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            Encapsulation Methods for Transport of Frame Relay over
                 Multiprotocol Label Switching (MPLS) Networks

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Abstract

   A frame relay pseudowire is a mechanism that exists between a
   provider's edge network nodes and that supports as faithfully as
   possible frame relay services over an MPLS packet switched network
   (PSN). This document describes the detailed encapsulation necessary
   to transport frame relay packets over an MPLS network.

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1.   Introduction

   In an MPLS or IP network, it is possible to use control protocols
   such as those specified in [RFC4447] to set up "pseudowires" (PWs)
   that carry the Protocol Data Units of layer 2 protocols across the
   network. A number of these emulated PWs may be carried in a single
   tunnel. The main functions required to support frame relay PW by a
   Provider Edge (PE) include:

   - encapsulation of frame relay specific information in a suitable
     pseudowire (PW) packet;

   - transfer of a PW packet across an MPLS network for delivery to a
     peer PE;

   - extraction of frame relay specific information from a PW packet by
     the remote peer PE;

   - regeneration of native frame relay frames for forwarding across an
     egress port of the remote peer PE; and

   - execution of any other operations as required to support frame
     relay service.

   This document specifies the encapsulation for the emulated frame
   relay VC over an MPLS PSN. 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. Other layer 2 protocols are described in
   separate documents. [ATM] [RFC4448] [RFC4618]

   The following figure describes the reference models that are derived
   from [RFC3985] to support the frame relay PW emulated services.

```
         |<-------------- Emulated Service ---------------->|
         |                                                  |
         |        |<------- Pseudowire ------->|            |
         |        |                            |            |
         |        |   |<-- PSN Tunnel -->|     |            |
         | PW End V   V                  V     V  PW End    |
         V Service +----+                +----+  Service V
    +-----+    |    | PE1|================| PE2|    |    +-----+
    |     |---------|.............PW1.............|---------|     |
    | CE1 |    |    |    |                    |    |    | CE2 |
    |     |---------|.............PW2.............|---------|     |
    +-----+  ^ |    |    |================|    |    | ^  +-----+
      ^      |      +----+                +----+      | |    ^
      |      |   Provider Edge 1       Provider Edge 2 | |
      |      |        (PE1)               (PE2)       | |
    Customer |                                        | Customer
    Edge 1   |                                        | Edge 2
      |      |                                        |
      |      |                                        |
     Attachment Circuit (AC)             Attachment Circuit (AC)
     native frame relay service          native frame relay service
```
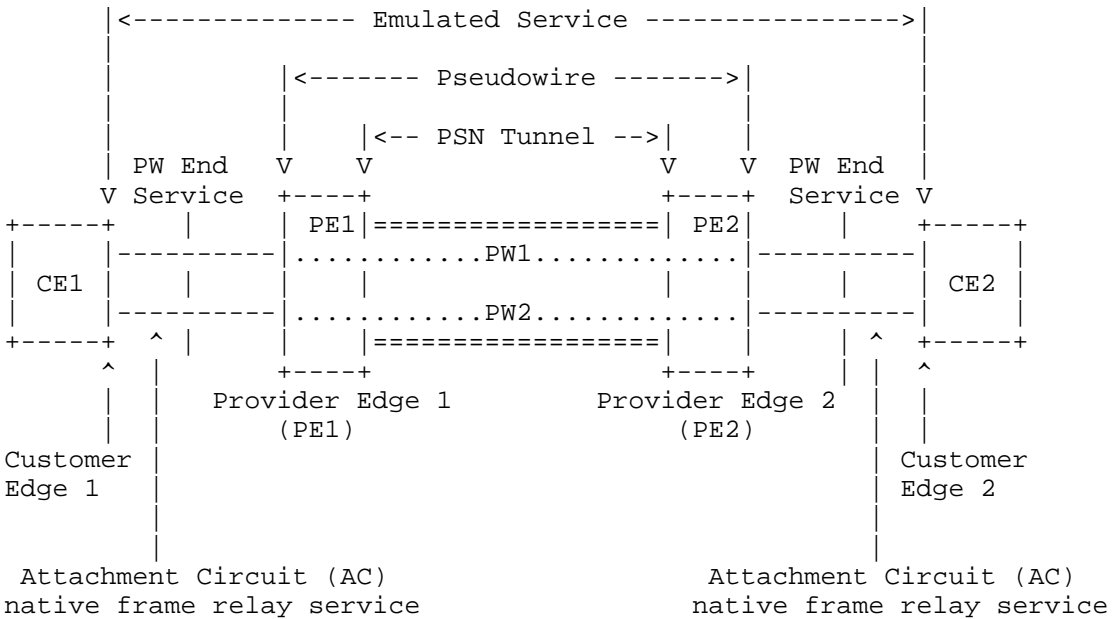
   Figure 1. PWE3 frame relay PVC interface reference configuration

