           Pseudowire Virtual Circuit Connectivity Verification (VCCV):
                   A Control Channel for Pseudowires

Status of This Memo

Abstract

   This document describes Virtual Circuit Connectivity Verification
   (VCCV), which provides a control channel that is associated with a
   pseudowire (PW), as well as the corresponding operations and
   management functions (such as connectivity verification) to be used
   over that control channel. VCCV applies to all supported access
   circuit and transport types currently defined for PWs.

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1. **Introduction**

   There is a need for fault detection and diagnostic mechanisms that
   can be used for end-to-end fault detection and diagnostics for a
   Pseudowire, as a means of determining the PW's true operational
   state. Operators have indicated in [RFC4377] and [RFC3916] that such
   a tool is required for PW operation and maintenance. This document
   defines a protocol called Virtual Circuit Connectivity Verification
   (VCCV) that satisfies these requirements. VCCV is, in its simplest
   description, a control channel between a pseudowire's ingress and
   egress points over which connectivity verification messages can be
   sent.

   The Pseudowire Edge-to-Edge Emulation (PWE3) Working Group defines a
   mechanism that emulates the essential attributes of a
   telecommunications service (such as a T1 leased line or Frame Relay)
   over a variety of Packet Switched Network (PSN) types [RFC3985].
   PWE3 is intended to provide only the minimum necessary functionality
   to emulate the service with the required degree of faithfulness for
   the given service definition. The required functions of PWs include
   encapsulating service-specific bit streams, cells, or PDUs arriving
   at an ingress port and carrying them across an IP path or MPLS
   tunnel. In some cases, it is necessary to perform other operations,
   such as managing their timing and order, to emulate the behavior and
   characteristics of the service to the required degree of
   faithfulness.

   From the perspective of Customer Edge (CE) devices, the PW is
   characterized as an unshared link or circuit of the chosen service.
   In some cases, there may be deficiencies in the PW emulation that
   impact the traffic carried over a PW and therefore limit the
   applicability of this technology. These limitations must be fully
   described in the appropriate service-specific documentation.

   For each service type, there will be one default mode of operation
   that all PEs offering that service type must support. However,
   optional modes have been defined to improve the faithfulness of the
   emulated service, as well as to offer a means by which older
   implementations may support these services.

   Figure 1 depicts the architecture of a pseudowire as defined in
   [RFC3985]. It further depicts where the VCCV control channel resides
   within this architecture, which will be discussed in detail shortly.

```
          |<-------------- Emulated Service --------------->|
          |             |<---------- VCCV ---------->|        |
          |             |<------- Pseudowire ------->|        |
          |             |                            |        |
          |             |    |<-- PSN Tunnel -->|    |        |
          |             V    V                  V    V        |
          V    AC     +----+                  +----+   AC    V
     +-----+    |     | PE1|==================| PE2|    |   +-----+
     |     |----------|...........PW1.............|----------|   |
     | CE1 |    |     |    |                  |    |    |   | CE2 |
     |     |----------|...........PW2.............|----------|   |
     +-----+  ^ |     |    |==================|    |    | ^ +-----+
         ^    |     +----+                  +----+    | | ^
         |    |   Provider Edge 1      Provider Edge 2  | |
         |    |                                         | |
     Customer |                                    | Customer
     Edge 1   |                                    | Edge 2
              |                                    |
              |                                    |
        Native service                       Native service
```
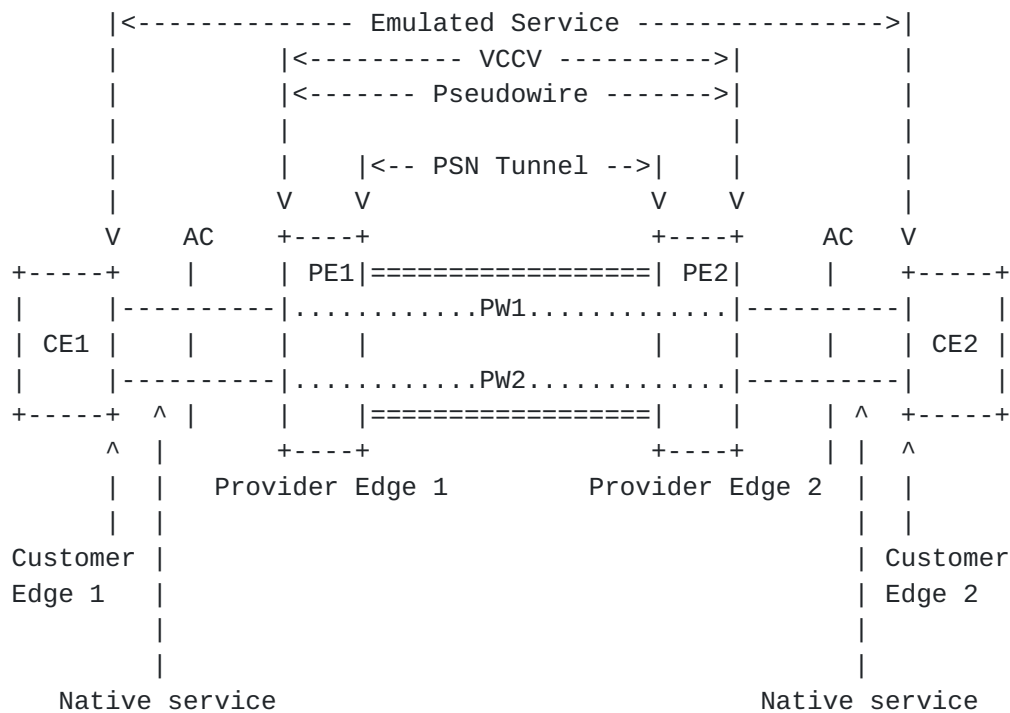
                Figure 1: PWE3 VCCV Operation Reference Model

From Figure 1, Customer Edge (CE) routers CE1 and CE2 are attached to
the emulated service via Attachment Circuits (ACs), and to each of
the Provider Edge (PE) routers (PE1 and PE2, respectively). An AC
can be a Frame Relay Data Link Connection Identifier (DLCI), an ATM
Virtual Path Identifier / Virtual Channel Identifier (VPI/VCI), an
Ethernet port, etc. The PE devices provide pseudowire emulation,
enabling the CEs to communicate over the PSN. A pseudowire exists
between these PEs traversing the provider network. VCCV provides
several means of creating a control channel over the PW, between the
PE routers that attach the PW.

