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Cable Modem TDM Emulation Interface Standard

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Contents

1	SCOPE AND PURPOSE	1
1.1	SCOPE	1
1.2	INTRODUCTION AND OVERVIEW	1
1.3	REQUIREMENTS AND CONVENTIONS	2
2	REFERENCES	3
2.1	NORMATIVE REFERENCES	3
2.2	INFORMATIVE REFERENCES	5
2.3	REFERENCE ACQUISITION	5
3	TERMS AND DEFINITIONS	6
4	ABBREVIATIONS AND ACRONYMS.....	8
5	TECHNICAL OVERVIEW	9
5.1	BACKGROUND	9
5.2	PRINCIPAL TECHNICAL CONSIDERATIONS	10
5.3	DEVICES/INTERFACES	10
5.3.1	TE-CM	10
5.3.2	TE-CMTS	11
5.3.3	Embedded TDM Emulation Adaptor (eTEA).....	12
5.3.4	TDM Emulation Adaptor (TEA)	13
5.4	ARCHITECTURE	14
5.4.1	TE-CM to TE-CMTS w/TEA.....	14
5.4.2	TE-CM to Centralized TEA	15
5.4.3	TE-CM to TE-CM through TE-CMTSs and Core.....	15
5.4.4	Other Architecture Considerations.....	16
5.4.5	M-CMTS & CMTS Architecture Considerations.....	17
5.5	NETWORK ENVIRONMENT	17
5.5.1	Clocking.....	17
5.5.2	Quality of Service (QoS)	19
6	TECHNICAL SPECIFICATION.....	21
6.1	GENERAL REQUIREMENTS.....	21
6.1.1	CU Clock Unit.....	21
6.1.2	PW Pseudo-Wire	21
6.1.3	IWF InterWorking Function.....	21
6.1.4	TSP TDM Service Processor.....	21
6.1.5	TEA TDM Emulation Adapter.....	23
6.1.6	eTEA Embedded TDM Emulation Adaptor	23
6.1.7	TE-CM TDM Emulation Cable Modem	23
6.1.8	TE-CMTS TDM Emulation CMTS.....	23
6.2	TDM-IP NETWORK INTERWORKING	24
6.2.1	IP Header Fields	25
6.2.2	UDP Header Fields.....	25
6.2.3	Control Word Header Fields.....	25
6.2.4	RTP Header Fields.....	26
6.2.5	RTCP Extended Report (XR) Option	27
6.3	PAYLOAD FORMATS.....	27
6.3.1	Structure Agnostic Transport	28
6.3.2	Structure Aware Transport.....	28
6.4	TIMING ASPECTS	31
6.4.1	Direct Clocking	31
6.4.2	Network Clock Recovery (NCR).....	32

6.4.3	<i>Prime Differential Clock Recovery (PDCR)</i>	33
6.4.4	<i>Adaptive Clock Recovery (ACR)</i>	35
6.4.5	<i>TE-CM Ethernet Timing Service</i>	35
6.4.6	<i>TE-CMTS Timing Requirements</i>	35
6.4.7	<i>Clock Recovery Performance Requirements</i>	36
6.5	DEFECTS AND MONITORING	43
6.5.1	<i>Alarm states and Alarms</i>	43
6.5.2	<i>Packet Reordering</i>	44
6.5.3	<i>Packet Loss Concealment</i>	44
6.5.4	<i>Packet Loss Statistics</i>	44
6.5.5	<i>Stray Packets</i>	44
6.5.6	<i>Packet Activity during Provisioning</i>	44
6.6	SECURITY	44
6.7	PROVISIONING AND SERVICE INITIATION	44
6.7.1	<i>Provisioning of Embedded TDM Emulation Adaptor (eTEA)</i>	44
6.7.2	<i>UGS Flow Provisioning</i>	64
6.7.3	<i>TDM Emulation Adaptor (TEA) Provisioning</i>	64
6.8	MANAGEMENT.....	64
6.8.1	<i>Management Model</i>	64
6.8.2	<i>Managed objects requirements</i>	65
6.8.3	<i>TLV to MIB Object Mapping</i>	67
ANNEX A	EVENT, SYSLOG, AND SNMP TRAP EXTENSIONS (NORMATIVE)	70
A.1	TEA EVENTS DESCRIPTION	70
A.1.1	<i>TEA event process "Init"</i>	70
A.1.2	<i>TEA event process "Oper"</i>	70
A.2	DOCSIS EVENTS EXTENSIONS	70
APPENDIX I	OPERATOR RECOMMENDATIONS (INFORMATIVE)	72
I.1	PREFERENTIAL TREATMENT FOR TE-CMS.....	72
I.1.1	<i>Segregation of T1 traffic</i>	72
I.1.2	<i>Preferential ranging opportunities</i>	72
I.2	SERVICE LEVEL AGREEMENT CONSIDERATIONS	72
I.3	STANDARD DOCSIS OPERATIONS	73
I.3.1	<i>Downloading</i>	73
I.3.2	<i>Scheduled Service</i>	73
I.3.3	<i>Provisioning</i>	73
I.3.4	<i>Balancing operations</i>	73
APPENDIX II	DELAY ASPECTS (INFORMATIVE)	74
II.1	UPSTREAM DELAY	74
II.1.1	<i>Packetization Delay</i>	74
II.1.2	<i>Processing Delay in TE-CM</i>	74
II.1.3	<i>Propagation Delay</i>	74
II.1.4	<i>Delay in CMTS</i>	75
II.1.5	<i>M-CMTS Delay</i>	75
II.2	DOWNSTREAM DELAY	75
II.2.1	<i>Packetization Delay</i>	75
II.2.2	<i>Delay in CMTS</i>	75
II.2.3	<i>Propagation Delay</i>	75
II.2.4	<i>Delay in TE-CM</i>	75
II.2.5	<i>M-CMTS delay</i>	75
APPENDIX III	BANDWIDTH USAGE (INFORMATIVE)	77
III.1	UPSTREAM BANDWIDTH USAGE	77
III.2	DOWNSTREAM BANDWIDTH USAGE	78

III.2.1	Downstream RF Bandwidth Usage.....	78
III.2.2	DEPI Bandwidth Usage.....	78
APPENDIX IV ETEA CONFIGURATION EXAMPLE (INFORMATIVE).....		79
IV.1	STRUCTURE AGNOSTIC T1 CONFIGURATION	79
IV.2	STRUCTURE AGNOSTIC E1 CONFIGURATION	80
IV.3	STRUCTURE AWARE 5xDS0 CONFIGURATION.....	80
IV.4	STRUCTURE AWARE 5xDS0 CONFIGURATION WITH CAS	81
IV.5	STRUCTURE AWARE T1 WITH RTP CONFIGURATION	83
APPENDIX V CLOCKING OPTIONS, BY EXAMPLE (INFORMATIVE).....		84
V.1	BACKGROUND	84
V.2	CLOCKING MODES	85
V.2.1	Network clocking.....	85
V.2.2	Prime Differential Clock Recovery.....	86
V.2.3	Adaptive Clock Recovery	86
V.3	CLOCKING DECISION TREE.....	87

List of Figures

FIGURE 1-1 - EXAMPLE OF T1 SERVICE DELIVERY	1
FIGURE 5-1 - TE-CM.....	11
FIGURE 5-2 - TE-CMTS	12
FIGURE 5-3 - eTEA	13
FIGURE 5-4 - TEA	14
FIGURE 5-5 - T1 TO HUB ARCHITECTURE	15
FIGURE 5-6 - T1 TO TDM CORE, IXC OR PSTN	15
FIGURE 5-7 - T1 PRIVATE LINE BETWEEN TWO CUSTOMER SITES	16
FIGURE 5-8 - COMPREHENSIVE PRIVATE AND PUBLIC T1/E1 SERVICES	17
FIGURE 6-1 - HEADER FORMAT (ONLY IPV4 SHOWN).....	24
FIGURE 6-2 - PAYLOAD FORMAT FOR STRUCTURE-AWARE TRANSPORT	29
FIGURE 6-3 - SIGNALING SUB-STRUCTURE	31
FIGURE 6-4 - DESCRIPTION OF PDCR "TRANSMIT" FUNCTION.....	34
FIGURE 6-5 - CLOCK RECOVERY - PERFORMANCE TEST ENVIRONMENT	36
FIGURE 6-6 - CLOCK RECOVERY INITIALIZATION TIME	41
FIGURE 6-7 - CLOCK RECOVERY SETTling TIME	42
FIGURE 6-8 - REJECTING IMPULSE NOISE	42
FIGURE 6-9 - DEVICE STATES AND STATE TRANSITIONS FOR BASIC FLOW PROVISIONING	45
FIGURE 6-10 - CONCEPTUAL LAYERING	65
FIGURE 6-11 - PW EXAMPLES.....	66
FIGURE V-1 - NETWORK CLOCKING - CMTS TO CM.....	85
FIGURE V-2 - PRIME DIFFERENTIAL CLOCK RECOVERY	86
FIGURE V-3 - ADAPTIVE CLOCK RECOVERY	87