   Two mapping modes can be defined between frame relay VCs and
   pseudowires: The first one is called "one-to-one" mapping, because
   there is a one-to-one correspondence between a frame relay VC and one
   pseudowire. The second mapping is called "many-to-one" mapping or
   "port mode" because multiple frame relay VCs assigned to a port are
   mapped to one pseudowire. The "port mode" encapsulation is identical
   to High-Level Data Link Control (HDLC) pseudowire encapsulation,
   which is described in [RFC4618].

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 RFC 2119.

   Below are the definitions for the terms used throughout the document.
   PWE3 definitions can be found in [RFC3916, RFC3985]. This section
   defines terms specific to frame relay.

   - Forward direction

     The forward direction is the direction taken by the frame being
     forwarded.

   - Backward direction

     In frame relay, it is the direction opposite to the direction taken
     by a frame being forwarded (see also forward direction).

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4. Acronyms and Abbreviations

        BECN   Backward Explicit Congestion Notification
        CE   Customer Edge
        C/R   Command/Response
        DE   Discard Eligibility
        DLCI   Data Link Connection Identifier
        FCS   Frame Check Sequence
        FECN   Forward Explicit Congestion Notification
        FR   Frame Relay
        LSP   Label Switched Path
        LSR   Label Switching Router
        MPLS   Multiprotocol Label Switching
        MTU   Maximum Transfer Unit
        NNI   Network-Network Interface
        PE   Provider Edge
        PSN   Packet Switched Network
        PW   Pseudowire
        PWE3   Pseudowire Emulation Edge to Edge
        POS   Packet over SONET/SDH
        PVC   Permanent Virtual Circuit
        QoS   Quality of Service
        SVC   Switched Virtual Circuit
        UNI   User-Network Interface
        VC   Virtual Circuit

5. Applicability Statement

    Frame relay over PW service is not intended to emulate the
    traditional frame relay service perfectly, but it can be used for
    applications that need frame relay transport service.

    The following are notable differences between traditional frame relay
    service and the protocol described in this document:

    - Frame ordering can be preserved using the OPTIONAL sequence field
      in the control word; however, implementations are not required to
      support this feature.

    - The Quality of Service model for traditional frame relay can be
      emulated; however, this is outside the scope of this document.

    - A Frame relay port mode PW does not process any frame relay status
      messages or alarms as described in [Q922] [Q933]

    - The frame relay BECN and FECN bit are transparent to the MPLS
      network and cannot reflect the status of the MPLS network.

   - Support for frame relay SVC and Switched Permanent Virtual Circuit
     (SPVC) is outside the scope of this document.

   - Frame relay Local Management Interface (LMI) is terminated locally
     in the PE connected to the frame relay attachment circuit.

   - The support of PVC link integrity check is outside the scope of
     this document.

6. General Encapsulation Method

   The general frame relay pseudowire packet format for carrying frame
   relay information (user's payload and frame relay control
   information) between two PEs is shown in Figure 2.

```
            +------------------------------+
            |                              |
            |     MPLS Transport header    |
            |         (As required)        |
            +------------------------------+
            |   Pseudowire (PW) Header      |
            +------------------------------+
            |       Control Word           |
            +------------------------------+
            |         FR Service           |
            |          Payload             |
            +------------------------------+
```
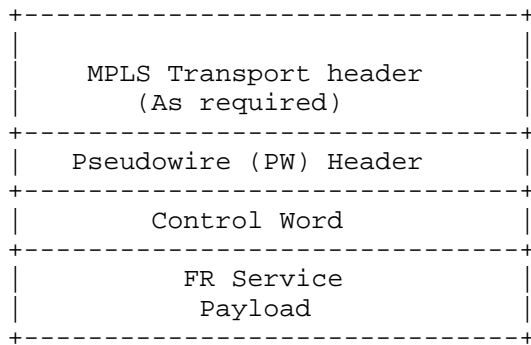
    Figure 2. General format of frame relay encapsulation over PSN

   The PW packet consists of the following fields: Control word and
   Payload, preceded by the MPLS Transport and pseudowire header. The
   meaning of the different fields is as follows:

   -i.   MPLS Transport header is specific to the MPLS network. This
          header is used to switch the PW packet through the MPLS core.

