Data-Over-Cable Service Interface Specifications
DCA - MHAv2

Remote Downstream External PHY Interface Specification

CM-SP-R-DEPI-I01-150615

ISSUED

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Work in Progress	An incomplete document designed to guide discussion and generate feedback, and may include several alternative solutions for consideration.
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1 SCOPE

1.1 Introduction and Purpose

This document describes the Remote DEPI and control plane operation of the Modular Headend Architecture version 2 (MHAv2). MHAv2/Remote PHY Architecture permits a CMTS to support an IP based digital HFC plant. In an IP based digital HFC plant, the fiber portion utilizes a baseband network transmission technology such as Ethernet, EPON (Ethernet over Passive Optical Networks), GPON (Gigabit Passive Optical Network), or any Layer 2 technology that would support a fiber based Layer 1. MHAv2 uses a Layer 3 pseudowire between a CCAP-Core and a series of Remote PHY Devices. One of the common locations for a Remote PHY Device is located at an optical node device that is located at the junction of the fiber and coax plants.

This document was created from the basis of the I08 version of the MHA DEPI specification, [DEPI].

1.2 MHAv2 Interface Documents

A list of the documents in the MHAv2 family of specifications is provided below. For updates, refer to http://www.cablelabs.com/specs/specification-search/.

Designation	Title
CM-SP-R-PHY	Remote PHY System Specification
CM-SP-R-DEPI	Remote Downstream External PHY Interface Specification
CM-SP-R-UEPI	Remote Upstream External PHY Interface Specification
CM-SP-GCP	Generic Control Plane Specification
CM-SP-R-DTI	Remote DOCSIS Timing Interface Specification
CM-SP-R-OOB	Remote Out-of-Band Specification
CM-SP-R-OSSI	Remote PHY OSS Interface Specification

NOTE: MHAv2 does not explicitly use any of the original Modular Headend Architecture specifications.

1.3 Requirements and Conventions

In this specification the following convention applies any time a bit field is displayed in a figure. The bit field should be interpreted by reading the figure from left to right, then from top to bottom, with the MSB being the first bit so read and the LSB being the last bit so read.

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, for example; another vendor may omit the same item.

2   REFERENCES

2.1   Normative References

In order to claim compliance with this specification, it is necessary to conform to the following standards and other works as indicated, in addition to the other requirements of this specification. Notwithstanding, intellectual property rights may be required to use or implement such normative references. At the time of publication, the editions indicated were valid. All references are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below. References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific. For a nonspecific reference, the latest version applies.

[DEPI]	Downstream External PHY Interface Specification, CM-SP-DEPI-I08-100611, June 11, 2010, Cable Television Laboratories, Inc.
[DRFI]	DOCSIS Downstream Radio Frequency Interface, CM-SP-DRFI-I14-131120, November 20, 2013, Cable Television Laboratories, Inc.
[DTI]	DOCSIS Timing Interface, CM-SP-DTI-I06-150305, March 5, 2015, Cable Television Laboratories, Inc.
[EQAM-VSI]	Edge QAM Video Stream Interface Specification, CM-SP-EQAM-VSI-I01-081107, November 7, 2008, Cable Television Laboratories, Inc.
[IANA-PORTS]	IANA, Port Numbers, June 2004.
[IEEE 802.1q]	IEEE Std 802.1Q-2003, Virtual Bridged Local Area Networks, May 2003.
[IEEE 802.3]	IEEE Std 802.3-2002, Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications, March 2002.
[IEEE 802.3as]	802.3as-2006 - IEEE Standard for Information technology-- Telecommunications and information exchange between systems-- Local and metropolitan area networks-- Specific requirements Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications
[ISO 13818-1]	ISO/IEC 13818-1:2013, Information technology, Generic Coding of Moving Pictures and Associated Audio Information. Part 1: System, May 23, 2013.
[ITU-T J.83]	ITU-T Recommendation J.83 (4/97), Digital multi-programme systems for television sound and data services for cable distribution.
[R-DTI]	Remote DOCSIS Timing Interface Specification, CM-SP-R-DTI-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[GCP]	Generic Control Plane Specification, CM-SP-GCP-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[MULPIv3.1]	DOCSIS 3.1 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv3.1-I06-150611, June 11, 2015, Cable Television Laboratories, Inc.
[R-OOB]	Remote Out-of-Band Specification, CM-SP-R-OOB-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[R-PHY]	Remote PHY Specification, CM-SP-R-PHY-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[R-OSSI]	Remote PHY OSS Interface Specification, CM-SP-R-OSSI-D02-150408, April 8, 2015, Cable Television Laboratories, Inc.
[R-UEPI]	Remote Upstream External PHY Interface Specification, CM-SP-R-UEPI-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[RFC 768]	IETF RFC 768, User Datagram Protocol, August 1980.
[RFC 791]	IETF RFC 791, Internet Protocol-DARPA, September 1981.
[RFC 1191]	IETF RFC 1191, MTU Path Discovery, November 1990.

[RFC 1981]	IETF RFC 1981, Path MTU Discovery for IP version 6, August 1996.
[RFC 2460]	IETF RFC 2460, Internet Protocol, Version 6 (IPv6) Specification, December 1998.
[RFC 2597]	IETF RFC 2597, Assured Forwarding PHB Group, June 1999.
[RFC 2983]	IETF RFC 2983, Differentiated Services and Tunnels, October 2000.
[RFC 3246]	IETF RFC 3246, An Expedited Forwarding PHB (Per-Hop Behavior), March 2002.
[RFC 3260]	IETF RFC 3260, New Terminology and Clarifications for Diffserv, April 2002.
[RFC 3308]	IETF RFC 3308, Layer Two Tunneling Protocol (L2TP) Differentiated Services Extension, November 2002.
[RFC 3931]	IETF RFC 3931, Layer Two Tunneling Protocol - Version 3 (L2TPv3), March 2005.
[RFC 5085]	IETF RFC 5085, Pseudowire Virtual Circuit Connectivity Verification (VCCV): A Control Channel for Pseudowires, December 2007.
[RFIv2.0]	DOCSIS Radio Frequency Interface Specification, CM-SP-RFIv2.0-C02-090422, April 22, 2009, Cable Television Laboratories, Inc.
[RMI-ERM-EDGE]	Edge Resource Manager - Edge Device Interface Specification, CM-SP-RMI-ERM-EDGE-I0-150528, May 28, 2015, Cable Television Laboratories, Inc.
[S-BFD-BASE]	S-BFD Base Internet draft, http://datatracker.ietf.org/doc/draft-ietf-bfd-seamless-base
[S-BFD-VCCV]	S-BFD for VCCV, http://tools.ietf.org/html/draft-gp-pals-seamless-vccv-00
[S-BFD-DSR-L2TP]	S-BFD discriminator for L2TPv3, http://tools.ietf.org/html/draft-gp-l2tpext-sbfd-discriminator-00

2.2   Informative References

This document uses the following informative references:

[IANA-L2TP]	IANA, Layer Two Tunneling Protocol (L2TP) Parameters.
[ISO 8802-2]	ISO/IEC 8802-2: 1994 (IEEE Std 802.2: 1994) - Information technology – Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 2: Logical link control.
[RFC 3140]	IETF RFC 3140, Per Hop Behavior Identification Codes, June 2001.
[RFC 5580]	IETF RFC 5580, Bidirectional Forwarding Detection (BFD), June 2010.
[SCTE 55-1]	ANSI/SCTE 55-1 2009, Digital Broadband Delivery System: Out of Band Transport Part 1: Mode A.
[SCTE 55-2]	ANSI/SCTE 55-2 2008, Digital Broadband Delivery System: Out of Band Transport Part 2: Mode B.

2.3   Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027; Phone +1-303-661-9100; Fax +1-303-661-9199; http://www.cablelabs.com

- European Telecommunications Standards Institute, ETSI, http://www.etsi.org

- The Institute of Electrical and Electronics Engineers, Inc., IEEE, Internet: http://standards.ieee.org

- Internet Assigned Numbers Authority, IANA, Internet: http://www.iana.org

- Internet Engineering Task Force (IETF) Secretariat, 48377 Fremont Blvd., Suite 117, Fremont, California 94538, USA, Phone: +1-510-492-4080, Fax: +1-510-492-4001. http://www.ietf.org.

- International Organization for Standardization (ISO), Tel.: +41 22 749 02 22, Fax: +41 22 749 01 55, www.standardsinfo.net
- International Telecommunication Union (ITU), Phone +41 22 730 5111 (ITU Switchboard), Fax +41 22 733 7256, http://www.itu.int/

3 TERMS AND DEFINITIONS

This specification uses the following terms:

Bonded Channels	A logical channel comprising multiple individual channels.
Cable Modem (CM)	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system.
CCAP-Core	A CCAP device that uses MHAv2 protocols to interconnect to an RPD.
Converged Interconnect Network	The network (generally gigabit Ethernet) that connects a CCAP-Core to an RPD.
Customer Premises Equipment (CPE)	Equipment at the end user's premises; may be provided by the service provider.
Data Rate	Throughput, data transmitted in units of time usually in bits per second (bps).
Decibels (dB)	Ratio of two power levels expressed mathematically as $dB = 10\log_{10}(P_{OUT}/P_{IN})$.
Decibel-Millivolt (dBmV)	Unit of RF power expressed in decibels relative to 1 millivolt, where $dBmV = 20\log_{10}$(value in mV/1 mV).
Downstream (DS)	1. Transmissions from CMTS to CM. This includes transmission from the CCAP-Core to the RPD, as well as the RF transmissions from the RPD to the CM. 2. RF spectrum used to transmit signals from a cable operator's headend or hub site to subscriber locations.
Edge QAM modulator (EQAM)	A head end or hub device that receives packets of digital video or data. It re-packetizes the video or data into an MPEG transport stream and digitally modulates the digital transport stream onto a downstream RF carrier using quadrature amplitude modulation (QAM).
Ephemeral	A TCP or UDP port number that is not assigned by the Internal Assigned Numbers Authority (IANA).
Flow	A stream of packets in DEPI used to transport data of a certain priority from the CCAP-Core to a particular QAM channel of the RPD. In PSP operation, there can exist several flows per QAM channel.
Gbps	Gigabits per second
Gigahertz (GHz)	A unit of frequency; 1,000,000,000 or 10^9 Hz.
GigE (GE)	Gigabit Ethernet (1 Gbps)
Hertz (Hz)	A unit of frequency; formerly cycles per second.
Hybrid Fiber/Coax (HFC) System	A broadband bidirectional shared-media transmission system using optical fiber trunks between the head-end and the fiber nodes, and coaxial cable distribution from the fiber nodes to the customer locations.
Institute of Electrical and Electronic Engineers (IEEE)	A voluntary organization which, among other things, sponsors standards committees and is accredited by the American National Standards Institute (ANSI).
Internet Engineering Task Force (IETF)	A body responsible for, among other things, developing standards used in the Internet.
Internet Protocol (IP)	An Internet network-layer protocol
kilohertz (kHz)	Unit of frequency; 1,000 or 10^3 Hz; formerly kilocycles per second
L2SS	Layer 2 Specific Sublayer. DEPI is an L2SS of L2TPv3.

L2TP Access Concentrator (LAC)	If an L2TP Control Connection Endpoint (LCCE) is being used to cross-connect an L2TP session directly to a data link, we refer to it as an L2TP Access Concentrator (LAC). An LCCE may act as both an L2TP Network Server (LNS) for some sessions and an LAC for others, so these terms must only be used within the context of a given set of sessions unless the LCCE is, in fact, single purpose for a given topology.
L2TP Attribute Value Pair (AVP)	The L2TP variable-length concatenation of a unique Attribute (represented by an integer), a length field, and a Value containing the actual value identified by the attribute.
L2TP Control Connection	An L2TP control connection is a reliable control channel that is used to establish, maintain, and release individual L2TP sessions, as well as the control connection itself.
L2TP Control Connection Endpoint (LCCE)	An L2TP node that exists at either end of an L2TP control connection. May also be referred to as an LAC or LNS, depending on whether tunneled frames are processed at the data link (LAC) or network layer (LNS).
L2TP Control Connection ID	The Control Connection ID field contains the identifier for the control connection, a 32-bit value. The Assigned Control Connection ID AVP, Attribute Type 61, contains the ID being assigned to this control connection by the sender. The Control Connection ID specified in the AVP must be included in the Control Connection ID field of all control packets sent to the peer for the lifetime of the control connection. Because a Control Connection ID value of 0 is used in this special manner, the zero value must not be sent as an Assigned Control Connection ID value.
L2TP Control Message	An L2TP message used by the control connection.
L2TP Data Message	L2TP message used by the data channel
L2TP Endpoint	A node that acts as one side of an L2TP tunnel
L2TP Network Server (LNS)	If a given L2TP session is terminated at the L2TP node and the encapsulated network layer (L3) packet processed on a virtual interface, we refer to this L2TP node as an L2TP Network Server (LNS). A given LCCE may act as both an LNS for some sessions and an LAC for others, so these terms must only be used within the context of a given set of sessions unless the LCCE is in fact single purpose for a given topology.
L2TP Pseudowire (PW)	An emulated circuit as it traverses a packet-switched network. There is one Pseudowire per L2TP Session.
L2TP Pseudowire Type	The payload type being carried within an L2TP session. Examples include PPP, Ethernet, and Frame Relay.
L2TP Session	An L2TP session is the entity that is created between two LCCEs in order to exchange parameters for and maintain an emulated L2 connection. Multiple sessions may be associated with a single Control Connection.
L2TP Session ID	A 32-bit field containing a non-zero identifier for a session. L2TP sessions are named by identifiers that have local significance only. That is, the same logical session will be given different Session IDs by each end of the control connection for the life of the session. When the L2TP control connection is used for session establishment, session IDs are selected and exchanged as Local Session ID AVPs during the creation of a session. The Session ID alone provides the necessary context for all further packet processing, including the presence, size, and value of the Cookie, the type of L2-Specific Sublayer, and the type of payload being tunneled.
MAC Domain	A grouping of Layer 2 devices that can communicate with each other without using bridging or routing. In DOCSIS is the group of CMs that are using upstream and downstream channels linked together through a MAC forwarding entity.

Maximum Transmission Unit (MTU)	The Layer 3 payload of a Layer 2 frame.
Mbps	Megabits per second
Media Access Control (MAC)	Used to refer to the Layer 2 element of the system which would include DOCSIS framing and signaling.
Megahertz (MHz)	A unit of frequency; 1,000,000 or 10^6 Hz; formerly megacycles per second
Microsecond (µs)	10^{-6} second
Millisecond (ms)	10^{-3} second
Modulation Error Ratio (MER)	The ratio of the average symbol power to average error power
Multiple System Operator (MSO)	A corporate entity that owns and/or operates more than one cable system.
Nanosecond (ns)	10^{-9} second
Packet Identifier (PID)	A unique integer value used to identify elementary streams of a program in a single or multi-program Transport Stream as described in section 2.4.3 of ITU-T Rec. H.222.0 |[ISO 13818-1]
Physical Media Dependent (PMD) Sublayer	A sublayer of the Physical layer which is concerned with transmitting bits or groups of bits over particular types of transmission link between open systems and which entails electrical, mechanical, and handshaking procedures.
Program Clock Reference	A timestamp in the Video Transport Stream from which decoder timing is derived.
QAM channel (QAM ch)	Analog RF channel that uses quadrature amplitude modulation (QAM) to convey information.
Quadrature Amplitude Modulation (QAM)	A modulation technique in which an analog signal's amplitude and phase vary to convey information, such as digital data.
Radio Frequency (RF)	In cable television systems, this refers to electromagnetic signals in the range 5 to 1000 MHz.
Radio Frequency Interface (RFI)	Term encompassing the downstream and the upstream radio frequency interfaces.
Request For Comments (RFC)	A technical policy document of the IETF; these documents can be accessed on the World Wide Web at http://www.rfc-editor.org/.
Remote PHY Device	The RPD is a device in the network which implements the Remote PHY specification to provide conversion from digital Ethernet transport to analog RF transport.
Session	An L2TPv3 data plane connection from the CCAP-Core to the QAM channel. There must be one session per Downstream Channel. There is one DEPI pseudowire type per session. There may be one MPT flow or one or more PSP flows per session. Multiple sessions may be bound to a single control connection.
StopCCN	L2TPv3 Stop-Control-Connection-Notification message.
Upconverter	A device used to change the frequency range of an analog signal, usually converting from a local oscillator frequency to an RF transmission frequency.
Upstream (US)	1. Transmissions from CM to CMTS. This includes transmission from the RPD to CCAP-Core as well as the RF transmissions from the CM to the RPD. 2. RF spectrum used to transmit signals from a subscriber location to a cable operator's headend or hub site.
Upstream Channel Descriptor (UCD)	The MAC Management Message used to communicate the characteristics of the upstream physical layer to the cable modems.

Video on Demand (VoD) System   System that enables individuals to select and watch video content over a network through an interactive television system.

