Emulation of TDM Circuits over MPLS Using Raw Encapsulation - Implementation Agreement

MFA 8.0.0

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Revision History

Version	Change	Date
MFA.8.0.0	Initial version	

1 Introduction

1.1 Objectives and Scope

This document describes a method for encapsulating TDM signals belonging to the PDH hierarchy (T1, E1, T3, E3, Nx64 kbit/s) as pseudo-wires over a MPLS network. It is fully aligned with the architecture of pseudo-wire emulation edge-to-edge (PWE3) described in [19].

In accordance with the principle of minimum intervention introduced in [19, Section 3.3.5], the proposed method uses encapsulation of raw TDM data into MPLS packets.

MPLS-based networks impose only minimal limitations on the sizes of packets they can carry (Path MTU). This permits the choice of the packet payload size to suit the specifics of the TDM service emulation, as needed.

This document describes the interface parameters that need to be established in order to allow interoperable implementations of TDM emulation. The setup and teardown of pseudo-wires carrying TDM services may be performed using generic methods such as those defined in [20] and [21].

To support emulation of TDM traffic, which includes leased line, voice, and data services, it is necessary to emulate the circuit characteristics of a TDM network. A circuit emulation header and an optional RTP-based mechanism for carrying the clock are used to encapsulate TDM signals and provide Circuit Emulation Service over a MPLS network (CESoMPLS).

A detailed specification of scope and requirements can be found in [18].

1.2 Abbreviations

AC	Attachment Circuit
AIS	Alarm Indication Signal
CAS	Channel Associated Signaling
CCS	Common Channel Signaling
CE	Customer Equipment
CEP	Circuit Emulation over Packets
CES	Circuit Emulation Services
CESoMPLS	Circuit Emulation Service over MPLS
CSRC	Contributing Source
ESF	Extended Super Frame
FCS	Frame Check Sequence
FDL	Facility Data Link
FEC	Forwarding Equivalence Class
IWF	Inter-Working Function
LOPS	Loss Of Packets State
LOS	Loss Of Signal

MIB	Management Information Base
MPLS	Multi-Protocol Label Switching
MTU	Maximal Transfer Unit
NSP	Native Service Processing
OOF	Out Of Frame
PDB	Per Domain Behavior
PDH	Plesiochronous Digital Hierarchy. PDH refers to the DS1/DS2/DS3 and E1/E3/E4 family of signals as defined by ITU-T and ATIS.
PE	Provider Edge device
PHB	Per Hop Behavior
PSN	Packet Switched Network
PT	Payload Type
PW	Pseudo-Wire
PWE3	Pseudo-Wire Emulation Edge-to-Edge
RDI	Reverse Defect Indication
RTP	Real-time Transport Protocol (an IETF protocol, described in RFC3550)
RTCP	Real-time Transport Control Protocol (an IETF protocol, described in RFC3550)
SF	Super Frame
SSRC	Synchronization Source
TDM	Time Division Multiplexing (examples of TDM services include NxDS0, DS1, DS3, T1, T3, E1, E3)

1.3 Structure-agnostic and structure-aware emulation

1.3.1 General considerations

This document considers two modes of emulation of TDM circuits: structure-agnostic (also known as "unstructured") emulation, and structure-aware (also known as "structured") emulation.

Structure-agnostic emulation: treats TDM signals as bit-streams and carries them across the MPLS network in their entirety; this includes TDM framing and the associated control information (if present), as well as the payload.

Structure-aware emulation: assumes that the TDM framing and control information are detected and possibly stripped from the TDM bit-stream at ingress, and are regenerated at egress by the appropriate Native Service Processing (NSP) blocks. The encapsulation treats the results of this processing as structured bit-streams [19], and preserves the structures across the PSN.

Applicability of structure-agnostic and structure-aware emulation depends on the specific deployment scenarios:

- Structure-agnostic emulation best serves applications where the SLA demarcation point occurs on the TDM attachment circuit between the CE and PE.

- Structure-aware emulation best serves applications where the SLA demarcation point occurs on the packet interface between the PE and the PSN. In addition, it provides for bandwidth saving in the MPLS network by suppressing unused channels.

1.3.2 Structure-agnostic emulation

CESoMPLS supports structure-agnostic emulation of the following TDM circuits:

1. DS1 (T1) at 1.544 Mbit/s as defined in [1, 5]
2. E1 at 2.048 Mbit/s as defined in [1]
3. DS3 (T3) at 44.736 Mbit/s as defined in [5]
4. E3 at 34.368 Mbit/s as defined in [3]

1.3.3 Structure-aware emulation

CESoMPLS supports structure-aware emulation of the following services:

1. Fractional or structured DS1 (T1) carrying N timeslots with N from 1 to 24, as defined in [2, 6]
2. Fractional or structured E1 carrying N timeslots with N from 1 to 31, as defined in [2]

All these services are considered special cases of the basic NxDS0 service. Emulation of structured or fractional services with Channel Associated Signaling (CAS) may also be supported, either by use of dedicated signaling packets, or by carrying the CAS in special structures within the data packets.

1.4 Specification of Requirement Levels

This document uses the following terms for specification of different requirement levels:

- **Must**, **Shall**, or **Mandatory** — the item is an absolute requirement of this implementation agreement.
- **Must Not**, or **Shall Not** - the item is an absolute prohibition of this implementation agreement.
- **Should,** or **Recommended** — there may be valid reasons for the implementer to ignore the requirement specified in the item. However, full understanding and careful consideration of all the implications for doing so is required.
- **May**, or **Optional** — the item is not compulsory, and may be followed or ignored according to the needs of the implementer.