   -ii.   PW header contains an identifier for multiplexing PWs within
          an MPLS tunnel.

   -iii. Control Word contains protocol control information for
          providing a frame relay service. Its structure is provided in
          the following sections.

   -iv.   The content of the frame relay service payload field depends
          on the mapping mode. In general it contains the layer 2 frame
          relay frame.

7. Frame Relay over MPLS PSN for the One-to-One Mode

7.1. MPLS PSN Tunnel and PW

   MPLS label switched paths (LSPs) called "MPLS Tunnels" are used
   between PEs and are used within the MPLS core network to forward PW
   packets. An MPLS tunnel corresponds to "PSN Tunnel" of Figure 1.

   Several PWs may be nested inside one MPLS tunnel. Each PW carries
   the traffic of a single frame relay VC. In this case, the PW header
   is an MPLS label called the PW label.

7.2. Packet Format over MPLS PSN

   For the one-to-one mapping mode for frame relay over an MPLS network,
   the PW packet format is as shown in Figure 3.

```
   +-----------------------------+
   |      MPLS Tunnel label(s)    | n*4 octets (four octets per label)
   +-----------------------------+
   |      PW label                |  4 octets
   +-----------------------------+
   |      Control Word            |
   |      (See Figure 4)          | 4 octets
   +-----------------------------+
   |            Payload           |
   |      (Frame relay frame      |
   |       information field)     | n octets
   |                              |
   +-----------------------------+
```
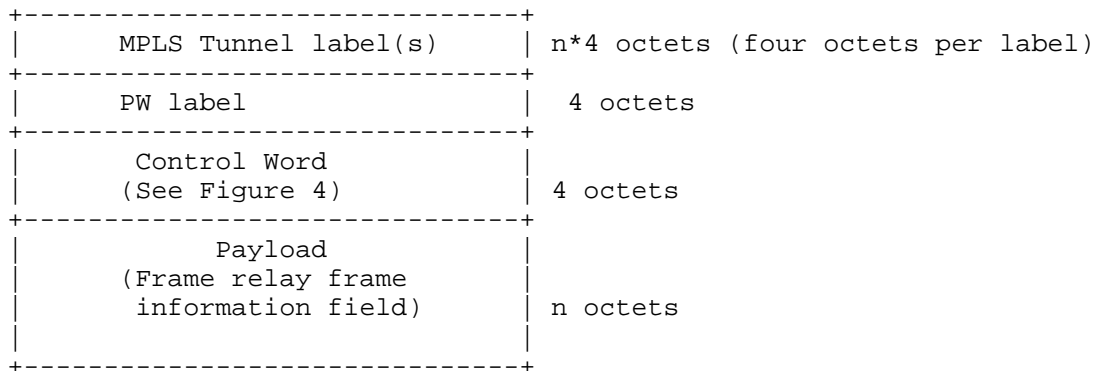
            Figure 3. Frame Relay over MPLS PSN Packet for the
                       One-to-One Mapping

   The meaning of the different fields is as follows:

   - MPLS Tunnel label(s)

     The MPLS Tunnel label(s) corresponds to the MPLS transport header
     of Figure 2. The label(s) is/are used by MPLS LSRs to forward a PW
     packet from one PE to the other.

   - PW Label

     The PW label identifies one PW (i.e., one LSP) assigned to a frame
     relay VC in one direction. It corresponds to the PW header of
     Figure 2. Together the MPLS Tunnel label(s) and PW label form an
     MPLS label stack [RFC3032].

   - Control Word

     The Control Word contains protocol control information. Its
     structure is shown in Figure 4.

