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Encapsulation Methods for Transport of Layer 2 Frames Over IP and MPLS Networks

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Abstract

    This document describes methods for encapsulating the Protocol Data
    Units (PDUs) of layer 2 protocols such as Frame Relay, ATM, or
    Ethernet for transport across an MPLS or IP network.

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1. Specification of Requirements

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

2. Introduction

In an MPLS or IP network, it is possible to use control protocols
such as those specified in [1] to set up "emulated virtual circuits"
that carry the the Protocol Data Units of layer 2 protocols across
the network. A number of these emulated virtual circuits may be
carried in a single tunnel. This requires of course that the layer 2
PDUs be encapsulated. We can distinguish three layers of this
encapsulation:

   - the "tunnel header", which contains the information needed to
     transport the PDU across the IP or MPLS network; this is header
     belongs to the tunneling protocol, e.g., MPLS, GRE, L2TP.

   - the "demultiplexer field", which is used to distinguish
     individual emulated virtual circuits within a single tunnel; this
     field must be understood by the tunneling protocol as well; it
     may be, e.g., an MPLS label or a GRE key field.

   - the "emulated VC encapsulation", which contains the information
     about the enclosed layer 2 PDU which is necessary in order to
     properly emulate the corresponding layer 2 protocol.

This document specifies the emulated VC encapsulation for a number of
layer 2 protocols. Although different layer 2 protocols require
different information to be carried in this encapsulation, an attempt
has been made to make the encapsulation as common as possible for all
layer 2 protocols.

This document also specifies the way in which the demultiplexer field
is added to the emulated VC encapsulation when an MPLS label is used
as the demultiplexer field.

QoS related issues are not discussed in this draft

For the purpose of this document R1 will be defined as the ingress
router, and R2 as the egress router. A layer 2 PDU will be received
at R1, encapsulated at R1, transported, decapsulated at R2, and
transmitted out of R2.

3. General encapsulation method

In most cases, it is not necessary to transport the layer 2
encapsulation across the network; rather, the layer 2 header can be
stripped at R1, and reproduced at R2. This is done using information
carried in the control word (see below), as well as information that
may already have been signaled from R1 to R2.

3.1. The Control Word

There are three requirements that may need to be satisfied when
transporting layer 2 protocols over an IP or MPLS backbone:

      -i. Sequentiality may need to be preserved.
     -ii. Small packets may need to be padded in order to be
          transmitted on a medium where the minimum transport unit is
          larger than the actual packet size.
    -iii. Control bits carried in the header of the layer 2 frame may
          need to be transported.

The control word defined here addresses all three of these
requirements. For some protocols this word is REQUIRED, and for
others OPTIONAL. For protocols where the control word is OPTIONAL
implementations MUST support sending no control word, and MAY support
sending a control word.

In all cases the egress router must be aware of whether the ingress
router will send a control word over a specific virtual circuit.
This may be achieved by configuration of the routers, or by
signaling, for example as defined in [1].

The control word is defined 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Rsvd  | Flags |0 0|   Length  |     Sequence Number           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In the above diagram the first 4 bits are reserved for future use.
They MUST be set to 0 when transmitting, and MUST be ignored upon
receipt.

The next 4 bits provide space for carrying protocol specific flags.
These are defined in the protocol-specific details below.

The next 2 bits MUST be set to 0 when transmitting.

The next 6 bits provide a length field, which is used as follows: If
the packet's length (defined as the length of the layer 2 payload
plus the length of the control word) is less than 64 bytes, the
length field MUST be set to the packet's length. Otherwise the length
field MUST be set to zero. The value of the length field, if non-
zero, can be used to remove any padding. When the packet reaches the
service provider's egress router, it may be desirable to remove the
padding before forwarding the packet.

The next 16 bits provide a sequence number that can be used to
guarantee ordered packet delivery. The processing of the sequence
number field is OPTIONAL.

The sequence number space is a 16 bit, unsigned circular space. The
sequence number value 0 is used to indicate an unsequenced packet.

