                   Encapsulation Methods for Transport of
                      Layer 2 Frames over 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, Asynchronous
   Transfer Mode (ATM), or Ethernet for transport across an MPLS
   network. This document describes the so-called "draft-martini"
   protocol, which has since been superseded by the Pseudowire Emulation
   Edge to Edge Working Group specifications described in RFC 4447 and
   related documents.

Table of Contents

1. Introduction

   In an MPLS network, it is possible to use control protocols such as
   those specified in [RFC4906] to set up "emulated virtual circuits"
   that carry the Protocol Data Units of layer 2 protocols across the
   network. A number of these emulated virtual circuits (VCs) 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 MPLS network; this header belongs
        to the tunneling protocol, e.g., MPLS, Generic Routing
        Encapsulation (GRE), and Layer 2 Tunneling Protocol (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 that 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.

   Quality of service (QoS)-related issues are not discussed in this
   document.

   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.

2. 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 [RFC2119].

3. Special Note

   This document describes the so called "draft-martini" protocol, which
   is used in many deployed implementations. This document and its
   contents have since been superseded by the Pseudowire Emulation Edge
   to Edge Working Group specifications: [RFC4447], [RFC4385],
   [RFC4448], [RFC4717], [RFC4618], [RFC4619], [RFC4553], [RFC4842], and
   related documents. This document serves as documentation of current
   implementations, and MUST NOT be used for new implementations. The
   PWE3 Label Distribution Protocol control protocol document [RFC4447],
   which is backward compatible with this document, MUST be used for all
   new implementations of this protocol.

4. 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.

4.1. The Control Word

   There are three requirements that may need to be satisfied when
   transporting layer 2 protocols over an 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 [RFC4906].

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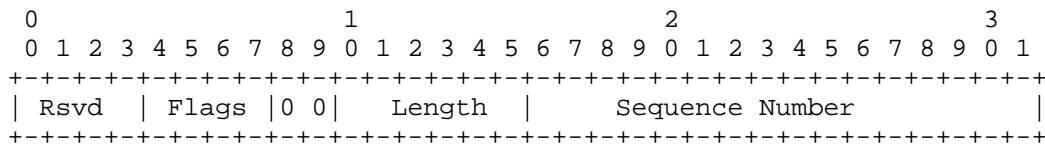
In the above diagram, the first 4 bits are reserved for future use.
They MUST be set to 0 when transmitting, and MUST be ignored upon
receipt.

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 0. 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.

4.1.1. 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 1 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.

4.1.2. 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.

      - Else 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.

      - Else 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 that 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.

4.2. 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
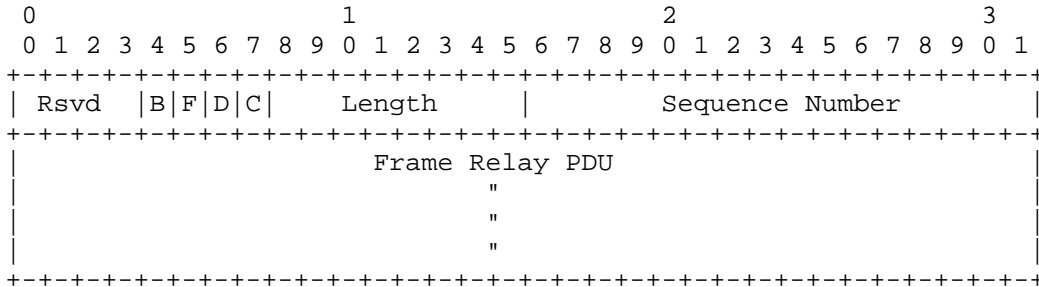interface, the PDU MUST be dropped.

5. Protocol-Specific Details

5.1. Frame Relay

   A Frame Relay PDU is transported without the Frame Relay header or
   the Frame Check Sequence (FCS). The control word is REQUIRED;
   however, its use is optional, although desirable. Use of the control
   word means that the ingress and egress Label Switching Routers (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 (Backward Explicit Congestion Notification), FECN (Forward
   Explicit Congestion Notification), DE (Discard Eligibility), and C/R
   (Command/Response) 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 0 to 1 in order to reflect congestion in
   the network that is known to the edge routers, and the D/E bit from 0
   to 1 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 1 to 0.

