

Internet Engineering Task Force (IETF)
Request for Comments: 8077
STD: 84
Obsoletes: 4447, 6723
Category: Standards Track
ISSN: 2070-1721

L. Martini, Ed.
G. Heron, Ed.
Cisco
February 2017

Pseudowire Setup and Maintenance Using the Label Distribution Protocol (LDP)

Abstract

Layer 2 services (such as Frame Relay, Asynchronous Transfer Mode, and Ethernet) can be emulated over an MPLS backbone by encapsulating the Layer 2 Protocol Data Units (PDUs) and then transmitting them over pseudowires (PWs). It is also possible to use pseudowires to provide low-rate Time-Division Multiplexed and Synchronous Optical NETWORKing circuit emulation over an MPLS-enabled network. This document specifies a protocol for establishing and maintaining the pseudowires, using extensions to the Label Distribution Protocol (LDP). Procedures for encapsulating Layer 2 PDUs are specified in other documents.

This document is a rewrite of RFC 4447 for publication as an Internet Standard.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <http://www.rfc-editor.org/info/rfc8077>.

Copyright Notice

Copyright (c) 2017 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

This document may contain material from IETF Documents or IETF Contributions published or made publicly available before November 10, 2008. The person(s) controlling the copyright in some of this material may not have granted the IETF Trust the right to allow modifications of such material outside the IETF Standards Process. Without obtaining an adequate license from the person(s) controlling the copyright in such materials, this document may not be modified outside the IETF Standards Process, and derivative works of it may not be created outside the IETF Standards Process, except to format it for publication as an RFC or to translate it into languages other than English.

Table of Contents

1. Introduction	4
2. Changes from RFC 4447	6
3. Specification of Requirements	6
4. The Pseudowire Label	7
5. Details Specific to Particular Emulated Services	9
5.1. IP Layer 2 Transport	9
6. LDP	9
6.1. The PWid FEC Element	9
6.2. The Generalized PWid FEC Element	11
6.2.1. Attachment Identifiers	12
6.2.2. Encoding the Generalized PWid FEC Element	14
6.2.2.1. PW Interface Parameters TLV	15
6.2.2.2. PW Group ID TLV	15
6.2.3. Signaling Procedures	16
6.3. Signaling of Pseudowire Status	17
6.3.1. Use of Label Mapping Messages	17
6.3.2. Signaling PW Status	18
6.3.3. Pseudowire Status Negotiation Procedures	19
6.4. Interface Parameter Sub-TLV	20
6.5. LDP Label Withdrawal Procedures	21
7. Control Word	22
7.1. PW Types for Which the Control Word Is REQUIRED	22
7.2. PW Types for Which the Control Word Is NOT Mandatory	22
7.3. Control-Word Renegotiation by Label Request Message	24
7.4. Sequencing Considerations	25
7.4.1. Label Advertisements	25
7.4.2. Label Release	25
8. IANA Considerations	26
8.1. LDP TLV TYPE	26
8.2. LDP Status Codes	26
8.3. FEC Type Name Space	26
9. Security Considerations	26
9.1. Data-Plane Security	27
9.2. Control-Plane Security	28
10. Interoperability and Deployment	29
11. References	29
11.1. Normative References	29
11.2. Informative References	30
Acknowledgments	31
Contributors	32
Authors' Addresses	35

1. Introduction

[RFC4619], [RFC4717], [RFC4618], and [RFC4448] explain how to encapsulate a Layer 2 Protocol Data Unit (PDU) for transmission over an MPLS-enabled network. Those documents specify that a "pseudowire header", consisting of a demultiplexer field, will be prepended to the encapsulated PDU. The pseudowire demultiplexer field is prepended before transmitting a packet on a pseudowire. When the packet arrives at the remote endpoint of the pseudowire, the demultiplexer is what enables the receiver to identify the particular pseudowire on which the packet has arrived. To transmit the packet from one pseudowire endpoint to another, the packet may need to travel through a "Packet Switched Network (PSN) tunnel"; this will require that an additional header be prepended to the packet.

[RFC4842] and [RFC4553] specify two methods for transporting time-division multiplexing (TDM) digital signals (TDM circuit emulation) over a packet-oriented MPLS-enabled network. The transmission system for circuit-oriented TDM signals is the Synchronous Optical Network (SONET) [ANSI] / Synchronous Digital Hierarchy (SDH) [ITU]. To support TDM traffic, which includes voice, data, and private leased-line service, the pseudowires must emulate the circuit characteristics of SONET/SDH payloads. The TDM signals and payloads are encapsulated for transmission over pseudowires. A pseudowire demultiplexer and a PSN tunnel header are prepended to this encapsulation.

[RFC4553] describes methods for transporting low-rate time-division multiplexing (TDM) digital signals (TDM circuit emulation) over PSNs, while [RFC4842] similarly describes transport of high-rate TDM (SONET/SDH). To support TDM traffic, the pseudowires must emulate the circuit characteristics of the original T1, E1, T3, E3, SONET, or SDH signals. [RFC4553] does this by encapsulating an arbitrary but constant amount of the TDM data in each packet, and the other methods encapsulate TDM structures.

In this document, we specify the use of the MPLS Label Distribution Protocol (LDP) [RFC5036] as a protocol for setting up and maintaining the pseudowires. In particular, we define new TLVs, Forwarding Equivalence Class (FEC) elements, parameters, and codes for LDP, which enable LDP to identify pseudowires and to signal attributes of pseudowires. We specify how a pseudowire endpoint uses these TLVs in LDP to bind a demultiplexer field value to a pseudowire and how it informs the remote endpoint of the binding. We also specify procedures for reporting pseudowire status changes, for passing additional information about the pseudowire as needed, and for releasing the bindings. These procedures are intended to be independent of the underlying version of IP used for LDP signaling.

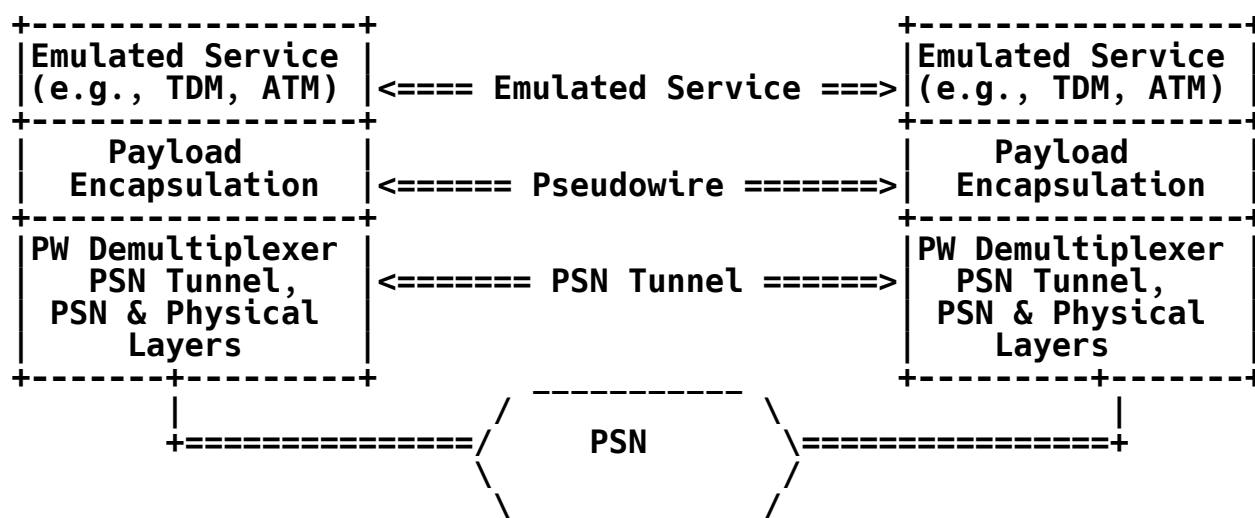


Figure 2: PWE3 Protocol Stack Reference Model

For the purpose of this document, PE1 (Provider Edge 1) will be defined as the ingress router, and PE2 as the egress router. A Layer 2 PDU will be received at PE1, encapsulated at PE1, transported and decapsulated at PE2, and transmitted out of PE2.

2. Changes from RFC 4447

The changes in this document are mostly minor fixes to spelling and grammar, or clarifications to the text, which were either noted as errata to [RFC4447] or found by the editors.

