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Use of Label Switching on Frame Relay Networks Specification

Status of this Memo

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Abstract

This document defines the model and generic mechanisms for Multiprotocol Label Switching on Frame Relay networks. Furthermore, it extends and clarifies portions of the Multiprotocol Label Switching Architecture described in [ARCH] and the Label Distribution Protocol (LDP) described in [LDP] relative to Frame Relay Networks. MPLS enables the use of Frame Relay Switches as Label Switching Routers (LSRs).

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1. Introduction

The Multiprotocol Label Switching Architecture is described in [ARCH]. It is possible to use Frame Relay switches as Label Switching Routers. Such Frame Relay switches run network layer routing algorithms (such as OSPF, IS-IS, etc.), and their forwarding is based on the results of these routing algorithms. No specific Frame Relay routing is needed.

When a Frame Relay switch is used for label switching, the top (current) label, on which forwarding decisions are based, is carried in the DLCI field of the Frame Relay data link layer header of a frame. Additional information carried along with the top (current) label, but not processed by Frame Relay switching, along with other labels, if the packet is multiply labeled, are carried in the generic MPLS encapsulation defined in [STACK].

Frame Relay permanent virtual circuits (PVCs) could be configured to carry label switching based traffic. The DLCIs would be used as MPLS Labels and the Frame Relay switches would become Frame Relay Label Switching Routers, while the MPLS traffic would be encapsulated according to this specification, and would be forwarded based on network layer routing information.

The keywords MUST, MUST NOT, MAY, OPTIONAL, REQUIRED, RECOMMENDED, SHALL, SHALL NOT, SHOULD, SHOULD NOT are to be interpreted as defined in RFC 2119.

This document is a companion document to [STACK] and [ATM].

2. Terminology

LSR

A Label Switching Router (LSR) is a device which implements the label switching control and forwarding components described in [ARCH].

LC-FR

A label switching controlled Frame Relay (LC-FR) interface is a Frame Relay interface controlled by the label switching control component. Packets traversing such an interface carry labels in the DLCI field.

FR-LSR

A FR-LSR is an LSR with one or more LC-FR interfaces which forwards frames between two such interfaces using labels carried in the DLCI field.

FR-LSR domain

A FR-LSR domain is a set of FR-LSRs, which are mutually interconnected by LC-FR interfaces.

Edge Set

The Edge Set of an FR-LSR domain is the set of LSRs, which are connected to the domain by LC-FR interfaces.

Forwarding Encapsulation

The Forwarding Encapsulation is the type of MPLS encapsulation (Frame Relay, ATM, Generic) of a packet that determines the packet's MPLS forwarding, or the network layer encapsulation if that packet is forwarded based on the network layer (IP, etc...)header.

Input Encapsulation

The Input Encapsulation is the type of MPLS encapsulation (Frame Relay, ATM, Generic) of a packet when that packet is received on an LSR's interface, or the network layer (IP, etc...)encapsulation if that packet has no MPLS encapsulation.

Output Encapsulation

The Output Encapsulation is the type of MPLS encapsulation (Frame Relay, ATM, Generic) of a packet when that packet is transmitted on an LSR's interface, or the network layer (IP, etc...)encapsulation if that packet has no MPLS encapsulation.

Input TTL

The Input TTL is the MPLS TTL of the top of the stack when a labeled packet is received on an LSR interface, or the network layer (IP) TTL if the packet is not labeled.

Output TTL

The Output TTL is the MPLS TTL of the top of the stack when a labeled packet is transmitted on an LSR interface, or the network layer (IP) TTL if the packet is not labeled.

Additionally, this document uses terminology from [ARCH].

3. Special characteristics of Frame Relay Switches

While the label switching architecture permits considerable flexibility in LSR implementation, a FR-LSR is constrained by the capabilities of the (possibly pre-existing) hardware and the restrictions on such matters as frame format imposed by the Multiprotocol Interconnect over Frame Relay [MIFR], or Frame Relay standards [FRF], etc.... Because of these constraints, some special procedures are required for FR-LSRs.

Some of the key features of Frame Relay switches that affect their behavior as LSRs are:

- the label swapping function is performed on fields (DLCI) in the frame's Frame Relay data link header; this dictates the size and placement of the label(s) in a packet. The size of the DLCI field can be 10 (default) or 23 bits, and it can span two or four bytes in the header.

