End iteration from 1.
   Goto FEC.2.

For Downstream On Demand Independent Control OR
For Downstream On Demand Ordered Control

1. Goto FEC.2. (See Note 2.)

FEC.2 Has LSR previously received and retained a label mapping for FEC from Next Hop?
If so, goto FEC.5

FEC.3 Is Next Hop an LDP peer?
If not, Goto FEC.6

FEC.4 Perform LSR Label Request procedure:

For Request Never

1. Goto FEC.6

For Request When Needed OR
For Request On Request

1. Execute procedure Prepare_Label_Request_Attributes (Next Hop, FEC, InitAttributes, SAttributes);

2. Execute procedure Send_Label_Request (Next Hop, FEC, SAttributes).
   Goto FEC.6.

FEC.5 Generate Event: Received Label Mapping from Next Hop. (See Note 3.)

FEC.6 DONE.

Notes:

1. An example of an attribute that might be part of InitAttributes is CoS. The means by which FEC InitAttributes, if any, are specified is beyond the scope of LDP. Note that the InitAttributes will not include a known Hop Count or a Path Vector.

2. An LSR using Downstream On Demand label distribution would send a label only if it had a previously received label request marked as pending. The LSR would have no such pending requests because it responds to any label request for an unknown FEC by sending the requesting LSR a No Route notification and discarding the label request; see LRq.3

3. If the LSR has a label for the FEC from the Next Hop, it should behave as if it had just received the label from the Next Hop. This occurs in the case of Liberal label retention mode.

### A.1.6. Detect change in FEC next hop

Summary:

The response by an LSR to a change in the next hop for a FEC may involve one or more of the following actions:

- Removal of the label from the FEC's old next hop from forwarding/switching use;

- Transmission of label mappping messages for the FEC to one or more LDP peers;

- Transmission of a label request to the FEC's new next hop;

- Any of the actions that can occur when the LSR receives a label mapping from the FEC's new next hop.

Context:

- LSR. The LSR handling the event.

- FEC. The FEC whose next hop changed.

- New Next Hop. The current next hop for the FEC.

- Old Next Hop. The previous next hop for the FEC.

- OldLabel. Label, if any, previously received from Old Next Hop.

- CurAttributes. The attributes, if any, currently associated with the FEC.

- SAttributes. Attributes to be included in Label Label Request message, if any, sent to New Next Hop.

Algorithm:

NH.1 Has LSR previously received and retained a label mapping for FEC from Old Next Hop?
If not, goto NH.6.

NH.2 Remove label from forwarding/switching use. (See Note 1.)

NH.3 Is LSR using Liberal label retention?
If so, goto NH.6.

NH.4 Execute procedure Send_Message (Old Next Hop, Label Release, OldLlabel).

NH.5 Delete label mapping for FEC previously received from Old Next Hop.

NH.6 Has LSR previously received and retained a label mapping for FEC from New Next Hop?
If not, goto NH.8.

NH.7 Generate Event: Received Label Mapping from New Next Hop.
Goto NH.11. (See Note 2.)

NH.8 Is LSR using Downstream on Demand advertisement? OR
Is Next Hop using Downstream on Demand advertisement? OR
Is LSR using Conservative label retention? (See Note 3.)
If so, goto NH.9. If not, goto NH.11.

NH.9 Execute procedure Prepare_Label_Request_Attributes (Next Hop, FEC, CurAttributes, SAttributes)

NH.10 Execute procedure Send_Label_Request (New Next Hop, FEC, SAttributes).
(See Note 4.)

NH.11 DONE.

Notes:

1. If Label is not in forwarding/switching use, NH.2 has no effect.

2. If the LSR has a label for the FEC from the New Next Hop, it should behave as if it had just received the label from the New Next Hop.

3. The purpose of the check on label retention mode is to avoid a race with steps LMp.10-LMp.11 of the procedure for handling a Label Mapping message where the LSR operating in Conservative Label retention mode may have released a label mapping received from the New Next Hop before it detected the FEC next hop had changed.