1.5 References

1.5.1 Normative References

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2. ITU-T Recommendation G.704 (10/98) - Synchronous frame structures used at 1544, 6312, 2048, 8448 and 44 736 kbit/s hierarchical levels
3. ITU-T Recommendation G.751 (11/88) - Digital Multiplex Equipments 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

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1.5.2 Informative References

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2 Definition of CESoMPLS Protocol

2.1 CESoMPLS Packet Format

The common format of a CESoMPLS packet is shown in Figure 2-1 below.

This diagram specifies the following elements:

1. Zero, one or more transport labels. This part of the MPLS label stack provides for delivery of the CESoMPLS packet from the ingress PE to the egress PE, and represents the PSN layer of the protocol.
2. A single PW label. This label must be marked as the bottom of the label stack; it identifies the specific CESoMPLS PW for the egress PE. It represents the demultiplexing layer of the protocol, and is distributed by the egress PE using the method described in [20] and [21].
3. The CESoMPLS control word. This field represents the Encapsulation and Payload Convergence layers of the protocol. Its format and usage are discussed in detail in Section 2.2.1
4. An optional fixed RTP header. If used, this field provides synchronization services for the protocol. Details of its usage are discussed in Section 2.2.2
5. TDM payload. The format of the TDM payload is discussed in Section 2.3 below.

Zero, one, or more "transport" labels
PW label (marked as the bottom of the label stack)
CESoMPLS Control Word (32 bits)
Optional Fixed RTP Header (see [7])
Packetized TDM Data (Payload)

Figure 2-1: General Format of a CESoMPLS Packet

Note: The control word may be extended to 64 bits. Support of this extension is optional. If it is used, the control word extension must be enabled by manual configuration at subscription time, must be used for the lifetime of the PW, and must apply to both directions of the PW. The format and usage of this extension are vendor-specific, and outside the scope of this document.

2.2 CESoMPLS Encapsulation Layer

2.2.1 CESoMPLS Control Word and its Usage

The structure of the CESoMPLS Control Word is shown in Figure 2-2 below. This structure is fully aligned with [17].

RSVD (4)	L (1)	R(1)	M (2)	FRG(2)	LEN(6)	Sequence Number(16)

Figure 2-2: The structure of the CESoMPLS Control Word

In this diagram:

- RSVD is a 4-bit reserved field that must be set to 0 at ingress. Setting RSVD to 0 allows the CESoMPLS service to function correctly over routers that discriminate among packet types on the basis of the first four bits of the packet.
- Bits L (1) and M(2) encode various conditions of the TDM Attachment Circuit, as shown in Table 2-1 below.
- Bit R - carries Remote Loss of Packets indication, i.e. it is set in packets transmitted by PE-2 to PE-1 if PE-2 detects loss of packets in the stream received from PE-1. Upon packet reception, a PE must detect changes in the state of the R bit, and report these to the management system. In the case of structure-aware emulation, the PE may generate RDI in the TDM attachment circuit if the R bit is set.
- FRG bits are used to denote fragmentation of the multiframe structure into multiple packets. They are only used for structure-aware emulation of NxDS0 services with CAS (see Section 2.3.6 below). In all other modes they must be set to 0, and ignored on packet reception. Usage of these bits for denoting the first, intermediate and last fragment of the multiframe structure is as follows:

  0 0 indicates that the entire (unfragmented) multiframe structure is carried in a single packet, or that no multiframe structure is being indicated

  0 1 indicates the packet carrying the first fragment

  1 0 indicates the packet carrying the last fragment

  1 1 indicates a packet carrying an intermediate fragment
- LEN is a 6-bit field that optionally can be used to indicate the length of the CESoMPLS packet. This length is defined as the size of the CESoMPLS encapsulation header (i.e., control word and, if present, a fixed RTP header) plus the size of the TDM payload. If the length exceeds 63 bytes, the LEN field must be set to 0. When a packet with the LEN field set to 0 is received, the preconfigured size of the CESoMPLS packet payload must be assumed.
- Sequence number is a 16-bit field that is set in accordance with the rules specified in [7], Section 5.1.

L	M	Interpretation
0	00	CESoMPLS data packet - no defects (normal condition).
0	01	Reserved for further study.
0	10	CESoMPLS data packet - RDI of the TDM AC has been detected (used only with structure-aware emulation). All implementations must play out the contents of the payload and should be capable, if so locally configured, of transmitting the TDM trunk RDI towards its local CE.
0	11	Indicates a non-TDM data packet (e.g. CESoMPLS signaling packet)
1	00	Indicates that there is no valid TDM data in the packet due to an outage of the TDM AC. The relevant outage conditions include, but are not necessarily limited to LOS, AIS, and OOF. The payload may be omitted. In the case of structure-agnostic emulation, an equivalent amount of an "all-ones" bit pattern must be played out for a packet marked this way. In the case of structure-aware emulation, an appropriate amount of the locally configured "idle code" must be played out. In addition, implementations should be capable, if so locally configured, of transmitting the TDM trunk AIS towards their local CE.
1	01	Idle condition of the TDM AC has been detected (applicable only for structure-agnostic emulation of T3, and requires the presence of a T3 framer that is operated in the "transparent" mode). The payload may be omitted.
1	10	Reserved for further study
1	11	Reserved for further study

Table 2-1: Encoding of Attachment Circuit Conditions

2.2.2 Usage of the Fixed RTP Header Fields

If a fixed RTP header is used with CESoMPLS, its fields (see [7], Section 5.1) are used in the following way:

1. V (version) must be set to 2
2. P (padding), X (header extension), CC (CSRC count) and M (marker) must be set to 0
3. PT (payload type) is used as follows:
   a) One PT value must be allocated from the range of dynamic values (see [8]) for each direction of the PW. The same PT value may be reused for both directions of the PW and also reused for other PWs
   b) The PE at the PW ingress must set the PT field in the RTP header to the allocated value
   c) The PE at the PW egress may use the received value to detect malformed packets
4. Sequence number must be equal to that in the CESoMPLS control word of the same packet.