- there is generally no capability to perform a 'TTL-decrement' function as is performed on IP headers in routers.

- congestion control is performed by each node based on parameters that are passed at circuit creation. Flags in the frame headers may be set as a consequence of congestion, or exceeding the contractual parameters of the circuit.

- although in a standard switch it may be possible to configure multiple input DLCIs to one output DLCI resulting in a multipoint-to-point circuit, multipoint-to-multipoint VCs are generally not fully supported.

This document describes ways of applying label switching to Frame Relay switches, which work within these constraints.

4. Label Encapsulation

By default, all labeled packets should be transmitted with the generic label encapsulation as defined in [STACK], using the frame relay null encapsulation mechanism:

```
              0                       1                       (Octets)
             +-----------------------+-----------------------+
   (Octets)0 |                                               |
             /                Q.922 Address                  /
             /            (length 'n' equals 2 or 4)         /
             |                                               |
             +-----------------------+-----------------------+
           n |                       .                       |
             /                       .                       /
             /                  MPLS packet                  /
             |                       .                       |
             +-----------------------+-----------------------+
```

"n" is the length of the Q.922 Address which can be 2 or 4 octets.

The Q.922 [ITU] representation of a DLCI (in canonical order - the first bit is stored in the least significant, i.e., the right-most bit of a byte in memory) [CANON] is the following:

```
           7     6     5     4     3     2     1     0      (bit order)
        +-----+-----+-----+-----+-----+-----+-----+-----+
(octet) 0  |            DLCI(high order)       |  0  |  0  |
        +-----+-----+-----+-----+-----+-----+-----+-----+
        1  |  DLCI(low order)      |  0  |  0  |  0  |  1  |
        +-----+-----+-----+-----+-----+-----+-----+-----+

             10 bits DLCI
```

```
            7     6     5     4     3     2     1     0      (bit order)
         +-----+-----+-----+-----+-----+-----+-----+-----00
(octet) 0  |            DLCI(high order)       |  0  |  0  |
         +-----+-----+-----+-----+-----+-----+-----+-----
        1  |  DLCI                 |  0  |  0  |  0  |  0  |
         +-----+-----+-----+-----+-----+-----+-----+-----+
        2  |             DLCI                        |  0  |
         +-----+-----+-----+-----+-----+-----+-----+-----+
        3  |       DLCI (low order)            |  0  |  1  |
         +-----+-----+-----+-----+-----+-----+-----+-----+

              23 bits DLCI
```

The use of the frame relay null encapsulation implies that labels implicitly encode the network protocol type.

Rules regarding the construction of the label stack, and error messages returned to the frame source are also described in [STACK].

The generic encapsulation contains "n" labels for a label stack of depth "n" [STACK], where the top stack entry carries significant values for the EXP, S , and TTL fields [STACK] but not for the label, which is rather carried in the DLCI field of the Frame Relay data link header encoded in Q.922 [ITU] address format.

5. Frame Relay Label Switching Processing

5.1 Use of DLCIs

Label switching is accomplished by associating labels with routes and using the label value to forward packets, including determining the value of any replacement label. See [ARCH] for further details. In a FR-LSR, the top (current) MPLS label is carried in the DLCI field of the Frame Relay data link layer header of the frame. The top label carries implicitly information about the network protocol type.

For two connected FR-LSRs, a full-duplex connection must be available for LDP. The DLCI for the LDP VC is assigned a value by way of configuration, similar to configuring the DLCI used to run IP routing protocols between the switches.

With the exception of this configured value, the DLCI values used for MPLS in the two directions of the link may be treated as belonging to two independent spaces, i.e., VCs may be half-duplex, each direction with its own DLCI.

The allowable ranges of DLCIs, the size of DLCIs, and the support for VC merging MUST be communicated through LDP messages. Note that the range of DLCIs used for labels depends on the size of the DLCI field.

5.2 Homogeneous LSPs

If <LSR1, LSR2, LSR3> is an LSP, it is possible that LSR1, LSR2, and LSR3 will use the same encoding of the label stack when transmitting packet P from LSR1, to LSR2, and then to LSR3. Such an LSP is homogeneous.

