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# Pseudowire (PW) Operations, Administration, and Maintenance (OAM) Message Mapping

## Abstract

This document specifies the mapping and notification of defect states between a pseudowire (PW) and the Attachment Circuits (ACs) of the end-to-end emulated service. It standardizes the behavior of Provider Edges (PEs) with respect to PW and AC defects. It addresses ATM, Frame Relay, Time Division Multiplexing (TDM), and Synchronous Optical Network / Synchronous Digital Hierarchy (SONET/SDH) PW services, carried over MPLS, MPLS/IP, and Layer 2 Tunneling Protocol version 3/IP (L2TPv3/IP) Packet Switched Networks (PSNs).

## 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 5741.

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/rfc6310.

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## 1. Introduction

This document specifies the mapping and notification of defect states between a pseudowire and the Attachment Circuits (AC) of the end-to-end emulated service. It covers the case where the ACs and the PWs are of the same type in accordance to the Pseudowire Emulation Edge-to-Edge (PWE3) architecture [RFC3985] such that a homogeneous PW service can be constructed.

This document is motivated by the requirements put forth in [RFC4377] and [RFC3916]. Its objective is to standardize the behavior of PEs with respect to defects on PWs and ACs, so that there is no ambiguity about the alarms generated and consequent actions undertaken by PEs in response to specific failure conditions.

This document addresses PWs over MPLS, MPLS/IP, L2TPv3/IP PSNs, ATM, Frame Relay, TDM, and SONET/SDH PW native services. Due to its unique characteristics, the Ethernet PW service is covered in a separate document [Eth-OAM-Inter].

This document provides procedures for PWs set up using Label Distribution Protocol (LDP) [RFC4447] or L2TPv3 [RFC3931] control protocols. While we mention fault reporting options for PWs established by other means (e.g., by static configuration or via BGP), we do not provide detailed procedures for such cases.

This document is scoped only to single segment PWs. The mechanisms described in this document could also be applied to terminating PEs (T-PEs) for multi-segment PWs (MS-PWs) ([RFC5254]). Section 10 of [RFC6073] details procedures for generating or relaying PW status by a switching PE (S-PE).

## 2. Abbreviations and Conventions

### 2.1. Abbreviations

| | |
|---|---|
| AAL5 | ATM Adaptation Layer 5 |
| AIS | Alarm Indication Signal |
| AC | Attachment Circuit |
| ATM | Asynchronous Transfer Mode |
| AVP | Attribute Value Pair |
| BFD | Bidirectional Forwarding Detection |
| CC | Continuity Check |
| CDN | Call Disconnect Notify |
| CE | Customer Edge |
| CV | Connectivity Verification |
| DBA | Dynamic Bandwidth Allocation |
| DLC | Data Link Connection |
| FDI | Forward Defect Indication |
| FR | Frame Relay |
| FRBS | Frame Relay Bearer Service |
| ICMP | Internet Control Message Protocol |
| LB | Loopback |
| LCCE | L2TP Control Connection Endpoint |
| LDP | Label Distribution Protocol |
| LSP | Label Switched Path |
| L2TP | Layer 2 Tunneling Protocol |
| MPLS | Multiprotocol Label Switching |
| NE | Network Element |
| NS | Native Service |
| OAM | Operations, Administration, and Maintenance |
| PE | Provider Edge |
| PSN | Packet Switched Network |
| PW | Pseudowire |
| RDI | Reverse Defect Indication |
| PDU | Protocol Data Unit |
| SDH | Synchronous Digital Hierarchy |
| SDU | Service Data Unit |
| SONET | Synchronous Optical Network |
| TDM | Time Division Multiplexing |
| TLV | Type Length Value |
| VCC | Virtual Channel Connection |
| VCCV | Virtual Connection Connectivity Verification |
| VPC | Virtual Path Connection |

## 2.2. Conventions

The words "defect" and "fault" are used interchangeably to mean any condition that negatively impacts forwarding of user traffic between the CE endpoints of the PW service.

The words "defect notification" and "defect indication" are used interchangeably to mean any OAM message generated by a PE and sent to other nodes in the network to convey the defect state local to this PE.

The PW can be carried over three types of Packet Switched Networks (PSNs). An "MPLS PSN" makes use of MPLS Label Switched Paths [RFC3031] as the tunneling technology to forward the PW packets. An "MPLS/IP PSN" makes use of MPLS-in-IP tunneling [RFC4023], with an MPLS shim header used as PW demultiplexer. An "L2TPv3/IP PSN" makes use of L2TPv3/IP [RFC3931] as the tunneling technology with the L2TPv3/IP Session ID as the PW demultiplexer.

If LSP-Ping [RFC4379] is run over a PW as described in [RFC5085], it will be referred to as "VCCV-Ping". If BFD is run over a PW as described in [RFC5885], it will be referred to as "VCCV-BFD".

While PWs are inherently bidirectional entities, defects and OAM messaging are related to a specific traffic direction. We use the terms "upstream" and "downstream" to identify PEs in relation to the traffic direction. A PE is upstream for the traffic it is forwarding and is downstream for the traffic it is receiving.

We use the terms "local" and "remote" to identify native service networks and ACs in relation to a specific PE. The local AC is attached to the PE in question, while the remote AC is attached to the PE at the other end of the PW.

A "transmit defect" is any defect that uniquely impacts traffic sent or relayed by the observing PE. A "receive defect" is any defect that impacts information transfer to the observing PE. Note that a receive defect also impacts traffic meant to be relayed, and thus can be considered to incorporate two defect states. Thus, when a PE enters both receive and transmit defect states of a PW service, the receive defect takes precedence over the transmit defect in terms of the consequent actions.

A "forward defect indication" (FDI) is sent in the same direction as the user traffic impacted by the defect. A "reverse defect indication" (RDI) is sent in the direction opposite to that of the impacted traffic.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

## 3. Reference Model and Defect Locations

Figure 1 illustrates the PWE3 network reference model with an indication of the possible defect locations. This model will be referenced in the remainder of this document for describing the OAM procedures.

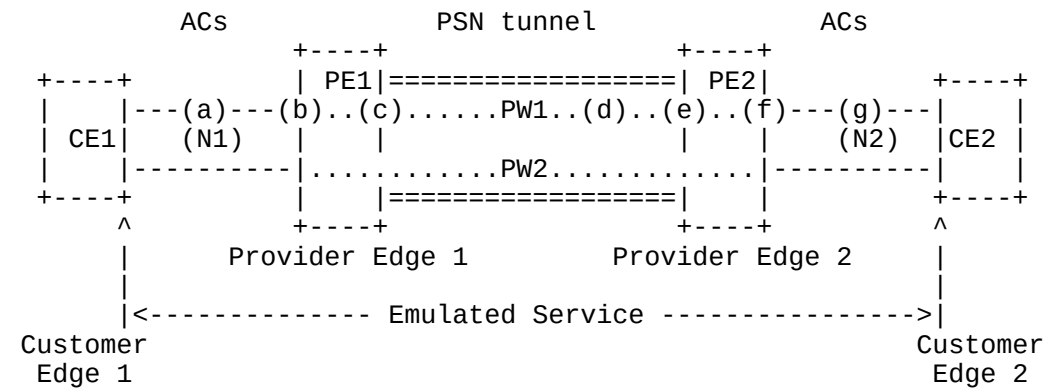


Figure 1: PWE3 Network Defect Locations

The procedures will be described in this document from the viewpoint of PE1, so that N1 is the local native service network and N2 is the remote native service network. PE2 will typically implement the same functionality. Note that PE1 is the upstream PE for traffic originating in the local NS network N1, while it is the downstream PE for traffic originating in the remote NS network N2.