List of Tables

TABLE 6-1 - G.823 AND G.824 CLOCK REQUIREMENTS	22
TABLE 6-2 - DOCSIS SYMBOL CLOCKS	32
TABLE 6-3 - MTIE OF CMTS MASTER CLOCK	36
TABLE 6-4 - TDEV OF CMTS MASTER CLOCK.....	36
TABLE 6-5 - NETWORK IMPAIRMENT CONSTANTS (NIM1)	39
TABLE 6-6 - NETWORK IMPAIRMENT CONSTANTS (NIM2)	40
TABLE 6-7 - NIM2 CHARACTERISTICS.....	40
TABLE 6-8 - CLOCK RECOVERY PERFORMANCE CONSTANTS.....	43
TABLE 6-9 - eTEA POWER-ON INITIALIZATION FLOW	46
TABLE 6-10 - eTEA INITIALIZATION FLOW	46
TABLE 6-11 - DHCP OPTION 43 SYNTAX	48
TABLE 6-12 - TLV DEFINITIONS	49
TABLE 6-13 - TLV TO MIB OBJECT MAPPING	67
TABLE A-1 - DOCSIS EVENTS EXTENSIONS.....	70
TABLE III-1 - UPSTREAM BANDWIDTH COMPUTED FROM DOCSIS 2.0.....	77
TABLE III-2 - AN EXAMPLE OF UPSTREAM BANDWIDTH USAGE	77
TABLE III-3 - AN EXAMPLE OF DOWNSTREAM BANDWIDTH USAGE	78
TABLE IV-1 - STRUCTURE AGNOSTIC T1 PW CONFIGURATION FILE EXAMPLE	79
TABLE IV-2 - STRUCTURE AGNOSTIC E1 PW CONFIGURATION FILE EXAMPLE	80
TABLE IV-3 - STRUCTURE AWARE NXDS0 PW CONFIGURATION FILE EXAMPLE	80
TABLE IV-4 - STRUCTURE AWARE NXDS0 PW CONFIGURATION FILE EXAMPLE	81
TABLE IV-5 - STRUCTURE AWARE NXDS0 PW CONFIGURATION FILE EXAMPLE	83
TABLE V-1 - BSoD CLOCKING MODES	84

1 SCOPE AND PURPOSE

This document is identical to SCTE 136-2 2013 except for informative components which may have been updated such as the title page, NOTICE text, headers and footers. No normative changes have been made to this document.

1.1 Scope

TDM Emulation service (TDM-E) is a method for cable operators to deliver T1, E1 and NxDS0 emulation services that meet or exceed the quality requirement of applications that use such services. This standard is part of the Cable Modem family of standards and in particular, defines the TDM-E architecture and components.

1.2 Introduction and Overview

In legacy telecommunication networks, telephone calls are often brought into households, one at a time, over twisted pair wires. To transport many telephone calls at once (i.e., between business, wireless base stations and in the telephone network), single calls are time-multiplexed together into 'T1' signals. A single T1 signal carries 24 individual calls, and a similar 'E1' signal carries 32 calls. Since T1 and E1 (T1/E1) services have been deployed for quite some time, the performance standards, tariffs and market are well defined. A number of ITU, ETSI and ANSI standards define the various aspects of T1/E1 services. Moreover, the usage and deployment models of T1/E1 lines are well understood.

This document outlines the methods by which T1/E1 structured, unstructured, and fractional signals can be converted to IP packets, transported over a DOCSIS IP network, and converted back to T1/E1 signals with high reliability and quality. Figure 1–1 shows a simple T1 Service delivered between two customer sites over DOCSIS.

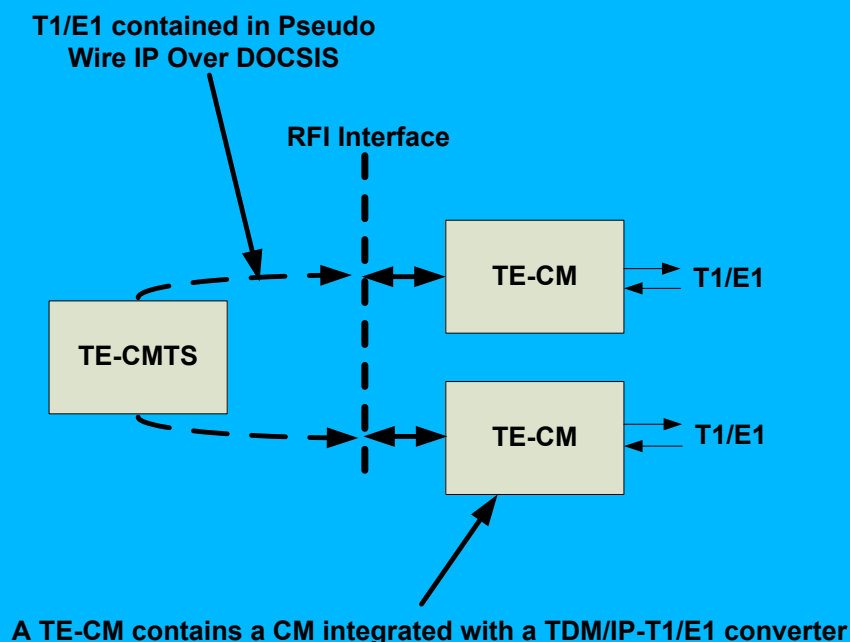


Figure 1–1 - Example of T1 Service Delivery

1.3 Requirements and Conventions

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST"	This word means that the item is an absolute requirement of this specification.
"MUST NOT"	This phrase means that the item is an absolute prohibition of this specification.
"SHOULD"	This word means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.
"SHOULD NOT"	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
"MAY"	This word means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, i.e., another vendor may omit the same item.

2 REFERENCES

The following documents contain provisions, which, through reference in this text, constitute provisions of the standard. At the time of Subcommittee approval, the editions indicated were valid. All standards are subject to revision; and while parties to any agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents may not be compatible with the referenced version.

2.1 Normative References

[DEPI]	ANSI/SCTE 137-2, DOCSIS Downstream External PHY Interface for Modular Cable Modem Termination Systems
[DRFI]	ANSI/SCTE 133, DOCSIS Downstream RF Interface for Cable Modem Termination Systems
[CMCI]	ANSI/SCTE 135-5, DOCSIS 3.0 Part 5: Cable Modem to Customer Premise Equipment Interface
[DTI]	ANSI/SCTE 137-1, DOCSIS Timing Interface for Cable Modem Termination Systems
[MULPIv3.0]	ANSI/SCTE 135-2, DOCSIS 3.0 Part 2: MAC and Upper Layer Protocols
[OSSIV2.0]	ANSI/SCTE 79-2, DOCSIS 2.0 Part 2: Operations Support System Interface
[OSSIV3.0]	ANSI/SCTE 135-4, DOCSIS 3.0 Part 4: Operations Support System Interface Specification
[PHYv3.0]	ANSI/SCTE 135-1, DOCSIS 3.0 Part 1: Physical Layer Specification
[RFI 1.1]	ANSI/SCTE 23-1, DOCSIS 1.1 Part 1: Radio Frequency Interface
[RFI 2.0]	ANSI/SCTE 79-1, DOCSIS 2.0 Part 1: Radio Frequency Interface
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[IEEE 1588]	"IEC/IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems", 61588-2004, November 15, 2004, IEEE.
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[ITU-T G.704]	ITU-T Recommendation G.704 (10/98) - Synchronous Frame Structures Used At 1544, 6312, 2048, 8488, and 44 736 Kbit/s Hierarchical Levels, International Telecommunication Union.
[ITU-T G.706]	ITU-T Recommendation G.706 (4/91) - "Frame alignment and cyclic redundancy check (CRC) procedures relating to basic frame structures defined in Recommendation G.704", International Telecommunication Union.
[ITU-T G.732]	ITU-T Recommendation G.732 (11/88) - "Characteristics of primary PCM multiplex equipment operating at 2048 kbit/s", International Telecommunication Union.
[ITU-T G.810]	ITU-T Recommendation G.810 (8/96) - "Definitions And Terminology For Synchronization Networks", International Telecommunication Union.
[ITU-T G.823]	ITU-T Recommendation G.823 (03/00) - "The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy", International Telecommunication Union.
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[ITU-T G.1050]	ITU-T Recommendation G.1050 (11/05) – Network model for evaluating multimedia transmission performance over internet protocol, International Telecommunication Union.

- [ITU-T J.83] ITU-T Recommendation J.83 (12/07) - Digital multi-program systems for television, sound and data services for cable distribution, International Telecommunication Union.
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- [TR-62411] AT&T Technical Reference 62411, "AT&T ACCUNET T1.5 Service Description and Interface Specification", December 1990, AT&T.

2.2 Informative References

This standard uses the following informative references.

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- [IANA UDP PORTS] Internet Assigned Numbers Authority, Port Numbers, January 4 2010, Refer to <http://www.iana.org/assignments/port-numbers>.
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- Society of Cable Telecommunications Engineers (SCTE), <http://www.scte.org>.
- Telecommunications Industry Associations (TIA), <http://www.tiaonline.org/>.
- Telcordia Technologies, <http://www.telcordia.com/>.