4. Regardless of the Label Request procedure in use by the LSR, it must send a label request if the conditions in NH.8 hold. Therefore it executes the Send_Label_Request procedure directly rather than perform LSR Label Request procedure.

### A.1.7. Receive Notification / No Label Resources

Summary:

When an LSR receives a No Label Resources notification from an LDP peer, it stops sending label request messages to the peer until it receives a Label Resources Available Notification from the peer.

Context:

- LSR. The LSR handling the event.

- FEC. The FEC for which a label was requested.

- MsgSource. The LDP peer that sent the Notification message.

Algorithm:

NoRes.1 Delete record of outstanding label request for FEC sent to MsgSource.

NoRes.2 Record label mapping for FEC from MsgSource is needed but that no label resources are available.

NoRes.3 Set status record indicating it is not OK to send label requests to MsgSource.

NoRes.4 DONE.

### A.1.8. Receive Notification / No Route

Summary:

When an LSR receives a No Route notification from an LDP peer in response to a Label Request message, the Label No Route procedure in use dictates its response. The LSR either will take no further action, or it will defer the label request by starting a timer and send another Label Request message to the peer when the timer later expires.

Context:

- LSR. The LSR handling the event.

- FEC. The FEC for which a label was requested.

- Attributes. The attibutes associated with the label request.

- MsgSource. The LDP peer that sent the Notification message.

Algorithm:

NoNH.1 Delete record of outstanding label request for FEC sent to MsgSource.

NoNH.2 Perform LSR Label No Route procedure.

For Request No Retry

1. Goto NoNH.3.

For Request Retry

1. Record deferred label request for FEC and Attributes to be sent to MsgSource.

2. Start timeout. Goto NoNH.3.

NoNH.3 DONE.

### A.1.9. Receive Notification / Loop Detected

Summary:

When an LSR receives a Loop Detected notification from an LDP peer in response to a Label Request message, it behaves as if it had received a No Route notification.

Context:

See "Receive Notification / No Route".

Algorithm:

See "Receive Notification / No Route"

### A.1.10. Receive Notification / Label Resources Available

Summary:

When an LSR receives a Label Resources Available notification from an LDP peer, it resumes sending label requests to the peer.

Context:

- LSR. The LSR handling the event.

- MsgSource. The LDP peer that sent the Notification message.

- SAttributes. Attributes stored with postponed Label Request message.

Algorithm:

Res.1 Set status record indicating it is OK to send label requests to MsgSource.

Res.2 Iterate through Res.6 for each record of a FEC label mapping needed from MsgSource for which no label resources are available.

Res.3 Is MsgSource the next hop for FEC?
If not, goto Res.5.

Res.4 Execute procedure Send_Label_Request (MsgSource, FEC, SAttributes). If the procedure fails, terminate iteration.

Res.5 Delete record that no resources are available for a label mapping for FEC needed from MsgSource.

Res.6 End iteration from Res.2

Res.7 DONE.

### A.1.11. Detect local label resources have become available

Summary:

After an LSR has sent a No Label Resources notification to an LDP peer, when label resources later become available it sends a Label Resources Available notification to each such peer.

Context:

- LSR. The LSR handling the event.

- Attributes. Attributes stored with postponed Label Mapping message.

Algorithm:

ResA.1 Iterate through ResA.4 for each Peer to which LSR has previously sent a No Label Resources notification.

ResA.2 Execute procedure Send_Notification (Peer, Label Resources Available)

ResA.3 Delete record that No Label Resources notification was previously sent to Peer.

ResA.4 End iteration from ResA.1

ResA.5 Iterate through ResA.8 for each record of a label mapping needed for FEC for Peer but no-label-resources. (See Note 1.)

ResA.6 Execute procedure Send_Label (Peer, FEC, Attributes). If the procedure fails, terminate iteration.

ResA.7 Clear record of FEC label mapping needed for peer but no-label-resources.

ResA.8 End iteration from ResA.5

ResA.9 DONE.

Notes:

1. Iteration ResA.5 through ResA.8 handles the situation where the LSR is using Downstream Unsolicited label distribution and was previously unable to allocate a label for a FEC.

