TDM Transport over MPLS Using AAL1 Technical Specification

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Revision History

Version	Change	Date
MPLS and Frame Relay Alliance 4.0	Initial version	April 2003
IP/MPLS Forum 4.1	Alignment with IETF RFC 5087,setup of TDM PW using PW FEC for TDM PW TLV's, Optional timing information using RTP-IETF RFC 3550	July 2008

1 Introduction

1.1 Purpose

The purpose of this Specification is to define network interworking between TDM circuits (n × 64 kbps, E1/T1/E3/T3) over MPLS Label Switched Paths (LSPs) by using AAL1 encapsulation.

Note: SDH/SONET circuit emulation over MPLS networks is outside the scope of this document.

1.2 Scope & Overview

MPLS has the potential to consolidate service providers' networks and services such as Frame Relay, ATM, voice, TDM circuit emulation, and IP services over a single infrastructure (see Figure *1-1*).

A multiservice over MPLS reference model is shown in *Figure 1-1*. It consists of 3 distinct network elements:

- MPLS Switches (P Routers) using cell or frame transport with MPLS control protocols
- Interworking Gateways (PEs) for adapting and interworking a variety of services for transport over an MPLS network
- Access / aggregation nodes that implement existing technologies.

This document specifies a method for transporting TDM (n × 64 kbps, E1/T1/E3/T3) traffic across MPLS networks between two interworking nodes. In particular, the following issues are addressed:

- A method for mapping TDM traffic (including Channel-Associated Signaling (CAS)) onto MPLS
- Definition of protocol data units and procedures for carrying user payloads between interworking nodes
- Exchanging alarm indications between interworking nodes
- MPLS packet loss monitoring.

The TDM services supported are defined in *Section 8, Table 2*.

1.3 Definitions

Must, Shall or Mandatory – the item is an absolute requirement of this implementation agreement.

Should – the item is desirable.

May or Optional – the item is not compulsory, and may be followed or ignored according to the needs of the implementer.

Circuit bundle – A circuit bundle is a stream of bits that have originated from the same physical interface or from different interfaces that share a common clock, and are transmitted from a specific ingress PE to a specific egress PE over a dedicated LSP. A PE typically handles more than one circuit bundle at a time. For example, bundles may comprise several 64 kbps timeslots originating from a single E1, or an entire T3 or E3. Circuit bundles are single-direction streams, but are frequently coupled with bundles in the opposite direction to enable full-duplex communications. More than one bundle can be transmitted between two PEs, as is the case when the PW limits the bundle's packet length.

Circuit Bundle Identifier – A unique identifier of a circuit bundle associated with a certain LSP.

Customer Edge – A Customer Edge (CE) device is the customer device connected to a Provider Edge device.

Egress – The point where the TDM service is decapsulated from a MPLS PDU (MPLS to TDM direction).

Ingress –The point where the TDM service is encapsulated into a MPLS PDU (TDM to MPLS direction).

Label Switched Path – A Label Switched Path (LSP) is the path through one or more MPLS nodes at one level of the hierarchy over which packets in a particular Forwarding Equivalence Class (FEC) are transmitted.

MPLS Node – An MPLS node is a device that is aware of MPLS control protocols, will operate one or more layer three routing protocols, and will be capable of forwarding packets based upon LSP labels, as defined in [22].

Pseudowire – A Pseudowire (PW) is a mechanism that carries the essential elements of an emulated service from one PE to another PE over an MPLS network (and some other networks not covered in this document).

Pseudowire Emulation Edge-to-Edge – pseudowire emulation edge-to-edge (PWE3) is a mechanism that emulates the essential attributes of a TDM service (and of some other services not covered in this document) over an MPLS network.

Provider Edge – A device that provides an emulated TDM services over an MPLS network to a CE. Reference Architecture

A TDM and MPLS network interworking reference model is shown in *Figure 1-1*. It consists of the following elements:

- MPLS core network consisting of P Routers
- Provider Edge (PE) devices providing network interworking functions between TDM and MPLS
- TDM devices connected via framed or unframed TDM Interfaces.

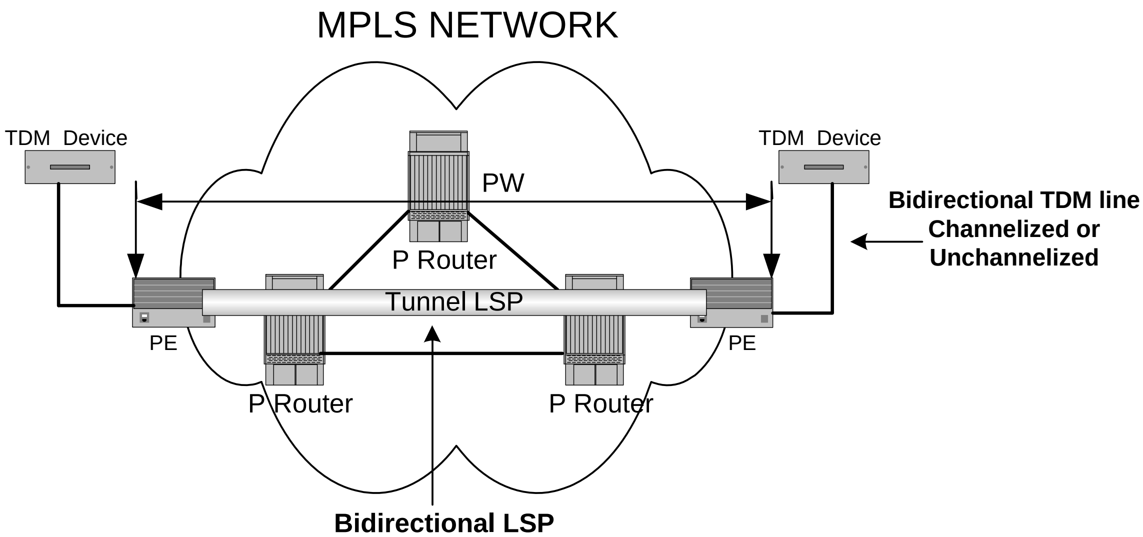

Figure 1-1 – TDM-MPLS Reference Architecture

TDM-MPLS network interworking connects two TDM networks and/or devices using an MPLS network. The TDM service is first provisioned between the TDM device and the TDM interface of the PE device. A pair of Tunnel LSPs (one in each direction) is created either by manual provisioning or signaling. A PW is established between the PEs through the tunnel LSPs to complete the circuit emulation connection. The use of the MPLS network by two TDM networks and/or devices is not visible to the end-users. The PE provides all mapping and encapsulation functions necessary to ensure that the service provided to the TDM networks and/or devices is unchanged by the presence of an MPLS transport network.