5.3 Heterogeneous LSPs

If <LSR1, LSR2, LSR3> is an LSP, it is possible that LSR1 will use one encoding of the label stack when transmitting packet P to LSR2, but LSR2 will use a different encoding when transmitting a packet P to LSR3. In general, the MPLS architecture supports LSPs with different label stack encodings on different hops. When a labeled packet is received, the LSR must decode it to determine the current value of the label stack, then must operate on the label stack to determine the new label value of the stack, and then encode the new value appropriately before transmitting the labeled packet to its next hop.

Naturally there will be MPLS networks which contain a combination of Frame Relay switches operating as LSRs, and other LSRs, which operate using other MPLS encapsulations, such as the Generic (MPLS shim header), or ATM encapsulation. In such networks there may be some LSRs, which have Frame Relay interfaces as well as MPLS Generic ("MPLS Shim") interfaces. This is one example of an LSR with different label stack encodings on different hops of the same LSP. Such an LSR may swap off a Frame Relay encoded label on an incoming interface and replace it with a label encoded into a Generic MPLS (MPLS shim) header on the outgoing interface.

5.4 Frame Relay Label Switching Loop Prevention and Control

FR-LSRs SHOULD operate on loop free FR-LSPs or LSP Frame Relay segments. Therefore, FR-LSRs SHOULD use loop detection and MAY use loop prevention mechanisms as described in [ARCH], and [LDP].

5.4.1 FR-LSRs Loop Control - MPLS TTL processing

The MPLS TTL encoded in the MPLS label stack is a mechanism used to:

(a) suppress loops;

(b) limit the scope of a packet.

When a packet travels along an LSP, it should emerge with the same TTL value that it would have had if it had traversed the same sequence of routers without having been label switched. If the packet travels along a hierarchy of LSPs, the total number of LSR-hops traversed should be reflected in its TTL value when it emerges from the hierarchy of LSPs [ARCH].

The initial value of the MPLS TTL is loaded into a newly pushed label stack entry from the previous TTL value, whether that is from the network layer header when no previous label stack existed, or from a pre-existent lower level label stack entry.

A FR-LSR switching same level labeled packets does not decrement the MPLS TTL. A sequence of such FR-LSR is a "non-TTL segment".

When a packet emerges from a "non-TTL LSP segment", it should however reflect in the TTL the number of LSR-hops it traversed. In the unicast case, this can be achieved by propagating a meaningful LSP length or LSP Frame Relay segment length to the FR-LSR ingress nodes, enabling the ingress to decrement the TTL value before forwarding packets into a non-TTL LSP segment [ARCH].

When an ingress FR-LSR determines upon decrementing the MPLS TTL that a particular packet's TTL will expire before the packet reaches the egress of the "non-TTL LSP segment", the FR-LSR MUST not label switch the packet, but rather follow the specifications in [STACK] in an attempt to return an error message to the packet's source:

- it treats the packet as an expired packet and return an ICMP message to its source.

- it forwards the packet, as an unlabeled packet, with a TTL that reflects the IP (network layer) forwarding.

If the incoming TTL is 1, only the first option applies.

In the multicast case, a meaningful LSP length or LSP segment length is propagated to the FR-LSR egress node, enabling the egress to decrement the TTL value before forwarding packets out of the non-TTL LSP segment.

5.4.2 Performing MPLS TTL calculations

The calculation applied to the "input TTL" that yields the "output TTL" depends on (i)the "input encapsulation", (ii)the "forwarding encapsulation", and (iii)the "output encapsulation". The relationship among (i),(ii), and (iii), can be defined as a function

"D" of "input encapsulation" (ie), "forwarding encapsulation" (fe), and "output encapsulation" (oe). Subsequently the calculation applied to the "input TTL" to yield the "output TTL" can be described as:

output TTL = input TTL - D(ie, fe, oe)

or in a brief notation:

output TTL = input TTL - d

where "d" has three possible values: "0","1", or "the number of hops of the LSP segment":

For unicast transmission:

d	Type of Input Encapsulation	Type of Forwarding Encapsulation	Type of Output Encapsulation
0	Frame Relay	Frame Relay	Frame Relay
1	any	Generic MPLS	Generic MPLS
number of hops of LSP segment	any	Generic MPLS or IP(network layer)	Frame Relay

The "number of hops of the LSP segment" is the value of the "hop count" that is attached with the label used when the packet is forwarded, if LDP [LDP] has provided such a "hop count" value when it distributed the label for the LSP, that is the LDP message had a "hop count object". If LDP didn’t provide a "hop count", or it provided an "unknown" value, the default value of the "number of hops of the segment" is 1.