5. Timestamps are used for carrying timing information over the network:
   a) Their values are generated in accordance with the rules established in [7]
   b) The frequency of the clock used for generating timestamps must be an integer multiple of 8 kHz. All implementations of CESoMPLS must support an 8 kHz clock. Other frequencies that are integer multiples of 8 kHz may be used if both sides agree.
   c) Possible modes of timestamp generation are discussed below.
6. The SSRC (synchronization source) value in the RTP header may be used for detection of stray packets.

The RTP header in CESoMPLS can be used in conjunction with at least the following modes of timestamp generation:

1. **Absolute mode**: the ingress PE sets timestamps using the clock recovered from the incoming TDM circuit. As a consequence, the timestamps are closely correlated with the sequence numbers. All CESoMPLS implementations must support this mode
2. **Differential mode**: the two PE devices connected by the PW must have access to the same high-quality synchronization source, and this synchronization source must be used for timestamp generation. Support of this mode is optional.

2.3 CESoMPLS Payload Format

2.3.1 Common Payload Format Considerations

CESoMPLS always uses the so-called "Telecom" ordering sequence, i.e.:

1. The order of the payload octets corresponds to their order on the attachment circuit line
2. Consecutive bits coming from the attachment circuit line fill each payload octet starting from its most significant bit to its least significant one.

All the CESoMPLS packets must carry the same amount of valid TDM data in both directions of the PW. The PE devices terminating a CESoMPLS PW must agree on the number of TDM payload octets in the PW packets for both directions of the PW at the time the PW is set up.

Notes:

1. CESoMPLS packets may omit invalid TDM data in order to save PSN bandwidth (see Section 2.2.1 above)
2. CESoMPLS PWs may carry CE signaling information either in separate packets or appended to packets carrying valid TDM data. If signaling information and valid TDM data are carried in the same CESoMPLS packet, the amount of the former (agreed between the pair of PE devices) must not affect the amount of the latter.

2.3.2 Structure-agnostic emulation

For structure-agnostic emulation, the payload of a CESoMPLS packet consists of a fixed number of octets filled with the raw TDM data received from the incoming line. The packet payload size must be defined during the PW setup, must be the same for both directions of the PW, and must remain unchanged for the lifespan of the PW.

All CESoMPLS implementations must support the following packet payload size values, and may support other values:

1. E1: 256 octets
2. T1: 192 octets
3. E3 and T3: 1024 octets

2.3.3 Structure-agnostic emulation of "octet-aligned" T1

A T1 AC is sometimes provided already padded to an integer number of bytes per frame, as described in Annex B of [12]. This occurs when the T1 is de-mapped from a SONET/SDH virtual tributary/container, or when it is processed by a dual-mode E1/T1 framer.

In order to facilitate operation in such cases, CESoMPLS defines a special "octet-aligned T1" transport mode. When operating in this mode, the CESoMPLS payload consists of an integer number of 25-byte sub-frames, each sub-frame carrying 193 bits of TDM data and 7 bits of padding. This mode is depicted in Figure 2-3 below.

Packetized TDM data (193 bits)
Padding (7 bits)
...
Packetized TDM data (193 bits)
Padding (7 bits)

Figure 2-3: CESoMPLS payload format for octet-aligned T1

Notes:

1. No alignment is implied with any framing structure that may be present in the the T1 bit-stream, i.e the 193 bit blocks of the packetized TDM data do not necessarily constitute entire T1 frames, see [12], Annex B.
2. An additional advantage of the octet-aligned T1 transport mode is the ability to select the packetization latency as an arbitrary integer multiple of 125 microseconds.

Support of the octet-aligned T1 mode for structure-agnostic emulation of T1 circuits is optional. All implementations supporting this mode must support a packet payload size of 200 bytes, which corresponds exactly to a 1ms packetization latency.

2.3.4 Common considerations for structure-aware emulation

Structure-aware emulation treats attachment circuits as sequences of structures that must be preserved across an MPLS network. These structures are described in the following sections.

CESoMPLS uses two mechanisms to preserve the basic structures across the MPLS network.

In the case of basic NxDS0 service, multiple structures can be packed into a single CESoMPLS packet while keeping the packetization time reasonably low. In this case CESoMPLS must use alignment of these structures with the packet payload boundaries to preserve them across the MPLS network. This means that each packet carries an integer number of the basic structures and that the first byte of the first structure in the packet is aligned with the first byte of the packet payload.

In the case of structured services with CAS, packetization of even a single structure is often too long to be acceptable. Accordingly, CESoMPLS provides two methods to preserve these structures:

1. A single structure per packet can be carried aligned with the packet payload boundary
2. A single structure can be fragmented into multiple packets, as described in Section 2.3.6 below.