Figure 2 depicts how the VCCV control channel is associated with the
pseudowire protocol stack.

```
      +-------------+                          +-------------+
      |  Layer2     |                          |  Layer2     |
      |  Emulated   |      < Emulated Service > |  Emulated   |
      |  Services   |                          |  Services   |
      +-------------+                          +-------------+
      |             |          VCCV/PW         |             |
      |Demultiplexer|     < Control Channel >   |Demultiplexer|
      +-------------+                          +-------------+
      |    PSN      |         < PSN Tunnel >    |    PSN      |
      +-------------+                          +-------------+
      |  Physical   |                          |  Physical   |
      +-----+-------+                          +-----+-------+
            |                                        |
            |            ____    ___     ____        |
            |          _/    \__/   \   _/    \_     |
            |         /            \__/         \_   |
            |        /                            \  |
        +--------|       MPLS or IP Network         |---+
             \                                     /
              \  ___     ___     ___      _/
               \_/    \___/    \___/   \___/
```

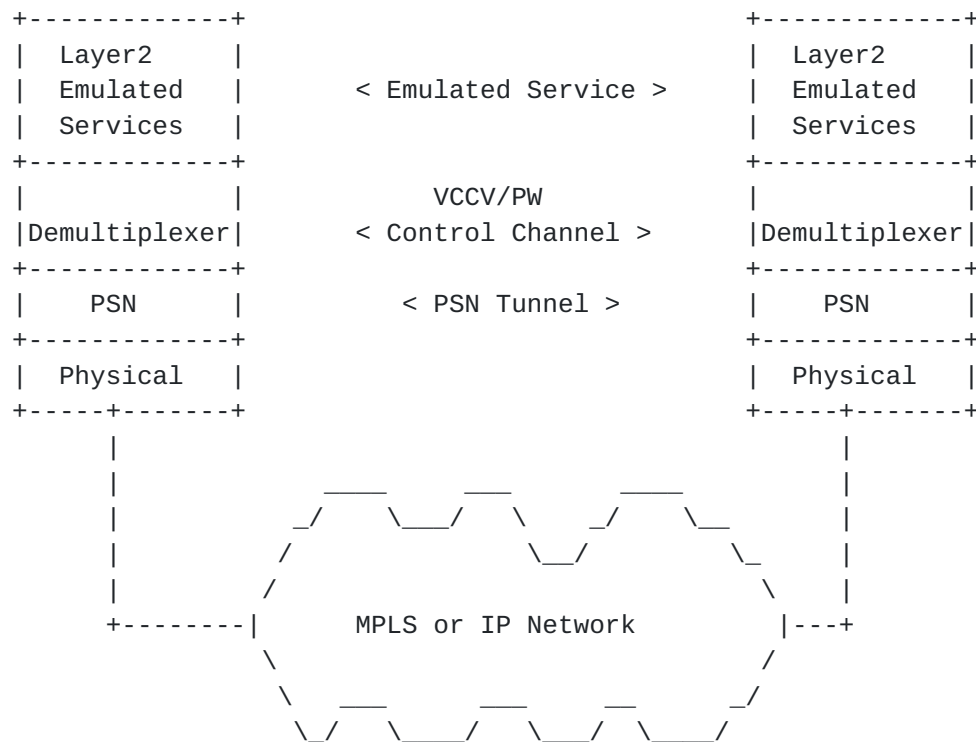   Figure 2: PWE3 Protocol Stack Reference Model including the VCCV
                                    Control Channel

   VCCV messages are encapsulated using the PWE3 encapsulation as
   described in Sections [5](5) and [6](6), so that they are handled and processed
   in the same manner (or in some cases, a similar manner) as the PW
   PDUs for which they provide a control channel. These VCCV messages
   are exchanged only after the capability (expressed as two VCCV type
   spaces, namely the VCCV Control Channel and Connectivity Verification
   Types) and desire to exchange such traffic has been advertised
   between the PEs (see Sections [5.3](5.3) and [6.3](6.3)), and VCCV types chosen.

[1.1](1.1). 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 [[RFC2119](RFC2119)].

[2](2). Abbreviations

   AC   Attachment Circuit [[RFC3985](RFC3985)].

   AVP   Attribute Value Pair [[RFC3931](RFC3931)].

   CC   Control Channel (used as CC Type).

CE   Customer Edge.

CV   Connectivity Verification (used as CV Type).

CW   Control Word [RFC3985].

L2SS   L2-Specific Sublayer [RFC3931].

LCCE   L2TP Control Connection Endpoint [RFC3931].

OAM   Operation and Maintenance.

PE   Provider Edge.

PSN   Packet Switched Network [RFC3985].

PW   Pseudowire [RFC3985].

PW-ACH PW Associated Channel Header [RFC4385].

VCCV   Virtual Circuit Connectivity Verification.

3. Overview of VCCV

The goal of VCCV is to verify and further diagnose the pseudowire
forwarding path. To this end, VCCV is comprised of different
components:

o a means of signaling VCCV capabilities to a peer PE,

o an encapsulation for the VCCV control channel messages that allows
   the receiving PE to intercept, interpret, and process them locally
   as OAM messages, and

o specifications for the operation of the various VCCV operational
   modes transmitted within the VCCV messages.

When a pseudowire is first signaled using the Label Distribution
Protocol (LDP) [RFC4447] or the Layer Two Tunneling Protocol version
3 (L2TPv3) [RFC3931], a message is sent from the initiating PE to the
receiving PE requesting that a pseudowire be set up. This message
has been extended to include VCCV capability information (see
Section 4). The VCCV capability information indicates to the
receiving PE which combinations of Control Channel (CC) and
Connectivity Verification (CV) Types it is capable of receiving. If
the receiving PE agrees to establish the PW, it will return its
capabilities in the subsequent signaling message to indicate which CC

and CV Types it is capable of processing. Precedence rules for which
CC and CV Type to choose in cases where more than one is specified in
this message are defined in Section 7 of this document.

Once the PW is signaled, data for the PW will flow between the PEs
terminating the PW. At this time, the PEs can begin transmitting
VCCV messages based on the CC and CV Type combinations just
discussed. To this end, VCCV defines an encapsulation for these
messages that identifies them as belonging to the control channel for
the PW. This encapsulation is designed to both allow the control
channel to be processed functionally in the same manner as the data
traffic for the PW in order to faithfully test the data plane for the
PE, and allow the PE to intercept and process these VCCV messages
instead of forwarding them out of the AC towards the CE as if they
were data traffic. In this way, the most basic function of the VCCV
control channel is to verify connectivity of the pseudowire and the
data plane used to transport the data path for the pseudowire. It
should be noted that because of the number of combinations of
optional and mandatory data-plane encapsulations for PW data traffic,
VCCV defines a number of Control Channel (CC) and Connectivity
Verification (CV) types in order to support as many of these as
possible. While designed to support most of the existing
combinations (both mandatory and optional), VCCV does define a
default CC and CV Type combination for each PW Demultiplexer type, as
will be described in detail later in this document.

VCCV can be used both as a fault detection and/or a diagnostic tool
for pseudowires. For example, an operator can periodically invoke
VCCV on a timed, on-going basis for proactive connectivity
verification on an active pseudowire, or on an ad hoc or as-needed
basis as a means of manual connectivity verification. When invoking
VCCV, the operator triggers a combination of one of its various CC
Types and one of its various CV Types. The CV Types include LSP Ping
[RFC4379] for MPLS PWs, and ICMP Ping [RFC0792] [RFC4443] for both
MPLS and L2TPv3 PWs. We define a matrix of acceptable CC and CV Type
combinations further in this specification.

The control channel maintained by VCCV can additionally carry fault
detection status between the endpoints of the pseudowire.
Furthermore, this information can then be translated into the native
OAM status codes used by the native access technologies, such as ATM,
Frame-Relay or Ethernet. The specific details of such status
interworking is out of the scope of this document, and is only noted
here to illustrate the utility of VCCV for such purposes. Complete
details can be found in [MSG-MAP] and [RFC4447].