3 TERMS AND DEFINITIONS

This standard uses the following terms:

Alarm Indication Signal	Also known as the <i>blue alarm</i> . When no incoming signal is detected, a CSU/DSU transmits an unframed all-ones pattern to the network to maintain synchronization and announce its presence to the network.
CU	A Clock Unit (CU) performs translations and distribution of TDM clocking information across (and between) physical, data, and network layers.
CRU	A Clock Recovery Unit (CRU) exists in the IWF and is responsible for regenerating the circuit's clock based on the average inter-arrival time of the packets in the adaptive clocking mode, or on the time stamp differentials received when operating in the differential clock mode. The output clock is provided to the CU.
Channel Service Unit	The piece of a CSU/DSU that talks to the Telco network, understands framing and line coding, and provides electrical isolation of the network from the Telco network.
Data Service Unit	The part of the CSU/DSU that interfaces with routers, switches, and packets. It has a serial port to interface with compatible data equipment.
DS0	Digital signal 0 (DS0) is a basic digital signaling rate of 64 kbit/s, corresponding to the capacity of one voice-frequency-equivalent channel.
E1	E1 is a physical layer telephony protocol carrying data at 2.048 Mbps. It can carry up to 32 DS0s, each of which can carry a telephone conversation.
eTEA	An eTEA is an eDOCSIS eSAFE; an embedded version of a TEA.
Fractional	A Fractional T1 or Fractional E1 carries only a portion of the total number of DS0s that a T1 or E1 carries.
IWF	An Interworking Function (IWF) is a logical entity. It consists of a TSP data interface on one side, an IP Packet interface on the other side, and the functionalities to encode TDM data into a Pseudo wire in one direction and decode TDM data from Pseudo Wire in the other direction.
J1	J1 is the Japanese version of a T1; it has some alarm and framing differences as compared with T1.
Jitter	The fluctuation in the arrival time of a regularly scheduled event such as a clock edge or a packet in a stream of packets. Jitter is defined in [ITU-T G.810] as fluctuations above 10 Hz. See Wander.
LCI	A Logical CPE Interface (LCI) is a logical 802.3/Ethernet MAC frame data interface.
Loss of Frame	Also called the <i>red alarm</i> . When a T1 CSU/DSU is unable to synchronize framing patterns with the remote end for 2.5 seconds, LOF is declared
Loss of signal	When no incoming pulses are received by a T1 CSU/DSU for a prescribed number of bit times, LOS is declared. Even if only zeros were transmitted as data, some framing bits should result in pulses on the line during that time. If LOS persists, LOF will eventually be declared because there is no incoming signal with which to synchronize.
MTIE	Maximum Time Interval Error as defined in [ITU-T G.810].
Out of Frame	When frame synchronization is lost, an OOF event is recorded. If OOF persists, LOF is declared. OOF is cleared when frame synchronization is regained.
Pseudo Wire	A Pseudo Wire (PW) is a logical entity capable of the emulation of a native service (i.e., T1) over a Packet Switched Network (like DOCSIS IP).

Remote alarm indication	Also known as <i>yellow alarm</i> . When a CSU/DSU enters the red alarm state, an RAI is transmitted in the outgoing direction. The RAI signals to the remote end that the local end is unable to synchronize framing patterns.
T1	T1 is a physical layer telephony protocol carrying data at 1.544Mbps. It can carry up to 24 DSOs, each of which can carry a telephone conversation. It is used mainly in North America.
TDEV	Time Deviation as defined in [ITU-T G.810].
TDM Interface	A physical Time Domain Multiplex (TDM) telephony interface such as T1, E1, or J1. Time Division Multiplexing (TDM) is the means by which multiple digital signals (DSOs) can be carried on a single transmission path by interleaving portions of each signal in time.
TEA	A TDM Emulation Adapter (TEA) is a logical entity containing various functions to provide a BSoD-TE circuit emulation service.
TE-CM	The TDM Emulation Cable Modem (TE-CM) is a special purpose cable modem that integrates a DOCSIS eCM with an eTEA.
TE-CMTS	A TE-CMTS is a CMTS or M-CMTS that can support a TE-CM and can meet the minimum clocking and performance goals to support BSoD-TE traffic. A TE-CMTS may or may not support integrated TEAs.
TSP	A TDM Service Processor (TSP) consists of a TSP data interface on one side, a TDM Interface on the other side, and the functionalities to encapsulate TSP data into TDM Interface signals in one direction and extract TSP data from TDM Interface signals in the other direction.
Wander	Low speed jitter. Wander is defined in [ITU-T G.810] as fluctuations below 10 Hz. See Jitter.

4 ABBREVIATIONS AND ACRONYMS

This standard uses the following abbreviations and acronyms:

ACR	Adaptive Clock Recovery
AIS	Alarm Indication Signal
A-TDMA	Advanced Time Division Multiple Access
CBR	Constant Bit Rate
CM	Cable Modem
CMTS	Cable Modem Termination System
CSU	Channel Service Unit
DEPI	DOCSIS External PHY Interface
DOCSIS®	Data-Over-Cable Service Interface Specifications
DS	Downstream
DSU	Data Service Unit
DTI	DOCSIS Timing Interface
HFC	Hybrid Fiber Coax
IP	Internet Protocol
LOF	Loss of frame
LOS	Loss of signal
MAC	Media Access Control
MPLS	Multiprotocol Label Switching
OOF	Out of frame
PDCR	Prime Differential Clock Recovery
PW	Pseudo Wire
RAI	Remote alarm indication
RF	Radio Frequency
S-CDMA	Synchronous Code Division Multiple Access
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service

5 TECHNICAL OVERVIEW

5.1 Background

Throughout the evolution of communication networks the T1 and E1 service that is delivered to the customer has remained relatively consistent (in large part due to the strict ITU and ANSI standards), however the method of delivering the T1 or E1 service has changed to increase efficiencies and leverage new technologies. Both SONET and ATM historically have been adapted to transport T1 and E1 services; now MPLS and IP networks are also being used. Various standards bodies and vendors have created methods for circuit emulation of T1 and E1 services across IP networks, leveraging the successful ATM circuit emulation technology developed in the 90s. This standard leverages the work done in the ITU and IETF to define circuit emulation of T1 and E1 over a DOCSIS network.

This standard describes the architecture and components of a network that delivers emulated T1 or E1 or NxDS0 services over DOCSIS. It defines the T1, E1, or NxDS0 service delivered to the end customer, the requirements of a BSoD-TE compliant cable modem (TE-CM), and the requirements of a BSoD-TE compliant CMTS (TE-CMTS), the requirements of the TDM Emulation Adaptor (TEA), and Pseudo Wires (PW) that cross the packet network connecting two TEAs.

In developing this standard, the following assumptions were made concerning the implementation and deployment of BSOD-TE systems:

- Interoperation with DOCSIS CMTS versions and options:
Existing CMTSs can lock their existing DOCSIS symbol clock or DOCSIS SYNC message generation to master clock inputs for both A-TDMA [RFI 2.0] and S-CDMA [PHYv3.0]. The chain of clock synchronization is that Stratum 1 Traceable Reference drives the DOCSIS master clock; the master clock drives the DOCSIS downstream timing; and the CM recovers timing from the DOCSIS downstream).
- Some CM silicon originally developed for DOCSIS 1.1 or 2.0 residential data modems can be used in a design where the symbol clock or DOCSIS SYNC message may be recovered to generate a T1/E1 clock.
- From time to time this document may refer to the voice communications capabilities of a TE-CM device / TDM-IP protocol in terms of "IP Telephony." The legal/regulatory classification of IP-based voice communications provided over cable networks and otherwise, and the legal/regulatory obligations, if any, borne by providers of such voice communications, are not yet fully defined by appropriate legal and regulatory authorities. Nothing in this standard is addressed to, or intended to affect, those issues. In particular, while this document uses standard terms such as "call," "call signaling," "telephony," etc., it should be recalled that, while a TE-CM device / TDM-IP protocol performs activities analogous to these PSTN functions, the manner by which it does so differs considerably from the manner in which they are performed in the PSTN by telecommunications carriers, and that these differences may be significant for legal/regulatory purposes. Moreover, while reference is made here to "IP Telephony," it should be recognized that this term embraces a number of different technologies and network architectures, each with different potential associated legal/regulatory obligations. No particular legal/regulatory consequences are assumed or implied by the use of this term.
- TE-CMs are always connected to a TE-CMTS with QoS support for constant bit rate flows. The TE-CMTS complies with DOCSIS 1.1 or 2.0. A DOCSIS 1.0 CMTS will not be able to host TE-CMs. DOCSIS 1.1 may be limited in upstream bandwidth; TE-CM data flows are symmetric upstream and downstream.
- J1 can be partially supported, as outline in Section 6.3.1.
- It's not in the scope of this standard to cover interoperation between dissimilar services, i.e., between E1 and T1.
- The following requirements are market specific and are out of scope in this standard:
 - Path redundancy and equipment redundancy (like redundant power supplies),
 - Environmental hardening, such as clock stability over temperature.

- There is not sufficient need to support the 'octet-aligned format' of [RFC 4553] section 5.2, which is designed to simplify the data handling in and out of a Sonet/SDH virtual tributary/container. This standard does not support that format.