3.1.1. Setting the sequence number

For a given emulated VC, and a pair of routers R1 and R2, if R1
supports packet sequencing then the following procedures should be
used:

  - the initial packet transmitted on the emulated VC MUST use
    sequence number 1
  - subsequent packets MUST increment the sequence number by one for
    each packet
  - when the transmit sequence number reaches the maximum 16 bit
    value (65535) the sequence number MUST wrap to 1

If the transmitting router R1 does not support sequence number
processing, then the sequence number field in the control word MUST
be set to 0.

3.1.2. Processing the sequence number

If a router R2 supports receive sequence number processing, then the
following procedures should be used:

When an emulated VC is initially set up, the "expected sequence
number" associated with it MUST be initialized to 1.

When a packet is received on that emulated VC, the sequence number
should be processed as follows:

     - if the sequence number on the packet is 0, then the packet passes
       the sequence number check

     - otherwise if the packet sequence number >= the expected sequence
       number and the packet sequence number - the expected sequence
       number < 32768, then the packet is in order.

     - otherwise if the packet sequence number < the expected sequence
       number and the expected sequence number - the packet sequence
       number >= 32768, then the packet is in order.

     - otherwise the packet is out of order.

   If a packet passes the sequence number check, or is in order then, it
   can be delivered immediately. If the packet is in order, then the
   expected sequence number should be set using the algorithm:

   expected_sequence_number := packet_sequence_number + 1 mod 2**16
   if (expected_sequence_number = 0) then expected_sequence_number := 1;

   Packets which are received out of order MAY be dropped or reordered
   at the discretion of the receiver.

   If a router R2 does not support receive sequence number processing,
   then the sequence number field MAY be ignored.

3.2. MTU Requirements

   The network MUST be configured with an MTU that is sufficient to
   transport the largest encapsulation frames. If MPLS is used as the
   tunneling protocol, for example, this is likely to be 12 or more
   bytes greater than the largest frame size. Other tunneling protocols
   may have longer headers and require larger MTUs. If the ingress
   router determines that an encapsulated layer 2 PDU exceeds the MTU of
   the tunnel through which it must be sent, the PDU MUST be dropped. If
   an egress router receives an encapsulated layer 2 PDU whose payload
   length (i.e., the length of the PDU itself without any of the
   encapsulation headers), exceeds the MTU of the destination layer 2
   interface, the PDU MUST be dropped.

4. Protocol-Specific Details

4.1. Frame Relay

A Frame Relay PDU is transported without the Frame Relay header or
the FCS. The control word is REQUIRED; however, its use is optional,
although desirable. Use of the control word means that the ingress
and egress LSRs follow the procedures below. If an ingress LSR
chooses not to use the control word, it MUST set the flags in the
control word to 0; if an egress LSR chooses to ignore the control
word, it MUST set the Frame Relay control bits to 0.

The BECN, FECN, DE and C/R bits are carried across the network in the
control word. The edge routers that implement this document MAY, when
either adding or removing the encapsulation described herein, change
the BECN and/or FECN bits from zero to one in order to reflect
congestion in the network that is known to the edge routers, and the
D/E bit from zero to one to reflect marking from edge policing of the
Frame Relay Committed Information Rate. The BECN, FECN, and D/E bits
SHOULD NOT be changed from one to zero.

The following is an example of a Frame Relay packet:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Rsvd  |B|F|D|C|    Length     |        Sequence Number        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Frame Relay PDU                        |
|                            "                                  |
|                            "                                  |
|                            "                                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

  * B (BECN) Bit

    The ingress router, R1, SHOULD copy the BECN field from the
    incoming Frame Relay header into this field. The egress router,
    R2, MUST generate a new BECN field based on the value of the B
    bit.

  * F (FECN) Bit

    The ingress router, R1, SHOULD copy the FECN field from the
    incoming Frame Relay header into this field. The egress router,
    R2, MUST generate a new FECN field based on the value of the F
    bit.