4. CC Types and CV Types

   The VCCV Control Channel (CC) Type defines several possible types of
   control channel that VCCV can support. These control channels can in
   turn carry several types of protocols defined by the Connectivity
   Verification (CV) Type. VCCV potentially supports multiple CV Types
   concurrently, but it only supports the use of a single CC Type. The
   specific type or types of VCCV packets that can be accepted and sent
   by a router are indicated during capability advertisement as
   described in Sections 5.3 and 6.3. The various VCCV CV Types
   supported are used only when they apply to the context of the PW
   demultiplexer in use. For example, the LSP Ping CV Type should only
   be used when MPLS Labels are utilized as PW Demultiplexer.

   Once a set of VCCV capabilities is received and advertised, a CC Type
   and CV Type(s) that match both the received and transmitted
   capabilities can be selected. That is, a PE router needs to only
   allow Types that are both received and advertised to be selected,
   performing a logical AND between the received and transmitted bitflag
   fields. The specific CC Type and CV Type(s) are then chosen within
   the constraints and rules specified in Section 7. Once a specific CC
   Type has been chosen (i.e., it matches both the transmitted and
   received VCCV CC capability), transmitted and replied to, this CC
   Type MUST be the only one used until such time as the pseudowire is
   re-signaled. In addition, based on these rules and the procedures
   defined in Section 5.2 of [RFC4447], the pseudowire MUST be re-
   signaled if a different set of capabilities types is desired. The
   relevant portion of Section 5.2 of [RFC4447] is:

         Interface Parameter Sub-TLV

         Note that as the "interface parameter sub-TLV" is part of the
         FEC, the rules of LDP make it impossible to change the
         interface parameters once the pseudowire has been set up.

   The CC and CV Type indicator fields are defined as 8-bit bitmasks
   used to indicate the specific CC or CV Type or Types (i.e., none,
   one, or more) of control channel packets that may be sent on the VCCV
   control channel. These values represent the numerical value
   corresponding to the actual bit being set in the bitfield. The
   definition of each CC and CV Type is dependent on the PW type
   context, either MPLS or L2TPv3, within which it is defined.

   Control Channel (CC) Types:

      The defined values for CC Types for MPLS PWs are:

         MPLS Control Channel (CC) Types:

         Bit (Value)   Description
         ============   =======================================
         Bit 0 (0x01) - Type 1: PWE3 Control Word with 0001b as
                        first nibble (PW-ACH, see [[RFC4385](#)])
         Bit 1 (0x02) - Type 2: MPLS Router Alert Label
         Bit 2 (0x04) - Type 3: MPLS PW Label with TTL == 1
         Bit 3 (0x08) - Reserved
         Bit 4 (0x10) - Reserved
         Bit 5 (0x20) - Reserved
         Bit 6 (0x40) - Reserved
         Bit 7 (0x80) - Reserved

      The defined values for CC Types for L2TPv3 PWs are:

         L2TPv3 Control Channel (CC) Types:

         Bit (Value)   Description
         ============   =======================================
         Bit 0 (0x01) - L2-Specific Sublayer with V-bit set
         Bit 1 (0x02) - Reserved
         Bit 2 (0x04) - Reserved
         Bit 3 (0x08) - Reserved
         Bit 4 (0x10) - Reserved
         Bit 5 (0x20) - Reserved
         Bit 6 (0x40) - Reserved
         Bit 7 (0x80) - Reserved

   Connectivity Verification (CV) Types:

      The defined values for CV Types for MPLS PWs are:

         MPLS Connectivity Verification (CV) Types:

         Bit (Value)   Description
         ============   =======================================
         Bit 0 (0x01) - ICMP Ping
         Bit 1 (0x02) - LSP Ping
         Bit 2 (0x04) - Reserved
         Bit 3 (0x08) - Reserved
         Bit 4 (0x10) - Reserved
         Bit 5 (0x20) - Reserved

```
      Bit 6 (0x40) - Reserved
      Bit 7 (0x80) - Reserved
```

   The defined values for CV Types for L2TPv3 PWs are:

   L2TPv3 Connectivity Verification (CV) Types:

```
   Bit (Value)    Description
   ============   =======================================
   Bit 0 (0x01) - ICMP Ping
   Bit 1 (0x02) - Reserved
   Bit 2 (0x04) - Reserved
   Bit 3 (0x08) - Reserved
   Bit 4 (0x10) - Reserved
   Bit 5 (0x20) - Reserved
   Bit 6 (0x40) - Reserved
   Bit 7 (0x80) - Reserved
```

   If none of the types above are supported, the entire CC and CV Type
   Indicator fields SHOULD be transmitted as 0x00 (i.e., all bits in the
   bitfield set to 0) to indicate this to the peer.

   If no capability is signaled, then the peer MUST assume that the peer
   has no VCCV capability and follow the procedures specified in this
   document for this case.

[5](#). VCCV Control Channel for MPLS PWs

   When MPLS is used to transport PW packets, VCCV packets are carried
   over the MPLS LSP as defined in this section. In order to apply IP
   monitoring tools to a PW, an operator may configure VCCV as a control
   channel for the PW between the PE's endpoints [[RFC3985](#)]. Packets
   sent across this channel from the source PE towards the destination
   PE either as in-band traffic with the PW's data, or out-of-band. In
   all cases, the control channel traffic is not forwarded past the PE
   endpoints towards the Customer Edge (CE) devices; instead, VCCV
   messages are intercepted at the PE endpoints for exception
   processing.

[5.1](#). VCCV Control Channel Types for MPLS

   As already described in [Section 4](#), the capability of which control
   channel types (CC Type) are supported is advertised by a PE. Once
   the receiving PE has chosen a CC Type mode to use, it MUST continue
   using this mode until such time as the PW is re-signaled. Thus, if a
   new CC Type is desired, the PW must be torn-down and re-established.

   Ideally, such a control channel would be completely in-band (i.e.,
   following the same data-plane faith as PW data). When a control word
   is present on the PW, it is possible to indicate the control channel
   by setting a bit in the control word header (see Section 5.1.1).

   Section 5.1.1 through Section 5.1.3 describe each of the currently
   defined VCCV Control Channel Types (CC Types).

5.1.1. In-Band VCCV (Type 1)

   CC Type 1 is also referred to as "PWE3 Control Word with 0001b as
   first nibble". It uses the PW Associated Channel Header (PW-ACH);
   see Section 5 of [RFC4385].

   The PW set-up protocol [RFC4447] determines whether a PW uses a
   control word. When a control word is used, and that CW uses the
   "Generic PW MPLS Control Word" format (see Section 3 of [RFC4385]), a
   Control Channel for use of VCCV messages can be created by using the
   PW Associated Channel CW format (see Section 5 of [RFC4385]).