4 ABBREVIATIONS AND ACRONYMS

This specification uses the following abbreviations:

ACK	L2TPv3 Explicit Acknowledgement message
ATM	Asynchronous Transfer Mode
AVP	L2TPv3 Attribute Value Pair
BAT	Buffer Alert Threshold
BFD	Bidirectional Forwarding Detection
CCAP™	Converged Cable Access Platform
CDN	L2TPv3 Call-Disconnect-Notify message
CIN	Converged Interconnect Network
CM	Cable Modem
CMTS	Cable Modem Termination System
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
CRC16	CRC of length 16
CSMA	Carrier Sense Multiple Access
CV	Connectivity Verification
DA	Destination Address
dB	Decibels
dBmV	Decibel-Millivolt
DCA	Distributed CCAP Architecture
DEPI	Downstream External-PHY Interface
DLM	DEPI Latency Measurement
DOCSIS	Data-Over-Cable Service Interface Specifications
DOCSIS-MPT (D-MPT)	DOCSIS MPT Mode
DRFI	Downstream Radio Frequency Interface
DS	Downstream
DSAP	Destination Service Access Point
DSCP	Differentiated Services Code Point
DTI	DOCSIS Timing Interface
DTS	DOCSIS Time Stamp, 32-bit
EMA	Exponential Moving Average
EQAM	Edge QAM
ERM	Edge Resource Manager
ERMI	Edge Resource Manager Interface
FC	Frame Control
FEC	Forward Error Correction
FQDN	Fully Qualified Domain Name
Gbps	Gigabits per second
GCP	Generic Control Plane

GE	Gigabit Ethernet (Gig E)
GHz	Gigahertz
HCS	Header Check Sequence
HDLC	High-Level Data Link Control
HELLO	L2TPv3 Hello message
HFC	Hybrid Fiber/Coax
Hz	Hertz
ICCN	L2TPv3 Incoming-Call-Connected message
ICRP	L2TPv3 Incoming-Call-Reply message
ICRQ	L2TPv3 Incoming-Call-Request message
ID	Identifier
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
IKE	Internet Key Exchange
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISO	International Standards Organization
ITU	International Telecommunications Union
ITU-T	Telecommunication Standardization Sector of the International Telecommunication Union
kbps	Kilobits per second
kHz	Kilohertz
L2TP	Layer 2 Transport Protocol
L2TPv3	Layer 2 Transport Protocol version 3
L3	Layer 3
LAC	L2TP Access Concentrator
LAG	Link Aggregation Group
LCCE	L2TP Control Connection Endpoint
LNS	L2TP Network Server
LSB	Least Significant Bit
MAC	Media Access Control
MAP	Upstream Bandwidth Allocation Map (referred to only as MAP)
Mbps	Megabits per second
MCM	Multi Channel MPEG
M-CMTS	Modular Cable Modem Termination System
MER	Modulation Error Ratio
MHz	Megahertz
MIB	Management Information Base
MLD	Multicast Listener Discovery
M/N	Relationship of integer numbers M,N that represents the ratio of the downstream symbol clock rate to the DOCSIS master clock rate

MPEG	Moving Picture Experts Group
MPEG-TS	Moving Picture Experts Group Transport Stream
MPLS	Multiprotocol Label Switching
MPT	MPEG-TS mode of DEPI
MPTS	Multi Program Transport Stream
ms	Millisecond
MSO	Multiple System Operator
MSB	Most Significant Bit
MTU	Maximum Transmission Unit
NDF	Narrowband Digital Forward
NDR	Narrowband Digital Reverse
ns	Nanosecond
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-of-band
OSSI	Operations System Support Interface
PCR	Program Clock Reference
PDU	Protocol Data Unit
PHB	Per Hop Behavior
PIM	Protocol-Independent Multicast
PHY	Physical Layer
PID	Packet Identifier
PHB-ID	Per Hop Behavior Identifier
PLC	PHY Link Channel
PMD	Physical Media Dependent Sublayer
PPP	Point-to-Point Protocol
PSI	Program Specific Information
PSP	Packet-Streaming-Protocol
PW	Pseudowire
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
R-DEPI	Remote DEPI
R-DTI	Remote DTI
RF	Radio Frequency
RFI	Radio Frequency Interface
RFC	Request For Comments
RPD	Remote PHY Device
R-PHY	Remote PHY
R-OOB	Remote Out-of-band
R-UEPI	Remote UEPI
SA	Source Address

SAR	Segmentation and Reassembly
S-BFD	Seamless BFD
SCCRN	L2TPv3 Start-Control-Connection-Connected message
SCCRP	L2TPv3 Start-Control-Connection-Reply message
SCCRQ	L2TPv3 Start-Control-Connection-Request message
S-CDMA	Synchronous Code Division Multiple Access
SC-QAM	Single Carrier Quadrature Amplitude Modulation
SDV	Switched Digital Video
SID	Service ID
SLA	Service Level Agreement
SLI	L2TPv3 Set Link Info message
SPR	Stream Processing Resource
SPTS	Single Program Transport Stream
SSAP	Source Service Access Point
StopCCN	L2TPv3 Stop-Control-Connection-Notification message
TC	Transmission Convergence
TCP	Transmission Control Protocol
TSID	MPEG2 Transport Stream ID
UCD	Upstream Channel Descriptor
UDP	User Datagram Protocol
UEPI	Upstream External-PHY Interface
UML	Unified Modeling Language
US	Upstream
VCCV	Virtual Circuit Connectivity Verification
VoD	Video On Demand
WFQ	Weighted Fair Queuing

5 OVERVIEW

5.1 System Architecture

5.1.1 Reference Architecture

The architecture for a MHAv2 system is shown in Figure 5–1. This architecture contains several pieces of equipment along with interfaces between those pieces of equipment. This section briefly introduces each device and interface.
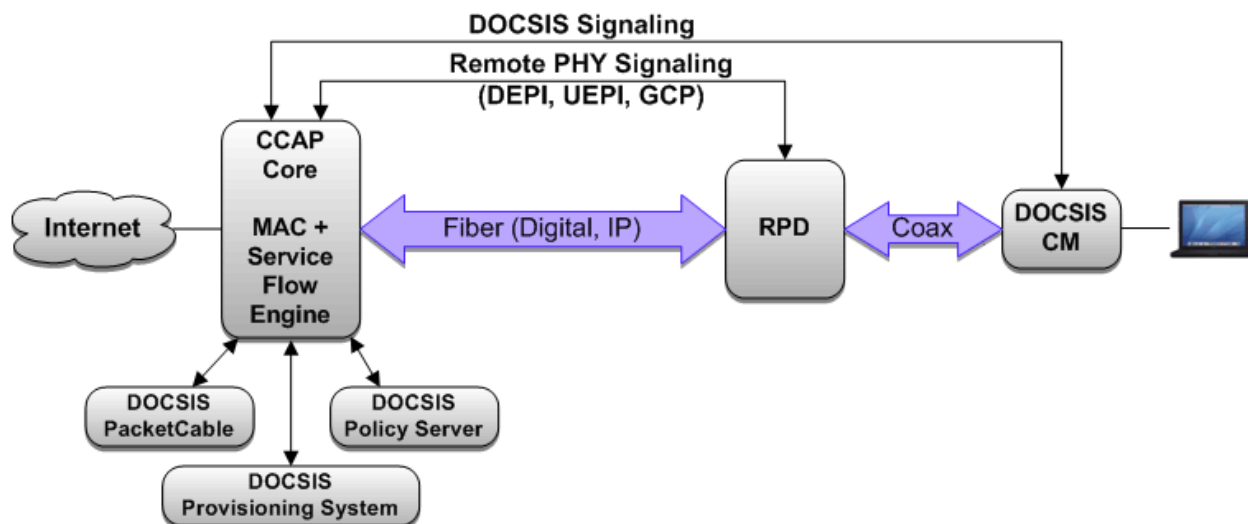
Figure 5–1 - MHAv2 / R-PHY System Architecture

The Remote PHY Device (RPD) is a device that has a network interface on one side and an RF interface on the other side. The RPD provides Layer 1 PHY conversion, Layer 2 MAC conversion, and Layer 3 pseudowire support. The RPD RF output may be combined with other overlay services such as analog or digital video services.

The CCAP-Core contains everything a traditional CCAP does, except for functions performed in the RPD. The CCAP-Core contains the downstream DOCSIS MAC, the upstream DOCSIS MAC, all the initialization and operational DOCSIS-related software as well as the majority of the video EQAM functions.

Note that the original MHA architecture had the downstream PHY external and the upstream PHY internal. MHA was used to interface to an EQAM (Edge QAM) device that was co-located at the head end with the CMTS Core. Thus, the main differences between MHAv1 and MHAv2 are the location of the upstream PHY, the division of EQAM functions between the CCAP-Core and the RPD, as well as the role of the solution in the marketplace. From a technical standpoint, the solutions are very similar.

Due to the physical separation of the downstream PHY and the upstream PHY in MHAv1, a DOCSIS Timing Interface (DTI) Server is needed to provide a common frequency of 10.24 MHz and a DOCSIS timestamp between the two MHAv1 elements. In MHAv2, the same DTI server is not required because the downstream and upstream PHYs are co-located in the RPD. A different timing solution referred to as **R-DTI** is used to provide timing services for functions such as DOCSIS scheduling.

R-DEPI, the Downstream External PHY Interface, is the downstream interface between the CCAP-Core and the RPD. R-DEPI is based on [DEPI]. More specifically, it is an IP pseudowire between the MAC and PHY in an MHAv2 system that contains both a data path for DOCSIS frames, video packets, and OOB packets, as well as a control path for setting up, maintaining, and tearing down sessions. MHAv1 used the MPT (MPEG-TS) encapsulation. MHAv2 retains the original MPT encapsulation for backward compatibility but also added a new MPEG encapsulation called MCM (Multi-channel MPEG). MHAv2 also requires the PSP (Packet Streaming Protocol) mode for transport of DOCSIS data, and supports new services like DOCSIS 3.1.

R-UEPI, the Upstream External PHY Interface, is the upstream interface between the RPD and the CCAP-Core. Like DEPI, it is an IP pseudowire between the PHY and MAC in an MHAv2 system that contains both a data path for DOCSIS frames, and a control path for setting up, maintaining, and tearing down sessions.

NSI, or the Network Side Interface, is unchanged, and is the physical interface the CMTS uses to connect to the backbone network. Today, this is typically 10 Gbps Ethernet.

CMCI, or Cable Modem to Customer Premise Equipment Interface, is also unchanged, and is typically Ethernet, USB, or WiFi.

5.1.2   DEPI Operation

DEPI is an IP Tunnel that exists between the DOCSIS or MPEG Video MAC in the CCAP-Core and the PHY that exists in the RPD. DEPI's job is to take either formatted DOCSIS frames or MPEG packets and transport them through a Layer 2 or Layer 3 network and deliver them to the RPD for transmission.

The base protocol that is used for the DEPI is the Layer 2 Tunneling Protocol version 3, or L2TPv3 for short (see [RFC 3931]). L2TPv3 is an IETF protocol that is a generic protocol for creating a pseudowire. A pseudowire is a mechanism to transparently transport a Layer 2 protocol over a Layer 3 network. Examples of protocols supported by L2TPv3 include ATM, HDLC, Ethernet, Frame Relay, and PPP.

Section 8.1 shows the format of an L2TPv3 data packet. Each data packet contains a 32-bit session ID that is associated with a single QAM Channel or a group of QAM channels.

L2TPv3 permits a subheader to exist whose definition is specific to the payload being carried. The control channel allows for signaling messages to be sent between the CCAP-Core and RPD. Typical control messages will set up a "control connection" between the CCAP-Core and RPD, and then set up multiple data sessions (one for each downstream QAM channel). Each session can be marked with different Differentiated Services Code Points (DSCPs) and can support different encapsulation protocols.

There are three basic tunneling techniques defined by DEPI. The first technique, known as D-MPT mode, transports multiple 188-byte MPEG-TS packets by placing them into the L2TPv3 payload with a unique subheader which contains a sequence number so packet drops can be detected. The encapsulation of DOCSIS frames into MPEG-TS packets is performed in the CCAP-Core.

The second technique, known as Multi-Channel-MPEG (or MCM) is a variation of the D-MPT technique. MCM allows a single DEPI packet to transport MPEG frames for multiple QAM channels. D-MPT and MCM can be utilized to carry data to SC-QAM channels.

The third technique, known as the Packet Streaming Protocol (PSP) can be used to transport DOCSIS frames and PLC information in the L2TPv3 payload. PSP can be utilized for transport of data to SC-QAM channels and OFDM channels. When sent to a SC-QAM channel, the DOCSIS frames are then encapsulated in MPEG-TS packets within the RPD. When sent to an OFDM channel, the OFDM Codeword Builder converts PSP packets into OFDM codewords and PLC messages. PSP mode allows DOCSIS frames to be both concatenated, to increase network performance, and fragmented, in case the tunneled packets exceed the network MTU size.

One of the technical considerations of the MHAv2 architecture is its impact on the round trip request-grant delay time. The request-grant delay time is the time from when a CM requests bandwidth using an uncontended bandwidth request (REQ), to when it receives a MAP message with the granted transmit opportunity.

To prevent the MAP from being slowed down by other traffic in the CIN, the DOCSIS traffic (or a subset containing the MAP messages) may be sent in an independent L2TPv3 flow that has a unique DSCP. The value of the marked DSCP value should be consistent with a configured "per hop behavior (PHB)" that will provide MAP messages with the highest priority and lowest latency across the CIN to the RPD.

5.1.3   Bonding Services Model

Downstream Channel Bonding refers to the forwarding of a stream of DOCSIS frames across multiple QAM carriers. The specifics of the forwarding are shown in Figure 5–2.
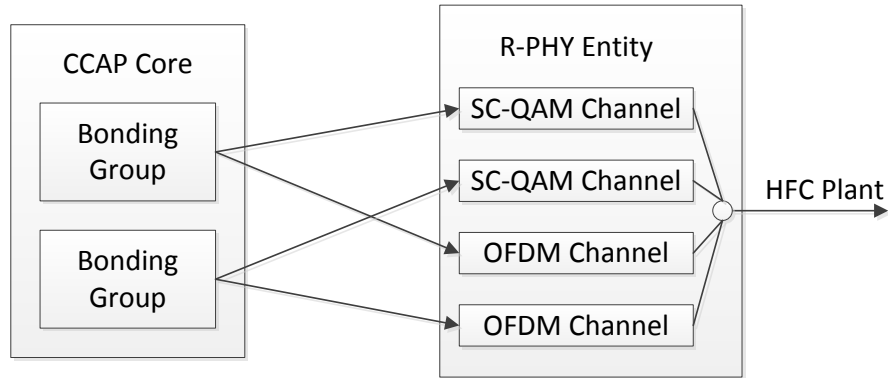
Figure 5–2 - Downstream Channel Bonding Services Model

In the MHAv2 architecture, the Downstream Channel Bonding is implemented in the CCAP-Core. At the CCAP-Core, a packet from the IP backbone is placed in a DOCSIS frame. That DOCSIS frame is then sent to one of several QAM channels in a Bonding Group. The frame may be transported over DEPI using D-MPT, MCM, or PSP techniques.

In this system, the RPD is unaware that it is performing bonding. It is also unaware of any of the details of the DOCSIS bonding protocol.

5.2   Multiple Services Model

DEPI supports both DOCSIS services and MPEG video services. The DOCSIS services and MPEG video services are delivered on a separate set of downstream channels and typically transported over DEPI through a separate set of pseudowires.

5.3   R-PHY System for MPEG-TS Video

The long-established and widely understood role of the EQAM in the video-on-demand (VoD) and switched-digital-video (SDV) architecture is to receive an IP unicast or multicast stream containing MPEG transport stream packets, and then produce that transport stream on one or more RF outputs for transmission over the hybrid fiber-coax (HFC) cable plant.

The chosen approach for MPEG video support in R-PHY architecture is to have the CCAP-Core perform the vast majority of the EQAM functions and have the RPD perform minimal functions. With this in mind, the CCAP-Core receives SPTS or MPTS streams, multiplexes the streams, and generates an MPEG-compliant MPTS stream that is then transported over L2TPv3 to the RPD. The RPD then performs de-jittering to handle the jitter that the intervening network had introduced.

5.3.1   CCAP-Core Video Functions

The CCAP-Core receives SPTS or MPTS streams and outputs MPTS streams. It performs a number of functions such as: demultiplexing, PID remapping/filtering, multiplexing, PSI parsing and re-generation, de-jittering, clock recovery and PCR restamping, NULL packet insertion, and encryption as described in [EQAM-VSI]. After performing all these functions, the CCAP-Core outputs a constant bit rate multiplex output and transports the multiplexed stream over L2TPv3, with up to 10 MPEG packets in one L2TPv3 packet.

The CCAP-Core also participates in the required control plane signaling for setup and teardown of sessions as described in [RMI-ERM-EDGE].

5.3.2   RPD Functions

The RPD receives only constant bit rate MPTS streams which themselves may contain streams for VoD/SDV/Broadcast applications. The RPD is unaware of any individual video sessions, or their setup and teardown. The rate of the incoming MPTS stream is signaled to the RPD from the CCAP-Core via the control plane.

One possible implementation of the RPD is that the RPD does not make any assumptions about the clock frequencies of the CCAP-Core and RPD being synchronized. Such an RPD has a MPEG-compliant clock and adds and/or deletes NULL packets to account for the clock frequency difference between the CCAP-Core and RPD. A block diagram of a Remote PHY implementation as described above is shown in Figure 5–3.
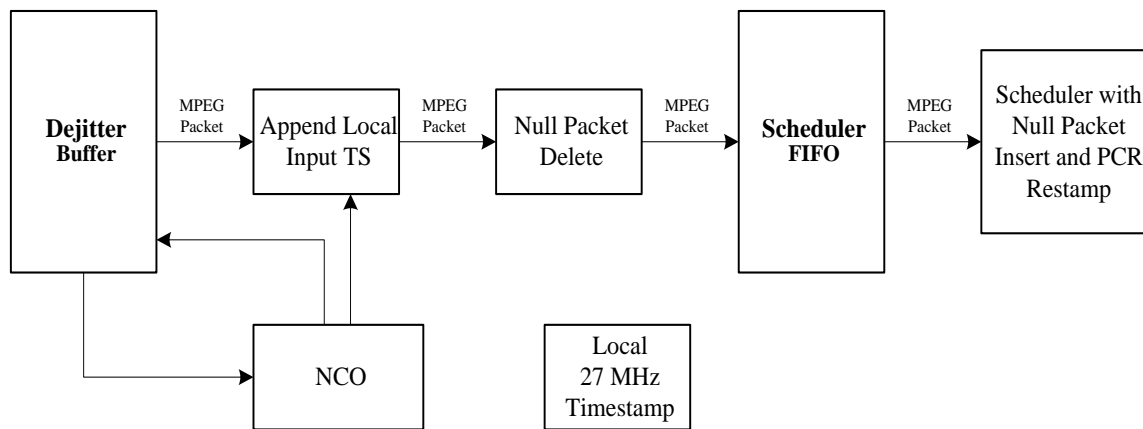
Figure 5–3 - Block Diagram of Typical Remote PHY Setup

The incoming MPTS stream is de-jittered to handle any jitter that was introduced in the intervening network. The incoming MPTS stream is assumed to be constant bit rate and the rate is known at the RPD. This allows the Remote PHY to detect if the clock frequency of the CCAP-Core is ahead or behind the RPD clock, and hence delete or insert NULL packets as needed. The RPD assumes that the PCR that was stamped in the incoming packets was MPEG compliant and hence only adjusts the PCR as needed to account for any NULL packets introduced or deleted in the RPD. For the system to operate properly, enough NULL packets should be present at the output of the CCAP-Core so that the RPD can delete them as needed to adjust for clock frequency differences.

