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Fault Tolerance for the Label Distribution Protocol (LDP)

Status of this Memo

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IESG Note

This specification includes procedures for failure detection and failover for a TCP connection carrying MPLS LDP control traffic, so that it can be switched to a new TCP connection. It does not provide a general approach to using multiple TCP connections to provide this kind of fault tolerance. The specification lacks adequate guidance for the timer and retry value choices related to the TCP connection fault tolerance procedures. The specification should not serve as a model for TCP connection fault tolerance design for any future document, and users are advised to test configurations based on this specification very carefully for problems such as premature failovers.

Abstract

Multiprotocol Label Switching (MPLS) systems will be used in core networks where system downtime must be kept to an absolute minimum. Many MPLS Label Switching Routers (LSRs) may, therefore, exploit Fault Tolerant (FT) hardware or software to provide high availability of the core networks.

The details of how FT is achieved for the various components of an FT LSR, including Label Distribution Protocol (LDP), the switching hardware and TCP, are implementation specific. This document identifies issues in the LDP specification in RFC 3036, "LDP Specification", that make it difficult to implement an FT LSR using the current LDP protocols, and defines enhancements to the LDP specification to ease such FT LSR implementations.

The issues and extensions described here are equally applicable to RFC 3212, "Constraint-Based LSP Setup Using LDP" (CR-LDP).

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1. Conventions and Terminology used in this document

Definitions of key words and terms applicable to LDP and CR-LDP are inherited from [RFC3212] and [RFC3036].

The term "FT Label" is introduced in this document to indicate a label for which some fault tolerant operation is used. A "non-FT Label" is not fault tolerant and is handled as specified in [RFC3036].

The term "Sequence Numbered FT Label" is used to indicate an FT label which is secured using the sequence number in the FT Protection TLV described in this document.

The term "Check-Pointable FT Label" is used to indicate an FT label which is secured by using the check-pointing techniques described in this document.

The extensions to LDP specified in this document are collectively referred to as the "LDP FT enhancements".

Within the context of this document, "Check-Pointing" refers to a process of message exchanges that confirm receipt and processing (or secure storage) of specific protocol messages.

When talking about the individual bits in the 16-bit FT Flag Field, the words "bit" and "flag" are used interchangeably.

In the examples quoted, the following notation is used: Ln : An LSP. For example L1. Pn : An LDP peer. For example P1.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14, RFC 2119 [RFC2119].

2. Contributing Authors

This document was the collective work of several individuals over a period of several years. The text and content of this document was contributed by the editor and the co-authors listed in section 15, "Authors' Addresses".

3. Introduction

High Availability (HA) is typically claimed by equipment vendors when their hardware achieves availability levels of at least 99.999% (five 9s). To implement this, the equipment must be capable of recovering from local hardware and software failures through a process known as fault tolerance (FT).

The usual approach to FT involves provisioning backup copies of hardware and/or software. When a primary copy fails, processing is switched to the backup copy. This process, called failover, should result in minimal disruption to the Data Plane.

In an FT system, backup resources are sometimes provisioned on a one-to-one basis (1:1), sometimes as one-to-many (1:n), and occasionally as many-to-many (m:n). Whatever backup provisioning is made, the system must switch to the backup automatically on failure of the primary, and the software and hardware state in the backup must be set to replicate the state in the primary at the point of failure.

3.1. Fault Tolerance for MPLS

MPLS is a technology that will be used in core networks where system downtime must be kept to an absolute minimum. Many MPLS LSRs may, therefore, exploit FT hardware or software to provide high availability of core networks.

In order to provide HA, an MPLS system needs to be able to survive a variety of faults with minimal disruption to the Data Plane, including the following fault types:

- failure/hot-swap of a physical connection between LSRs.

- failure/hot-swap of the switching fabric in an LSR.

- failure of the TCP or LDP stack in an LSR.

- software upgrade to the TCP or LDP stacks in an LSR.

The first two examples of faults listed above are confined to the Data Plane. Such faults can be handled by providing redundancy in the Data Plane which is transparent to LDP operating in the Control Plane. The last two example types of fault require action in the Control Plane to recover from the fault without disrupting traffic in the Data Plane. This is possible because many recent router architectures separate the Control and Data Planes such that forwarding can continue unaffected by recovery action in the Control Plane.

3.2. Issues with LDP

LDP uses TCP to provide reliable connections between LSRs over which they exchange protocol messages to distribute labels and set up LSPs. A pair of LSRs that have such a connection are referred to as LDP peers.

TCP enables LDP to assume reliable transfer of protocol messages. This means that some of the messages do not need to be acknowledged (for example, Label Release).

LDP is defined such that if the TCP connection fails, the LSR should immediately tear down the LSPs associated with the session between the LDP peers, and release any labels and resources assigned to those LSPs.

It is notoriously hard to provide a Fault Tolerant implementation of TCP. To do so might involve making copies of all data sent and received. This is an issue familiar to implementers of other TCP applications such as BGP.

During failover affecting the TCP or LDP stacks, the TCP connection may be lost. Recovery from this position is made worse by the fact that LDP control messages may have been lost during the connection failure. Since these messages are unconfirmed, it is possible that LSP or label state information will be lost.

This document describes a solution which involves:

- negotiation between LDP peers of the intent to support extensions to LDP that facilitate recovery from failover without loss of LSPs.

- selection of FT survival on a per LSP/label basis.

- acknowledgement of LDP messages to ensure that a full handshake is performed on those messages either frequently (such as per message) or less frequently as in check-pointing.

- solicitation of up-to-date acknowledgement (check-pointing) of previous LDP messages to ensure the current state is flushed to disk/NVRAM, with an additional option that allows an LDP partner to request that state is flushed in both directions if graceful shutdown is required.

- re-issuing lost messages after failover to ensure that LSP/label state is correctly recovered after reconnection of the LDP session.

The issues and objectives described above are equally applicable to CR-LDP.

Other objectives of this document are to:

- offer backward-compatibility with LSRs that do not implement these extensions to LDP.

- preserve existing protocol rules described in [RFC3036] for handling unexpected duplicate messages and for processing unexpected messages referring to unknown LSPs/labels.

- avoid full state refresh solutions (such as those present in RSVP: see [RFC2205], [RFC2961], [RFC3209] and [RFC3478]) whether they be continual, or limited to post-failover recovery.

Note that this document concentrates on the preservation of label state for labels exchanged between a pair of adjacent LSRs when the TCP connection between those LSRs is lost. This is a requirement for Fault Tolerant operation of LSPs, but a full implementation of end-to-end protection for LSPs requires that this be combined with other techniques that are outside the scope of this document.

In particular, this document does not attempt to describe how to modify the routing of an LSP or the resources allocated to a label or LSP, which is covered by [RFC3214]. This document also does not

address how to provide automatic layer 2 or layer 3 protection switching for a label or LSP, which is a separate area for study.

This specification does not preclude an implementation from attempting (or require it to attempt) to use the FT behavior described here to recover from a preemptive failure of a connection on a non-FT system due to, for example, a partial system crash. Note, however, that there are potential issues too numerous to list here - not least the likelihood that the same crash will immediately occur when processing the restored data.

4. Overview of LDP FT Enhancements

The LDP FT enhancements consist of the following main elements, which are described in more detail in the sections that follow.

- The presence of an FT Session TLV on the LDP Initialization message indicates that an LSR supports some form of protection or recovery from session failure. A flag bit within this TLV (the S bit) indicates that the LSR supports the LDP FT enhancements on this session. Another flag (the C bit) indicates that the check-pointing procedures are to be used.

- An FT Reconnect Flag in the FT Session TLV (the R bit) indicates whether an LSR has preserved FT Label state across a failure of the TCP connection.

- An FT Reconnection Timeout, exchanged on the LDP Initialization message, that indicates the maximum time peer LSRs will preserve FT Label state after a failure of the TCP connection.

- An FT Protection TLV used to identify operations that affect LDP labels. All LDP messages carrying the FT Protection TLV need to be secured (e.g. to NVRAM) and ACKed to the sending LDP peer so that the state for Sequence Numbered FT Labels can be correctly recovered after LDP session reconnection.

  Note that the implementation within an FT system is left open by this document. An implementation could choose to secure entire messages relating to Sequence Numbered FT Labels, or it could secure only the relevant state information.

- Address advertisement may also be secured by use of the FT Protection TLV. This enables recovery after LDP session reconnection without the need to re-advertise what may be a very large number of addresses.

- The FT Protection TLV may also be used on the Keepalive message to flush acknowledgement of all previous FT operations. This enables a check-point for future recovery, either in mid-session or prior to graceful shutdown of an LDP session. This procedure may also be used to check-point all (that is both FT and non-FT) operations for future recovery.

4.1. Establishing an FT LDP Session

In order that the extensions to LDP [RFC3036] described in this document can be used successfully on an LDP session between a pair of LDP peers, they MUST negotiate that the LDP FT enhancements are to be used on the LDP session.

This is done on the LDP Initialization message exchange using a new FT Session TLV. Presence of this TLV indicates that the peer wants to support some form of protection or recovery processing. The S bit within this TLV indicates that the peer wants to support the LDP FT enhancements on this LDP session. The C bit indicates that the peer wants to support the check-pointing functions described in this document. The S and C bits may be set independently.

The relevant LDP FT enhancements MUST be supported on an LDP session if both LDP peers include an FT Session TLV on the LDP Initialization message and have the same setting of the S or C bit.

If either LDP Peer does not include the FT Session TLV LDP Initialization message, or if there is no match of S and C bits between the peers, the LDP FT enhancements MUST NOT be used during this LDP session. Use of LDP FT enhancements by a sending LDP peer in these cases MUST be interpreted by the receiving LDP peer as a serious protocol error causing the session to be terminated.

An LSR MAY present different FT/non-FT behavior on different TCP connections, even if those connections are successive instantiations of the LDP session between the same LDP peers.

4.1.1 Interoperation with Non-FT LSRs

The FT Session TLV on the LDP Initialization message carries the U-bit. If an LSR does not support any protection or recovery mechanisms, it will ignore this TLV. Since such partners also do not include the FT Session TLV, all LDP sessions to such LSRs will not use the LDP FT enhancements.

The rest of this document assumes that the LDP sessions under discussion are between LSRs that support the LDP FT enhancements, except where explicitly stated otherwise.

4.2. TCP Connection Failure

4.2.1 Detecting TCP Connection Failures

TCP connection failures may be detected and reported to the LDP component in a variety of ways. These should all be treated in the same way by the LDP component.

- Indication from the management component that a TCP connection or underlying resource is no longer active.
- Notification from a hardware management component of an interface failure.
- Sockets keepalive timeout.
- Sockets send failure.
- New (incoming) Socket opened.
- LDP protocol timeout.

4.2.2 LDP Processing after Connection Failure

If the LDP FT enhancements are not in use on an LDP session, the action of the LDP peers on failure of the TCP connection is as specified in [RFC3036].

All state information and resources associated with non-FT Labels MUST be released on the failure of the TCP connection, including deprogramming the non-FT Label from the switching hardware. This is equivalent to the behavior specified in [RFC3036].

If the LDP FT enhancements are in use on an LDP session, both LDP peers SHOULD preserve state information and resources associated with FT Labels exchanged on the LDP session. Both LDP peers SHOULD use a timer to release the preserved state information and resources associated with FT-labels if the TCP connection is not restored within a reasonable period. The behavior when this timer expires is equivalent to the LDP session failure behavior described in [RFC3036].