   The PW Associated Channel for VCCV control channel traffic is defined
   in [RFC4385] as shown in Figure 3:

```
    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 1|Version|   Reserved    |         Channel Type          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

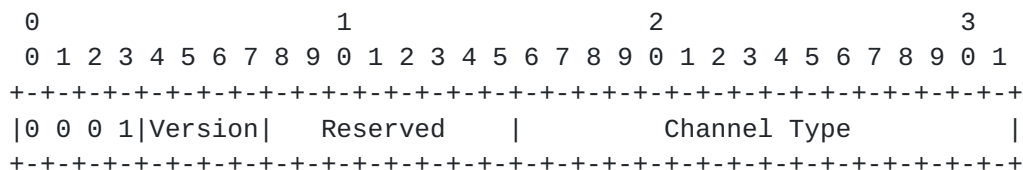   Figure 3: PW Associated Channel Header

   The first nibble is set to 0001b to indicate a channel associated
   with a pseudowire (see Section 5 of [RFC4385] and Section 3.6 of
   [RFC4446]). The Version and the Reserved fields are set to 0, and
   the Channel Type is set to 0x0021 for IPv4 and 0x0057 for IPv6
   payloads.

   For example, Figure 4 shows how the Ethernet [RFC4448] PW-ACH would
   be received containing an LSP Ping payload corresponding to a choice
   of CC Type of 0x01 and a CV Type of 0x02:

```
    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 1|0 0 0 0|0 0 0 0 0 0 0 0|   0x21 (IPv4) or 0x57 (IPv6)  |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
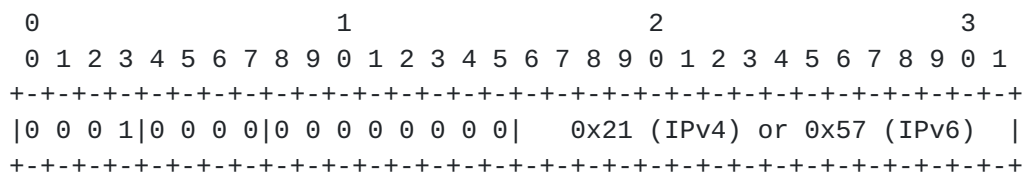
               Figure 4: PW Associated Channel Header for VCCV

It should be noted that although some PW types are not required to
carry the control word, this type of VCCV can only be used for those
PW types that do employ the control word when it is in use. Further,
this CC Type can only be used if the PW CW follows the "Generic PW
MPLS Control Word" format. This mode of VCCV operation MUST be
supported when the control word is present.

5.1.2. Out-of-Band VCCV (Type 2)

CC Type 2 is also referred to as "MPLS Router Alert Label".

A VCCV control channel can alternatively be created by using the MPLS
router alert label [RFC3032] immediately above the PW label. It
should be noted that this approach could result in a different Equal
Cost Multi-Path (ECMP) hashing behavior than pseudowire PDUs, and
thus result in the VCCV control channel traffic taking a path which
differs from that of the actual data traffic under test. Please see
Section 2 of [RFC4928].

CC Type 2 can be used whether the PW is set-up with a Control Word
present or not.

This is the preferred mode of VCCV operation when the Control Word is
not present.

If the Control Word is in use on this PW, it MUST also be included
before the VCCV message. This is done to avoid the different ECMP
hashing behavior. In this case, the CW uses the PW-ACH format
described in Section 5.1.1 (see Figures 3 and 4). If the Control
Word is not in use on this PW, the VCCV message follows the PW Label
directly.

5.1.3. TTL Expiry VCCV (Type 3)

CC Type 3 is also referred to as "MPLS PW Label with TTL == 1".

The TTL of the PW label can be set to 1 to force the packet to be
processed within the destination router's control plane. This
approach could also result in a different ECMP hashing behavior and
VCCV messages taking a different path than the PW data traffic.

CC Type 3 can be used whether the PW is set-up with a Control Word
present or not.

If the Control Word is in use on this PW, it MUST also be included
before the VCCV message. This is done to avoid the different ECMP
hashing behavior. In this case, the CW uses the PW-ACH format

described in Section 5.1.1 (see Figures 3 and 4). If the Control
Word is not in use on this PW, the VCCV message follows the PW Label
directly.

5.2. VCCV Connectivity Verification Types for MPLS

5.2.1. ICMP Ping

When this optional connectivity verification mode is used, an ICMP
Echo packet using the encoding specified in [RFC0792] (ICMPv4) or
[RFC4443] (ICMPv6) achieves connectivity verification.
Implementations MUST use ICMPv4 [RFC0792] if the signaling for VCCV
used IPv4 addresses, or ICMPv6 [RFC4443] if IPv6 addresses were used.
If the pseudowire is set up statically, then the encoding MUST use
that which was used for the pseudowire in the configuration.

5.2.2. MPLS LSP Ping

The LSP Ping header MUST be used in accordance with [RFC4379] and
MUST also contain the target FEC Stack containing the sub-TLV of sub-
Type 8 for the "L2 VPN endpoint", 9 for "FEC 128 Pseudowire
(deprecated)", 10 for "FEC 128 Pseudowire", or 11 for the "FEC 129
Pseudowire". The sub-TLV value indicates the PW to be verified.

5.3. VCCV Capability Advertisement for MPLS PWs

To permit the indication of the type or types of PW control
channel(s) and connectivity verification mode or modes over a
particular PW, a VCCV parameter is defined in Section 5.3.1 that is
used as part of the PW establishment signaling. When a PE signals a
PW and desires PW OAM for that PW, it MUST indicate this during PW
establishment using the messages defined in Section 5.3.1.
Specifically, the PE MUST include the VCCV interface parameter sub-
TLV (0x0C) assigned in [RFC4446] in the PW set-up message [RFC4447].

The decision of the type of VCCV control channel is left completely
to the receiving control entity, although the set of choices is given
by the sender in that it indicates the control channels and
connectivity verification type or types that it can understand. The
receiver SHOULD choose a single Control Channel Type from the match
between the choices sent and received, based on the capability
advertisement selection specified in Section 7, and it MUST continue
to use this type for the duration of the life of the control channel.
Changing Control Channel Types after one has been established to be
in use could potentially cause problems at the receiving end and
could also lead to interoperability issues; thus, it is NOT
RECOMMENDED.

When a PE sends a label mapping message for a PW, it uses the VCCV
parameter to indicate the type of OAM control channels and
connectivity verification type or types it is willing to receive and
can send on that PW. A remote PE MUST NOT send VCCV messages before
the capability of supporting the control channel(s) (and connectivity
verification type(s) to be used over them) is signaled. Then, it can
do so only on a control channel and using the connectivity
verification type(s) from the ones indicated.

If a PE receives VCCV messages prior to advertising capability for
this message, it MUST discard these messages and not reply to them.
In this case, the PE SHOULD increment an error counter and optionally
issue a system and/or SNMP notification to indicate to the system
administrator that this condition exists.

When LDP is used as the PW signaling protocol, the requesting PE
indicates its configured VCCV capability or capabilities to the
remote PE by including the VCCV parameter with appropriate options in
the VCCV interface parameter sub-TLV field of the PW ID FEC TLV (FEC
128) or in the interface parameter sub-TLV of the Generalized PW ID
FEC TLV (FEC 129). These options indicate which control channel and
connectivity verification types it supports. The requesting PE MAY
indicate that it supports multiple control channel options, and in
doing so, it agrees to support any and all indicated types if
transmitted to it. However, it MUST do so in accordance with the
rules stipulated in [Section 5.3.1](#) (VCCV Capability Advertisement Sub-
TLV.)