The following is a brief description of the defect locations:

a. Defect in NS network N1. This covers any defect in network N1 (including any CE1 defect) that impacts all or some ACs attached to PE1, and is thus a local AC defect. The defect is conveyed to PE1 and to NS network N2 using NS specific OAM defect indications.

b. Defect on a PE1 AC interface (another local AC defect).

c. Defect on a PE1 PSN interface.

d. Defect in the PSN network. This covers any defect in the PSN that impacts all or some PWs between PE1 and PE2. The defect is conveyed to the PE using a PSN and/or a PW specific OAM defect

indication. Note that both data plane defects and control plane defects must be taken into consideration. Although control messages may follow a different path than PW data plane traffic, a control plane defect may affect the PW status.

e. Defect on a PE2 PSN interface.

f. Defect on a PE2 AC interface (a remote AC defect).

g. Defect in NS network N2 (another remote AC defect). This covers any defect in N2 (including any CE2 defect) that impacts all or a subset of ACs attached to PE2. The defect is conveyed to PE2 and to NS network N1 using the NS OAM defect indication.

## 4. Abstract Defect States

PE1 must track four defect states that reflect the observed states of both directions of the PW service on both the AC and the PW sides. Defects may impact one or both directions of the PW service.

The observed state is a combination of defects directly detected by PE1 and defects of which it has been made aware via notifications.

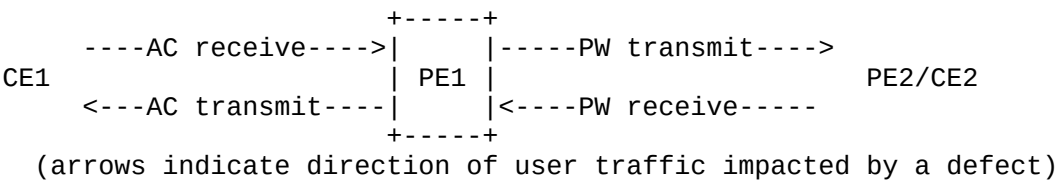


Figure 2: Receive and Transmit Defect States

PE1 will directly detect or be notified of AC receive or PW receive defects as they occur upstream of PE1 and impact traffic being sent to PE1. As a result, PE1 enters the AC or PW receive defect state.

In Figure 2, PE1 may be notified of a receive defect in the AC by receiving a forward defect indication, e.g., ATM AIS, from CE1 or an intervening network. This defect notification indicates that user traffic sent by CE1 may not be received by PE1 due to a defect. PE1 can also directly detect an AC receive defect if it resulted from a failure of the receive side in the local port or link over which the AC is configured.

Similarly, PE1 may detect or be notified of a receive defect in the PW by receiving a forward defect indication from PE2. If the PW status TLV is used for fault notification, this message will indicate a Local PSN-facing PW (egress) Transmit Fault or a Local AC (ingress)

Receive Fault at PE2, as described in Section 6.1.1. This defect notification indicates that user traffic sent by CE2 may not be received by PE1 due to a defect. As a result, PE1 enters the PW receive defect state.

Note that a forward defect indication is sent in the same direction as the user traffic impacted by the defect.

Generally, a PE cannot detect transmit defects by itself and will therefore need to be notified of AC transmit or PW transmit defects by other devices.

In Figure 2, PE1 may be notified of a transmit defect in the AC by receiving a reverse defect indication, e.g., ATM RDI, from CE1. This defect relates to the traffic sent by PE1 to CE1 on the AC.

Similarly, PE1 may be notified of a transmit defect in the PW by receiving a reverse defect indication from PE2. If PW status is used for fault notification, this message will indicate a Local PSN-facing PW (ingress) Receive Fault or a Local Attachment Circuit (egress) Transmit Fault at PE2, as described in Section 6.1.1. This defect impacts the traffic sent by PE1 to CE2. As a result, PE1 enters the PW transmit defect state.

Note that a reverse defect indication is sent in the reverse direction to the user traffic impacted by the defect.

The procedures outlined in this document define the entry and exit criteria for each of the four states with respect to the set of PW services within the document scope and the consequent actions that PE1 must perform.

When a PE enters both receive and transmit defect states related to the same PW service, then the receive defect takes precedence over transmit defect in terms of the consequent actions.

## 5. OAM Modes

A homogeneous PW service forwards packets between an AC and a PW of the same type. It thus implements both NS OAM and PW OAM mechanisms. PW OAM defect notification messages are described in Section 6.1. NS OAM messages are described in Appendix A.

This document defines two different OAM modes, the distinction being the method of mapping between the NS and PW OAM defect notification messages.

The first mode, illustrated in Figure 3, is called the "single emulated OAM loop" mode. Here, a single end-to-end NS OAM loop is emulated by transparently passing NS OAM messages over the PW. Note that the PW OAM is shown outside the PW in Figure 3, as it is transported in LDP messages or in the associated channel, not inside the PW itself.

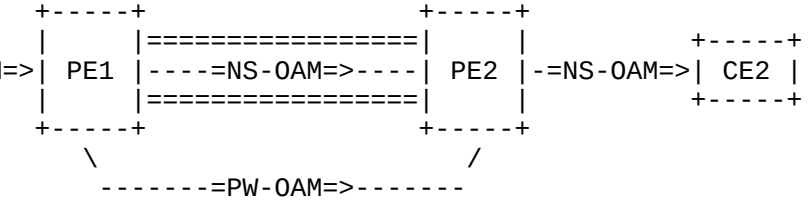


Figure 3: Single Emulated OAM Loop Mode

The single emulated OAM loop mode implements the following behavior:

a. The upstream PE (PE1) MUST transparently relay NS OAM messages over the PW.

b. The upstream PE MUST signal local defects affecting the AC using a NS defect notification message sent over the PW. In the case that it is not possible to generate NS OAM messages (e.g., because the defect interferes with NS OAM message generation), the PE MUST signal local defects affecting the AC using a PW defect notification message.

c. The upstream PE MUST signal local defects affecting the PW using a PW defect notification message.

d. The downstream PE (PE2) MUST insert NS defect notification messages into its local AC when it detects or is notified of a defect in the PW or remote AC. This includes translating received PW defect notification messages into NS defect notification messages for defects signaled by the upstream PE.