1.4 Acronyms

AAL1	ATM Adaptation Layer type 1
ATM	Asynchronous Transfer Mode
CAS	Channel-Associated Signaling
CB	Circuit Bundle
CBID	Circuit Bundle Identifier
CE	Customer Edge
FEC	Forwarding Equivalence Class
IETF	Internet Engineering Task Force
IP	Internet Protocol
LDP	Label Distribution Protocol
LSB	Least Significant Bit
LSP	Label Switched Path
LSR	Label Switching Router
MPLS	Multi Protocol Label Switching

MSB	Most Significant Bit
OOS	Out Of Service
PE	Provider Edge
PPP	Point–to-Point Protocol
PW	Pseudowire
RAI	Remote Alarm Indication
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical NETwork
TDM	Time Division Multiplexing
VCI	Virtual Channel Identifier (ATM networks)
VPI	Virtual Path Identifier (ATM networks)

1.5 References

1.5.1 Normative

[1] ITU-T Recommendation G.704 (10/98) Synchronous frame structures used at 1544, 6312, 2048, 8448 and 44736 kbps hierarchical levels

[2] ITU-T Recommendation G.823 (03/00) The control of jitter and wander within digital networks which are based on the 2048 kbps hierarchy

[3] ITU-T Recommendation G.824 (03/00) The control of jitter and wander within digital networks which are based on the 1544 kbps hierarchy

[4] ITU-T Recommendation I.363.1 (08/96) B-ISDN ATM Adaptation Layer (AAL) specification: Type 1

[5] ATM forum specification atm-vtoa-0078 (CES 2.0) (1/97) Circuit Emulation Service Interoperability Specification Version 2.0

[6] IETF RFC 2615, PPP over SONET/SDH, June 1999

[7] IETF RFC 3032, MPLS Label Stack encoding, January 2001

[8] ITU-T Recommendation Y.1411 (2003) ATM-MPLS Network Interworking- Cell mode User Plane Interworking

[9] ITU-T Recommendation G.703 (1998): Physical / Electrical Characteristics of Hierarchical Digital Interfaces.

[10] ITU-T Recommendation G.751 (1988): Digital Multiplex Equipment Operating at the third order bit rate of 34368 Kbit/s and the fourth order bit rate of 139264 Kbit/s and

Using Positive Justification.

[11] IETF RFC 3550 (2003): RTP: A Transport Protocol for Real-Time Applications.

[12] IETF RFC 5087, "TDM over IP ", December 2007

[13] ITU-T Recommendation I.231.1 (1998) "Circuit Mode Bearer Service Categories Circuit Mode 64 kbit/s Unrestricted, 8 kHz Structured Bearer Service.

[14] ITU-T Recommendation Y.1413 (2004) "TDM MPLS Network Interworking – User Plane Interworking".

[15] ATM forum specification af-arch-0204.000 (1/05) AAL1 Circuit Emulation Over Packet Switched Networks version 1.0.

[16] IANA Pseudowires Name Spaces, http://www.iana.org/assignments/pwe3-parameters.

[17] ANSI T1.107 (1995): Digital Hierarchy - Format Specification.

[18] IETF RFC 3270 (2002): MPLS Support of Differentiated Services

1.5.2 Informative

[19] IETF RFC 3985 (2005) Pseudowire Emulation Edge-to-Edge (PWE3) Architecture.

[20] IETF RFC 4447 (2006) Martini, "Pseudowire Setup and Maintenance Using LDP", (PWE3).

[21] IETF RFC 4385 (2006) Stewart Bryant et al, "PWE3 Control Word for use over an MPLS PSN".

[22] IETF RFC 3031 (2001) Multiprotocol Label Switching Architecture.

2 TDM and MPLS Network Interworking Requirements

This section lists the requirements to be met in a TDM and MPLS network interworking configuration.

TDM Transport – Must support transfer of TDM traffic: framed (including fractional/ channelized) and unframed E1/T1, n × 64 kbps, and E3/T3 over MPLS

Frame Ordering – Must preserve frame ordering end-to-end

Signaling – Must provide for transparent transfer of CAS

Timing – May provide a mechanism for reconstruction of the TDM clock per ANSI/T1.101-1999 or appropriate ITU-T G.81x/G.82x recommendations

Alarm Mapping – Must support the transport of standard alarms to and from the physical interface, across the MPLS network

Interworking – Should allow connection to existing n × 64 kbps, E1/T1, E3/T3 equipment. In addition, connection to AAL1 and TDMoIP equipment should not require extensive processing capabilities. May support compatibility with ATM PW N:1 mode as per, [8].

Overhead vs. Latency Tradeoff – The option to configure, by user or by signaling protocol, the TDMoMPLS payload size per frame in order to balance overhead and latency.

3 Protocol Stack and Frame Format

3.1 TDM-MPLS Frame Format

Figure 3-1 shows the frame format and encapsulation of TDM-MPLS frames expressed in number of bytes per component. The TDM-MPLS frame format consists of a TDM-MPLS header followed by the payload. An MPLS LSP label stack [7] precedes the TDM-MPLS frame. This frame is encapsulated in a link layer frame (e.g., Ethernet, PPP in HDLC framing [6]).

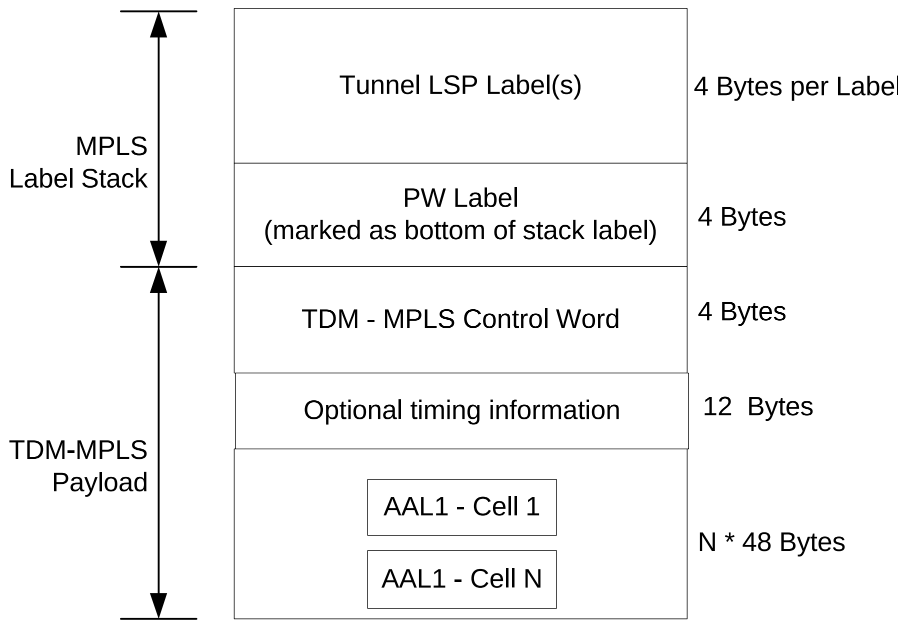

Figure 3-1 – Format and General Encapsulation of TDM-MPLS Frame

Note: Overhead vs. latency tradeoff – A larger number N leads to increased latency and smaller overhead; and vice versa, a smaller number N results in decreased latency and larger overhead. The number of cells per frame must be user-configurable or signaling protocol-configurable.