   - Payload

     The payload field corresponds to X.36/X.76 frame relay frame
     information field with the following components removed: bit/byte
     stuffing, frame relay header, and FCS. It is RECOMMENDED to
     support a frame size of at least 1600 bytes. The maximum length of
     the payload field MUST be agreed upon by the two PEs. This can be
     achieved by using the MTU interface parameter when the PW is
     established. [RFC4447]

7.3. The Control Word

   The control word defined below is REQUIRED for frame relay one-to-one
   mode. The control word carries certain frame relay specific
   information that is necessary to regenerate the frame relay frame on
   the egress PE. Additionally, the control word also carries a
   sequence number that can be used to preserve sequentiality when
   carrying frame relay over an MPLS network. Its structure 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 0 0|F|B|D|C|FRG|  Length   | Sequence Number               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
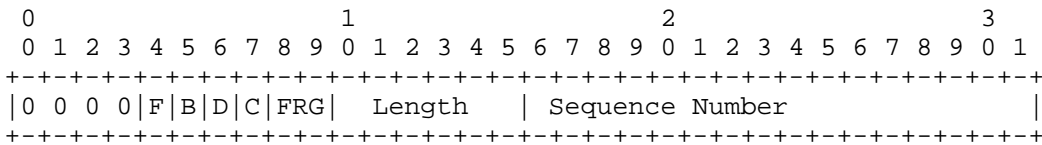
   Figure 4. Control Word structure for the one-to-one mapping mode

   The meaning of the Control Word fields (Figure 4) is as follows (see
   also [X36 and X76] for frame relay bits):

   - Bits 0 to 3

      In the above diagram, the first 4 bits MUST be set to 0 to
      indicate PW data.

   - F (bit 4) FR FECN (Forward Explicit Congestion Notification) bit.

   - B (bit 5) FR BECN (Backward Explicit Congestion Notification) bit.

   - D (bit 6) FR DE bit (Discard Eligibility) bit.

   - C (bit 7) FR frame C/R (Command/Response) bit.

   - FRG (bits 8 and 9): These bits are defined by [RFC4623].

   - Length (bits 10 to 15)

      If the PW traverses a network link that requires a minimum frame
      size (a notable example is Ethernet), padding is required to reach
      its minimum frame size. If the frame's length (defined as the
      length of the layer 2 payload plus the length of the control word)
      is less than 64 octets, the length field MUST be set to the PW
      payload length. Otherwise, the length field MUST be set to zero.
      The value of the length field, if non-zero, is used to remove the
      padding characters by the egress PE.

   - Sequence number (Bit 16 to 31)

      Sequence numbers provide one possible mechanism to ensure the
      ordered delivery of PW packets. 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 that the sequence number check algorithm is not used.