When sending a label binding upstream, the "hop count" associated with the corresponding binding from downstream, if different than the "unknown" value, MUST be incremented by 1, and the result transmitted upstream as the hop count associated with the new binding (the "unknown" value is transmitted unchanged). If the new "hop count" value exceeds the "maximum" value, the FR-LSR MUST NOT pass the binding upstream, but instead MUST send an error upstream [LDP][ARCH].

For multicast transmission:

d	Type of Input Encapsulation	Type of Forwarding Encapsulation	Type of Output Encapsulation
0	Frame Relay	Frame Relay	Frame Relay
1	any	Generic MPLS or IP(network layer)	Frame Relay
number of hops of LSP segment	Frame Relay	Generic MPLS or IP(network layer)	any

Referring to the "forwarding encapsulation" with the abbreviation "I" for IP (network layer), "G" for Generic MPLS, and "F" for Frame Relay MPLS, referring to an LSR interface with the abbreviation "i" if the input or output encapsulation is IP and no MPLS encapsulation, "g" when the input or output MPLS encapsulation is Generic MPLS, "f" when it is Frame Relay, "a" when it is ATM, and furthermore considering the symbols "iIf", "gGf", "fFf", etc... as LSRs with input, forwarding and output encapsulations as referred above, the following describes examples of TTL calculations for the Homogeneous and Heterogeneous LSPs discussed in previous sections:

```
                         Homogeneous LSP
                         ---------------
        IP_ttl = n                                     IP_ttl=mpls_ttl-1 = n-6
        --------->iIf                       fIi--------->
                    | mpls_ttl = n-5        ^
                    |                       |
number of hops     1|     Frame Relay       |5
                    |                       |
                    V   2      3      4     |
                    fFf--->fFf--->fFf--->fFf
```

 "iIf" is "ingress LSR" in Frame Relay LSP and
        calculates: mpls_ttl = IP_TTL - number of hops = n-5
 "fIi" is "egress LSR" from Frame Relay LSP, and
        calculates: IP_ttl = mpls_ttl-1 = n-6

```
                          Heterogeneous LSP
                          -----------------
ingress LSR                                                 egress LSR
IP_ttl = n                                              IP_ttl = n - 15
links   LAN   PPP        FR           ATM    PPP    FR     LAN
 --->iIg-->gGg-->gGf           fGa       aGg-->gGf       fGg-->gIi--->
hops     1     2   |     6      | |   9   |  10   |  13   ^  14    15
                   |1          4| |1     3|       |1     3|
                   V  2     3   | V   2   |       V   2   |
                  fFf-->fFf-->fFf aAa-->aAa       fFf-->fFf
mpls_ttl
       n-1   n-2  (n-2)-4=n-6  (n-6)-3=n-9  n-10  n-13     n-14


"iIg" is "ingress LSR" in LSP; it calculates: mpls_ttl=n-1
"gGf" is "egress LSR" from Generic MPLS segment, and
      "ingress LSR" in Frame Relay segment and calculates: mpls_ttl=n-6
"fGa" "egress LSR" from Frame Relay segment, and
      "ingress LSR" in ATM segment and calculates: mpls_ttl=n-9
"gGf" is "egress LSR" from Generic MPLS segment, and
      "ingress LSR" in Frame Relay segment and calculates: mpls_ttl=n-13
"fGg" is "egress LSR" from Frame Relay segment, and
      ingress LSR" in Generic MPLS segment and calculates: mpls_ttl=n-14
"gIi" is "egress LSR" from  LSP and calculates: IP_ttl=n-15
```