The FT Reconnection Timeout each LDP peer intends to apply to the LDP session is carried in the FT Session TLV on the LDP Initialization messages. Both LDP peers MUST use the value that corresponds to the lesser timeout interval of the two proposed timeout values from the LDP Initialization exchange, where a value of zero is treated as positive infinity.

4.3. Data Forwarding During TCP Connection Failure

An LSR that implements the LDP FT enhancements SHOULD preserve the programming of the switching hardware across a failover. This ensures that data forwarding is unaffected by the state of the TCP connection between LSRs.

It is an integral part of FT failover processing in some hardware configurations that some data packets might be lost. If data loss is not acceptable to the applications using the MPLS network, the LDP FT enhancements described in this document SHOULD NOT be used.

4.4. FT LDP Session Reconnection

When a new TCP connection is established, the LDP peers MUST exchange LDP Initialization messages. When a new TCP connection is established after failure, the LDP peers MUST re-exchange LDP Initialization messages.

If an LDP peer includes the FT Session TLV with the S bit set in the LDP Initialization message for the new instantiation of the LDP session, it MUST also set the FT Reconnect Flag according to whether it has been able to preserve label state. The FT Reconnect Flag is carried in the FT Session TLV.

If an LDP peer has preserved all state information for previous instantiations of the LDP session, then it SHOULD set the FT Reconnect Flag to 1 in the FT Session TLV. Otherwise, it MUST set the FT Reconnect Flag to 0.

If either LDP peer sets the FT Reconnect Flag to 0, or omits the FT Session TLV, both LDP peers MUST release any state information and resources associated with the previous instantiation of the LDP session between the same LDP peers, including FT Label state and Addresses. This ensures that network resources are not permanently lost by one LSR if its LDP peer is forced to undergo a cold start.

If an LDP peer changes any session parameters (for example, the label space bounds) from the previous instantiation, the nature of any preserved labels may have changed. In particular, previously allocated labels may now be out of range. For this reason, session reconnection MUST use the same parameters as were in use on the session before the failure. If an LDP peer notices that the parameters have been changed by the other peer, it SHOULD send a Notification message with the 'FT Session parameters changed' status code.

If both LDP peers set the FT Reconnect Flag to 1, both LDP peers MUST use the procedures indicated in this document to complete any label operations on Sequence Numbered FT Labels that were interrupted by the LDP session failure.

If an LDP peer receives an LDP Initialization message with the FT Reconnect Flag set before it sends its own Initialization message, but has retained no information about the previous version of the session, it MUST respond with an Initialization message with the FT Reconnect Flag clear. If an LDP peer receives an LDP Initialization message with the FT Reconnect Flag set in response to an Initialization message that it has sent with the FT Reconnect Flag clear, it MUST act as if no state was retained by either peer on the session.

4.5. Operations on FT Labels

Label operations on Sequence Numbered FT Labels are made Fault Tolerant by providing acknowledgement of all LDP messages that affect Sequence Numbered FT Labels. Acknowledgements are achieved by means of sequence numbers on these LDP messages.

The message exchanges used to achieve acknowledgement of label operations and the procedures used to complete interrupted label operations are detailed in section 5, "FT Operations".

Using these acknowledgements and procedures, it is not necessary for LDP peers to perform a complete re-synchronization of state for all Sequence Numbered FT Labels, either on re-connection of the LDP session between the LDP peers or on a timed basis.

4.6. Check-Pointing

Check-pointing is a useful feature that allows nodes to reduce the amount of processing that they need to do to acknowledge LDP messages. The C bit in the FT Session TLV is used to indicate that check-pointing is supported.

Under the normal operation on Sequence Numbered FT Labels, acknowledgments may be deferred during normal processing and only sent periodically. Check-pointing may be used to flush acknowledgement from a peer by including a sequence number on a Keepalive message requesting acknowledgement of that message and all previous messages. In this case, all Sequence Numbered FT Labels are Check-Pointable FT Labels.

If the S bit is not agreed upon, check-pointing may still be used. In this case it is used to acknowledge all messages exchanged between the peers, and all labels are Check-Pointable FT Labels.

This offers an approach where acknowledgements need not be sent to every message or even frequently, but are only sent as check-points in response to requests carried on Keepalive messages. Such an approach may be considered optimal in systems that do not show a high degree of change over time (such as targeted LDP sessions) and that are prepared to risk loss of state for the most recent LDP exchanges. More dynamic systems (such as LDP discovery sessions) are more likely to want to acknowledge state changes more frequently so that the maximum amount of state can be preserved over a failure.

Note that an important consideration of this document is that nodes acknowledging messages on a one-for-one basis, nodes deferring acknowledgements, and nodes relying on check-pointing, should all interoperate seamlessly and without protocol negotiation beyond session initialization.

Further discussion of this feature is provided in section 5, "FT Operations".

4.6.1 Graceful Termination

A feature that builds on check-pointing is graceful termination.

In some cases, such as controlled failover or software upgrade, it is possible for a node to know in advance that it is going to terminate its session with a peer.

In these cases the node that intends terminating the session can flush acknowledgement using a check-point request as described above. The sender SHOULD not send further label or address-related messages after requesting shutdown check-pointing in order to preserve the integrity of its saved state.

This, however, only provides for acknowledgement in one direction, and the node that is being terminated also requires verification that it has secured all state sent by its peer. This is achieved by a three-way hand shake of the check-point which is requested by an additional TLV (the Cork TLV) in the Keepalive message.

Further discussion of this feature is provided in section 5, "FT Operations".

4.7. Label Space Depletion and Replenishment

When an LDP peer is unable to satisfy a Label Request message because it has no more available labels, it sends a Notification message carrying the status code 'No label resources'. This warns the requesting LDP peer that subsequent Label Request messages are also likely to fail for the same reason. This message does not need to be acknowledged for FT purposes since Label Request messages sent after session recovery will receive the same response. However, the LDP peer that receives a 'No label resources' Notification stops sending Label Request messages until it receives a 'Label resources available' Notification message. Since this unsolicited Notification might get lost during session failure, it may be protected using the procedures described in this document.

An alternative approach allows that an implementation may always assume that labels are available when a session is re-established. In this case, it is possible that it may throw away the 'No label resources' information from the previous incarnation of the session and may send a batch of LDP messages on session re-establishment that will fail and that it could have known would fail.

Note that the sender of a 'Label resources available' Notification message may choose whether to add a sequence number requesting acknowledgement. Conversely, the receiver of 'Label resources available' Notification message may choose to acknowledge the message without actually saving any state.

This is an implementation choice made possible by making the FT parameters on the Notification message optional. Implementations will interoperate fully if they take opposite approaches, but additional LDP messages may be sent unnecessarily on session recovery.

4.8. Tunneled LSPs

The procedures described in this document can be applied to LSPs that are tunnels and to LSPs that are carried by tunnels. Recall that tunneled LSPs are managed by a single LDP session that runs end to end, while the tunnel is managed by a different LDP session for each hop along the path. Nevertheless, a break in one of the sessions that manages the tunnel is likely to correspond with a break in the session that manages the tunneled LSP. This is certainly the case when the LDP exchanges share a failed link, but need not be the case if the LDP messages have been routed along a path that is different from that of the tunnel, or if the failure in the tunnel is caused by an LDP software failure at a transit LSR.

In order that the forwarding path of a tunneled LSP be preserved, the forwarding path of the tunnel itself must be preserved. This means that the tunnel must not be torn down if there is any session failure along its path. To achieve this, the label exchanges between each pair of LDP peers along the path of the tunnel must use one of the procedures in this document or in [RFC3478].

It is perfectly acceptable to mix the restart procedures used for the tunnel and the tunneled LSP. For example, the tunnel could be set up using just check-pointing because it is a stable LSP, but the tunneled LSPs might use full FT procedures so that they can recover active state.

Lastly, it is permissible to carry tunneled LSPs that do not have FT protection in an LSP that has FT protection.

5. FT Operations

Once an FT LDP session has been established, using the S bit in the FT Session TLV on the Session Initialization message as described in section 4.1, "Establishing an FT LDP Session", both LDP peers MUST apply the procedures described in this section for FT LDP message exchanges.

If the LDP session has been negotiated to not use the LDP FT enhancements, these procedures MUST NOT be used.

5.1. FT LDP Messages

5.1.1 Sequence Numbered FT Label Messages

A label is identified as being a Sequence Numbered FT Label if the initial Label Request or Label Mapping message relating to that label carries the FT Protection TLV.

It is a valid implementation option to flag all labels as Sequence Numbered FT Labels. Indeed this may be a preferred option for implementations wishing to use Keepalive messages carrying the FT Protection TLV to achieve periodic saves of the complete label forwarding state.

If a label is a Sequence Numbered FT Label, all LDP messages affecting that label MUST carry the FT Protection TLV so that the state of the label can be recovered after a failure of the LDP session.

A further valid option is for no labels to be Sequence Numbered FT Labels. In this case, check-pointing using the Keepalive message applies to all messages exchanged on the session.

5.1.1.1 Scope of FT Labels

The scope of the FT/non-FT status of a label is limited to the LDP message exchanges between a pair of LDP peers.

In Ordered Control, when the message is forwarded downstream or upstream, the TLV may be present or absent according to the requirements of the LSR sending the message.

If a platform-wide label space is used for FT Labels, an FT Label value MUST NOT be reused until all LDP FT peers to which the label was passed have acknowledged the withdrawal of the FT Label, either by an explicit LABEL WITHDRAW/LABEL RELEASE, exchange or implicitly if the LDP session is reconnected after failure but without the FT Reconnect Flag set. In the event that a session is not re-established within the Reconnection Timeout, a label MAY become available for re-use if it is not still in use on some other session.

5.1.2 FT Address Messages

If an LDP session uses the LDP FT enhancements, both LDP peers MUST secure Address and Address Withdraw messages using FT Operation ACKs, as described below. This avoids any ambiguity over whether an Address is still valid after the LDP session is reconnected.

If an LSR determines that an Address message it sent on a previous instantiation of a recovered LDP session is no longer valid, it MUST explicitly issue an Address Withdraw for that address when the session is reconnected.

If the FT Reconnect Flag is not set by both LDP peers upon reconnection of an LDP session (i.e. state has not been preserved), both LDP peers MUST consider all Addresses to have been withdrawn. The LDP peers SHOULD issue new Address messages for all their valid addresses, as specified in [RFC3036].

5.1.3 Label Resources Available Notifications

In LDP, it is possible that a downstream LSR may not have labels available to respond to a Label Request. In this case, as specified in RFC 3036, the downstream LSR must respond with a Notification - No Label Resources message. The upstream LSR then suspends asking for new labels until it receives a Notification - Label Resources Available message from the downstream LSR.

When the FT extensions are used on a session, implementations may choose whether or not to secure the label resource state of their peer. This choice impacts the number of LDP messages that will be incorrectly routed to a peer with depleted resources on session re-establishment, but does not otherwise impact interoperability.

For full preservation of state:

- The downstream LSR must preserve the label availability state across a failover so that it remembers to send Notification - Label Resources Available when the resources become available.

- The upstream LSR must recall the label availability state across failover so that it can optimize not sending Label Requests when it recovers.

- The downstream LSR must use sequence numbers on Notification - Label Resources Available so that it can check that LSR A has received the message and clear its secured state, or resend the message if LSR A recovers without having received it.