3.2 TDM-MPLS Control Word Format

The TDM-MPLS control word is shown below. *Table3-1* defines the role of each field.

BIT	0-3	4	5	6-7	8-9	10-15	16-31
	Reserved	L	R	M	RS	Length	Sequence Number

Figure 3-2 – TDM-MPLS Control Word

Table 3-1 – TDM-MPLS Frame Control Word Fields

Field	Meaning
Bits 0-3: Reserved	Reserved bits. Must be Set to zero on transmission and ignored on reception, as per [21].
Bit 4: L bit	As per [14] section 8.3.1. See section 5.3 for encoding details.
Bit5: R bit	As per [14] section 8.3.1
Bits 6-7: M bits	As per [14] section 3.8.1 (see section 5.3 for encoding details).

Bits 8-9: Reserved	Reserved bits. Set to zero on transmission and ignored on reception.
Bits 10-15: Length	As per [14] section 8.3.3
Bits 16-31: Sequence number	As defined in [12] section 2 – Sequence number

3.3 Optional Timing Information

Optional timing information may be carried using the RTP header defined in sub-clause 5.1 of [11].

If the RTP header is present, it shall appear in each interworking packet immediately after the control word and immediately before the payload. The fields of the RTP header shall be encoded as defined in [14] section 8.4.

4 TDM-MPLS Payload

The AAL1/2 family of protocols is a natural choice for trunking applications. Although originally developed to adapt various types of application data to the fixed cell format of ATM, the mechanisms are general solutions to the problem of transporting constant or variable bandwidth data streams over a byte-oriented packet network. For the prevalent case in which the timeslot allocation is static, and no activity detection is performed, the payload can be most efficiently encoded using constant bit rate AAL1 adaptation. The AAL1 format is described in ITU-T Recommendation I.363.1 [4], and its use for TDM circuit emulation is explained in ATM Forum specification atm-vtoa-0078 (CES 2.0)[5].

The TDM-MPLS payload consists of between one and thirty-one 48-octet sub-frames. The number of sub-frames, which can be inferred by the receiving side from the total length of the payload, is preconfigured, and typically chosen according to latency and bandwidth constraints. Using a single sub-frame reduces latency to a minimum, but incurs the highest overhead. Using eight sub-frames, for example, reduces the overhead percentage, while increasing the latency by a factor of eight.

TDM-MPLS header	48 Octet Sub-frame

Figure 4-1 – Single TDM-MPLS-AAL1 Sub-Frame per TDM-MPLS Frame

TDM-MPLS header	48 Octet Sub-frame (1)	48 Octet Sub-frame (n)

Figure 4-2 – Multiple TDM-MPLS-AAL1 Sub-Frames per TDM-MPLS Frame

Bit 0	Bits 1-3	Bits 4-6	Bit 7	
C	SN	CRC	P	47 octets of payload

Figure 4-3 – Sub-Frame Format

where:

C – (1 bit) convergence sub-layer indication; its use here is limited to indication of the existence of a pointer (see below)
C=0 means no pointer; C=1 means a pointer is present.

SN – (3 bits) sequence number, increments from sub-frame to sub-frame

CRC – (3 bits) is a 3-bit error cyclic redundancy code on C and SN

P – (1 bit) even byte parity

Incrementing the sequence number forms an eight sub-frame sequence number cycle.

The MPLS frame is protected by layer 2 frame protection (e.g. CRC); hence for TDM network interworking, the receiver should not check the content of the CRC and P bits in the AAL1 cell header. On the other hand, for ATM service interworking, the CRC and P bits of the AAL1 sub-frame must be checked, since the sub-frame had originated in the ATM network. Hence checking the CRC and P bits in the AAL1 sub-frame shall be configurable by the user or by a signaling protocol.

The structure of the remaining 47 octets in the TDM-MPLS AAL1 sub-frame depends upon the sub-frame type, of which there are three, corresponding to the three types of AAL1 circuit emulation service defined in ATM Forum specification af-vtoa-0078 [5]. These are known as unstructured circuit emulation, structured circuit emulation and structured circuit emulation with CAS.

The simplest sub-frame is the unstructured one, which is used for the transparent transfer of whole trunks (T1, E1, T3, E3), and serial Nx64Kbps interfaces. The 47 octets after the sequence number octet contain 376 bits from the TDM bit stream. No frame synchronization is supplied or implied, and framing is solely the responsibility of the end-user equipment. Hence the unstructured mode can be used for leased lines which carry data rather than n × 64 kbps timeslots, and for trunks with nonstandard frame synchronization. For the T1 case, the raw frame consists of 193 bits, and hence one 183/193 T1 frame fits into each TDM-MPLS AAL1 sub-frame. The E1 frame consists of 256 bits, and so one 15/32 E1 frame fits into each sub-frame. In either case, if a single sub-frame is used per TDM-MPLS frame, the overhead is 12 header octets when using a stack of 2 labels + 1 octet of AAL1 sub-frame header for every 47 TDM payload octets, i.e. 21.6%. However, for eight TDM-MPLS AAL1 sub-frames per TDM-MPLS frame, the payload is 8 × 47=376 octets, resulting in an overhead of about 3.3%. These overhead figures do not include layer 2 overhead.

When the TDM trunk is segmented into timeslots according to ITU-T Recommendation G.704 [1], and it is desired to transport n × 64 kbps circuit where n is only a fraction of the full E1 or T1, it is more efficient to use one of the structured AAL1 circuit emulation services. Structured AAL1 views the data not merely as a bit stream, but as a bundle of timeslots. Furthermore, when CAS is used it can be formatted such that it can be readily detected and manipulated.

In the structured circuit emulation mode without CAS, n octets from the n timeslots to be transported are first arranged in order of timeslot number. Thus, if timeslots 2, 3, 5, 7 and 11 are to be transported, the corresponding five octets are placed in the sub-frame immediately after the sequence number octet.

This placement is repeated until all 47 octets in the sub-frame are taken.