Additionally, Section 7.3 ("Control-Word Renegotiation by Label Request Message") has been added, obsoleting [RFC6723]. The diagram of C-bit handling procedures has also been removed. A note has been added in Section 6.3.2 to clarify that the C-bit is part of the FEC.

A reference has also been added to [RFC7358] to indicate the use of downstream unsolicited mode to distribute PW FEC label bindings, independent of the negotiated label advertisement mode of the LDP session.

3. 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].

4. The Pseudowire Label

Suppose that it is desired to transport Layer 2 PDUs from ingress LSR PE1 to egress LSR PE2, across an intervening MPLS-enabled network. We assume that there is an MPLS tunnel from PE1 to PE2. That is, we assume that PE1 can cause a packet to be delivered to PE2 by encapsulating the packet in an "MPLS tunnel header" and sending the result to one of its adjacencies. The MPLS tunnel is an MPLS Label Switched Path (LSP); thus, putting on an MPLS tunnel encapsulation is a matter of pushing on an MPLS label.

We presuppose that a large number of pseudowires can be carried through a single MPLS tunnel. Thus, it is never necessary to maintain state in the network core for individual pseudowires. We do not presuppose that the MPLS tunnels are point to point; although the pseudowires are point to point, the MPLS tunnels may be multipoint to point. We do not presuppose that PE2 will even be able to determine the MPLS tunnel through which a received packet was transmitted. (For example, if the MPLS tunnel is an LSP and penultimate hop popping is used, when the packet arrives at PE2, it will contain no information identifying the tunnel.)

When PE2 receives a packet over a pseudowire, it must be able to determine that the packet was in fact received over a pseudowire, and it must be able to associate that packet with a particular pseudowire. PE2 is able to do this by examining the MPLS label that serves as the pseudowire demultiplexer field shown in Figure 2. Call this label the "PW label".

When PE1 sends a Layer 2 PDU to PE2, it creates an MPLS packet by adding the PW label to the packet, thus creating the first entry of the label stack. If the PSN tunnel is an MPLS LSP, the PE1 pushes another label (the tunnel label) onto the packet as the second entry of the label stack. The PW label is not visible again until the MPLS packet reaches PE2. PE2's disposition of the packet is based on the PW label.

If the payload of the MPLS packet is, for example, an ATM Adaptation Layer 5 (AAL5) PDU, the PW label will generally correspond to a particular ATM Virtual Circuit (VC) at PE2. That is, PE2 needs to be able to infer from the PW label the outgoing interface and the VPI/VCID (Virtual Path Identifier / Virtual Circuit Identifier) value for the AAL5 PDU. If the payload is a Frame Relay PDU, then PE2 needs to be able to infer from the PW label the outgoing interface and the Data Link Connection Identifier (DLCI) value. If the payload is an Ethernet frame, then PE2 needs to be able to infer from the PW label the outgoing interface, and perhaps the VLAN identifier. This process is unidirectional and will be repeated independently for

bidirectional operation. When using the PWid FEC Element, it is REQUIRED that the same PW ID and PW type be assigned for a given circuit in both directions. The Group ID (see below) MUST NOT be required to match in both directions. The transported frame MAY be modified when it reaches the egress router. If the header of the transported Layer 2 frame is modified, this MUST be done at the egress LSR only. Note that the PW label must always be at the bottom of the packet's label stack, and labels MUST be allocated from the per-platform label space.

This document does not specify a method for distributing the MPLS tunnel label or any other labels that may appear above the PW label on the stack. Any acceptable method of MPLS label distribution will do. This document specifies a protocol for assigning and distributing the PW label. This protocol is LDP, extended as specified in the remainder of this document. An LDP session must be set up between the pseudowire endpoints. LDP MUST exchange PW FEC label bindings in downstream unsolicited mode, independent of the negotiated label advertisement mode of the LDP session according to the specifications in [RFC7358]. LDP's "liberal label retention" mode SHOULD be used. However, all the LDP procedures that are specified in [RFC5036] and that are also applicable to this protocol specification MUST be implemented.

This document requires that a receiving LSR MUST respond to a Label Request message with either a Label Mapping for the requested label or a Notification message that indicates why it cannot satisfy the request. These procedures are specified in [RFC5036], Sections 3.5.7 ("Label Mapping Message") and 3.5.8 ("Label Request Message"). Note that sending these responses is a stricter requirement than is specified in [RFC5036], but these response messages are REQUIRED to ensure correct operation of this protocol.

In addition to the protocol specified herein, static assignment of PW labels may be used, and implementations of this protocol SHOULD provide support for static assignment. PW encapsulation is always symmetrical in both directions of traffic along a specific PW, whether or not the PW uses an LDP control plane.

This document specifies all the procedures necessary to set up and maintain the pseudowires needed to support "unswitched" point-to-point services, where each endpoint of the pseudowire is provisioned with the identity of the other endpoint. There are also protocol mechanisms specified herein that can be used to support switched services and other provisioning models. However, the use of the protocol mechanisms to support those other models and services is not described in this document.

5. Details Specific to Particular Emulated Services

5.1. IP Layer 2 Transport

This mode carries IP packets over a pseudowire. The encapsulation used is according to [RFC3032]. The PW control word MAY be inserted between the MPLS label stack and the IP payload. The encapsulation of the IP packets for forwarding on the Attachment Circuit is implementation specific, is part of the native service processing (NSP) function [RFC3985], and is outside the scope of this document.

6. LDP

The PW label bindings are distributed using the LDP downstream unsolicited mode described in [RFC5036]. The PEs will establish an LDP session using the Extended Discovery mechanism described in Sections 2.4.2 and 2.5 of [RFC5036].

An LDP Label Mapping message contains a FEC TLV, a Label TLV, and zero or more optional parameter TLVs.

The FEC TLV is used to indicate the meaning of the label. In the current context, the FEC TLV would be used to identify the particular pseudowire that a particular label is bound to. In this specification, we define two new FEC TLVs to be used for identifying pseudowires. When setting up a particular pseudowire, only one of these FEC TLVs is used. The one to be used will depend on the particular service being emulated and on the particular provisioning model being supported.

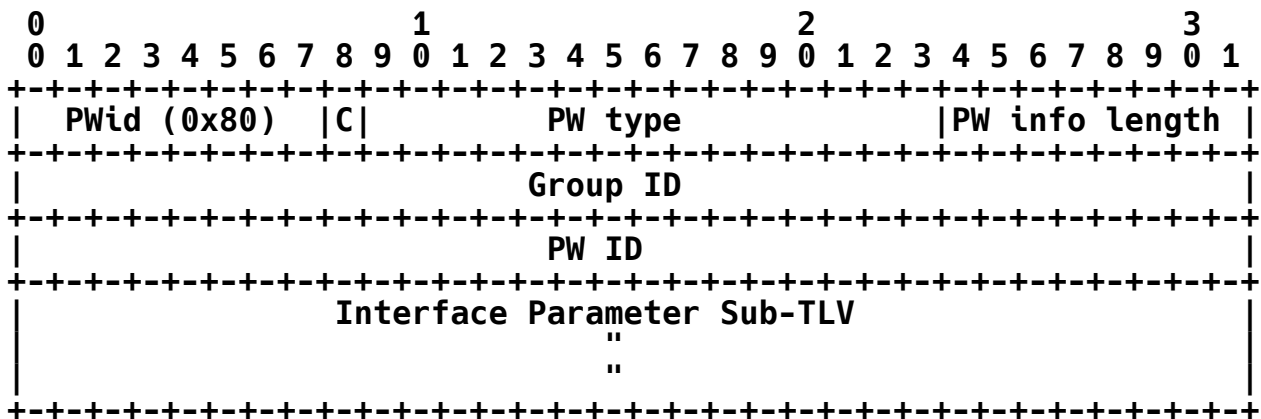
LDP allows each FEC TLV to consist of a set of FEC elements. For setting up and maintaining pseudowires, however, each FEC TLV MUST contain exactly one FEC element.

The LDP base specification has several kinds of label TLVs, including the Generic Label TLV, as specified in Section 3.4.2.1 of [RFC5036]. For setting up and maintaining pseudowires, the Generic Label TLV MUST be used.

6.1. The PWid FEC Element

The PWid FEC Element may be used whenever both pseudowire endpoints have been provisioned with the same 32-bit identifier for the pseudowire.

