Constraint-Based LSP Setup using LDP

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Abstract

   This document specifies mechanisms and TLVs (Type/Length/Value) for
   support of CR-LSPs (constraint-based routed Label Switched Path)
   using LDP (Label Distribution Protocol).

   This specification proposes an end-to-end setup mechanism of a CR-LSP
   initiated by the ingress LSR (Label Switching Router). We also
   specify mechanisms to provide means for reservation of resources
   using LDP.

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in RFC 2119 [6].

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1. Introduction

   Label Distribution Protocol (LDP) is defined in [1] for distribution
   of labels inside one MPLS domain. One of the most important services
   that may be offered using MPLS in general and LDP in particular is
   support for constraint-based routing of traffic across the routed
   network. Constraint-based routing offers the opportunity to extend
   the information used to setup paths beyond what is available for the
   routing protocol. For instance, an LSP can be setup based on
   explicit route constraints, QoS constraints, and other constraints.
   Constraint-based routing (CR) is a mechanism used to meet Traffic
   Engineering requirements that have been proposed by, [2] and [3].
   These requirements may be met by extending LDP for support of
   constraint-based routed label switched paths (CR-LSPs). Other uses
   for CR-LSPs include MPLS-based VPNs [4]. More information about the
   applicability of CR-LDP can be found in [5].

   The need for constraint-based routing (CR) in MPLS has been explored
   elsewhere [2], and [3]. Explicit routing is a subset of the more
   general constraint-based routing function. At the MPLS WG meeting
   held during the Washington IETF (December 1997) there was consensus
   that LDP should support explicit routing of LSPs with provision for
   indication of associated (forwarding) priority. In the Chicago
   meeting (August 1998), a decision was made that support for explicit
   path setup in LDP will be moved to a separate document. This
   document provides that support and it has been accepted as a working
   document in the Orlando meeting (December 1998).

This specification proposes an end-to-end setup mechanism of a
constraint-based routed LSP (CR-LSP) initiated by the ingress LSR. We
also specify mechanisms to provide means for reservation of resources
using LDP.

This document introduce TLVs and procedures that provide support for:

        - Strict and Loose Explicit Routing
        - Specification of Traffic Parameters
        - Route Pinning
        - CR-LSP Preemption though setup/holding priorities
        - Handling Failures
        - LSPID
        - Resource Class

Section 2 introduces the various constraints defined in this
specification. Section 3 outlines the CR-LDP solution. Section 4
defines the TLVs and procedures used to setup constraint-based routed
label switched paths. Appendix A provides several examples of CR-LSP
path setup. Appendix B provides Service Definition Examples.

2. Constraint-based Routing Overview

Constraint-based routing is a mechanism that supports the Traffic
Engineering requirements defined in [3]. Explicit Routing is a
subset of the more general constraint-based routing where the
constraint is the explicit route (ER). Other constraints are defined
to provide a network operator with control over the path taken by an
LSP. This section is an overview of the various constraints
supported by this specification.

Like any other LSP a CR-LSP is a path through an MPLS network. The
difference is that while other paths are setup solely based on
information in routing tables or from a management system, the
constraint-based route is calculated at one point at the edge of
network based on criteria, including but not limited to routing
information. The intention is that this functionality shall give
desired special characteristics to the LSP in order to better support
the traffic sent over the LSP. The reason for setting up CR-LSPs
might be that one wants to assign certain bandwidth or other Service
Class characteristics to the LSP, or that one wants to make sure that
alternative routes use physically separate paths through the network.

2.1 Strict and Loose Explicit Routes

   An explicit route is represented in a Label Request Message as a list
   of nodes or groups of nodes along the constraint-based route. When
   the CR-LSP is established, all or a subset of the nodes in a group
   may be traversed by the LSP. Certain operations to be performed
   along the path can also be encoded in the constraint-based route.

   The capability to specify, in addition to specified nodes, groups of
   nodes, of which a subset will be traversed by the CR-LSP, allows the
   system a significant amount of local flexibility in fulfilling a
   request for a constraint-based route. This allows the generator of
   the constraint-based route to have some degree of imperfect
   information about the details of the path.

   The constraint-based route is encoded as a series of ER-Hops
   contained in a constraint-based route TLV. Each ER-Hop may identify
   a group of nodes in the constraint-based route. A constraint-based
   route is then a path including all of the identified groups of nodes
   in the order in which they appear in the TLV.

   To simplify the discussion, we call each group of nodes an "abstract
   node". Thus, we can also say that a constraint-based route is a path
   including all of the abstract nodes, with the specified operations
   occurring along that path.

2.2 Traffic Characteristics

   The traffic characteristics of a path are described in the Traffic
   Parameters TLV in terms of a peak rate, committed rate, and service
   granularity. The peak and committed rates describe the bandwidth
   constraints of a path while the service granularity can be used to
   specify a constraint on the delay variation that the CR-LDP MPLS
   domain may introduce to a path's traffic.

2.3 Preemption

   CR-LDP signals the resources required by a path on each hop of the
   route. If a route with sufficient resources can not be found,
   existing paths may be rerouted to reallocate resources to the new
   path. This is the process of path preemption. Setup and holding
   priorities are used to rank existing paths (holding priority) and the
   new path (setup priority) to determine if the new path can preempt an
   existing path.

   The setupPriority of a new CR-LSP and the holdingPriority attributes
   of the existing CR-LSP are used to specify priorities. Signaling a
   higher holding priority express that the path, once it has been

established, should have a lower chance of being preempted. Signaling
a higher setup priority expresses the expectation that, in the case
that resource are unavailable, the path is more likely to preempt
other paths. The exact rules determining bumping are an aspect of
network policy.

The allocation of setup and holding priority values to paths is an
aspect of network policy.

The setup and holding priority values range from zero (0) to seven
(7). The value zero (0) is the priority assigned to the most
important path. It is referred to as the highest priority. Seven
(7) is the priority for the least important path. The use of default
priority values is an aspect of network policy. The recommended
default value is (4).

The setupPriority of a CR-LSP should not be higher (numerically less)
than its holdingPriority since it might bump an LSP and be bumped by
the next "equivalent" request.

2.4 Route Pinning

Route pinning is applicable to segments of an LSP that are loosely
routed - i.e. those segments which are specified with a next hop with
the "L" bit set or where the next hop is an abstract node. A CR-LSP
may be setup using route pinning if it is undesirable to change the
path used by an LSP even when a better next hop becomes available at
some LSR along the loosely routed portion of the LSP.

2.5 Resource Class

The network operator may classify network resources in various ways.
These classes are also known as "colors" or "administrative groups".
When a CR-LSP is being established, it's necessary to indicate which
resource classes the CR-LSP can draw from.

3. Solution Overview

CR-LSP over LDP Specification is designed with the following goals:

   1. Meet the requirements outlined in [3] for performing traffic
      engineering and provide a solid foundation for performing more
      general constraint-based routing.

   2. Build on already specified functionality that meets the
      requirements whenever possible. Hence, this specification is
      based on [1].

3. Keep the solution simple.

In this document, support for unidirectional point-to-point CR-LSPs is specified. Support for point-to-multipoint, multipoint-to-point, is for further study (FFS).

Support for constraint-based routed LSPs in this specification depends on the following minimal LDP behaviors as specified in [1]:

- Use of Basic and/or Extended Discovery Mechanisms.
- Use of the Label Request Message defined in [1] in downstream on demand label advertisement mode with ordered control.
- Use of the Label Mapping Message defined in [1] in downstream on demand mode with ordered control.
- Use of the Notification Message defined in [1].
- Use of the Withdraw and Release Messages defined in [1].
- Use of the Loop Detection (in the case of loosely routed segments of a CR-LSP) mechanisms defined in [1].

In addition, the following functionality is added to what's defined in [1]:

- The Label Request Message used to setup a CR-LSP includes one or more CR-TLVs defined in Section 4. For instance, the Label Request Message may include the ER-TLV.

- An LSR implicitly infers ordered control from the existence of one or more CR-TLVs in the Label Request Message. This means that the LSR can still be configured for independent control for LSPs established as a result of dynamic routing. However, when a Label Request Message includes one or more of the CR-TLVs, then ordered control is used to setup the CR-LSP. Note that this is also true for the loosely routed parts of a CR-LSP.

- New status codes are defined to handle error notification for failure of established paths specified in the CR-TLVs. All of the new status codes require that the F bit be set.

Optional TLVs MUST be implemented to be compliant with the protocol. However, they are optionally carried in the CR-LDP messages to signal certain characteristics of the CR-LSP being established or modified.

Examples of CR-LSP establishment are given in Appendix A to illustrate how the mechanisms described in this document work.

3.1 Required Messages and TLVs

   Any Messages, TLVs, and procedures not defined explicitly in this
   document are defined in the LDP Specification [1]. The reader can
   use [7] as an informational document about the state transitions,
   which relate to CR-LDP messages.

   The following subsections are meant as a cross-reference to the [1]
   document and indication of additional functionality beyond what's
   defined in [1] where necessary.