However, the following options also exist:

- The downstream LSR may choose to not include a sequence number on Notification - Label Resources Available. This means that on session re-establishment it does not know what its peer thinks the LSR's resource state is, because the Notification may or may not have been delivered. Such an implementation MUST begin recovered sessions by sending an additional Notification - Label Resources Available to reset its peer.

- The upstream node may choose not to secure information about its peer's resource state. It would acknowledge a Notification - Label Resources Available, but would not save the information. Such an implementation MUST assume that its peer's resource state has been reset to Label Resources Available when the session is re-established.

If the FT Reconnect Flag is not set by both LDP peers upon reconnection of an LDP session (i.e. state has not been preserved), both LDP peers MUST consider the label availability state to have been reset as if the session had been set up for the first time.

5.2. FT Operation ACKs

Handshaking of FT LDP messages is achieved by use of ACKs. Correlation between the original message and the ACK is by means of the FT Sequence Number contained in the FT Protection TLV, and passed back in the FT ACK TLV. The FT ACK TLV may be carried on any LDP message that is sent on the TCP connection between LDP peers.

An LDP peer maintains a separate FT sequence number for each LDP session in which it participates. The FT Sequence number is incremented by one for each FT LDP message (i.e. containing the FT Protection TLV) issued by this LSR on the FT LDP session with which the FT sequence number is associated.

When an LDP peer receives a message containing the FT Protection TLV, it MUST take steps to secure this message (or the state information derived from processing the message). Once the message is secured, it MUST be ACKed. However, there is no requirement on the LSR to send this ACK immediately.

ACKs may be accumulated to reduce the message flow between LDP peers. For example, if an LSR received FT LDP messages with sequence numbers 1, 2, 3, 4, it could send a single ACK with sequence number 4 to ACK receipt, securing of all these messages. There is no protocol reason why the number of ACKs accumulated, or the time for which an ACK is deferred, should not be allowed to become relatively large.

ACKs MUST NOT be sent out of sequence, as this is incompatible with the use of accumulated ACKs. Duplicate ACKs (that is two successive messages that acknowledge the same sequence number) are acceptable.

If an LDP peer discovers that its sequence number space for a specific session is full of un-acknowledged sequence numbers (because its partner on the session has not acknowledged them in a timely way), it cannot allocate a new sequence number for any further FT LPD message. It SHOULD send a Notification message with the status code 'FT Seq Numbers Exhausted'.

5.3. Preservation of FT State

If the LDP FT enhancements are in use on an LDP session, each LDP peer SHOULD NOT release the state information and resources associated with FT Labels exchanged on that LDP session when the TCP connection fails. This is contrary to [RFC3036], but allows label operations on FT Labels to be completed after re-connection of the TCP connection.

Both LDP peers on an LDP session that is using the LDP FT enhancements SHOULD preserve the state information and resources they hold for that LDP session as described below.

- An upstream LDP peer SHOULD release the resources (in particular bandwidth) associated with a Sequence Numbered FT Label when it initiates a Label Release or Label Abort message for the label. The upstream LDP peer MUST preserve state information for the Sequence Numbered FT Label, even if it releases the resources associated with the label, as it may need to reissue the label operation if the TCP connection is interrupted.

- An upstream LDP peer MUST release the state information and resources associated with a Sequence Numbered FT Label when it receives an acknowledgement to a Label Release or Label Abort message that it sent for the label, or when it sends a Label Release message in response to a Label Withdraw message received from the downstream LDP peer.

- A downstream LDP peer SHOULD NOT release the resources associated with a Sequence Numbered FT Label when it sends a Label Withdraw message for the label as it has not yet received confirmation that the upstream LDP peer has ceased to send data using the label. The downstream LDP peer MUST NOT release the state information it holds for the label as it may yet have to reissue the label operation if the TCP connection is interrupted.

- A downstream LDP peer MUST release the resources and state information associated with a Sequence Numbered FT Label when it receives an acknowledgement to a Label Withdraw message for the label.

- When the FT Reconnection Timeout expires, an LSR SHOULD release all state information and resources from previous instantiations of the (permanently) failed LDP session.

- Either LDP peer MAY elect to release state information based on its internal knowledge of the loss of integrity of the state information or an inability to pend (or queue) LDP operations (as described in section 5.4.1, "LDP Operations During TCP Failure") during a TCP failure. That is, the peer is not required to wait for the duration of the FT Reconnection Timeout before releasing state; the timeout provides an upper limit on the persistence of state. However, in the event that a peer releases state before the expiration of the Reconnection Timeout, it MUST NOT re-use any label that was in use on the session until the Reconnection Timeout has expired.

- When an LSR receives a Status TLV with the E-bit set in the status code, which causes it to close the TCP connection, the LSR MUST release all state information and resources associated with the session. This behavior is mandated because it is impossible for the LSR to predict the precise state and future behavior of the partner LSR that set the E-bit without knowledge of the implementation of that partner LSR.

  Note that the 'Temporary Shutdown' status code does not have the E-bit set, and MAY be used during maintenance or upgrade operations to indicate that the LSR intends to preserve state across a closure and re-establishment of the TCP session.

- If an LSR determines that it must release state for any single FT Label during a failure of the TCP connection on which that label was exchanged, it MUST release all state for all labels on the LDP session.

The release of state information and resources associated with non-FT labels is as described in [RFC3036].

Note that a Label Release and the acknowledgement to a Label Withdraw may be received by a downstream LSR in any order. The downstream LSR MAY release its resources upon receipt of the first message and MUST release its resources upon receipt of the second message.

5.4. FT Procedure After TCP Failure

When an LSR discovers or is notified of a TCP connection failure it SHOULD start an FT Reconnection Timer to allow a period for re-connection of the TCP connection between the LDP peers.

The RECOMMENDED default value for this timer is 5 seconds. During this time, failure must be detected and reported, new hardware may need to be activated, software state must be audited, and a new TCP session must be set up.

Once the TCP connection between LDP peers has failed, the active LSR SHOULD attempt to re-establish the TCP connection. The mechanisms, timers and retry counts to re-establish the TCP connection are an implementation choice. It is RECOMMENDED that any attempt to re-establish the connection should take into account the failover processing necessary on the peer LSR, the nature of the network between the LDP peers, and the FT Reconnection Timeout chosen on the previous instantiation of the TCP connection (if any).

If the TCP connection cannot be re-established within the FT Reconnection Timeout period, the LSR detecting this timeout SHOULD release all state preserved for the failed LDP session. If the TCP connection is subsequently re-established (for example, after a further Hello exchange to set up a new LDP session), the LSR MUST set the FT Reconnect Flag to 0 if it released the preserved state information on this timeout event.

If the TCP connection is successfully re-established within the FT Reconnection Timeout, both peers MUST re-issue LDP operations that were interrupted by (that is, un-acknowledged as a result of) the TCP connection failure. This procedure is described in section 5.5, "FT Procedure After TCP Re-connection".

The Hold Timer for an FT LDP Session (see [RFC3036] section 2.5.5) SHOULD be ignored while the FT Reconnection Timer is running. The hold timer SHOULD be restarted when the TCP connection is re-established.

5.4.1 FT LDP Operations During TCP Failure

When the LDP FT enhancements are in use for an LDP session, it is possible for an LSR to determine that it needs to send an LDP message to an LDP peer, but that the TCP connection to that peer is currently down. These label operations affect the state of FT Labels preserved for the failed TCP connection, so it is important that the state changes are passed to the LDP peer when the TCP connection is restored.

If an LSR determines that it needs to issue a new FT LDP operation to an LDP peer to which the TCP connection is currently failed, it MUST pend the operation (e.g. on a queue) and complete that operation with the LDP peer when the TCP connection is restored, unless the label operation is overridden by a subsequent additional operation during the TCP connection failure (see section 5.5, "FT Procedure After TCP Re-connection").

If, during TCP Failure, an LSR determines that it cannot pend an operation which it cannot simply fail (for example, a Label Withdraw, Release or Abort operation), it MUST NOT attempt to re-establish the previous LDP session. The LSR MUST behave as if the Reconnection Timer expired and release all state information with respect to the LDP peer. An LSR may be unable (or unwilling) to pend operations; for instance, if a major routing transition occurred while TCP was inoperable between LDP peers, it might result in excessively large numbers of FT LDP Operations. An LSR that releases state before the expiration of the Reconnection Timeout MUST NOT re-use any label that was in use on the session until the Reconnection Timeout has expired.

In ordered operation, received FT LDP operations that cannot be correctly forwarded because of a TCP connection failure MAY be processed immediately (provided sufficient state is kept to forward the label operation) or pended for processing when the onward TCP connection is restored and the operation can be correctly forwarded upstream or downstream. Operations on existing FT Labels SHOULD NOT be failed during TCP session failure.

It is RECOMMENDED that Label Request operations for new FT Labels not be pended awaiting the re-establishment of TCP connection that is awaiting recovery at the time the LSR determines that it needs to issue the Label Request message. Instead, such Label Request operations SHOULD be failed and, if necessary, a notification message containing the 'No LDP Session' status code sent upstream.

Label Requests for new non-FT Labels MUST be rejected during TCP connection failure, as specified in [RFC3036].

5.5. FT Procedure After TCP Re-connection

The FT operation handshaking described above means that all state changes for Sequence Numbered FT Labels and Address messages are confirmed or reproducible at each LSR.

If the TCP connection between LDP peers fails but is re-connected within the FT Reconnection Timeout, and both LSRs have indicated they will be re-establishing the previous LDP session, both LDP peers on the connection MUST complete any label operations for Sequence Numbered FT Labels that were interrupted by the failure and re-connection of the TCP connection.

The procedures for FT Reconnection Timeout MAY have been invoked as a result of either LDP peer being unable (or unwilling) to pend operations which occurred during the TCP Failure (as described in section 5.4.1, "LDP Operations During TCP Failure").

If, for any reason, an LSR has been unable to pend operations with respect to an LDP peer, as described in section 5.4.1, "LDP Operations During TCP Failure", the LSR MUST set the FT Reconnect Flag to 0 on re-connection to that LDP peer indicating that no FT state has been preserved.

Label operations are completed using the following procedure.

5.5.1 Re-Issuing FT Messages

Upon restoration of the TCP connection between LDP peers, any LDP messages for Sequence Numbered FT Labels that were lost because of the TCP connection failure are re-issued. The LDP peer that receives a re-issued message processes the message as if received for the first time.

"Net-zero" combinations of messages need not be re-issued after re-establishment of the TCP connection between LDP peers. This leads to the following rules for re-issuing messages that are not ACKed by the LDP peer on the LDP Initialization message exchange after re-connection of the TCP session.

- A Label Request message MUST be re-issued unless a Label Abort would be re-issued for the same Sequence Numbered FT Label.

- A Label Mapping message MUST be re-issued unless a Label Withdraw message would be re-issued for the same Sequence Numbered FT Label.

- All other messages on the LDP session that were sent and carried the FT Protection TLV MUST be re-issued if an acknowledgement was not previously been received.

Any FT Label operations that were pended (see section 5.4.1, "LDP Operations During TCP Failure") during the TCP connection failure MUST also be issued upon re-establishment of the LDP session, except where they form part of a "net-zero" combination of messages according to the above rules.