Multiple multiframe structures must not be packed into a single CESoMPLS packet.

2.3.5 Basic Nx64 kbit/s Service

The structure preserved across the PSN for the basic NxDS0 service consists of N octets filled with the data of the corresponding DS0 channels belonging to the same frame of the originating trunk(s), such that the i^{th} octet contains the data of the i^{th} DS0 channel (timeslot) in the bundle. The service generates 8000 such structures per second, i.e. packetization latency of a single structure is 125 μsec. The structures must be aligned with the packet payload boundaries. This means that each packet carries an integer number of the basic structures and that the first byte of the first structure in the packet is aligned with the first byte of the packet payload.

Packetization latency, number of timeslots, and payload size are linked by the following obvious relationship:

$$L = 8*N*D$$

where:

- L is packet payload size, in octets
- N is number of DS0 channels.
- D is packetization latency, in milliseconds

CESoMPLS implementations supporting Nx64 kbit/s services must support the following set of configurable packetization latency values:

- For N >= 4: 1 millisecond (with the corresponding packet payload size of 8*N octets)
- For 2 <= N <= 3: 4 milliseconds (with the corresponding packet payload size of 32*N octets).
- For N = 1: 8 milliseconds (with the corresponding packet payload size of 64*N octets).

Usage of any other packetization latency that is a multiple of 125 μsec (or, in other words, any packet payload size that is a multiple of N) is optional.

Structure-aware emulation can also be optionally extended to support any form of telephony signaling (CAS or CCS) by carrying the signals in dedicated signaling packets. Support of this method of signaling is either provisioned or signaled. Signaling packets should be carried in a separate pseudo-wire (different PW label), and must use a separate numbering scheme for setting the sequence numbers. If an RTP header is used, an additional RTP payload type must be allocated from the range of dynamically allocated types, and the SSRC value must be different from that used for the TDM data packets. The method of associating a pair of PWs during setup (e.g. one carrying the TDM data packets and the other carrying signaling packets) is outside the scope of this Implementation Agreement.

Encoding of CAS in the CESoMPLS signaling packets is shown in Figure 2-4 below.

Zero, one, or more "transport" labels
PW label (marked as the bottom of the label stack)
CESoMPLS Control Word (32 bits): L=0, M=11
Optional Fixed RTP Header (see [7])
Encoded CAS bits for DS0 channel #1 (see [13])
...
Encoded CAS bits for DS0 channel #N (see [13])

Figure 2-4: Format of a CESoMPLS Signaling Packet

Note: The numbering of the DS0 channels used in the diagram above represents their relative order in the bundle, and not their absolute position in the TDM E1 or T1 trunk.

The encoded CAS bits in a CESoMPLS signaling packet must be encoded in accordance with RFC2833 [13]. Signaling packets should be sent three times at an interval of 5ms on any of the following events:

1. Setup of the emulated circuit
2. A change in the signaling state of the emulated circuit
3. Loss of packets defect has been cleared
4. Remote loss of packets defect has been cleared

In the absence of any of these events, signaling packets should be sent every 5 seconds, except when there is a failure of the local TDM circuit leading to the L flag being set in the associated data frames.

2.3.6 Trunk-specific Nx64 kbit/s with CAS

The structures preserved by CESoMPLS for this group of services correspond to TDM multiframes of the originating E1 or T1 trunks, as defined in [2], sections 2.1.3.1 (for T1) and 2.3 (for E1). Each such structure contains a payload and signaling sub-structure, defined as follows:

1. The payload sub-structure can be considered as a matrix of N columns by M rows, where
   a) N is the number of DS0 channels (timeslots)
   b) M is the number of frames in the originating trunk multiframe
   c) Each row is the structure preserved in emulation of the corresponding basic NxDS0 service described above
   d) This matrix is mapped into the packet payload "row by row"
2. The signaling sub-structure uses the format defined in [9]. This is an array of N nibbles, padded by one more nibble in cases where N is odd. The i^{th} nibble carries the CAS bits of the i^{th} DS0 channel in the bundle. It directly follows the payload sub-structure.

3. Since the multiframe structures differ for different trunk types, this results in the following incompatible services:
   a) E1-originated NxDS0 with CAS. In this case:
      i) M = 16, and it takes 2 ms to packetize the structure
      ii) The i^{th} nibble of the signaling sub-structure is filled with CAS bits A, B, C, and D for the i^{th} DS0 channel taken from the corresponding E1 multiframe, starting from the most significant bit
   b) T1/ESF-originated NxDS0 with CAS. In this case:
      i) M = 24, and it takes 3 ms to packetize the structure
      ii) The i^{th} nibble of the signaling sub-structure is filled with CAS bits A, B, C, and D for the i^{th} DS0 channel taken from the corresponding T1 multiframe, starting from the most significant bit
   c) T1/SF-originated NxDS0 with CAS. In this case:
      i) Emulation preserves a structure comprising two consecutive trunk multiframes and the signaling sub-structure, so that M = 24 and it takes 3 ms to packetize the structure
      ii) The i^{th} nibble of the signaling sub-structure carries signaling bits A, B, A', and B' of the i^{th} DS0 channel taken from two consecutive multiframes of the originating trunk.

CESoMPLS implementations supporting trunk-specific Nx64 kbit/s services with CAS must not carry more TDM data per packet than is contained in a single structure. The signaling substructures must be appended to each CESoMPLS packet which contains the last octet of the payload structure (as marked by the FRG bits in the CESoMPLS control word).