* D (DE) Bit

   The ingress router, R1, SHOULD copy the DE field from the
   incoming Frame Relay header into this field. The egress router,
   R2, MUST generate a new DE field based on the value of the D bit.

   If the tunneling protocol provides a field which can be set to
   specify a Quality of Service, the ingress router, R1, MAY
   consider the DE bit of the Frame Relay header when determining
   the value of that field. The egress router MAY then consider the
   value of this field when queuing the layer 2 PDU for egress.
   Note however that frames from the same VC MUST NOT be reordered.

* C (C/R) Bit

   The ingress router, R1, SHOULD copy the C/R bit from the received
   Frame Relay PDU to the C bit of the control word. The egress
   router, R2, MUST copy the C bit into the output frame.

4.2. ATM

Two encapsulations are supported for ATM transport: one for ATM AAL5
and another for ATM cells.

The AAL5 CPCS-SDU encapsulation consists of the REQUIRED control
word, and the AAL5 CPCS-SDU. The ATM cell encapsulation consists of
an OPTIONAL control word, a 4 byte ATM cell header, and the ATM cell
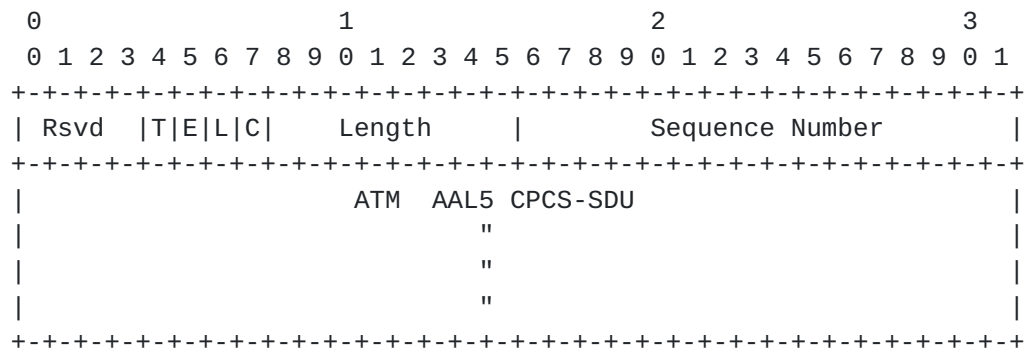payload.

4.2.1. ATM AAL5 CPCS-SDU Mode

In ATM AAL5 mode the ingress router is required to reassemble AAL5
CPCS-SDUs from the incoming VC and transport each CPCS-SDU as a
single packet. No AAL5 trailer is transported. The control word is
REQUIRED; its use, however, is optional, although desirable. Use of
the control word means that the ingress and egress LSRs follow the
procedures below. If an ingress LSR chooses not to use the control
word, it MUST set the flags in the control word to 0; if an egress
LSR chooses to ignore the control word, it MUST set the ATM control
bits to 0.

The EFCI and CLP bits are carried across the network in the control
word. The edge routers that implement this document MAY, when either
adding or removing the encapsulation described herein, change the
EFCI bit from zero to one in order to reflect congestion in the

network that is known to the edge routers, and the CLP bit from zero
to one to reflect marking from edge policing of the ATM Sustained
Cell Rate. The EFCI and CLP bits MUST NOT be changed from one to
zero.

The AAL5 CPCS-SDU is prepended by the following header:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Rsvd  |T|E|L|C|   Length    |        Sequence Number         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     ATM   AAL5 CPCS-SDU                       |
|                           "                                  |
|                           "                                  |
|                           "                                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   * T (transport type) bit

     Bit (T) of the control word indicates whether the packet contains
     an ATM cell or an AAL5 CPCS-SDU. If set the packet contains an
     ATM cell, encapsulated according to the ATM cell mode section
     below, otherwise it contains an AAL5 CPCS-SDU. The ability to
     transport an ATM cell in the AAL5 mode is intended to provide a
     means of enabling OAM functionality over the AAL5 VC.