Octet	1	2	3	4	5	6	7	8	9	10	...	41	42	43	44	45	46	47
Timeslot	2	3	5	7	11	2	3	5	7	11	…	2	3	5	7	11	2	3

The next sub-frame commences where the present sub-frame leaves off

Octet	1	2	3	4	5	6	7	8	9	10	...	41	42	43	44	45	46	47
Timeslot	5	7	11	2	3	5	7	11	2	3	…	5	7	11	2	3	5	7

and so forth. The set of timeslots {2, 3, 5, 7,11} is called a structure, and the point where one structure ends and the next commences is a structure boundary.

The problem with this arrangement is the lack of an explicit indication of the octet identities. As can be seen in the above example, each TDM-MPLS AAL1 sub-frame starts with a different timeslot, so a single lost frame will result in misidentifying timeslots from that point onwards, without possibility of recovery. The solution to this deficiency is the periodic introduction of a pointer to the next structure boundary. This pointer need not be used too frequently, as the timeslot identification is uniquely inferable unless frames are lost.

The particular method used in AAL1 is to insert a pointer once every sequence number cycle of length eight sub-frames. The pointer is seven bits and protected by an even parity MSB, and so occupies a single octet. Since seven bits are sufficient to represent offsets larger than 47, we can limit the placement of the pointer octet to sub-frames with an even sequence number. Unlike usual TDM-MPLS AAL1 sub-frames with 47 octets available for payload, sub-frames that contain a pointer, called P-format sub frames, have the following format:

Bit 0	Bits 1-3	Bits 4-6	Bit 7	Bit 0	Bits 1- 7	
C	SN	CRC	P	E	Pointer	46 octets of payload

where

C – (1 bit) convergence sub-layer indication, C=1 for P-format sub frames

SN – (3 bits) even sequence number

CRC – (3 bits) is a 3 bit error cyclic redundancy code on C and SN

P – (1 bit) even byte parity LSB for sequence number octet

E – (1 bit) even byte parity MSB for pointer octet

Pointer – (7 bits) byte pointer to next structure boundary

The MPLS frame is protected by layer 2 frame protection (e.g., CRC); hence in TDM -MPLS network interworking the MPLS receiver should not check the content of CRC, P and E bits in the AAL1 cell to detect errors in the AAL1 sub-frame. On the other hand, in TDM-ATM service interworking over MPLS (see section 10), the CRC, P and E bits of the AAL1 sub-frame must be checked, since the sub-frame had originated in the ATM network. Hence checking the CRC, P and E bits in the AAL1 sub-frame shall be configurable by the user or the signaling protocol.

P-format sub-frames have 46 octets of payload and the next sub-frame has 47 octets. Viewed as a single entity, the pointer needs to indicate one of 93 octets. If P=0, the structure commences with the following octet (i.e. the first octet in the payload belongs to the lowest numbered timeslot).

P=93 means that the last octet of the second sub-frame is the final octet of the structure, and the following sub-frame commences with a new structure. The value P=127 indicates that there is no structure boundary to be indicated (needed when extremely large structures are being transported).

The P-format sub-frame is always placed at the first possible position in the sequence number cycle that a structure boundary occurs, and can only occur once per cycle.

The only difference between the formats for structured circuit emulation and structured circuit emulation with CAS is the definition of the structure. Whereas in structured circuit emulation the structure is composed of the N timeslots, in structured circuit emulation with CAS the structure encompasses the super-frame consisting of multiples of the N timeslots followed by the CAS bits. The CAS bits are tightly packed into octets, and the final octet is padded with zeros, if required.

For example, for E1 trunks the CAS bits are updated once per super-frame consisting of 16 frames. Hence the structure for N × 64, derived from an E1 with CAS consists of 16 multiples of N octets, followed by N sets of the four ABCD bits, and finally, if N is odd, four zero bits. For example, the structure for timeslots 2, 3 and 5 will be as follows:

2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 2 3 5

2 3 5 2 3 5 2 3 5 2 3 5 2 3 5 [ABCD2 ABCD3] [ABCD5 0000]

Similarly for T1 ESF (Extended Super Frame) trunks, the super-frame consists of 24 frames, and the structure consists of 24 multiples of N octets, followed by the ABCD bits as before. For T1 SF (Super Frame, D4), the signaling bits will in general appear twice, in their regular (bit-robbed) positions, and at the end of the structure.

5 General Requirements

5.1 Quality of Service

TDM-MPLS does not provide a mechanism to ensure timely delivery or provide other quality of service guarantees. Hence these service guarantees must be provided by the MPLS layer or a lower layer.

TDM-MPLS assumes a relatively benevolent environment. On the MPLS side, this means a network with prioritization and sufficient bandwidth, and with low probability of bit error, packet order interchange and lost packets.

If layer 2 is Ethernet, the VLAN priority field can be used to prioritize the TDM-MPLS stream. Priority in the MPLS layer can be provided by using the EXP bits or MPLS traffic engineering protocol extensions. Switches and routers, which the TDM-MPLS stream must traverse, should be configured to respect these priorities. Sufficient bandwidth can be guaranteed by under-subscription and/or traffic engineering.

5.2 Jitter and Packet Loss

In order to compensate for packet delay variation, which exists in any MPLS network, a jitter buffer shall be provided. The length of this buffer should be configurable, and may be dynamic (i.e., grow and shrink in length according to the statistics of the delay variation).

In order to handle infrequent packet loss and mis-ordering, a packet order integrity mechanism shall be provided. This mechanism shall track the sequence numbers of packets in the jitter buffer, and must take appropriate action when an unexpected sequence number occurs. When missing packet(s) are detected, the mechanism shall output interpolation packet(s) in order to retain TDM timing. Packets with incorrect sequence numbers or other detectable header errors may be discarded. Packets arriving in incorrect order may be reordered. Whenever possible, interpolation packets should ensure that proper synchronization bits are sent to the TDM network.

Packet loss causes degradation of the perceived audio quality of voice services. Hence, for TDM timeslots known to be transporting voice services, the contents of the interpolation packets can be important. In the simplest implementation, predefined constant values may be substituted for the lost TDM data, resulting in preservation of TDM timing but rapid deterioration of voice quality. An alternative is to replay TDM data, so that each timeslot is fed with data previously received; if the TDM system utilizes CAS, then such replay should be performed in such a fashion as to ensure the integrity of the CAS.

5.3 Alarms and Indication Handling

The TDM-MPLS PE must be able to transfer alarms and indications representing traffic- affecting conditions, and map them between TDM, ATM and MPLS networks.