5.2 Principal technical considerations

This section describes the principle technologies and operational considerations germane to the development of a T1/E1-bearing TE-CM and its use. Major sub-topics include:

- Clocking - T1/E1 transport technology is synchronous in nature; requiring accurate and stable clocking. Since T1 transport requires that T1 signals are handed from one service provider to another, each service provider must adhere to the same clocking requirements. Further, these synchronous clocking requirements must be very stringent to ensure reliable operation. The section on clocking (Section 5.5.1) will further describe these requirements largely based on existing ITU and ATIS requirements.
- Data Protocol
 1. Voice protocol - Phone calls at termination are completely analog, carrying linear voice signals over dedicated wires. It wasn't long before the phone companies realized that a wire could carry more than one phone call if the calls were time-multiplexed on the wire. Calls are now time-sampled, and the resulting digital signals are time-multiplexed over wires in T1/E1 formats (among others).
 2. Data protocol - It did not take long for engineers to realize that T1/E1 transport could be used for standard data (not just voice). T1 signals are now used to transport digital data in many different data formats which are beyond the scope of this spec. This standard accommodates the transport of either voice or data by specifying more than one data format for the IP packets that carry the T1 information over DOCSIS channels. The sections below addressing 'structure agnostic' protocol are germane to data transport. Most of this standard addresses T1 transport of voice calls, but the standard accommodates data transport as well.
 3. Signaling data protocol - To successfully combine several voice phone calls into a T1 structure, data describing the state of each call must be included. Such call state data may include the progress of the call and the health of the transport network carrying the call. Several existing standards describe this signaling data. This standard describes the format for signaling data in the IP packets that carry the T1 information over DOCSIS channels.
- Operations - The synchronous transport systems put together by telecommunications carriers for T1 data have been refined over the years to become very reliable. But the manner by which a DOCSIS transport system performs this service differs considerably from the manner in which they are performed in the PSTN by telecommunications carriers. Operators of DOCSIS systems can alter their standard operating procedures to accommodate these differences. This standard makes many suggestions for operators who must configure DOCSIS systems to carry emulated T1/E1 data as specified herein.

5.3 Devices/Interfaces

5.3.1 TE-CM

A TE-CM is a standard DOCSIS cable modem that contains an embedded TDM Emulation Adaptor (eTEA) giving it the ability to offer T1/E1 services. A TE-CM may have architecture and interfaces similar to that shown in Figure 5-1 below. The power supply and other functionality that is out of scope are not shown. The elements/interfaces are described as follows:

- DOCSIS eCM - This is a standard DOCSIS CM conforming to DOCSIS 1.1, 2.0, 3.0 or greater. It must be able to carry a constant bit rate service flow carrying packets at bit rates sufficient to handle T1/E1 data, management and signaling as defined herein. It also contains [eDOCSIS] functions sufficient to support eTEA and Ethernet functionality. Per DOCSIS, it has both RF and Ethernet interfaces. The embedded DOCSIS CM chipset provides clocking to the eTEA recovered from the DOCSIS symbol clock or DOCSIS SYNC message as defined in Section 6.4.
- eTEA - The TE-CM contains an eTEA that operates as an eDOCSIS eSAFE.

- T1/E1 Interface - This interface is a standard T1/E1 connector.
- Ethernet Interface - This interface is a standard Ethernet connector (RJ45). It may, in future, provide the capability to exchange IP packets with eTEA or other BSoD-TE entities that may exist outside the TE-CM.
- Logical CPE Interface - This is an unspecified interface between the eTEA and eCM.

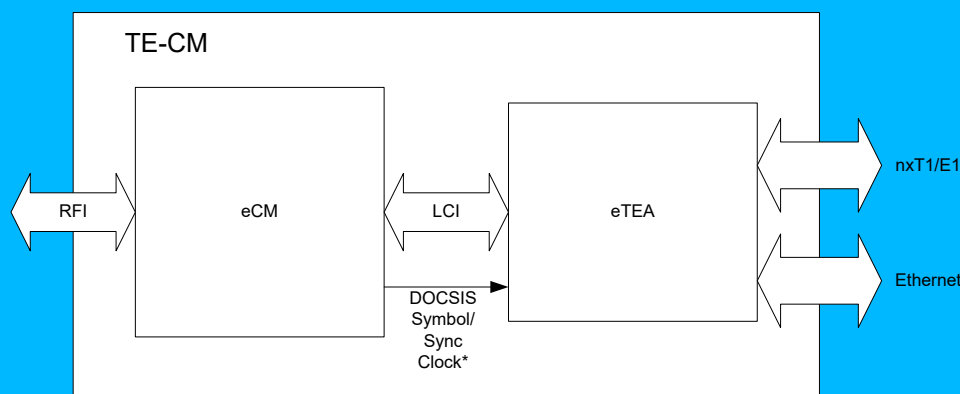


Figure 5-1 - TE-CM

NOTE: [eDOCSIS] specifications apply to the eCM. The DOCSIS Symbol/Sync clock is Stratum 1 Traceable.

5.3.2 TE-CMTS

A TE-CMTS is a standard DOCSIS CMTS that contains the necessary clocking functionality necessary to support a TE-CM and may also include a TDM Emulation Adaptor (TEA) giving it the ability to terminate T1/E1 services. A TE-CMTS may have architecture and interfaces similar to that shown in Figure 5-2 below. The power supply and other functionality that is out of scope are not shown. The elements/interfaces are described as follows:

- RF - This is the standard DOCSIS CMTS signal as transceived on the HFC network.
- DOCSIS CMTS - This is a standard DOCSIS CMTS conforming to DOCSIS 1.1, 2.0, 3.0 or greater. It must be able to carry a constant bit rate service flow carrying packets at bit rates sufficient to handle the IP Pseudo Wire traffic and management as defined herein. Per DOCSIS, it has both RF and IP interfaces. The CMTS may be an M-CMTS in which case the M-CMTS specification defines compliant IP, RF, and synchronization interfaces.
- Clocking Unit - When the TEA is not integrated within the TE-CMTS, at a minimum the Clocking Unit functionality must be implemented as part of the TE-CMTS. A TE-CMTS has either a [DTI] or a BITS external synchronization interface as defined in Section 6.4. This is used to time and/or clock the DOCSIS symbol clock or DOCSIS SYNC message for a TE-CM to recover.
- TEA - A TE-CMTS may contain a TEA and TDM interface(s).
- Ethernet Interface - The Ethernet interface will carry IP traffic to and from the managed IP network.

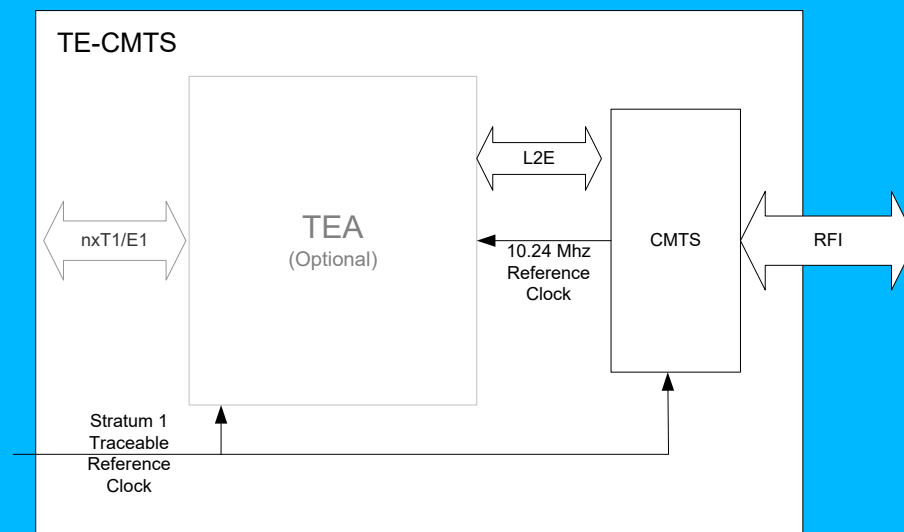


Figure 5–2 - TE-CMTS

L2E is an unspecified Layer 2 Ethernet Interface.

5.3.3 Embedded TDM Emulation Adaptor (eTEA)

An Embedded TDM Emulation Adaptor (eTEA) is an eSAFE device as specified by [eDOCSIS]. An eTEA is embedded in a TE-CM.

An eTEA has a T1, E1, or J1 interface connector and contains the following elements/interfaces:

- L2 Ethernet - This is the Layer 2 Ethernet element where IP Pseudo Wires are transceived.
- Pseudo Wires (PW1, PW2, ..., PWN) - Pseudo Wires are logical IP packet flows that contain encapsulated TDM traffic. Pseudo Wires are terminated and generated by IWF.
- Interworking Function (IWF) - The Interworking function consists of a TSP data interface on one side, an IP Packet interface on the other side, and the functionalities to encapsulate TDM data into a Pseudo wire in one direction and extract TDM data from Pseudo Wire in the other direction. Encapsulation and transmission may involve clocking from the CU.
- TDM Service Flows (TS1, TS2, ..., TSN) - TDM data associated with a Pseudo Wire and TDM interface. The TDM Service Flows may be multiplexed onto one or more TDM interfaces through the TDM Service Processor.
- TDM Service Processor - The TDM Service Processor connects and may multiple TDM Service Flows onto one or more TDM interfaces.
- Ethernet Interface. This Customer facing Ethernet interface has the following uses:
 - To launch the optional 1588 local master timing function on the customer Ethernet network per Section 6.4.5;
 - For DOCSIS testing of an eCM;
 - For testing of clock recovery per Section 6.4.7.1;
 - For (out of scope) use to carry TDM data per Section 5.3.1.