The determination of "net-zero" FT Label operations according to the above rules MAY be performed on pended messages prior to the re-establishment of the TCP connection in order to optimize the use of queue resources. Messages that were sent to the LDP peer before the TCP connection failure, or pended messages that were paired with them, MUST NOT be subject to such optimization until an FT ACK TLV is received from the LDP peer. This ACK allows the LSR to identify which messages were received by the LDP peer prior to the TCP connection failure.

6. Check-Pointing Procedures

Check-Pointing can be selected independently from the FT procedures described above by using the C bit in the FT Session TLV on the Session Initialization message. Note, however, that check-pointing is an integral part of the FT procedures. Setting the S and the C bit will achieve the same function as setting just the S bit.

If the C bit is set, but the S bit is not set, no label is a Sequence Numbered FT Label. Instead, all labels are Check-Pointable FT Labels. Check-Pointing is used to synchronize all label exchanges. No message, apart from the check-point request and acknowledgement, carries an active sequence number. (Note that the Session Initialization message may carry a sequence number to confirm that the check-point is still in place).

It is an implementation matter to decide the ordering of received messages and check-point requests to ensure that check-point acknowledgements are secured.

If the S and C bits are both set, or only the S bit is set, check-pointing applies only to Sequence Numbered FT Labels and to address messages.

The set of all messages check-pointed in this way is called the Check-Pointable Messages.

6.1 Check-Pointing with the Keepalive Message

If an LSR receives a FT Protection TLV on a Keepalive message, this is a request to flush the acknowledgements for all previously received Check-Pointable Messages on the session.

As soon as the LSR has completed securing the Check-Pointable Messages (or state changes consequent on those messages) received before the Keepalive, it MUST send an acknowledgement to the sequence number of the Keepalive message.

In the case where the FT procedures are in use and acknowledgements have been stored up, this may occur immediately upon receipt of the Keepalive.

An example message flow showing this use of the Keepalive message to perform a periodic check-point of state is shown in section 9.2, "Use of Check-Pointing With FT Procedures".

An example message flow showing the use of check-pointing without the FT procedures is shown in section 9.5, "Check-Pointing Without FT Procedures".

6.2 Quiesce and Keepalive

If the Keepalive Message also contains the FT Cork TLV, this indicates that the peer LSR wishes to quiesce the session prior to a graceful restart.

It is RECOMMENDED that upon receiving a Keepalive with the FT CORK TLV, an LSR should cease to send any further label or address related messages on the session until it has been disconnected and reconnected, other than messages generated while processing and securing previously unacknowledged messages received from the peer requesting the quiesce. It should also attempt to complete this processing and return a Keepalive with the FT ACK TLV as soon as possible in order to allow the session to be quiesced.

An example message flow showing this use of the FT Cork TLV to achieve a three-way handshake of state synchronization between two LDP peers is given in section 9.4, "Temporary Shutdown With FT Procedures and Check-Pointing".

7. Changes to Existing Messages

7.1. LDP Initialization Message

The LDP FT enhancements add the following optional parameters to a LDP Initialization message:

Optional Parameter	Length	Value
FT Session TLV	4	See Below
FT ACK TLV	4	See Below

The encoding for these TLVs is found in Section 8, "New Fields and Values".

FT Session TLV
If present, specifies the FT behavior of the LDP session.

FT ACK TLV
If present, specifies the last FT message that the sending LDP peer was able to secure prior to the failure of the previous instantiation of the LDP session. This TLV is only present if the FT Reconnect flag is set in the FT Session TLV, in which case this TLV MUST be present.

7.2. LDP Keepalive Messages

The LDP FT enhancements add the following optional parameters to a LDP Keepalive message:

Optional Parameter	Length	Value
FT Protection TLV	4	See below
FT Cork TLV	0	See below
FT ACK TLV	4	See below

The encoding for these TLVs is found in Section 8, "New Fields and Values".

FT Protection TLV
: If present, specifies the FT Sequence Number for the LDP message. When present on a Keepalive message, this indicates a solicited flush of the acknowledgements to all previous LDP messages containing sequence numbers and issued by the sender of the Keepalive on the same session.

FT Cork TLV
: Indicates that the remote LSR wishes to quiesce the LDP session. See section 5, "FT Operations", for the recommended action in such cases.

FT ACK TLV
: If present, specifies the most recent FT message that the sending LDP peer has been able to secure.

7.3. All Other LDP Session Messages

The LDP FT enhancements add the following optional parameters to all other message types that flow on an LDP session after the LDP Initialization message

Optional Parameter	Length	Value
FT Protection TLV	4	See below
FT ACK TLV	4	See below

The encoding for these TLVs is found in section 8, "New Fields and Values".

FT Protection TLV
: If present, specifies the FT Sequence Number for the LDP message.

FT ACK TLV
If present, identifies the most recent FT LDP message ACKed by the sending LDP peer.

8. New Fields and Values

8.1. Status Codes

The following new status codes are defined to indicate various conditions specific to the LDP FT enhancements. These status codes are carried in the Status TLV of a Notification message.

The "E" column is the required setting of the Status Code E-bit; the "Status Data" column is the value of the 30-bit Status Data field in the Status Code TLV.

Note that the setting of the Status Code F-bit is at the discretion of the LSR originating the Status TLV. However, it is RECOMMENDED that the F-bit is not set on Notification messages containing status codes except 'No LDP Session' because the duplication of messages SHOULD be restricted to being a per-hop behavior.

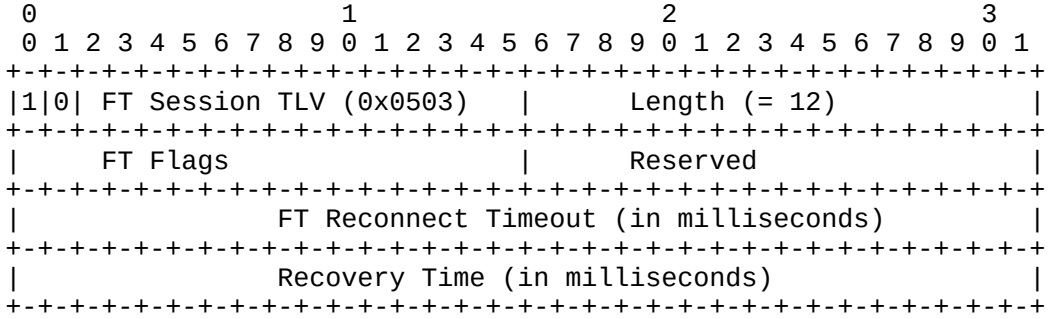
Status Code	E	Status Data
No LDP Session	0	0x0000001A
Zero FT seqnum	1	0x0000001B
Unexpected TLV / Session Not FT	1	0x0000001C
Unexpected TLV / Label Not FT	1	0x0000001D
Missing FT Protection TLV	1	0x0000001E
FT ACK sequence error	1	0x0000001F
Temporary Shutdown	0	0x00000020
FT Seq Numbers Exhausted	1	0x00000021
FT Session parameters / changed	1	0x00000022
Unexpected FT Cork TLV	1	0x00000023

The 'Temporary Shutdown' status code SHOULD be used in place of the 'Shutdown' status code (which has the E-bit set) if the LSR that is shutting down wishes to inform its LDP peer that it expects to be able to preserve FT Label state and return to service before the FT Reconnection Timer expires.

8.2. FT Session TLV

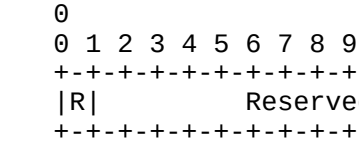
LDP peers can negotiate whether the LDP session between them supports FT extensions by using a new OPTIONAL parameter, the FT Session TLV, on LDP Initialization Messages.

The FT Session TLV is encoded as follows.



FT Flags

FT Flags: A 16 bit field that indicates various attributes the FT support on this LDP session. This field is formatted as follows:



R: FT Reconnect Flag.
Set to 1 if the sending LSR has preserved state and resources for all FT-labels since the previous LDP session between the same LDP peers, and is otherwise set to 0. See section 5.4, "FT Procedures After TCP Failure", for details of how this flag is used.

If the FT Reconnect Flag is set, the sending LSR MUST include an FT ACK TLV on the LDP Initialization message.

S: Save State Flag.
Set to 1 if the use of the FT Protection TLV is supported on messages other than the KeepAlive message used for check-pointing (see the C bit). I.e., the S bit indicates that some label on the session may be a Sequence Numbered FT Label.

A: All-Label Protection Required
Set to 1 if all labels on the session MUST be treated as Sequence Numbered FT Labels. This removes from a node the option of

treating some labels as FT Labels and some labels as non-FT Labels.

Passing this information may be considered helpful to a peer since it may allow it to make optimizations in its processing.

The A bit only has meaning if the S bit is set.

C: Check-Pointing Flag.
Set to 1 to indicate that the check-Pointing procedures in this document are in use.

If the S bit is also set to 1 then the C bit indicates that check-pointing is applied only to Sequence Numbered FT Labels.

If the S bit is set to 0 (zero) then the C bit indicates that check-pointing applies to all labels - all labels are Check-Pointable FT Labels.

L: Learn From Network Flag.
Set to 1 if the Fault Recovery procedures of [RFC3478] are to be used to re-learn state from the network.

It is not valid for all of the S, C and L bits to be zero.

It is not valid for both the L and either the S or C bits to be set to 1.

All other bits in this field are currently reserved and SHOULD be set to zero on transmission and ignored upon receipt.

The following table summarizes the settings of these bits.

S	A	C	L	Comments
0	x	0	0	Invalid
0	0	0	1	See [RFC3478]
0	1	0	1	Invalid
0	x	1	0	Check-Pointing of all labels
0	x	1	1	Invalid
1	0	0	0	Full FT on selected labels
1	1	0	0	Full FT on all labels
1	x	0	1	Invalid
1	x	1	0	Same as (S=1,A=x,C=0,L=0)
1	x	1	1	Invalid.

FT Reconnection Timeout
If the S bit or C bit in the FT Flags field is set, this indicates the period of time the sending LSR will preserve state and resources for FT Labels exchanged on the previous instantiation of an FT LDP session that has recently failed. The timeout is encoded as a 32-bit unsigned integer number of milliseconds.

A value of zero in this field means that the sending LSR will preserve state and resources indefinitely.

See section 4.4 for details of how this field is used.

If the L bit is set to 1 in the FT Flags field, the meaning of this field is defined in [RFC3478].

Recovery Time
The Recovery Time only has meaning if the L bit is set in the FT Flags. The meaning is defined in [RFC3478].

8.3. FT Protection TLV

LDP peers use the FT Protection TLV to indicate that an LDP message contains an FT label operation.

The FT Protection TLV MUST NOT be used in messages flowing on an LDP session that does not support the LDP FT enhancements. Its presence in such messages SHALL be treated as a protocol error by the receiving LDP peer which SHOULD send a Notification message with the 'Unexpected TLV Session Not FT' status code. LSRs that do not recognize this TLV SHOULD respond with a Notification message with the 'Unknown TLV' status code.

The FT Protection TLV MAY be carried on an LDP message transported on the LDP session after the initial exchange of LDP Initialization messages. In particular, this TLV MAY optionally be present on the following messages:

- Label Request Messages in downstream on-demand distribution mode.

- Label Mapping messages in downstream unsolicited mode.

- Keepalive messages used to request flushing of acknowledgement of all previous messages that contained this TLV.