Local policy may direct the PE to support certain OAM capability and
to indicate it. The absence of the VCCV parameter indicates that no
OAM functions are supported by the requesting PE, and thus the
receiving PE MUST NOT send any VCCV control channel traffic to it.
The reception of a VCCV parameter with no options set MUST be ignored
as if one is not transmitted at all.

The receiving PE similarly indicates its supported control channel
types in the label mapping message. These may or may not be the same
as the ones that were sent to it. The sender should examine the set
that is returned to understand which control channels it may
establish with the remote peer, as specified in Sections [4](#) and [7](#).
Similarly, it MUST NOT send control channel traffic to the remote PE
for which the remote PE has not indicated it supports.

[5.3.1](#). **VCCV Capability Advertisement LDP Sub-TLV**

[RFC4447] defines an Interface Parameter Sub-TLV field in the LDP PW
ID FEC (FEC 128) and an Interface Parameters TLV in the LDP
Generalized PW ID FEC (FEC 129) to signal different capabilities for

specific PWs. An optional sub-TLV parameter is defined to indicate
the capability of supporting none, one, or more control channel and
connectivity verification types for VCCV. This is the VCCV parameter
field. If FEC 128 is used, the VCCV parameter field is carried in
the Interface Parameter sub-TLV field. If FEC 129 is used, it is
carried as an Interface Parameter sub-TLV in the Interface Parameters
TLV.

The VCCV parameter ID is defined as follows in [[RFC4446](#)]:

```
Parameter ID    Length      Description
  0x0c             4           VCCV
```

The format of the VCCV parameter field 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     0x0c      |     0x04      |   CC Types    |   CV Types    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Control Channel Type field (CC Type) defines a bitmask used to
indicate the type of control channel(s) (i.e., none, one, or more)
that a router is capable of receiving control channel traffic on. If
more than one control channel is specified, the router agrees to
accept control traffic over either control channel; however, see the
rules specified in Sections [4](#) and [7](#) for more details. If none of the
types are supported, a CC Type Indicator of 0x00 SHOULD be
transmitted to indicate this to the peer. However, if no capability
is signaled, then the PE MUST assume that its peer is incapable of
receiving any of the VCCV CC Types and MUST NOT send any OAM control
channel traffic to it. Note that the CC and CV Types definitions are
consistent regardless of the PW's transport or access circuit type.
The CC and CV Type values are defined in [Section 4](#).

[6](#). VCCV Control Channel for L2TPv3/IP PWs

When L2TPv3 is used to set up a PW over an IP PSN, VCCV packets are
carried over the L2TPv3 session as defined in this section. L2TPv3
provides a "Hello" keepalive mechanism for the L2TPv3 control plane
that operates in-band over IP or UDP (see [Section 4.4 of [RFC3931]](#)).
This built-in Hello facility provides dead peer and path detection
only for the group of sessions associated with the L2TP Control
Connection. VCCV, however, allows individual L2TP sessions to be
tested. This provides a more granular mechanism which can be used to
troubleshoot potential problems within the data plane of L2TP
endpoints themselves, or to provide additional connection status of
individual pseudowires.

The capability of which Control Channel Type (CC Type) to use is
advertised by a PE to indicate which of the potentially various
control channel types are supported. Once the receiving PE has
chosen a mode to use, it MUST continue using this mode until such
time as the PW is re-signaled. Thus, if a new CC Type is desired,
the PW must be torn down and re-established.

An LCCE sends VCCV messages on an L2TPv3-signaled pseudowire for
fault detection and diagnostic of the L2TPv3 session. The VCCV
message travels in-band with the Session and follows the exact same
path as the user data for the session, because the IP header and
L2TPv3 Session header are identical. The egress LCCE of the L2TPv3
session intercepts and processes the VCCV message, and verifies the
signaling and forwarding state of the pseudowire on reception of the
VCCV message. It is to be noted that the VCCV mechanism for L2TPv3
is primarily targeted at verifying the pseudowire forwarding and
signaling state at the egress LCCE. It also helps when L2TPv3
Control Connection and Session paths are not identical.

[6.1](#). VCCV Control Channel Type for L2TPv3

In order to carry VCCV messages within an L2TPv3 session data packet,
the PW MUST be established such that an L2-Specific Sublayer (L2SS)
that defines the V-bit is present. This document defines the V-bit
for the Default L2-Specific Sublayer [[RFC3931](#)] and the ATM-Specific
Sublayer [[RFC4454](#)] using the Bit 0 position (see Sections [8.3.2](#) and
8.3.3). The L2-Specific Sublayer presence and type (either the
Default or a PW-Specific L2SS) is signaled via the L2-Specific
Sublayer AVP, Attribute Type 69, as defined in [[RFC3931](#)]. The V-bit
within the L2-Specific Sublayer is used to identify that a VCCV
message follows, and when the V-bit is set the L2SS has the format
shown in Figure 5:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |1|0 0 0|Version|   Reserved    |        Channel Type           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
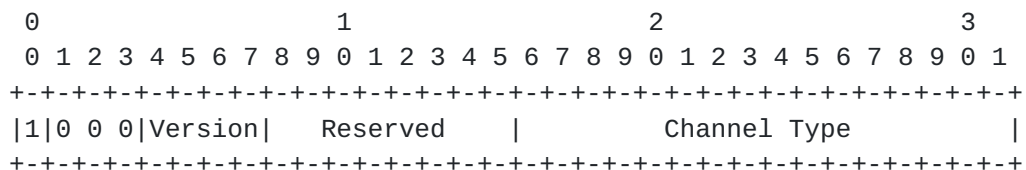
 Figure 5: L2-Specific Sublayer Format when the V-bit (bit 0) is set

The VCCV messages are distinguished from user data by the V-bit. The
V-bit is set to 1, indicating that a VCCV session message follows.
The next three bits MUST be set to 0 when sending and ignored upon
receipt. The remaining fields comprising 28 bits (i.e., Version,
Reserved, and Channel Type) follow the same definition, format, and
number registry from [Section 5 of [RFC4385]](#).

The Version and Reserved fields are set to 0. For the CV Type
currently defined of ICMP Ping (0x01), the Channel Type can indicate
IPv4 (0x0021) or IPv6 (0x0057) (see [[RFC4385](#)]) as the VCCV payload
directly following the L2SS.

[6.2](#). VCCV Connectivity Verification Type for L2TPv3

The VCCV message over L2TPv3 directly follows the L2-Specific
Sublayer with the V-bit set. It MUST contain an ICMP Echo packet as
described in [Section 6.2.1](#).

[6.2.1](#). L2TPv3 VCCV using ICMP Ping

When this connectivity verification mode is used, an ICMP Echo packet
using the encoding specified in [[RFC0792](#)] for (ICMPv4) or [[RFC4443](#)]
(for ICMPv6) achieves connectivity verification. Implementations
MUST use ICMPv4 [[RFC0792](#)] if the signaling for the L2TPv3 PW used
IPv4 addresses, or ICMPv6 [[RFC4443](#)] if IPv6 addresses were used. If
the pseudowire is set-up statically, then the encoding MUST use that
which was used for the pseudowire in the configuration.