An alternate RPD implementation could in fact synchronize the RPD clock to the CCAP-Core clock via R-DTI. An RPD that operates in such a synchronous mode could in fact avoid PCR re-stamping, by simply replacing lost packets with NULL packets. Lost packets could be detected by checking sequence numbers contained in D-MPT headers. However, the RPD will still need to de-jitter the incoming MPTS stream to remove the effects of the CIN jitter.

5.4   R-PHY System for OOB

The R-PHY System for Out-of-Band control data is described in the [R-OOB] specification.

5.5   Multicast Support on R-PHY

The primary use case for multicast delivery between CCAP-Core and the RPD is for the delivery of broadcast video services from a single CCAP-Core element to a number of RPDs. This allows the system to scale by allowing a single CCAP-Core element to generate and serve streams to all the RPDs that are configured to receive the same broadcast lineup. Since broadcast Serving Groups are quite large (~100,000 or more subscribers), using multicast to deliver the same copy to hundreds of Remote PHY devices provides significant cost savings for operators. This mechanism can be used for broadcast video delivered via MPEG QAM channels or for that delivered via IP over DOCSIS. It is meant for the replication of an entire QAM channel to multiple RPDs.

The data plane itself consists of D-MPT or PSP packets which are encapsulated in a Multicast IP packet. The intervening network only sees standard IP multicast packets and hence standard multicast forwarding works as expected. The RPD participates in multicast signaling using IGMPv3/MLDv2, which ensures proper forwarding of the multicast packets over the intervening network. The RPD learns which multicast streams to join via the L2TP control plane. The L2TPv3 control plane itself remains point-to-point.

6   DEPI ARCHITECTURE

6.1   DEPI Data Path

A simplified logical block diagram of the internal downstream DOCSIS and video data path of the RPD is shown in Figure 6–1.
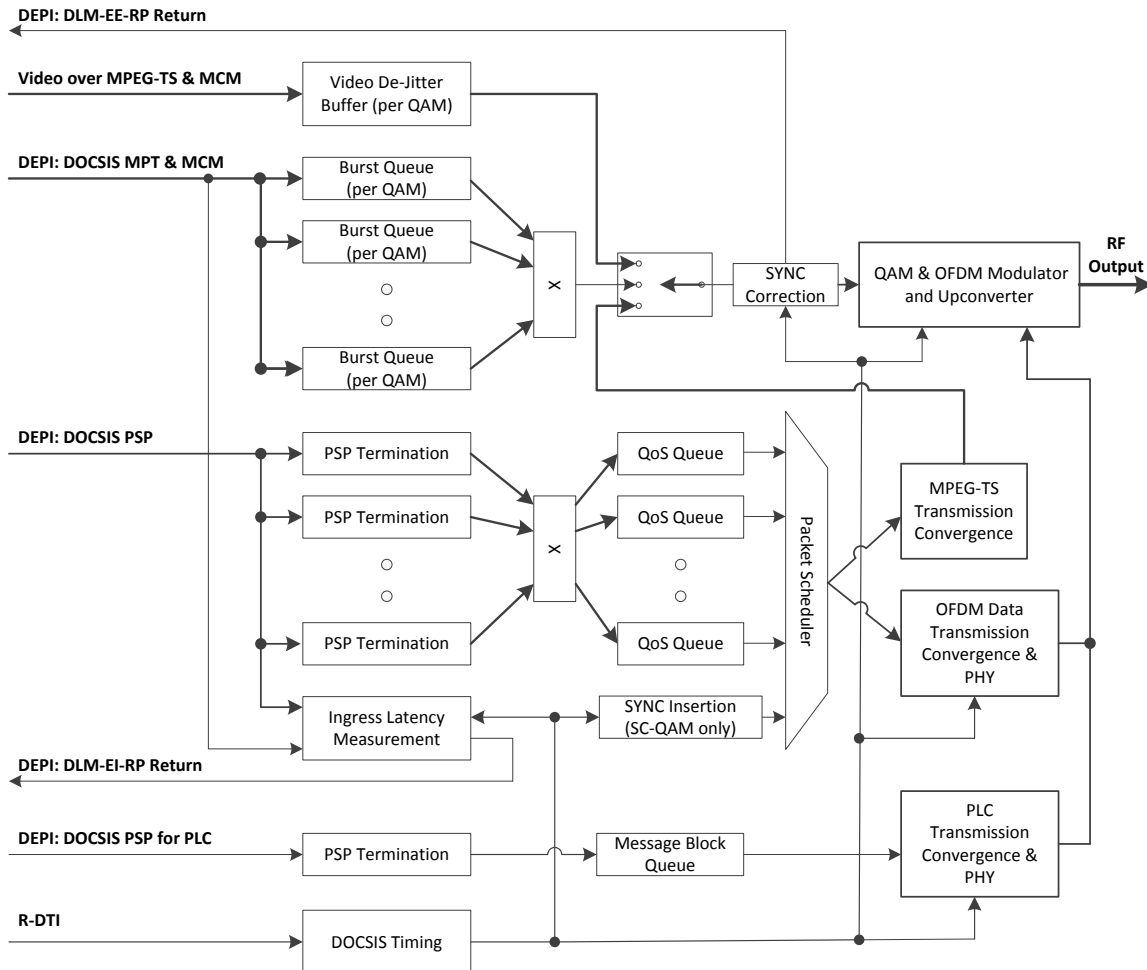
Figure 6–1 - Downstream DOCSIS and Video R-PHY Block Diagram

The requirements for processing MPEG Video are described in Section 6.3.

The CCAP-Core MUST support PSP mode for transport of data on DOCSIS SC-QAM and OFDM channels.

The CCAP-Core MAY support D-MPT mode or MCM Mode, or both modes for transport of data on DOCSIS SC-QAM channels.

The RPD MUST support PSP mode for transport of data on DOCSIS SC-QAM and OFDM channels.

The RPD MAY support D-MPT mode, MCM Mode, or both modes for transport of data on DOCSIS SC-QAM channels.

The CCAP-Core creates an L2TPv3 session with either a PSP or non-PSP pseudowire type (e.g., D-MPT or MCM). The RPD is not intended to simultaneously support PSP and non-PSP traffic within a single session. For non-PSP sessions, the RPD transmits information from L2TPv3 data packets directly to a downstream RF channel in order of packet sequence number. The "FlowId" field of the L2TPv3 sublayer for non-PSP sessions is reserved; it is

transmitted as 0 and ignored on receipt. For PSP sessions, packets are grouped into one or more PSP "flows" in each direction. The RPD supports reception and assembly of PSP-fragmented packets on each downstream flow. The RPD enqueues each assembled downstream packet onto a "QOS queue" for scheduling by a Packet Scheduler onto a downstream channel.

The RPD is not intended to simultaneously support D-MPT and PSP within a single session.

For both non-PSP and PSP modes, the RPD MUST insert null MPEG packets when it has no data to send. The RPD SHOULD NOT insert a null MPEG packet if it has data to send. Note that MPEG null insertion should take place prior to the correction of the DOCSIS SYNC message (see Section6.1.3).

In the upstream direction, an RF channel is assigned by the CCAP-Core (via GCP) to a set of PSP sessions. Upstream data PSP sessions may have more than one PSP flow; other pseudowire types have a single upstream PSP flow. Each upstream PSP flow applies to a level of QoS in the CIN. This specification does not specify how the RPD schedules upstream traffic from multiple PSP flows or multiple sessions onto an upstream CIN.

6.1.1   DOCSIS D-MPT Data Path

The DEPI DOCSIS D-MPT flows contain DOCSIS frames using the format described in Section 8.2. All DOCSIS frames, including packet based frames and MAC management based frames, are included within the one D-MPT flow. The RPD searches the D-MPT or MCM payload for any DOCSIS SYNC messages and performs SYNC corrections as described in Section 6.1.3.2. It then forwards the D-MPT packet to the RF interface.

In D-MPT mode, MPEG packets are received by the RPD and forwarded directly to the RF interface without having to terminate and regenerate the MPEG framing. The only manipulation of the D-MPT payload is the SYNC correction.

6.1.2   PSP Data Path

The Packet Stream Protocol (PSP) is a Layer 3 convergence layer protocol, which allows packets to be consecutively streamed together and fragmented at arbitrary boundaries. The primary rationale for PSP mode is to facilitate Quality of Service. This mode is to be used for transporting traditional DOCSIS data and signaling messages that use one or more DSCP values. For example, in order to reduce Request-Grant latency, MAP MAC management messages may be sent using a different DSCP on a different PSP flow than the rest of the DOCSIS channel; see Section 7.6.2.1.1 for more information.

The RPD MUST support reception and reassembly of PSP packets on at least four (4) downstream PSP flows per PSP session. The RPD MUST support transmission of at least four (4) upstream PSP flows for upstream data pseudowire types and one (1) PSP flow for all other pseudowire types.

6.1.2.1   PSP Downstream Data Path Packet Scheduler

Each downstream PSP flow is terminated, and the DOCSIS frames within the flow are extracted. The DOCSIS frames are placed into corresponding output QoS queues.

The output of the QoS queues go to a Packet Scheduler, which decides which queue is to be serviced based upon the PHB (negotiated between the CCAP-Core and RPD) of the PSP flow that carried the DOCSIS frames. The Packet Scheduler is also responsible for inserting DOCSIS SYNC messages within the time interval specified by the GCP protocol. The Packet Scheduler SHOULD support a strict priority scheduler. The Packet Scheduler MAY support other queue scheduling logic.

The phrase "packet scheduler" is a general term that describes a method of applying priorities to different queues as packets are moved from different input queues to the output queue. An example of a typical packet scheduling algorithm is Weighted Fair Queuing (WFQ), where some streams are given priority over other streams, but only up to some limit. Packet scheduling should not be confused with the more complex DOCSIS upstream scheduler, which deals with both requests and grants.

The output of the Packet Scheduler goes to a Transmission Convergence engine that places the DOCSIS frames into MPEG packets according to the requirements in [DRFI]. This includes the insertion of null bytes and the DOCSIS SYNC message as described by Section 6.1.3. The output of the Transmission Convergence (TC) engine is sent to the RF Interface.

PSP mode provides acceleration of MAPs through the network, in an attempt to reduce Request Grant latency. The PSP mode is most useful when all or nearly all traffic has migrated to DOCSIS, and therefore, marking MAPs with higher QoS, when compared to other DOCSIS traffic that is needed in order to provide lower latency for MAPs, when traversing a fully subscribed network. Therefore, PSP has value in the long term and is included to address the case where most or all traffic is carried to the home via DOCSIS technology.

For downstream PSP sessions carrying DOCSIS traffic (pseudowire types PSP and PSP-OFDM) the CCAP-Core SHOULD transmit MAPs and UCDs on the same downstream PSP flow that is assigned to the Expedited Forwarding (46) PHB-ID.

The RPD downstream packet scheduler MUST support at least two QoS queues on which it enqueues packets from PSP downstream flows assigned to the Expedited Forwarding (46) and Best Effort (0) PHB-IDs, respectively. The RPD SHOULD provide strict high priority scheduling to the QoS queue for PSP flows assigned to the Expedited Forwarding (46) PHB-ID.

6.1.3   DOCSIS SYNC Message

6.1.3.1   *SYNC Message Format*

The DOCSIS Time Synchronization (SYNC) MAC message is transmitted by a CCAP-Core at a periodic interval to establish MAC sublayer timing in cable modems. This message MUST use an FC field with FC_TYPE = MAC Specific Header and FC_PARM = Timing MAC Header. This MUST be followed by a Packet PDU in the format shown in Figure 6–2.
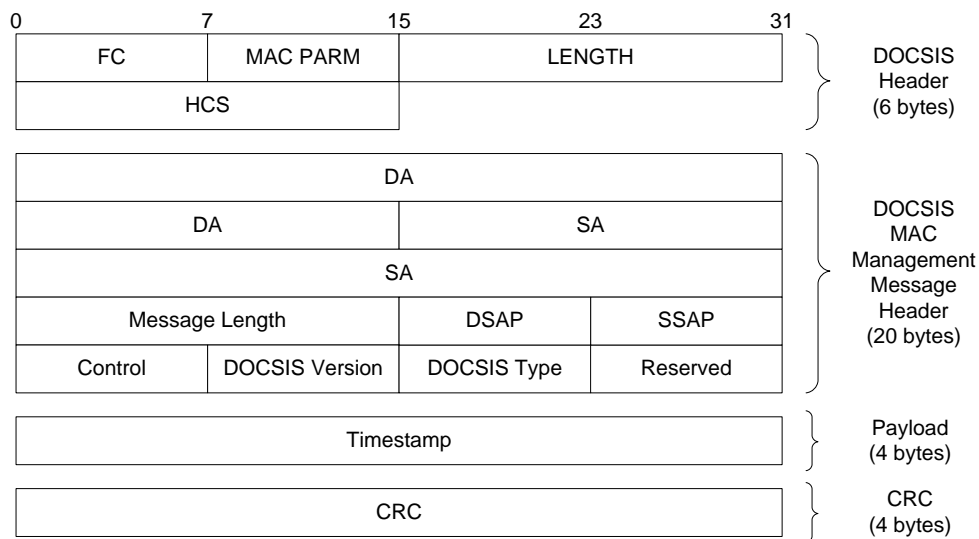
Figure 6–2 - Format of a DOCSIS SYNC MAC Message

The CCAP-Core MUST send a MAC message with fields defined as shown in Table 6–1.

Table 6–1 - DOCSIS SYNC MAC Message Fields

Field	Description
FC, MAC PARM, LEN, HCS	Common MAC frame header with FC_PARM field to indicate a timing header; refer to [RFIv2.0] for details.
Destination Address (DA)	Always set to the DOCSIS MAC multicast address of 01-E0-2F-00-00-01.
Source Address (SA)	The MAC address of the CCAP-Core. In PSP mode, the RPD learns the appropriate CCAP-Core MAC address via explicit signaling during GCP setup.
Msg Length	Length of the MAC message from DSAP to the end of the payload.
DSAP	The LLC null destination SAP (00), as defined by [ISO 8802-2].

Field	Description
SSAP	The LLC null source SAP (00), as defined by [ISO 8802-2].
Control	Unnumbered information frame (03), as defined by [ISO 8802-2].
DOCSIS Version	Set to 1.
DOCSIS Type	Set to 1 to indicate a SYNC message.
CMTS Timestamp	The count state of an incrementing 32-bit binary counter clocked with the 10.24 MHz master clock derived from [DTI].

The CMTS timestamp represents the count state at the instant that the first byte (or a fixed time offset from the first byte) of the Time Synchronization MAC Management message is transferred from the downstream transmission convergence sublayer, to the downstream physical media dependent sublayer, as described in [DRFI].

6.1.3.2   *Correction and Insertion*

The RPD MUST derive a local DOCSIS timestamp as specified in [R-DTI]. In the D-MPT or MCM mode, the RPD MUST be capable of correcting all embedded SYNC messages in the DOCSIS stream. For the DOCSIS PSP mode, the RPD MUST be capable of inserting DOCSIS SYNC messages based on its internal timestamp into the downstream MPEG-TS stream. In PSP mode, the RPD MUST insert the SYNC message starting at the sixth byte of the MPEG-TS frame (the fifth byte is the MPEG pointer field). When referencing a timebase to use for SYNC timestamp insertion or correction, the RPD MUST utilize a timebase that is delayed by no less than 0 and no more than 100 clock cycles (approximately 10 µs) of the master clock (10.24 MHz) compared to the time communicated via the R-DTI Client Test Port output.

This time difference between the time communicated via the R-DTI Client Test Port output and the time reference applied by an RPD is expected to be essentially constant. All timing and jitter requirements that are stated in this specification and [DRFI] still apply. The requirements here do not preclude an RPD from taking longer than 100 clock cycles to process the R-DTI conveyed time, but in that case, the EQAM would need to internally adjust the applied timebase such that it is delayed between zero and 100 clock cycles from the R-DTI conveyed timebase.

When using the D-MPT mode, the CCAP-Core MUST generate SYNC messages and include them in the D-MPT payload for DOCSIS channels. The CCAP-Core MUST insert the SYNC message starting at the sixth byte of the MPEG-TS frame (the fifth byte is the MPEG pointer field). This simplifies the EQAM implementation by allowing the EQAM to check only the Payload_Unit_Start indicator bit and the fifth and sixth byte (which together will contain 0x00C0) of the MPEG-TS packet to locate a DOCSIS SYNC message. Note that the CMTS timestamp in the SYNC messages generated by the CCAP-Core is not required to accurately reflect the current timestamp received via an R-DTI Client in the CCAP-Core. For example, it is permissible for the CCAP-Core to use a value of zero for the CMTS timestamp in all SYNC messages. When using the DOCSIS PSP mode, the CCAP-Core MUST NOT generate SYNC messages as part of the PSP payload.

6.1.4   **Latency and Skew Requirements for DOCSIS Channels**

6.1.4.1   *Latency*

For PSP DEPI DOCSIS sessions, latency is defined as the absolute difference in time from when the last bit of a DEPI packet containing the last bit of a single DOCSIS MAC frame enters the RPD DEPI port to the time that the first bit of the DOCSIS MAC frame exits the RPD RFI port. For D-MPT and MCM DEPI sessions, latency is defined as the absolute difference in time from when the last bit of a DEPI packet enters the RPD DEPI port to the time that the first bit of the first MPEG packet contained within said DEPI packet exits the RPD RFI port. At the RPD input, the last bit of the arriving DEPI packet is used because the RPD's Layer 2 interface (e.g., GigE or 10 GigE port) must receive the entire packet before the RPD can begin processing.