All CESoMPLS implementations supporting trunk-specific Nx64 kbit/s with CAS must support the default mode where a single CESoMPLS packet carries exactly one trunk special structure (i.e. the payload and signaling blocks) aligned with the packet payload. In this case:

1. Packetization latency is:
   a) 2 milliseconds for E1 Nx64 kbit/s
   b) 3 milliseconds for T1 Nx64 kbit/s (both SF and ESF)
2. The packet payload size is:
   a) 16*N + floor((N+1)/2) for E1-Nx64 kbit/s
   b) 24*N + floor((N+1)/2) for T1/ESF-Nx64 kbit/s and T1/SF-Nx64 kbit/s

In order to provide lower packetization latency, CESoMPLS implementations of trunk-specific Nx64 kbit/s with CAS may support fragmentation of the special structures into multiple CESoMPLS packets as follows:

1. The payload block of the structure must be fragmented into fragments of equal size so that:
   a) Each fragment comprises an integer number of basic structures of the associated basic NxDS0 service
   b) These structures are aligned with the boundaries of the packet payload
2. The signaling substructure must be appended to the last payload fragment
3. The first, intermediate, and last fragments of the structure are indicated by setting the FRG bits in the CESoMPLS control word.

The resulting CESoMPLS packet payload format is shown in Figure 2-5 (a) and (b) below. In this diagram K (the number of frames in the payload sub-structure) is an integer factor of M (the number of frames in the multiframe of the originating frame).

Notes:

1. While the packet payload size of CESoMPLS packets differs from packet to packet (since some packets contain the signaling sub-structure), these packets contain a fixed amount of TDM payload.
2. In the case of a T1 trunk, the signaling bits are carried in the TDM data as well as in the signaling substructure. However, the receiver must use the CAS bits as carried in the signaling sub-structures.

Frame 1	Timeslot 1
	...
	Timeslot N
...	...
Frame K	Timeslot 1
	...
	Timeslot N

a) Packet that does not carry the signaling substructure (first or intermediate fragment)

Frame 1	Timeslot 1	
	...	
	Timeslot N	
...	...	
Frame K	Timeslot 1	
	...	
	Timeslot N	
Signaling substructure	Signaling timeslot #1	...
	Signaling timeslot #N	Padding

b) Packet that carries the signaling substructure (last fragment)

Figure 2-5: The packet payload format for trunk-specific NxDS0 with CAS

3 CESoMPLS Operation

3.1 Common Considerations

Edge-to-edge service emulation of a TDM service using CESoMPLS assumes the following elements:

- Two attachment circuits of the same type and bit rate
- Packetizer at the PW ingress
- Jitter buffer and de-packetizer at the PW egress.

Setup, teardown and maintenance of CESoMPLS PWs are based on distribution of PW labels and interface parameters. Section 3.2 describes the interface parameters required, while section 3.3 describes the locally-configured parameters that do not need to be exchanged between PEs.

The distribution of labels and parameters is outside the scope of this document. It may be achieved using either of the two forms of the PW FEC described in [20]. In the case of a PWid FEC, TDM-specific parameters are part of the Interface Parameters Field within this FEC. In the case of the Generalized PW FEC, these parameters are part of the separate Interface Parameters TLV in the Label Mapping message.

The Control Word bit in the PW FEC must be set for TDM PWs (since these always use a control word). If a PWid FEC is used for setup of TDM PWs (see [20]), PW ID values should be even for PWs carrying TDM data.

3.2 CESoMPLS PW FEC

3.2.1 Service Types and Bit Rates

The following PW types are defined in this document for CESoMPLS-based PWs:

Service Type value (to be assigned by IANA)	Attachment circuit type	Matching values of the Service Bit Rate Interface Parameter	Comment
0x0011	E1	32	Structure-agnostic emulation
0x0012	T1	24 (default) for the basic emulation mode	Structure-agnostic emulation
		25 for the "octet-aligned" emulation mode	
0x0013	E3	535	Structure-agnostic emulation
0x0014	T3	699	Structure-agnostic emulation
0x0015	Basic NxDS0	N	Structure-aware emulation
0x0017	NxDS0 with CAS	N	Structure-aware emulation

Table 3-1: CESoMPLS Service Types and Bit Rates

The CEP/TDM service bit rate is defined as an interface parameter which, if present, expresses the bit rate of the attachment circuit as known to the advertizing PE in "units" of 64 kbit/s.

The CEP/TDM service bit-rate interface parameter may be omitted in the CESoMPLS PW FEC for structure-agnostic emulation. In this case, the matching bit rate value (or the default value in the case of structure-agnostic T1 emulation) must be assumed.

The CEP/TDM service bit rate interface parameter must be present in the CESoMPLS PW FEC for structure-aware emulation.

In all cases, attempts to establish a CESoMPLS PW between attachment circuits of different type and/or bit rate must be rejected for one of the following reasons:

- incompatible bit rate
- CEP/TDM misconfiguration

These reasons should be returned as status codes by the specific protocol used for the label distribution (e.g. [20], [21]).