   Note that use of the Status TLV is not limited to Notification
   messages as specified in Section 3.4.6 of [1]. A message other than
   a Notification message may carry a Status TLV as an Optional
   Parameter. When a message other than a Notification carries a Status
   TLV the U-bit of the Status TLV should be set to 1 to indicate that
   the receiver should silently discard the TLV if unprepared to handle
   it.

3.2 Label Request Message

   The Label Request Message is as defined in 3.5.8 of [1] with the
   following modifications (required only if any of the CR-TLVs is
   included in the Label Request Message):

       - The Label Request Message MUST include a single FEC-TLV
          element. The CR-LSP FEC TLV element SHOULD be used. However,
          the other FEC- TLVs defined in [1] MAY be used instead for
          certain applications.

       - The Optional Parameters TLV includes the definition of any of
          the Constraint-based TLVs specified in Section 4.

       - The Procedures to handle the Label Request Message are
          augmented by the procedures for processing of the CR-TLVs as
          defined in Section 4.

The encoding for the CR-LDP Label Request Message is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|  Label Request (0x0401)   |          Message Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Message ID                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          FEC TLV                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          LSPID TLV          (CR-LDP, mandatory) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          ER-TLV             (CR-LDP, optional)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Traffic  TLV       (CR-LDP, optional)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Pinning TLV        (CR-LDP, optional)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Resource Class TLV (CR-LDP, optional)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Preemption  TLV    (CR-LDP, optional)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
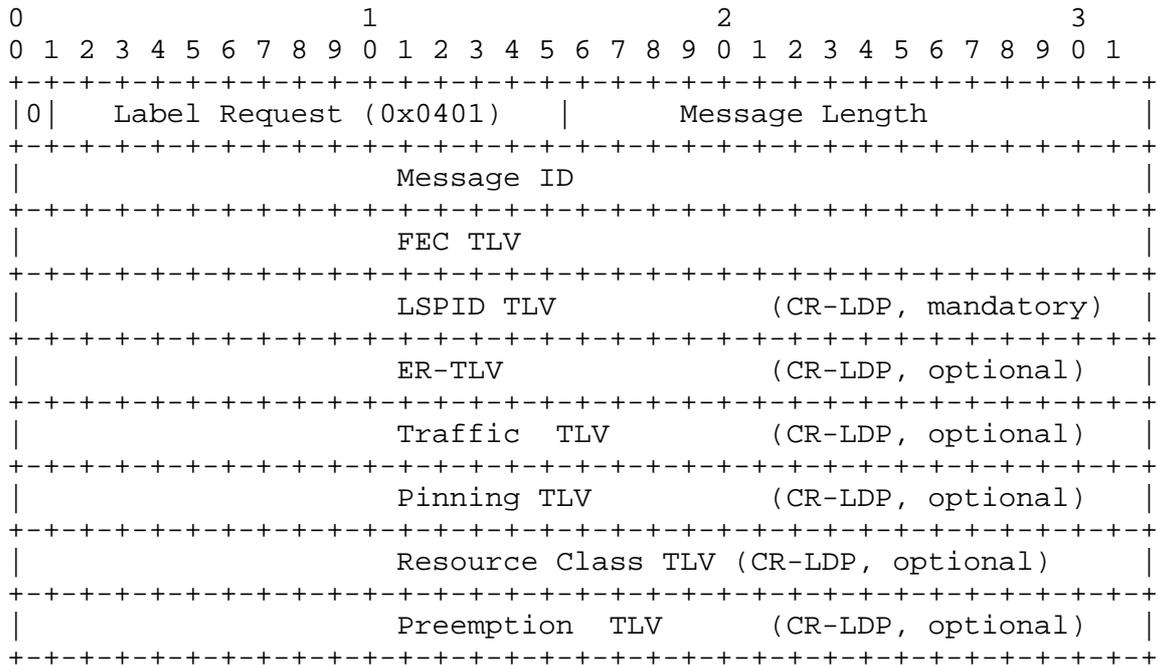
3.3 Label Mapping Message

   The Label Mapping Message is as defined in 3.5.7 of [1] with the
   following modifications:

      - The Label Mapping Message MUST include a single Label-TLV.

      - The Label Mapping Message Procedures are limited to downstream
         on demand ordered control mode.

   A Mapping message is transmitted by a downstream LSR to an upstream
   LSR under one of the following conditions:

      1. The LSR is the egress end of the CR-LSP and an upstream mapping
         has been requested.

      2. The LSR received a mapping from its downstream next hop LSR for
         an CR-LSP for which an upstream request is still pending.

The encoding for the CR-LDP Label Mapping Message is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|  Label Mapping (0x0400)    |        Message Length           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Message ID                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            FEC TLV                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Label TLV                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Label Request Message ID TLV                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    LSPID TLV       (CR-LDP, optional)    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Traffic  TLV    (CR-LDP, optional)    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
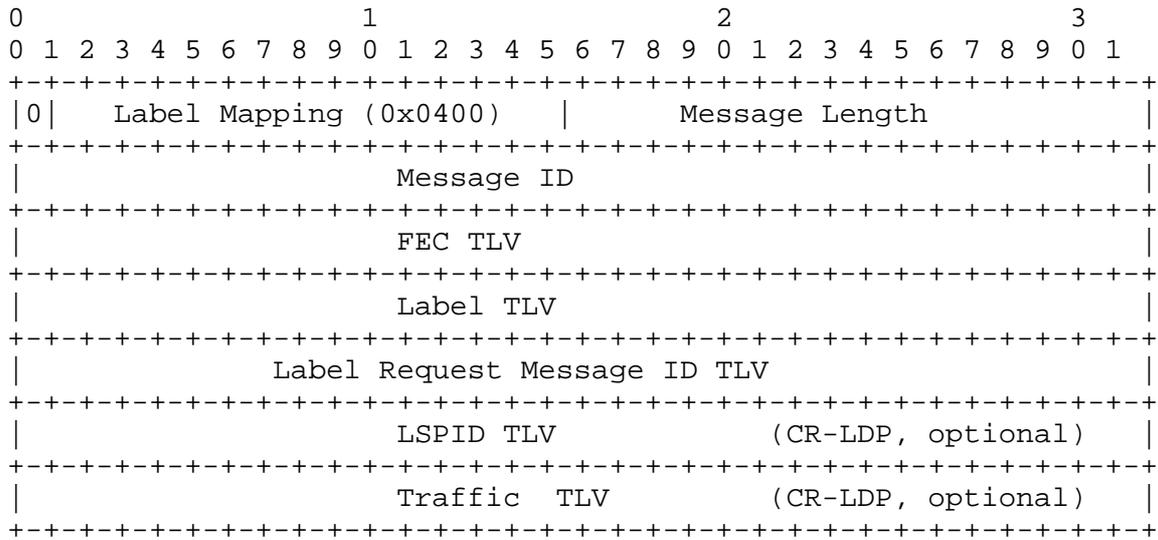
3.4 Notification Message

   The Notification Message is as defined in Section 3.5.1 of [1] and
   the Status TLV encoding is as defined in Section 3.4.6 of [1].
   Establishment of an CR-LSP may fail for a variety of reasons. All
   such failures are considered advisory conditions and they are
   signaled by the Notification Message.

   Notification Messages carry Status TLVs to specify events being
   signaled. New status codes are defined in Section 4.11 to signal
   error notifications associated with the establishment of a CR-LSP and
   the processing of the CR-TLV. All of the new status codes require
   that the F bit be set.

   The Notification Message MAY carry the LSPID TLV of the corresponding
   CR-LSP.

   Notification Messages MUST be forwarded toward the LSR originating
   the Label Request at each hop and at any time that procedures in this
   specification - or in [1] - specify sending of a Notification Message
   in response to a Label Request Message.

The encoding of the notification message is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|   Notification (0x0001)     |         Message Length        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Message ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Status (TLV)                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Optional Parameters                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
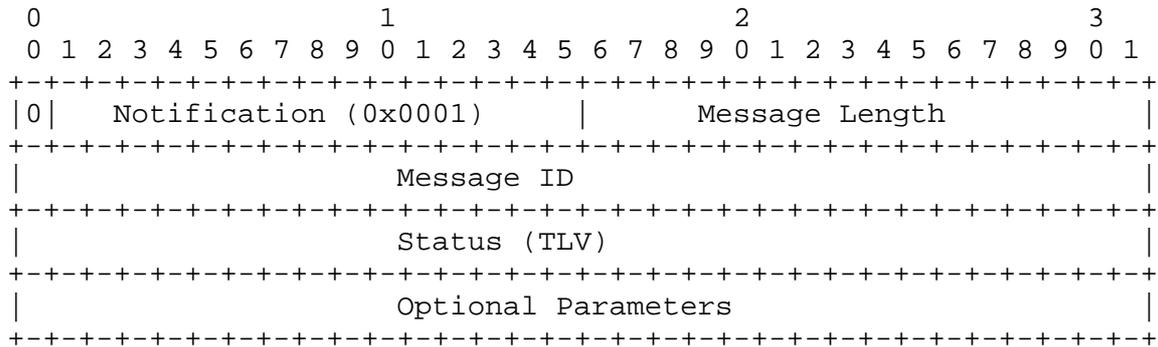
3.5 Release , Withdraw, and Abort Messages

   The Label Release , Label Withdraw, and Label Abort Request Messages
   are used as specified in [1]. These messages MAY also carry the
   LSPID TLV.