At the RPD output, the first bit of the first MPEG packet (in D-MPT or MCM mode) or DOCSIS frame (in PSP mode) inside the DEPI packet is used to guarantee that the data complies with the definition of "isolated packets" (see following paragraphs). If this were not done, the measurement could be corrupted by delays incurred due to queuing of data behind other packets destined for the same RF interface.

In PSP DEPI sessions, the multiple flows supported in the RPD provide for prioritized access to the channel. This specification defines a concept of "isolated packet stream" for the purpose of establishing a requirement of forwarding latency through an RPD in the case when the internal buffering and queuing effects on latency are smallest. Isolated packets are spaced such that, at the nominal downstream data rate, the RPD would complete transmission of the current packet before the arrival of the next packet.

In the absence of higher priority traffic, and regardless of the amount of lower priority traffic, the RPD MUST forward isolated packets in each DEPI flow with a latency of less than 200 µs plus the delay of the interleaver.

NOTE: The value stated in the above requirement accounts for the OFDM channel codeword builder delays.

The "isolated packet" forwarding delay requirements, outlined above, are applicable only to the forwarding of DOCSIS packets. These requirements are not applicable to forwarding of video, or any other type of traffic.

6.1.4.2   Skew

Skew is defined as the difference between the maximum latency and the minimum latency through the RPD, as measured from two reference bits on the network interface to the same bits on two separate RF outputs. Skew is measured with the PHY parameters set equally on the downstream channels under measurement.

The skew between any two bonded downstream channels within an RPD MUST be less than 500 µs plus the delay introduced by the OFDM channel codeword builder, if applicable. The skew requirements for the RPD are implicitly met when the RPD meets the latency requirements described in Section 6.1.4.1. This requirement is intended for the transmission of skew-sensitive traffic such as bonded traffic.

6.1.4.3   Buffering Requirements for DOCSIS Channels

The RPD MUST allow enough buffer memory per DOCSIS channel to buffer at least 8 ms worth of traffic across all L2TPv3 sessions destined for that DOCSIS channel.

6.1.4.4   Buffering Requirements for Video Channels

For D-MPT video sessions, latency is defined as the absolute difference in time from when the last bit of a DEPI packet enters the RPD DEPI port to the time that the first bit of the first MPEG packet contained within said DEPI packet exits the RPD RFI port. The RPD MUST allow enough buffer memory per video QAM channel to buffer at least 10 ms worth of traffic for that video QAM channel.

6.2   System Timing Considerations

System timing considerations are described in [R-DTI].

6.3   MPEG-TS Requirements

The CCAP-Core MUST support the [EQAM-VSI] specification. The output of the CCAP-Core must be a constant bit rate MPTS stream with NULL packets inserted as needed for video channels and PCR timestamps that comply with MPEG specifications. Null packet insertion for DOCSIS channels is optional. The output MPTS stream is then transported using the D-MPT pseudowire.

The RPD MUST support the D-MPT pseudowire for MPEG video packets.

The CCAP-Core MUST support the D-MPT pseudowire for MPEG video packets.

The CCAP-Core SHOULD comply with [RMI-ERM-EDGE]. The CCAP-Core MUST participate in session signaling for setup and teardown of VoD and SDV sessions.

The RPD MUST have an MPEG-compliant clock per [ISO 13818-1]. Detailed clock requirements for the RPD can be found in [R-DTI].

The RPD MUST insert or delete NULL packets as needed to create an MPEG-compliant output MPTS. PCR timestamps at the output of the RPD MUST be in compliance with [ISO 13818-1].

6.4 Multicast DEPI Requirements

CCAP-Core SHOULD support PIM, IGMPv3, and MLDv2 on the DEPI interfaces. The CCAP-Core SHOULD support the DEPI Remote Multicast Join AVP and the DEPI Remote Multicast Leave AVP.

The RPD MUST support IGMPv3 and MLDv2 on the CIN-facing interfaces. The RPD MUST support the DEPI Remote Multicast Join AVP and the DEPI Remote Multicast Leave AVP. On receiving a DEPI Remote Multicast Join AVP, the RPD MUST join the signaled multicast stream via IGMPv3/MLDv2. On receiving a DEPI Remote Multicast Leave AVP, the RPD MUST leave the multicast stream associated with the session via IGMPv3/MLDv2.

7   REMOTE PHY CONTROL PLANE PROTOCOL (NORMATIVE)

The R-PHY Control Plane protocol described in this section is responsible for managing all types of pseudowires and features including DEPI (DOCSIS and video), UEPI, OOB, NDR/NDF, etc.

The R-PHY protocol control plane signaling is conducted via GCP and L2TPv3 control protocol. The R-PHY L2TP control protocol signaling is based on the L2TPv3 control protocol introduced in [DEPI]. When compared to the original DEPI, the scope of control plane functionality conducted via L2TP control protocol has been reduced. All higher level control primitives, such as QAM channel configuration parameter management, have been removed from the R-PHY L2TP control protocol.

The L2TPv3 control protocol is used exclusively for managing the parameters of the R-PHY data plane connections: L2TPv3 pseudowires, including DEPI, UEPI, and OOB pseudowires. All other aspects of control plane operation, including RPD capability negotiation and RPD configuration management, are now conducted using GCP protocol.

This specification intentionally follows the provisions of [RFC 3931]. This section provides some examples of how L2TPv3 signaling is used, and includes the extensions and interpretations of the [RFC 3931] specification as it applies to R-PHY.

All requirements from [RFC 3931] MUST be met by both the CCAP-Core and the RPD unless this specification explicitly states that a particular requirement from [RFC 3931] is not required.

The examples presented in the following sections are intended to represent selected aspects of the R-PHY topology. The R-PHY architecture is not limited only to the topologies shown in the examples. Other topologies—or combinations of topologies presented in the examples—may be supported by an R-PHY system.

7.1   Remote PHY Topology

Figure 7–1 shows how the Remote PHY architecture maps to L2TP topology in a scenario where a single CCAP-Core device is attached to a single RPD.
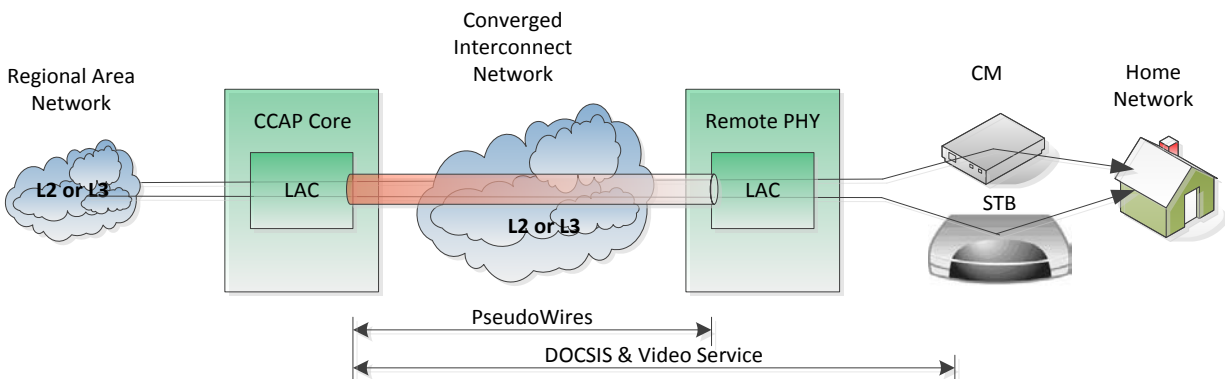
Figure 7–1 - End-to-end Remote PHY Topology

In L2TPv3 nomenclature, the CCAP-Core and the RPD are known as an L2TP Access Concentrator (LAC). The CCAP-Core and the RPD are considered to be peers and may also be referred to as L2TP nodes or as L2TP Control Connection Endpoints (LCCEs). For the purposes defined in this specification, each LCCE is identified on the network by a single IP address. The connections between two LCCEs are known as Pseudowires (PWs).

L2TP supports both a data path and an in-band control path. In L2TPv3 nomenclature, data messages are sent on the data channel, and control messages are sent on the control connection.

In the scenario presented above in Figure 7–1, a single L2TP connection is established between the pair of LCCEs as well as a single GCP connection.

First a GCP connection is established between the two LCCEs, through which the RPD advertises its capabilities to the CCAP-Core and through which the CCAP-Core configures the parameters of the peer RPD. A single GCP connection is utilized to configure all parameters, including those within the scope of DEPI, UEPI, OOB channels, or R-DTI.

Next, an L2TP control connection is established between the two LCCEs, and sessions are established. An L2TP session is established before L2TP begins to forward session frames for data transmission. Multiple sessions, including DEPI, UEPI, and OOB, are typically bound to a single L2TP control connection.
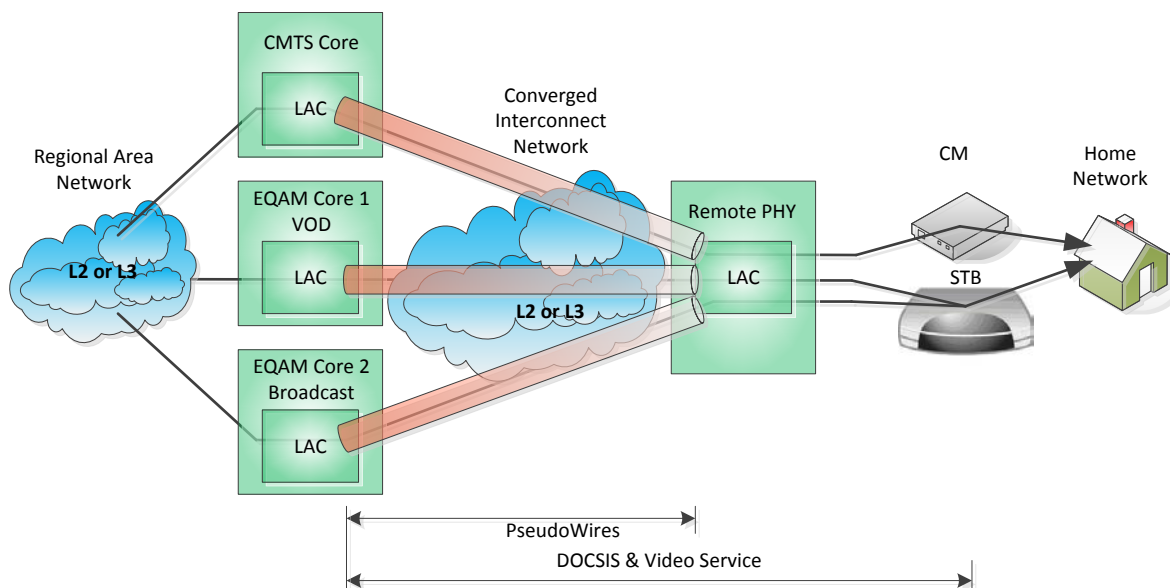
Figure 7–2 - Remote PHY Topology with Separate CMTS Core and EQAM Cores

Figure 7–2 depicts an arrangement where the CCAP-Core consists of three individual core devices. The DOCSIS service is facilitated by a CMTS Core which terminates all DOCSIS DEPI and UEPI tunnels. Two separate EQAM Cores provide video service:

- EQAM Core 1 supplies VoD service transmitted over a dedicated set of video QAM channels in the RPD.
- EQAM Core 2 produces a set of broadcast video channels for transmission over another set of video QAM channels of the RPD.

In the Figure 7–2 example, the RPD maintains three separate connection sets, one set for each core device. Each of the core devices has its own GCP connection and L2TP control connection. Each core device is responsible for managing the parameters of its associated channels and for the administration of its corresponding L2TP pseudowires.

An important peer multi-connectivity aspect of R-PHY topology is presented in Figure 7–3.
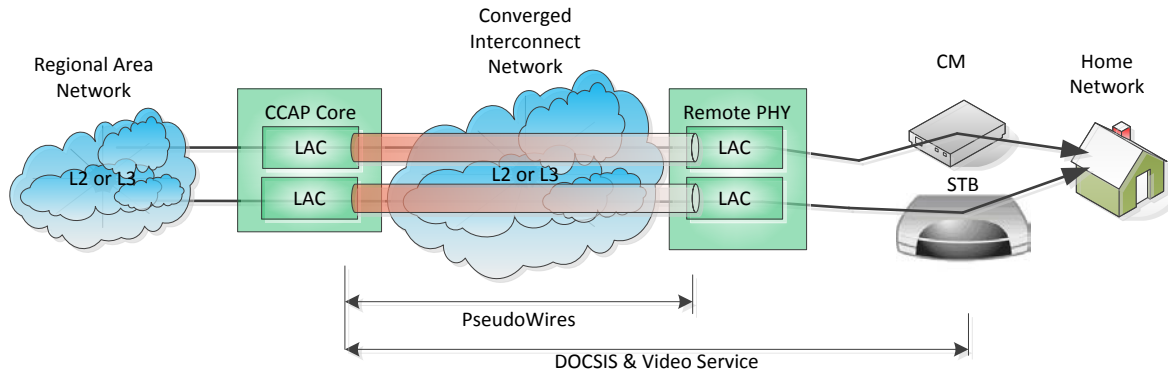
Figure 7–3 - Remote PHY Topology with Multiple Connections

In the Figure 7–3 example, both the CCAP-Core and the RPD include multiple network ports through which R-PHY network traffic is transmitted and received. In the figure, each of the ports is represented by an LAC/LCCE with an individual IP address. As shown in Figure 7–3, two DEPI tunnels are established between different pairs of network ports of each device. In such a topology, a single GCP and two L2TP control connections are created to manage R-PHY parameters and L2TP data pseudowires.

RPDs support the optional ability to provide daisy-chain connectivity to other RPDs. A daisy chain is a connection of RPDs in a series, one after another. To support daisy chaining, the R-PHY has to provide at least one network port to which another RPD can be connected. Daisy chaining introduces another variation of the R-PHY topology.

7.2   Remote PHY Addressing

The set of network connections between a pair of devices consisting of one CCAP-Core and one RPD includes:

- Exactly one GCP connection per pair of CCAP-Core and RPD, and;

- A number of L2TPv3 Control Connections: one L2TPv3 Control Connection per pair of interconnected L2TP Control Connection Endpoints (LCCEs) , and;

- A number of L2TPv3 pseudowires (sessions), one or more per channel, and;

- Sessions utilizing the PSP pseudowire format may consist of multiple data flows.

An example of hierarchy in R-PHY connectivity is presented in Figure 7–4. In the figure, the CCAP-Core contains two LCCEs (LCCE M and LCCE N) and the RPD contains 2 LCCEs (LCCE P and LCCE Q). Each LCCE represents two DEPI channels, an SC-QAM channel and an OFDM channel.

Figure 7–4 shows a single GCP connection between the two devices, two L2TP Control Connections, one L2TP Control Connection per pair of interconnected LCCEs, a DEPI data session for each channel, and two data flows for each data session.
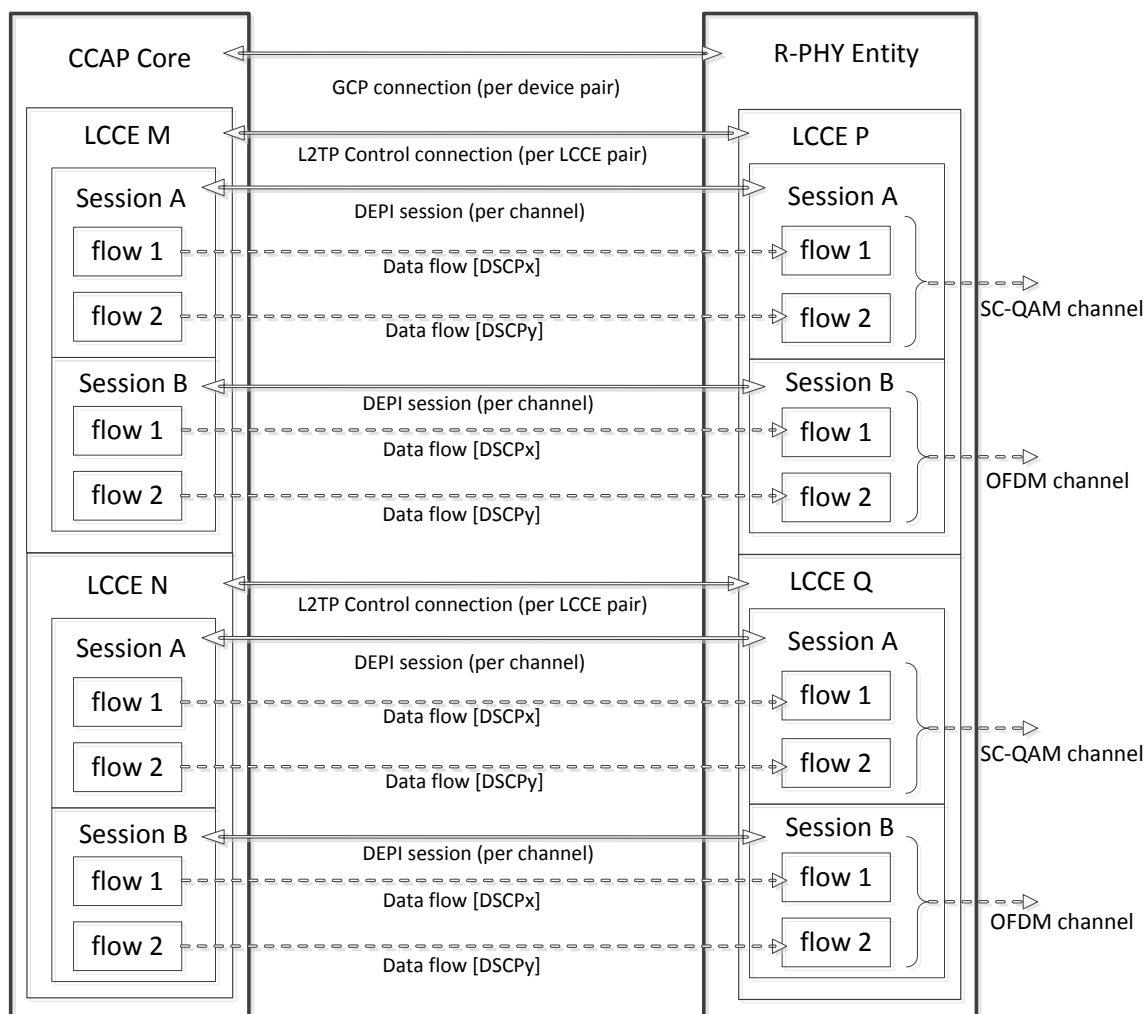
Figure 7–4 - R-PHY Connectivity Hierarchy

The RPD MUST use the IP address of the CCAP-Core to establish the GCP control connection during the initial system configuration. The RPD MUST establish exactly one GCP connection for each interconnected CCAP-Core device.