The egress PE should be able to generate an OOS code towards the TDM interface when there is an MPLS failure (such as an unrecoverable MPLS tunnel failure or LOS on the MPLS port). When there is a TDM failure, the egress PE should be able to set the L-bit in the TDM-MPLS Control Word . When the Circuit Bundle contains CAS, an OOS code should also be generated. In addition the TDM-MPLS PE should set the R-bit in the TDM-MPLS CW, or send an MPLS OAM message, as described below.

The ingress PE should be able to stop transmission of TDM traffic towards the MPLS network upon reception of a corresponding lower layer defect (such as LOS or AIS from the TDM interface) and update the L-bit in the TDM-MPLS CW, or send an MPLS OAM message.

Two types of indication, L (Local defect) and R (Remote defect) must be supported:

<u>L-Bit and M bits</u>
L-bit : Local TDM failure when set, indicates that the PE has detected or has been informed of a TDM defect impacting the TDM data being forwarded. When the L-bit is set, the contents of the frame may not be meaningful, and the payload may be suppressed in order to conserve bandwidth. Once set, the L-bit must be cleared when the TDM fault is rectified.

When interworking with ATM, the L-bit indicates ATM layer fault (e.g. F4/F5 AIS or physical layer failure in the ATM environment.

The L and M bits are used as follows:

L	M	
0	00	indicates no local defect
0	01	reserved

0	10	reports a far-end TDM RAI condition.
0	11	reserved.
1	00	indicates a local defect. When interworking with TDM networks, it indicates a local trunk failure (e.g., LOS, OOF) or a TDM layer failure (e.g., TDM AIS). Although it may be the case that several trunks are multiplexed together, these must be related trunks that share a common timing source, and so may indeed simultaneously fail. When interworking with ATM networks, it indicates an ATM layer failure (e.g., F4/F5 AIS) or physical layer failure.
1	01	reserved.
1	10	reserved.
1	11	reserved.

R-Bit

The R-bit indicates that the source is not receiving packets at its TDM-MPLS receiving port, indicating a failure of that direction of the bi-directional connection.

This bit is the equivalent of F4/F5-RDI in the ATM environment.

6 TDM-MPLS Frame Processing

6.1 Generating TDM-MPLS Frames

The generation process of a TDM-MPLS frame consists of generating AAL1 cells and aggregating several cells into one packet. Thereafter, the following TDM-MPLS frame header fields, including the L-R and M-bits, are prepended.

The length field will be generated according to the rules specified in Table 3. The sequence number field is set according to the current sequence number of the circuit bundle.

The AAL1 PDUs are constructed as per ITU-T Recommendation I.363.1 [4] and atm-vtoa-0078 (CES 2.0) [5], the number of cells per packet being set according to configuration or signaling protocol.

Once the TDM-MPLS frame has been generated, lower layers (such as Ethernet) will perform additional processing.

6.1.1 Setting the sequence number

The sequence number is defined separately for each CB and increments by one for each TDM-MPLS frame sent for that CB. It may be used by the receiver to detect packet loss and to restore the packet sequence. In addition, since the basic clock rate for each CB is constant, the sequence number may be used as an approximate timestamp for synchronization purposes.

The following procedure must be used by the ingress PE for a given TDM-MPLS service:

- For security purposes, the sequence number shall be set to a pseudo-random value for the first packet transmitted on the PW associated with the TDMoMPLS service.
- For each TDMoMPLS frame sent over a given PW, the corresponding CB's sequence number shall be incremented by 1, modulo 2^{16}.
- When RTP is used, its sequence number shall be set to a value that is identical to the sequence number in the control word.

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6.1.2 Generating the L, M and R bits

The following procedure must be used by the ingress PE in a given TDMoMPLS service:

When a TDM AIS, OOF or LOS is detected at the TDM interface of the ingress PE:

Set L=1, M=00

Note that if the L-bit is set, the contents of the packet may not be meaningful, and the payload size may be reduced in order to conserve bandwidth

When TDM RAI is detected at the TDM interface of an ingress PE:

Set L=0, M=10

When none of the defects listed above are detected:

Set L=0, M=00

All Other Combinations of L and M:

Are reserved for future use.

Note : Handling the M bit is optional

When persistent packet loss is detected at the MPLS interface of the Ingress PE:

Set R=1

Note: This response is recommended but not mandatory. Persistent packet loss is defined as no packets received for a preconfigured interval. The default value of this interval is 1 second.

When persistent packet loss is not detected.

Set R=0

6.1.3 Setting the Length Field

The Length field provides, in units of octets, the size of the TDMoMPLS frame payload, whose value is the sum of:

a. size of the control word (4 octets),

b. size of the optional timing information, and

c. size of the payload (total of all of the constituent sub-frames);

If this sum equals or exceeds 64 octets, the Length field shall be set to zero.

6.2 Generating the MPLS and PW Labels

Tunnel label (20 bits): The tunnel label identifies the MPLS LSP used to tunnel the TDM packets through the MPLS network. The label can be assigned either by manual provisioning or via an MPLS control protocol. While transiting the MPLS network there may be zero, one or several tunnel labels. For label stack usage see [7].

EXP (3 bits): The experimental field may optionally be used as defined in [18].

S (1 bit):The stacking bit indicates MPLS stack bottom. S=0 for all tunnel labels, and S=1 for the PW label.

TTL (8 bits): The MPLS Time-to-live field should be set to 2 for the PW label.

PW Label (20 bits):This label must be a valid MPLS label, and may be configured or signaled.

6.3 Generating the Optional RTP Header

An RTP header is optionally generated according to [11]. The RTP sequence number must match the sequence number of the TDMoMPLS control word.

The fields of RTP header shall be used as follows:

V (version) is always set to 2

P (padding), X (header extension), CC (CSRC count) and M (marker) are always set to 0. Accordingly, RTP header extensions, padding and contributing synchronization sources are never used.

PT (payload type):

- A PT value shall be allocated from the range of dynamic values for each direction of the PW.
- The ingress PE shall set the PT field in the RTP header to its allocated value.

Timestamps are used for carrying timing information over the network:

- Their values are generated in accordance with the rules established in [11].
- The clock frequency used for generating timestamps should be an integer multiple of 8 kHz.

The SSRC (synchronization source) field in the RTP header may be used for detection of misconnections.