For this purpose, a new type of FEC element is defined. The FEC element type is 0x80 and is defined as follows:



- Control word bit (C)

The C-bit is used to flag the presence of a control word as follows:

- C = 1 control word present on this PW.
- C = 0 no control word present on this PW.

Please see Section 7 ("Control Word") for further explanation.

- PW type

A 15-bit quantity containing a value that represents the type of PW. Assigned Values are specified in "IANA Allocations for Pseudowire Edge to Edge Emulation (PWE3)" [RFC4446].

- PW info length

Length of the PW ID field and the Interface Parameter Sub-TLV field in octets. If this value is 0, then it references all PWs using the specified Group ID, and there is no PW ID present, nor are there any Interface Parameter Sub-TLVs.

- Group ID

An arbitrary 32-bit value that represents a group of PWs that is used to create groups in the PW space. The Group ID is intended to be used as a port index or a virtual tunnel index. To simplify configuration, a particular PW Group ID at ingress could be part of a Group ID assigned to the virtual tunnel for transport to the egress router. The Group ID is very useful for sending wildcard label withdrawals or PW wildcard status Notification messages to remote PEs upon physical port failure.

- PW ID

A non-zero, 32-bit connection ID that together with the PW type identifies a particular PW. Note that the PW ID and the PW type MUST be the same at both endpoints.

- Interface Parameter Sub-TLV

This variable length TLV is used to provide interface-specific parameters, such as Attachment Circuit MTU.

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. Thus, the interface parameters field must not be used to pass information, such as status information, that may change during the life of the pseudowire. Optional parameter TLVs should be used for that purpose.

Using the PWid FEC, each of the two pseudowire endpoints independently initiates the setup of a unidirectional LSP. An outgoing LSP and an incoming LSP are bound together into a single pseudowire if they have the same PW ID and PW type.

6.2. The Generalized PWid FEC Element

The PWid FEC Element can be used if a unique 32-bit value has been assigned to the PW and if each endpoint has been provisioned with that value. The Generalized PWid FEC Element requires that the PW endpoints be uniquely identified; the PW itself is identified as a pair of endpoints. In addition, the endpoint identifiers are structured to support applications where the identity of the remote endpoints needs to be auto-discovered rather than statically configured.

The "Generalized PWid FEC Element" is FEC type 0x81.

The Generalized PWid FEC Element does not contain anything corresponding to the Group ID of the PWid FEC Element. The functionality of the Group ID is provided by a separate optional LDP TLV, the PW Group ID TLV, described in Section 6.2.2.2. The interface parameters field of the PWid FEC Element is also absent; its functionality is replaced by the optional PW Interface Parameters TLV, described in Section 6.2.2.1.

6.2.1. Attachment Identifiers

As discussed in [RFC3985], a pseudowire can be thought of as connecting two "forwarders". The protocol used to set up a pseudowire must allow the forwarder at one end of a pseudowire to identify the forwarder at the other end. We use the term "Attachment Identifier", or "AI", to refer to the field that the protocol uses to identify the forwarders. In the PWid FEC, the PWid field serves as the AI. In this section, we specify a more general form of AI that is structured and of variable length.

Every Forwarder in a PE must be associated with an Attachment Identifier (AI), either through configuration or through some algorithm. The Attachment Identifier must be unique in the context of the PE router in which the Forwarder resides. The combination <PE router IP address, AI> must be globally unique.

It is frequently convenient to regard a set of Forwarders as being members of a particular "group", where PWs may only be set up among members of a group. In such cases, it is convenient to identify the Forwarders relative to the group, so that an Attachment Identifier would consist of an Attachment Group Identifier (AGI) plus an Attachment Individual Identifier (AII).

An Attachment Group Identifier may be thought of as a VPN-id, or a VLAN identifier, some attribute that is shared by all the Attachment PWs (or pools thereof) that are allowed to be connected.

The details of how to construct the AGI and AII fields identifying the pseudowire endpoints are outside the scope of this specification. Different pseudowire applications, and different provisioning models, will require different sorts of AGI and AII fields. The specification of each such application and/or model must include the rules for constructing the AGI and AII fields.

As previously discussed, a (bidirectional) pseudowire consists of a pair of unidirectional LSPs, one in each direction. If a particular pseudowire connects PE1 with PE2, the PW direction from PE1 to PE2 can be identified as:

<PE1, <AGI, AII1>, PE2, <AGI, AII2>>,

and the PW direction from PE2 to PE1 can be identified by:

<PE2, <AGI, AII2>, PE1, <AGI, AII1>>.

Note that the AGI must be the same at both endpoints, but the AII will in general be different at each endpoint. Thus, from the perspective of a particular PE, each pseudowire has a local or "Source AII", and a remote or "Target AII". The pseudowire setup protocol can carry all three of these quantities:

- Attachment Group Identifier (AGI)
- Source Attachment Individual Identifier (SAII)
- Target Attachment Individual Identifier (TAII)

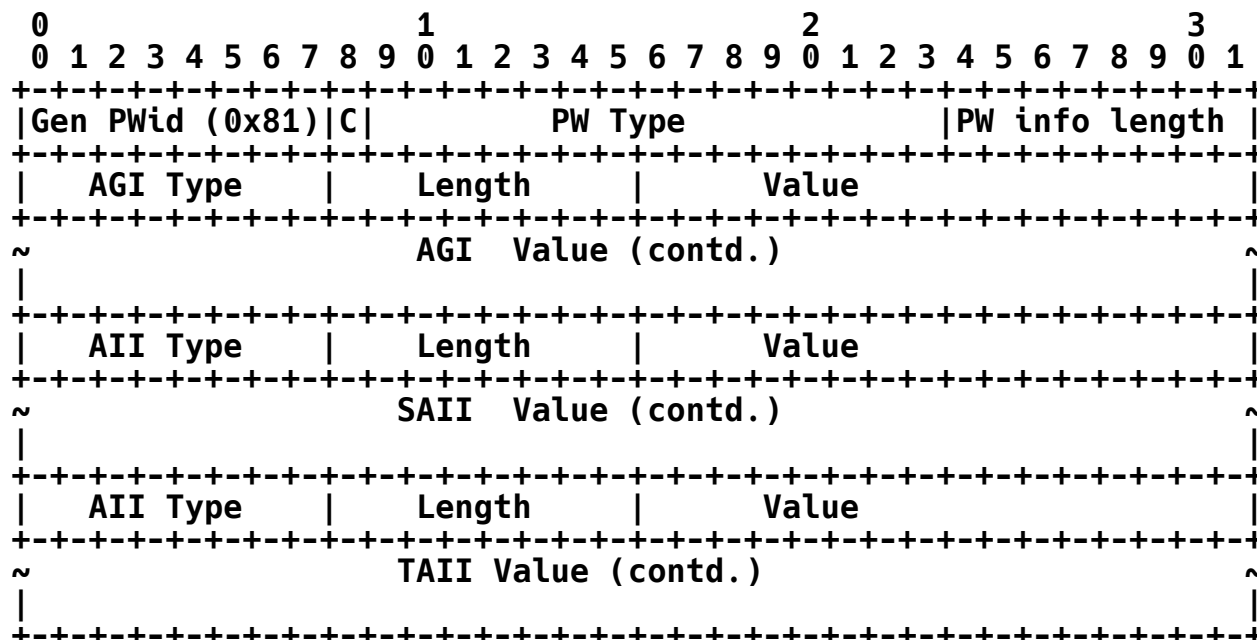
If the AGI is non-null, then the Source AI (SAI) consists of the AGI together with the SAII, and the Target AI (TAI) consists of the TAII together with the AGI. If the AGI is null, then the SAII and TAII are the SAI and TAI, respectively.

The interpretation of the SAI and TAI is a local matter at the respective endpoint.

The association of two unidirectional LSPs into a single bidirectional pseudowire depends on the SAI and the TAI. Each application and/or provisioning model that uses the Generalized PWid FEC must specify the rules for performing this association.

6.2.2. Encoding the Generalized PWid FEC Element

FEC element type 0x81 is used. The FEC element is encoded as follows:



This document does not specify the AII and AGI type field values; specification of the type field values to be used for a particular application is part of the specification of that application. IANA has assigned these values using the method defined in [RFC4446].