- **TDM Interface** - The TDM interface is one or more T1, E1, J1 or higher rate interface as further defined in Section 3.
- **Clocking Unit (CU)** - This element provides high quality and reliable frequency to the IWF and TDM Service Processor. The CU receives clocking from the eDOCSIS module. The eDOCSIS module through DOCSIS requirements must lock to the DOCSIS symbol clock and DOCSIS SYNC message. The eDOCSIS module must provide one of these recovered clocking signals to the CU. Since a TE-CMTS is synchronized to a Stratum 1 traceable reference, the recovered clock from DOCSIS not only has the stability needed for DOCSIS operation, it also has stability needed for T1/E1 synchronization. Section 6.4 describes several clocking modes that may include the CU interfacing with the TDM Service Processor and IWF.

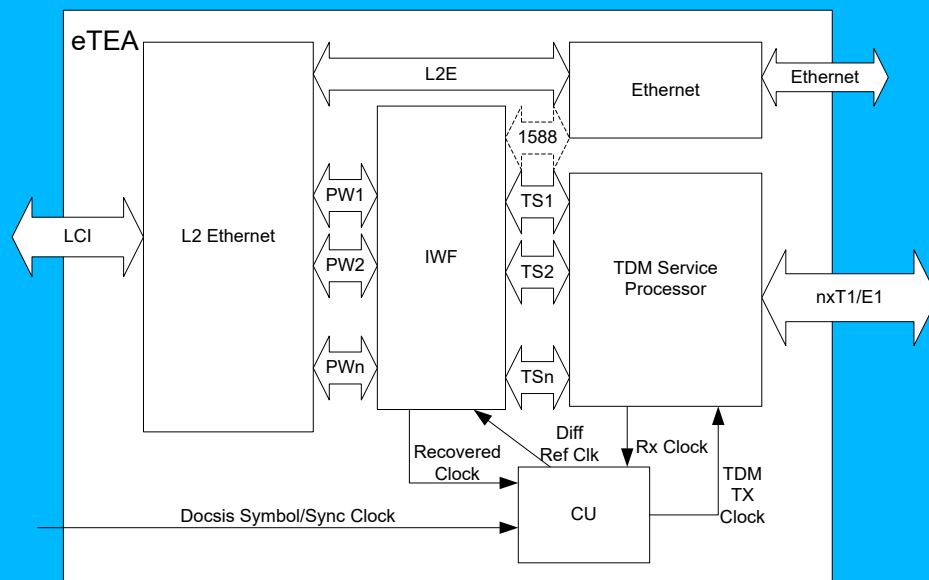


Figure 5-3 - eTEA

5.3.4 TDM Emulation Adaptor (TEA)

A TDM Emulation Adaptor (TEA) may be implemented in a TE-CMTS or other device unspecified in the network.

A TEA has a T1, E1, or J1 TDM Interface connector and contains the following elements/interfaces:

- **L2 Ethernet** - This is the Layer 2 Ethernet element where IP Pseudo Wires are transceived.
- **Pseudo Wires (PW1, PW2, ..., PWN)** - Pseudo Wires are logical IP packet flows that contain encapsulated TDM traffic. Pseudo Wires are terminated and generated by IWF.
- **Interworking Function (IWF)** - The Interworking function consists of a TSP data interface on one side, an IP Packet interface on the other side, and the functionalities to encapsulate TDM data into a Pseudo wire in one direction and extract TDM data from Pseudo Wire in the other direction. Encapsulation and transmission may involve clocking from the CU.
- **TDM Streams (TS1, TS2, ..., TSN)** - TDM data associated with a Pseudo Wire and TDM interface. The TDM Streams may be multiplexed onto one or more TDM interfaces through the TDM Service Processor.
- **TDM Service Processor** - The TDM Service Processor connects and may multiplex TDM Streams onto one or more TDM interfaces.
- **TDM Interface** - The TDM interface is one or more T1, E1, J1 (or higher rate) TDM interface.

- **Clocking Unit (CU)** - This element provides high quality and reliable frequency to the IWF and TDM Service Processor. The CU receives clocking from a Stratum 1 traceable reference through either a DTI or BITS interface, and a recovered clock from the clock recovery unit within the IWF. Section 6.4 describes several clocking modes that may include the CU interfacing with the TDM Service Processor and IWF.

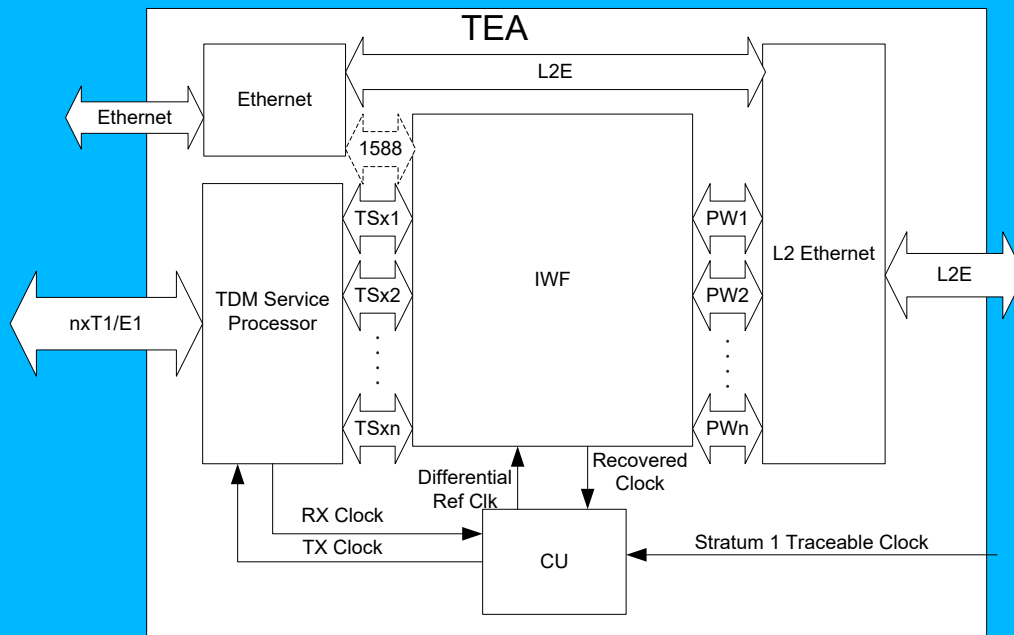


Figure 5-4 - TEA

5.4 Architecture

A BSoD-TE service can be deployed in several architectures. In any architecture the BSoD-TE service has two end points that each contain a TEA or eTEA (TEA peers). Each device presents a TDM interface to the customer or network and a Pseudo Wire connecting the TEA peers logically across the IP network.

Three general architectures exist based on the existing market for T1 and E1 services. In all three architectures one end of the BSoD-TE service originates in a TE-CM containing an eTEA. The three architectures differ based on where the other end of the service is terminated and thus where the other TEA/eTEA exists.

There are a variety of existing T1/E1 services including wireless backhaul, private line, PBX extension, PBX PSTN access, etc. Comprehensive T1/E1 service may include a combination of these three architectures and may include partnering with other operators for part of the implementation.

5.4.1 TE-CM to TE-CMTS w/TEA

In this architecture the BSoD-TE service originates in a TE-CM (containing an eTEA) and terminates at the TE-CMTS which contains a TEA. Figure 5-5 shows this architecture with the Pseudo Wire flow shown as the dotted line. This is not the termination of the T1 or E1 circuit, just the two ends of the BSoD-TE circuit emulation. The T1 or E1 service will continue from the CMTS into the traditional TDM network.

This architecture places delay and QoS requirements on the DOCSIS network, but minimizes the impairments that the IP network may place on the BSoD-TE service. This architecture however requires TDM transport facilities at the hub/headend locations where the CMTS is located which may not be feasible or cost effective for some operators that prefer or require the BSoD-TE service to have a more centralized termination.

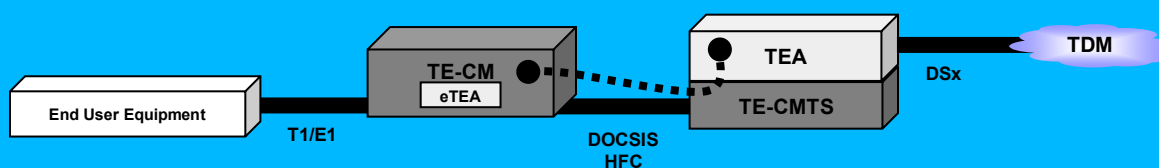


Figure 5-5 - T1 to Hub Architecture

5.4.2 TE-CM to Centralized TEA

In this architecture the BSoD-TE service originates in a TE-CM and terminates in a centralized router or other unspecified device that contains a TEA. The TEA may exist in a router, gateway, switch or other device which is out-of-scope for this standard with the exception of the TEA functionality. Figure 5-6 shows this architecture with the Pseudo Wire flow shown as the dotted line. This is not the termination of the T1 or E1 circuit, just the two ends of the BSoD-TE circuit emulation. The T1 or E1 service will continue from the CMTS to its termination within traditional TDM network.