If a label is to be a Sequence Numbered FT Label, then the Protection TLV MUST be present:

- on the Label Request message in downstream on-demand distribution mode.

- on the Label Mapping message in in downstream unsolicited distribution mode.

- on all subsequent messages concerning this label.

Here 'subsequent messages concerning this label' means any message whose Label TLV specifies this label or whose Label Request Message ID TLV specifies the initial Label Request message.

If a label is not to be a Sequence Numbered FT Label, then the Protection TLV MUST NOT be present on any of these messages that relate to the label. The presence of the FT TLV on a message relating to a non-FT Label SHALL be treated as a protocol error by the receiving LDP peer which SHOULD send a notification message with the 'Unexpected TLV Label Not FT' status code.

Where a Label Withdraw or Label Release message contains only an FEC TLV and does not identify a single specific label, the FT TLV should be included in the message if any label affected by the message is a Sequence Numbered FT Label. If there is any doubt as to whether an FT TLV should be present, it is RECOMMENDED that the sender add the TLV.

When an LDP peer receives a Label Withdraw Message or Label Release message that contains only a FEC, it SHALL accept the FT TLV if it is present regardless of the FT status of the labels that it affects.

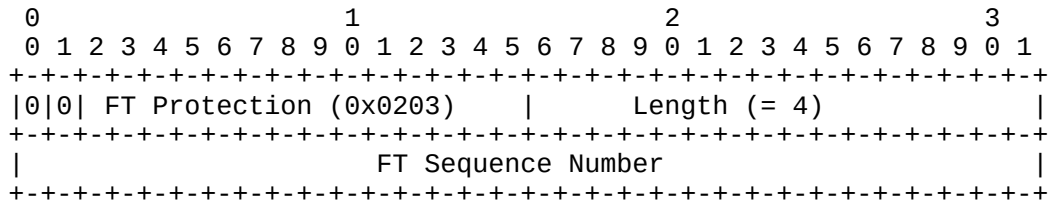
If an LDP session is an FT session as determined by the presence of the FT Session TLV, with the S bit set on the LDP Initialization messages, the FT Protection TLV MUST be present on all Address messages on the session.

If the session is an FT session, the FT Protection TLV may also optionally be present:

- on Notification messages on the session that have the status code 'Label Resources Available'.

- on Keepalive messages.

The FT Protection TLV is encoded as follows.



FT Sequence Number
The sequence number for this Sequence Numbered FT Label operation. The sequence number is encoded as a 32-bit unsigned integer. The initial value for this field on a new LDP session is 0x00000001 and is incremented by one for each FT LDP message issued by the sending LSR on this LDP session. This field may wrap from 0xFFFFFFFF to 0x00000001.

This field MUST be reset to 0x00000001 if either LDP peer does not set the FT Reconnect Flag upon re-establishment of the TCP connection.

See section 5.2, "FT Operation Acks" for details of how this field is used.

The special use of 0x00000000 is discussed in the section 8.4, "FT ACK TLV" below.

If an LSR receives an FT Protection TLV on a session that does not support the FT LDP enhancements, it SHOULD send a Notification message to its LDP peer containing the 'Unexpected TLV, Session Not FT' status code. LSRs that do not recognize this TLV SHOULD respond with a Notification message with the 'Unknown TLV' status code.

If an LSR receives an FT Protection TLV on an operation affecting a label that it believes is a non-FT Label, it SHOULD send a Notification message to its LDP peer containing the 'Unexpected TLV, Label Not FT' status code.

If an LSR receives a message without the FT Protection TLV affecting a label that it believes is a Sequence Numbered FT Label, it SHOULD send a Notification message to its LDP peer containing the 'Missing FT Protection TLV' status code.

If an LSR receives an FT Protection TLV containing a zero FT Sequence Number, it SHOULD send a Notification message to its LDP peer containing the 'Zero FT Seqnum' status code.

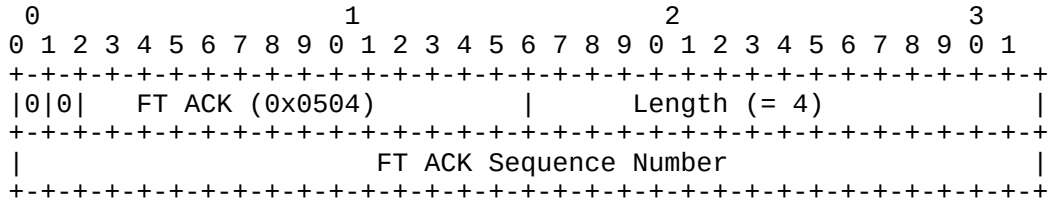
8.4. FT ACK TLV

LDP peers use the FT ACK TLV to acknowledge FT Label operations.

The FT ACK TLV MUST NOT be used in messages flowing on an LDP session that does not support the LDP FT enhancements. Its presence on such messages SHALL be treated as a protocol error by the receiving LDP peer.

The FT ACK TLV MAY be present on any LDP message exchanged on an LDP session after the initial LDP Initialization messages. It is RECOMMENDED that the FT ACK TLV be included in all FT Keepalive messages in order to ensure that the LDP peers do not build up a large backlog of unacknowledged state information.

The FT ACK TLV is encoded as follows.



FT ACK Sequence Number

The sequence number for the most recent FT label message that the sending LDP peer has received from the receiving LDP peer and secured against failure of the LDP session. It is not necessary for the sending peer to have fully processed the message before ACKing it. For example, an LSR MAY ACK a Label Request message as soon as it has securely recorded the message, without waiting until it can send the Label Mapping message in response.

ACKs are cumulative. Receipt of an LDP message containing an FT ACK TLV with an FT ACK Sequence Number of 12 is treated as the acknowledgement of all messages from 1 to 12 inclusive (assuming the LDP session started with a sequence number of 1).

This field MUST be set to 0 if the LSR sending the FT ACK TLV has not received any FT label operations on this LDP session. This applies to LDP sessions, to new LDP peers or after an LSR determines that it must drop all state for a failed TCP connection.

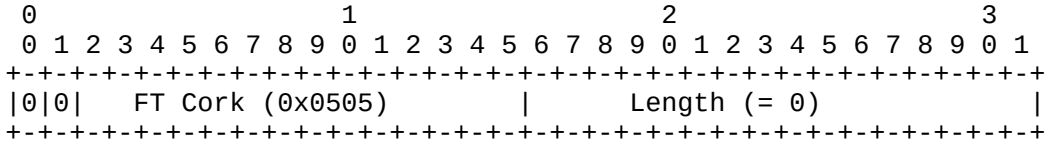
See section 5.2, "FT Operation Acks" for details of how this field is used.

If an LSR receives an FT ACK TLV that contains an FT ACK Sequence Number that is less than the previously received FT ACK Sequence Number (remembering to take account of wrapping), it SHOULD send a Notification message to its LDP peer containing the 'FT ACK Sequence Error' status code.

8.5. FT Cork TLV

LDP peers use the FT Cork TLV on FT Keepalive messages to indicate that they wish to quiesce the LDP session prior to a controlled shutdown and restart, for example during control-plane software upgrade.

The FT Cork TLV is encoded as follows.



Upon receipt of a Keepalive message with the FT Cork TLV and the FT Protection TLV, an LSR SHOULD perform the following actions:

- Process and secure any messages from the peer LSR that have sequence numbers less than (accounting for wrap) that contained in the FT Protection TLV on the Keepalive message.

- Send a Keepalive message back to the peer containing the FT Cork TLV and the FT ACK TLV specifying the FT ACK sequence number equal to that in the original Keepalive message (i.e. ACKing all messages up to that point).

- If this LSR has not yet received an FT ACK to all the messages it has sent containing the FT Protection TLV, then also include an FT Protection TLV on the Keepalive sent to the peer LSR. This tells the remote peer that the local LSR has saved state prior to quiesce but is still awaiting confirmation that the remote peer has saved state.

- Cease sending any further state changing messages on this LDP session until it has been disconnected and recovered.

On receipt of a Keepalive message with the FT Cork TLV and an FT ACK TLV that acknowledges the previously sent Keepalive that carried the FT Cork TLV, an LSR knows that quiesce is complete. If the received Keepalive also carries the FT Protection TLV, the LSR must respond with a further Keepalive to complete the 3-way handshake. It SHOULD

now send a "Temporary Shutdown" Notification message, disconnect the TCP session and perform whatever control plane actions required this session shutdown.

An example of such a 3-way handshake for controlled shutdown is given in section section 9.4, "Temporary Shutdown With FT Procedures and Check-Pointing".

If an LSR receives a message that should not carry the FT Cork TLV, or if the FT Cork TLV is used on a Keepalive message without one of the FT Protection or FT ACK TLVs present, it SHOULD send a Notification message to its LDP peer containing the 'Unexpected FT Cork TLV' status code.

9. Example Use

Consider two LDP peers, P1 and P2, implementing LDP over a TCP connection that connects them, and the message flow shown below.

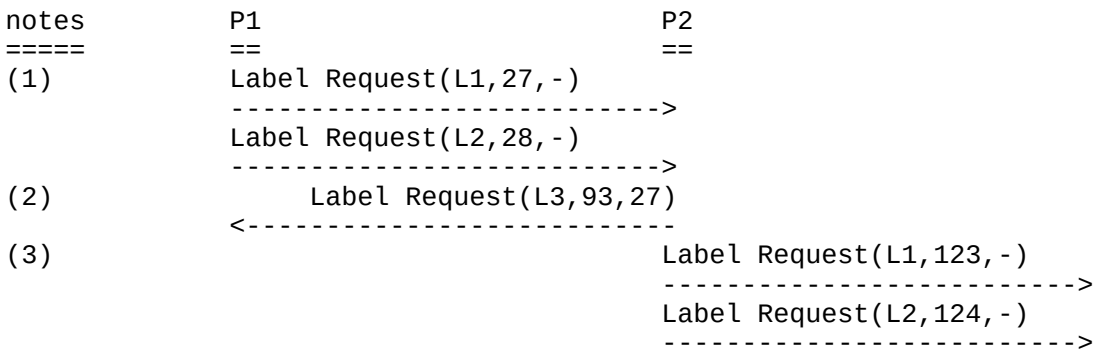
The parameters shown on each message below are as follows:

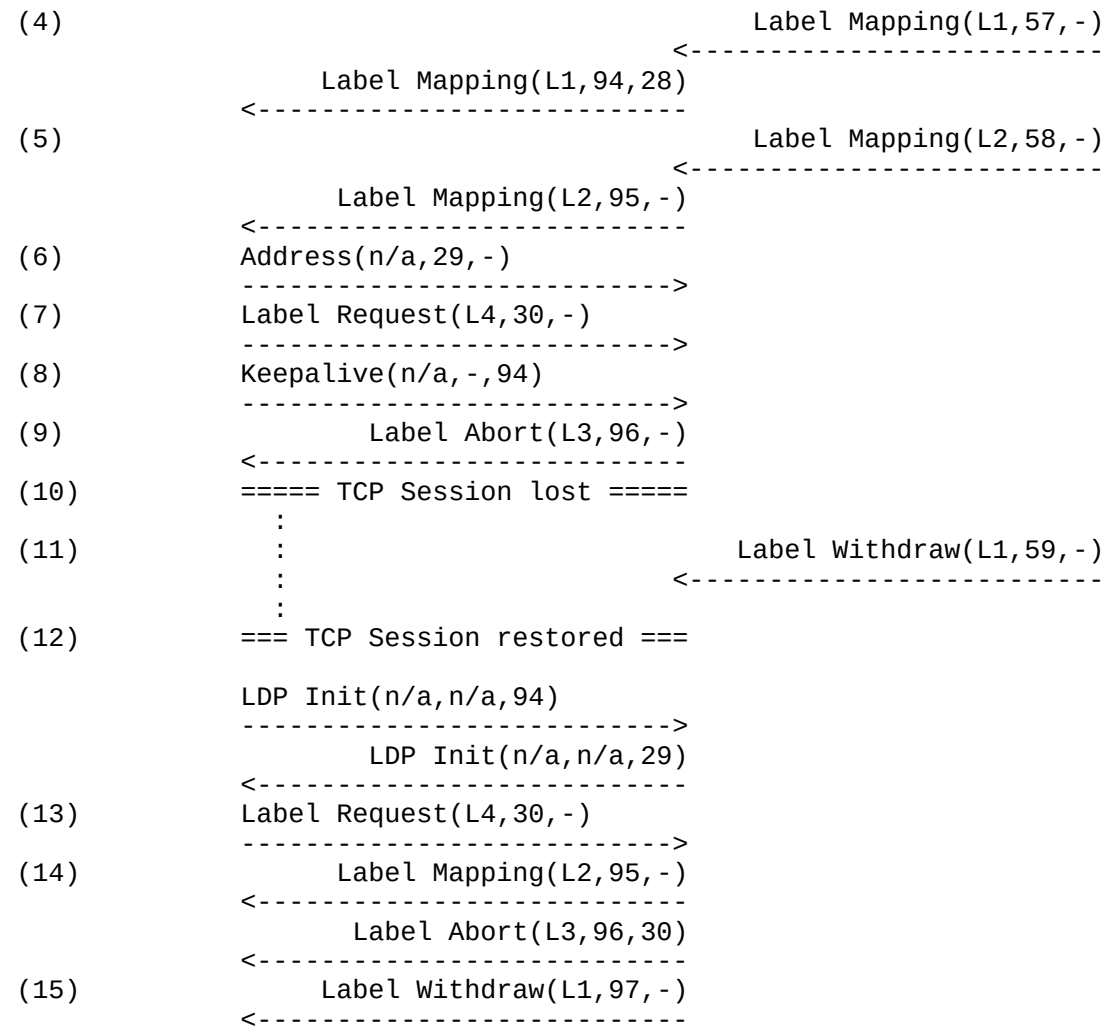
message (label, senders FT sequence number, FT ACK number)

A "-" for FT ACK number means that the FT ACK TLV is not included on that message. "n/a" means that the parameter in question is not applicable to that type of message.

In the diagrams below, time flows from top to bottom. The relative position of each message shows when it is transmitted. See the notes for a description of when each message is received, secured for FT or processed.

9.1. Session Failure and Recovery - FT Procedures





Notes:
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(1) Assume that the LDP session has already been initialized. P1 issues 2 new Label Requests using the next sequence numbers.

(2) P2 issues a Label Request to P1. At the time of sending this request, P2 has secured the receipt of the label request for L1 from P1, so it includes an ACK for that message.

(3) P2 processes the Label Requests for L1 and L2 and forwards them downstream. Details of downstream processing are not shown in the diagram above.

(4) P2 receives a Label Mapping from downstream for L1, which it forwards to P1. It includes an ACK to the Label Request for L2, as that message has now been secured and processed.

(5) P2 receives the Label Mapping for L2, which it forwards to P1. This time it does not include an ACK as it has not received any further messages from P1.

(6) Meanwhile, P1 sends a new Address Message to P2.

(7) P1 also sends a fourth Label Request to P2

(8) P1 sends a Keepalive message to P2, on which it includes an ACK for the Label Mapping for L1, which is the latest message P1 has received and secured at the time the Keepalive is sent.

(9) P2 issues a Label Abort for L3.

(10) At this point, the TCP session goes down.

(11) While the TCP session is down, P2 receives a Label Withdraw Message for L1, which it queues.

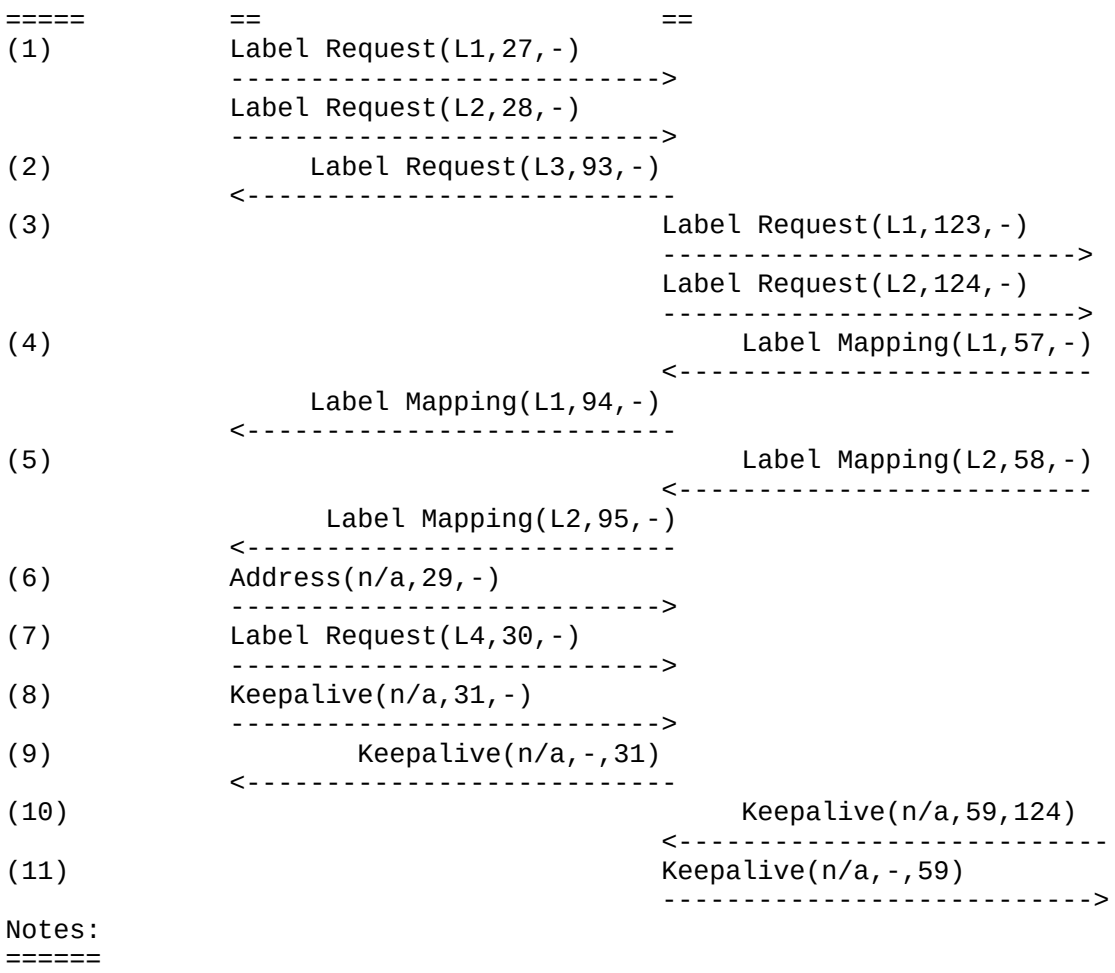
(12) The TCP session is reconnected and P1 and P2 exchange LDP Initialization messages on the recovered session, which include ACKS for the last message each peer received and secured prior to the failure.

(13) From the LDP Init exchange, P1 determines that it needs to re-issue the Label request for L4.

(14) Similarly, P2 determines that it needs to re-issue the Label Mapping for L2 and the Label Abort.

(15) P2 issues the queued Label Withdraw to P1.

9.2. Use of Check-Pointing With FT Procedures



Notes:
======

Notes (1) through (7) are as in the previous example except note that no acknowledgements are piggy-backed on reverse direction messages. This means that at note (8) there are deferred acknowledgements in both directions on both links.

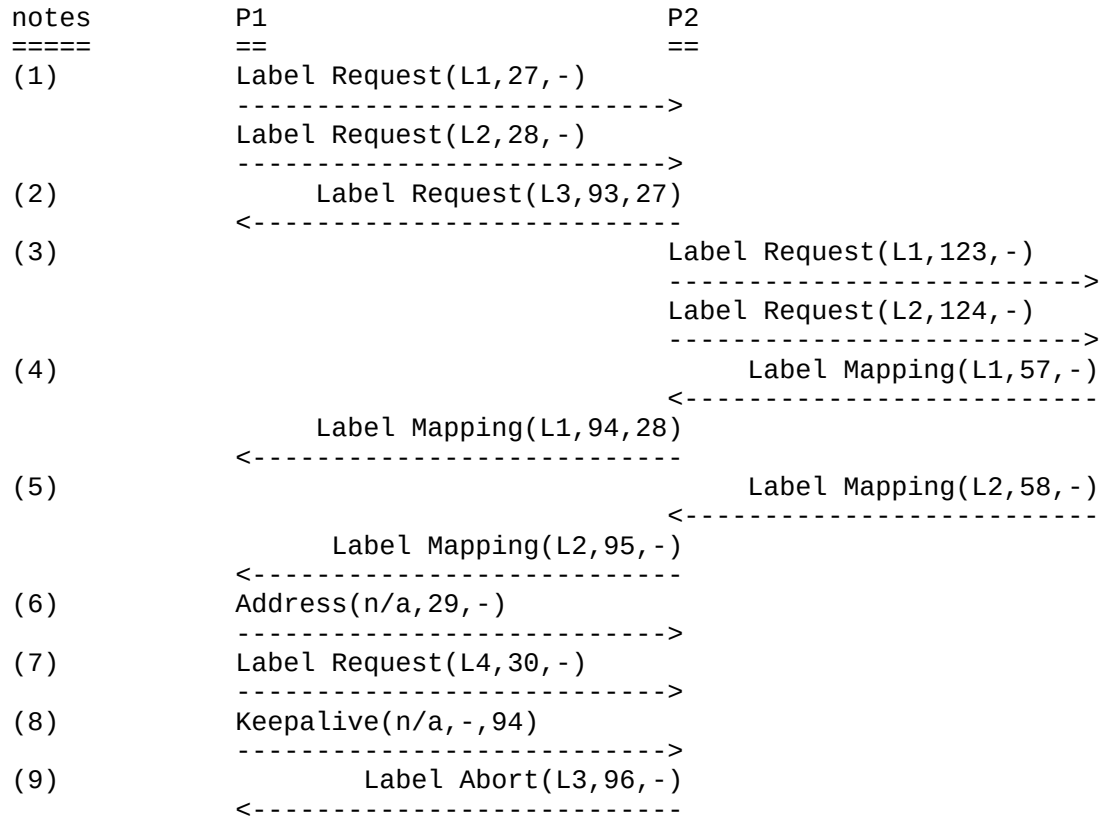
(8) P1 wishes to synchronize state with P2. It sends a Keepalive message containing an FT Protection TLV with sequence number 31. Since it is not interested in P2’s perception of the state that it has stored, it does not include an FT ACK TLV.