4. Protocol Specification

   The Label Request Message defined in [1] MUST carry the LSPID TLV and
   MAY carry one or more of the optional Constraint-based Routing TLVs
   (CR-TLVs) defined in this section. If needed, other constraints can
   be supported later through the definition of new TLVs. In this
   specification, the following TLVs are defined:

      - Explicit Route TLV
      - Explicit Route Hop TLV
      - Traffic Parameters TLV
      - Preemption TLV
      - LSPID TLV
      - Route Pinning TLV
      - Resource Class TLV
      - CR-LSP FEC TLV

4.1 Explicit Route TLV (ER-TLV)

   The ER-TLV is an object that specifies the path to be taken by the
   LSP being established. It is composed of one or more Explicit Route
   Hop TLVs (ER-Hop TLVs) defined in Section 4.2.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|        Type = 0x0800     |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          ER-Hop TLV 1                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          ER-Hop TLV 2                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                          ............                        ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          ER-Hop TLV n                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
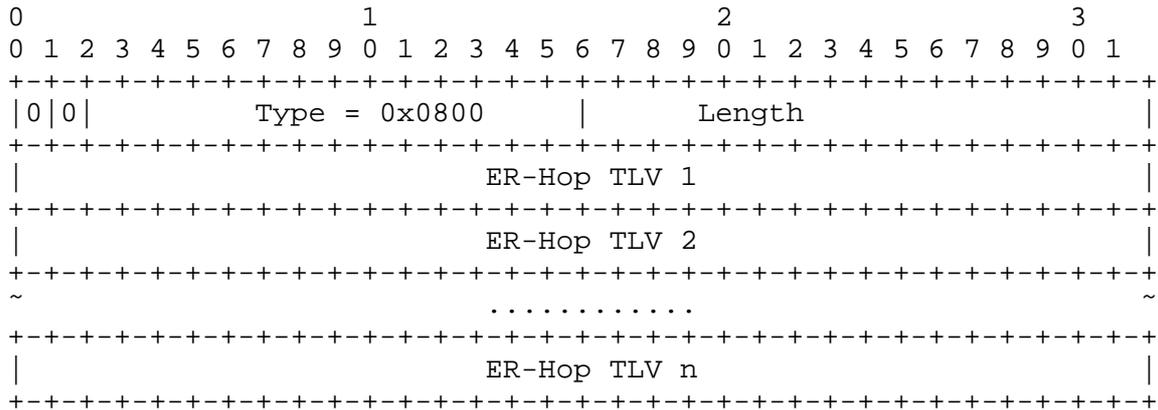
Type
     A fourteen-bit field carrying the value of the ER-TLV
     Type = 0x0800.

Length
     Specifies the length of the value field in bytes.

ER-Hop TLVs
     One or more ER-Hop TLVs defined in Section 4.2.

4.2 Explicit Route Hop TLV (ER-Hop TLV)

   The contents of an ER-TLV are a series of variable length ER-Hop
   TLVs.

   A node receiving a label request message including an ER-Hop type
   that is not supported MUST not progress the label request message to
   the downstream LSR and MUST send back a "No Route" Notification
   Message.

   Each ER-Hop TLV has the form:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|                 Type      |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|                           Content //                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
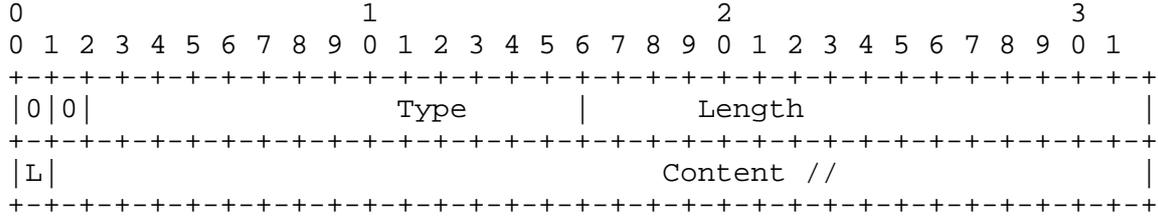
ER-Hop Type
     A fourteen-bit field carrying the type of the ER-Hop contents.
     Currently defined values are:

     Value Type
     ------ ------------------------
     0x0801 IPv4 prefix
     0x0802 IPv6 prefix
     0x0803 Autonomous system number
     0x0804 LSPID

Length
     Specifies the length of the value field in bytes.

L bit
     The L bit in the ER-Hop is a one-bit attribute. If the L bit
     is set, then the value of the attribute is "loose." Otherwise,
     the value of the attribute is "strict." For brevity, we say
     that if the value of the ER-Hop attribute is loose then it is a
     "loose ER-Hop." Otherwise, it's a "strict ER-Hop." Further,
     we say that the abstract node of a strict or loose ER-Hop is a
     strict or a loose node, respectively. Loose and strict nodes
     are always interpreted relative to their prior abstract nodes.
     The path between a strict node and its prior node MUST include
     only network nodes from the strict node and its prior abstract
     node.

     The path between a loose node and its prior node MAY include
     other network nodes, which are not part of the strict node or
     its prior abstract node.

Contents
     A variable length field containing a node or abstract node
     which is one of the consecutive nodes that make up the
     explicitly routed LSP.

4.3 Traffic Parameters TLV

   The following sections describe the CR-LSP Traffic Parameters. The
   required characteristics of a CR-LSP are expressed by the Traffic
   Parameter values.

   A Traffic Parameters TLV, is used to signal the Traffic Parameter
   values. The Traffic Parameters are defined in the subsequent
   sections.

The Traffic Parameters TLV contains a Flags field, a Frequency, a
Weight, and the five Traffic Parameters PDR, PBS, CDR, CBS, EBS.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|      Type = 0x0810       |         Length = 24           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Flags     |   Frequency  |    Reserved   |    Weight     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Peak Data Rate (PDR)                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Peak Burst Size (PBS)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Committed Data Rate (CDR)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Committed Burst Size (CBS)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Excess Burst Size (EBS)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
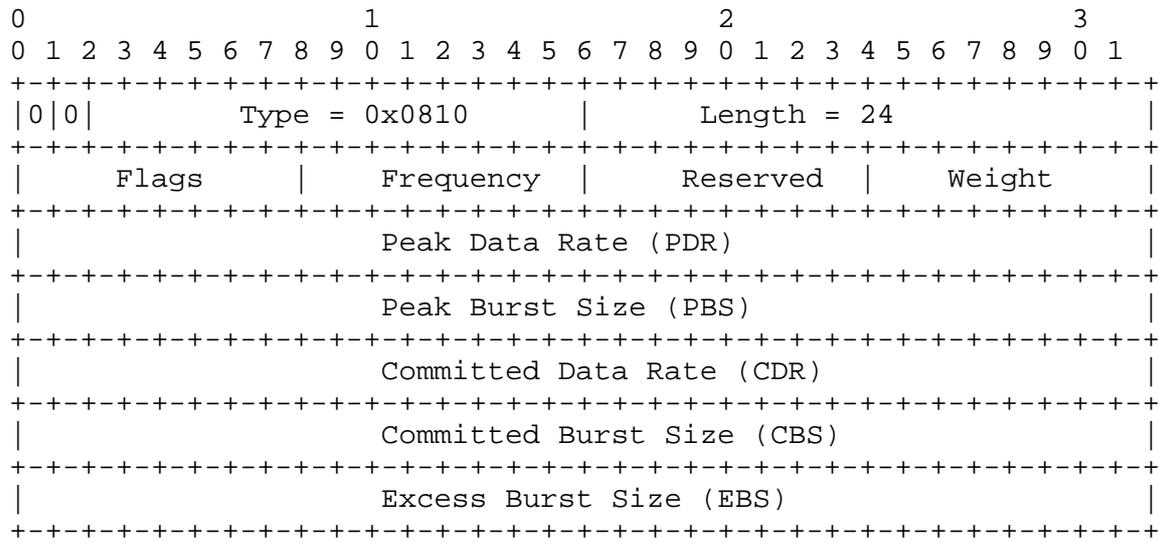
Type
      A fourteen-bit field carrying the value of the Traffic
      Parameters TLV Type = 0x0810.

Length
      Specifies the length of the value field in bytes = 24.

Flags
      The Flags field is shown below:

```
      +--+--+--+--+--+--+--+--+
      | Res |F6|F5|F4|F3|F2|F1|
      +--+--+--+--+--+--+--+--+
```
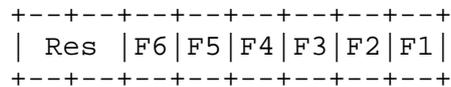
      Res - These bits are reserved.
      Zero on transmission.
      Ignored on receipt.
      F1 - Corresponds to the PDR.
      F2 - Corresponds to the PBS.
      F3 - Corresponds to the CDR.
      F4 - Corresponds to the CBS.
      F5 - Corresponds to the EBS.
      F6 - Corresponds to the Weight.