The single emulated OAM loop mode is suitable for PW services that have a widely deployed NS OAM mechanism. This document specifies the use of this mode for ATM PW, TDM PW, and Circuit Emulation over Packet (CEP) PW services. It is the default mode of operation for all ATM cell mode PW services and the only mode specified for CEP and Structure-Agnostic TDM over Packets / Circuit Emulation Service over Packet Switched Network (SAToP/CESoPSN) TDM PW services. It is optional for AAL5 PDU transport and AAL5 SDU transport modes.

The second OAM mode operates three OAM loops joined at the AC/PW boundaries of the PEs. This is referred to as the "coupled OAM loops" mode and is illustrated in Figure 4. Note that in contrast to Figure 3, NS OAM messages are never carried over the PW.

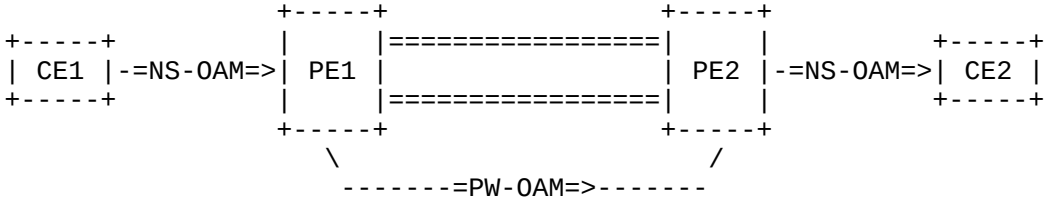


Figure 4: Coupled OAM Loops Mode

The coupled OAM loops mode implements the following behavior:

a. The upstream PE (PE1) MUST terminate and translate a received NS defect notification message into a PW defect notification message.

b. The upstream PE MUST signal local failures affecting its local AC using PW defect notification messages to the downstream PE.

c. The upstream PE MUST signal local failures affecting the PW using PW defect notification messages.

d. The downstream PE (PE2) MUST insert NS defect notification messages into the AC when it detects or is notified of defects in the PW or remote AC. This includes translating received PW defect notification messages into NS defect notification messages.

This document specifies the coupled OAM loops mode as the default mode for the Frame Relay, ATM AAL5 PDU transport, and AAL5 SDU transport services. It is an optional mode for ATM VCC cell mode services. This mode is not specified for TDM, CEP, or ATM VPC cell mode PW services. RFC 5087 defines a similar but distinct mode, as will be explained in Section 9. For the ATM VPC cell mode case a pure coupled OAM loops mode is not possible as a PE MUST transparently pass VC-level (F5) ATM OAM cells over the PW while terminating and translating VP-level (F4) OAM cells.

## 6. PW Defect States and Defect Notifications

### 6.1. PW Defect Notification Mechanisms

For MPLS and MPLS/IP PSNs, a PE that establishes a PW using the Label Distribution Protocol [RFC5036], and that has negotiated use of the LDP status TLV per Section 5.4.3 of [RFC4447], MUST use the PW status

TLV mechanism for AC and PW status and defect notification. Additionally, such a PE MAY use VCCV-BFD Connectivity Verification (CV) for fault detection only (CV types 0x04 and 0x10 [RFC5885]).

A PE that establishes an MPLS PW using means other than LDP, e.g., by static configuration or by use of BGP, MUST support some alternative method of status reporting. The design of a suitable mechanism to carry the aforementioned status TLV in the PW associated channel is work in progress [Static-PW-Status]. Additionally, such a PE MAY use VCCV-BFD CV for both fault detection and status notification (CV types 0x08 and 0x20 [RFC5885]).

For a L2TPv3/IP PSN, a PE SHOULD use the Circuit Status Attribute Value Pair (AVP) as the mechanism for AC and PW status and defect notification. In its most basic form, the Circuit Status AVP [RFC3931] in a Set-Link-Info (SLI) message can signal active/inactive AC status. The Circuit Status AVP as described in [RFC5641] is proposed to be extended to convey status and defects in the AC and the PSN-facing PW in both ingress and egress directions, i.e., four independent status bits, without the need to tear down the sessions or control connection.

When a PE does not support the Circuit Status AVP, it MAY use the Stop-Control-Connection-Notification (StopCCN) and the Call-Disconnect-Notify (CDN) messages to tear down L2TP sessions in a fashion similar to LDP's use of Label Withdrawal to tear down a PW. A PE may use the StopCCN to shut down the L2TP control connection, and implicitly all L2TP sessions associated with that control connection, without any explicit session control messages. This is useful for the case of a failure which impacts all L2TP sessions (all PWs) managed by the control connection. It MAY use CDN to disconnect a specific L2TP session when a failure only affects a specific PW.

Additionally, a PE MAY use VCCV-BFD CV types 0x04 and 0x10 for fault detection only, but SHOULD notify the remote PE using the Circuit Status AVP. A PE that establishes a PW using means other than the L2TP control plane, e.g., by static configuration or by use of BGP, MAY use VCCV-BFD CV types 0x08 and 0x20 for AC and PW status and defect notification. These CV types SHOULD NOT be used when the PW is established via the L2TP control plane.

The CV types are defined in Section 6.1.3 of this document.

### 6.1.1. LDP Status TLV

[RFC4446] defines the following PW status code points:

0x00000000 - Pseudowire forwarding (clear all failures)

0x00000001 - Pseudowire Not Forwarding

0x00000002 - Local Attachment Circuit (ingress) Receive Fault

0x00000004 - Local Attachment Circuit (egress) Transmit Fault

0x00000008 - Local PSN-facing PW (ingress) Receive Fault

0x00000010 - Local PSN-facing PW (egress) Transmit Fault

[RFC4447] specifies that the "Pseudowire forwarding" code point is used to indicate that all faults are to be cleared. It also specifies that the "Pseudowire Not Forwarding" code point means that a defect has been detected that is not represented by the defined code points.

The code points used in the LDP status TLV in a PW status notification message report defects from the viewpoint of the originating PE. The originating PE conveys this state in the form of a forward defect or a reverse defect indication.

The forward and reverse defect indication definitions used in this document map to the LDP Status TLV codes as follows:

Forward defect indication corresponds to the logical OR of:

* Local Attachment Circuit (ingress) Receive Fault,
* Local PSN-facing PW (egress) Transmit Fault, and
* PW Not Forwarding.

Reverse defect indication corresponds to the logical OR of:

* Local Attachment Circuit (egress) Transmit Fault and
* Local PSN-facing PW (ingress) Receive Fault.

A PE MUST use PW status notification messages to report all defects affecting the PW service including, but not restricted to, the following:

- o defects detected through fault detection mechanisms in the MPLS and MPLS/IP PSN,
- o defects detected through VCCV-Ping or VCCV-BFD CV types 0x04 and 0x10 for fault detection only,
- o defects within the PE that result in an inability to forward traffic between the AC and the PW,
- o defects of the AC or in the Layer 2 network affecting the AC as per the rules detailed in Section 5 for the "single emulated OAM loop" mode and "coupled OAM loops" modes.