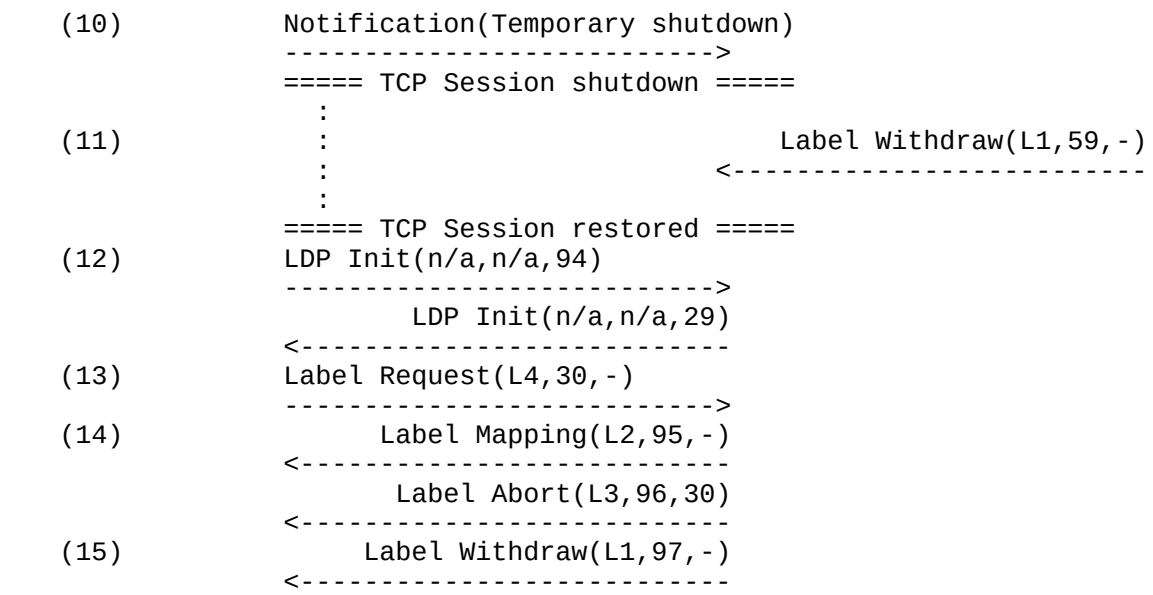
(9) P2 responds at once with a Keepalive acknowledging the sequence number on the received Keepalive. This tells P1 that P2 has preserved all state/messages previously received on this session.

(10) The downstream node wishes to synchronize state with P2. It sends a Keepalive message containing an FT Protection TLV with sequence number 59. P3 also takes this opportunity to get up to date with its acknowledgements to P2 by including an FT ACK TLV acknowledging up to sequence number 124.

(11) P2 responds at once with a Keepalive acknowledging the sequence number on the received Keepalive.

9.3. Temporary Shutdown With FT Procedures





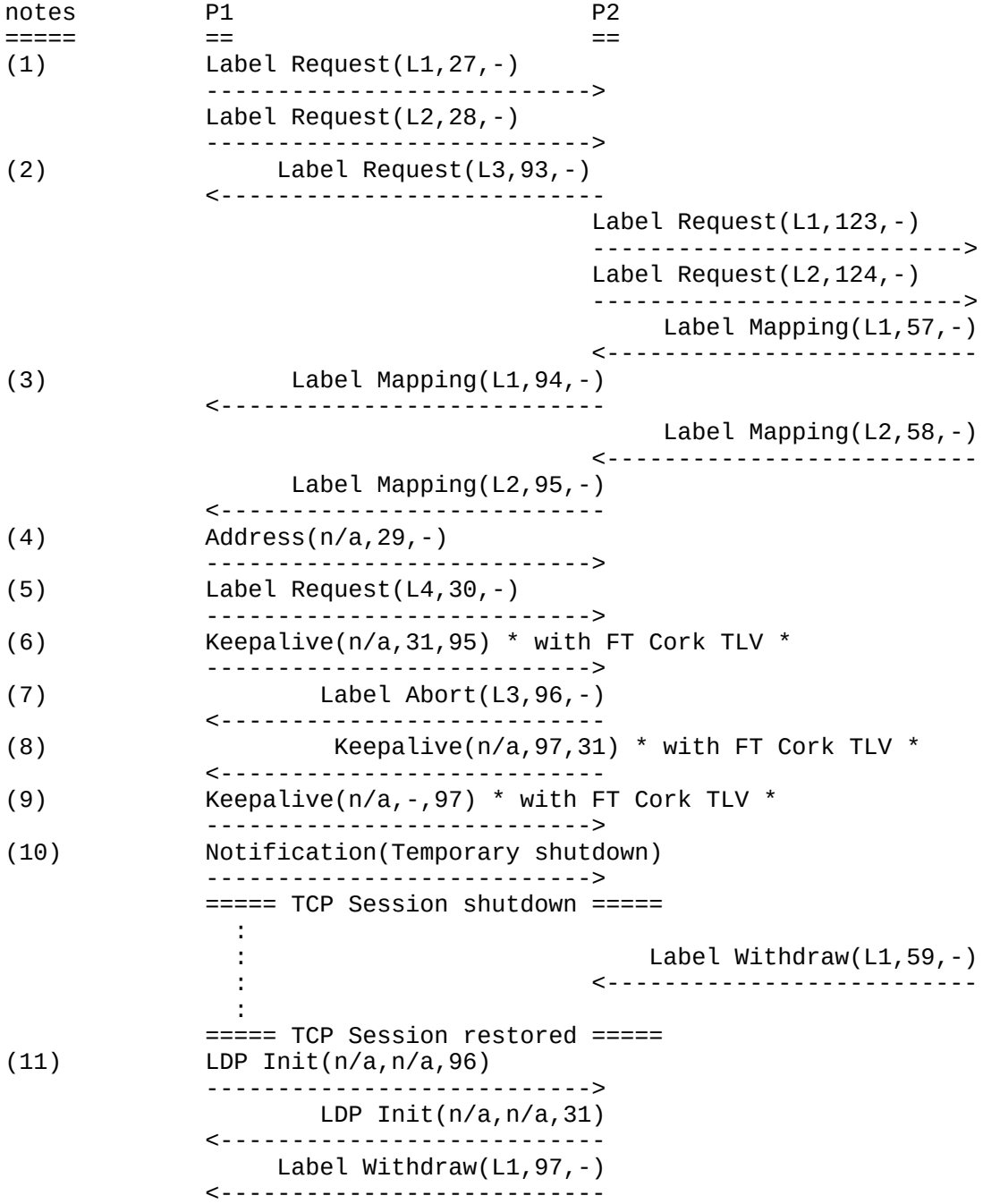

```
              ===== TCP Session shutdown =====
                :
(11)            :                          Label Withdraw(L1,59,-)
                :                       <--------------------------
                :
              ===== TCP Session restored =====
(12)          LDP Init(n/a,n/a,94)
              ---------------------------->
                      LDP Init(n/a,n/a,29)
              <----------------------------
(13)          Label Request(L4,30,-)
              ---------------------------->
(14)               Label Mapping(L2,95,-)
              <----------------------------
                    Label Abort(L3,96,30)
              <----------------------------
(15)               Label Withdraw(L1,97,-)
              <----------------------------
```

Notes:
======

Notes are as in the previous example except as follows.

(10) P1 needs to upgrade the software or hardware that it is running. It issues a Notification message to terminate the LDP session, but sets the status code as 'Temporary shutdown' to inform P2 that this is not a fatal error, and P2 should maintain FT state. The TCP connection may also fail during the period that the LDP session is down (in which case it will need to be re-established), but it is also possible that the TCP connection will be preserved.

9.4. Temporary Shutdown With FT Procedures and Check-Pointing



Notes:
======

This example operates much as the previous one. However, at (1), (2), (3), (4) and (5), no acknowledgements are made.

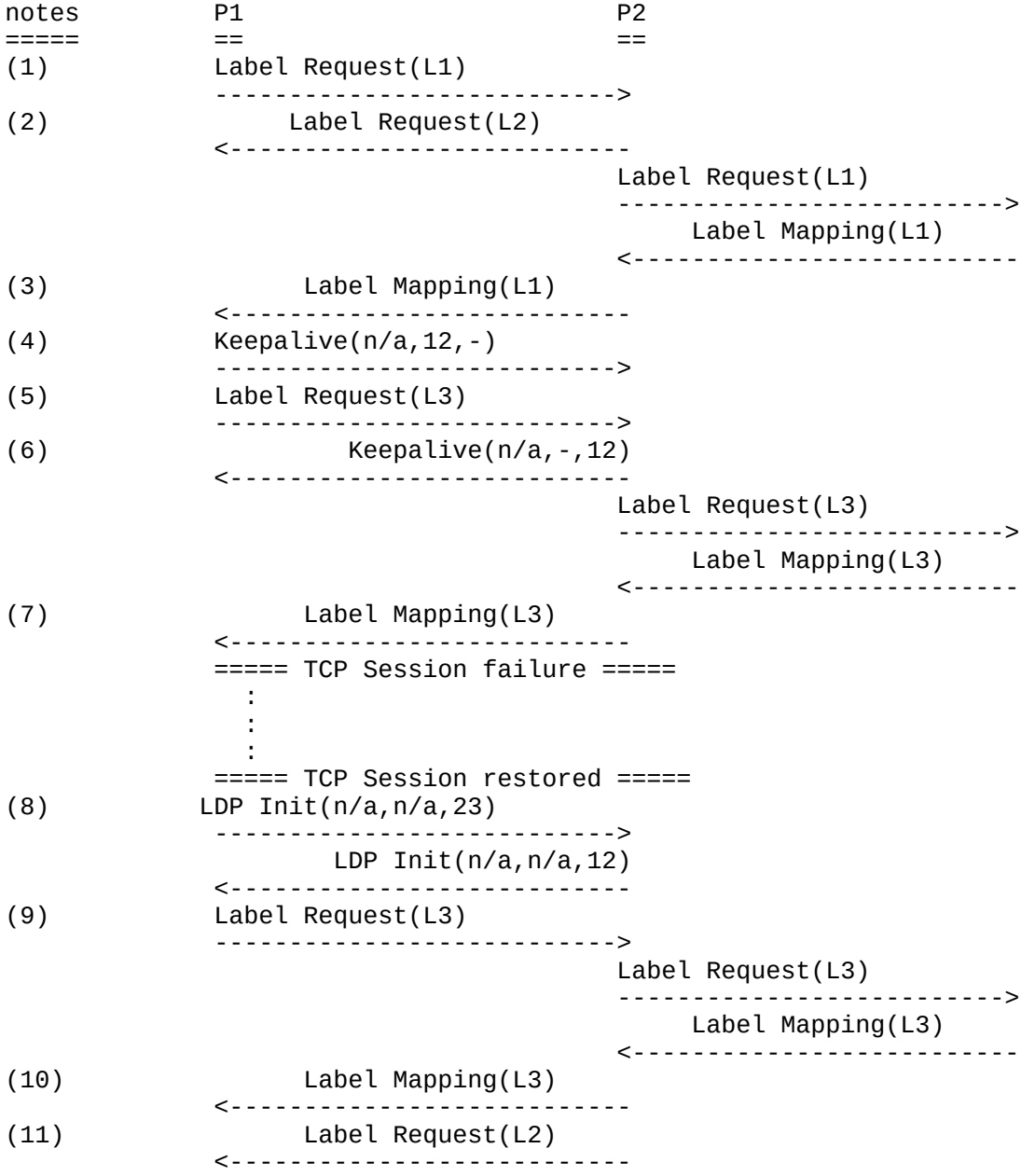
At (6), P1 determines that graceful shutdown is required and sends a Keepalive acknowledging all previously received messages and itself containing an FT Protection TLV number and the FT Cork TLV.