The ICMP Ping packet directly follows the L2SS with the V-bit set.
In the ICMP Echo request, the IP Header fields MUST have the
following values: the destination IP address is set to the remote
LCCE's IP address for the tunnel endpoint, the source IP address is
set to the local LCCE's IP address for the tunnel endpoint, and the
TTL or Hop Limit is set to 1.

[6.3](#). L2TPv3 VCCV Capability Advertisement for L2TPv3

A new optional AVP is defined in [Section 6.3.1](#) to indicate the VCCV
capabilities during session establishment. An LCCE MUST signal its
desire to use connectivity verification for a particular L2TPv3
session and its VCCV capabilities using the VCCV Capability AVP.

An LCCE MUST NOT send VCCV packets on an L2TPv3 session unless it has
received VCCV capability by means of the VCCV Capability AVP from the
remote end. If an LCCE receives VCCV packets and it is not VCCV
capable or it has not sent VCCV capability indication to the remote
end, it MUST discard these messages. It should also increment an
error counter. In this case the LCCE MAY optionally issue a system
and/or SNMP notification.

[6.3.1](#). L2TPv3 VCCV Capability AVP

The "VCCV Capability AVP", Attribute Type 96, specifies the VCCV
capabilities as a pair of bitflags for the Control Channel (CC) and
Connectivity Verification (CV) Types. This AVP is exchanged during

session establishment (in ICRQ (Incoming-Call-Request), ICRP
(Incoming-Call-Reply), OCRQ (Outgoing-Call-Request), or OCRP
(Outgoing-Call-Reply) messages). The value field has the following
format:

VCCV Capability AVP (ICRQ, ICRP, OCRQ, OCRP)

```
    0                   1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    CC Types    |   CV Types    |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

CC Types:

   The Control Channel (CC) Types field defines a bitmask used to
   indicate the type of control channel(s) that may be used to
   receive OAM traffic on for the given Session. The router agrees
   to accept VCCV traffic at any time over any of the signaled VCCV
   control channel types. CC Type values are defined in [Section 4](#).
   Although there is only one value defined in this document, the CC
   Types field is included for forward compatibility should further
   CC Types need to be defined in the future.

   A CC Type of 0x01 may only be requested when there is an L2-
   Specific Sublayer that defines the V-bit present. If a CC Type of
   0x01 is requested without requesting an L2-Specific Sublayer AVP
   with an L2SS type that defines the V-bit, the session MUST be
   disconnected with a Call-Disconnect-Notify (CDN) message.

   If no CC Type is supported, a CC Type Indicator of 0x00 SHOULD be
   sent.

CV Types:

   The Connectivity Verification (CV) Types field defines a bitmask
   used to indicate the specific type or types (i.e., none, one, or
   more) of control packets that may be sent on the specified VCCV
   control channel. CV Type values are defined in [Section 4](#).

If no VCCV Capability AVP is signaled, then the LCCE MUST assume that
the peer is incapable of receiving VCCV and MUST NOT send any OAM
control channel traffic to it.

All L2TP AVPs have an M (Mandatory) bit, H (Hidden) bit, Length, and
Vendor ID. The Vendor ID for the VCCV Capability AVP MUST be 0,
indicating that this is an IETF-defined AVP. This AVP MAY be hidden
(the H bit MAY be 0 or 1). The M bit for this AVP SHOULD be set to
0. The Length (before hiding) of this AVP is 8.

[7](#). Capability Advertisement Selection

When a PE receives a VCCV capability advertisement, the advertisement
may potentially contain more than one CC or CV Type. Only matching
capabilities can be selected. When multiple capabilities match, only
one CC Type MUST be used.

In particular, as already specified, once a valid CC Type is used by
a PE (traffic sent using that encapsulation), the PE MUST NOT send
any traffic down another CC Type control channel.

For cases where multiple CC Types are advertised, the following
precedence rules apply when choosing the single CC Type to use:

1. Type 1: PWE3 Control Word with 0001b as first nibble

2. Type 2: MPLS Router Alert Label

3. Type 3: MPLS PW Label with TTL == 1

For MPLS PWs, the CV Type of LSP Ping (0x02) is the default, and the
CV Type of ICMP Ping (0x01) is optional.

[8](#). IANA Considerations

[8.1](#). VCCV Interface Parameters Sub-TLV

The VCCV Interface Parameters Sub-TLV codepoint is defined in
[[RFC4446](#)]. IANA has created and will maintain registries for the CC
Types and CV Types (bitmasks in the VCCV Parameter ID). The CC Type
and CV Type new registries (see Sections [8.1.1](#) and [8.1.2](#),
respectively) have been created in the Pseudo Wires Name Spaces,
reachable from [[IANA.pwe3-parameters](#)]. The allocations must be done
using the "IETF Consensus" policy defined in [[RFC2434](#)].

[8.1.1](#). MPLS VCCV Control Channel (CC) Types

IANA has set up a registry of "MPLS VCCV Control Channel Types".
These are 8 bitfields. CC Type values 0x01, 0x02, and 0x04 are
specified in [Section 4](#) of this document. The remaining bitfield
values (0x08, 0x10, 0x20, 0x40, and 0x80) are to be assigned by IANA
using the "IETF Consensus" policy defined in [[RFC2434](#)]. A VCCV

   Control Channel Type description and a reference to an RFC approved
   by the IESG are required for any assignment from this registry.

      MPLS Control Channel (CC) Types:

      Bit (Value)   Description
      ===========   =======================================
      Bit 0 (0x01) - Type 1: PWE3 Control Word with 0001b as
                     first nibble (PW-ACH, see [[RFC4385](#)])
      Bit 1 (0x02) - Type 2: MPLS Router Alert Label
      Bit 2 (0x04) - Type 3: MPLS PW Label with TTL == 1
      Bit 3 (0x08) - Reserved
      Bit 4 (0x10) - Reserved
      Bit 5 (0x20) - Reserved
      Bit 6 (0x40) - Reserved
      Bit 7 (0x80) - Reserved

   The most significant (high order) bit is labeled Bit 7, and the least
   significant (low order) bit is labeled Bit 0, see parenthetical
   "Value".

[8.1.2](#). MPLS VCCV Connectivity Verification (CV) Types

   IANA has set up a registry of "MPLS VCCV Control Verification Types".
   These are 8 bitfields. CV Type values 0x01 and 0x02 are specified in
   [Section 4](#) of this document. The remaining bitfield values (0x04,
   0x08, 0x10, 0x20, 0x40, and 0x80) are to be assigned by IANA using
   the "IETF Consensus" policy defined in [[RFC2434](#)]. A VCCV Control
   Verification Type description and a reference to an RFC approved by
   the IESG are required for any assignment from this registry.

      MPLS Connectivity Verification (CV) Types:

      Bit (Value)   Description
      ===========   =======================================
      Bit 0 (0x01) - ICMP Ping
      Bit 1 (0x02) - LSP Ping
      Bit 2 (0x04) - Reserved
      Bit 3 (0x08) - Reserved
      Bit 4 (0x10) - Reserved
      Bit 5 (0x20) - Reserved
      Bit 6 (0x40) - Reserved
      Bit 7 (0x80) - Reserved

   The most significant (high order) bit is labeled Bit 7, and the least
   significant (low order) bit is labeled Bit 0, see parenthetical
   "Value".

8.2. PW Associated Channel Type

   The PW Associated Channel Types used by VCCV as defined in Sections
   5.1.1 and 6.1 rely on previously allocated numbers from the
   Pseudowire Associated Channel Types Registry [RFC4385] in the Pseudo
   Wires Name Spaces reachable from [IANA.pwe3-parameters]. In
   particular, 0x21 (Internet Protocol version 4) MUST be used whenever
   an IPv4 payload follows the Pseudowire Associated Channel Header, or
   0x57 MUST be used when an IPv6 payload follows the Pseudowire
   Associated Channel Header.

8.3. L2TPv3 Assignments

   Section 8.3.1 through Section 8.3.3 are registrations of new L2TP
   values for registries already managed by IANA. Section 8.3.4 is a
   new registry that has been added to the existing L2TP name spaces,
   and will be maintained by IANA accordingly. The Layer Two Tunneling
   Protocol "L2TP" Name Spaces are reachable from
   [IANA.l2tp-parameters].

8.3.1. Control Message Attribute Value Pairs (AVPs)

   An additional AVP Attribute is specified in Section 6.3.1. It was
   defined by IANA as described in Section 2.2 of [RFC3438].

      Attribute
      Type   Description
      ---------   ----------------------------------
      96   VCCV Capability AVP

8.3.2. Default L2-Specific Sublayer Bits

   The Default L2-Specific Sublayer contains 8 bits in the low-order
   portion of the header. This document defines one reserved bit in the
   Default L2-Specific Sublayer in Section 6.1, which was assigned by
   IANA following IETF Consensus [RFC2434].

      Default L2-Specific Sublayer bits - per [RFC3931]

      Bit 0 - V (VCCV) bit

8.3.3. ATM-Specific Sublayer Bits

   The ATM-Specific Sublayer contains 8 bits in the low-order portion of
   the header. This document defines one reserved bit in the ATM-
   Specific Sublayer in Section 6.1, which was assigned by IANA
   following IETF Consensus [RFC2434].