Each flag Fi is a Negotiable Flag corresponding to a Traffic
Parameter. The Negotiable Flag value zero denotes
NotNegotiable and value one denotes Negotiable.

Frequency
     The Frequency field is coded as an 8 bit unsigned integer with
     the following code points defined:

     0- Unspecified
     1- Frequent
     2- VeryFrequent
     3-255 - Reserved
     Reserved - Zero on transmission. Ignored on receipt.

Weight
     An 8 bit unsigned integer indicating the weight of the CR-LSP.
     Valid weight values are from 1 to 255. The value 0 means that
     weight is not applicable for the CR-LSP.

Traffic Parameters
     Each Traffic Parameter is encoded as a 32-bit IEEE single-
     precision floating-point number. A value of positive infinity
     is represented as an IEEE single-precision floating-point
     number with an exponent of all ones (255) and a sign and
     mantissa of all zeros. The values PDR and CDR are in units of
     bytes per second. The values PBS, CBS and EBS are in units of
     bytes.

     The value of PDR MUST be greater than or equal to the value of
     CDR in a correctly encoded Traffic Parameters TLV.

4.3.1 Semantics

4.3.1.1 Frequency

The Frequency specifies at what granularity the CDR allocated to the
CR-LSP is made available. The value VeryFrequent means that the
available rate should average at least the CDR when measured over any
time interval equal to or longer than the shortest packet time at the
CDR. The value Frequent means that the available rate should average
at least the CDR when measured over any time interval equal to or
longer than a small number of shortest packet times at the CDR.

The value Unspecified means that the CDR MAY be provided at any
granularity.

4.3.1.2 Peak Rate

   The Peak Rate defines the maximum rate at which traffic SHOULD be
   sent to the CR-LSP. The Peak Rate is useful for the purpose of
   resource allocation. If resource allocation within the MPLS domain
   depends on the Peak Rate value then it should be enforced at the
   ingress to the MPLS domain.

   The Peak Rate is defined in terms of the two Traffic Parameters PDR
   and PBS, see section 4.3.1.5 below.

4.3.1.3 Committed Rate

   The Committed Rate defines the rate that the MPLS domain commits to
   be available to the CR-LSP.

   The Committed Rate is defined in terms of the two Traffic Parameters
   CDR and CBS, see section 4.3.1.6 below.

4.3.1.4 Excess Burst Size

   The Excess Burst Size may be used at the edge of an MPLS domain for
   the purpose of traffic conditioning. The EBS MAY be used to measure
   the extent by which the traffic sent on a CR-LSP exceeds the
   committed rate.

   The possible traffic conditioning actions, such as passing, marking
   or dropping, are specific to the MPLS domain.

   The Excess Burst Size is defined together with the Committed Rate,
   see section 4.3.1.6 below.

4.3.1.5 Peak Rate Token Bucket

   The Peak Rate of a CR-LSP is specified in terms of a token bucket P
   with token rate PDR and maximum token bucket size PBS.

   The token bucket P is initially (at time 0) full, i.e., the token
   count $Tp(0)$ = PBS. Thereafter, the token count Tp, if less than PBS,
   is incremented by one PDR times per second. When a packet of size B
   bytes arrives at time t, the following happens:

      - If $Tp(t)-B >= 0$, the packet is not in excess of the peak rate
         and Tp is decremented by B down to the minimum value of 0, else

      - the packet is in excess of the peak rate and Tp is not
         decremented.

Note that according to the above definition, a positive infinite value of either PDR or PBS implies that arriving packets are never in excess of the peak rate.

The actual implementation of an LSR doesn't need to be modeled according to the above formal token bucket specification.

4.3.1.6 Committed Data Rate Token Bucket

The committed rate of a CR-LSP is specified in terms of a token bucket C with rate CDR. The extent by which the offered rate exceeds the committed rate MAY be measured in terms of another token bucket E, which also operates at rate CDR. The maximum size of the token bucket C is CBS and the maximum size of the token bucket E is EBS.

The token buckets C and E are initially (at time 0) full, i.e., the token count $Tc(0) = CBS$ and the token count $Te(0) = EBS$.

Thereafter, the token counts Tc and Te are updated CDR times per second as follows:

- If Tc is less than CBS, Tc is incremented by one, else
- if Te is less then EBS, Te is incremented by one, else neither
   Tc nor Te is incremented.

When a packet of size B bytes arrives at time t, the following happens:

- If $Tc(t)-B >= 0$, the packet is not in excess of the Committed
   Rate and Tc is decremented by B down to the minimum value of 0,
   else

- if $Te(t)-B >= 0$, the packet is in excess of the Committed rate
   but is not in excess of the EBS and Te is decremented by B down
   to the minimum value of 0, else

- the packet is in excess of both the Committed Rate and the EBS
   and neither Tc nor Te is decremented.

Note that according to the above specification, a CDR value of positive infinity implies that arriving packets are never in excess of either the Committed Rate or EBS. A positive infinite value of either CBS or EBS implies that the respective limit cannot be exceeded.

The actual implementation of an LSR doesn't need to be modeled according to the above formal specification.

4.3.1.7 Weight

   The weight determines the CR-LSP's relative share of the possible
   excess bandwidth above its committed rate. The definition of
   "relative share" is MPLS domain specific.

4.3.2 Procedures

4.3.2.1 Label Request Message

   If an LSR receives an incorrectly encoded Traffic Parameters TLV in
   which the value of PDR is less than the value of CDR then it MUST
   send a Notification Message including the Status code "Traffic
   Parameters Unavailable" to the upstream LSR from which it received
   the erroneous message.

   If a Traffic Parameter is indicated as Negotiable in the Label
   Request Message by the corresponding Negotiable Flag then an LSR MAY
   replace the Traffic Parameter value with a smaller value.

   If the Weight is indicated as Negotiable in the Label Request Message
   by the corresponding Negotiable Flag then an LSR may replace the
   Weight value with a lower value (down to 0).

   If, after possible Traffic Parameter negotiation, an LSR can support
   the CR-LSP Traffic Parameters then the LSR MUST reserve the
   corresponding resources for the CR-LSP.

   If, after possible Traffic Parameter negotiation, an LSR cannot
   support the CR-LSP Traffic Parameters then the LSR MUST send a
   Notification Message that contains the "Resource Unavailable" status
   code.

4.3.2.2 Label Mapping Message

   If an LSR receives an incorrectly encoded Traffic Parameters TLV in
   which the value of PDR is less than the value of CDR then it MUST
   send a Label Release message containing the Status code "Traffic
   Parameters Unavailable" to the LSR from which it received the
   erroneous message. In addition, the LSP should send a Notification
   Message upstream with the status code 'Label Request Aborted'.

   If the negotiation flag was set in the label request message, the
   egress LSR MUST include the (possibly negotiated) Traffic Parameters
   and Weight in the Label Mapping message.

   The Traffic Parameters and the Weight in a Label Mapping message MUST
   be forwarded unchanged.

An LSR SHOULD adjust the resources that it reserved for a CR-LSP when
it receives a Label Mapping Message if the Traffic Parameters differ
from those in the corresponding Label Request Message.

4.3.2.3 Notification Message

If an LSR receives a Notification Message for a CR-LSP, it SHOULD
release any resources that it possibly had reserved for the CR-LSP.
In addition, on receiving a Notification Message from a Downstream
LSR that is associated with a Label Request from an upstream LSR, the
local LSR MUST propagate the Notification message using the
procedures in [1]. Further the F bit MUST be set.

4.4 Preemption TLV

The default value of the setup and holding priorities should be in
the middle of the range (e.g., 4) so that this feature can be turned
on gradually in an operational network by increasing or decreasing
the priority starting at the middle of the range.

Since the Preemption TLV is an optional TLV, LSPs that are setup
without an explicitly signaled preemption TLV SHOULD be treated as
LSPs with the default setup and holding priorities (e.g., 4).

When an established LSP is preempted, the LSR that initiates the
preemption sends a Withdraw Message upstream and a Release Message
downstream.

When an LSP in the process of being established (outstanding Label
Request without getting a Label Mapping back) is preempted, the LSR
that initiates the preemption, sends a Notification Message upstream
and an Abort Message downstream.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|     Type = 0x0820        |         Length = 4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SetPrio      | HoldPrio     |         Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type
     A fourteen-bit field carrying the value of the Preemption-TLV
     Type = 0x0820.

Length
     Specifies the length of the value field in bytes = 4.

   Reserved
        Zero on transmission. Ignored on receipt.

   SetPrio
        A SetupPriority of value zero (0) is the priority assigned to
        the most important path. It is referred to as the highest
        priority. Seven (7) is the priority for the least important
        path. The higher the setup priority, the more paths CR-LDP can
        bump to set up the path. The default value should be 4.