   * E (EFCI) Bit

     The ingress router, R1, SHOULD set this bit to 1 if the EFCI bit
     of the final cell of those that transported the AAL5 CPCS-SDU is
     set to 1, or if the EFCI bit of the single ATM cell to be
     transported in the packet is set to 1. Otherwise this bit
     SHOULD be set to 0. The egress router, R2, SHOULD set the EFCI
     bit of all cells that transport the AAL5 CPCS-SDU to the value
     contained in this field.

   * L (CLP) Bit

     The ingress router, R1, SHOULD set this bit to 1 if the CLP bit
     of any of the ATM cells that transported the AAL5 CPCS-SDU is set
     to 1, or if the CLP bit of the single ATM cell to be transported
     in the packet is set to 1. Otherwise this bit SHOULD be set to
     0. The egress router, R2, SHOULD set the CLP bit of all cells
     that transport the AAL5 CPCS-SDU to the value contained in this
     field.

   * C (Command / Response Field) Bit

     When FRF.8.1 Frame Relay / ATM PVC Service Interworking [3]
     traffic is being transported, the CPCS-UU Least Significant Bit
     (LSB) of the AAL5 CPCS-SDU may contain the Frame Relay C/R bit.
     The ingress router, R1, SHOULD copy this bit to the C bit of the
     control word. The egress router, R2, SHOULD copy the C bit to the
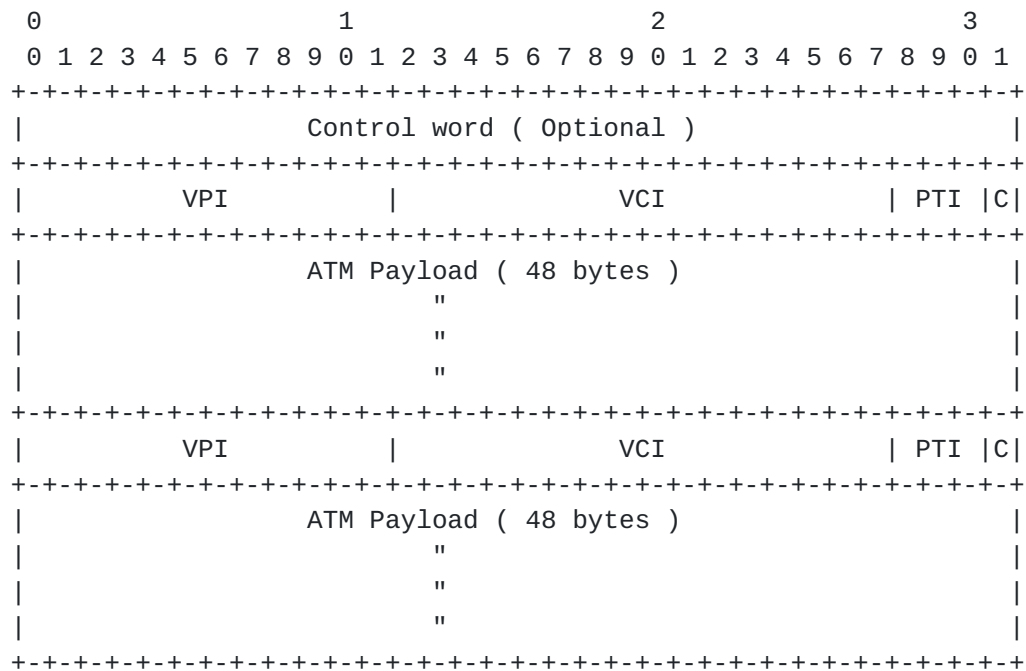   CPCS-UU Least Significant Bit (LSB) of the AAL5 CPCS PDU.