The SAI, TAI, and AGI are simply carried as octet strings. The Length byte specifies the size of the Value field. The null string can be sent by setting the Length byte to 0. If a particular application does not need all three of these sub-elements, it MUST send all the sub-elements but set the Length to 0 for the unused sub-elements.

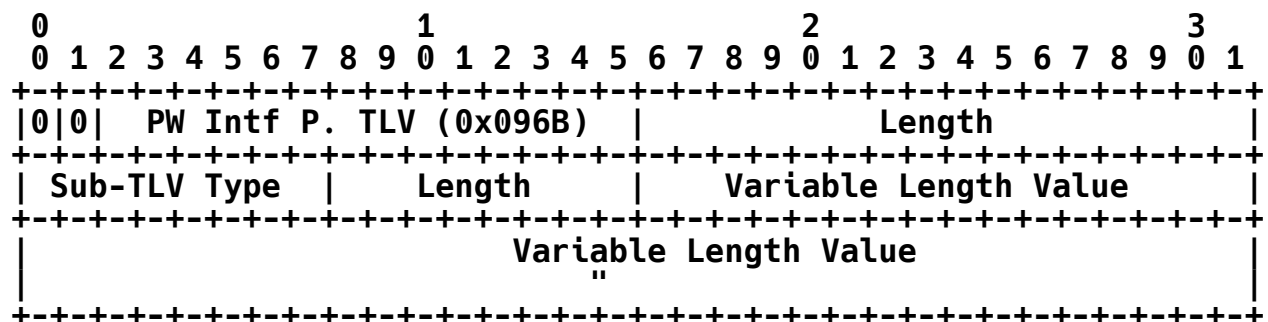
The PW information length field contains the length of the SAI, TAI, and AGI, combined in octets. If this value is 0, then it references all PWs using the specific Group ID (specified in the PW Group ID TLV). In this case, there are no other FEC element fields (AGI, SAI, etc.) present, nor any PW Interface Parameters TLVs.

Note that the interpretation of a particular field as AGI, SAI, or TAI depends on the order of its occurrence. The Type field identifies the type of the AGI, SAI, or TAI. When comparing two

occurrences of an AGI (or SAII or TAI), the two occurrences are considered identical if the Type, Length, and Value fields of one are identical, respectively, to those of the other.

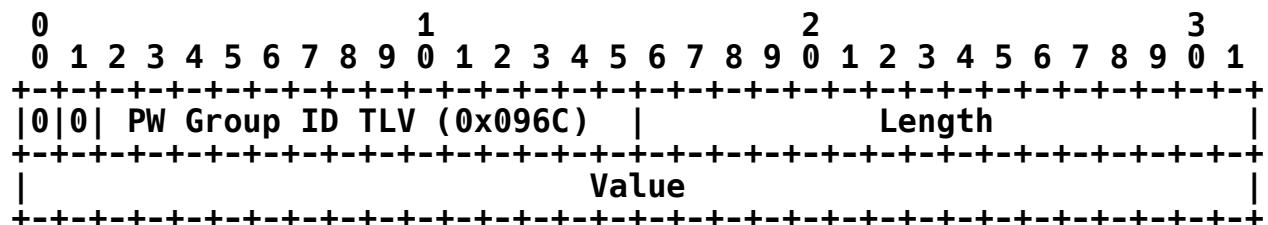
6.2.2.1. PW Interface Parameters TLV

This TLV MUST only be used when sending the Generalized Pwid FEC. It specifies interface-specific parameters. Specific parameters, 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.



A more detailed description of this field can be found in Section 6.4 ("Interface Parameter Sub-TLV").

6.2.2.2. PW Group ID TLV



The PW Group ID is an arbitrary 32-bit value that represents an arbitrary group of PWs. It is used to create group PWs; for example, a PW Group ID can be used as a port index and assigned to all PWs that lead to that port. Use of the PW Group ID enables a PE to send "wildcard" label withdrawals, or "wildcard" status Notification messages, to remote PEs upon physical port failure.

Note Well: The PW Group ID is different from and has no relation to the Attachment Group Identifier.

The PW Group ID TLV is not part of the FEC and will not be advertised except in the PW FEC advertisement. The advertising PE MAY use the wildcard withdraw semantics, but the remote PEs MUST implement support for wildcard messages. This TLV MUST only be used when sending the Generalized PWid FEC.

To issue a wildcard command (status or withdraw):

- Set the PW Info Length to 0 in the Generalized PWid FEC Element.
- Send only the PW Group ID TLV with the FEC (no AGI/SAII/TAII is sent).

6.2.3. Signaling Procedures

In order for PE1 to begin signaling PE2, PE1 must know the address of the remote PE2 and a TAI. This information may have been configured at PE1, or it may have been learned dynamically via some auto-discovery procedure.

The egress PE (PE1), which has knowledge of the ingress PE, initiates the setup by sending a Label Mapping message to the ingress PE (PE2). The Label Mapping message contains the FEC TLV, carrying the Generalized PWid FEC Element (type 0x81). The Generalized PWid FEC Element contains the AGI, SAI, and TAI information.

Next, when PE2 receives such a Label Mapping message, PE2 interprets the message as a request to set up a PW whose endpoint (at PE2) is the Forwarder identified by the TAI. From the perspective of the signaling protocol, exactly how PE2 maps AIs to Forwarders is a local matter. In some Virtual Private Wire Service (VPWS) provisioning models, the TAI might, for example, be a string that identifies a particular Attachment Circuit, such as "ATM3VPI4VCI5", or it might, for example, be a string, such as "Fred", that is associated by configuration with a particular Attachment Circuit. In Virtual Private LAN Service (VPLS), the AGI could be a VPN-id, identifying a particular VPLS instance.

If PE2 cannot map the TAI to one of its Forwarders, then PE2 sends a Label Release message to PE1, with a Status Code of "Unassigned/Unrecognized TAI", and the processing of the Label Mapping message is complete.

The FEC TLV sent in a Label Release message is the same as the FEC TLV received in the Label Mapping message being released (but without the interface parameter TLV). More generally, the FEC TLV is the

same in all LDP messages relating to the same PW. In a Label Release message, this means that the SAII is the remote peer's AII and the TAII is the sender's local AII.

If the Label Mapping message has a valid TAI, PE2 must decide whether to accept it. The procedures for so deciding will depend on the particular type of Forwarder identified by the TAI. Of course, the Label Mapping message may be rejected due to standard LDP error conditions as detailed in [RFC5036].

If PE2 decides to accept the Label Mapping message, then it has to make sure that a PW LSP is set up in the opposite (PE1-->PE2) direction. If it has already signaled for the corresponding PW LSP in that direction, nothing more needs to be done. Otherwise, it must initiate such signaling by sending a Label Mapping message to PE1. This is very similar to the Label Mapping message PE2 received, but the SAI and TAI are reversed.

Thus, a bidirectional PW consists of two LSPs, where the FEC of one has the SAII and TAII reversed with respect to the FEC of the other.

6.3. Signaling of Pseudowire Status

6.3.1. Use of Label Mapping Messages

The PEs MUST send Label Mapping messages to their peers as soon as the PW is configured and administratively enabled, regardless of the Attachment Circuit state. The PW label should not be withdrawn unless the operator administratively configures the pseudowire down (or the PW configuration is deleted entirely). Using the procedures outlined in this section, a simple label withdraw method MAY also be supported as a legacy means of signaling PW status and AC status. In any case, if the label-to-PW binding is not available, the PW MUST be considered in the down state.

Once the PW status negotiation procedures are completed, if they result in the use of the label withdraw method for PW status communication, and this method is not supported by one of the PEs, then that PE must send a Label Release message to its peer with the following error:

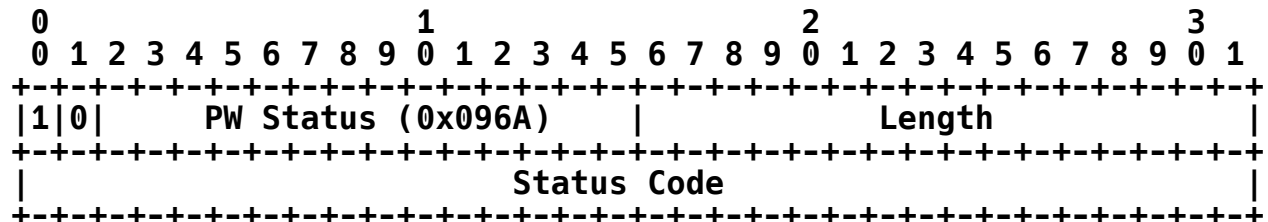
"Label Withdraw PW Status Method Not Supported"

If the label withdraw method for PW status communication is selected for the PW, it will result in the Label Mapping message being advertised only if the Attachment Circuit is active. The PW status signaling procedures described in this section MUST be fully implemented.