   HoldPrio
        A HoldingPriority of value zero (0) is the priority assigned to
        the most important path. It is referred to as the highest
        priority. Seven (7) is the priority for the least important
        path. The default value should be 4.
        The higher the holding priority, the less likely it is for CR-
        LDP to reallocate its bandwidth to a new path.

4.5 LSPID TLV

   LSPID is a unique identifier of a CR-LSP within an MPLS network.

   The LSPID is composed of the ingress LSR Router ID (or any of its
   own Ipv4 addresses) and a Locally unique CR-LSP ID to that LSR.

   The LSPID is useful in network management, in CR-LSP repair, and in
   using an already established CR-LSP as a hop in an ER-TLV.

   An "action indicator flag" is carried in the LSPID TLV. This "action
   indicator flag" indicates explicitly the action that should be taken
   if the LSP already exists on the LSR receiving the message.

   After a CR-LSP is set up, its bandwidth reservation may need to be
   changed by the network operator, due to the new requirements for the
   traffic carried on that CR-LSP. The "action indicator flag" is used
   indicate the need to modify the bandwidth and possibly other
   parameters of an established CR-LSP without service interruption.
   This feature has application in dynamic network resources management
   where traffic of different priorities and service classes is
   involved.

   The procedure for the code point "modify" is defined in [8]. The
   procedures for other flags are FFS.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|       Type = 0x0821        |           Length = 4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved             |ActFlg |     Local CR-LSP ID    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Ingress LSR Router ID                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
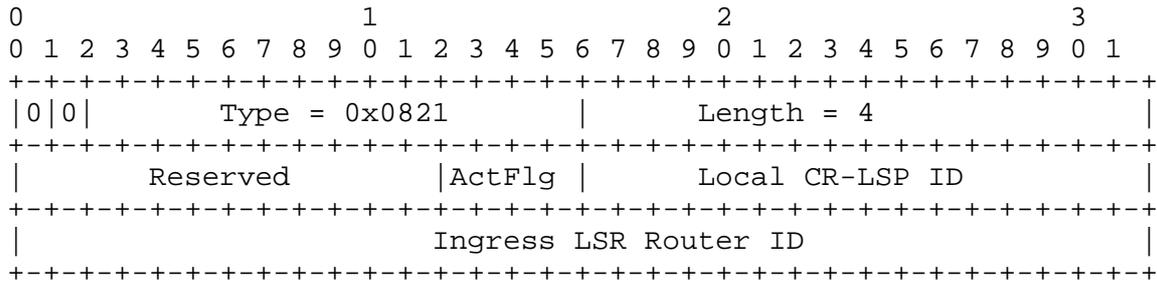
Type
      A fourteen-bit field carrying the value of the LSPID-TLV
      Type = 0x0821.

Length
      Specifies the length of the value field in bytes = 4.

ActFlg
      Action Indicator Flag: A 4-bit field that indicates explicitly
      the action that should be taken if the LSP already exists on
      the LSR receiving the message. A set of indicator code points
      is proposed as follows:

            0000: indicates initial LSP setup
            0001: indicates modify LSP

Reserved
      Zero on transmission. Ignored on receipt.

Local CR-LSP ID
      The Local LSP ID is an identifier of the CR-LSP locally unique
      within the Ingress LSR originating the CR-LSP.

Ingress LSR Router ID
      An LSR may use any of its own IPv4 addresses in this field.

4.6 Resource Class (Color) TLV

   The Resource Class as defined in [3] is used to specify which links
   are acceptable by this CR-LSP. This information allows for the
   network's topology to be pruned.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|         Type = 0x0822       |          Length = 4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             RsCls                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
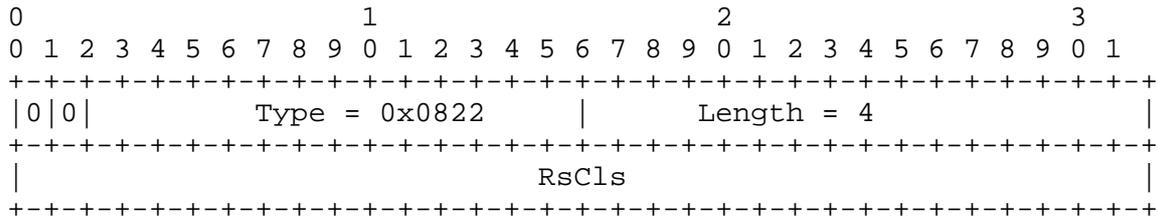
   Type
        A fourteen-bit field carrying the value of the ResCls-TLV
        Type = 0x0822.

   Length
        Specifies the length of the value field in bytes = 4.

   RsCls
        The Resource Class bit mask indicating which of the 32
        "administrative groups" or "colors" of links the CR-LSP can
        traverse.

4.7 ER-Hop semantics

4.7.1. ER-Hop 1: The IPv4 prefix

   The abstract node represented by this ER-Hop is the set of nodes,
   which have an IP address, which lies within this prefix. Note that a
   prefix length of 32 indicates a single IPv4 node.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|         Type = 0x0801       |          Length = 8          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|      Reserved                 |            PreLen            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      IPv4 Address (4 bytes)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
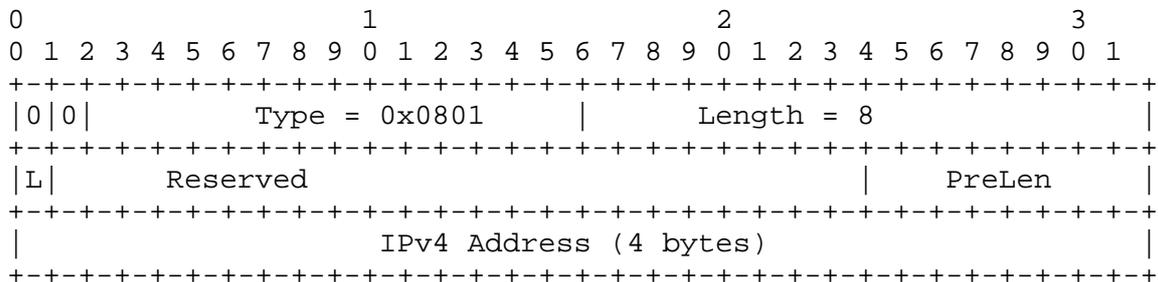
   Type
        A fourteen-bit field carrying the value of the ER-Hop 1, IPv4
        Address, Type = 0x0801

   Length
        Specifies the length of the value field in bytes = 8.

   L Bit
        Set to indicate Loose hop.
        Cleared to indicate a strict hop.

        Reserved
              Zero on transmission. Ignored on receipt.

        PreLen
              Prefix Length 1-32

        IP Address
              A four-byte field indicating the IP Address.