```
   ATM-Specific Sublayer bits - per [RFC4454]
   ---------------------------
   Bit 0 - V (VCCV) bit
```

[8.3.4](#). **VCCV Capability AVP Values**

   This is a new registry that IANA maintains in the L2TP Name Spaces.

   IANA created and maintains a registry for the CC Types and CV Types
   bitmasks in the VCCV Capability AVP, defined in [Section 6.3.1](#). The
   allocations must be done using the "IETF Consensus" policy defined in
   [[RFC2434](#)]. A VCCV CC or CV Type description and a reference to an
   RFC approved by the IESG are required for any assignment from this
   registry.

   IANA has reserved the following bits in this registry:

```
   VCCV Capability AVP (Attribute Type 96) Values
   ------------------------------------------------

   L2TPv3 Control Channel (CC) Types:

      Bit (Value)    Description
      ===========    ======================================
      Bit 0 (0x01) - L2-Specific Sublayer with V-bit set
      Bit 1 (0x02) - Reserved
      Bit 2 (0x04) - Reserved
      Bit 3 (0x08) - Reserved
      Bit 4 (0x10) - Reserved
      Bit 5 (0x20) - Reserved
      Bit 6 (0x40) - Reserved
      Bit 7 (0x80) - Reserved

   L2TPv3 Connectivity Verification (CV) Types:

      Bit (Value)    Description
      ===========    ======================================
      Bit 0 (0x01) - ICMP Ping
      Bit 1 (0x02) - Reserved
      Bit 2 (0x04) - Reserved
      Bit 3 (0x08) - Reserved
      Bit 4 (0x10) - Reserved
      Bit 5 (0x20) - Reserved
      Bit 6 (0x40) - Reserved
      Bit 7 (0x80) - Reserved
```

The most significant (high order) bit is labeled Bit 7, and the least
significant (low order) bit is labeled Bit 0, see parenthetical
"Value".

9. Congestion Considerations

The bandwidth resources used by VCCV are recommended to be minimal
compared to those of the associated PW. The bandwidth required for
the VCCV channel is taken outside any allocation for PW data traffic,
and can be configurable. When doing resource reservation or network
planning, the bandwidth requirements for both PW data and VCCV
traffic need to be taken into account.

VCCV applications (i.e., Connectivity Verification (CV) Types) MUST
consider congestion and bandwidth usage implications and provide
details on bandwidth or packet frequency management. VCCV
applications can have built-in bandwidth management in their
protocols. Other VCCV applications can have their bandwidth
configuration-limited, and rate-limiting them can be harmful as it
could translate to incorrectly declaring connectivity failures. For
all other VCCV applications, outgoing VCCV messages SHOULD be rate-
limited to prevent aggressive connectivity verification consuming
excessive bandwidth, causing congestion, becoming denial-of-service
attacks, or generating an excessive packet rate at the CE-bound PE.

If these conditions cannot be followed, an adaptive loss-based scheme
SHOULD be applied to congestion-control outgoing VCCV traffic, so
that it competes fairly with TCP within an order of magnitude. One
method of determining an acceptable bandwidth for VCCV is described
in [RFC3448] (TFRC); other methods exist. For example, bandwidth or
packet frequency management can include any of the following: a
negotiation of transmission interval/rate, a throttled transmission
rate on "congestion detected" situations, a slow-start after shutdown
due to congestion and until basic connectivity is verified, and other
mechanisms.

The ICMP and MPLS LSP PING applications SHOULD be rate-limited to
below 5% of the bit-rate of the associated PW. For this purpose, the
considered bit-rate of a pseudowire is dependent on the PW type. For
pseudowires that carry constant bit-rate traffic (e.g., TDM PWs) the
full bit-rate of the PW is used. For pseudowires that carry variable
bit-rate traffic (e.g., Ethernet PWs), the mean or sustained bit-rate
of the PW is used.

As described in Section 10, incoming VCCV messages can be rate-
limited as a protection against denial-of-service attacks. This
throttling or policing of incoming VCCV messages should not be more
stringent than the bandwidth allocated to the VCCV channel to prevent
false indications of connectivity failure.

10. Security Considerations

Routers that implement VCCV create a Control Channel (CC) associated
with a pseudowire. This control channel can be signaled (e.g., using
LDP or L2TPv3 depending on the PWE3) or statically configured. Over
this control channel, VCCV Connectivity Verification (CV) messages
are sent. Therefore, three different areas are of concern from a
security standpoint.

The first area of concern relates to control plane parameter and
status message attacks, that is, attacks that concern the signaling
of VCCV capabilities. MPLS PW Control Plane security is discussed in
Section 8.2 of [RFC4447]. L2TPv3 PW Control Plane security is
discussed in Section 8.1 of [RFC3931]. The addition of the
connectivity verification negotiation extensions does not change the
security aspects of Section 8.2 of [RFC4447], or Section 8.1 of
 [RFC3931]. Implementation of IP source address filters may also aid
in deterring these types of attacks.

A second area of concern centers on data-plane attacks, that is,
attacks on the associated channel itself. Routers that implement the
VCCV mechanisms are subject to additional data-plane denial-of-
service attacks as follows:

   An intruder could intercept or inject VCCV packets effectively
   providing false positives or false negatives.

   An intruder could deliberately flood a peer router with VCCV
   messages to deny services to others.

   A misconfigured or misbehaving device could inadvertently flood a
   peer router with VCCV messages which could result in denial of
   services. In particular, if a router has either implicitly or
   explicitly indicated that it cannot support one or all of the
   types of VCCV, but is sent those messages in sufficient quantity,
   it could result in a denial of service.

To protect against these potential (deliberate or unintentional)
attacks, multiple mitigation techniques can be employed:

   VCCV message throttling mechanisms can be used, especially in
   distributed implementations which have a centralized control-plane

processor with various line cards attached by some control-plane
data path. In these architectures, VCCV messages may be processed
on the central processor after being forwarded there by the
receiving line card. In this case, the path between the line card
and the control processor may become saturated if appropriate VCCV
traffic throttling is not employed, which could lead to a complete
denial of service to users of the particular line card. Such
filtering is also useful for preventing the processing of unwanted
VCCV messages, such as those which are sent on unwanted (and
perhaps unadvertised) control channel types or VCCV types.

Section 8.1 of [RFC4447] discusses methods to protect the data
plane of MPLS PWs from data-plane attacks. However the
implementation of the connectivity verification protocol expands
the range of possible data-plane attacks. For this reason
implementations MUST provide a method to secure the data plane.
This can be in the form of encryption of the data by running IPsec
on MPLS packets encapsulated according to [RFC4023], or by
providing the ability to architect the MPLS network in such a way
that no external MPLS packets can be injected (private MPLS
network).

For L2TPv3, data packet spoofing considerations are outlined in
Section 8.2 of [RFC3931]. While the L2TPv3 Session ID provides
traffic separation, the optional Cookie field provides additional
protection to thwart spoofing attacks. To maximize protection
against a variety of data-plane attacks, a 64-bit Cookie can be
used. L2TPv3 can also be run over IPsec as detailed in Section
4.1.3 of [RFC3931].

A third and last area of concern relates to the processing of the
actual contents of VCCV messages, i.e., LSP Ping and ICMP messages.
Therefore, the corresponding security considerations for these
protocols (LSP Ping [RFC4379], ICMPv4 Ping [RFC0792], and ICMPv6 Ping
[RFC4443]) apply as well.

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[12](#). References

[12.1](#). Normative References

[RFC0792]   Postel, J., "Internet Control Message Protocol", STD 5,
            [RFC 792](#), September 1981.

[RFC2119]   Bradner, S., "Key words for use in RFCs to Indicate
            Requirement Levels", [BCP 14](#), [RFC 2119](#), March 1997.

[RFC3032]   Rosen, E., Tappan, D., Fedorkow, G., Rekhter, Y.,
            Farinacci, D., Li, T., and A. Conta, "MPLS Label Stack
            Encoding", [RFC 3032](#), January 2001.

[RFC3931]   Lau, J., Townsley, M., and I. Goyret, "Layer Two Tunneling
            Protocol - Version 3 (L2TPv3)", [RFC 3931](#), March 2005.

[RFC4379]   Kompella, K. and G. Swallow, "Detecting Multi-Protocol
            Label Switched (MPLS) Data Plane Failures", [RFC 4379](#),
            February 2006.

[RFC4385]   Bryant, S., Swallow, G., Martini, L., and D. McPherson,
            "Pseudowire Emulation Edge-to-Edge (PWE3) Control Word for
            Use over an MPLS PSN", [RFC 4385](#), February 2006.

[RFC4443]   Conta, A., Deering, S., and M. Gupta, "Internet Control
            Message Protocol (ICMPv6) for the Internet Protocol
            Version 6 (IPv6) Specification", [RFC 4443](#), March 2006.

[RFC4446]   Martini, L., "IANA Allocations for Pseudowire Edge to Edge
            Emulation (PWE3)", [BCP 116](#), [RFC 4446](#), April 2006.

[RFC4447]   Martini, L., Rosen, E., El-Aawar, N., Smith, T., and G.
            Heron, "Pseudowire Setup and Maintenance Using the Label
            Distribution Protocol (LDP)", [RFC 4447](#), April 2006.

[12.2](#). Informative References

[IANA.l2tp-parameters]
            Internet Assigned Numbers Authority, "Layer Two Tunneling
            Protocol "L2TP"", April 2007,
            <http://www.iana.org/assignments/l2tp-parameters>.

[IANA.pwe3-parameters]
            Internet Assigned Numbers Authority, "Pseudo Wires Name
            Spaces", June 2007,
            <http://www.iana.org/assignments/pwe3-parameters>.

   [MSG-MAP] Nadeau, T., "Pseudo Wire (PW) OAM Message Mapping",
              Work in Progress, March 2007.

   [RFC2434] Narten, T. and H. Alvestrand, "Guidelines for Writing an
              IANA Considerations Section in RFCs", BCP 26, RFC 2434,
              October 1998.

   [RFC3438] Townsley, W., "Layer Two Tunneling Protocol (L2TP)
              Internet Assigned Numbers Authority (IANA) Considerations
              Update", BCP 68, RFC 3438, December 2002.

   [RFC3448] Handley, M., Floyd, S., Padhye, J., and J. Widmer, "TCP
              Friendly Rate Control (TFRC): Protocol Specification",
              RFC 3448, January 2003.

   [RFC3916] Xiao, X., McPherson, D., and P. Pate, "Requirements for
              Pseudo-Wire Emulation Edge-to-Edge (PWE3)", RFC 3916,
              September 2004.

   [RFC3985] Bryant, S. and P. Pate, "Pseudo Wire Emulation Edge-to-
              Edge (PWE3) Architecture", RFC 3985, March 2005.

   [RFC4023] Worster, T., Rekhter, Y., and E. Rosen, "Encapsulating
              MPLS in IP or Generic Routing Encapsulation (GRE)",
              RFC 4023, March 2005.

   [RFC4377] Nadeau, T., Morrow, M., Swallow, G., Allan, D., and S.
              Matsushima, "Operations and Management (OAM) Requirements
              for Multi-Protocol Label Switched (MPLS) Networks",
              RFC 4377, February 2006.

   [RFC4448] Martini, L., Rosen, E., El-Aawar, N., and G. Heron,
              "Encapsulation Methods for Transport of Ethernet over MPLS
              Networks", RFC 4448, April 2006.

   [RFC4454] Singh, S., Townsley, M., and C. Pignataro, "Asynchronous
              Transfer Mode (ATM) over Layer 2 Tunneling Protocol
              Version 3 (L2TPv3)", RFC 4454, May 2006.

   [RFC4928] Swallow, G., Bryant, S., and L. Andersson, "Avoiding Equal
              Cost Multipath Treatment in MPLS Networks", BCP 128,
              RFC 4928, June 2007.

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