The Label abort at (7) crosses with this Keepalive, so at (8) P2 sends a Keepalive that acknowledges all messages received so far, but also includes the FT Protection and FT Cork TLVs to indicate that there are still messages outstanding to be acknowledged.

P1 is then able to complete the 3-way handshake at (9) and close the TCP session at (10).

Upon recovery at (11), there are no messages to be re-sent because the KeepAlives flushed the acknowledgements. The only messages sent after recovery is the Label Withdraw that was pended during the TCP session failure.

9.5. Check-Pointing Without FT Procedures



Notes:
======

(1), (2) and (3) show label distribution without FT sequence numbers.

(4) A check-Point request from P1. It carries the sequence number of the check-point request.

(5) P1 immediately starts a new label distribution request.

(6) P2 confirms that it has secured all previous transactions.

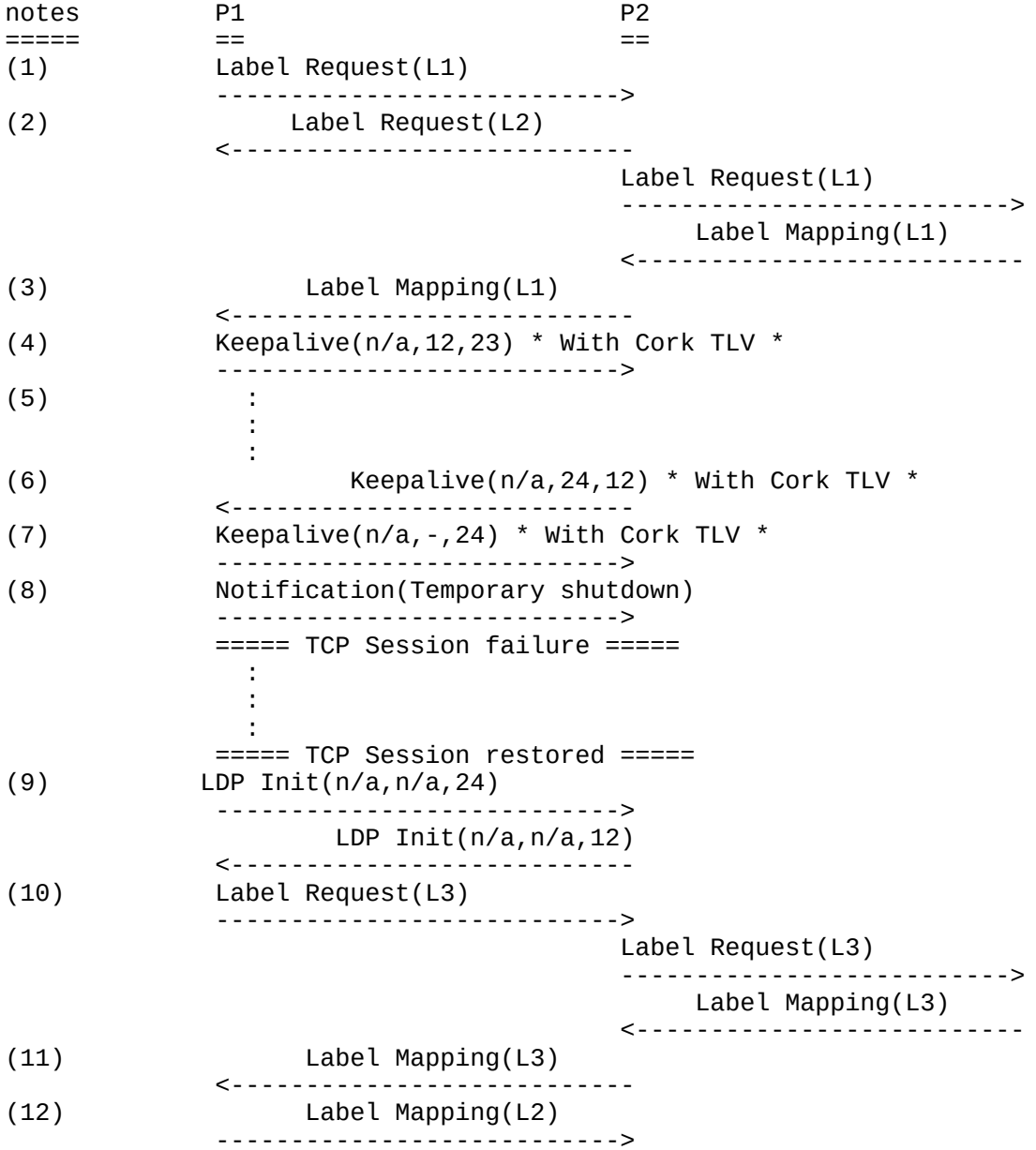
(7) The subsequent (un-acknowledged) label distribution completes.

(8) The session fails and is restarted. Initialization messages confirm the sequence numbers of the secured check-points.

(9) P1 recommences the unacknowledged label distribution request.

(10) P2 recommences an unacknowledged label distribution request.

9.6. Graceful Shutdown With Check-Pointing But No FT Procedures



Notes:
======

(1), (2) and (3) show label distribution without FT sequence numbers.

(4) A check-point request from P1. It carries the sequence number of the check-point request and a Cork TLV.

(5) P1 has sent a Cork TLV so quieces.

(6) P2 confirms the check-point and continues the three-way handshake by including a Cork TLV itself.

(7) P1 completes the three-way handshake. All operations have now been check-pointed and the session is quiesced.

(8) The session is gracefully shut down.

(9) The session recovers and the peers exchange the sequence numbers of the last secured check-points.

(10) P1 starts a new label distribution request.

(11) P1 continues processing a previously received label distribution request.

10. Security Considerations

The LDP FT enhancements inherit similar security considerations to those discussed in [RFC3036].

The LDP FT enhancements allow the re-establishment of a TCP connection between LDP peers without a full re-exchange of the attributes of established labels, which renders LSRs that implement the extensions specified in this document vulnerable to additional denial-of-service attacks as follows:

- An intruder may impersonate an LDP peer in order to force a failure and reconnection of the TCP connection, but where the intruder does not set the FT Reconnect Flag upon re-connection. This forces all FT labels to be released.

- Similarly, an intruder could set the FT Reconnect Flag on re-establishment of the TCP session without preserving the state and resources for FT labels.

- An intruder could intercept the traffic between LDP peers and override the setting of the FT Label Flag to be set to 0 for all labels.

All of these attacks may be countered by use of an authentication scheme between LDP peers, such as the MD5-based scheme outlined in [RFC3036].

Alternative authentication schemes for LDP peers are outside the scope of this document, but could be deployed to provide enhanced security to implementations of LDP and the LDP FT enhancements.

As with LDP, a security issue may exist if an LDP implementation continues to use labels after expiration of the session that first caused them to be used. This may arise if the upstream LSR detects the session failure after the downstream LSR has released and re-used the label. The problem is most obvious with the platform-wide label space and could result in mis-forwarding of data to other than intended destinations and it is conceivable that these behaviors may be deliberately exploited to either obtain services without authorization or to deny services to others.

In this document, the validity of the session may be extended by the FT Reconnection Timeout, and the session may be re-established in this period. After the expiry of the Reconnection Timeout, the session must be considered to have failed and the same security issue applies as described above.

However, the downstream LSR may declare the session as failed before the expiration of its Reconnection Timeout. This increases the period during which the downstream LSR might reallocate the label while the upstream LSR continues to transmit data using the old usage of the label. To reduce this issue, this document requires that labels not be re-used until the Reconnection Timeout has expired.

A further issue might apply if labels were re-used prior to the expiration of the FT Reconnection Timeout, but this is forbidden by this document.

The issue of re-use of labels extends to labels managed through other mechanisms including direct configuration through management applications and distribution through other label distribution protocols. Avoiding this problem may be construed as an implementation issue (see below), but failure to acknowledge it could result in the mis-forwarding of data between LSPs established using some other mechanism and those recovered using the methods described in this document.

11. Implementation Notes

11.1. FT Recovery Support on Non-FT LSRs

In order to take full advantage of the FT capabilities of LSRs in the network, it may be that an LSR that does not itself contain the ability to recover from local hardware or software faults still needs to support the LDP FT enhancements described in this document.

Consider an LSR, P1, that is an LDP peer of a fully Fault Tolerant LSR, P2. If P2 experiences a fault in the hardware or software that serves an LDP session between P1 and P2, it may fail the TCP connection between the peers. When the connection is recovered, the LSPs/labels between P1 and P2 can only be recovered if both LSRs were applying the FT recovery procedures to the LDP session.

11.2. ACK generation logic

FT ACKs SHOULD be returned to the sending LSR as soon as is practicable in order to avoid building up a large quantity of unacknowledged state changes at the LSR. However, immediate one-for-one acknowledgements would waste bandwidth unnecessarily.

A possible implementation strategy for sending ACKs to FT LDP messages is as follows:

- An LSR secures received messages in order and tracks the sequence number of the most recently secured message, Sr.

- On each LDP KeepAlive that the LSR sends, it attaches an FT ACK TLV listing Sr.

- Optionally, the LSR may attach an FT ACK TLV to any other LDP message sent between Keepalive messages if, for example, Sr has increased by more than a threshold value since the last ACK sent.

This implementation combines the bandwidth benefits of accumulating ACKs while still providing timely ACKs.

11.2.1 Ack Generation Logic When Using Check-Pointing

If check-pointing is in use, the LSRs need not be concerned with sending ACKs in such a timely manner.

Check-points are solicitations for acknowledgements conveyed as a sequence number in an FT Protection TLV on a Keepalive message. Such check-point requests could be issued on a timer, after a significant amount of change, or before controlled shutdown of a session.

The use of check-pointing may considerably simplify an implementation since it does not need to track the sequence numbers of all received LDP messages. It must, however, still ensure that all received messages (or the consequent state changes) are secured before acknowledging the sequence number on the Keepalive.

This approach may be considered optimal in systems that do not show a high degree of change over time (such as targeted LDP sessions) and that are prepared to risk loss of state for the most recent LDP exchanges. More dynamic systems (such as LDP discovery sessions) are more likely to want to acknowledge state changes more frequently so that the maximum amount of state can be preserved over a failure.

11.3 Interactions With Other Label Distribution Mechanisms

Many LDP LSRs also run other label distribution mechanisms. These include management interfaces for configuration of static label mappings, other distinct instances of LDP, and other label distribution protocols. The last example includes the traffic engineering label distribution protocol that is used to construct tunnels through which LDP LSPs are established.

As with re-use of individual labels by LDP within a restarting LDP system, care must be taken to prevent labels that need to be retained by a restarting LDP session or protocol component from being used by another label distribution mechanism since that might compromise data security amongst other things.

It is a matter for implementations to avoid this issue through the use of techniques such as a common label management component or segmented label spaces.

12. Acknowledgments

The work in this document is based on the LDP ideas expressed by the authors of [RFC3036].

The ACK scheme used in this document was inspired by the proposal by David Ward and John Scudder for restarting BGP sessions now included in [BGP-RESTART].

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14. References

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