Note that there are two situations that require PW label withdrawal as opposed to a PW status notification by the PE. The first one is when the PW is taken down administratively in accordance with [RFC4447]. The second one is when the Target LDP session established between the two PEs is lost. In the latter case, the PW labels will need to be re-signaled when the Targeted LDP session is re-established.

#### 6.1.2. L2TP Circuit Status AVP

[RFC3931] defines the Circuit Status AVP in the Set-Link-Info (SLI) message to exchange initial status and status changes in the circuit to which the pseudowire is bound. [RFC5641] defines extensions to the Circuit Status AVP that are analogous to the PW Status TLV defined for LDP. Consequently, for L2TPv3/IP, the Circuit Status AVP is used in the same fashion as the PW Status described in the previous section. Extended circuit status for L2TPv3/IP is described in [RFC5641].

If the extended Circuit Status bits are not supported, and instead only the "A bit" (Active) is used as described in [RFC3931], a PE MAY use CDN messages to clear L2TPv3/IP sessions in the presence of session-level failures detected in the L2TPv3/IP PSN.

A PE MUST set the Active bit in the Circuit Status to clear all faults, and it MUST clear the Active bit in the Circuit Status to convey any defect that cannot be represented explicitly with specific Circuit Status flags from [RFC3931] or [RFC5641].

The forward and reverse defect indication definitions used in this document map to the L2TP Circuit Status AVP as follows:

Forward defect indication corresponds to the logical OR of:

* Local Attachment Circuit (ingress) Receive Fault,

* Local PSN-facing PW (egress) Transmit Fault, and

* PW Not Forwarding.

Reverse defect indication corresponds to the logical OR of:

* Local Attachment Circuit (egress) Transmit Fault and

* Local PSN-facing PW (ingress) Receive Fault.

The status notification conveys defects from the viewpoint of the originating LCCE (PE).

When the extended Circuit Status definition of [RFC5641] is supported, a PE SHALL use the Circuit Status to report all failures affecting the PW service including, but not restricted to, the following:

- defects detected through defect detection mechanisms in the L2TPv3/IP PSN,

- defects detected through VCCV-Ping or VCCV-BFD CV types 0x04 (BFD IP/UDP-encapsulated, for PW Fault Detection only) and 0x10 (BFD PW-ACH-encapsulated (without IP/UDP headers), for PW. Fault Detection and AC/PW Fault Status Signaling) for fault detection only which are described in Section 6.1.3 of this document,

- defects within the PE that result in an inability to forward traffic between the AC and the PW,

- defects of the AC or in the L2 network affecting the AC as per the rules detailed in Section 5 for the "single emulated OAM loop" mode and the "coupled OAM loops" modes.

When the extended Circuit Status definition of [RFC5641] is not supported, a PE SHALL use the A bit in the Circuit Status AVP in the SLI to report:

- defects of the AC or in the L2 network affecting the AC as per the rules detailed in Section 5 for the "single emulated OAM loop" mode and the "coupled OAM loops" modes.

When the extended Circuit Status definition of [RFC5641] is not supported, a PE MAY use the CDN and StopCCN messages in a similar way to an MPLS PW label withdrawal to report:

- defects detected through defect detection mechanisms in the L2TPv3/IP PSN (using StopCCN),
- defects detected through VCCV (pseudowire level) (using CDN),
- defects within the PE that result in an inability to forward traffic between ACs and PW (using CDN).

For ATM L2TPv3/IP pseudowires, in addition to the Circuit Status AVP, a PE MAY use the ATM Alarm Status AVP [RFC4454] to indicate the reason for the ATM circuit status and the specific alarm type, if any. This AVP is sent in the SLI message to indicate additional information about the ATM circuit status.

L2TP control connections use Hello messages as a keep-alive facility. It is important to note that if PSN failure is detected by keep-alive timeout, the control connection is cleared. L2TP Hello messages are sent in-band so as to follow the data plane with respect to the source and destination addresses, IP protocol number, and UDP port (when UDP is used).

#### 6.1.3. BFD Diagnostic Codes

BFD [RFC5880] defines a set of diagnostic codes that partially overlap the set of defects that can be communicated through LDP Status TLV or L2TP Circuit Status AVP. This section describes the behavior of the PEs with respect to using one or both of these methods for detecting and propagating defect state.

In the case of an MPLS PW established via LDP signaling, the PEs negotiate VCCV capabilities during the label mapping messages exchange used to establish the two directions of the PW. This is achieved by including a capability TLV in the PW Forward Error Correction (FEC) interface parameters TLV. In the L2TPv3/IP case, the PEs negotiate the use of VCCV during the pseudowire session initialization using the VCCV AVP [RFC5085].

The CV Type Indicators field in the OAM capability TLV or VCCV AVP defines a bitmask used to indicate the specific OAM capabilities that the PE can use over the PW being established.

A CV type of 0x04 or 0x10 [RFC5885] indicates that BFD is used for PW fault detection only. These CV types MAY be used any time the PW is established using LDP or L2TP control planes. In this mode, only the following diagnostic (Diag) codes specified in [RFC5880] will be used:

0 - No diagnostic

1 - Control detection time expired

3 - Neighbor signaled session down

7 - Administratively Down

A PE using VCCV-BFD MUST use diagnostic code 0 to indicate to its peer PE that it is correctly receiving BFD control messages. It MUST use diagnostic code 1 to indicate to its peer that it has stopped receiving BFD control messages and will thus declare the PW to be down in the receive direction. It MUST use diagnostic code 3 to confirm to its peer that the BFD session is going down after receiving diagnostic code 1 from this peer. In this case, it will declare the PW to be down in the transmit direction. A PE MUST use diagnostic code 7 to bring down the BFD session when the PW is brought down administratively. All other defects, such as AC/PW defects and PE internal failures that prevent it from forwarding traffic, MUST be communicated through the LDP Status TLV in the case of MPLS or MPLS/IP PSN, or through the appropriate L2TP codes in the Circuit Status AVP in the case of L2TPv3/IP PSN.

A CV type of 0x08 or 0x20 in the OAM capabilities TLV indicates that BFD is used for both PW fault detection and Fault Notification. In addition to the above diagnostic codes, a PE uses the following codes to signal AC defects and other defects impacting forwarding over the PW service:

6 - Concatenated Path Down

8 - Reverse Concatenated Path Down

As specified in [RFC5085], the PEs negotiate the use of VCCV during PW setup. When a PW transported over an MPLS-PSN is established using LDP, the PEs negotiate the use of the VCCV capabilities using the optional VCCV Capability Advertisement Sub-TLV parameter in the Interface Parameter Sub-TLV field of the LDP PW ID FEC or using an Interface Parameters TLV of the LDP Generalized PW ID FEC. In the case of L2TPv3/IP PSNs, the PEs negotiate the use of VCCV during the pseudowire session initialization using VCCV AVP.