6.3.2. Signaling PW Status

The PE devices use an LDP TLV to indicate status to their remote peers. This PW Status TLV contains more information than the alternative simple Label Withdraw message.

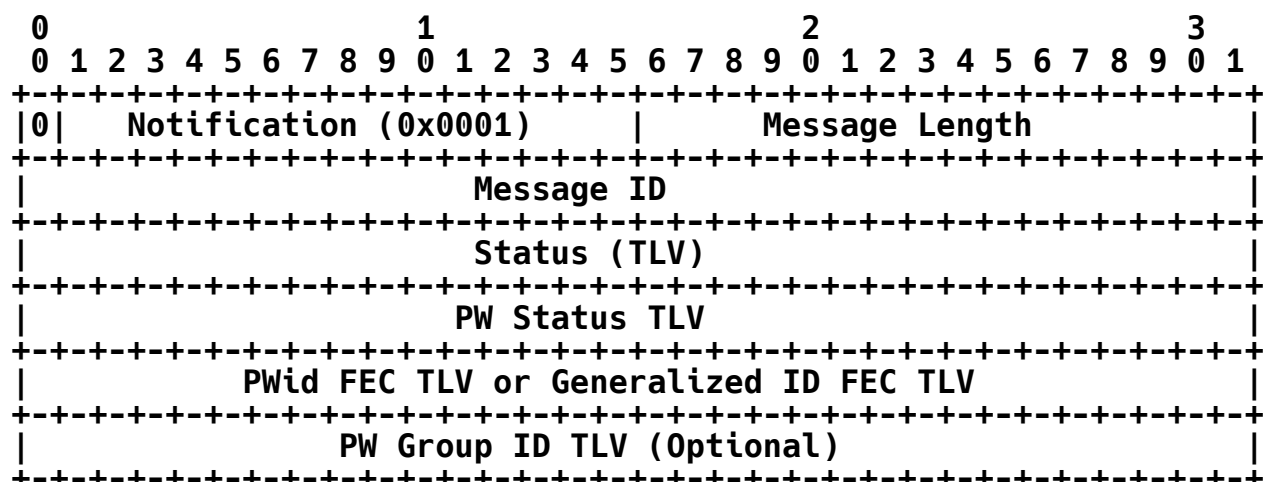
The format of the PW Status TLV is:



The status code is a 4-octet bit field as specified in "IANA Allocations for Pseudowire Edge to Edge Emulation (PWE3)" [RFC4446]. The Length field specifies the length of the Status Code field in octets (equal to 4).

Each bit in the Status Code field can be set individually to indicate more than a single failure at once. Each fault can be cleared by sending an appropriate Notification message in which the respective bit is cleared. The presence of the lowest bit (PW Not Forwarding) acts only as a generic failure indication when there is a link-down event for which none of the other bits apply.

The Status TLV is transported to the remote PW peer via the LDP Notification message as described in [RFC5036]. The format of the Notification message for carrying the PW Status is as follows:



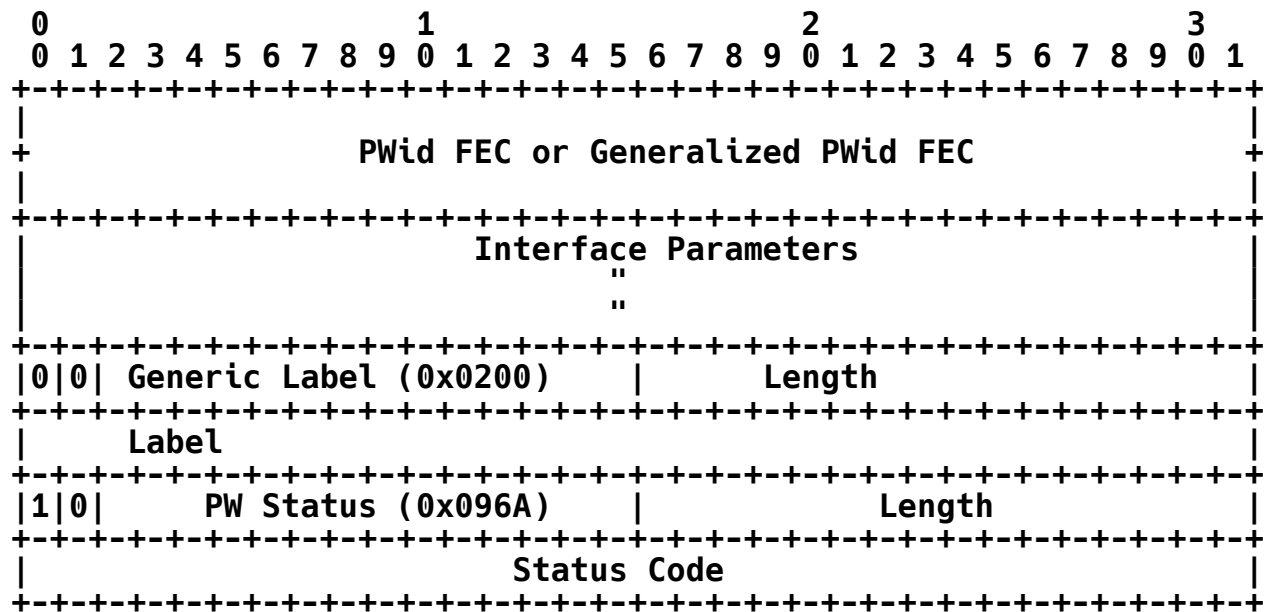
The Status TLV status code is set to 0x00000028, "PW status", to indicate that PW status follows. Since this notification does not refer to any particular message, the Message ID field is set to 0.

The PW FEC TLV SHOULD NOT include the Interface Parameter Sub-TLVs, as they are ignored in the context of this message. However, the PW FEC TLV MUST include the C-bit, where applicable, as it is part of the FEC. When a PE's Attachment Circuit encounters an error, use of the PW Notification message allows the PE to send a single "wildcard" status message, using a PW FEC TLV with only the Group ID set, to denote this change in status for all affected PW connections. This status message contains either the PW FEC TLV with only the Group ID set, or else it contains the Generalized FEC TLV with only the PW Group ID TLV.

As mentioned above, the Group ID field of the Pwid FEC Element, or the PW Group ID TLV used with the Generalized Pwid FEC Element, can be used to send a status notification for all arbitrary sets of PWs. This procedure is OPTIONAL, and if it is implemented, the LDP Notification message should be as follows: If the Pwid FEC Element is used, the PW information length field is set to 0, the PW ID field is not present, and the Interface Parameter Sub-TLVs are not present. If the Generalized FEC Element is used, the AGI, SAII, and TAI are not present, the PW information length field is set to 0, the PW Group ID TLV is included, and the PW Interface Parameters TLV is omitted. For the purpose of this document, this is called the "wildcard PW status notification procedure", and all PEs implementing this design are REQUIRED to accept such a Notification message but are not required to send it.