This architecture places delay, synchronization and QoS requirements on the TE-CMTS, which in this case does not contain a TEA. This architecture places delay and QoS requirements on the DOCSIS and core managed IP network. While this architecture requires a slightly more complex provisioning of the network, it centralizes the termination of the BSoD-TE circuit emulation in the core. This means there are fewer BSoD-TE devices to manage and that the TE-CMTS does not have an integrated TEA. This simplifies the TE-CMTS and reduces or eliminates modifications to existing installed CMTSs. This architecture eliminates the need for TDM transport facilities at each hub/headend since the Pseudo Wires will pass through the TE-CMTS (as IP packets) and be routed over the existing IP transport to the core.

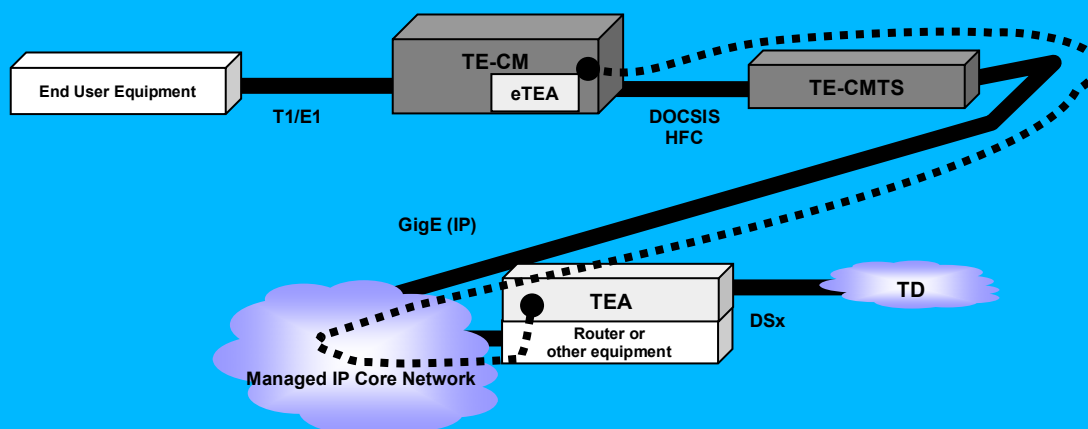


Figure 5-6 - T1 to TDM core, IXC or PSTN

5.4.3 TE-CM to TE-CM through TE-CMTSs and Core

In this architecture the BSoD-TE service originates in a TE-CM (containing an eTEA) and in a second TE-CM (containing an eTEA). Figure 5-7 shows this architecture with the Pseudo Wire flow shown as the dotted line. In this architecture the T1 service is end-to-end with transport of the circuit through the managed IP core network. If the T1 circuit requested by the customer is accessible by a single hub/headend a single TE-CMTS may be utilized with the Pseudo Wire being routed locally.

This architecture places delay, synchronization and QoS requirements on the TE-CMTS, which in this case does not have a TEA. This architecture places delay and QoS requirements on the DOCSIS and core managed IP network.

While this architecture requires a more complex provisioning of the network, it can be deployed with minimal upgrades to the existing installed CMTSs and does not require any modifications to the core equipment. This architecture eliminates the need for TDM transport facilities at each hub/headend since the Pseudo Wires will pass through the TE-CMTSs and existing IP transport in the core between the two TE-CMs. There are however service limitations imposed by this architecture. This architecture only enables a provider to offer private line T1/E1 services between two customer sites. This architecture does not enable T1/E1 services to the PSTN or any other TDM network.

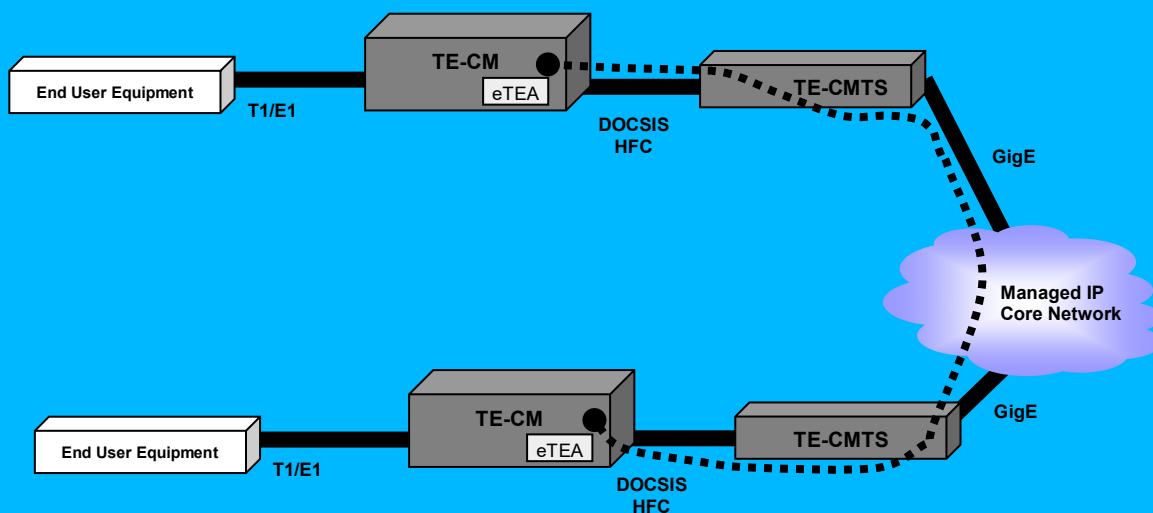


Figure 5-7 - T1 private line between two customer sites

5.4.4 Other Architecture Considerations

For many operators, a complete T1/E1 service offering will require a mixture of these three architectures. In most cases this will be a mixture from Sections 5.4.3 and either Section 5.4.1 or 5.4.2. Figure 5-8 depicts a potential hybrid architecture.

An MSO may also choose to partner with other MSOs creating exchange agreements where a Pseudo Wire may flow over both of their managed IP networks and terminate in a TE-CM in each of their networks. Moreover, a MSO may choose to partner with another operator to offer T1/E1 services outside their network nationally or internationally. In most cases this will require the MSO to terminate and aggregate the BSoD-TE circuit emulation for handoff as a high rate TDM interface, like a DS3. This would also be the case if an MSO chooses to offer wireless backhaul services. The MSO would need to aggregate multiple Pseudo Wire IP flows from several TE-CMs, terminate the BSoD-TE circuit emulation and handoff to the wireless operator in a high speed aggregate TDM DS3 type interface. Lastly, an operator could choose the TEA defined in this standard to transport TDM traffic across the managed IP core network between two routers or other devices. The details of this are out-of-scope for this standard; however, it is possible with this technology.

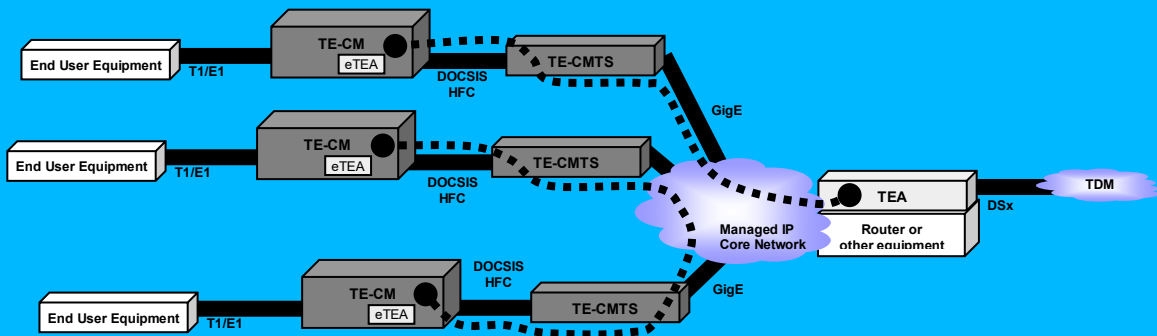


Figure 5-8 - Comprehensive private and public T1/E1 services

5.4.5 M-CMTS & CMTS Architecture Considerations

The Modular-CMTS (M-CMTS) architecture offers many advantages when considering a BSoD-TE service. Since a T1 or E1 service has constant symmetric bandwidth of 1.5M.bits to 2M.bits, a traditional CMTS architecture may not scale as well as an M-CMTS. The M-CMTS architecture decouples the upstream and downstream into separate devices that can be scaled independently. Since BSoD-TE, residential broadband data service, VoIP and other services all utilize the DOCSIS network this independent scalability offers greater economics and flexibility as various services are deployed.

In addition to the scalability, Modular-CMTS requires the DOCSIS Timing Interface ([DTI]). This is used for Modular-CMTS operation, but can also be used to support BSoD-TE synchronization requirements as described in Section 6.4.