Note that a defect that causes the generation of the "PW not forwarding code" (diagnostic code 6 or 8) does not necessarily result in the BFD session going down. However, if the BFD session times out, then diagnostic code 1 MUST be used since it signals a state change of the BFD session itself. In general, when a BFD session changes state, the PEs MUST use state change diagnostic codes 0, 1, 3, and 7 in accordance with [RFC5880], and they MUST override any of the AC/PW status diagnostic codes (codes 6 or 8) that may have been signaled prior to the BFD session changing state.

The forward and reverse defect indications used in this document map to the following BFD codes:

Forward defect indication corresponds to the logical OR of:

* Concatenated Path Down (BFD diagnostic code 06)

* Pseudowire Not Forwarding (PW status code 0x00000001).

Reverse defect indication corresponds to:

* Reverse Concatenated Path Down (BFD diagnostic code 08).

These diagnostic codes are used to signal forward and reverse defect states, respectively, when the PEs negotiated the use of BFD as the mechanism for AC and PW fault detection and status signaling notification. As stated in Section 6.1, these CV types SHOULD NOT be used when the PW is established with the LDP or L2TP control plane.

## 6.2. PW Defect State Entry/Exit

### 6.2.1. PW Receive Defect State Entry/Exit Criteria

PE1, as downstream PE, will enter the PW receive defect state if one or more of the following occurs:

- It receives a forward defect indication (FDI) from PE2 indicating either a receive defect on the remote AC or that PE2 detected or was notified of downstream PW fault.

- It detects loss of connectivity on the PSN tunnel upstream of PE1, which affects the traffic it receives from PE2.

- It detects a loss of PW connectivity through VCCV-BFD or VCCV-PING, which affects the traffic it receives from PE2.

Note that if the PW control session (LDP session, the L2TP session, or the L2TP control connection) between the PEs fails, the PW is torn down and needs to be re-established. However, the consequent actions towards the ACs are the same as if the PW entered the receive defect state.

PE1 will exit the PW receive defect state when the following conditions are met. Note that this may result in a transition to the PW operational state or the PW transmit defect state.

- o All previously detected defects have disappeared, and
- o PE2 cleared the FDI, if applicable.

#### 6.2.2. PW Transmit Defect State Entry/Exit Criteria

PE1, as upstream PE, will enter the PW transmit defect state if the following conditions occur:

- o It receives a Reverse Defect Indication (RDI) from PE2 indicating either a transmit fault on the remote AC or that PE2 detected or was notified of a upstream PW fault, and
- o it is not already in the PW receive defect state.

PE1 will exit the transmit defect state if it receives an OAM message from PE2 clearing the RDI, or it has entered the PW receive defect state.

For a PW over L2TPv3/IP using the basic Circuit Status AVP [RFC3931], the PW transmit defect state is not valid and a PE can only enter the PW receive defect state.

## 7. Procedures for ATM PW Service

The following procedures apply to Asynchronous Transfer Mode (ATM) pseudowires [RFC4717]. ATM terminology is explained in Appendix A.2 of this document.

### 7.1. AC Receive Defect State Entry/Exit Criteria

When operating in the coupled OAM loops mode, PE1 enters the AC receive defect state when any of the following conditions are met:

a. It detects or is notified of a physical layer fault on the ATM interface.

b. It receives an end-to-end Flow 4 OAM (F4) Alarm Indication Signal (AIS) OAM flow on a Virtual Path (VP) AC or an end-to-end Flow 5 (F5) AIS OAM flow on a Virtual Circuit (VC) as per ITU-T Recommendation I.610 [I.610], indicating that the ATM VPC or VCC is down in the adjacent Layer 2 ATM network.

c. It receives a segment F4 AIS OAM flow on a VP AC, or a segment F5 AIS OAM flow on a VC AC, provided that the operator has provisioned segment OAM and the PE is not a segment endpoint.

d. It detects loss of connectivity on the ATM VPC/VCC while terminating segment or end-to-end ATM continuity check (ATM CC) cells with the local ATM network and CE.

When operating in the coupled OAM loops mode, PE1 exits the AC receive defect state when all previously detected defects have disappeared.

When operating in the single emulated OAM loop mode, PE1 enters the AC receive defect state if any of the following conditions are met:

a. It detects or is notified of a physical layer fault on the ATM interface.

b. It detects loss of connectivity on the ATM VPC/VCC while terminating segment ATM continuity check (ATM CC) cells with the local ATM network and CE.

When operating in the single emulated OAM loop mode, PE1 exits the AC receive defect state when all previously detected defects have disappeared.

The exact conditions under which a PE enters and exits the AIS state, or declares that connectivity is restored via ATM CC, are defined in Section 9.2 of [I.610].

### 7.2. AC Transmit Defect State Entry/Exit Criteria

When operating in the coupled OAM loops mode, PE1 enters the AC transmit defect state if any of the following conditions are met:

a. It terminates an end-to-end F4 RDI OAM flow, in the case of a VPC, or an end-to-end F5 RDI OAM flow, in the case of a VCC, indicating that the ATM VPC or VCC is down in the adjacent L2 ATM.

b. It receives a segment F4 RDI OAM flow on a VP AC, or a segment F5 RDI OAM flow on a VC AC, provided that the operator has provisioned segment OAM and the PE is not a segment endpoint.

PE1 exits the AC transmit defect state if the AC state transitions to working or to the AC receive defect state. The exact conditions for exiting the RDI state are described in Section 9.2 of [I.610].

Note that the AC transmit defect state is not valid when operating in the single emulated OAM loop mode, as PE1 transparently forwards the received RDI cells as user cells over the ATM PW to the remote CE.

### 7.3. Consequent Actions

In the remainder of this section, the text refers to AIS, RDI, and CC without specifying whether there is an F4 (VP-level) flow or an F5 (VC-level) flow, or whether it is an end-to-end or a segment flow. Precise ATM OAM procedures for each type of flow are specified in Section 9.2 of [I.610].

#### 7.3.1. PW Receive Defect State Entry/Exit

On entry to the PW receive defect state:

a. PE1 MUST commence AIS insertion into the corresponding AC.

b. PE1 MUST cease generation of CC cells on the corresponding AC, if applicable.

c. If the PW defect was detected by PE1 without receiving FDI from PE2, PE1 MUST assume PE2 has no knowledge of the defect and MUST notify PE2 by sending RDI.

On exit from the PW receive defect state:

a. PE1 MUST cease AIS insertion into the corresponding AC.

b. PE1 MUST resume any CC cell generation on the corresponding AC, if applicable.

c. PE1 MUST clear the RDI to PE2, if applicable.

#### 7.3.2. PW Transmit Defect State Entry/Exit

On entry to the PW Transmit Defect State:

a. PE1 MUST commence RDI insertion into the corresponding AC.

b. If the PW failure was detected by PE1 without receiving RDI from PE2, PE1 MUST assume PE2 has no knowledge of the defect and MUST notify PE2 by sending FDI.

On exit from the PW Transmit Defect State:

a. PE1 MUST cease RDI insertion into the corresponding AC.

b. PE1 MUST clear the FDI to PE2, if applicable.