### A.1.12. LSR decides to no longer label switch a FEC

Summary:

An LSR may unilaterally decide to no longer label switch a FEC for an LDP peer. An LSR that does so must send a label withdraw message for the FEC to the peer.

Context:

- Peer. The peer.

- FEC. The FEC.

- PrevAdvLabel. The label for FEC previously advertised to Peer.

Algorithm:

NoLS.1 Execute procedure Send_Label_Withdraw (Peer, FEC, PrevAdvLabel). (See Note 1.)

NoLS.2 DONE.

Notes:

1. The LSR may remove the label from forwarding/switching use as part of this event or as part of processing the label release from the peer in response to the label withdraw.

### A.1.13. Timeout of deferred label request

Summary:

Label requests are deferred in response to No Route and Loop Detected notifications. When a deferred FEC label request for a peer times out, the LSR sends the label request.

Context:

- LSR. The LSR handling the event.

- FEC. The FEC associated with the timeout event.

- Peer. The LDP peer associated with the timeout event.

- Attributes. Attributes stored with deferred Label Request message.

Algorithm:

TO.1 Retrieve the record of the deferred label request.

TO.2 Is Peer the next hop for FEC?
If not, goto TO.4.

TO.3 Execute procedure Send_Label_Request (Peer, FEC).

TO.4 DONE.

### A.2. Common Label Distribution Procedures

This section specifies utility procedures used by the algorithms that handle label distribution events.

#### A.2.1. Send_Label

Summary:

The Send_Label procedure allocates a label for a FEC for an LDP peer, if possible, and sends a label mapping for the FEC to the peer. If the LSR is unable to allocate the label and if it has a pending label request from the peer, it sends the LDP peer a No Label Resources notification.

Parameters:

- Peer. The LDP peer to which the label mapping is to be sent.

- FEC. The FEC for which a label mapping is to be sent.

- Attributes. The attributes to be included with the label mapping.

Additional Context:

- LSR. The LSR executing the procedure.

- Label. The label allocated and sent to Peer.

Algorithm:

SL.1 Does LSR have a label to allocate?
If not, goto SL.9.

SL.2 Allocate Label and bind it to the FEC.

SL.3 Install Label for forwarding/switchng use.

SL.4 Execute procedure Send_Message (Peer, Label Mapping, FEC, Label, Attributes).

SL.5 Record label mapping for FEC with Label and Attributes has been sent to Peer.

SL.6 Does LSR have a record of a FEC label request from Peer marked as pending?
If not, goto SL.8.

SL.7 Delete record of pending label request for FEC from Peer.

SL.8 Return success.

SL.9 Does LSR have a label request for FEC from Peer marked as pending?
If not, goto SL.13.

SL.10 Execute procedure Send_Notification (Peer, No Label Resources).

SL.11 Delete record of pending label request for FEC from Peer.

SL.12 Record No Label Resources notification has been sent to Peer.
Goto SL.14.

SL.13 Record label mapping needed for FEC and Attributes for Peer, but no-label-resources. (See Note 1.)

SL.14 Return failure.

Notes:

1. SL.13 handles the case of Downstream Unsolicited label distribution when the LSR is unable to allocate a label for a FEC to send to a Peer.

### A.2.2. Send_Label_Request

Summary:

An LSR uses the Send_Label_Request procedure to send a request for a label for a FEC to an LDP peer if currently permitted to do so.

Parameters:

- Peer. The LDP peer to which the label request is to be sent.

- FEC. The FEC for which a label request is to be sent.

- Attributes. Attributes to be included in the label request. E.g., Hop Count, Path Vector, CoS.

Additional Context:

- LSR. The LSR executing the procedure.

Algorithm:

SLRq.1 Has a label request for FEC previously been sent to Peer and is it marked as outstanding?
If so, Return success. (See Note 1.)

SLRq.2 Is status record indicating it is OK to send label requests to Peer set?
If not, goto SLRq.6

SLRq.3 Execute procedure Send_Message (Peer, Label Request, FEC, Attributes).