The CCAP-Core SHOULD use the IP address of the RPD and the TSID identifier of a channel to uniquely identify a QAM Channel within an RPD during L2TP session configuration.

The CCAP-Core MUST establish at most one L2TP control connection for each interconnected LCCE pair. This control connection manages all L2TP data sessions between the pair of LCCEs in the CCAP-Core and the RPD. Since each device may be logically represented as multiple LCCEs, more than one L2TP connection can be created for a set comprising one CCAP-Core and one RPD.

The CCAP-Core MUST support the creation of a single DEPI session per SC-QAM channel. The RPD MUST support a single session per SC-QAM channel.

The CCAP-Core MUST support the creation of a single data DEPI session per OFDM channel. The CCAP-Core MUST support the creation of a single DEPI session for PLC data per OFDM channel. The RPD MUST support a single data session per OFDM channel. The RPD MUST support a single session for PLC data for an OFDM channel.

The session scaling requirements for UEPI and OOB are listed in [R-UEPI] and [R-OOB], respectively.

Each R-PHY session uses one of the Pseudowire types described in Table 7-6. Per [RFC 3931], both the CCAP-Core and the RPD assign a unique L2TPv3 session ID for each session.

The CCAP-Core MUST NOT attempt to create a session for a channel for which the CCAP-Core already has an active session of the same type. Unless specifically configured otherwise, the RPD MUST reject an attempt to establish a session to a channel for which a session of same type has already been established. The requirements listed above are modified when RPD and the CCAP-Core operate in redundant mode. For more information on R-PHY redundancy support, see Annex D.

The CCAP-Core MAY create multiple PSP flows per DEPI session. Different RPD implementations may support different numbers of PSP flows in any given DEPI session, which is described further in Section 6.1. During L2TPv3 session setup, the RPD MUST assign each flow a unique flow ID. Reassembly, if applicable, is done per flow ID at the RPD.

7.3   Connection Initialization Sequence

This list describes the sequence of control and data plane initialization:

- The GCP connection is established (typically, by the RPD).
- R-DTI initialization.
- The RPD advertises its capabilities to the CCAP-Core.
- The CCAP-Core configures channels and other parameters of the RPD.
- The CCAP-Core initiates the L2TP connection establishment.
- The data starts flowing over the tunnels between the devices.

7.4   GCP Protocol

Generic Control Plane (GCP) is a generic control plane encapsulation protocol. GCP sets up a control plane tunnel over a generic transport protocol such as TCP. TCP provides reliable transport, message acknowledgement, message segmentation for large messages, and windowing so that multiple messages can be outstanding at once.

The formal definition of the GCP protocol can be found in [GCP].

7.4.1   RPD Model

GCP protocol exchange between the CCAP-Core and the RPD operates based on the UML model of the RPD. The R-PHY UML model is divided into three top-level divisions:

- RF ports
- Ethernet ports
- Device settings

Additionally, the RF port group contains groups of upstream channels, downstream channels, [SCTE 55-1] channels, [SCTE 55-2] channels and NDR/NDF channels. The top-level divisions of the RPD object model are shown in Figure 7–5.
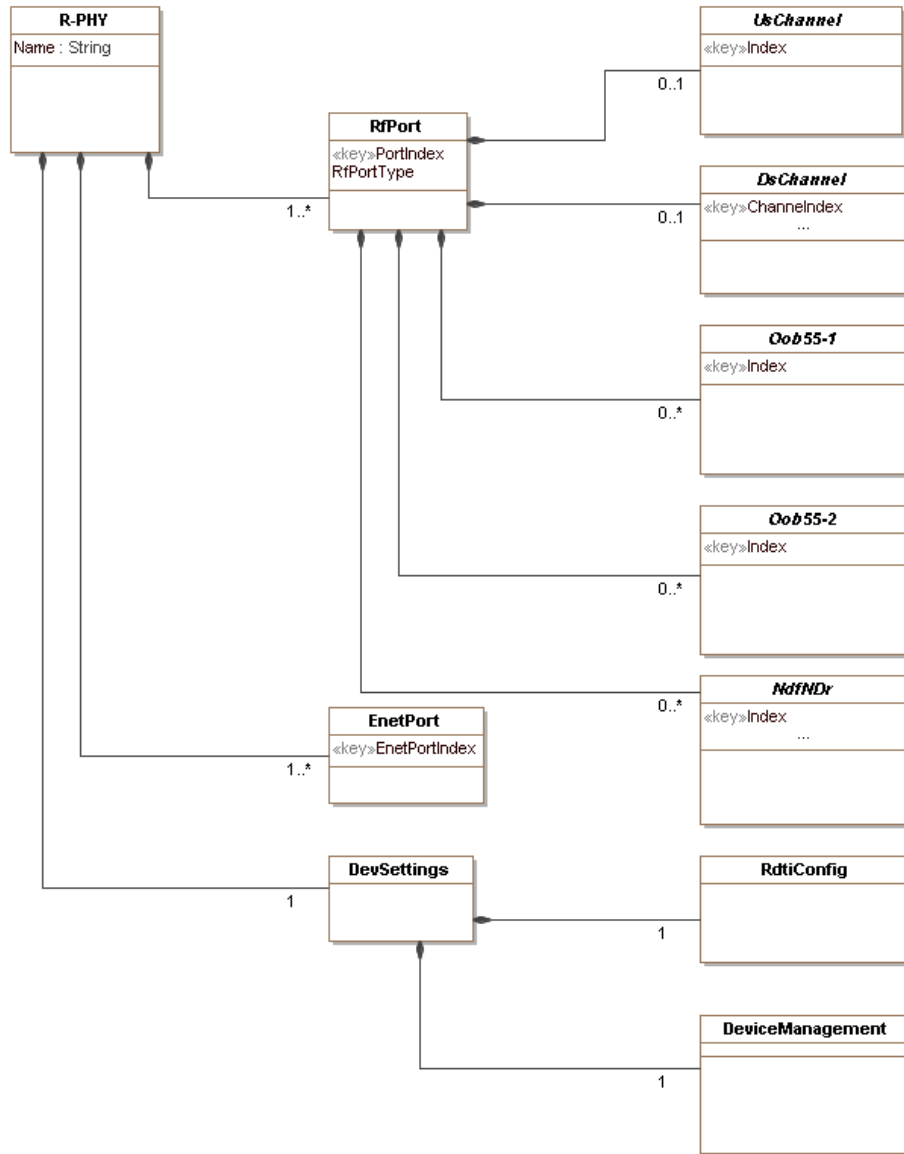
Figure 7–5 - Top-level Divisions of the RPD Model

7.4.2   Downstream Channel Model

The properties of the RPD downstream channel object model are shown in Figure 7–6.
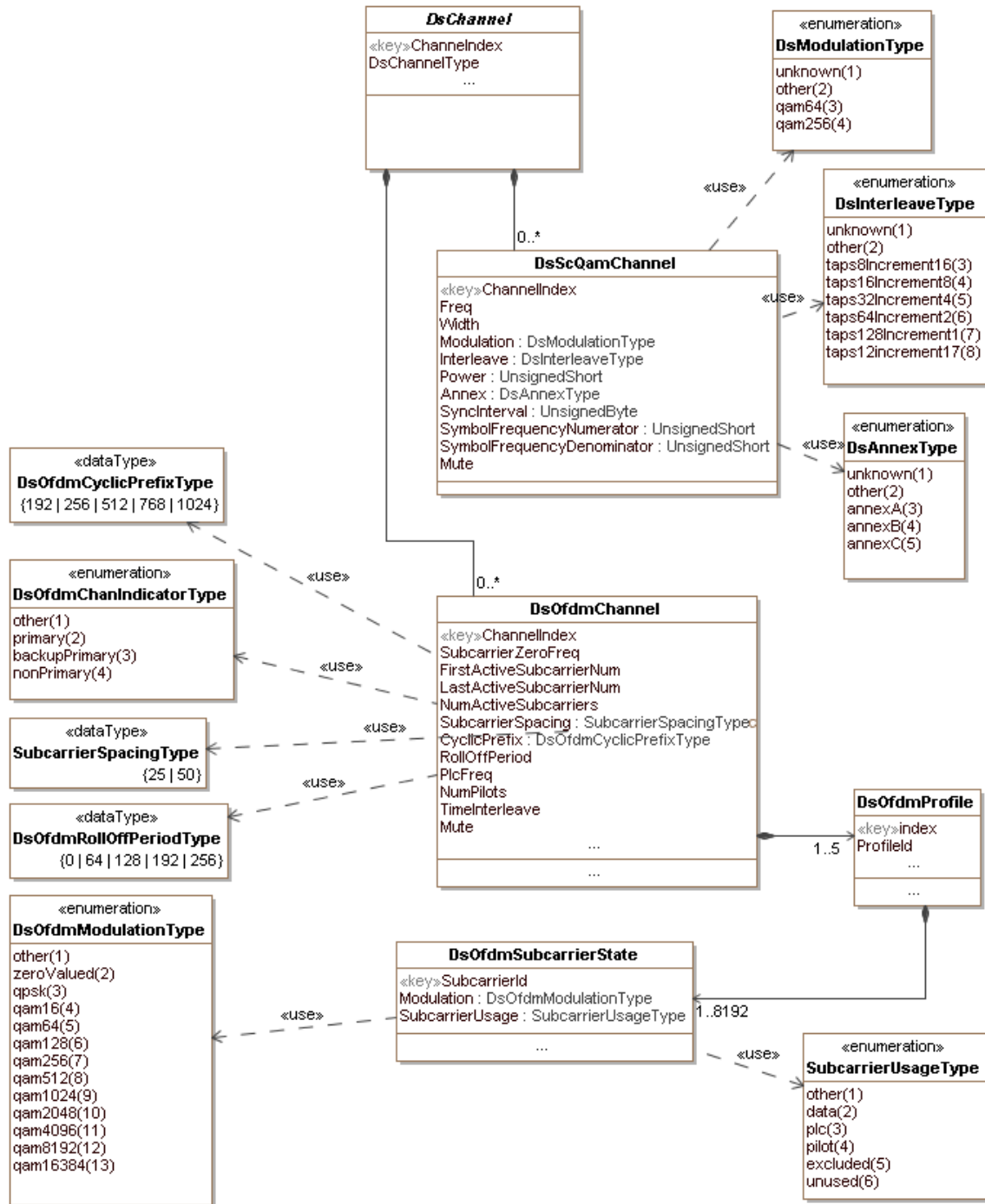
Figure 7–6 - Downstream Channel UML Model for the RPD

7.4.3   Upstream Channel Model

The properties of the RPD upstream channel object model are shown in Figure 7–7.
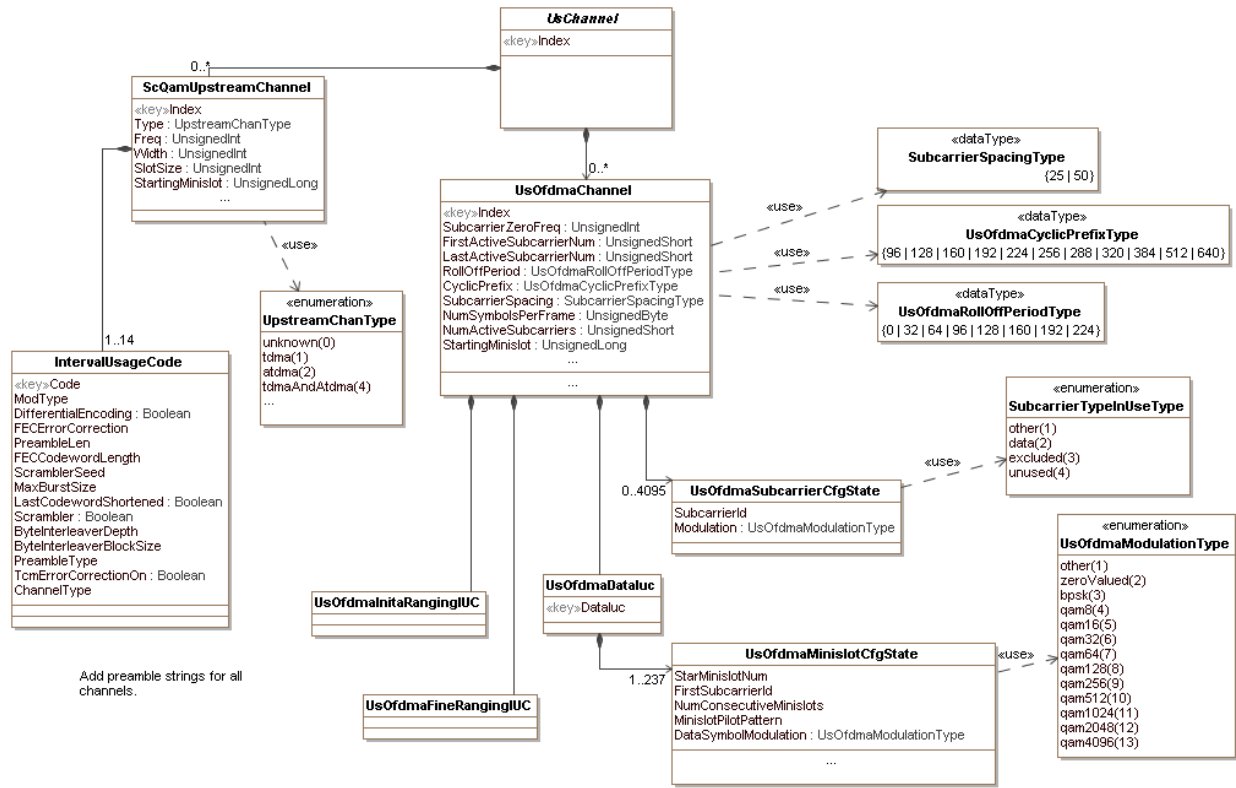
Figure 7–7 - Upstream Channel UML Model for the RPD

7.5   L2TP Control Message Format

7.5.1   L2TP Control Message without UDP Header

The properties of the L2TP control message header are shown in Figure 7–8.

0	7	15	23	31		
DA						Ethernet
DA		SA				802.3
SA						Header
Length/Type						(14 bytes)
User Priority / CFI / VLAN Identifier		MAC Client Length/Type				Ethernet 802.1Q Optional Header (4 bytes)
Version / IHL / DS Field / ECN		Total Length				IPv4
Identification		Flags / Fragment Offset				Header
Time to Live / Protocol = 115		Header Checksum				(20 bytes)
Source IP Address						
Destination IP Address						
Session ID = 0						L2TPv3
T L X X S X X X X X X X / Ver		Length				Control Header
Control Connection ID						(16 bytes)
Ns		Nr				
M H / Resv / Length		Vendor ID				List of AVPs
Attribute Type		Attribute Value ...				N *(6+ bytes)
… (until length is reached)						
CRC						CRC (4 bytes)

Figure 7–8 - L2TP Control Message without UDP Header

7.5.2   L2TP Control Message with a UDP Header

The structure of the L2TP control message header is shown in Figure 7–9.
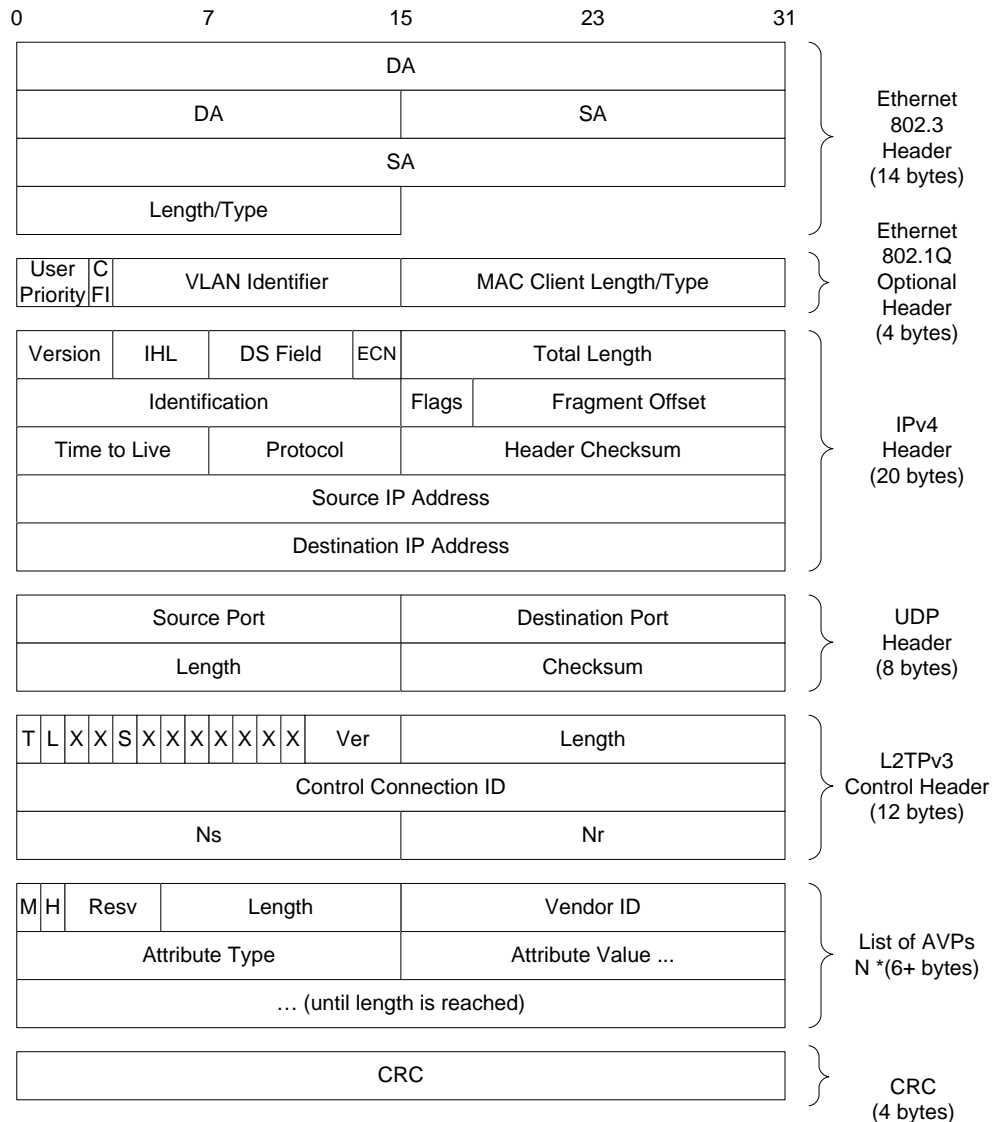
Figure 7–9 - L2TPv3 Control Packet with UDP Header

7.5.3   Common Headers for Control and Data Messages

7.5.3.1   *Ethernet 802.3 Header*

The Ethernet header is defined by [IEEE 802.3]. The Ethernet Destination Address is an individual address. The operation of R-PHY protocols over Ethernet group addresses is not specified at this time. The Ethernet Destination Address may be locally or globally administered.