### 7.3.3. PW Defect State in ATM Port Mode PW Service

In case of transparent cell transport PW service, i.e., "port mode", where the PE does not keep track of the status of individual ATM VPCs or VCCs, a PE cannot relay PW defect state over these VCCs and VPCs. If ATM CC is run on the VCCs and VPCs end-to-end (CE1 to CE2), or on a segment originating and terminating in the ATM network and spanning the PSN network, it will time out and cause the CE or ATM switch to enter the ATM AIS state.

### 7.3.4. AC Receive Defect State Entry/Exit

On entry to the AC receive defect state and when operating in the coupled OAM loops mode:

a. PE1 MUST send FDI to PE2.

b. PE1 MUST commence insertion of ATM RDI cells into the AC towards CE1.

When operating in the single emulated OAM loop mode, PE1 must be able to support two options, subject to the operator’s preference. The default option is the following:

On entry to the AC receive defect state:

a. PE1 MUST transparently relay ATM AIS cells, or, in the case of a local AC defect, commence insertion of ATM AIS cells into the corresponding PW towards CE2.

b. If the defect interferes with NS OAM message generation, PE1 MUST send FDI to PE2.

c. PE1 MUST cease the generation of CC cells on the corresponding PW, if applicable.

In certain operational models, for example, in the case that the ATM access network is owned by a different provider than the PW, an operator may want to distinguish between defects detected in the ATM access network and defects detected on the AC directly adjacent to the PE. Therefore, the following option MUST also be supported:

a. PE1 MUST transparently relay ATM AIS cells over the corresponding PW towards CE2.

b. Upon detection of a defect on the ATM interface on the PE or in the PE itself, PE1 MUST send FDI to PE2.

c. PE1 MUST cease generation of CC cells on the corresponding PW, if applicable.

On exit from the AC receive defect state and when operating in the coupled OAM loops mode:

a. PE1 MUST clear the FDI to PE2.

b. PE1 MUST cease insertion of ATM RDI cells into the AC.

On exit from the AC receive defect state and when operating in the single emulated OAM loop mode:

a. PE1 MUST cease insertion of ATM AIS cells into the corresponding PW.

b. PE1 MUST clear the FDI to PE2, if applicable.

c. PE1 MUST resume any CC cell generation on the corresponding PW, if applicable.

#### 7.3.5. AC Transmit Defect State Entry/Exit

On entry to the AC transmit defect state and when operating in the coupled OAM loops mode:

* PE1 MUST send RDI to PE2.

On exit from the AC transmit defect state and when operating in the coupled OAM loops mode:

* PE1 MUST clear the RDI to PE2.

## 8. Procedures for Frame Relay PW Service

The following procedures apply to Frame Relay (FR) pseudowires [RFC4619]. Frame Relay (FR) terminology is explained in Appendix A.1 of this document.

### 8.1. AC Receive Defect State Entry/Exit Criteria

PE1 enters the AC receive defect state if one or more of the following conditions are met:

a. A Permanent Virtual Circuit (PVC) is not deleted from the FR network and the FR network explicitly indicates in a full status report (and optionally by the asynchronous status message) that this PVC is inactive [Q.933]. In this case, this status maps across the PE to the corresponding PW only.

b. The Link Integrity Verification (LIV) indicates that the link from the PE to the Frame Relay network is down [Q.933]. In this case, the link down indication maps across the PE to all corresponding PWs.

c. A physical layer alarm is detected on the FR interface. In this case, this status maps across the PE to all corresponding PWs.

PE1 exits the AC receive defect state when all previously detected defects have disappeared.

### 8.2. AC Transmit Defect State Entry/Exit Criteria

The AC transmit defect state is not valid for a FR AC.

### 8.3. Consequent Actions

#### 8.3.1. PW Receive Defect State Entry/Exit

The A (Active) bit indicates whether the FR PVC is ACTIVE (1) or INACTIVE (0) as explained in [RFC4591].

On entry to the PW receive defect state:

a. PE1 MUST clear the Active bit for the corresponding FR AC in a full status report, and optionally in an asynchronous status message, as per [Q.933], Annex A.

b. If the PW failure was detected by PE1 without receiving FDI from PE2, PE1 MUST assume PE2 has no knowledge of the defect and MUST notify PE2 by sending RDI.

On exit from the PW receive defect state:

a. PE1 MUST set the Active bit for the corresponding FR AC in a full status report, and optionally in an asynchronous status message, as per [Q.933], Annex A. PE1 does not apply this procedure on a transition from the PW receive defect state to the PW transmit defect state.

b. PE1 MUST clear the RDI to PE2, if applicable.

### 8.3.2. PW Transmit Defect State Entry/Exit

On entry to the PW transmit defect state:

a. PE1 MUST clear the Active bit for the corresponding FR AC in a full status report, and optionally in an asynchronous status message, as per [Q.933], Annex A.

b. If the PW failure was detected by PE1 without RDI from PE2, PE1 MUST assume PE2 has no knowledge of the defect and MUST notify PE2 by sending FDI.

On exit from the PW transmit defect state:

a. PE1 MUST set the Active bit for the corresponding FR AC in a full status report, and optionally in an asynchronous status message, as per [Q.933], Annex A. PE1 does not apply this procedure on a transition from the PW transmit defect state to the PW receive defect state.

b. PE1 MUST clear the FDI to PE2, if applicable.

### 8.3.3. PW Defect State in the FR Port Mode PW Service

In case of port mode PW service, STATUS ENQUIRY and STATUS messages are transported transparently over the PW. A PW Failure will therefore result in timeouts of the Q.933 link and PVC management protocol at the Frame Relay devices at one or both sites of the emulated interface.

### 8.3.4. AC Receive Defect State Entry/Exit

On entry to the AC receive defect state:

* PE1 MUST send FDI to PE2.

On exit from the AC receive defect state:

* PE1 MUST clear the FDI to PE2.

### 8.3.5. AC Transmit Defect State Entry/Exit

The AC transmit defect state is not valid for an FR AC.

## 9. Procedures for TDM PW Service

The following procedures apply to SAToP [RFC4553], CESoPSN [RFC5086] and TDMoIP [RFC5087]. These technologies utilize the single emulated OAM loop mode. RFC 5087 distinguishes between trail-extended and trail-terminated scenarios; the former is essentially the single emulated loop model. The latter applies to cases where the NS networks are run by different operators and defect notifications are not propagated across the PW.

Since TDM is inherently real-time in nature, many OAM indications must be generated or forwarded with minimal delay. This requirement rules out the use of messaging protocols, such as PW status messages. Thus, for TDM PWs, alternate mechanisms are employed.

The fact that TDM PW packets are sent at a known constant rate can be exploited as an OAM mechanism. Thus, a PE enters the PW receive defect state whenever a preconfigured number of TDM PW packets do not arrive in a timely fashion. It exits this state when packets once again arrive at their proper rate.