And further examples:

```
                Frame Relay Unicast -- TTL calculated at ingress

   (ingress LSR)  1     2        3      4
            x--->---+--->---+--->>--+-->>---x (egress LSR)
      o.ttl=i.ttl-4         |     2      3
                            ^
    hops                   1|
                            |
                            x (ingress LSR)
                              o.ttl=i.ttl-3


          Frame Relay Multicast -- TTL calculated at egress

                (egress LSR)x  o.ttl=i.ttl-3
    hops                    |
                            ^3
     (ingress LSR)          |            o.ttl=i.ttl-4
            x--->---+--->---+--->---+--->---x (egress LSR)
                1       2       3       4
```

5.5 Label Processing by Ingress FR-LSRs

When a packet first enters an MPLS domain, the packet is forwarded by normal network layer forwarding operations with the exception that the outgoing encapsulation will include an MPLS label stack [STACK] with at least one entry. The frame relay null encapsulation will carry information about the network layer protocol implicitly in the label, which MUST be associated only with that network protocol. The TTL field in the top label stack entry is filled with the network layer TTL (or hop limit) resulted after network layer forwarding [STACK]. The further FR-LSR processing is similar in both possible cases:

(a) the LSP is homogeneous -- Frame Relay only -- and the FR-LSR is the ingress.

(b) the LSP is heterogeneous -- Frame Relay, PPP, Ethernet, ATM, etc... segments form the LSP -- and the FR-LSR is the ingress into a Frame Relay segment.

For unicast packets, the MPLS TTL SHOULD be decremented with the number of hops of the Frame Relay LSP (homogeneous), or Frame Relay segment of the LSP (heterogeneous). An LDP constructing the LSP SHOULD pass meaningful information to the ingress FR-LSR regarding the number of hops of the "non-TTL segment".

For multicast packets, the MPLS TTL SHOULD be decremented by 1. An LDP constructing the LSP SHOULD pass meaningful information to the egress FR-LSR regarding the number of hops of the "non-TTL segment".

Next, the MPLS encapsulated packet is passed down to the Frame Relay data link driver with the top label as output DLCI. The Frame Relay frame carrying the MPLS encapsulated packet is forwarded onto the Frame Relay VC to the next LSR.

5.6 Label Processing by Core FR-LSRs

In a FR-LSR, the current (top) MPLS label is carried in the DLCI field of the Frame Relay data link layer header of the frame. Just as in conventional Frame Relay, for a frame arriving at an interface, the DLCI carried by the Frame Relay data link header is looked up in the DLCI Information Base, replaced with the correspondent output DLCI, and transmitted on the outgoing interface (forwarded to the next hop node).

The current label information is also carried in the top of the label stack. In the top-level entry, all fields except the label information, which is carried and switched in the Frame Relay frame data link-layer header, are of current significance.

5.7 Label Processing by Egress FR-LSRs

When reaching the end of a Frame Relay LSP, the FR-LSR pops the label stack [ARCH]. If the label popped is the last label, it is necessary to determine the particular network layer protocol which is being carried. The label stack carries no explicit information to identify the network layer protocol. This must be inferred from the value of the label which is popped from the stack.

If the label popped is not the last label, the previous top level MPLS TTL is propagated to the new top label stack entry.

If the FR-LSR is the egress switch of a Frame Relay segment of a hybrid LSP, and the end of the Frame Relay segment is not the end of the LSP, the MPLS packet will be processed for forwarding onto the next segment of the LSP based on the information held in the Next Hop Label Forwarding Entry (NHLFE) [ARCH]. The output label is set to the value from the NHLFE, and the MPLS TTL is decremented by the appropriate value depending the type of the output interface and the type of transmit operation (see section 6.3). Further, the MPLS packet is forwarded according to the MPLS specifications for the particular link of the next segment of the LSP.

For unicast packets, the MPLS TTL SHOULD be decremented by one if the output interface is a generic one, or with the number of hops of the next ATM segment of the LSP (heterogeneous), if the output interface is an ATM (non-TTL) interface.

For multicast packets, the MPLS TTL SHOULD be decremented by the number of hops of the FR segment being exited. An LDP constructing the LSP SHOULD pass meaningful information to the egress FR-LSR regarding the number of hops of the FR "non-TTL segment".