Existing CMTS architectures may be utilized for BSoD-TE as well as the M-CMTS devices that are inherently compliant. Existing CMTS may or may not have been designed with BSoD-TE in mind and may need some modifications. The potential for a CMTS to be made compliant to BSoD-TE as a TE-CMTS is vendor and platform dependent. The CMTS will need to have a synchronization interface and support QoS requirements in order to support advanced clocking modes beyond adaptive clock recovery. This may not require any modifications for some vendors, for others rather minor changes and for some it may not be possible on existing platforms. Moreover, some vendors may be able to offer upgrades to existing CMTS platforms to not only include TE-CMTS functionality, but also an integrated TEA.

5.5 Network Environment

The architecture shown in Section 5.4 serves as the basis for explaining how DOCSIS can be used to carry T1/E1 using BSoD-TE. The architectures do not, however, show details of the environment; details that are just as important as the devices. To adequately explain these extended architectures, it's important to outline the environmental details related to Clocking and QoS.

5.5.1 Clocking

5.5.1.1 Background

T1/E1 signals are designed to simultaneously connect multiple calls over a shared wire using time domain multiplexing (TDM). This imposes certain restrictions on the T1/E1 clocks used at both ends of the connection.

- **Frequency** - To make sure that each TDM circuit stays properly connected, the clocks at both ends of the circuit must be at the same frequency. This ensures that both ends of the TDM connection continue to use the same shared data time-slot, without either end slowly slipping into the next time-slot. In other words, the data rate in and the data rate out must be precisely aligned and not deviate. The responsibility for maintaining the same frequency is shared by the two TEAs and the clock distribution system described below in Section 5.5.1.2.

- Synchronization - To make sure that each DS0 frame is correctly multiplexed into the TDM circuit, the peer TEAs must both be synchronized to the frame of the incoming T1/E1 signal. The responsibility for maintaining frame synchronization is shared by the peer TEAs; they should be configured in a similar manner.

5.5.1.2 Clock Distribution Environment

There are several options available to ensure that the peer TEAs operate at the same clock frequency. From wherever the source clock exists, the frequency information about that clock must be distributed to each TEA. A few different distribution paths and methodologies exist over which a TEA or eTEA can obtain this clock information.

5.5.1.2.1 Direct clocking

Direct clocking methodology means the TEA is receiving its clocking directly from a Stratum 1 traceable reference source. This may be one of two technologies: [DTI] or BITS.

- DTI - The DOCSIS Timing Interface standard is specified as part of the DOCSIS M-CMTS family. [DTI] describes a Client / Server architecture for time and frequency distribution. An M-CMTS device, CMTS or any device containing a TEA may implement a DTI Client interface for connection to a DTI Server. This will enable it to not only receive timing for BSoD-TE service, but also DOCSIS. The DTI Server being used to time a device containing a TEA must implement the External Reference Mode of [DTI] in order to comply with BSoD-TE. There are no additional requirements for the DTI Client.
- BITS - BITS is a generic term used to describe frequency distribution of Stratum 1 clocks in a TDM, SDH or PDH network. BITS is described in detail in ANSI+ T11 101-1999. In a typical deployment a Primary Reference Source (PRS) is containing a Stratum 1 clock or GPS (Stratum 1 traceable) connection is distributed in a Central Office, Headend or hub site directly from the PRS or through a Building Integrated Timing Supply Shelf (BITS shelf). In some cases the PRS and BITS shelf may be integrated into a single shelf called a Synchronization Supply Unit (SSU). A network element that needs frequency synchronization will typically have a primary and secondary frequency input, typically labeled BITS input. The BITS input may have a variety of physical interfaces including T1, E1, or RS422. There are a few quality levels of BITS connections depending on the PRS and BITS topology and architecture. The same specifications [ITU-T G.823] and [ITU-T G.824] that govern customer T1/E1 synchronization quality, also describe the PRS BITS quality used for direct clocking.

5.5.1.2.2 Network Clock Recovery (NCR)

Network Clock Recovery methodology means the TEA is receiving its clocking over the transport network (in our case DOCSIS) from a device (in our case a TE-CMTS) that has direct clocking. A device using NCR is thus traceable to a Stratum 1 clock, but has slightly lower quality clocking than a device that is directly clocked using DTI or BITS. Since DTI and BITS are both inter-office technologies, NCR is the best methodology to provide clocking to a modem. There are two methods for a TE-CM to implement NCR: DOCSIS Symbol Clock recovery and DOCSIS SYNC Message Recovery.

- DOCSIS Symbol Clock (SC) - The TE-CM can receive clock information encoded into the DOCSIS Symbol Clock. The CMTS or M-CMTS connected to the TE-CM has a clocking interface to which the DOCSIS master clock is locked. This ensures that the DOCSIS symbol clock not only meets DOCSIS requirements, but also the T1/E1 clocking requirements. The TE-CM can then provide the recovered DOCSIS symbol clock to the eTEA. This is the most reliable and accurate method of clock distribution. One example of how this might be done is described in Section 6.4.2.2.
- DOCSIS SYNC Message Recovery - The TE-CM can receive clock information encoded in a DOCSIS SYNC Message. The CMTS or M-CMTS connected to the TE-CM has a clocking interface to which the DOCSIS master clock is locked. This ensures that the DOCSIS SYNC message not only meets DOCSIS requirements, but also T1 clocking requirements. The TE-CM can then provide a frequency reference to the eTEA disciplined by the arrival of the DOCSIS SYNC Message. One example of how this might be done is described in Section 6.4.2.3.

Direct clocking and NCR are the two most widely deployed and accurate timing methodologies deployed in communication networks today. They both are well documented and specified by the ITU and ATIS to ensure

reliable and interoperable equipment and services globally. Historically these two methodologies have been bedrock for TDM, SDH, PDH and ATM networks. However, IP/Ethernet networks are just now considering how to provide direct clocking and network clocking. DOCSIS is the first widely deployed access technology that can transport IP traffic and Stratum 1 traceable synchronization. BSoD-TE leverages this capability to provide a more robust IP circuit emulation service than specified by other existing Circuit Emulation standards that do not have direct clocking or NCR capabilities at this time.

5.5.1.2.3 Prime Differential Clock Recovery (PDCR)

Prime Differential Clock Recovery methodology leverages NCR enabling peer TEAs to precisely measure the customers T1/E1 clock and transport these measurements over the network. PDCR may be very useful for some data or cellular applications where Stratum 1 quality is needed; however, the customer has a different reference clock in their equipment.

5.5.1.2.4 Adaptive Clock Recovery (ACR)

Adaptive Clock Recovery methodology uses the customer clock to discipline a TEA (or eTEA). At the second TEA the packet arrival rate is used to derive the original clock. In this methodology complex algorithms and hardware are needed to filter out the jitter and wander to meet T1/E1 clocking standards. Various tradeoffs regarding cost, reliability and interoperability should be considered when using ACR. Startup time, instantaneous network delay, delay variation, packet loss, loading, and QoS all affect the clocking. The margin of safety is largely dependent on the QoS agreements that the service provider can offer.

When using ACR in the upstream direction, the quality of the recovered clock is not only affected by the IP network, it is affected by the upstream DOCSIS flow. UGS is the best method to use in DOCSIS to ensure that the BSoD-TE service has the highest possible quality. The contention in the upstream A-TDMA or S-CDMA DOCSIS transmission will cause packet delay variation even with UGS. The effect of this will typically not have an effect on the data content or delivery; however it may have effects on the quality of timing. To ensure high quality clocking is delivered to the customer direct clocking, NCR or PDCR should be used if available.

When using ACR across an IP network, the QoS must be provided end to end. This may impose unspecified restrictions on the combined IP network. Differential clocking (PDCR) does have some dependencies on the IP network, but is less restrictive than ACR because the actual clock is not being transmitted across the network. Rather each TEA is being timed from a Stratum 1 traceable source using NCR and the difference between the network clock and customer clock is being transmitted.

5.5.2 Quality of Service (QoS)

5.5.2.1 Background

T1 Services provide transport for Constant Bit Rate (CBR) signals. Because the transport of a Pseudo Wire involves the sharing of resources, with the attendant requirements for reservations, IP data flows are inherently not CBR. There are two classical ways to make up for this deficiency:

- Buffering - Delay all of the IP data; buffer it into queues, and clock it out in a CBR manner. This can be done in the middle of the network IP path, but it is best done at the edge of the network, where the PW terminates in the IWF. The buffering is provided by the IWF and is configured therein. Section 5.5.2.2.1 further describes buffering. While not strictly a 'QoS' consideration, the buffer size of the IWF must be well matched to the level of QoS so it can smooth out the IP data flow.
- QoS - Give the PW data priority over other types of data and tag it as CBR data. The IP network elements may provide QoS options allowing the operator to specify the proper priority.

5.5.2.2 QoS Environment

5.5.2.2.1 QoS

The principal requirement (for a DOCSIS transport system implementing BSoD-TE) is to guarantee CBR transport of Pseudo Wire packets. In the theoretical best case, every bit presented to the network is immediately sent through

the network with low and consistent delay. In the practical case, the network cannot be quite that accommodating. It may be forced by contending users to buffer (delay) traffic now and then and then catch up later by transporting data at a higher rate. The QoS mechanisms provided by DOCSIS can limit the amount of buffering that occurs in the network. The buffer in the TEA must be more than a match for the network buffering, or the system will break down. The better the QoS afforded to Pseudo Wire packets, the better the BSoD-TE service will function. The MSOs should provision the downstream and upstream of a TE-CMTS and TE-CM for the delivery of Constant Bit Rate PWs. In the upstream, this will likely mean UGS as further defined in Section 6.7. If the Pseudo Wire packets leave the DOCSIS network, they must be transported with equivalent QoS. Such methods are out of scope. The weakest link in the transport network will set the expectations for remedial buffering in the TEA.