Upon transmission of this frame by the CCAP-Core, the Ethernet Destination Address will be the Ethernet address of the RPD or of the next hop router. When the RPD receives this frame, the Ethernet Source Address will be the Ethernet address of the output port of the CCAP-Core or of the previous hop router.

If the networking interface is Ethernet, the CCAP-Core MUST support the Ethernet header. If the networking interface is Ethernet, the RPD MUST support the Ethernet header. If another physical layer interface is used instead of Ethernet, then the Ethernet header would be replaced with the header format pertaining to that physical layer.

7.5.3.2   Ethernet 802.1Q Header

The Ethernet 802.1Q header is defined by [IEEE 802.1q]. This header provides frame prioritization and VLAN support at Layer 2.

The CCAP-Core MUST be able to support the Ethernet 802.1Q header. The CCAP-Core SHOULD support mapping of 802.1Q user priority of tunneled packets based on the DSCP value of a tunnel's IP packet. The RPD SHOULD support the Ethernet 802.1Q header.

7.5.3.3   IPv4 Header

The format of an IPv4 header is defined by [RFC 791].

Because of implementation considerations and for coexistence with network policies that are not amenable to IP fragmentation, the receiving devices (R-PHY entities in DEPI, CCAP-Core in UEPI) are not required to perform IP reassembly. The CCAP-Core MUST NOT use IP fragmentation. The CCAP-Core MUST set the IP DF (Don't Fragment) bit in transmitted packets. The RPD MUST NOT use IP fragmentation. The RPD MUST set the IP DF (Don't Fragment) bit in transmitted packets.

The CCAP-Core MUST support a configurable 6 bit Differentiated Services Code Point (DSCP) as defined by [RFC 2983] and [RFC 3260].

The CCAP-Core MUST support the IPv4 header. The RPD MUST support the IPv4 header.

7.5.3.3.1   LCCE IP Addresses

A CCAP-Core MAY initiate L2TPv3 from an LCCE entity IP address that differs from the GCP entity IP address with which it communicates to the RPD. A CCAP-Core MAY initiate an L2TPv3 session to any IP address reported by the RPD as representing an LCCE entity, even if the address does not match the IP address with which the RPD maintains a GCP session with the CCAP-Core.

The RPD MUST support CCAP-Core LCCE entity IP addresses that differ from the CCAP-Core GCP Entity. The RPD MUST support at least four (4) different values of the GCP LCCE entity IP address.

If IKEv2 mutual authentication was established for the CCAP-Core and the RPD GCP entity IP addresses, the CCAP-Core and RPD MUST establish derived security associations for each pair of LCCE entity IP addresses before attempting to start a control session between those LCCE IP addresses.

Both the CCAP-Core and the RPD MUST use the same LCCE IP address for the control session and all data sessions started by that control session.

7.5.3.3.2   DSCP

The R-PHY OSSI specification defines a minimum standard policy by which the CCAP-Core selects DSCP values for L2TPv3 packets sent by itself and the RPD. The specification also permits the CCAP-Core to have a vendor-specific L2TPv3 DHCP policy.

For L2TPv3 control packets, the CCAP-Core MUST transmit with the DSCP specified by its L2TPv3 DSCP policy. When its L2TPv3 control DSCP is other than BestEffort(0), the CCAP-Core MUST communicate that DSCP value to the RPD with a Control Connection DSCP AVP (see Section 7.7.1.6). When it receives a Control Connection DSCP AVP, the RPD MUST transmit all upstream L2TPv3 control packets with that DSCP. When the RPD does not receive a Control Connection DSCP AVP, the RPD MUST transmit upstream control packets with a DSCP of BestEffort(0).

For downstream L2TPv3 data sublayer packets, the CCAP-Core MUST transmit with a DSCP selected by its L2TPv3 policy, e.g., as configured for a pseudowire type or DOCSIS service flow Traffic Priority. Note that this DSCP may or may not match the PHB-ID signaled to the RPD for the flow in the DEPI Resource Allocation

Request AVP (Section 7.7.2.2). This applies for PSP and non-PSP pseudowires with downstream sublayer data (see Table 7-7).

For downstream L2TPv3 DLM sublayer packets (which include a downstream flow ID), the CCAP-Core MUST transmit with the same DSCP value selected by its policy for the identified downstream flow. For L2TPv3 sessions with downstream flows (PSP or non-PSP) that are eligible for a DLM request, the CCAP-Core MUST signal an Upstream Flow AVP with a corresponding upstream flow for the DLM response with a flow ID equal to the downstream flow ID. The RPD MUST transmit a DLM response to a DLM request for a downstream flow ID with a DSCP equal to the PHB-ID signaled in the Upstream Flow AVP for the session for the matching upstream flow ID.

S-BFD packets apply to a pseudowire as a whole and do not signal a flow ID in the L2TPv3 sublayer header. This specification requires S-BFD to be encapsulated for flow ID 0 in each direction. For downstream S-BFD requests, the CCAP-Core MUST transmit with a DSCP specified by its DHCP policy for flow ID 0.

For pseudowires eligible for S-BFD requests, the CCAP-Core MUST signal an Upstream Flow AVP that defines upstream flow ID 0. The RPD MUST transmit an upstream S-BFD response with a DSCP equal to the PHB-ID signaled in the Upstream Flow AVP for the session with flow ID 0.

For pseudowires with upstream sublayer data (see Table 7-7), the CCAP-Core MUST include the Upstream Flow AVP of the ICRP control message it sends to establish the L2TPv3 data session with a PHB-ID equal to the DSCP set by its policy.

When an RPD receives an Upstream Flow AVP for a session, it MUST transmit upstream L2TPv3 sublayer data packets with a DSCP that is equal to the PHB-ID assigned in that AVP for each upstream flow ID.

7.5.3.4   IPv6 Header

The IPv6 header is defined by [RFC 2460].

The CCAP-Core MUST support a configurable 6 bit Differentiated Service Code Point (DSCP) of the IPv6 Traffic Class as defined by [RFC 2983] and [RFC 3260].

The CCAP-Core MUST support the IPv6 header. The RPD MUST support the IPv6 header.

The CCAP-Core MUST support for IPv6 headers all requirements of Sections 7.5.3.3.1 and 7.5.3.3.2.

The RPD MUST support for IPv6 headers all requirements of Sections 7.5.3.3.1 and 7.5.3.3.2.

7.5.3.5   UDP Header

To enhance dispersion of traffic across Link Aggregation Groups (LAGs) in the CIN, R-DEPI supports the optional inclusion of a UDP header in L2TPv3 control and data traffic. Currently, most commercial CIN routers do not include the L2TPv3 session ID in the hash calculation that selects a particular LAG link, but almost all include the UDP source and destination port number in the hash calculation.

The CCAP-Core MUST support L2TPv3 with a UDP header. The RPD MAY support L2TPv3 with a UDP header. An RPD that supports UDP MUST indicate its capability to do so via GCP. A CCAP-Core MUST use a UDP header for all L2TPV3 control and data packets when configured to use UDP headers via OSSI configuration and the RPD reports it is capable. An RPD MUST use a UDP header for all L2TPv3 control and data packets when it is capable of supporting UDP headers and receives an initial SCCRQ control message from a CCAP that includes a UDP header.

Separate AVPs are used to negotiate the UDP port numbers used for control, downstream data, and upstream data L2TPv3 packets.

7.5.3.5.1   Control Packet UDP Port Numbers

When using UDP headers, CCAP-Core and RPD MUST negotiate a pair of ephemeral UDP ports for the LCCE control connection as follows:

1. The CCAP-Core MUST send the initial SCCRQ to an RPD with the well-known destination UDP port 1701 (as assigned to L2TPv3 per [IANA-PORTS]) and an ephemeral source UDP port number denoted here as *core-control-port*;

2. The RPD MUST send its SCCRP reply with the destination UDP port set to *core-control-port* and an ephemeral source UDP port number denoted here as *rpd-control-port*;

3. The CCAP-Core MUST send all control packets of an LCCE control connection after SCCRQ to the destination UDP port *rpd-control-port* with the source UDP port *core-control-port*;

4. The RPD MUST send all control packets of an LCCE control connection after SCCRP to the destination UDP port *core-control-port* and the source UDP port *rpd-control-port*.

7.5.3.5.2   Downstream Data UDP Port Numbers

When using UDP headers, the CCAP-Core and RPD MUST negotiate the destination UDP port number for each downstream L2TPv3 data flow with the following requirements:

1. For pseudowires with downstream sublayer data (see Table 7-7), the CCAP-Core MUST include a DEPI Resource Allocation Request AVP (see Section 7.7.2.2) in the ICRP it sends to an RPD;

2. If the RPD accepts the requested PHB-ID for all downstream flows, it MUST respond with a DEPI Resource Allocation Reply AVP in the ICRP that includes non-zero ephemeral destination UDP ports it assigns for each downstream flow;

3. The RPD MUST select a destination UDP port that is unique per L2TPv3 session ID received by an RPD LCCE IP address;

4. The RPD MAY select different UDP destination ports for the different downstream flows of a session;

5. The RPD MAY select the same UDP destination port some or all flows of the same session;

6. The CCAP-Core MUST send downstream sublayer data packets with the destination UDP port number assigned by the RPD for each flow ID in the DEPI Resource Allocation Response AVP;

7. The CCAP-Core MAY select an arbitrary ephemeral UDP source port number for downstream L2TPv3 data packets. The CCAP-Core MUST use the same source UDP port for all downstream data packets of a particular flow.

7.5.3.5.3   Upstream Data UDP Port Numbers

In R-DEPI, all upstream data is transmitted with a PSP-type pseudowire. When using UDP headers, the CCAP-Core and RPD negotiate the destination UDP port number for each upstream PSP flow as follows:

1. For sessions that send upstream sublayer data packets (per Table 7-7), the CCAP-Core MUST include an Upstream Flow AVP (see Section 7.7.2.9) in the ICRP it sends to an RPD with a flow ID, PHB-ID and Destination UDP Port for each upstream PSP flow of the session;

2. For the UEPI Data pseudowire types (PSP-UEPI-SCQAM and PS-UEPI-OFDMA, see [R-UEPI] for details):

    *   The CCAP-Core MUST assign flow ID 0 in the Upstream Flow AVP as the default upstream flow for the pseudowire;

    *   The CCAP-Core MAY define multiple flows in the Upstream Flow AVP;

    *   The CCAP-Core SHOULD define an upstream flow ID corresponding to every downstream flow ID on which it may send DLM or S-BFD requests;

    *   Before upstream service flows are made active, the CCAP-Core SHOULD send GCP messages to the RPD to assign the upstream SID(s) for the service flow to an upstream flow ID on each channel for which data can be received for the service flow;

    *   When upstream DOCSIS bursts for a SID are received, the RPD MUST transmit upstream L2TPv3 data packets on the PSP flow assigned to that SID, or to flow ID 0 if the SID is not assigned, using the destination UDP port number assigned to that flow in the Upstream Flow AVP;

3. For upstream pseudowire types other than the UEPI Data types:

    *   The CCAP-Core MUST define a single flow ID 0 in the Upstream Flow AVP;

- The RPD MUST transmit upstream L2TPv3 data packets using the destination UDP port assigned to upstream flow ID 0;

4. For pseudowires with downstream sublayer data with downstream flow eligible for sending a DLM request, the CCAP-Core MUST include an Upstream Flow AVP with an upstream flow with the same upstream flow ID as the DLM-eligible downstream flow;

5. For responses to DLM (which are to a particular downstream flow ID), the RPD MUST respond on an upstream flow with the same 3-bit flow ID as the downstream PSP flow when such an upstream flow is defined, or to flow ID 0 when such a flow is not defined;

6. For responses to S-BFD requests, the RPD MUST transmit with the destination UDP port assigned to upstream flow ID 0.

The RPD MAY select an arbitrary ephemeral source UDP port number per upstream PSP session. The RPD MAY select the same source UDP port for all upstream PSP sessions. The RPD MUST use the same source UDP port for all upstream data packets of a particular upstream flow.

7.5.3.5.4   UDP Checksum

When L2TPv3 Control Message Authentication is not in use and UDP headers are enabled, both the RPD and CCAP-Core MUST support UDP checksum verification as defined in [RFC 768] for L2TPv3 control packets. The sender of a control packet MUST calculate and populate the UDP checksum as per [RFC 768]. The receiver of a control packet MUST support validation of a nonzero UDP as per [RFC 768]. The receiver of a control packet MUST reject a packet with a 0 checksum or one that fails UDP checksum verification.

When L2TPv3 Control Message Authentication is in use, the UDP checksum verification is redundant. Therefore, when L2TPv3 Control Message Authentication is in use and UDP headers are enabled, the sender of a control packet MAY set the UDP checksum field to 0, and the receiver MUST ignore a UDP checksum of 0.

For L2TPV3 data packets, the sender (CCAP-Core or RPD) SHOULD set the UDP checksum to 0. For L2TPv3 data packets, the receiver (CCAP-Core or RPD) MUST ignore a UDP checksum of 0 and MAY ignore a UDP checksum that is nonzero.

7.5.3.6   CRC

The CRC is CRC-32 and is defined by [IEEE 802.3].

The CCAP-Core MUST support the CRC field. The RPD MUST support the CRC field.

7.5.4   Specific Headers for Control Messages

7.5.4.1   L2TPv3 Control Header

These fields are defined in [RFC 3931] and are repeated here for reference. Table 7-1 describes the significance of the fields.

Table 7-1 - L2TPv3 Control Header Fields

Field	Description
T	Type bit. The T bit MUST be set to 1, indicating that this is a control message.
L	Length bit. The L bit MUST be set to 1, indicating that the Length field is present.
S	Sequence bit. The S bit MUST be set to 1 indicating that sequence numbers (Ns and Nr) are present.
X	Reserved bits. All reserved bits MUST be set to 0 on outgoing messages and be ignored on incoming messages.
Ver	Version. 4 bits. Set to 3.
Length	2 bytes. The Length field indicates the total length of the message in octets, always calculated from the start of the control message header itself, beginning with the T bit. It does not include the Session ID (when present).
CCID	Control Connection Identifier. 4 bytes. Negotiated per control connection.

Field	Description
Ns	Sending Sequence Number. 2 bytes. Indicates sending sequence of this control message.
Nr	Received Sequence Number. 2 bytes. Indicates next expected received sequence number.

7.5.4.2   Attribute Value Pairs (AVP)

There can be one or more attribute value pairs (AVPs) per R-PHY control message. Table 7-2 describes the significance of the fields.

Table 7-2 - R-PHY Control Message AVPs

Field	Description
M	Mandatory bit. If this bit is set to a 1 and this AVP is rejected, the control connection or session setup in which the AVP is carried will be torn down, according to the procedures outlined in [RFC 3931].
H	Hidden bit. This bit is set to a 1 when the contents of the AVP message are encrypted and a 0 when the contents of the AVP message are not encrypted. Encryption of AVP messages is not required for DEPI.
Resv	Reserved. 4 bits. Set to all zeroes on transmit. Ignored on receive.
Length	10 bits. Equal to the length of the attribute value field plus 6 bytes.
Vendor ID	2 bytes. For AVPs defined by [RFC 3931], this field is set to 0. For AVPs defined by this specification, this field is set to the IANA assigned CableLabs vendor ID of 4491 (0x118B). For AVPs defined outside the scope of this specification, this may be set to a vendor specific ID.
Attribute Type	2 bytes.
Attribute Value	N bytes.
Reserved	8 bits. If an AVP has a reserved field, the bits in this field should be set to 0 on transmit and ignored on the receive.

If an LCCE receives an AVP with a Vendor ID that it doesn't recognize, and the M bit is set to 0, the LCCE MUST silently discard the AVP.

7.6   L2TP Signaling

The supported L2TPv3 messages for the R-PHY control plane are shown in Table 7-3:

Table 7-3 - R-PHY L2TP Control Messages

#	Mnemonic	Name
Control Connection Management		
1	SCCRQ	Start-Control-Connection-Request
2	SCCRP	Start-Control-Connection-Reply
3	SCCCN	Start-Control-Connection-Connected
4	StopCCN	Stop-Control-Connection-Notification
6	HELLO	Hello
20	ACK	Explicit Acknowledgement
Session Management		
10	ICRQ	Incoming-Call-Request
11	ICRP	Incoming-Call-Reply
12	ICCN	Incoming-Call-Connected
14	CDN	Call-Disconnect-Notify
16	SLI	Set Link Info

L2TPv3 outgoing call messages (OCRQ, OCRP, OCCN) and the WAN-Error-Notify (WEN) message are not required to be supported.