3.2.2 CEP/TDM Payload Bytes

This interface parameter is defined as the number of octets of TDM payload carried in each CESoMPLS packet. For NxDS0 with CAS, this excludes the CAS sub-structure carried in the last packet of every multiframe structure. Its usage on the CESoMPLS PW FEC is as follows:

1. This interface parameter may be omitted in the CESoMPLS PW FEC. In this case the default payload size (as defined in Section 2.3 for the corresponding service type and bit rate) must be assumed.
2. If the values of this parameter distributed by the two CESoMPLS PW endpoints differ, or if one of the endpoints cannot support the (non-default) value advertised by its peer, the setup attempt must be rejected, specifying CEP/TDM misconfiguration as the reason. The service endpoints should then be reconfigured.

3.2.3 TDM Options

"TDM Options" is an interface parameter defining the various configuration options associated with CESoMPLS. The format of this parameter is shown in Table 3-2 below.

Field Name	Size (bits)	Value	Comment
Parameter ID	8	0x0b	To be assigned by IANA
Length	8	4, 8 or 12	Depends on which fields are present
FLAGS	16		See Table 3-3 below
PT	8	Expected RTP payload type or 0	Value 0 means that RTP payload type will not be used for checking malformed packets. Must be omitted if RTP is not used.
RSVD	8	0	Reserved
FREQ	16	-	Frequency of the timestamping clock in units of 8 kHz. Must be omitted if RTP is not used
SSRC	32	Expected RTP synchronization source ID, or 0	Must be omitted if RTP is not used. Value 0 means that the RTP SSRC value will not be used for checking stray packets. In this case this field may be also omitted.

Table 3-2: Format of the TDM Options Interface Parameter.

The structure of the FLAGS field of the TDM Options interface parameter is shown in Table 3-3 below:

Field Name	Size (bits)	Usage
R	1	Must be set if the CESoMPLS PW endpoint distributing the FEC expects an RTP header in the encapsulation, otherwise must be cleared
D	1	Must be set if the CESoMPLS PW endpoint distributing the FEC expects differential timestamping, otherwise must be cleared.
F	1	Must be cleared for CESoMPLS.
X	1	Must be set if the CESoMPLS PW endpoint distributing the FEC expects a Control Word extension, otherwise must be cleared. A Control Word extension is used for the lifetime of the PW, and applies to both directions of the PW.
SP	2	This field encodes usage of signaling packets as follows: • 00 - the PW caries only data packets. This value must be used with structure-agnostic emulation • 01 - the PW carries TDM data packets, with the associated CE application signaling packets carried in a separate PW • 10 - the PW carries only CE application signaling packets, with the associated TDM data packets carried in a separate PW • 11 - the PW carries both TDM data packets and associated CE signaling packets
CAS	2	Must be cleared for all service types excluding trunk-specific NxDS0 with CAS. For these services the trunk framing expected by the CESoMPLS PW endpoint distributing the FEC must be indicated using the following encoding: ● 01 - an E1 trunk ● 10 - a T1/ESF trunk ● 11 - a T1/SF trunk.
RSVD	8	Must be cleared for CESoMPLS.

Table 3-3: Format of the TDM Options FLAGS field

The TDM Options interface parameter may be omitted for all structure-agnostic services and basic NxDS0 services. In this case it must be assumed that an RTP header is not expected by the CESoMPLS PW endpoint distributing the corresponding FEC.

The TDM Options interface parameter must be present for trunk-specific NxDS0 services with CAS.

Any mismatch between the expectations of the CESoMPLS PW endpoints to be interconnected must result in rejection of connection establishment, indicating a CEP/TDM misconfiguration. The PW endpoints must be reconfigured by the operator.

3.3 CESoMPLS Locally Configured Parameters

The following parameters are configured locally, and hence do not need to be exchanged as part of the PW FEC.

3.3.1 Control Word Parameters (see section 2.2.1)

- Number of consecutive lost packets after which the 'R' bit is set in the control word
- Number of consecutive received packets after which the 'R' bit is cleared in the control word
- Action on receipt of packet containing the 'R' bit set
- Conditions that will cause a PE to set the 'L' bit on packet transmission (see Table 2-1)
- Payload suppression on packets containing the 'L' bit set
- Action on receipt of packet containing the 'L' bit set (see Table 2-1)
- Action on receipt of a packet containing 'L'=0, 'M'=10 (see Table 2-1)

3.3.2 Defect Alarm Parameters (see section 3.5)

The following locally configured parameters are applicable to all defect alarms:

- Duration of high defect level after which the relevant alarm is triggered (default is 2.5s)
- Duration of low defect level after which the relevant alarm is cleared (default is 10s)

3.4 Packetization and Depacketization

Each CESoMPLS IWF instance consists of two elements:

- The PSN-bound IWF, or "packetizer"
- The CE-bound IWF, or "depacketizer"

We shall refer to the PSN-bound IWF within a given CESoMPLS instance as the "local packetizer" of its CE-bound IWF, and vice versa.

3.4.1 Packetization

The CESoMPLS PSN-bound IWF (packetizer) operates as follows:

- TDM data is packetized using the configured number of payload bytes per packet.
- Sequence numbers, flags, and timestamps (if the RTP header is used) are inserted into the CESoMPLS headers.
- The CESoMPLS header, the PW label, and if necessary, the transport labels, are prepended to the packetized service data.
- The resulting packets are transmitted over the PSN.

3.4.2 Depacketization

The CESoMPLS CE-bound IWF (depacketizer) includes a "jitter buffer", where the payload of received packets is stored prior to play-out to the local TDM attachment circuit. The size of this buffer must be locally configurable to allow accommodation of the PSN-specific packet delay variation.

The depacketizer must detect lost and misordered packets. This must be done using the sequence number in the CESoMPLS control word.