6. Label Switching Control Component for Frame Relay

To support label switching a Frame Relay Switch MUST implement the control component of label switching, which consists primarily of label allocation and maintenance procedures. Label binding information MAY be communicated by several mechanisms, one of which is the Label Distribution Protocol (LDP) [LDP].

Since the label switching control component uses information learned directly from network layer routing protocols, this implies that the switch MUST participate as a peer in these protocols (e.g., OSPF, IS-IS).

In some cases, LSRs may use other protocols (e.g., RSVP, PIM, BGP) to distribute label bindings. In these cases, a Frame Relay LSR should participate in these protocols.

In the case where Frame Relay circuits are established via LDP, or RSVP, or others, with no involvement from traditional Frame Relay mechanisms, it is assumed that circuit establishing contractual information such as input/output maximum frame size, incoming/outgoing requested/agreed throughput, incoming/outgoing acceptable throughput, incoming/outgoing burst size, incoming/outgoing frame rate, used in transmitting, and congestion control MAY be passed to the FR-LSRs through RSVP, or can be statically configured. It is also assumed that congestion control and frame header flagging as a consequence of congestion, would be done by the FR-LSRs in a similar fashion as for traditional Frame Relay circuits. With the goal of emulating a best-effort router as default, the default VC parameters, in the absence of LDP, RSVP, or other mechanisms participation to setting such parameters, should be zero CIR, so that input policing will set the DE bit in incoming frames, but no frames are dropped.

Control and state information for the circuits based on MPLS MAY be communicated through LDP.

Support of label switching on a Frame Relay switch requires conformance only to [FRF] (framing, bit-stuffing, headers, FCS) except for section 2.3 (PVC control signaling procedures, aka LMI). Q.933 signaling for PVCs and/or SVCs is not required. PVC and/or SVC signaling may be used for non-MPLS (standard Frame Relay) PVCs and/or SVCs when both are running on the same interface as MPLS, as discussed in the next section.

6.1 Hybrid Switches (Ships in the Night)

The existence of the label switching control component on a Frame Relay switch does not preclude the ability to support the Frame Relay control component defined by the ITU and Frame Relay Forum on the same switch and the same interfaces (NICs). The two control components, label switching and those defined by ITU/Frame Relay Forum, would operate independently.

Definition of how such a device operates is beyond the scope of this document. However, only a small amount of information needs to be consistent between the two control components, such as the portions of the DLCI space which are available to each component.

7. Label Allocation and Maintenance Procedures

The mechanisms and message formats of a Label Distribution Protocol are documented in [ARCH] and [LDP]. The "downstream-on-demand" label allocation and maintenance mechanism discussed in this section MUST be used by FR-LSRs that do not support VC merging, and it MAY also be used by FR-LSRs that do support VC merging (note that this mechanism applies to hop-by-hop routed traffic):

7.1 Edge LSR Behavior

Consider a member of the Edge Set of a FR-LSR domain. Assume that, as a result of its routing calculations, it selects a FR-LSR as the next hop of a certain route (FEC), and that the next hop is reachable via a LC-Frame Relay interface. Assume that the next-hop FR-LSR is an "LDP-peer" [ARCH][LDP]. The Edge LSR sends an LDP "request" message for a label binding from the next hop, downstream LSR. When the Edge LSR receives in response from the downstream LSR the label binding information in an LDP "mapping" message, the label is stored in the Label Information Base (LIB) as an outgoing label for that FEC. The "mapping" message may contain the "hop count" object, which represents the number of hops a packet will take to cross the FR-LSR domain to the Egress FR-LSR when using this label. This information may be stored for TTL calculation. Once this is done, the LSR may use MPLS forwarding to transmit packets in that FEC.

When a member of the Edge Set of the FR-LSR domain receives an LDP "request" message from a FR-LSR for a FEC, it means it is the Egress-FR-LSR. It allocates a label, creates a new entry in its Label Information Base (LIB), places that label in the incoming label component of the entry, and returns (via LDP) a "mapping" message containing the allocated label back upstream to the LDP peer that originated the request. The "mapping" message contains the "hop count" object value set to 1.

When a routing calculation causes an Edge LSR to change the next hop for a route, and the former next hop was in the FR-LSR domain, the Edge LSR should notify the former next hop (via an LDP "release" message) that the label binding associated with the route is no longer needed.