4.2.2. ATM Cell Mode

   In this encapsulation mode ATM cells are transported individually
   without a SAR process. The ATM cell encapsulation consists of an
   OPTIONAL control word, and one or more ATM cells - each consisting of
   a 4 byte ATM cell header and the 48 byte ATM cell payload. This ATM
   cell header is defined as in the FAST encapsulation [4] section
   3.1.1, but without the trailer byte. The length of each frame,
   without the encapsulation headers, is a multiple of 52 bytes long.
   The maximum number of ATM cells that can be fitted in a frame, in
   this fashion, is limited only by the network MTU and by the ability
   of the egress router to process them. The ingress router MUST NOT
   send more cells than the egress router is willing to receive. The
   number of cells that the egress router is willing to receive may
   either be configured in the ingress router or may be signaled, for
   example using the methods described in [1]. The number of cells
   encapsulated in a particular frame can be inferred by the frame
   length. The control word is OPTIONAL. If the control word is used
   then the flag bits in the control word are not used, and MUST be set
   to 0 when transmitting, and MUST be ignored upon receipt.

   The EFCI and CLP bits are carried across the network in the ATM cell
   header. The edge routers that implement this document MAY, when
   either adding or removing the encapsulation described herein, change
   the EFCI bit from zero to one in order to reflect congestion in the
   network that is known to the edge router, and the CLP bit from zero
   to one to reflect marking from edge policing of the ATM Sustained
   Cell Rate. The EFCI and CLP bits SHOULD NOT be changed from one to
   zero.

   This diagram illustrates an encapsulation of two ATM cells:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Control word ( Optional )                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        VPI        |            VCI           | PTI |C|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 ATM Payload ( 48 bytes )                     |
|                         "                                    |
|                         "                                    |
|                         "                                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        VPI        |            VCI           | PTI |C|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 ATM Payload ( 48 bytes )                     |
|                         "                                    |
|                         "                                    |
|                         "                                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

* VPI

  The ingress router MUST copy the VPI field from the incoming cell
  into this field. For particular emulated VCs, the egress router
  MAY generate a new VPI and ignore the VPI contained in this
  field.

* VCI

  The ingress router MUST copy the VCI field from the incoming ATM
  cell header into this field. For particular emulated VCs, the
  egress router MAY generate a new VCI.

* PTI & CLP (C bit)

  The PTI and CLP fields are the PTI and CLP fields of the incoming
  ATM cells. The cell headers of the cells within the packet are
  the ATM headers (without HEC) of the incoming cell.

4.2.3. OAM Cell Support

OAM cells MAY be transported on the VC LSP. An egress router that
does not support transport of OAM cells MUST discard frames that
contain an ATM cell with the high-order bit of the PTI field set to
1. A router that supports transport of OAM cells MUST follow the
procedures outlined in [4] section 8 for mode 0 only, in addition to

the applicable procedures specified in [1].

4.2.4. CLP bit to Quality of Service mapping

The ingress router MAY consider the CLP bit when determining the
value to be placed in the Quality of Service fields (e.g. the EXP
fields of the MPLS label stack) of the encapsulating protocol. This
gives the network visibility of the CLP bit. Note however that cells
from the same VC MUST NOT be reordered.

4.3. Ethernet VLAN

For an Ethernet 802.1q VLAN the entire Ethernet frame without the
preamble or FCS is transported as a single packet. The control word
is OPTIONAL. If the control word is used then the flag bits in the
control word are not used, and MUST be set to 0 when transmitting,
and MUST be ignored upon receipt. The 4 byte VLAN tag is transported
as is, and MAY be overwritten by the egress router.

The ingress router MAY consider the user priority field [5] of the
VLAN tag header when determining the value to be placed in the
Quality of Service field of the encapsulating protocol (e.g., the EXP
fields of the MPLS label stack). In a similar way, the egress router
MAY consider the Quality of Service field of the encapsulating
protocol when queuing the packet for egress. Ethernet packets
containing hardware level CRC errors, framing errors, or runt packets
MUST be discarded on input.