SLRq.4 Record label request for FEC has been sent to Peer and mark it as outstanding.

SLRq.5 Return success.

SLRq.6 Postpone the label request by recording label mapping for FEC and Attributes from Peer is needed but that no label resources are available.

SLRq.7 Return failure.

Notes:

1. If the LSR is a non-merging LSR it must distinguish between attempts to send label requests for a FEC triggered by different upstream LDP peers from duplicate requests. This procedure will not send a duplicate label request.

### A.2.3. Send_Label_Withdraw

Summary:

An LSR uses the Send_Label_Withdraw procedure to withdraw a label for a FEC from an LDP peer. To do this the LSR sends a Label Withdraw message to the peer.

Parameters:

- Peer. The LDP peer to which the label withdraw is to be sent.

- FEC. The FEC for which a label is being withdrawn.

- Label. The label being withdrawn

Additional Context:

- LSR. The LSR executing the procedure.

Algorithm:

SWd.1 Execute procedure Send_Message (Peer, Label Withdraw, FEC, Label)

SWd.2 Record label withdraw for FEC has been sent to Peer and mark it as outstanding.

### A.2.4. Send_Notification

Summary:

An LSR uses the Send_Notification procedure to send an LDP peer a notificaction message.

Parameters:

- Peer. The LDP peer to which the label withdraw is to be sent.

- Status. Status code to be included in the Notification message.

Additional Context:

None.

Algorithm:

SNt.1 Execute procedure Send_Message (Peer, Notification, Status)

### A.2.5. Send_Message

Summary:

An LSR uses the Send_Message procedure to send an LDP peer an LDP message.

Parameters:

- Peer. The LDP peer to which the message is to be sent.

- Message Type. The type of message to be sent.

- Additional message contents . . . .

Additional Context:

None.

Algorithm:

This procedure is the means by which an LSR sends an LDP message of the specified type to the specified LDP peer.

### A.2.6. Check_Received_Attributes

Summary:

Check the attributes received in a Label Mapping or Label Request message. If the attributes include a Hop Count or Path Vector, perform a loop detection check. If a loop is detected, send a Loop Detected Notification message to MsgSource.

Parameters:

- MsgSource. The LDP peer that sent the message.

- RAttributes. The attributes in the message.

Additional Context:

- LSR Id. The unique LSR Id of this LSR.

- Hop Count. The Hop Count, if any, in the received attributes.

- Path Vector. The Path Vector, if any in the received attributes.

Algorithm:

CRa.1 Do RAttributes include Hop Count?
If not, goto CRa.5.

CRa.2 Does Hop Count exceed Max allowable hop count?
If so, goto CRa.6.

CRa.3 Do RAttributes include Path Vector?
If not, goto CRa.5.

CRa.4 Does Path Vector Include LSR Id? OR
Does length of Path Vector exceed Max allowable length?
If so, goto CRa.6

CRa.5 Return No Loop Detected.

CRa.6 Execute procedure Send_Notification (MsgSource, Loop Detected)

CRa.7 Return Loop Detected.

CRa.8 DONE

### A.2.7. Prepare_Label_Request_Attributes

Summary:

This procedure is used whenever a Label Request is to be sent to a Peer to compute the Hop Count and Path Vector, if any, to include in the message.

Parameters:

- Peer. The LDP peer to which the message is to be sent.

- FEC. The FEC for which a label request is to be sent.

- RAttributes. The attributes this LSR associates with the LSP for FEC.

- SAttributes. The attributes to be included in the Label Request message.

Additional Context:

- LSR Id. The unique LSR Id of this LSR.

Algorithm:

PRqA.1 Is Hop Count required for this Peer (see Note 1.) ? OR
Do RAttributes include a Hop Count? OR
Is Loop Detection configured on LSR?
If not, goto PRqA.14.

PRqA.2 Is LSR ingress for FEC?
If not, goto PRqA.6.

PRqA.3 Include Hop Count of 1 in SAttributes.

PRqA.4 Is Loop Detection configured on LSR?
If not, goto PRqA.14.