Native TDM carries OAM indications in overhead fields that travel along with the data. TDM PWs emulate this behavior by sending urgent OAM messages in the PWE control word.

The TDM PWE3 control word contains a set of flags used to indicate PW and AC defect conditions. The L bit is an AC forward defect indication used by the upstream PE to signal NS network defects to the downstream PE. The M field may be used to modify the meaning of receive defects. The R bit is a PW reverse defect indication used by the PE to signal PSN failures to the remote PE. Upon reception of packets with the R bit set, a PE enters the PW transmit defect state. L bits and R bits are further described in [RFC5087].

### 9.1. AC Receive Defect State Entry/Exit Criteria

PE1 enters the AC receive defect state if any of the following conditions are met:

a. It detects a physical layer fault on the TDM interface (Loss of Signal, Loss of Alignment, etc., as described in [G.775]).

b. It is notified of a previous physical layer fault by detecting AIS.

The exact conditions under which a PE enters and exits the AIS state are defined in [G.775]. Note that Loss of Signal and AIS detection can be performed by PEs for both structure-agnostic and structure-aware TDM PW types. Note that PEs implementing structure-agnostic PWs cannot detect Loss of Alignment.

### 9.2. AC Transmit Defect State Entry/Exit Criteria

PE1 enters the AC transmit defect state when it detects RDI according to the criteria in [G.775]. Note that PEs implementing structure-agnostic PWs cannot detect RDI.

### 9.3. Consequent Actions

#### 9.3.1. PW Receive Defect State Entry/Exit

On entry to the PW receive defect state:

a. PE1 MUST commence AIS insertion into the corresponding TDM AC.

b. PE1 MUST set the R bit in all PW packets sent back to PE2.

On exit from the PW receive defect state:

a. PE1 MUST cease AIS insertion into the corresponding TDM AC.

b. PE1 MUST clear the R bit in all PW packets sent back to PE2.

Note that AIS generation can, in general, be performed by both structure-aware and structure-agnostic PEs.

#### 9.3.2. PW Transmit Defect State Entry/Exit

On entry to the PW Transmit Defect State:

* A structure-aware PE1 MUST commence RDI insertion into the corresponding AC.

On exit from the PW Transmit Defect State:

* A structure-aware PE1 MUST cease RDI insertion into the corresponding AC.

Note that structure-agnostic PEs are not capable of injecting RDI into an AC.

#### 9.3.3. AC Receive Defect State Entry/Exit

On entry to the AC receive defect state and when operating in the single emulated OAM loop mode:

a. PE1 SHOULD overwrite the TDM data with AIS in the PW packets sent towards PE2.

b. PE1 MUST set the L bit in these packets.

c. PE1 MAY omit the payload in order to conserve bandwidth.

d. A structure-aware PE1 SHOULD send RDI back towards CE1.

e. A structure-aware PE1 that detects a potentially correctable AC defect MAY use the M field to indicate this.

On exit from the AC receive defect state and when operating in the single emulated OAM loop mode:

a. PE1 MUST cease overwriting PW content with AIS and return to forwarding valid TDM data in PW packets sent towards PE2.

b. PE1 MUST clear the L bit in PW packets sent towards PE2.

c. A structure-aware PE1 MUST cease sending RDI towards CE1.

## 10. Procedures for CEP PW Service

The following procedures apply to SONET/SDH Circuit Emulation [RFC4842]. They are based on the single emulated OAM loop mode.

Since SONET and SDH are inherently real-time in nature, many OAM indications must be generated or forwarded with minimal delay. This requirement rules out the use of messaging protocols, such as PW status messages. Thus, for CEP PWs alternate mechanisms are employed.

The CEP PWE3 control word contains a set of flags used to indicate PW and AC defect conditions. The L bit is a forward defect indication used by the upstream PE to signal to the downstream PE a defect in its local attachment circuit. The R bit is a PW reverse defect indication used by the PE to signal PSN failures to the remote PE. The combination of N and P bits is used by the local PE to signal loss of pointer to the remote PE.

The fact that CEP PW packets are sent at a known constant rate can be exploited as an OAM mechanism. Thus, a PE enters the PW receive defect state when it loses packet synchronization. It exits this state when it regains packet synchronization. See [RFC4842] for further details.

## 10.1. Defect States

### 10.1.1. PW Receive Defect State Entry/Exit

In addition to the conditions specified in Section 6.2.1, PE1 will enter the PW receive defect state when one of the following becomes true:

- It receives packets with the L bit set.
- It receives packets with both the N and P bits set.
- It loses packet synchronization.

### 10.1.2. PW Transmit Defect State Entry/Exit

In addition to the conditions specified in Section 6.2.2, PE1 will enter the PW transmit defect state if it receives packets with the R bit set.

### 10.1.3. AC Receive Defect State Entry/Exit

PE1 enters the AC receive defect state when any of the following conditions are met:

a. It detects a physical layer fault on the TDM interface (Loss of Signal, Loss of Alignment, etc.).

b. It is notified of a previous physical layer fault by detecting of AIS.

The exact conditions under which a PE enters and exits the AIS state are defined in [G.707] and [G.783].

#### 10.1.4. AC Transmit Defect State Entry/Exit

The AC transmit defect state is not valid for CEP PWs. RDI signals are forwarded transparently.

### 10.2. Consequent Actions

#### 10.2.1. PW Receive Defect State Entry/Exit

On entry to the PW receive defect state:

a. PE1 MUST commence AIS-P/V insertion into the corresponding AC. See [RFC4842].

b. PE1 MUST set the R bit in all PW packets sent back to PE2.

On exit from the PW receive defect state:

a. PE1 MUST cease AIS-P/V insertion into the corresponding AC.

b. PE1 MUST clear the R bit in all PW packets sent back to PE2.

See [RFC4842] for further details.

#### 10.2.2. PW Transmit Defect State Entry/Exit

On entry to the PW Transmit Defect State:

a. A structure-aware PE1 MUST commence RDI insertion into the corresponding AC.

On exit from the PW Transmit Defect State:

a. A structure-aware PE1 MUST cease RDI insertion into the corresponding AC.

#### 10.2.3. AC Receive Defect State Entry/Exit

On entry to the AC receive defect state:

a. PE1 MUST set the L bit in these packets.

b. If Dynamic Bandwidth Allocation (DBA) has been enabled, PE1 MAY omit the payload in order to conserve bandwidth.

c. If Dynamic Bandwidth Allocation (DBA) is not enabled, PE1 SHOULD insert AIS-V/P in the SDH/SONET client layer in the PW packets sent towards PE2.

On exit from the AC receive defect state:

a. PE1 MUST cease overwriting PW content with AIS-P/V and return to forwarding valid data in PW packets sent towards PE2.

b. PE1 MUST clear the L bit in PW packets sent towards PE2.

See [RFC4842] for further details.

## 11. Security Considerations

The mapping messages described in this document do not change the security functions inherent in the actual messages. All generic security considerations applicable to PW traffic specified in Section 10 of [RFC3985] are applicable to NS OAM messages transferred inside the PW.