When a Frame Relay-LSR receives an LDP "request" message for a certain route (FEC) from an LDP peer connected to the FR-LSR over a LC-FR interface, the FR-LSR takes the following actions:

- it allocates a label, creates a new entry in its Label Information Base (LIB), and places that label in the incoming label component of the entry;

- it propagates the "request", by sending an LDP "request" message to the next hop LSR, downstream for that route (FEC);

In the "ordered control" mode [ARCH], the FR-LSR will wait for its "request" to be responded from downstream with a "mapping" message before returning the "mapping" upstream in response to a "request" ("ordered control" approach [ARCH]). In this case, the FR-LSR increments the hop count it received from downstream and uses this value in the "mapping" it returns upstream.

Alternatively, the FR-LSR may return the binding upstream without waiting for a binding from downstream ("independent control" approach [ARCH]). In this case, it uses a reserved value for hop count in the "mapping", indicating that it is 'unknown'. The correct value for hop count will be returned later, as described below.

Since both the "ordered" and "independent" control has advantages and disadvantages, this is left as an implementation, or configuration choice.

Once the FR-LSR receives in response the label binding in an LDP "mapping" message from the next hop, it places the label into the outgoing label component of the LIB entry.

Note that a FR-LSR, or a member of the edge set of a FR-LSR domain, may receive multiple binding requests for the same route (FEC) from the same FR-LSR. It must generate a new "mapping" for each "request" (assuming adequate resources to do so), and retain any existing mapping(s). For each "request" received, a FR-LSR should also generate a new binding "request" toward the next hop for the route (FEC).

When a routing calculation causes a FR-LSR to change the next hop for a route (FEC), the FR-LSR should notify the former next hop (via an LDP "release" message) that the label binding associated with the route is no longer needed.

When a LSR receives a notification that a particular label binding is no longer needed, the LSR may deallocate the label associated with the binding, and destroy the binding. This mode is the "conservative label retention mode" [ARCH]. In the case where a FR-LSR receives such notification and destroys the binding, it should notify the next hop for the route that the label binding is no longer needed. If a LSR does not destroy the binding (the FR-LSR is configured in "liberal label retention mode" [ARCH]), it may re-use the binding only if it receives a request for the same route with the same hop count as the request that originally caused the binding to be created.

When a route changes, the label bindings are re-established from the point where the route diverges from the previous route. LSRs upstream of that point are (with one exception, noted below) oblivious to the change. Whenever a LSR changes its next hop for a particular route, if the new next hop is a FR-LSR or a member of the edge set reachable via a LC-FR interface, then for each entry in its LIB associated with the route the LSR should request (via LDP) a binding from the new next hop.

When a FR-LSR receives a label binding from a downstream neighbor, it may already have provided a corresponding label binding for this route to an upstream neighbor, either because it is using "independent control" or because the new binding from downstream is the result of a routing change. In this case, it should extract the hop count from the new binding and increment it by one. If the new hop count is different from that which was previously conveyed to the upstream neighbor (including the case where the upstream neighbor was given the value 'unknown') the FR-LSR must notify the upstream neighbor of the change. Each FR-LSR in turn increments the hop count and passes it upstream until it reaches the ingress Edge LSR.

Whenever a FR-LSR originates a label binding request to its next hop LSR as a result of receiving a label binding request from another (upstream) LSR, and the request to the next hop LSR is not satisfied, the FR-LSR should destroy the binding created in response to the received request, and notify the requester (via an LDP "withdraw" message).

When an LSR determines that it has lost its LDP session with another LSR, the following actions are taken:

- MUST discard any binding information learned via this connection;

- For any label bindings that were created as a result of receiving label binding requests from the peer, the LSR may destroy these bindings (and deallocate labels associated with these binding).

7.2 Efficient use of label space - Merging FR-LSRs

The above discussion assumes that an edge LSR will request one label for each prefix in its routing table that has a next hop in the FR-LSR domain. In fact, it is possible to significantly reduce the number of labels needed by having the edge LSR request instead one label for several routes. Use of many-to-one mappings between routes (address prefixes) and labels using the notion of Forwarding Equivalence Classes (as described in [ARCH]) provides a mechanism to conserve the number of labels.