4.7.2. ER-Hop 2: The IPv6 address

```
   0                   1                   2                   3
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |0|0|         0x0802          |         Length = 20            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |L|              Reserved                  |      PreLen       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      IPV6 address                            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                IPV6 address (continued)                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                IPV6 address (continued)                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                IPV6 address (continued)                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
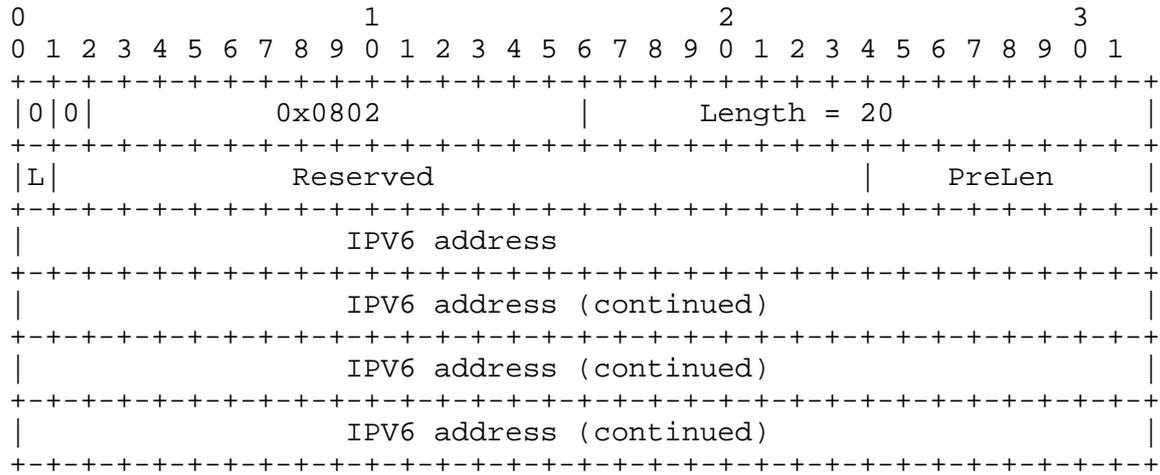
        Type
              A fourteen-bit field carrying the value of the ER-Hop 2, IPv6
              Address, Type = 0x0802

        Length
              Specifies the length of the value field in bytes = 20.

        L Bit
              Set to indicate Loose hop.
              Cleared to indicate a strict hop.

        Reserved
   Zero on transmission. Ignored on receipt.

        PreLen
   Prefix Length 1-128

        IPv6 address
              A 128-bit unicast host address.

4.7.3. ER-Hop 3: The autonomous system number

   The abstract node represented by this ER-Hop is the set of nodes
   belonging to the autonomous system.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|        0x0803            |         Length = 4             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|          Reserved         |            AS Number           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
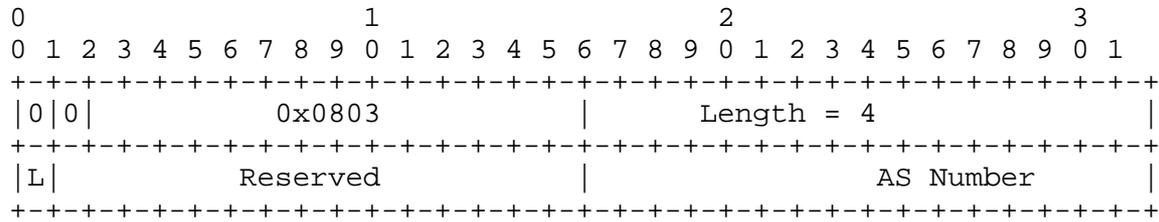
   Type
         A fourteen-bit field carrying the value of the ER-Hop 3, AS
         Number, Type = 0x0803

   Length
         Specifies the length of the value field in bytes = 4.

   L Bit
         Set to indicate Loose hop.
         Cleared to indicate a strict hop.

   Reserved
         Zero on transmission. Ignored on receipt.

   AS Number
         Autonomous System number

4.7.4. ER-Hop 4: LSPID

   The LSPID is used to identify the tunnel ingress point as the next
   hop in the ER. This ER-Hop allows for stacking new CR-LSPs within an
   already established CR-LSP. It also allows for splicing the CR-LSP
   being established with an existing CR-LSP.

   If an LSPID Hop is the last ER-Hop in an ER-TLV, than the LSR may
   splice the CR-LSP of the incoming Label Request to the CR-LSP that
   currently exists with this LSPID. This is useful, for example, at
   the point at which a Label Request used for local repair arrives at
   the next ER-Hop after the loosely specified CR-LSP segment. Use of
   the LSPID Hop in this scenario eliminates the need for ER-Hops to
   keep the entire remaining ER-TLV at each LSR that is at either
   (upstream or downstream) end of a loosely specified CR-LSP segment as
   part of its state information. This is due to the fact that the

upstream LSR needs only to keep the next ER-Hop and the LSPID and the
downstream LSR needs only to keep the LSPID in order for each end to
be able to recognize that the same LSP is being identified.

If the LSPID Hop is not the last hop in an ER-TLV, the LSR must
remove the LSP-ID Hop and forward the remaining ER-TLV in a Label
Request message using an LDP session established with the LSR that is
the specified CR-LSP's egress. That LSR will continue processing of
the CR-LSP Label Request Message. The result is a tunneled, or
stacked, CR-LSP.

To support labels negotiated for tunneled CR-LSP segments, an LDP
session is required [1] between tunnel end points - possibly using
the existing CR-LSP. Use of the existence of the CR-LSP in lieu of a
session, or other possible session-less approaches, is FFS.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|         0x0804          |           Length = 8           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|          Reserved         |            Local LSPID         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Ingress LSR Router ID                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
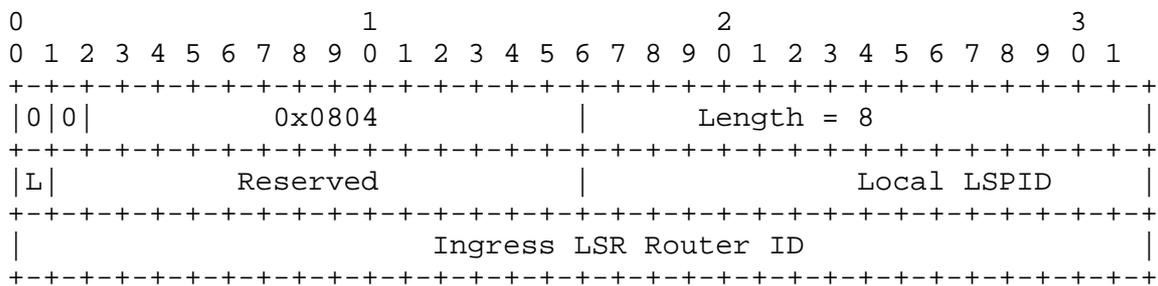
Type
      A fourteen-bit field carrying the value of the ER-Hop 4, LSPID,
      Type = 0x0804

Length
      Specifies the length of the value field in bytes = 8.

L Bit
      Set to indicate Loose hop.
      Cleared to indicate a strict hop.

Reserved
      Zero on transmission. Ignored on receipt.

Local LSPID
      A 2 byte field indicating the LSPID which is unique with
      reference to its Ingress LSR.

Ingress LSR Router ID
      An LSR may use any of its own IPv4 addresses in this field.

4.8. Processing of the Explicit Route TLV

4.8.1. Selection of the next hop

   A Label Request Message containing an explicit route TLV must
   determine the next hop for this path. Selection of this next hop may
   involve a selection from a set of possible alternatives. The
   mechanism for making a selection from this set is implementation
   dependent and is outside of the scope of this specification.
   Selection of particular paths is also outside of the scope of this
   specification, but it is assumed that each node will make a best
   effort attempt to determine a loop-free path. Note that such best
   efforts may be overridden by local policy.

   To determine the next hop for the path, a node performs the following
   steps:

      1. The node receiving the Label Request Message must first
         evaluate the first ER-Hop. If the L bit is not set in the
         first ER-Hop and if the node is not part of the abstract node
         described by the first ER-Hop, it has received the message in
         error, and should return a "Bad Initial ER-Hop Error" status.
         If the L bit is set and the local node is not part of the
         abstract node described by the first ER-Hop, the node selects a
         next hop that is along the path to the abstract node described
         by the first ER-Hop. If there is no first ER-Hop, the message
         is also in error and the system should return a "Bad Explicit
         Routing TLV Error" status using a Notification Message sent
         upstream.

      2. If there is no second ER-Hop, this indicates the end of the
         explicit route. The explicit route TLV should be removed from
         the Label Request Message. This node may or may not be the end
         of the LSP. Processing continues with section 4.8.2, where a
         new explicit route TLV may be added to the Label Request
         Message.

      3. If the node is also a part of the abstract node described by
         the second ER-Hop, then the node deletes the first ER-Hop and
         continues processing with step 2, above. Note that this makes
         the second ER-Hop into the first ER-Hop of the next iteration.

      4. The node determines if it is topologically adjacent to the
         abstract node described by the second ER-Hop. If so, the node
         selects a particular next hop which is a member of the abstract
         node. The node then deletes the first ER-Hop and continues
         processing with section 4.8.2.

      5. Next, the node selects a next hop within the abstract node of
         the first ER-Hop that is along the path to the abstract node of
         the second ER-Hop. If no such path exists then there are two
         cases:

         5.a If the second ER-Hop is a strict ER-Hop, then there is an
             error and the node should return a "Bad Strict Node Error"
             status.

         5.b Otherwise, if the second ER-Hop is a loose ER-Hop, then the
             node selects any next hop that is along the path to the
             next abstract node. If no path exists within the MPLS
             domain, then there is an error, and the node should return
             a "Bad Loose Node Error" status.

      6. Finally, the node replaces the first ER-Hop with any ER-Hop
         that denotes an abstract node containing the next hop. This is
         necessary so that when the explicit route is received by the
         next hop, it will be accepted.

      7. Progress the Label Request Message to the next hop.

4.8.2. Adding ER-Hops to the explicit route TLV

   After selecting a next hop, the node may alter the explicit route in
   the following ways.

   If, as part of executing the algorithm in section 4.8.1, the explicit
   route TLV is removed, the node may add a new explicit route TLV.

   Otherwise, if the node is a member of the abstract node for the first
   ER-Hop, then a series of ER-Hops may be inserted before the first
   ER-Hop or may replace the first ER-Hop. Each ER-Hop in this series
   must denote an abstract node that is a subset of the current abstract
   node.

   Alternately, if the first ER-Hop is a loose ER-Hop, an arbitrary
   series of ER-Hops may be inserted prior to the first ER-Hop.

4.9 Route Pinning TLV

   Section 2.4 describes the use of route pinning. The encoding of the
   Route Pinning TLV is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|         Type = 0x0823    |         Length = 4             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|P|                         Reserved                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
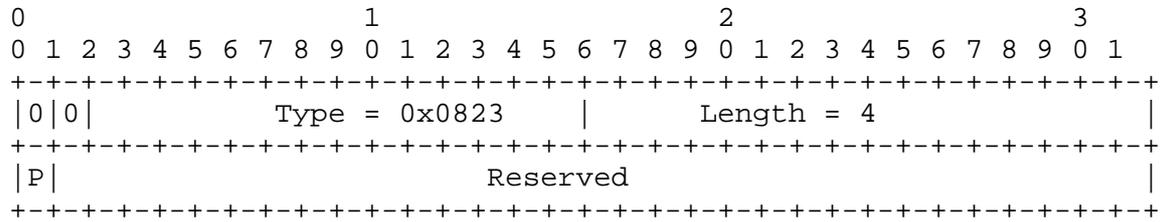
   Type
         A fourteen-bit field carrying the value of the Pinning-TLV
         Type = 0x0823

   Length
         Specifies the length of the value field in bytes = 4.

   P Bit
         The P bit is set to 1 to indicate that route pinning is
         requested.
         The P bit is set to 0 to indicate that route pinning is not
         requested

   Reserved
         Zero on transmission. Ignored on receipt.

4.10 CR-LSP FEC Element

   A new FEC element is introduced in this specification to support CR-
   LSPs. A FEC TLV containing a FEC of Element type CR-LSP (0x04) is a
   CR-LSP FEC TLV. The CR-LSP FEC Element is an opaque FEC to be used
   only in Messages of CR-LSPs.

   A single FEC element MUST be included in the Label Request Message.
   The FEC Element SHOULD be the CR-LSP FEC Element. However, one of
   the other FEC elements (Type=0x01, 0x02, 0x03) defined in [1] MAY be
   in CR-LDP messages instead of the CR-LSP FEC Element for certain
   applications. A FEC TLV containing a FEC of Element type CR-LSP
   (0x04) is a CR-LSP FEC TLV.

         FEC Element   Type   Value
         Type name

         CR-LSP   0x04   No value; i.e., 0 value octets;

The CR-LSP FEC TLV encoding is as follows:

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|         Type = 0x0100        |        Length = 1             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| CR-LSP (4)    |
+-+-+-+-+-+-+-+-+
```
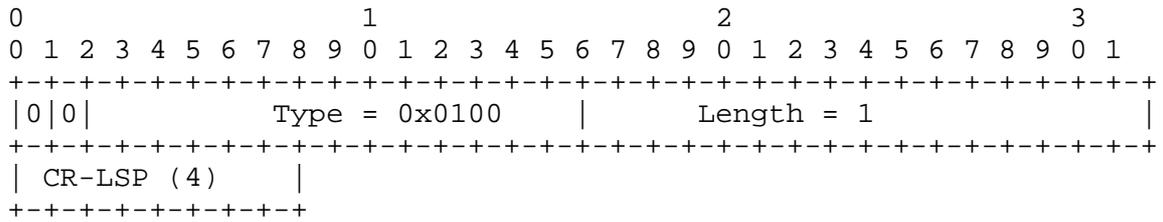
Type
    A fourteen-bit field carrying the value of the FEC TLV
    Type = 0x0100