Security considerations in Section 10 of RFC 5085 for VCCV apply to the OAM messages thus transferred. Security considerations applicable to the PWE3 control protocol of RFC 4447 Section 8.2 apply to OAM indications transferred using the LDP status message.

Since the mechanisms of this document enable propagation of OAM messages and fault conditions between native service networks and PSNs, continuity of the end-to-end service depends on a trust relationship between the operators of these networks. Security considerations for such scenarios are discussed in Section 7 of [RFC5254].

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# Appendix A. Native Service Management (Informative)

## A.1. Frame Relay Management

The management of Frame Relay Bearer Service (FRBS) connections can be accomplished through two distinct methodologies:

a. Based on [Q.933], Annex A, Link Integrity Verification procedure, where STATUS and STATUS ENQUIRY signaling messages are sent using DLCI=0 over a given User-Network Interface (UNI) and Network-Network Interface (NNI) physical link.

b. Based on FRBS Local Management Interface (LMI), and similar to ATM Integrated LMI (ILMI) where LMI is common in private Frame Relay networks.

In addition, ITU-T I.620 [I.620] addressed Frame Relay loopback. This Recommendation was withdrawn in 2004, and its deployment was limited.

It is possible to use either, or both, of the above options to manage Frame Relay interfaces. This document will refer exclusively to Q.933 messages.

The status of any provisioned Frame Relay PVC may be updated through:

a. Frame Relay STATUS messages in response to Frame Relay STATUS ENQUIRY messages; these are mandatory.

b. Optional unsolicited STATUS updates independent of STATUS ENQUIRY (typically, under the control of management system, these updates can be sent periodically (continuous monitoring) or only upon detection of specific defects based on configuration).

In Frame Relay, a Data Link Connection (DLC) is either up or down. There is no distinction between different directions. To achieve commonality with other technologies, down is represented as a receive defect.

Frame Relay connection management is not implemented over the PW using either of the techniques native to FR; therefore, PW mechanisms are used to synchronize the view each PE has of the remote Native Service/Attachment Circuit (NS/AC). A PE will treat a remote NS/AC failure in the same way it would treat a PW or PSN failure, that is, using AC facing FR connection management to notify the CE that FR is down.

## A.2. ATM Management

ATM management and OAM mechanisms are much more evolved than those of Frame Relay. There are five broad management-related categories, including fault management (FT), Performance management (PM), configuration management (CM), Accounting management (AC), and Security management (SM). [I.610] describes the functions for the operation and maintenance of the physical layer and the ATM layer, that is, management at the bit and cell levels. Because of its scope, this document will concentrate on ATM fault management functions. Fault management functions include the following:

a. Alarm Indication Signal (AIS).

b. Remote Defect Indication (RDI).

c. Continuity Check (CC).

d. Loopback (LB).

Some of the basic ATM fault management functions are described as follows: Alarm Indication Signal (AIS) sends a message in the same direction as that of the signal, to the effect that an error has been detected.

The Remote Defect Indication (RDI) sends a message to the transmitting terminal that an error has been detected. Alarms related to the physical layer are indicated using path AIS/RDI. Virtual path AIS/RDI and virtual channel AIS/RDI are also generated for the ATM layer.

OAM cells (F4 and F5 cells) are used to instrument virtual paths and virtual channels, respectively, with regard to their performance and availability. OAM cells in the F4 and F5 flows are used for monitoring a segment of the network and end-to-end monitoring. OAM cells in F4 flows have the same VPI as that of the connection being monitored. OAM cells in F5 flows have the same VPI and VCI as that of the connection being monitored. The AIS and RDI messages of the F4 and F5 flows are sent to the other network nodes via the VPC or the VCC to which the message refers. The type of error and its location can be indicated in the OAM cells. Continuity check is another fault management function. To check whether a VCC that has been idle for a period of time is still functioning, the network elements can send continuity-check cells along that VCC.

## Appendix B. PW Defects and Detection Tools

### B.1. PW Defects

Possible defects that impact PWs are the following:

a. Physical layer defect in the PSN interface.

b. PSN tunnel failure that results in a loss of connectivity between ingress and egress PE.

c. Control session failures between ingress and egress PE.

In case of an MPLS PSN and an MPLS/IP PSN there are additional defects:

a. PW labeling error, which is due to a defect in the ingress PE, or to an over-writing of the PW label value somewhere along the LSP path.

b. LSP tunnel label swapping errors or LSP tunnel label merging errors in the MPLS network. This could result in the termination of a PW at the wrong egress PE.

c. Unintended self-replication; e.g., due to loops or denial-of-service attacks.

### B.2. Packet Loss

Persistent congestion in the PSN or in a PE could impact the proper operation of the emulated service.

A PE can detect packet loss resulting from congestion through several methods. If a PE uses the sequence number field in the PWE3 Control Word for a specific pseudowire [RFC3985] and [RFC4385], it has the ability to detect packet loss. Translation of congestion detection to PW defect states is beyond the scope of this document.

There are congestion alarms that are raised in the node and to the management system when congestion occurs. The decision to declare the PW down and to select another path is usually at the discretion of the network operator.

### B.3. PW Defect Detection Tools

To detect the defects listed above, Service Providers have a variety of options available.

Physical Layer defect detection and notification mechanisms include SONET/SDH Loss of Signal (LOS), Loss of Alignment (LOA), and AIS/RDI.

PSN defect detection mechanisms vary according to the PSN type.

For PWs over L2TPv3/IP PSNs, with L2TP as encapsulation protocol, the defect detection mechanisms described in [RFC3931] apply. These include, for example, the keep-alive mechanism performed with Hello messages for detection of loss of connectivity between a pair of LCCEs (i.e., dead PE peer and path detection). Furthermore, the tools Ping and Traceroute, based on ICMP Echo Messages [RFC0792] apply and can be used to detect defects on the IP PSN. Additionally, VCCV-Ping [RFC5085] and VCCV-BFD [RFC5885] can also be used to detect defects at the individual pseudowire level.

For PWs over MPLS or MPLS/IP PSNs, several tools can be used:

a. LSP-Ping and LSP-Traceroute [RFC4379] for LSP tunnel connectivity verification.

b. LSP-Ping with Bi-directional Forwarding Detection [RFC5885] for LSP tunnel continuity checking.

c. Furthermore, if Resource Reservation Protocol - Traffic Engineering (RSVP-TE) is used to set up the PSN Tunnels between ingress and egress PE, the hello protocol can be used to detect loss of connectivity [RFC3209], but only at the control plane.

### B.4. PW Specific Defect Detection Mechanisms

[RFC4377] describes how LSP-Ping and BFD can be used over individual PWs for connectivity verification and continuity checking, respectively.

Furthermore, the detection of a fault could occur at different points in the network and there are several ways the observing PE determines a fault exists:

a. Egress PE detection of failure (e.g., BFD).

b. Ingress PE detection of failure (e.g., LSP-PING).

c. Ingress PE notification of failure (e.g., RSVP Path-err).

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