6.4 Receiving TDM-MPLS Frames

When a PE receives a TDM-MPLS frame, it checks the layer 2 checksum. If the checksum is incorrect, the frame is discarded. If the checksum is correct, the PE processes the TDM-MPLS frame header fields and AAL1 cell contents. The processing is performed as per ITU-T Recommendation I.363.1 [4] and atm-vtoa-0078 (CES 2.0) [5] in order to extract the TDM traffic for transmission through one of the PE's TDM interfaces. The PE performs the following actions (not necessarily in the order shown):

- It processes the length and sequence number fields.
- It processes the AAL1 header field of each PDU, and generates the TDM traffic towards the TDM interface.
- The CRC, P and E bits in the sub-frame are checked, dependent upon whether the receiver was configured to check them. When an error is detected, the AAL1 cell is discarded, and filler data is inserted into the jitter buffer

6.4.1 Processing the sequence number

The following procedure must be used by the egress PE:

- The expected sequence number is considered to be unknown until the first PDU has been received from the MPLS network.
- The first PDU received from the MPLS network is always considered "in order"; the expected sequence number is set to the value contained in that first packet.
- If the received sequence number is equal to or greater than the expected sequence number in a cyclic sense, then the frame's content is placed into the play out buffer, and the expected sequence number is set to the received number incremented by 1 modulo 2^{16}.
- Otherwise, the received frame is dropped, and the expected sequence number is left unchanged.

The Sequence number processing pseudo-code can be found at [12] Appendix A

When a frame has been lost, the appropriate amount of filler data must be inserted into the jitter buffer.

PW frames that are received out of order may be dropped or reordered at the discretion of the egress PE.

Frame loss causes degradation of the perceived audio quality of voice services. For TDM timeslots known to be transporting voice services, the contents of the interpolation frames can be important. In the simplest implementation, predefined constant values may be substituted for the lost TDM voice data, resulting in preservation of TDM timing but rapid deterioration of voice quality. An alternative replays TDM data, so that each timeslot is fed with data previously received. If the TDM system utilizes CAS signaling then data shall be replayed in such a fashion as to ensure its integrity.

6.5 Handling the L, M and R bits

The following procedure must be used by the egress PE in a given TDMoMPLS service:

When L=0, M=00 is received

The egress PE must clear any existing alarm conditions related to these bits.

When L=1, M=00 is received

The egress PE must ignore the payload and generate AIS or Trunk Conditioning on its TDM interface. AIS generation applies to structure-agnostic mode. Trunk Conditioning generation applies to the unstructured mode. The egress PE should suppress alarms that result from buffer starvation.

When L=0, M=10 is received

The egress PE may generate TDM RAI on its TDM interface, depending upon its configuration.

For all other combinations of L and M

The PSN CES PE must ignore these values and operate as if L=0 and M=00 had been received.

When a transition in R occurs (from 0 to 1)

The egress PE must generate the applicable alarm / notification to the NMS.

When a transition in R occurs (from 1 to 0)

The egress PE must clear the applicable alarm / notification to the NMS.

7 Clock Recovery

Some TDM networks are inherently synchronous. Somewhere in the network there will be at least one extremely accurate primary reference clock, with long-term accuracy of one part in $10E^{-11}$. This node provides reference timing to secondary nodes with somewhat lower accuracy, and these in turn distribute timing information further. This hierarchy of time synchronization is essential for the proper functioning of the network as a whole; for details see [2].[3].

Packets in MPLS networks reach their destination with delay that has a random component, known as packet delay variation (PDV). When emulating TDM on an MPLS network, extracting data from the jitter buffer at a constant rate overcomes much of the high frequency component of this randomness ("jitter"). The rate at which data is extracted from the jitter buffer is determined by the destination clock; were this to be precisely matched to the source clock, proper timing would be maintained. Unfortunately the source clock information is not disseminated through an MPLS network, and the destination clock frequency will only nominally equal the source clock frequency, leading to low frequency ("wander") timing inaccuracies.

In broadest terms, there are three methods of overcoming this difficulty; in the first method, the timing information is provided by some means independent of the MPLS network. In the second method a common clock is assumed to be available to both gateways, and the relationship between the TDM source clock and this clock is encoded in the packet. This encoding may take the form of RTP timestamps, or may utilize the SRTS bits in the AAL1 overhead. In the final method (adaptive clock recovery), the timing must be deduced solely based upon the packet arrival times. Example scenarios are detailed in [14].

From the packets arriving from the MPLS network, adaptive clock recovery utilizes only observable characteristics such as the precise time of arrival of the packet at the egress PE, or the fill-level of the jitter buffer as a function of time. Due to the packet delay variation in the MPLS network, filtering processes that combat the statistical nature of the observable characteristics must be employed. Frequency Locked Loops (FLL) and Phase Locked Loops (PLL) are well suited for this task.

Whatever timing recovery mechanism is employed, the output of the egress PE TDM interface MUST conform to the jitter and wander specifications of TDM traffic interfaces, as defined in [2],[3]. For some applications, more stringent jitter and wander tolerances may be required.

8 TDM-MPLS Operation

[20] defines extensions to LDP [RFC3036] that are required to exchange PW labels for PWs emulating various Layer 2 services (Ethernet, FR, ATM, HDLC etc.). Setup of TDM PWs requires interpretation of the information elements included in these extensions.

The status of attachment circuits of TDM PWs can be exchanged between the terminating PEs, using the mechanism defined in [20]. However, usage of this mechanism with TDM PWs is NOT RECOMMENDED since an indication of the status of the TDM attachment circuits is carried in-band in the data plane.

8.1 PW FEC for Setup of TDM PWs

[20] uses LDP's Label Mapping message [RFC3036] for advertising FEC-to-PW Label binding, and defines two types of PW FEC that can be used for this purpose. Either the PW ID FEC (128) or the Generalized ID FEC (129) may be used for setup of TDM PWs with appropriate selection of PW types and interface parameters.

TDMoMPLS PWs use PW type 0x0016 (TDMoMPLS AAL1 mode), as defined in [16].

Since all TDM PW encapsulations use a control word, the Control Word bit in both FEC 128 and FEC 129 must be set for TDM PWs.

8.2 Interface Parameters for TDM PWs

8.2.1 Number of TDMoMPLS AAL1 cells per packet (0x0E)

This parameter may be present for TDMoMPLS AAL1 mode PWs (PW type 0x0016); it specifies the number of 48-byte AAL1 PDUs per MPLS packet. Any values consistent with the MTU of the underlying PSN may be specified. If this parameter is not specified, it should default to 1 PDU per packet for low bit-rates (CEP/TDM Bit-Rate less than or equal to 32), and to 5 for high bit-rates (CEP/TDM Bit-Rate of 535 or 699).

8.2.2 TDMoMPLS AAL1 mode (0x10)

This parameter may be present for TDMoMPLS AAL1 mode PWs (PW type 0x0016); it specifies the AAL1 mode. If this parameter is not present, the AAL1 mode defaults to "structured". When specified, the values have the following significance:

0 unstructured AAL1

2 structured AAL1

3 structured AAL1 with CAS.