6.3.3. Pseudowire Status Negotiation Procedures

When a PW is first set up, the PEs MUST attempt to negotiate the usage of the PW Status TLV. This is accomplished as follows: A PE that supports the PW Status TLV MUST include it in the initial Label Mapping message following the PW FEC and the Interface Parameter Sub-TLVs. The PW Status TLV will then be used for the lifetime of the pseudowire. This is shown in the following diagram:



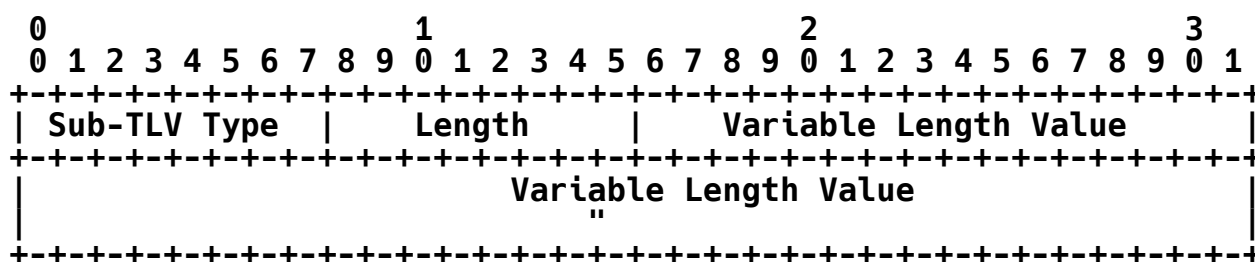
If a PW Status TLV is included in the initial Label Mapping message for a PW, then if the Label Mapping message from the remote PE for that PW does not include a PW Status TLV, or if the remote PE does not support the PW Status TLV, the PW will revert to the label withdraw method of signaling PW status. Note that if the PW Status TLV is not supported by the remote peer, the peer will automatically ignore it, since the I (ignore) bit is set in the TLV. The PW Status TLV, therefore, will not be present in the corresponding FEC advertisement from the remote LDP peer, which results in exactly the above behavior.

If the PW Status TLV is not present following the FEC TLV in the initial PW Label Mapping message received by a PE, then the PW Status TLV will not be used, and both PEs supporting the pseudowire will revert to the label withdraw procedure for signaling status changes.

If the negotiation process results in the usage of the PW Status TLV, then the actual PW status is determined by the PW Status TLV that was sent within the initial PW Label Mapping message. Subsequent updates of PW status are conveyed through the Notification message.

6.4. Interface Parameter Sub-TLV

This field specifies interface-specific parameters. When applicable, it **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 field structure is defined as follows:



The Length field is defined as the length of the interface parameter including the Sub-TLV Type and Length field itself. Processing of the interface parameters should continue when unknown interface parameters are encountered, and they MUST be silently ignored.

The Interface Parameter Sub-TLV Type values are specified in "IANA Allocations for Pseudowire Edge to Edge Emulation (PWE3)" [RFC4446].

- Interface MTU sub-TLV type

A 2-octet value indicating the MTU in octets. This is the Maximum Transmission Unit, excluding encapsulation overhead, of the egress packet interface that will be transmitting the decapsulated PDU that is received from the MPLS-enabled network. This parameter is applicable only to PWs transporting packets and is REQUIRED for these PW types. If this parameter does not match in both directions of a specific PW, that PW MUST NOT be enabled.

- Optional Interface Description string sub-TLV type

This arbitrary, and OPTIONAL, interface description string is used to send a human-readable administrative string describing the interface to the remote PE. This parameter is OPTIONAL and is applicable to all PW types. The interface description parameter string length is variable and can be from 0 to 80 octets. Human-readable text MUST be provided in the UTF-8 charset using the Default Language [RFC2277].

6.5. LDP Label Withdrawal Procedures

As mentioned above, the Group ID field of the Pwid FEC Element, or the PW Group ID TLV used with the Generalized Pwid FEC Element, can be used to withdraw all PW labels associated with a particular PW group. This procedure is OPTIONAL, and if it is implemented, the LDP Label Withdraw message should be as follows: If the Pwid FEC Element is used, the PW information length field is set to 0, the PW ID field is not present, the Interface Parameter Sub-TLVs are not present, and the Label TLV is not present. If the Generalized FEC Element is used, the AGI, SAI, and TAI are not present, the PW information

length field is set to 0, the PW Group ID TLV is included, the PW Interface Parameters TLV is not present, and the Label TLV is not present. For the purpose of this document, this is called the "wildcard withdraw procedure", and all PEs implementing this design are REQUIRED to accept such withdraw messages but are not required to send it. Note that the PW Group ID TLV only applies to PWs using the Generalized ID FEC Element, while the Group ID only applies to PWid FEC Element.

The Interface Parameter Sub-TLVs, or TLV, MUST NOT be present in any LDP PW Label Withdraw or Label Release message. A wildcard Label Release message MUST include only the Group ID or PW Group ID TLV. A Label Release message initiated by a PE router must always include the PW ID.

7. Control Word

7.1. PW Types for Which the Control Word Is REQUIRED

The Label Mapping messages that are sent in order to set up these PWs MUST have C=1. When a Label Mapping message for a PW of one of these types is received and C=0, a Label Release message MUST be sent, with an "Illegal C-bit" status code. In this case, the PW will not be enabled.

7.2. PW Types for Which the Control Word Is NOT Mandatory

If a system is capable of sending and receiving the control word on PW types for which the control word is not mandatory, then each such PW endpoint MUST be configurable with a parameter that specifies whether the use of the control word is PREFERRED or NOT PREFERRED. For each PW, there MUST be a default value of this parameter. This specification does NOT state what the default value should be.

If a system is NOT capable of sending and receiving the control word on PW types for which the control word is not mandatory, then it behaves exactly as if it were configured for the use of the control word to be NOT PREFERRED.

If a Label Mapping message for the PW has already been received but no Label Mapping message for the PW has yet been sent, then the procedure is as follows:

- i. If the received Label Mapping message has C=0, send a Label Mapping message with C=0; the control word is not used.

- ii. If the received Label Mapping message has C=1, and the PW is locally configured such that the use of the control word is preferred, then send a Label Mapping message with C=1; the control word is used.
- iii. If the received Label Mapping message has C=1, and the PW is locally configured such that the use of the control word is not preferred or the control word is not supported, then act as if no Label Mapping message for the PW had been received (i.e., proceed to the next paragraph).

If a Label Mapping message for the PW has not already been received (or if the received Label Mapping message had C=1 and either local configuration says that the use of the control word is not preferred or the control word is not supported), then send a Label Mapping message in which the C-bit is set to correspond to the locally configured preference for use of the control word. (That is, set C=1 if locally configured to prefer the control word, and set C=0 if locally configured to prefer not to use the control word or if the control word is not supported).

The next action depends on what control message is next received for that PW. The possibilities are as follows:

- i. A Label Mapping message with the same C-bit value as specified in the Label Mapping message that was sent. PW setup is now complete, and the control word is used if C=1 but is not used if C=0.
- ii. A Label Mapping message with C=1, but the Label Mapping message that was sent has C=0. In this case, ignore the received Label Mapping message and continue to wait for the next control message for the PW.
- iii. A Label Mapping message with C=0, but the Label Mapping message that was sent has C=1. In this case, send a Label Withdraw message with a "Wrong C-bit" status code, followed by a Label Mapping message that has C=0. PW setup is now complete, and the control word is not used.
- iv. A Label Withdraw message with the "Wrong C-bit" status code. Treat as a normal Label Withdraw message, but do not respond. Continue to wait for the next control message for the PW.

If at any time after a Label Mapping message has been received a corresponding Label Withdraw or Release is received, the action taken is the same as for any Label Withdraw or Release messages that might be received at any time.

If both endpoints prefer the use of the control word, this procedure will cause it to be used. If either endpoint prefers not to use the control word or does not support the control word, this procedure will cause it not to be used. If one endpoint prefers to use the control word but the other does not, the one that prefers not to use it has no extra protocol to execute; it just waits for a Label Mapping message that has C=0.

7.3. Control-Word Renegotiation by Label Request Message

It is possible that after the PW C-bit negotiation procedure described above is complete, the local PE is re-provisioned with a different control word preference. Therefore, once the control-word negotiation procedures are complete, the procedure can be restarted as follows:

- i. If the local PE previously sent a Label Mapping message, it MUST send a Label Withdraw message to the remote PE and wait until it has received a Label Release message from the remote PE.
- ii. The local PE MUST send a Label Release message to the remote PE for the specific label associated with the FEC that was advertised for this specific PW. Note: The above-mentioned steps of the Label Release message and Label Withdraw message are not required to be executed in any specific sequence.
- iii. The local PE MUST send a Label Request message to the peer PE and then MUST wait until it receives a Label Mapping message containing the remote PE's currently configured preference for use of the control word.

Once the remote PE has successfully processed the Label Withdraw message and Label Release messages, it will reset the C-bit negotiation state machine and its use of the control word with the locally configured preference.

From this point on, the local and remote PEs will follow the C-bit negotiation procedures defined in the previous section.

The above C-bit renegotiation process SHOULD NOT be interrupted until it is completed, or unpredictable results might occur.