Length
    Specifies the length of the value field in bytes = 1.

CR-LSP FEC Element Type

    0x04

5. IANA Considerations

CR-LDP defines the following name spaces, which require management:

    - TLV types.
    - FEC types.
    - Status codes.

The following sections provide guidelines for managing these name spaces.

5.1 TLV Type Name Space

RFC 3036 [1] defines the LDP TLV name space. This document further subdivides the range of RFC 3036 from that TLV space for TLVs associated with the CR-LDP in the range 0x0800 - 0x08FF.

Following the policies outlined in [IANA], TLV types in this range are allocated through an IETF Consensus action.

Initial values for this range are specified in the following table:

TLV	Type
Explicit Route TLV	0x0800
Ipv4 Prefix ER-Hop TLV	0x0801
Ipv6 Prefix ER-Hop TLV	0x0802
Autonomous System Number ER-Hop TLV	0x0803
LSP-ID ER-Hop TLV	0x0804
Traffic Parameters TLV	0x0810
Preemption TLV	0x0820
LSPID TLV	0x0821
Resource Class TLV	0x0822
Route Pinning TLV	0x0823

5.2 FEC Type Name Space

   RFC 3036 defines the FEC Type name space. Further, RFC 3036 has
   assigned values 0x00 through 0x03. FEC types 0 through 127 are
   available for assignment through IETF consensus action. This
   specification makes the following additional assignment, using the
   policies outlined in [IANA]:

FEC Element	Type
CR-LSP FEC Element	0x04

5.3 Status Code Space

   RFC 3036 defines the Status Code name space. This document further
   subdivides the range of RFC 3036 from that TLV space for TLVs
   associated with the CR-LDP in the range 0x04000000 - 0x040000FF.

   Following the policies outlined in [IANA], TLV types in this range
   are allocated through an IETF Consensus action.

Initial values for this range are specified in the following table:

```
Status Code                                    Type
--------------------------------------         ----------

Bad Explicit Routing TLV Error                 0x04000001
Bad Strict Node Error                          0x04000002
Bad Loose  Node Error                          0x04000003
Bad Initial ER-Hop Error                       0x04000004
Resource Unavailable                           0x04000005
Traffic Parameters Unavailable                 0x04000006
LSP Preempted                                  0x04000007
Modify Request Not Supported                   0x04000008
```

6. Security Considerations

   CR-LDP inherits the same security mechanism described in Section 4.0
   of [1] to protect against the introduction of spoofed TCP segments
   into LDP session connection streams.

7. Acknowledgments

   The messages used to signal the CR-LSP setup are based on the work
   done by the LDP [1] design team.

   The list of authors provided with this document is a reduction of the
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8. Intellectual Property Consideration

   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.

9. References

   [1] Andersson, L., Doolan, P., Feldman, N., Fredette, A. and B.
       Thomas, "Label Distribution Protocol Specification", RFC 3036,
       January 2001.

   [2] Rosen, E., Viswanathan, A. and R. Callon, "Multiprotocol Label
       Switching Architecture", RFC 3031, January 2001.

   [3] Awduche, D., Malcolm, J., Agogbua, J., O'Dell, M. and J. McManus,
       "Requirements for Traffic Engineering Over MPLS", RFC 2702,
       September 1999.

   [4] Gleeson, B., Lin, A., Heinanen, Armitage, G. and A. Malis, "A
       Framework for IP Based Virtual Private Networks", RFC 2764,
       February 2000.

   [5] Ash, J., Girish, M., Gray, E., Jamoussi, B. and G. Wright,
       "Applicability Statement for CR-LDP", RFC 3213, January 2002.

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

   [7] Boscher, C., Cheval, P., Wu, L. and E. Gray, "LDP State Machine",
       RFC 3215, January 2002.

   [8] Ash, J., Lee, Y., Ashwood-Smith, P., Jamoussi, B., Fedyk, D.,
       Skalecki, D. and L. Li, "LSP Modification Using CR-LDP", RFC
       3214, January 2002.

Appendix A: CR-LSP Establishment Examples

A.1 Strict Explicit Route Example

   This appendix provides an example for the setup of a strictly routed
   CR-LSP. In this example, a specific node represents each abstract
   node.

   The sample network used here is a four node network with two edge
   LSRs and two core LSRs as follows:

   abc
   LSR1------LSR2------LSR3------LSR4

   LSR1 generates a Label Request Message as described in Section 3.1 of
   this document and sends it to LSR2. This message includes the CR-
   TLV.

   A vector of three ER-Hop TLVs <a, b, c> composes the ER-TLV. The ER-
   Hop TLVs used in this example are of type 0x0801 (IPv4 prefix) with a
   prefix length of 32. Hence, each ER-Hop TLV identifies a specific
   node as opposed to a group of nodes. At LSR2, the following
   processing of the ER-TLV per Section 4.8.1 of this document takes
   place:

      1. The node LSR2 is part of the abstract node described by the
         first hop <a>. Therefore, the first step passes the test. Go
         to step 2.

      2. There is a second ER-Hop, <b>. Go to step 3.

      3. LSR2 is not part of the abstract node described by the second
         ER-Hop <b>. Go to Step 4.

      4. LSR2 determines that it is topologically adjacent to the
         abstract node described by the second ER-Hop <b>. LSR2 selects
         a next hop (LSR3) which is the abstract node. LSR2 deletes the
         first ER-Hop <a> from the ER-TLV, which now becomes <b, c>.
         Processing continues with Section 4.8.2.

   At LSR2, the following processing of Section 4.8.2 takes place:
   Executing algorithm 4.8.1 did not result in the removal of the ER-
   TLV.

   Also, LSR2 is not a member of the abstract node described by the
   first ER-Hop <b>.

   Finally, the first ER-Hop <b> is a strict hop.

Therefore, processing section 4.8.2 does not result in the insertion
of new ER-Hops. The selection of the next hop has been already done
is step 4 of Section 4.8.1 and the processing of the ER-TLV is
completed at LSR2. In this case, the Label Request Message including
the ER-TLV <b, c> is progressed by LSR2 to LSR3.

At LSR3, a similar processing to the ER-TLV takes place except that
the incoming ER-TLV = <b, c> and the outgoing ER-TLV is <c>.