8.2.3 CEP/TDM bit rate (0x07)

This interface parameter represents the bit-rate of the TDM service in multiples of the basic" 64 Kbit/s rate. Its usage for all types of TDM PWs assumes the following semantics:

This interface parameter must be present

For unstructured AAL1 mode

a) Unstructured E1 emulation - 32

b) Unstructured T1 emulation - 24:

c) Unstructured E3 emulation - 535

d) Unstructured T3 emulation - 699

For Structured, or Structured with CAS AAL1 mode, this parameter must be set to N, where N is the number of DS0 channels in the corresponding attachment circuit.

Note: 1. The value 24 does not represent the actual bit-rate of the T1 circuit (1.544 Mbit/s) in units of 64 kbit/s. The values mentioned above are used for convenience.
2. For Structured with CAS mode, this parameter must be set to the number of traffic bearer channels (N=30 for a full E1 with CAS)

8.2.4 TDM Options (0x0B)

. This is an Interface Parameter ID and its format is shown in Fig. 8-1 below:

0	1-7		0	1	2	3	4-5	6-7	
Parameter ID		Length	R	D	F	X	SP	CAS	RSVD-1
0	PT	RSVD-2	FREQ						
SSRC									

Figure 8-1- Format of the TDM Options Interface Parameter

The fields shown in this diagram are used as following:

Parameter ID	Identifies the TDM PW Options interface parameter(0x0B)
Length	4, 8 or 12 (see below)
R	The RTP Header Usage bit: if set, indicates that the PW end-point distributing this FEC expects to receive a RTP header in the encapsulation. A RTP header will be used only if both end-points expect to receive it. If this bit is cleared, Length must be set to 4, otherwise it must be either 8 or 12 (see section 8 below). If the peer PW end-point cannot meet this requirement, the Label Mapping message containing the FEC in question must be rejected, with the appropriate status code (see Section 8 below).
D	The Dynamic Timestamping Mode bit: if set, indicates that the PW end-point distributing this FEC expects the peer to use Differential timestamping mode in the packets sent to it. If the peer PW end-point cannot meet this requirement, the Label Mapping message containing the FEC in question must be rejected with the appropriate status code (see Section 8 below).
F, X	Reserved for future extensions. Must be cleared when distributed and must be ignored upon reception
SP	Unused bits, must be set to 0 by the PW end-point distributing this FEC, and must be ignored by the receiver
CAS	Must be cleared for all types of TDM PWs, excluding trunk-specific NxDS0 services with CAS. For these services it encodes the trunk framing per the following: '01' - an E1 trunk '10' - a T1/ESF trunk

	'11' - a T1 SF trunk
RSVD-1 and RSVD-2	Reserved bits, must be set to 0 by the PW end-point distributing this FEC, and must be ignored by the receiver
PT	Indicates the value of Payload Type in the RTP header expected by the PW end-point distributing this FEC. Value 0 means that PT value check will not be used for detecting malformed packets
FREQ	Frequency of the timestamping clock in units of 8 kHz
SSRC	Indicates the value of SSRC ID in the RTP header expected by the PW end-point distributing this FEC. Value 0 means that SSRC ID value check will not be used for detecting misconnections. Alternatively, Length can be set to 8 in this case.

Notes:

This interface parameter may be omitted when RTP is not used and CAS is not present.

A TDM PW encapsulation must either use or not use RTP in both directions. However, it is possible to use Differential timestamping mode in just one direction of the PW.

8.3 LDP Status Codes

In addition to the status codes defined in section 5.3 of [20], the following status codes defined in [16] may be used to indicate the reason of failure to establish a TDM PW.

8.3.1 Incompatible bit rate:

(a)In the case of mismatch of T1 encapsulation modes (basic vs. octet-aligned)

(b)In case of mismatch in the number of timeslots for NxDS0 basic services or trunk-specific NxDS0 services with CAS

8.3.2 CEP/TDM mis-configuration:

(a)In the case of mismatch in the desired usage of RTP header

(b)In the case of mismatch of the desired time stamping clock frequency

(c) In the case of TDMoMPLS PWs with different AAL1 modes

specified by the end-points

In cases 8.3.2 a, b and c above, the user may reconfigure the end-points and attempt to set up the PW once again.

Note that setting of the Control bit to zero must result in an LDP status of “Illegal C-Bit”.

8.4 TDMoMPLS Configurations

The LDP signaling protocol enables the transport of some configuration parameters over the PW during its setup. In addition there are several locally-configured parameters that might be configured independently at each end-point of the PW. This specification does not mandate the use of a signaling protocol; each TDMoMPLS gateway may use manual configuration as well.

For every TDM PW the following parameters should be provisioned or signaled:

Table 8-1 – TDM-Parameters

Parameter	Values	TDM Interface parameters TLV	Comments
PW label	As per label range		
PW type	TDMoMPLS AAL1 (0x16)	Interface parameters	
TDM rate	n x DS0 – n Unstructured E1 -32 Unstructured T1 - 24 Unstructured E3- 535 Unstructured T3- 699	CEP/TDM bit rate (0x07)	
AAL1 type	unstructured, structured, structured with CAS	TDMoMPLS AAL1 mode (0x10)	
Number of AAL1 PDUs per packet	1 to 30	Number of TDMoMPLS AAL1 cells per packet (0x0E)	
Clock recovery method	local, loop-back timing, adaptive, common clock	N/A Local parameter	
Jitter buffer depth	In Microseconds	N/A local parameter	
Use of RTP (if used: frequency of	Yes or No	TDM Options TLV (0x0B)	See TDM options parameters Note: May be omitted if RTP is not

common clock, PT and SSRC values).			used
Idle code pattern to play out towards the CE	01-0xFF	N/A local parameter	Applicable in case of structured or structured with CAS emulation
Payload suppression on packets containing the “L” bit	Enable or Disable	N/A local parameter	

8.4.1 TDMoMPLS Defects and impairments

During operation, the following impairment indications should be collected for each TDMoMPLS PW by the PE, and reported locally on the TDMoMPLS GW or via the management system:

Table 8-2 – TDM-MPLS indications

Indication
Indication of mis-ordered packets (successfully reordered or dropped packets)
Indication of malformed PDUs (incorrect CRC, bad C, P or E)
Indication of cells with pointer mismatch
Indication of jitter buffer over-run event
Indication of jitter buffer under-run event
Indication of remote packet loss event (R bit is set)

8.4.2 TDMoMPLS Statistics counters

During operation, the following statistics counters may be collected for each

TDMoMPLS PW, and reported to the management system per 15 minute interval, and as a total for the lifetime of the PW:

Table 8-3 – TDM-MPLS counters

Counter
Number of packets sent to the MPLS network (Current, 15 Minute interval, and total)
Number of packets received from MPLS network (Current, 15 Minute interval, and total)
Number of malformed packets (Current, 15 Minute interval, and total)
Number of Miss ordered packets (Current, 15 Minute interval, and total)
Number of Out of sequence packets (Current, 15 Minute interval, and total)
Number jitter buffer over-run events (Current, 15 Minute interval, and total)
Number of jitter buffer under-run events (Current, 15 Minute interval, and total)

9 TDM Services

TDM-MPLS is designed to transport TDM services over an MPLS network. The TDM service maps several TDM circuits to an MPLS LSP. As such, it enables DS0/DS1/DS3 cross-connect over the MPLS network. Table 2 describes supported TDM services.