7.4. Sequencing Considerations

In the case where the router considers the sequence number field in the control word, it is important to note the following details when advertising labels.

7.4.1. Label Advertisements

After a label has been withdrawn by the output router and/or released by the input router, care must be taken not to advertise (reuse) the same released label until the output router can be reasonably certain that old packets containing the released label no longer persist in the MPLS-enabled network.

This precaution is required to prevent the imposition router from restarting packet forwarding with a sequence number of 1 when it receives a Label Mapping message that binds the same FEC to the same label if there are still older packets in the network with a sequence number between 1 and 32768. For example, if there is a packet with sequence number= n , where n is in the interval $[1, 32768]$ traveling through the network, it would be possible for the disposition router to receive that packet after it re-advertises the label. Since the label has been released by the imposition router, the disposition router SHOULD be expecting the next packet to arrive with a sequence number of 1. Receipt of a packet with a sequence number equal to n will result in n packets potentially being rejected by the disposition router until the imposition router imposes a sequence number of $n+1$ into a packet. Possible methods to avoid this are for the disposition router always to advertise a different PW label, or for the disposition router to wait for a sufficient time before attempting to re-advertise a recently released label. This is only an issue when sequence number processing is enabled at the disposition router.

7.4.2. Label Release

In situations where the imposition router wants to restart forwarding of packets with sequence number 1, the router shall 1) send to the disposition router a Label Release message, and 2) send to the disposition router a Label Request message. When sequencing is supported, advertisement of a PW label in response to a Label Request message MUST also consider the issues discussed in Section 7.4.1 ("Label Advertisements").

8. IANA Considerations

8.1. LDP TLV TYPE

This document uses several new LDP TLV types; IANA already maintains a registry titled "TLV Type Name Space", defined by RFC 5036. The following values have been assigned from said registry:

TLV Type	Description
=====	
0x096A	PW Status TLV
0x096B	PW Interface Parameters TLV
0x096C	PW Group ID TLV

8.2. LDP Status Codes

This document uses several new LDP status codes; IANA already maintains a registry titled "Status Code Name Space", defined by RFC 5036. The following values have been assigned:

Range/Value	E	Description	Reference
-----	----	-----	-----
0x00000024	0	Illegal C-Bit	[RFC8077]
0x00000025	0	Wrong C-Bit	[RFC8077]
0x00000026	0	Incompatible bit-rate	[RFC8077]
0x00000027	0	CEP-TDM mis-configuration	[RFC8077]
0x00000028	0	PW Status	[RFC8077]
0x00000029	0	Unassigned/Unrecognized TAI	[RFC8077]
0x0000002A	0	Generic Misconfiguration Error	[RFC8077]
0x0000002B	0	Label Withdraw PW Status	[RFC8077]
		Method Not Supported	

8.3. FEC Type Name Space

This document uses two new FEC element types, 0x80 and 0x81, from the registry "Forwarding Equivalence Class (FEC) Type Name Space" for the Label Distribution Protocol (LDP) [RFC5036].

9. Security Considerations

This document specifies the LDP extensions that are needed for setting up and maintaining pseudowires. The purpose of setting up pseudowires is to enable Layer 2 frames to be encapsulated in MPLS and transmitted from one end of a pseudowire to the other. Therefore, we address the security considerations for both the data plane and the control plane.

9.1. Data-Plane Security

With regard to the security of the data plane, the following areas must be considered:

- MPLS PDU inspection
- MPLS PDU spoofing
- MPLS PDU alteration
- MPLS PSN protocol security
- Access Circuit security
- Denial-of-service prevention on the PE routers

When an MPLS PSN is used to provide pseudowire service, there is a perception that security must be at least equal to the currently deployed Layer 2 native protocol networks that the MPLS/PW network combination is emulating. This means that the MPLS-enabled network **SHOULD** be isolated from outside packet insertion in such a way that it **SHOULD NOT** be possible to insert an MPLS packet into the network directly. To prevent unwanted packet insertion, it is also important to prevent unauthorized physical access to the PSN, as well as unauthorized administrative access to individual network elements.

As mentioned above, an MPLS-enabled network should not accept MPLS packets from its external interfaces (i.e., interfaces to CE devices or to other providers' networks) unless the top label of the packet was legitimately distributed to the system from which the packet is being received. If the packet's incoming interface leads to a different Service Provider (SP) (rather than to a customer), an appropriate trust relationship must also be present, including the trust that the other SP also provides appropriate security measures.

The three main security problems faced when using an MPLS-enabled network to transport PWs are spoofing, alteration, and inspection. First, there is a possibility that the PE receiving PW PDUs will get a PDU that appears to be from the PE transmitting the PW into the PSN but that was not actually transmitted by the PE originating the PW. (That is, the specified encapsulations do not by themselves enable the decapsulator to authenticate the encapsulator.) A second problem is the possibility that the PW PDU will be altered between the time it enters the PSN and the time it leaves the PSN (i.e., the specified encapsulations do not by themselves assure the decapsulator of the packet's integrity.) A third problem is the possibility that the PDU's contents will be seen while the PDU is in transit through the PSN (i.e., the specification encapsulations do not ensure privacy.) How significant these issues are in practice depends on the security requirements of the applications whose traffic is being sent through the tunnel and how secure the PSN itself is.

9.2. Control-Plane Security

General security considerations with regard to the use of LDP are specified in Section 5 of [RFC5036]. Those considerations also apply to the case where LDP is used to set up pseudowires.

A pseudowire connects two Attachment Circuits. It is important to make sure that LDP connections are not arbitrarily accepted from anywhere, or else a local Attachment Circuit might get connected to an arbitrary remote Attachment Circuit. Therefore, an incoming LDP session request **MUST NOT** be accepted unless its IP source address is known to be the source of an "eligible" LDP peer. The set of eligible peers could be preconfigured (either as a list of IP addresses or as a list of address/mask combinations), or it could be discovered dynamically via an auto-discovery protocol that is itself trusted. (Obviously, if the auto-discovery protocol were not trusted, the set of eligible peers it produces could not be trusted.)

Even if an LDP connection request appears to come from an eligible peer, its source address may have been spoofed. Therefore, some means of preventing source address spoofing must be in place. For example, if all the eligible peers are in the same network, source address filtering at the border routers of that network could eliminate the possibility of source address spoofing.

The LDP MD5 authentication key option, as described in Section 2.9 of [RFC5036], **MUST** be implemented, and for a greater degree of security, it must be used. This provides integrity and authentication for the LDP messages and eliminates the possibility of source address spoofing. Use of the MD5 option does not provide privacy, but privacy of the LDP control messages is not usually considered important. As the MD5 option relies on the configuration of pre-shared keys, it does not provide much protection against replay attacks. In addition, its reliance on pre-shared keys may make it very difficult to deploy when the set of eligible neighbors is determined by an auto-configuration protocol.

When the Generalized PWid FEC Element is used, it is possible that a particular LDP peer may be one of the eligible LDP peers but may not be the right one to connect to the particular Attachment Circuit identified by the particular instance of the Generalized PWid FEC Element. However, given that the peer is known to be one of the eligible peers (as discussed above), this would be the result of a configuration error rather than a security problem. Nevertheless, it may be advisable for a PE to associate each of its local Attachment Circuits with a set of eligible peers rather than have just a single set of eligible peers associated with the PE as a whole.

10. Interoperability and Deployment

Section 2.2 of [RFC6410] specifies four requirements that an Internet Standard must meet. This section documents how this document meets those requirements.

The pseudowire technology was first deployed in 2001 and has been widely deployed by many carriers. [RFC7079] documents the results of a survey of PW implementations with specific emphasis on control-word usage. [EANTC] documents a public multi-vendor interoperability test of MPLS and Carrier Ethernet equipment, which included testing of Ethernet, ATM, and TDM pseudowires.

The errata against [RFC4447] are generally editorial in nature and have been addressed in this document.

All features in this specification have been implemented by multiple vendors.

No IPR disclosures have been made to the IETF related to this document, to RFCs 4447 or 6723, or to the Internet-Drafts that resulted in RFCs 4447 and 6723.