7.4. The Martini Legacy Mode Control Word

   For backward compatibility to existing implementations, the following
   version of the control word is defined as the "martini mode CW" for
   frame relay.

```
    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 0 0|B|F|D|C|FRG| Length    | Sequence Number               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
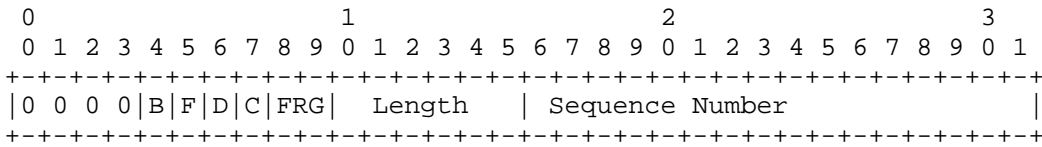
   Figure 5. Control Word structure for the frame relay martini mode

   Note that the "B" and "F" bits are reversed.

   This control word format is used for PW type "Frame Relay DLCI (
   Martini Mode)"

7.5. PW Packet Processing

7.5.1. Encapsulation of Frame Relay Frames

   The encapsulation process of a frame relay frame is initiated when a
   PE receives a frame relay frame from one of its frame relay UNI or
   NNI [FRF1] [FRF2] interfaces. The PE generates the following fields

of the control word from the corresponding fields of the frame relay
frame as follows:

- Command/Response (C/R or C) bit: The C bit is copied unchanged in
  the PW Control Word.

- The DE bit of the frame relay frame is copied into the D bit field.
  However, if the D bit is not already set, it MAY be set as a result
  of ingress frame policing. If it is not already set by the copy
  operation, setting of this bit by a PE is OPTIONAL. The PE MUST
  NOT clear this bit (set it to 0 if it was received with the value
  of 1).

- The FECN bit of the frame relay frame is copied into the F bit
  field. However, if the F bit is not already set, it MAY be set to
  reflect a congestion situation detected by the PE. If it is not
  already set by the copy operation, setting of this bit by a PE is
  OPTIONAL. The PE MUST NOT clear this bit (set it to 0 if it was
  received with the value of 1)

- The BECN bit of the frame relay frame is copied into the B bit
  field. However, if the B bit is not already set, it MAY be set to
  reflect a congestion situation detected by the PE. If it is not
  already set by the copy operation, setting of this bit by a PE is
  OPTIONAL. The PE MUST NOT clear this bit (set it to 0 if it was
  received with the value of 1).

- If the PW packet length (defined as the length of the payload plus
  the length of the control word) is less than 64 octets, the length
  field MUST be set to the packet's length. Otherwise, the length
  field MUST be set to zero.

- The sequence number field is processed if the PW uses sequence
  numbers. [RFC4385]

- The payload of the PW packet is the contents of ITU-T
  Recommendations X.36/X.76 [X36] [X76] frame relay frame information
  field stripped from any bit or byte stuffing.

7.5.2. Setting the Sequence Number

   For a given PW and a pair of routers PE1 and PE2, if PE1 supports
   packet sequencing, then the procedures in [RFC4385], Section 4.1,
   MUST be followed.

7.6. Decapsulation of PW Packets

   When a PE receives a PW packet, it processes the different fields of
   the control word in order to decapsulate the frame relay frame for
   transmission to a CE on a frame relay UNI or NNI. The PE performs
   the following actions (not necessarily in the order shown):

   - It generates the following frame relay frame header fields from the
     corresponding fields of the PW packet.

   - The C/R bit MUST be copied in the frame relay header.

   - The D bit MUST be copied into the frame relay header DE bit.

   - The F bit MUST be copied into the frame relay header FECN bit. If
     the F bit is set to zero, the FECN bit may be set to one, depending
     on the congestion state of the PE device in the forward direction.
     Changing the state of this bit by a PE is OPTIONAL.

   - The B bit MUST be copied into the frame relay header BECN bit. If
     the B bit is set to zero, the BECN bit may be set to one, depending
     on the congestion state of the PE device in the backward direction.
     Changing the state of this bit by a PE is OPTIONAL.

   - It processes the length and sequence field, the details of which
     are in the following sub-sections.

   - It copies the frame relay information field from the contents of
     the PW packet payload after removing any padding.

   Once the above fields of a FR frame have been processed, the standard
   HDLC operations are performed on the frame relay frame: the HDLC
   header is added, any bit or byte stuffing is added as required, and
   the FCS is also appended to the frame. The FR frame is then queued
   for transmission on the selected frame relay UNI or NNI interface.

7.6.1. Processing the Sequence Number

   If a router PE2 supports received sequence number processing, then
   the procedures in [RFC4385], Section 4.2, MUST be used.

7.6.2. Processing of the Length Field by the Receiver

   Any padding octet, if present, in the payload field of a PW packet
   received MUST be removed before forwarding the data.

   - If the Length field is set to zero, then there are no padding
     octets following the payload field.

   - Otherwise, if the payload is longer, then the length specified in
     the control word padding characters are removed according to the
     length field.

7.7. 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 Experimental Use
   Bits (EXP) field of the PW MPLS label [RFC3032]. 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.

7.8. MPLS Shim S Bit Value