A reliable control message delivery mechanism is accomplished either by sending an Explicit Acknowledgement (ACK) message after any of the control messages or by piggybacking an acknowledgment with the Nr and Ns fields in a later control message. If control messages are not acknowledged within the time specified by Control Message Timeout (refer to Annex A), then the control message MUST be retransmitted up to the value of Control Message Retry Count (refer to Annex A). For example, the control message must be retransmitted a total of 10 times using an exponential back-off value starting at 1 second and growing to a maximum value of 8 seconds.

NOTE: There will be 7 intervals of 8 seconds each in this scheme.

Control message authentication MAY be supported. If control message authentication is supported, the methods described in section 5.4.1 of [RFC 3931] SHOULD be followed.

The following sections show flow diagrams that show typical DEPI message exchanges along with the required AVPs from L2TPv3 and DEPI. Optional AVPs are not shown but may also be present.

7.6.1   Control Connection Signaling

7.6.1.1   Control Connection Setup

Figure 7–10 shows the DEPI message exchange that sets up the control connection.

CCAP Core   **R-PHY Entity**

SCCRQ {Message Type, Host Name, Router ID, Assigned Control
Connection ID, Pseudowire Capabilities List, Control Session
DSCP}

SCCRP {Message Type, Host Name, Router ID, Assigned Control
Connection ID, Pseudowire Capabilities List}

SCCCN {Message Type}
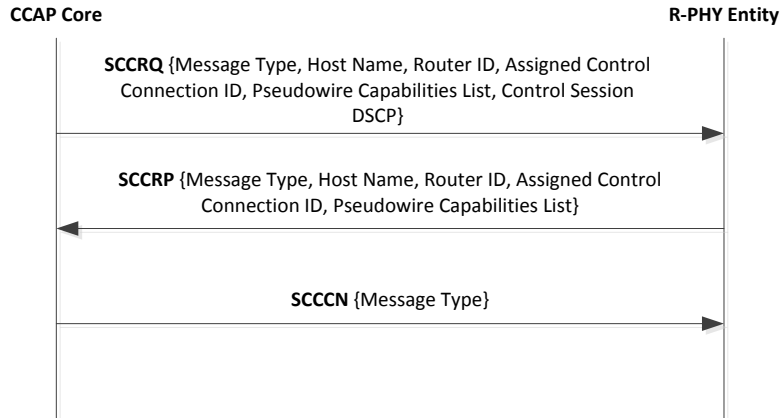
Figure 7–10 - R-PHY L2TP Control Connection Setup

In order to tunnel DOCSIS frames over IP using L2TPv3, an L2TPv3 Control Connection is first established as described in [RFC 3931]. Establishment of the control connection involves an exchange of AVPs that identifies the peer and its capabilities. Note that any L2TP Control Connection setup follows establishment of the GCP connection, including capability identification and device configuration. Each control connection has a Control Connection ID that is assigned by the recipient, and negotiated with Connection ID AVPs during the creation of a control connection.

The CCAP-Core MUST support the ability to initiate control connection signaling (L2TPv3 caller). The RPD MUST support the ability to receive incoming control connection requests from the CCAP-Core (L2TPv3 callee).

Establishment of L2TP control connections by the RPD is not required for the R-PHY protocol and is outside the scope of this specification.

7.6.1.2 Control Connection Teardown

Figure 7–11 shows the DEPI message exchange that tears down the control connection.
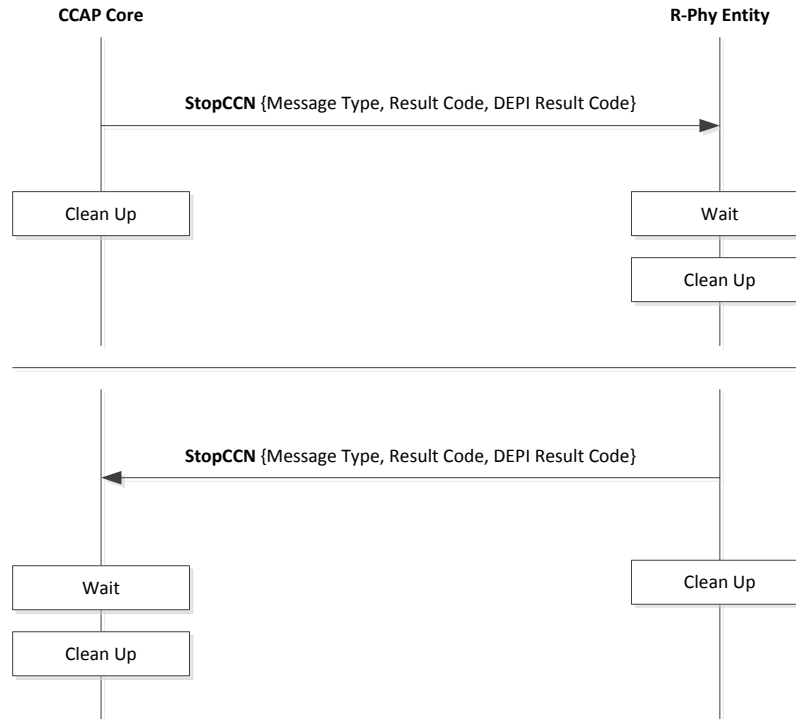
Figure 7–11 - R-PHY L2TP Control Connection Teardown

Control connection teardown may be initiated by either LCCE and is accomplished by sending a single StopCCN control message. An implementation may shut down an entire control connection and all sessions associated with the control connection by sending the StopCCN message. Thus, it is not necessary to clear each session individually when tearing down the entire control connection. The peer receiving the StopCCN message MUST maintain session and control state for a period of time equal to StopCCN Timeout (see Annex A) after acknowledging the StopCCN. This provision is for managing lost acknowledgments.

In some cases, such as after a reboot, an LCCE may receive a Hello message for a control connection for which it is unaware. If the LCCE receives a Hello message with an unknown Connection ID, the LCCE SHOULD send a StopCCN message with the Connection ID set to 0, Result Code 2 – General error, and Error Code 1 – No control connection exists yet for this pair of LCCEs. If the LCCE receives a StopCCN message with a Control Connection ID set to 0, it MUST tear down all control connections with the other LCCE that sent the StopCCN message.

7.6.1.3   Control Connection Keep-Alive

Figure 7–12 shows the DEPI message exchange that refreshes the control connection.
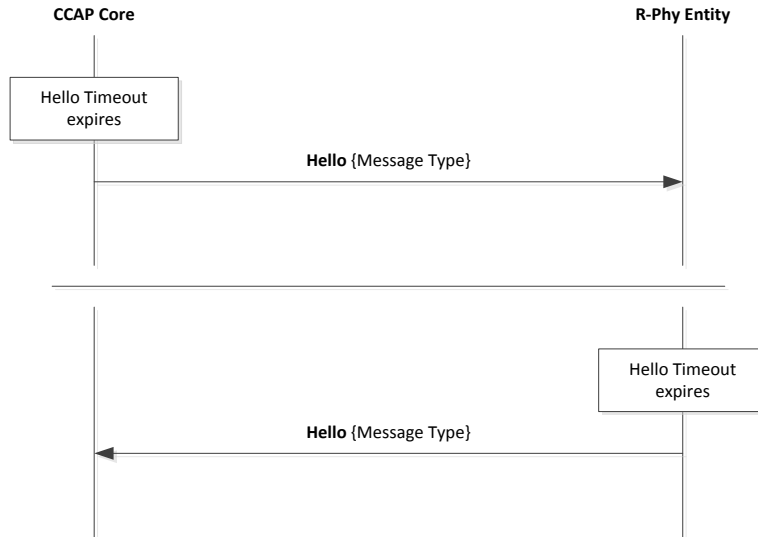
Figure 7–12 - R-PHY L2TP Keep-alive

A periodic keep-alive for the control connection is implemented by sending a Hello message if a period of time known as the Hello Timeout (refer to Figure 7–12) has passed without receiving any message (data or control) from the peer.

7.6.2   Session Signaling

7.6.2.1   Session Setup

Figure 7–13 shows the DEPI message exchange that sets up a DOCSIS session.
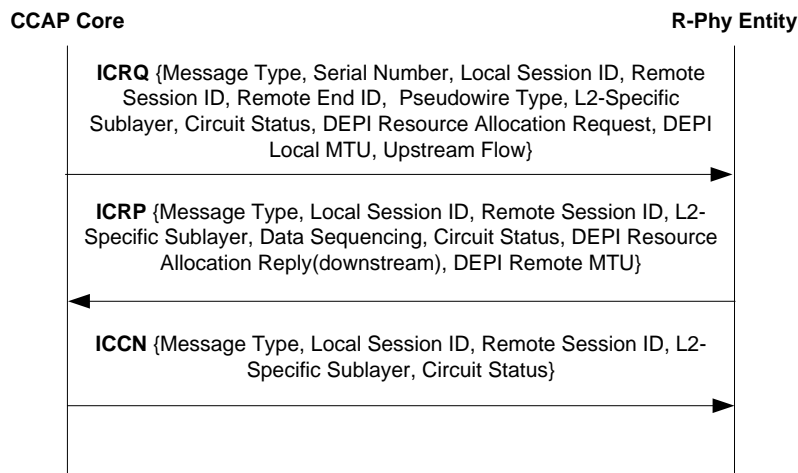
Figure 7–13 - R-PHY L2TP Session Setup

After successful control connection establishment, individual sessions may be created. Each session corresponds to a single data stream between the two LCCEs. The R-PHY protocol introduces new pseudowire types, some of which

tunnel data from the RPD to the CCAP-Core. In addition to the mandatory and optional AVPs in [RFC 3931], the DEPI-specific AVPs shown in Figure 7–13 are used as part of the session setup.

The ICRQ message contains the Remote End ID AVP that contains the TSID of the QAM Channel for which the session is intended.

The Session ID selection method and protocol signaling differs between unicast and multicast DEPI sessions.

For unicast DEPI sessions, the CCAP-Core sets the Remote Session ID AVP in the ICRQ message to zero per [RFC 3931].

For multicast DEPI sessions, the CCAP-Core allocates the session ID from the multicast session ID pool and sends its value in the Remote Session ID AVP in an ICRQ message. The multicast session ID pool consists of a set of reserved ID values in a range from 0x80000001 to 0x8000FFFF. The range of the multicast session ID pool can be further restricted by the operator via administrative controls to prevent two CCAP-Cores serving overlapping sets of RPDs from using the same set of multicast session IDs.

The CCAP-Core MUST ensure that it assigns a set of unique multicast Session ID values to any of its attached RPDs.

The CCAP-Core MUST NOT select session ID values from the multicast session ID pool range for unicast DEPI sessions. The RPD MUST NOT select session ID values from the multicast session ID pool range for unicast DEPI sessions.

These requirements are intended to allow for RPD implementations in which individual L2TPv3 sessions can be identified by the Session ID alone, without relying on protocol identifiers from other layers.

7.6.2.1.1   ICRP, ICRQ, and ICCN Messages

The ICRP message contains the Local Session AVP that indicates the session ID the RPD wants to use. As mentioned earlier, the RPD does not allocate its session ID for multicast DEPI sessions. In an ICRP message related to a multicast DEPI session, the value of Local Session ID in that ICRP message is the same value which was provided by the CCAP-Core to the RPD via Remote Session ID AVP in the ICRQ message. Note that the ICRP does not contain a suite of QAM Channel AVPs that indicate the RPD's current configuration and whose parameters can be changed. These parameters are negotiated prior to L2TP session establishment via GCP. The ICRQ message for R-PHY protocol can still include the DEPI Resource Allocation AVP needed for management of DSCP values for the pseudowire.

The receipt and processing of the ICCN triggers the initiation of data forwarding within the RPD for the channel associated with the session. The RPD SHOULD NOT buffer data before the channel corresponding to the activated session is ready for data forwarding.

The RPD SHOULD set the Circuit Status AVP in the ICRP message to the down state. After the ICCN is received and when the channel associated with the session is operational, then the RPD SHOULD send an SLI message to the CCAP-Core with the Circuit Status AVP set to the up state (refer to Section 7.7.1.5).

The CCAP-Core MAY also set its circuit status to the down state in the ICRQ message, and then set its circuit status to the up state in the ICCN message or a follow-on SLI message.

The CCAP-Core MUST be able to generate session establishment signaling. The RPD MUST support the ability to receive incoming session establishment requests from the CCAP-Core.

NOTE: Establishment of L2TP sessions by the RPD is outside the scope of this specification.

7.6.2.2   Session Teardown

Figure 7–14 shows the DEPI message exchange that tears down a DOCSIS session.
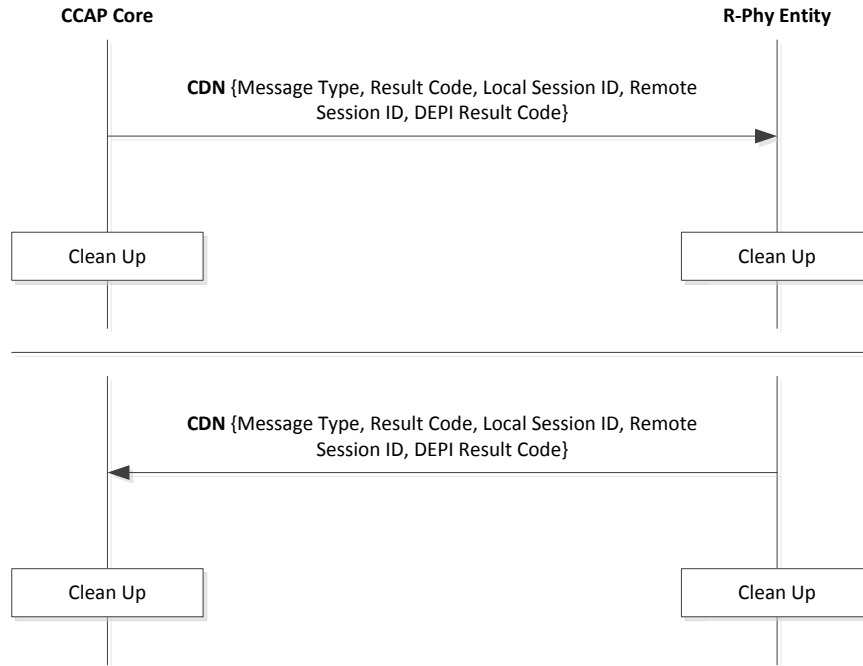
Figure 7–14 - R-PHY Session Teardown

Session teardown may be initiated by either LCCE and is accomplished by sending a single CDN control message. An implementation may shut down an entire control connection and all sessions associated with the control connection by sending a StopCCN message. Thus, it is not necessary to clear each session individually when tearing down the entire control connection.

7.6.2.3   Session Updates

Figure 7–15 shows the DEPI message exchange that updates a DOCSIS session.
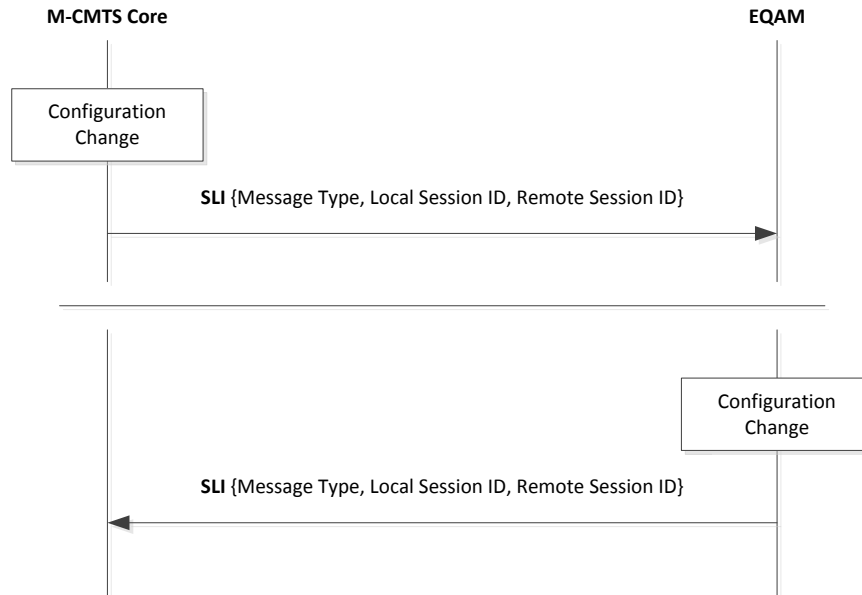
Figure 7–15 - R-PHY Session Updates

If there is a configuration change to one of the pseudowire parameters at the CCAP-Core that is described by a DEPI AVP, the CCAP-Core MUST send the updated AVP to the RPD with the Set-Link-Info (SLI) message. If there is a configuration change to one of the RPD parameters that is described by a DEPI AVP, the RPD MUST send the updated AVP to the CCAP-Core using an SLI message.

7.6.3   Mandatory and Optional AVPs

In addition to the mandatory and optional AVPs listed in [RFC 3931] and modified by Table 7-5, the DEPI AVPs listed in Table 7-4 MUST be present in the R-PHY L2TP control message if mandatory, and MAY be present in R-PHY L2TP control messages if optional.

Table 7-4 - R-PHY L2TP Mandatory and Optional AVPs

R-PHY L2TP Control Message	DEPI Mandatory AVPs	DEPI Optional AVPs
ICRQ	DEPI Resource Allocation Request DEPI Local MTU Local UDP Port Upstream Flow	
ICRP	DEPI Resource Allocation Reply DEPI Remote MTU Local UDP Port (1)	Downstream QAM Channel TSID Group
ICCN		
SCCRQ	DEPI Multicast Capability	
SCCRP	DEPI Multicast Capability	
CDN		DEPI Result Code
StopCCN		DEPI Result Code
SLI		DEPI Result Code
Note 1. Required for upstream sublayer sessions only.		

7.7   AVP Definition Updates

7.7.1   Conventional L2TPv3 AVPs

The AVP types from [RFC 3931] and [RFC 3308] that are supported as part of this specification are listed in Table 7-5.