   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 that 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.

5.2. ATM

   Two encapsulations are supported for ATM transport: one for ATM
   Adaption Layer 5 (AAL5) and another for ATM cells.
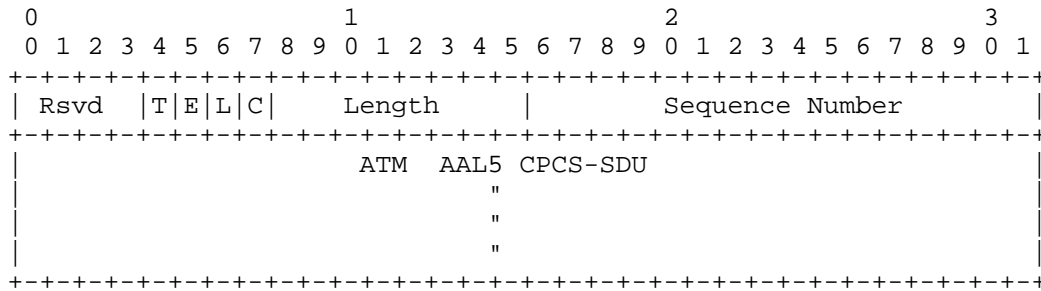
   The AAL5 Common Part Convergence Sublayer - Service Data Unit
   (CPCS-SDU) encapsulation consists of the REQUIRED control word and
   the AAL5 CPCS-SDU. The ATM cell encapsulation consists of an
   OPTIONAL control word, a 4-byte ATM cell header, and the ATM cell
   payload.

5.2.1. 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 (Explicit Forward Congestion Indication) and CLP (Cell Loss
   Priority) 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 0 to 1 in order to reflect congestion in the network that is
   known to the edge routers, and the CLP bit from 0 to 1 to reflect
   marking from edge policing of the ATM Sustained Cell Rate. The EFCI
   and CLP bits MUST NOT be changed from 1 to 0.

   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 Operations and
         Management (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
      [FRF.8.1] 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.

5.2.2. ATM Cell Mode

   In this encapsulation mode, ATM cells are transported individually
   without a Segmentation and Reassembly (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 in the FAST
   encapsulation [FAST] 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
   [RFC4906]. 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 0 to 1 in order to reflect congestion in the
network that is known to the edge router, and the CLP bit from 0 to 1
to reflect marking from edge policing of the ATM Sustained Cell Rate.
The EFCI and CLP bits SHOULD NOT be changed from 1 to 0.

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 (Virtual Path Identifier)

     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 (Virtual Circuit Identifier)

     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 (Payload Type Identifier) & 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.

5.2.3. 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 [FAST] section 8 for mode 0 only, in addition
   to the applicable procedures specified in [RFC4906].

5.2.4. 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.

5.3. 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 [IEEE802.3ac]
   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 Cyclic Redundancy Check (CRC) errors,
   framing errors, or runt packets MUST be discarded on input.

5.4. 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.

5.5. High-Level Data Link Control (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
   User-Network Interface (UNI) or Network-Network Interface (NNI)
   traffic. It must be noted, however, that this mode is transparent to
   the FECN, BECN, and DE bits.

5.6. PPP

   PPP mode provides point to point transport of PPP-encapsulated
   traffic, as specified in [RFC1661]. 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
   [RFC4906] is not affected by PPP Maximum Receive Unit (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.

6. Using an MPLS Label as the Demultiplexer Field

   To use an MPLS label as the demultiplexer field, a 32-bit label stack
   entry [RFC3032] 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
[RFC4906]) or by configuration. Other fields of the label stack
entry are set as follows.

6.1. 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.

6.2. 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.

6.3. MPLS Shim TTL Values

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

7. 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. More
   detailed security considerations are also described in Section 8 of
   [RFC4447].

8. Normative References

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