   The ingress LSR, PE1, MUST set the S bit of the PW label to a value
   of 1 to denote that the PW label is at the bottom of the stack.

7.9. Control Plane Details for Frame Relay Service

   The PE MUST provide frame relay PVC status signaling to the frame
   relay network. If the PE detects a service-affecting condition for a
   particular DLCI, as defined in [Q933] Q.933, Annex A.5, sited in IA
   FRF1.1, the PE MUST communicate to the remote PE the status of the PW
   that corresponds to the frame relay DLCI status. The Egress PE
   SHOULD generate the corresponding errors and alarms as defined in
   [Q922] [Q933] on the egress Frame relay PVC.

   There are two frame relay flags to control word bit mappings
   described below. The legacy bit ordering scheme will be used for a
   PW of type 0x0001, "Frame Relay DLCI (Martini Mode)", and the new bit
   ordering scheme will be used for a PW of type 0x0019, "Frame Relay
   DLCI". The IANA allocation registry of "Pseudowire Type" is defined
   in [RFC4446] along with initial allocated values.

7.9.1. Frame Relay Specific Interface Parameter Sub-TLV

   A separate document, [RFC4447], describes the PW control and
   maintenance protocol in detail, including generic interface parameter
   sub-TLVs. The interface parameter information, when applicable, MUST
   be used to validate that the PEs and the ingress and egress ports at
   the edges of the circuit have the necessary capabilities to
   interoperate with each other. The Interface parameter TLV is defined
   in [RFC4447], and the IANA registry with initial values for interface
   parameter sub-TLV types is defined in [RFC4446], but the frame relay
   specific interface parameter sub-TLV types are specified as follows:

   - 0x08 Frame Relay Header Length Sub-TLV

An optional 16-bit value indicating the length of the FR Header,
expressed in octets. This OPTIONAL interface parameter Sub-TLV can
have value of 2, 3, or 4, the default being 2. If this Sub-TLV is
not present, the default value of 2 is assumed.

8. Frame Relay Port Mode

The frame relay port mode PW shares the same encapsulation as the
HDLC PW and is described in the respective document. [RFC4618]

9. Congestion Control

As explained in [RFC3985], the PSN carrying the PW may be subject to
congestion, the characteristics of which depend on PSN type, network
architecture, configuration, and loading. During congestion, the PSN
may exhibit packet loss that will impact the service carried by the
frame relay PW. In addition, since frame relay PWs carry a variety
of services across the PSN, including but not restricted to TCP/IP,
they may or may not behave in a TCP-friendly manner prescribed by
[RFC2914]. In the presence of services that reduce transmission
rate, frame relay PWs may thus consume more than their fair share and
in that case SHOULD be halted.

Whenever possible, frame relay PWs should be run over traffic-
engineered PSNs providing bandwidth allocation and admission control
mechanisms. IntServ-enabled domains providing the Guaranteed Service
(GS) or DiffServ-enabled domains using EF (expedited forwarding) are
examples of traffic-engineered PSNs. Such PSNs will minimize loss
and delay while providing some degree of isolation of the frame relay
PW's effects from neighboring streams.

Note that when transporting frame relay, DiffServ-enabled domains may
use AF (Assured Forwarding) and/or DF (Default Forwarding) instead of
EF, in order to place less burden on the network and to gain
additional statistical multiplexing advantage. In particular, if the
Committed Information Rate (CIR) of a frame relay VC is zero, then it
is equivalent to a best-effort UDP over IP stream regarding
congestion: the network is free to drop frames as necessary. In
this case, the "DF" Per Hop Behavior (PHB) would be appropriate in a
diff-serv-TE domain. Alternatively, if the CIR of a frame relay VC
is nonzero and the DE bit is zero in the FR header, then "AF31" would
be appropriate to be used, and if the CIR of a frame relay VC is
nonzero but the DE bit is on, then "AF32" would be appropriate
[RFC3270].

The PEs SHOULD monitor for congestion (by using explicit congestion
notification, [VCCV], or by measuring packet loss) in order to ensure
that the service using the frame relay PW may be maintained. When a

PE detects significant congestion while receiving the PW PDUs, the
BECN bits of the frame relay frame transmitted on the same PW SHOULD
be set to notify the remote PE and the remote frame relay switch of
the congestion situation. In addition, the FECN bits SHOULD be set
in the FR frames sent out the attachment circuit, to give the FR DTE
a chance to adjust its transport layer advertised window, if
possible.

If the PW has been set up using the protocol defined in [RFC4447],
then procedures specified in [RFC4447] for status notification can be
used to disable packet transmission on the ingress PE from the egress
PE. The PW may be restarted by manual intervention, or by automatic
means after an appropriate waiting time.

10. Security Considerations

PWE3 provides no means of protecting the contents or delivery of the
PW packets on behalf of the native service. PWE3 may, however,
leverage security mechanisms provided by the MPLS Tunnel Layer. A
more detailed discussion of PW security is given in [RFC3985,
RFC4447, RFC3916].

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