5.5.2.2.2 IWF Buffering

The IWF has a configurable number of bytes to buffer each incoming Pseudo Wire packet stream. The IWF then performs InterWorking on the Pseudo Wire packets generating a TDM stream to the TSP.

5.5.2.2.3 Latency vs. Buffering Errors

There is a tradeoff between the size of the buffer and the statistical chance of errors. At any level of QoS, there will be a statistical spread of packet delay. Each packet may get delayed a different amount. For the most part, a large delay would be rarer than a smaller delay. The IWF buffer must be able to accommodate almost every possible packet delay and packet delay variation. It must do so without overflow or underflow, both of which will create data errors in the T1/E1 service noticeable to the customer as BER, slips or LOS. To play it safe, the PW could always be configured with a very large buffer. This would minimize data errors. Unfortunately, many of the services carried over T1/E1 connections can only tolerate certain maximum delay times (out of scope). This max delay time puts a cap on the allowable size of the IWF buffer in that application. The cap on buffer size, in turn, places requirements for QoS on the DOCSIS network. Everything must be well matched. The goal is to simultaneously minimize the size of the buffer on each PW and stay within the statistical bounds allowable for the probability of buffer errors. Operational guidelines are out of scope for this document.

6 TECHNICAL SPECIFICATION

6.1 General Requirements

BSoD-TE circuit emulation service provides emulation of T1 or E1 or nxDS0 service over a DOCSIS network. A system providing this service may consist of a TDM Emulation capable CMTS (TE-CMTS), a TDM Emulation Cable Modem (TE-CM), and possibly another router on the network side that contains a TDM Emulation Adapter (TEA).

6.1.1 CU Clock Unit

A CU gathers, transforms, and redistributes clocking information within a given device. There are many options as to how this may be done. The requirements for the sources of the clocking information, the transformation methods, and the redistribution methods are documented in Section 6.4.

6.1.2 PW Pseudo-Wire

A Pseudo Wire (PW) is a flow of encapsulated TDM data within IP packets. A PW always flows between TEA peers across DOCSIS and a Packet Switched Network.

6.1.3 IWF InterWorking Function

An IWF encodes TDM flows into IP Pseudo Wire flows and decodes IP Pseudo Wire flows into TDM flows.

An IWF **MUST** support at least one PW. An IWF **MAY** support multiple PWs. If the IWF supports multiple PWs, the configuration of each PW may be independent.

An IWF **MUST** have a configurable-sized input buffer to receive each incoming Pseudo Wire flow large enough to hold at least 10 msec of data at the PW line rate. For certain network conditions, larger buffers may be needed. An IWF **SHOULD** have a configurable-sized input buffer to receive incoming Pseudo Wire flows large enough to hold 50 msec of data at the PW line rate. The IWF should have internal control algorithms that will make sure the buffer operates near the center of its range during normal transport (after the service is provisioned and initialized) for each PW. This will minimize buffer overflow and underflow and will help minimize the size of buffer that is needed. The buffer size should be configured to the minimum effective size to minimize latency. The algorithm necessary to control the buffer is out of scope.

An IWF **MUST** support TDM-IP Interworking as defined in Section 6.2.

An IWF **MUST** support structure agnostic encapsulation as defined in Section 6.3.1.

An IWF **MUST** support structure-aware encapsulation as defined in Section 6.3.2.

An IWF **MUST** support TDM Application signaling defined in Section 6.3.2.1.

An IWF **SHOULD** support PDCR as defined in Section 6.4.3.

An IWF **MAY** support ACR as defined in Section 6.4.4.

If ACR or PDCR are supported for encapsulated PWs, the IWF **MUST** be capable of gathering clocking information from those PWs and supplying it to/from the CU.

6.1.4 TSP TDM Service Processor

A TSP **MUST** have a TDM Interface for each TDM flow it can simultaneously support; the interfaces may be removable if they are only used during testing.

A TSP **MUST** accept clocking from the CU.

The TSP **MUST** provide the TDM Receive clock to the CU.

If the TSP TDM Interface is a T1 or a J1, it **MUST** comply with:

- [TR-62411];

- [ITU-T G.703];
- [ITU-T G.704];
- [T1-403];
- [ITU-T G.824] as further defined in Table 6–1.

If the TSP TDM Interface is an E1, it MUST comply with:

- [ITU-T G.703];
- [ITU-T G.704];
- [ITU-T G.706];
- [ITU-T G.732];
- [ITU-T G.823] as further defined in Table 6–1.

ITU Recommendations [ITU-T G.823] and [ITU-T G.824] differ in the requirements placed on a 'Traffic Interface' and 'Synchronization Interface' as defined therein. This standard places normative requirements on TDM Interfaces to conform to these ITU Recommendations and Table 6–1 below is required to fully specify which clauses of the ITU Recommendations apply. Table 6–1 is used to specify different requirements for different TDM clocking methods which are defined in the sections cited in the table.

A TSP TDM T1 'Traffic' Interface MUST comply with:

- [ITU-T G.824] table 1 for 1544kbit/s digital rate interfaces;
- [ITU-T G.824] table 2.

A TSP TDM T1 'Synchronization' Interface MUST comply with:

- [ITU-T G.824] table 1 for 1544kbit/s digital rate interfaces;
- [ITU-T G.824] table 5, figure 3;
- [ITU-T G.824] table 6, figure 4.

A TSP TDM E1 'Traffic' Interface MUST comply with:

- [ITU-T G.823] table 1 for 2048kbit/s digital rate interfaces;
- [ITU-T G.823] table 2, figure 1.

A TSP TDM E1 'Synchronization' Interface MUST comply with:

- [ITU-T G.823] table 5 for PDH synchronization;
- [ITU-T G.823] table 12, figure 10;
- [ITU-T G.823] table 13, figure 11.

Table 6–1 - G.823 and G.824 Clock requirements

Clocking method	Section	Traffic/Synchronization
Direct	6.4.1	Synchronization
NCR	6.4.2	Synchronization
PDCR	6.4.3	Synchronization
ACR	6.4.4	Traffic

A TSP Interface that complies with [ITU-T G.823] or [ITU-T G.824] Recommendations SHOULD comply as a 'Synchronization Interface'.

6.1.5 TEA TDM Emulation Adapter

A TEA MUST contain an IWF.

A TEA MUST contain a TSP.

A TEA MUST contain a CU supporting a synchronized clock input to support NCR or Direct Clocking modes.

A TEA SHOULD contain an IWF supporting PDCR mode.

A TEA MAY contain an IWF supporting ACR.

A TEA SHOULD indicate when the CU, IWF or TSP are not locked to a valid clock, including periods when it is acquiring a clock signal using ACR (Section 6.4.3), PDCR (Section 6.4.3), or SC (Section 6.1.6).

A TEA must be associated with a static IP address.

A TEA MUST have an LCI interface capable of accepting IP packets.

If a TEA contains an IWF that contains multiple PWs:

- the TEA MUST be capable of supporting UDP addressing per Section 6.2.2.,
- the TEA MUST meet this specification on all TDM Interfaces and PWs simultaneously,
- the TEA MUST be configurable for each PW without disturbing configuration on any other PW (exclusive of intentionally shared parameters).

A TEA MUST make available every active TDM Interface of the embedded TSP.

A TEA MUST support the provisioning of the CU, the TSP, the IWF, and the PWs it contains.

6.1.6 eTEA Embedded TDM Emulation Adaptor

An eTEA MUST meet the normative requirements of a TEA.

6.1.7 TE-CM TDM Emulation Cable Modem

A TDM Emulation Cable Modem (TE-CM) is a cable modem with additional functionalities to provide TDM emulation services.

A TE-CM MUST support either DOCSIS 1.1 [RFI 1.1], DOCSIS 2.0 ([RFI 2.0]) or greater.

A TE-CM MUST contain an eCM as defined in [eDOCSIS].

A TE-CM MUST contain an eTEA as defined in Section 6.1.5.

A TE-CM MUST make available every TDM Interface made available by its embedded eTEA.

A TE-CM MUST be compliant to [CMCI], including an interface with 10BASE-T capability. A TE-CM SHOULD have an interface with 100BASE-T capability. The 10BASE-T or 100BASE-T interface MAY be compliant to Section 6.4.

A TE-CM MUST contain a CU that accepts a synchronized clock input in order to support NCR mode. This allows the TE-CM to lock to the DOCSIS ([RFI 2.0]) symbol clock or DOCSIS SYNC message and provide it to the TSP and IWF as described in Section 6.4.

A TE-CM MAY contain an Ethernet timing service based on IEEE-1588 as outlined in Section 6.4.5.

6.1.8 TE-CMTS TDM Emulation CMTS

A TDM Emulation Cable Modem Termination System (TE-CMTS) is a CMTS (or M-CMTS) with additional functionalities to enable TDM emulation services.