Note that conserving label space (VC merging) may be restricted in case the frame traffic requires Frame Relay fragmentation. The issue is that Frame Relay fragments must be transmitted in sequence, i.e., fragments of distinct frames must not be interleaved. If the fragmenting FR-LSR ensures the transmission in sequence of all fragments of a frame, without interleaving with fragments of other frames, then label conservation (VC merging) can be performed.

When label conservation is used, when a FR-LSR receives a binding request from an upstream LSR for a certain FEC, and it does already have an outgoing label binding for that FEC, it does not need to issue a downstream binding request. Instead, it may allocate an incoming label, and return that label in a binding to the upstream requester. Packets received from the requester, with that label as top label, will be forwarded after replacing the label with the existing outgoing label for that FEC. If the FR-LSR does not have an outgoing label binding for that FEC, but does have an outstanding request for one, it need not issue another request. This means that in a label conservation case, a FR-LSR must respond with a new binding for every upstream request, but it may need to send one binding request downstream.

In case of label conservation, if a change in the routing table causes FR-LSR to select a new next hop for one of its FECs, it MAY release the binding for that route from the former next hop. If it doesn’t already have a corresponding binding for the new next hop, it must request one (note that the choice depends on the label retention mode [ARCH]).

If a new binding is obtained, which contain a hop count that differs from that of the old binding, the FR-LSR must process the new hop count: increment by 1, if different than "unknown", and notify the upstream neighbors who have label bindings for this FEC of the new value. To ensure that loops will be detected, if the new hop count exceeds the "maximum" value, the label values for this FEC must be withdrawn from all upstream neighbors to whom a binding was previously sent.

7.3 LDP messages specific to Frame Relay

The Label Distribution Protocol [LDP] messages exchanged between two Frame Relay "LDP-peer" LSRs may contain Frame Relay specific information such as:

"Frame Relay Label Range":

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Reserved    |Len|                     Minimum DLCI            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Reserved        |                     Maximum DLCI            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

with the following fields:

Reserved
This fields are reserved. They must be set to zero on transmission and must be ignored on receipt.

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

Len	DLCI bits
0	10
2	23

Len values 1 and 3 are reserved for future use.

Minimum DLCI
This 23 bit field is the binary value of the lower bound of a block of Data Link Connection Identifiers (DLCIs) that is supported by the originating FR-LSR. The Minimum DLCI should be right justified in this field and the preceding bits should be set to 0.

Maximum DLCI
This 23 bit field is the binary value of the upper bound of a block of Data Link Connection Identifiers (DLCIs) that is supported by the originating FR-LSR. The Maximum DLCI should be right justified in this field and the preceding bits should be set to 0.

"Frame Relay Merge":

```
     0 1 2 3 4 5 6 7
    +-+-+-+-+-+-+-+-+
    | Reserved    |M|
    +-+-+-+-+-+-+-+-+
```

with the following fields:

Merge
One bit field that specifies the merge capabilities of the FR-LSR:

Value	Meaning
0	Merge NOT supported
1	Merge supported

A FR-LSR that supports VC merging MUST ensure that fragmented frames from distinct incoming DLCIs are not interleaved on the outgoing DLCI.

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

and "Frame Relay Label":

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Reserved    |Len|                     DLCI                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

with the following fields:

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

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

Len	DLCI bits
0	10
2	23

Len values 1 and 3 are reserved for future use.

DLCI
The binary value of the Frame Relay Label. The significant number of bits (10 or 23) of the label value are to be encoded into the Data Link Connection Identifier (DLCI) field when part of the Frame Relay data link header (see Section 4.).

8. Security Considerations

This section looks at the security aspects of:

(a) frame traffic,

(b) label distribution.

MPLS encapsulation has no effect on authenticated or encrypted network layer packets, that is IP packets that are authenticated or encrypted will incur no change.

The MPLS protocol has no mechanisms of its own to protect against misdirection of packets or the impersonation of an LSR by accident or malicious intent.

Altering by accident or forgery an existent label in the DLCI field of the Frame Relay data link layer header of a frame or one or more fields in a potentially following label stack affects the forwarding of that frame.

The label distribution mechanism can be secured by applying the appropriate level of security to the underlying protocol carrying label information - authentication or encryption - see [LDP].

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