PRqA.5 Is LSR merge-capable?
If so, goto PRqA.14.
If not, goto PRqA.13.

PRqA.6 Do RAttributes include a Hop Count?
If not, goto PRqA.8.

PRqA.7 Increment RAttributes Hop Count and copy the resulting Hop Count to SAttributes. (See Note 2.)
Goto PRqA.9.

PRqA.8 Include Hop Count of unknown (0) in SAttributes.

PRqA.9 Is Loop Detection configured on LSR?
If not, goto PRqA.14.

PRqA.10 Do RAttributes have a Path Vector?

If so, goto PRqA.12.

PRqA.11 Is LSR merge-capable?
If so, goto PRqA.14.
If not, goto PRqA.13.

PRqA.12 Add LSR Id to beginning of Path Vector from RAttributes and copy the resulting Path Vector into SAttributes.
Goto PRqA.14.

PRqA.13 Include Path Vector of length 1 containing LSR Id in SAttributes.

PRqA.14 DONE.

Notes:

1. The link with Peer may require that Hop Count be included in Label Request messages; for example, see [ATM].

2. For hop count arithmetic, unknown + 1 = unknown.

### A.2.8. Prepare_Label_Mapping_Attributes

Summary:

This procedure is used whenever a Label Mapping is to be sent to a Peer to compute the Hop Count and Path Vector, if any, to include in the message.

Parameters:

- Peer. The LDP peer to which the message is to be sent.

- FEC. The FEC for which a label request is to be sent.

- RAttributes. The attributes this LSR associates with the LSP for FEC.

- SAttributes. The attributes to be included in the Label Request message.

- IsPropagating. The LSR is sending the Label Mapping message to propagate one received from the FEC next hop.

- PrevHopCount. The Hop Count, if any, this LSR associates with the LSP for the FEC.

Additional Context:

- LSR Id. The unique LSR Id of this LSR.

Algorithm:

PMpA.1 Is Hop Count required for this Peer (see Note 1.) ? OR
Do RAttributes include a Hop Count? OR
Is Loop Detection configured on LSR?
If not, goto PMpA.19.

PMpA.2 Is LSR egress for FEC?
If not, goto PMpA.4.

PMpA.3 Include Hop Count of 1 in SAttributes. Goto PMpA.19.

PMpA.4 Do RAttributes have a Hop Count?
If not, goto PMpA.6.

PMpA.5 Increment RAttributes Hop Count and copy the resulting Hop Count to SAttributes. See Note 2. Goto PMpA.7.

PMpA.6 Include Hop Count of unknown (0) in SAttributes.

PMpA.7 Is Loop Detection configured on LSR?
If not, goto PMpA.19.

PMpA.8 Do RAttributes have a Path Vector?
If so, goto PMpA.17.

PMpA.9 Is LSR propagating a received Label Mapping?
If not, goto PMpA.18.

PMpA.10 Does LSR support merging?
If not, goto PMpA.12.

PMpA.11 Has LSR previously sent a Label Mapping for FEC to Peer?
If not, goto PMpA.18.

PMpA.12 Do RAttributes include a Hop Count?
If not, goto PMpA.19.

Res.13 Is Hop Count in Rattributes unknown(0)?
If so, goto PMpA.18.

PMpA.14 Has LSR previously sent a Label Mapping for FEC to Peer?
If not goto PMpA.19.

PMpA.15 Is Hop Count in RAttributes different from PrevHopCount ?
If not goto PMpA.19.

PMpA.16 Is the Hop Count in RAttributes > PrevHopCount? OR
Is PrevHopCount unknown(0)
If not, goto PMpA.19.

PMpA.17 Add LSR Id to beginning of Path Vector from RAttributes and copy the resulting Path Vector into SAttributes. Goto PMpA.19.

PMpA.18 Include Path Vector of length 1 containing LSR Id in SAttributes.

PMpA.19 DONE.

Notes:

1. The link with Peer may require that Hop Count be included in Label Mapping messages; for example, see [ATM].

2. For hop count arithmetic, unknown + 1 = unknown.