The depacketizer may reorder misordered packets. Misordered packets that cannot be reordered must be discarded and treated as lost.

The depacketizer must support play-out of the dedicated "idle code" pattern towards its local CE. All implementations of CESoMPLS must support the "all ones" pattern as the idle code. The "idle code" pattern may be locally configurable for structure-aware emulation.

Before a PW has been set up and after a PW has been torn down, the depacketizer must play out the "idle code" pattern to its TDM attachment circuit.

Once the PW has been set up, the depacketizer begins to receive CESoMPLS packets and store their payload in the jitter buffer, but continues to play out the "idle code" pattern to its TDM attachment circuit. This *intermediate state* of the depacketizer persists until a preconfigured amount of TDM data (usually half of the jitter buffer) has been received in consecutive CESoMPLS packets, or until a preconfigured intermediate state timer expires.

Once the preconfigured amount of the TDM data has been received, the depacketizer enters its *normal operation state* where it continues to receive CESoMPLS packets and store their payload in the jitter buffer while playing out the contents of the jitter buffer in accordance with the required clock. In this state the CE-bound IWF performs clock recovery (if required), should monitor PW defects, and should collect PW performance monitoring data.

The payload of each lost CESoMPLS packet must be replaced with the equivalent amount of replacement data. The contents of the replacement data are implementation-specific, and may be locally configurable. By default, all CESoMPLS implementations operating in the structure-agnostic emulation mode must support generation of the "all ones" pattern as the replacement data.

The payload of the received CESoMPLS packets marked as not carrying valid TDM data should be replaced by the equivalent amount of the "idle code" pattern even if this payload has not been omitted.

In structure-aware emulation, the depacketizer may be locally configured to force the TDM attachment circuit to transmit RDI condition towards the local CE while playing out packets marked with R = 1 or with (L = 0, M = 10) in the control word.

If the depacketizer detects loss of a preconfigured number of consecutive packets, or if the intermediate state timer expires before the required amount of TDM data has been received, it enters a *loss of packets state* (LOPS). While in this state, the depacketizer must play out the "idle code" pattern to the local CE, and its local packetizer must mark every packet it transmits with the R bit set. The depacketizer exits this state and transitions to normal operation once a preconfigured number of consecutive CESoMPLS packets have been received.

The state machine describing the behavior of the depacketizer is shown in Figure 3-1 below.