11. References

11.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC5036] Andersson, L., Ed., Minei, I., Ed., and B. Thomas, Ed., "LDP Specification", RFC 5036, DOI 10.17487/RFC5036, October 2007, <<http://www.rfc-editor.org/info/rfc5036>>.
- [RFC3032] Rosen, E., Tappan, D., Fedorkow, G., Rekhter, Y., Farinacci, D., Li, T., and A. Conta, "MPLS Label Stack Encoding", RFC 3032, DOI 10.17487/RFC3032, January 2001, <<http://www.rfc-editor.org/info/rfc3032>>.
- [RFC4446] Martini, L., "IANA Allocations for Pseudowire Edge to Edge Emulation (PWE3)", BCP 116, RFC 4446, DOI 10.17487/RFC4446, April 2006, <<http://www.rfc-editor.org/info/rfc4446>>.

- [RFC7358] Raza, K., Boutros, S., Martini, L., and N. Leymann, "Label Advertisement Discipline for LDP Forwarding Equivalence Classes (FECs)", RFC 7358, DOI 10.17487/RFC7358, October 2014, <<http://www.rfc-editor.org/info/rfc7358>>.

11.2. Informative References

- [RFC2277] Alvestrand, H., "IETF Policy on Character Sets and Languages", BCP 18, RFC 2277, DOI 10.17487/RFC2277, January 1998, <<http://www.rfc-editor.org/info/rfc2277>>.
- [RFC3985] Bryant, S., Ed., and P. Pate, Ed., "Pseudo Wire Emulation Edge-to-Edge (PWE3) Architecture", RFC 3985, DOI 10.17487/RFC3985, March 2005, <<http://www.rfc-editor.org/info/rfc3985>>.
- [RFC4842] Malis, A., Pate, P., Cohen, R., Ed., and D. Zelig, "Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) Circuit Emulation over Packet (CEP)", RFC 4842, DOI 10.17487/RFC4842, April 2007, <<http://www.rfc-editor.org/info/rfc4842>>.
- [RFC4553] Vainshtein, A., Ed., and YJ. Stein, Ed., "Structure-Agnostic Time Division Multiplexing (TDM) over Packet (SAToP)", RFC 4553, DOI 10.17487/RFC4553, June 2006, <<http://www.rfc-editor.org/info/rfc4553>>.
- [RFC4619] Martini, L., Ed., Kawa, C., Ed., and A. Malis, Ed., "Encapsulation Methods for Transport of Frame Relay over Multiprotocol Label Switching (MPLS) Networks", RFC 4619, DOI 10.17487/RFC4619, September 2006, <<http://www.rfc-editor.org/info/rfc4619>>.
- [RFC4717] Martini, L., Jayakumar, J., Bocci, M., El-Aawar, N., Brayley, J., and G. Koleyni, "Encapsulation Methods for Transport of Asynchronous Transfer Mode (ATM) over MPLS Networks", RFC 4717, DOI 10.17487/RFC4717, December 2006, <<http://www.rfc-editor.org/info/rfc4717>>.
- [RFC4618] Martini, L., Rosen, E., Heron, G., and A. Malis, "Encapsulation Methods for Transport of PPP/High-Level Data Link Control (HDLC) over MPLS Networks", RFC 4618, DOI 10.17487/RFC4618, September 2006, <<http://www.rfc-editor.org/info/rfc4618>>.

- [RFC4448] Martini, L., Ed., Rosen, E., El-Aawar, N., and G. Heron, "Encapsulation Methods for Transport of Ethernet over MPLS Networks", RFC 4448, DOI 10.17487/RFC4448, April 2006, <<http://www.rfc-editor.org/info/rfc4448>>.
- [RFC4447] Martini, L., Ed., Rosen, E., El-Aawar, N., Smith, T., and G. Heron, "Pseudowire Setup and Maintenance Using the Label Distribution Protocol (LDP)", RFC 4447, DOI 10.17487/RFC4447, April 2006, <<http://www.rfc-editor.org/info/rfc4447>>.
- [RFC6410] Housley, R., Crocker, D., and E. Burger, "Reducing the Standards Track to Two Maturity Levels", BCP 9, RFC 6410, DOI 10.17487/RFC6410, October 2011, <<http://www.rfc-editor.org/info/rfc6410>>.
- [RFC6723] Jin, L., Ed., Key, R., Ed., Delord, S., Nadeau, T., and S. Boutros, "Update of the Pseudowire Control-Word Negotiation Mechanism", RFC 6723, DOI 10.17487/RFC6723, September 2012, <<http://www.rfc-editor.org/info/rfc6723>>.
- [RFC7079] Del Regno, N., Ed., and A. Malis, Ed., "The Pseudowire (PW) and Virtual Circuit Connectivity Verification (VCCV) Implementation Survey Results", RFC 7079, DOI 10.17487/RFC7079, November 2013, <<http://www.rfc-editor.org/info/rfc7079>>.
- [ANSI] American National Standards Institute, "Telecommunications - Synchronous Optical Network (SONET) - Basic Description Including Multiplex Structures, Rates, and Formats", ANSI T1.105, October 1995.
- [ITU] International Telecommunications Union, "Network node interface for the synchronous digital hierarchy (SDH)", ITU-T Recommendation G.707, May 1996.
- [EANTC] European Advanced Networking Test Center, "MPLS and Carrier Ethernet: Service - Connect - Transport. Public Multi-Vendor Interoperability Test", February 2009.

Acknowledgments

The authors wish to acknowledge the contributions of Vach Kompella, Vanson Lim, Wei Luo, Himanshu Shah, and Nick Weeds. The authors wish to also acknowledge the contribution of the authors of RFC 6723, whose work has been incorporated in this document: Lizhong Jin, Raymond Key, Simon Delord, Tom Nadeau, and Sami Boutros.

Contributors

The following individuals were either authors or contributing authors for RFC 4447. They are listed here in recognition of their work on that document.

Nasser El-Aawar
Level 3 Communications, LLC.
1025 Eldorado Blvd.
Broomfield, CO 80021
United States of America

Email: nna@level3.net

Eric C. Rosen
Cisco Systems, Inc.
1414 Massachusetts Avenue
Boxborough, MA 01719
United States of America

Email: erosen@cisco.com

Dan Tappan
Cisco Systems, Inc.
1414 Massachusetts Avenue
Boxborough, MA 01719
United States of America

Email: tappan@cisco.com

Toby Smith
Google
6425 Penn Ave. #700
Pittsburgh, PA 15206
United States of America

Email: tob@google.com

Dimitri Vlachos
Riverbed Technology

Email: dimitri@riverbed.com

Jayakumar Jayakumar
Cisco Systems Inc.
3800 Zanker Road, MS-SJ02/2
San Jose, CA 95134
United States of America

Email: jjayakum@cisco.com

Alex Hamilton,
Cisco Systems Inc.
485 East Tasman Drive, MS-SJC07/3
San Jose, CA 95134
United States of America

Email: tahamilt@cisco.com

Steve Vogelsang
ECI Telecom
Omega Corporate Center
1300 Omega Drive
Pittsburgh, PA 15205
United States of America

Email: stephen.vogelsang@ecitele.com

John Shirron
ECI Telecom
Omega Corporate Center
1300 Omega Drive
Pittsburgh, PA 15205
United States of America

Email: john.shirron@ecitele.com

Andrew G. Malis
Verizon
60 Sylvan Rd.
Waltham, MA 02451
United States of America

Email: andrew.g.malis@verizon.com

Vinai Sirkay
Reliance Infocomm
Dhirubai Ambani Knowledge City
Navi Mumbai 400 709
India

Email: vinai@sirkay.com

Vasile Radoaca
Nortel Networks
600 Technology Park
Billerica MA 01821
United States of America

Email: vasile@nortelnetworks.com

Chris Liljenstolpe
149 Santa Monica Way
San Francisco, CA 94127
United States of America

Email: ietf@cdl.asgaard.org

Dave Cooper
Global Crossing
960 Hamlin Court
Sunnyvale, CA 94089
United States of America

Email: dcooper@gblix.net

Kireeti Kompella
Juniper Networks
1194 N. Mathilda Ave
Sunnyvale, CA 94089
United States of America

Email: kireeti@juniper.net

Authors' Addresses

Luca Martini (editor)
Cisco Systems, Inc.
1899 Wynkoop Street, Suite 600
Denver, CO 80202
United States of America

Email: lmartini@monoski.com

Giles Heron (editor)
Cisco Systems
10 New Square
Bedfont Lakes
Feltham
Middlesex
TW14 8HA
United Kingdom

Email: giheron@cisco.com