4.4. Ethernet

For simple Ethernet port to port transport, the entire Ethernet frame
without the preamble or FCS is transported as a single packet. The
control word is OPTIONAL. If the control word is used then the flag
bits in the control word are not used, and MUST be set to 0 when
transmitting, and MUST be ignored upon receipt. As in the Ethernet
VLAN case, Ethernet packets with hardware level CRC errors, framing
errors, and runt packets MUST be discarded on input.

4.5. **HDLC**

   HDLC mode provides port to port transport of HDLC encapsulated
   traffic. The HDLC PDU is transported in its entirety, including the
   HDLC address, control and protocol fields, but excluding HDLC flags
   and the FCS. Bit/Byte stuffing is undone. The control word is
   OPTIONAL. If the control word is used then the flag bits in the
   control word are not used, and MUST be set to 0 when transmitting,
   and MUST be ignored upon receipt.

   The HDLC mode is suitable for port to port transport of Frame Relay
   UNI or NNI traffic. It must be noted, however, that this mode is
   transparent to the FECN, BECN and DE bits.

4.6. **PPP**

   PPP mode provides point to point transport of PPP encapsulated
   traffic, as specified in [6]. The PPP PDU is transported in its
   entirety, including the protocol field (whether compressed using PFC
   or not), but excluding any media-specific framing information, such
   as HDLC address and control fields or FCS. Since media-specific
   framing is not carried the following options will not operate
   correctly if the PPP peers attempt to negotiate them:

     - Frame Check Sequence (FCS) Alternatives
     - Address-and-Control-Field-Compression (ACFC)
     - Asynchronous-Control-Character-Map (ACCM)

   Note also that VC LSP Interface MTU negotiation as specified in [1]
   is not affected by PPP MRU advertisement. Thus if a PPP peer sends a
   PDU with a length in excess of that negotiated for the VC LSP that
   PDU will be discarded by the ingress router.

   The control word is OPTIONAL. If the control word is used then the
   flag bits in the control word are not used, and MUST be set to 0 when
   transmitting, and MUST be ignored upon receipt.

5. **Using an MPLS Label as the Demultiplexer Field**

   To use an MPLS label as the demultiplexer field, a 32-bit label stack
   entry [2] is simply prepended to the emulated VC encapsulation, and
   hence will appear as the bottom label of an MPLS label stack. This
   label may be called the "VC label". The particular emulated VC
   identified by a particular label value must be agreed by the ingress
   and egress LSRs, either by signaling (e.g, via the methods of [1]) or
   by configuration. Other fields of the label stack entry are set as

   follows.

5.1. MPLS Shim EXP Bit Values

   If it is desired to carry Quality of Service information, the Quality
   of Service information SHOULD be represented in the EXP field of the
   VC label. If more than one MPLS label is imposed by the ingress LSR,
   the EXP field of any labels higher in the stack SHOULD also carry the
   same value.

5.2. MPLS Shim S Bit Value

   The ingress LSR, R1, MUST set the S bit of the VC label to a value of
   1 to denote that the VC label is at the bottom of the stack.

5.3. MPLS Shim TTL Values

   The ingress LSR, R1, SHOULD set the TTL field of the VC label to a
   value of 2.

6. Security Considerations

   This document specifies only encapsulations, and not the protocols
   used to carry the encapsulated packets across the network. Each such
   protocol may have its own set of security issues, but those issues
   are not affected by the encapsulations specified herein.

7. Intellectual Property Disclaimer

   This document is being submitted for use in IETF standards
   discussions.

8. References

   [1] "Transport of Layer 2 Frames Over MPLS", draft-martini-
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   [2] "MPLS Label Stack Encoding", E. Rosen, Y. Rekhter, D. Tappan, G.
        Fedorkow, D. Farinacci, T. Li, A. Conta. RFC3032

   [3] "Frame Relay / ATM PVC Service Interworking Implementation

Agreement", Frame Relay Forum 2000.

[4] "Frame Based ATM over SONET/SDH Transport (FAST)," 2000.

[5] "IEEE 802.3ac-1998" IEEE standard specification.

[6] "The Point-to-Point Protocol (PPP)", RFC 1661.

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