Specific implementations may support any or all subset of these services.

Table9-1 – TDM-MPLS Services

Service	Type	Standard	Rate
Synchronous serial	Unstructured	V.36,V.37	-----------
T1	Unstructured	G.703 [9]	1.544Mbps
E1	Unstructured	G.703 [9]	2.048Mbps
E3	Unstructured	G.751 [10]	34.368Mbps
T3	Unstructured	T1.107 [17]	44.736Mbps
N * 64K	Structured	I.231 [13]	N x 64kbps
E1	Structured	G.704 [1]	1.984 Mbps (see Note 2)
Fractional E1	Structured	G.704 [1]	n x 64Kbps 1<= n <=31
T1	Structured	G.704 [1]	1.536 Mbps (see Note 2)
Fractional T1	Structured	T1.107 [17]	n x 64Kbps, n x 56Kbps 1<= n <=23
Channelized / Fractional T1 with CAS	Structured	G.704 [1], T1.107 [17]	n x 64 Kbps, n x 56 Kbps 1 <= n <= 23
Channelized / Fractional E1 with CAS	Structured	G.704 [1]	n x 64 Kbps, 1 <= n <= 30
AAL-1	Unstructured, Structured (see Note 1)	ITU-T I.363.1 [4], af-vtoa-0078.000 (1997) [5]	All of the above

- Both data and clock information must be transferred edge–to-edge.
- When present, CAS signaling is transparently transferred edge–to-edge.
- Trunk-associated CCS signaling is transparently transferred edge-to-edge.
- Standard TDM alarms are generated when required, and transferred edge-to -edge.

Note: Service interworking between different TDM service types is outside the scope of this specification.

10 TDM ATM Service Interworking

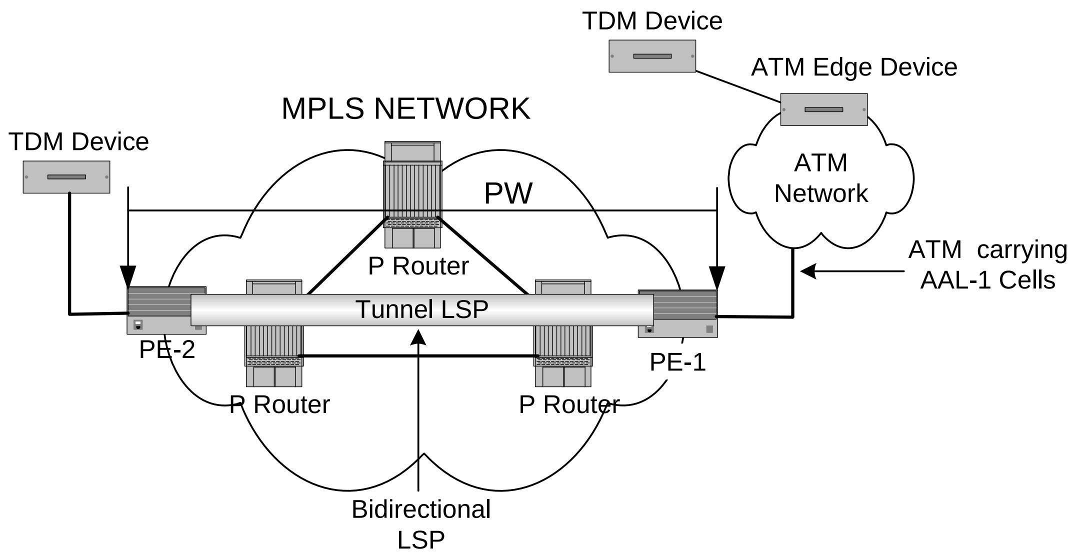

Figure 10-1 – ATM-AAL1 Service Interworking

Figure 9-1 shows a case where TDM data is transmitted across an ATM and MPLS network. It is carried over the ATM network using AAL1 circuit emulation. PE-1 extracts the AAL1 cells from the ATM stream, maps them according to VCI/VPI, to PW, appends a TDM over MPLS header, and builds a TDM-MPLS packet. At the remote side, PE-2 removes the headers, reassembles a bit stream from the AAL1 cells, and restores the TDM traffic. This model supports bi-directional service interworking.

The detailed procedures of the interworking are explained in [15].

11 ATM PW Compatibility Mode

Since TDM traffic can be carried over ATM circuit emulation services using AAL1, the protocols described in [8], may be used to indirectly transport TDM over Pseudowires. In such a case the TDM is first converted into an AAL1 ATM flow according to [4] and [5], and thereafter this ATM flow is encapsulated as described in [8],.

N:1 mode concatenates ATM cells, including their cell headers, with the exception of the HEC. Hence, a valid and locally-unique VPI/VCI must be allocated to the TDM bundle before this mode can be utilized.

The format of the control word and payload are as follows:

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

0	0	0	0	0	0	0	0	0	0	Length	Sequence Number		
VPI											VCI	PTI	C
ATM AAL1 Payload (48 bytes)													
VPI											VCI	PTI	C
ATM AAL1 Payload (48 bytes)													

VPI (12 bits), VCI (16 bits) are the ATM labels taken from the ATM cell header.

PTI (3 bits) is the ATM payload type identifier copied from the ATM header; it indicates congestion, as well as differentiating between cells containing user data and those used for maintenance.

C (1 bit) is the cell loss priority field copied from the ATM header, with C=1 indicating lower priority.

When using N:1 mode with n greater than one, MPLS OAM signaling must be employed to signal local and remote defects.

While ATM PW compatibility mode enables utilization of network devices designed according to [8], and facilitates service interworking with existing ATM circuit emulation systems, it has higher overhead (an additional 4 bytes per 48 byte cell) and its use impedes exploitation of some features of the intrinsic AAL1 mode. For example, due to the separation of the TDM processing from the edge devices, access to timing-related information may be lost, resulting in jitter and wander attenuation inferior to that obtainable via the intrinsic AAL1 mode. Packet interpolation (see section 5.2) may suffer as compared with other TDM-MPLS modes.

TDM-MPLS mode can be configured by manual provisioning or by using some signaling protocol (outside the scope of this specification.)

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