At LSR4, the following processing of section 4.8.1 takes place:

1. The node LSR4 is part of the abstract node described by the
    first hop <c>. Therefore, the first step passes the test. Go
    to step 2.

2. There is no second ER-Hop, this indicates the end of the CR-
    LSP. The ER-TLV is removed from the Label Request Message.
    Processing continues with Section 4.8.2.

At LSR4, the following processing of Section 4.8.2 takes place:
Executing algorithm 4.8.1 resulted in the removal of the ER-TLV. LSR4
does not add a new ER-TLV.

Therefore, processing section 4.8.2 does not result in the insertion
of new ER-Hops. This indicates the end of the CR-LSP and the
processing of the ER-TLV is completed at LSR4.

At LSR4, processing of Section 3.2 is invoked. The first condition
is satisfied (LSR4 is the egress end of the CR-LSP and upstream
mapping has been requested). Therefore, a Label Mapping Message is
generated by LSR4 and sent to LSR3.

At LSR3, the processing of Section 3.2 is invoked. The second
condition is satisfied (LSR3 received a mapping from its downstream
next hop LSR4 for a CR-LSP for which an upstream request is still
pending). Therefore, a Label Mapping Message is generated by LSR3
and sent to LSR2.

At LSR2, a similar processing to LSR 3 takes place and a Label
Mapping Message is sent back to LSR1, which completes the end-to-end
CR-LSP setup.

A.2 Node Groups and Specific Nodes Example

A request at ingress LSR to setup a CR-LSP might originate from a
management system or an application, the details are implementation
specific.

The ingress LSR uses information provided by the management system or the application and possibly also information from the routing database to calculate the explicit route and to create the Label Request Message.

The Label request message carries together with other necessary information an ER-TLV defining the explicitly routed path. In our example the list of hops in the ER-Hop TLV is supposed to contain an abstract node representing a group of nodes, an abstract node representing a specific node, another abstract node representing a group of nodes, and an abstract node representing a specific egress point.

In--{Group 1}--{Specific A}--{Group 2}--{Specific Out: B}
The ER-TLV contains four ER-Hop TLVs:

    1. An ER-Hop TLV that specifies a group of LSR valid for the first
       abstract node representing a group of nodes (Group 1).

    2. An ER-Hop TLV that indicates the specific node (Node A).

    3. An ER-Hop TLV that specifies a group of LSRs valid for the
       second abstract node representing a group of nodes (Group 2).

    4. An ER-Hop TLV that indicates the specific egress point for the
       CR-LSP (Node B).

All the ER-Hop TLVs are strictly routed nodes.

The setup procedure for this CR-LSP works as follows:

    1. The ingress node sends the Label Request Message to a node
        that is a member the group of nodes indicated in the first ER-
        Hop TLV, following normal routing for the specific node (A).

    2. The node that receives the message identifies itself as part
        of the group indicated in the first ER-Hop TLV, and that it is
        not the specific node (A) in the second. Further it realizes
        that the specific node (A) is not one of its next hops.

    3. It keeps the ER-Hop TLVs intact and sends a Label Request
        Message to another node that is part of the group indicated in
        the first ER-Hop TLV (Group 1), following normal routing for
        the specific node (A).

4. The node that receives the message identifies itself as part
    of the group indicated in the first ER-Hop TLV, and that it is
    not the specific node (A) in the second ER-Hop TLV. Further
    it realizes that the specific node (A) is one of its next
    hops.

5. It removes the first ER-Hop TLVs and sends a Label Request
    Message to the specific node (A).

6. The specific node (A) recognizes itself in the first ER-Hop
    TLV. Removes the specific ER-Hop TLV.

7. It sends a Label Request Message to a node that is a member of
    the group (Group 2) indicated in the ER-Hop TLV.

8. The node that receives the message identifies itself as part
    of the group indicated in the first ER-Hop TLV, further it
    realizes that the specific egress node (B) is one of its next
    hops.

9. It sends a Label Request Message to the specific egress node
    (B).

10. The specific egress node (B) recognizes itself as the egress
    for the CR-LSP, it returns a Label Mapping Message, that will
    traverse the same path as the Label Request Message in the
    opposite direction.

Appendix B. QoS Service Examples

B.1 Service Examples

   Construction of an end-to-end service is the result of the rules
   enforced at the edge and the treatment that packets receive at the
   network nodes. The rules define the traffic conditioning actions
   that are implemented at the edge and they include policing with pass,
   mark, and drop capabilities. The edge rules are expected to be
   defined by the mutual agreements between the service providers and
   their customers and they will constitute an essential part of the
   SLA. Therefore edge rules are not included in the signaling
   protocol.

   Packet treatment at a network node is usually referred to as the
   local behavior. Local behavior could be specified in many ways. One
   example for local behavior specification is the service frequency
   introduced in section 4.3.2.1, together with the resource reservation
   rules implemented at the nodes.

Edge rules and local behaviors can be viewed as the main building blocks for the end-to-end service construction. The following table illustrates the applicability of the building block approach for constructing different services including those defined for ATM.

Service Examples	PDR	PBS	CDR	CBS	EBS	Service Frequency	Conditioning Action
DS	S	S	=PDR	=PBS	0	Frequent	drop>PDR
TS	S	S	S	S	0	Unspecified	drop>PDR,PBS mark>CDR,CBS
BE	inf	inf	inf	inf	0	Unspecified	-
FRS	S	S	CIR	~B_C	~B_E	Unspecified	drop>PDR,PBS mark>CDR,CBS,EBS
ATM-CBR	PCR	CDVT	=PCR	=CDVT	0	VeryFrequent	drop>PCR
ATM-VBR.3(rt)	PCR	CDVT	SCR	MBS	0	Frequent	drop>PCR mark>SCR,MBS
ATM-VBR.3(nrt)	PCR	CDVT	SCR	MBS	0	Unspecified	drop>PCR mark>SCR,MBS
ATM-UBR	PCR	CDVT	-	-	0	Unspecified	drop>PCR
ATM-GFR.1	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR
ATM-GFR.2	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR mark>MCR,MFS
int-serv-CL	p	m	r	b	0	Frequent	drop>p drop>r,b

S= User specified

In the above table, the DS refers to a delay sensitive service where the network commits to deliver with high probability user datagrams at a rate of PDR with minimum delay and delay requirements. Datagrams in excess of PDR will be discarded.

The TS refers to a generic throughput sensitive service where the network commits to deliver with high probability user datagrams at a rate of at least CDR. The user may transmit at a rate higher than CDR but datagrams in excess of CDR would have a lower probability of being delivered.

The BE is the best effort service and it implies that there are no
expected service guarantees from the network.

B.2 Establishing CR-LSP Supporting Real-Time Applications

In this scenario the customer needs to establish an LSP for
supporting real-time applications such as voice and video. The
Delay-sensitive (DS) service is requested in this case.

The first step is the specification of the traffic parameters in the
signaling message. The two parameters of interest to the DS service
are the PDR and the PBS and the user based on his requirements
specifies their values. Since all the traffic parameters are
included in the signaling message, appropriate values must be
assigned to all of them. For DS service, the CDR and the CBS values
are set equal to the PDR and the PBS respectively. An indication of
whether the parameter values are subject to negotiation is flagged.

The transport characteristics of the DS service require Frequent
frequency to be requested to reflect the real-time delay requirements
of the service.

In addition to the transport characteristics, both the network
provider and the customer need to agree on the actions enforced at
the edge. The specification of those actions is expected to be a
part of the service level agreement (SLA) negotiation and is not
included in the signaling protocol. For DS service, the edge action
is to drop packets that exceed the PDR and the PBS specifications.
The signaling message will be sent in the direction of the ER path
and the LSP is established following the normal LDP procedures. Each
LSR applies its admission control rules. If sufficient resources are
not available and the parameter values are subject to negotiation,
then the LSR could negotiate down the PDR, the PBS, or both.

The new parameter values are echoed back in the Label Mapping
Message. LSRs might need to re-adjust their resource reservations
based on the new traffic parameter values.

B.3 Establishing CR-LSP Supporting Delay Insensitive Applications

In this example we assume that a throughput sensitive (TS) service is
requested. For resource allocation the user assigns values for PDR,
PBS, CDR, and CBS. The negotiation flag is set if the traffic
parameters are subject to negotiation.
Since the service is delay insensitive by definition, the Unspecified
frequency is signaled to indicate that the service frequency is not
an issue.

Similar to the previous example, the edge actions are not subject for
signaling and are specified in the service level agreement between
the user and the network provider.

For TS service, the edge rules might include marking to indicate high
discard precedence values for all packets that exceed CDR and the
CBS. The edge rules will also include dropping of packets that
conform to neither PDR nor PBS.

Each LSR of the LSP is expected to run its admission control rules
and negotiate traffic parameters down if sufficient resources do not
exist. The new parameter values are echoed back in the Label Mapping
Message. LSRs might need to re-adjust their resources based on the
new traffic parameter values.

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