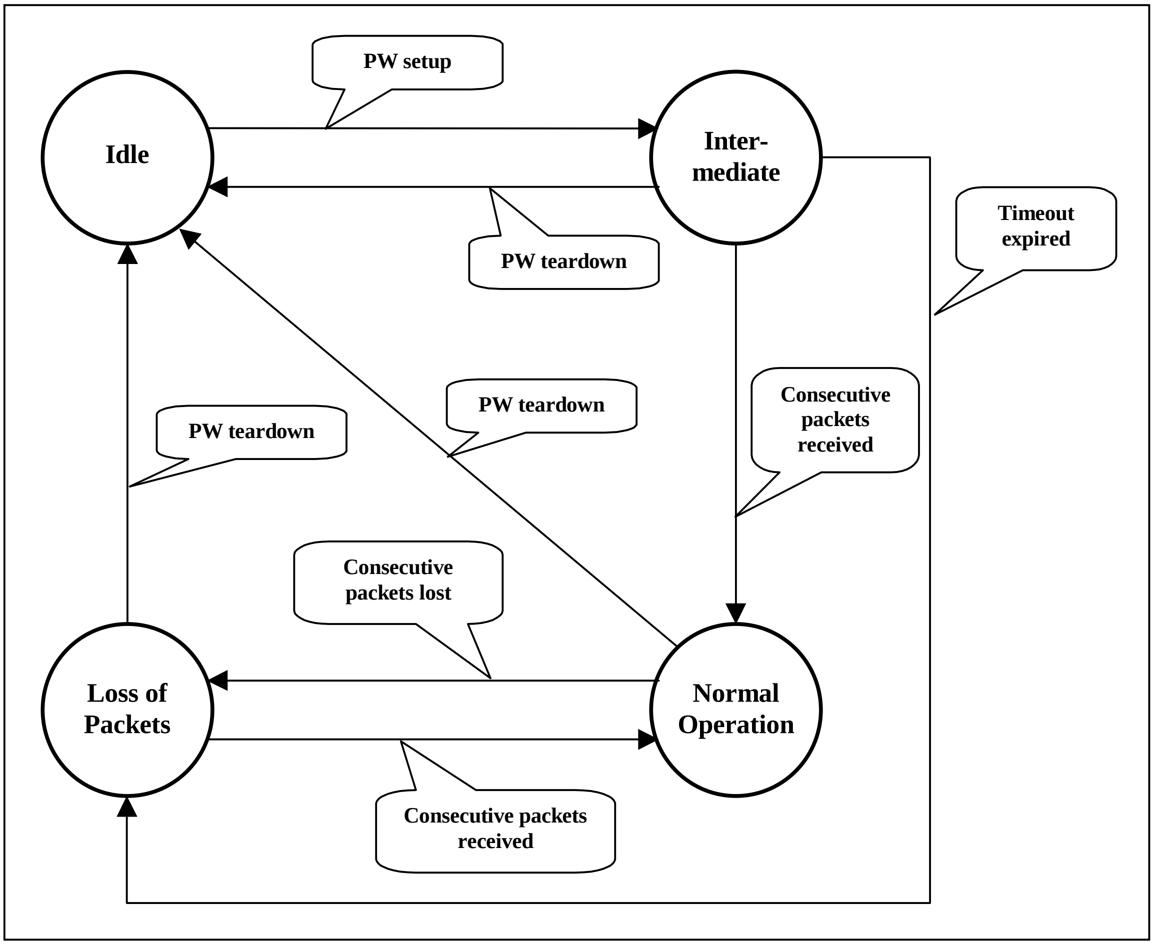

Figure 3-1: The depacketizer state machine

CESoMPLS implementations that include a TDM NSP block capable of forcing transmission of an AIS pattern to the local CE upon an appropriate command, should support the ability to locally configure the depacketizer to send such a command to the NSP when it is not in its normal operation state, or while playing out packets marked as not carrying valid TDM data.

Structure-aware CESoMPLS implementations that include a TDM NSP block capable of forcing transmission of the RDI pattern to the local CE upon an appropriate command, should support the ability to locally configure the depacketizer to send such a command to the NSP while playing out packets marked either with the R bit set or with RDI indication on.

3.5 CESoMPLS Defects

In addition to the loss of packets state (LOPS) defined above, the depacketizer may detect the following defects:

- Stray packets
- Malformed packets
- Excessive packet loss rate
- Buffer overrun
- Remote packet loss.

Detection of these defects only happens in the normal operational state of the depacketizer.

Corresponding to each defect is a defect state of the IWF, criteria for the detection and clearance of the defect that trigger transition between the normal operation state and the appropriate defect state, and an alarm that may be reported to the management system and thereafter cleared. Alarms are only reported when the defect state persists for a preconfigured amount of time (typically 2.5 seconds), and must be cleared after the corresponding defect is undetected for a second preconfigured amount of time (typically 10 seconds). The trigger and release times for the various alarms may be independent.

Stray packets may be detected by the PSN and multiplexing layers. When RTP is used, the SSRC field in the RTP header may be used for this purpose as well. Stray packets must be discarded by the depacketizer. Their detection must not affect mechanisms for detection of packet loss.

Malformed packets are detected by a mismatch between the expected packet size (taking the value of the L bit into account) and the actual packet size. The latter can be inferred from the PSN and multiplexing layers or from the LEN field in the CESoMPLS word if it is non-zero. When RTP is used, a mismatch between the expected and actual PT values may also be used for this purpose. Malformed in-order packets must be discarded by the CE-bound IWF and replacement data generated as for lost packets.

Excessive packet loss rate is detected by computing the average packet loss rate over a configurable period of time and comparing it with a preconfigured threshold.

Buffer overrun is detected in the normal operation state when the CE-bound IWF jitter buffer cannot accommodate newly-arrived CESoMPLS packets.

Remote packet loss is indicated by reception of packets with their R bit set.

3.6 Performance Monitoring

3.6.1 Errored Data Blocks

Reference [4] defines the concepts of error events, errored data blocks, and defects that serve as the basis for the collection of performance monitoring parameters of TDM circuits.

The following definitions of error events and errored data blocks for CESoMPLS provide for the collection of compatible performance monitoring parameters of CESoMPLS PWs:

- Every lost CESoMPLS packet is an error event
- An errored data block is a data block defined in accordance with [4] that has experienced at least one error event
- A defect is a transition of the CESoMPLS packetizer to its packet loss state.

These definitions can be used to define Errored Seconds, Severely Errored Seconds, and Unavailable Seconds in accordance with [4].

3.6.2 Statistics counters

This section describes the statistics counters that should be maintained. This list is based on a set of MIBs currently under development within the IETF’s PWE3 working group [23, 24, 25].

An MPLS-bound CES IWF should maintain the following statistics counters:

1. Number of packets transmitted
2. Number of payload octets transmitted

A TDM-bound CES IWF should maintain the following statistics counters:

1. Number of packets received
2. Number of payload octets received
3. Number of lost packets detected
4. Number of packets received that are out-of-sequence, but successfully re-ordered
5. Number of transitions from the normal state to the loss of packets state (LOPS)
6. Number of malformed packets received
7. Number of jitter buffer overruns
8. Number of jitter buffer underruns

3.7 QoS Issues

Normal CESoMPLS operation is possible if the underlying MPLS network meets the following conditions for delivery of CESoMPLS packets between a pair of terminating PEs:

1. Low packet loss (see [15]).
2. Limited and, preferably, low packet delay variation (PDV), see [16]).

Since the MPLS network observes only top transport labels, CESoMPLS packets should be marked at the top transport label level in order to be distinguished from the rest of the traffic. The recommended way to do so is to operate a Diffserv-enabled MPLS network [11] that implements a Per Domain Behavior (PDB, see [10]) that guarantees low-jitter and low-loss. PDBs based on the Expedited Forwarding (EF) PHB (see [14]) and appropriate admission rules are recommended for this purpose (see [22]).

CESoMPLS PWs should be operated over transport LSPs that support EF PHB.

If L-LSPs are used as transport LSPs, the entire bandwidth allocated for these LSPs may be consumed by CESoMPLS PWs, so oversubscription must not be allowed.

If E-LSPs are used as transport LSPs, CESoMPLS packets should be marked with the appropriate EXP bit values, and the Uniform tunneling model should be used in order to guarantee preservation of this marking end-to-end. Bandwidth restrictions on CESoMPLS in this case are left for further study.

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