Table 7-5 - R-PHY Supported L2TPv3 AVPs

Attribute Type	Control, Session	Description	Required	Not Required
0	C, S	Message Type	●	
1	S	Result Code	●	
5	C, S	Control/Session Tie Breaker		●
7	C	Host Name	●	
8	C	Vendor Name		●
10	C	Receive Window Size		●
15	S	Serial Number	●	
25	S	Physical Channel ID		●
34	S	Circuit Errors		●
36	C, S	Random Vector		●
47	C	Control Connection DSCP	●	
48	S	Session DSCP	●	
58	C, S	Extended Vendor ID AVP		●
59	C, S	Message Digest		●
60	C	Router ID	●	
61	C	Assigned Control Connection ID	●	

Attribute Type	Control, Session	Description	Required	Not Required
62	C	Pseudowire Capabilities List	●	
63	S	Local Session ID	●	
64	S	Remote Session ID	●	
65	S	Assigned Cookie		●
66	S	Remote End ID	●	
68	S	Pseudowire Type	●	
69	S	L2-Specific Sublayer	●	
70	S	Data Sequencing	●	
71	S	Circuit Status	●	
72	C	Preferred Language		●
73	C	Control Message Authentication Nonce		●
74	S	Tx Connect Speed		●
75	S	Rx Connect Speed		●

Conventional AVPs whose usage is specific to the R-PHY protocol are described below. A more complete description, as well as requirements for the conventional AVPs, can be found in [RFC 3931].

The CCAP-Core and RPD MUST transmit AVP fields marked as "reserved" with zero (0). The CCAP-Core and RPD MUST ignore AVP fields marked as "reserved".

7.7.1.1   Message Type (All Messages)

Figure 7–16 shows the Message Type AVP.

0		7	15	23	31
M	H	Resv	Length = 8	Vendor ID = 0	
	Attribute Type = 0			Message Type	
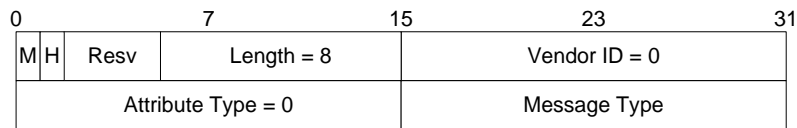
Figure 7–16 - Message Type AVP

This AVP identifies the particular type of L2TPv3 Control Message that is being sent. It is always the first AVP.

7.7.1.2   Result Code (StopCCN, CDN)

Figure 7–17 shows the Result Code AVP.

0		7	15	23	31
M	H	Resv	Length = 8+N	Vendor ID = 0	
	Attribute Type = 1			Result Code	
	Error Code (Optional)			Error Message ...	
	… Error Message (Optional)				
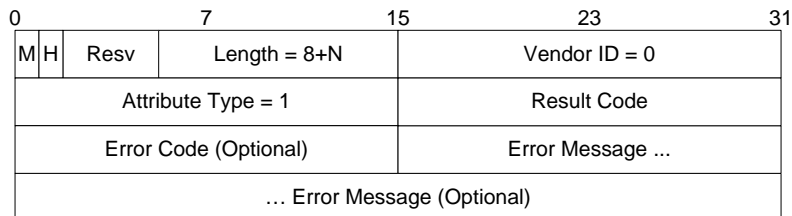
Figure 7–17 - Result Code AVP

This message contains results codes, optional error codes, and optional error messages when tearing down a control connection or a session.

7.7.1.3   Host Name (SCCRQ, SCCRP)

Figure 7–18 shows the Host Name AVP.

0			7	15	23	31
M	H	Resv	Length = 6+N		Vendor ID = 0	
Attribute Type = 7					Host ...	
… Name ...						

Figure 7–18 - Host Name AVP

The host name is typically the fully qualified domain name (FQDN) of each device.

7.7.1.4   Vendor Name (SCCRQ, SCCRP)

Figure 7–19 shows the Vendor Name AVP.

0			7	15	23	31
M	H	Resv	Length = 6+N		Vendor ID = 0	
Attribute Type = 8					Vendor ...	
… Name ...						

Figure 7–19 - Vendor Name AVP

The CCAP-Core SHOULD identify itself with an ASCII Vendor ID string during the SCCRQ message. The RPD SHOULD identify itself with an ASCII Vendor ID string during the SCCRP message. Note that this is an optional AVP in [RFC 3931].

7.7.1.5   Serial Number (ICRQ, OCRQ)

Figure 7–20 shows the Serial Number AVP.

0			7	15	23	31
M	H	Resv	Length = 10		Vendor ID = 0	
Attribute Type = 15					Serial ...	
… Number						

Figure 7–20 - Serial Number AVP

This number is assigned by the originator of the message and is similar in concept to a transaction ID. Its main use is to aid in debugging message flows.

7.7.1.6 *Control Connection DSCP (SCCRQ)*

Figure 7–21 shows the Control Connection DSCP AVP. This AVP, if present in the ICRP message, signals a PHB-ID as the DSCP value selected by the CCAP-Core for all packets of the L2TPv3 control session.

0		7	15	23	31
M	H	Resv	Length = 8	Vendor ID = 0	
Attribute Type = 47				reserved	PHB-ID
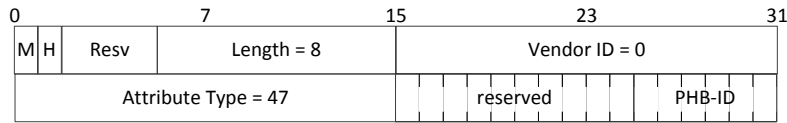
Figure 7–21 - Control Connection DSCP AVP

7.7.1.7 *Router ID (SCCRQ, SCCRP)*

Figure 7–22 shows the Router ID AVP.

0		7	15	23	31
M	H	Resv	Length = 10	Vendor ID = 0	
Attribute Type = 60				Router ...	
… ID					
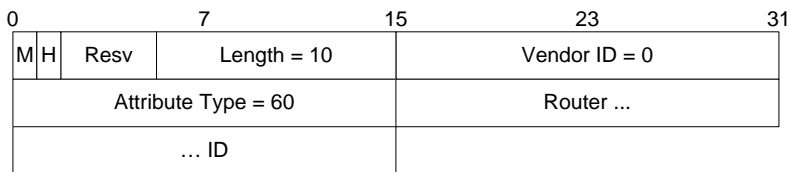
Figure 7–22 - Router ID AVP

The Router ID is an opaque number that uniquely identifies the sending LCCE. It may be the IP address of the sending LCCE, but this cannot be assumed.

7.7.1.8 *Assigned Control Connection ID (SCCRQ, SCCRP, StopCCN)*

Figure 7–23 shows the Assigned Control Connection ID AVP.

0		7	15	23	31
M	H	Resv	Length = 10	Vendor ID = 0	
Attribute Type = 61				Control Connection ...	
… ID					
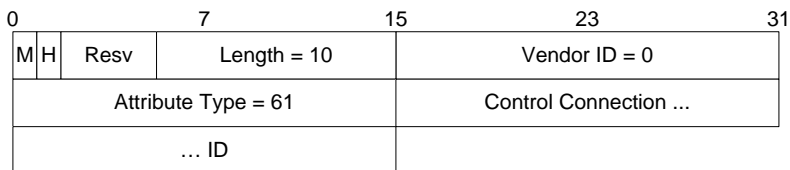
Figure 7–23 - Assigned Control Connection ID AVP

This is the assigned control connection ID for the R-PHY protocol. During SCCRQ, the CCAP-Core uses this AVP to inform the RPD what value of Control Connection ID to use in the L2TPv3 Control Header for control messages originated by the RPD. During SCCRP, the RPD uses this AVP to inform the CCAP-Core what value of Control Connection ID to use in the L2TPv3 Control Header for control messages originated by the CCAP-Core. Since the CCAP-Core has not been informed by the RPD prior to the first SCCRQ message, the CCAP-Core uses a value of 0 for the control connection ID in the L2TPv3 Control Header of the SCCRQ message.

7.7.1.9   Pseudowire Capabilities List (SCCRQ, SCCRP)

Figure 7–24 shows the Pseudowire Capabilities List AVP.

0		7	15	23	31
M	H	Resv	Length = 6 + 2N	Vendor ID = 0	
Attribute Type = 62				Pseudowire Type 0	
Pseudowire Type 1				Pseudowire Type N	

Figure 7–24 - Pseudowire Capabilities List AVP

The Pseudowire Capabilities List AVP indicates the capabilities of the CCAP-Core and RPD. There are multiple PW Types defined for an RPD and a CCAP-Core; refer to Table 7-6 for details.

Table 7-6 - Pseudowire Types

Pseudowire (PW) Type	Mnemonic	Value
MPT Pseudowire	MPTPW	0x000C*
PSP Pseudowire	PSPPW	0x000D*
MCM Pseudowire	MCM-PW	TBD
PSP-OFDM Pseudowire	PSP-OFDM-PW	TBD
PSP-OFDM-PLC Pseudowire	PSP-PLC-PW	TBD
PSP-UEPI-SCQAM Pseudowire	PSP-UEPI-SCQ	TBD
PSP-UEPI-OFDMA Pseudowire	PSP-UEPI-OFDMA	TBD
PSP-BW-REQ-SCQ	PSP-BW-REQ-SCQ	TBD
PSP-BW-REQ-OFDMA	PSP-BW-REQ-OFDMA	TBD
PSP-PROBE	PSP-BW-PROBE	TBD
PSP-RNG-REQ-SCQ Pseudowire	PSP-RNG-REQ-SCQ	TBD
PSP-RNG-REQ-OFDMA Pseudowire	PSP-RNG-REQ-OFDMA	TBD
PSP-MAP-SCQ Pseudowire	PSP-MAP-SCQ	TBD
PSP-MAP-OFDMA Pseudowire	PSP-MAP-OFDMA	TBD
PSP-SPECMAN Pseudowire	PSP-SPECMAN	TBD
PSP-PNM Pseudowire	PSP-PNM	TBD
PSP-55-1-FWD Pseudowire	PSP-55-1-FWD	TBD
PSP-55-1-RET Pseudowire	PSP-55-1-RET	TBD
PSP-55-2-FWD Pseudowire	PSP-55-2-FWD	TBD
PSP-55-2-RET Pseudowire	PSP-55-2-RET	TBD
PSP-NDF Pseudowire	PSP-NDF	TBD
PSP-NDR Pseudowire	PSP-NDR	TBD

The CCAP-Core MUST indicate its support for pseudowire types by including one or more of the PW Types in the Pseudowire Capabilities List. The RPD MUST indicate its support for pseudowire types by including one or more of the PW Types in the Pseudowire Capabilities List.

An "Upstream Data Pseudowire" refers to a pseudowire with type PSP-UEPI-SCQ or PSP-UEPI-OFDM.

7.7.1.10 Local Session ID (ICRQ, ICRP, ICCN, CDN, SLI)

Figure 7–25 shows the Local Session ID AVP.

0			7	15	23	31
M	H	Resv	Length = 10		Vendor ID = 0	
	Attribute Type = 63				Local Session ...	
	… ID					
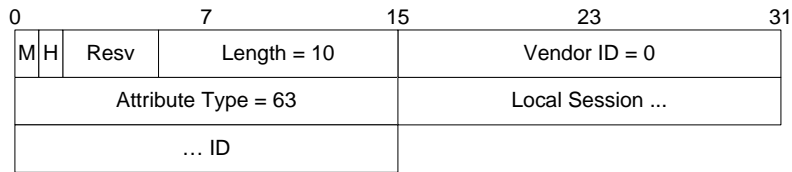
Figure 7–25 - Local Session ID AVP

When a session is established, the CCAP-Core and RPD each choose their own session ID and advertise it to each other with this AVP. This means that a single session setup sets up two unidirectional sessions, one in each direction.
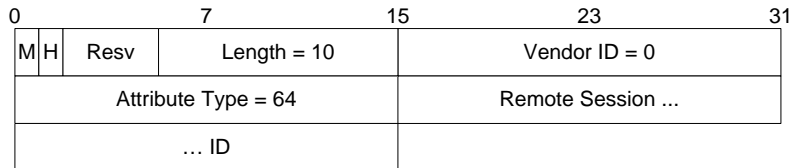
7.7.1.11 Remote Session ID (ICRQ, ICRP, ICCN, CDN, SLI)

Figure 7–26 shows the Remote Session ID AVP.

0			7	15	23	31
M	H	Resv	Length = 10		Vendor ID = 0	
	Attribute Type = 64				Remote Session ...	
	… ID					

Figure 7–26 - Remote Session ID AVP

When the CCAP-Core or RPD send a session message to each other, the Remote Session ID is set to the session ID learned previously from the Local Session ID AVP. If the Remote Session ID is not yet known, it is set to 0.

The CCAP-Core allocates session ID values for multicast DEPI sessions from the multicast session ID pool. The CCAP-Core MUST send the Remote Session ID value in the ICRQ message when signaling multicast DEPI sessions.

7.7.1.12 Remote End ID (ICRQ)

Figure 7–27 shows the Remote End ID AVP.

0			7	15	23	31
M	H	Resv	Length = 8		Vendor ID = 0	
	Attribute Type = 66				Remote ID = TSID	

Figure 7–27 - Remote End ID AVP

DEPI uses the TSID from the QAM Channel as the Remote End ID. The TSID is an unsigned two-octet integer and is used to bind a session to a QAM Channel.

7.7.1.13 Pseudowire Type (ICRQ)

Figure 7–28 shows the Pseudowire Type AVP.

| 0	7	15	23	31
M	H	Resv	Length = 8	Vendor ID = 0
Attribute Type = 68			Pseudowire Type	

Figure 7–28 - Pseudowire Type AVP

R-DEPI uses the Pseudowire Type values defined in Table 7-6 to indicate the type of DEPI session requested.

7.7.1.14 L2-Specific Sublayer (ICRQ, ICRP, ICCN)

Figure 7–29 shows the L2-Specific Sublayer AVP.

0	7	15	23	31
M	H	Resv	Length = 8	Vendor ID = 0
Attribute Type = 69			L2-Specific Sublayer Type	

Figure 7–29 - L2-Specific Sublayer AVP

The CCAP-Core MUST include the L2-Specific Sublayer AVP in the ICRQ and ICCN messages, indicating the L2-Specific Sublayer Header Type consistent with the Pseudowire type for the DEPI flow. The RPD MUST include the L2-Specific Sublayer AVP in the ICRP message, indicating the L2-Specific Sublayer Header Type consistent with the Pseudowire type for the R-PHY protocol flow.

Although L2TPv3 defines sessions as bidirectional, the Remote PHY architecture defines its sublayers with a single direction of downstream or upstream data flow, as indicated in Table 7-7. Note that DLM and S-BFD packets are considered (and marked in the sublayer header) as sublayer control packets, not sublayer data packets, and are transmitted in both directions.

Table 7-7 - L2-Specific Sublayer Types

L2-Specific Sublayer Type	Value	Direction
MPT Specific Sublayer	3*	Downstream
PSP Specific Sublayer	4*	Downstream
MCM Specific Sublayer	TBD	Downstream
PSP-OFDM Specific Sublayer	TBD	Downstream
PSP-OFDM-PLC Specific Sublayer	TBD	Downstream
PSP-UEPI-SCQAM Specific Sublayer	TBD	Upstream
PSP-UEPI-OFDMA Specific Sublayer	TBD	Upstream
PSP-BW-REQ-SCQ	TBD	Upstream
PSP-BW-REQ-OFDMA	TBD	Upstream
PSP-PROBE	TBD	Upstream
PSP-RNG-REQ-SCQ Specific Sublayer	TBD	Upstream
PSP-RNG-REQ-OFDMA Specific Sublayer	TBD	Upstream
PSP-MAP-SCQ Specific Sublayer	TBD	Downstream
PSP-MAP-OFDMA Specific Sublayer	TBD	Downstream
PSP-SPECMAN Specific Sublayer	TBD	??
PSP-PNM Specific Sublayer	TBD	Downstream
PSP-55-1-FWD Specific Sublayer	TBD	Downstream

L2-Specific Sublayer Type	Value	Direction
PSP-55-1-RET Specific Sublayer	TBD	Upstream
PSP-55-2-FWD Specific Sublayer	TBD	Downstream
PSP-55-2-RET Specific Sublayer	TBD	Upstream
PSP-NDF Specific Sublayer	TBD	Downstream
PSP-NDR Specific Sublayer	TBD	Upstream

7.7.1.15 Data Sequencing (ICRP)
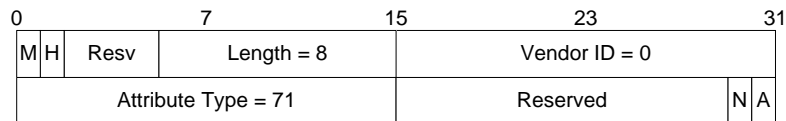
Figure 7–30 shows the Data Sequencing AVP.
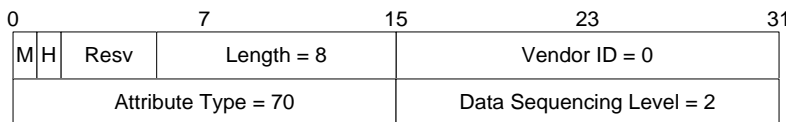
Figure 7–30 - Data Sequencing AVP

The RPD MUST include the Data Sequencing AVP in the ICRP message, indicating Data Sequencing Level 2 is required (all incoming data packets require sequencing).

7.7.1.16 Circuit Status (ICRQ, ICRP, ICCN, SLI)

Figure 7–31 shows the Circuit Status AVP.

Figure 7–31 - Circuit Status AVP

Table 7-8 - Circuit Status AVP Details

Field	Description
N	1 bit. New bit. Indicates whether the status indication is for a new R-PHY session (1) or an existing R-PHY session (0). The New bit SHOULD be set the first time the DEPI session is established after provisioning.
A	1 bit. 1 Active bit. Indicates whether the R-PHY session is up (1) or down (0). Once the CCAP-Core is aware that the R-PHY session is down, the CCAP-Core MUST NOT attempt to pass data traffic on the R-PHY session.

LCCEs utilize the Circuit Status AVP to indicate whether the R-PHY session is up and able to pass data traffic, or down and unable to pass data traffic. The Circuit Status ID does not control the RF output of the QAM Channel. Note that the Circuit Status AVP can be sent by both the CCAP-Core and the RPD.

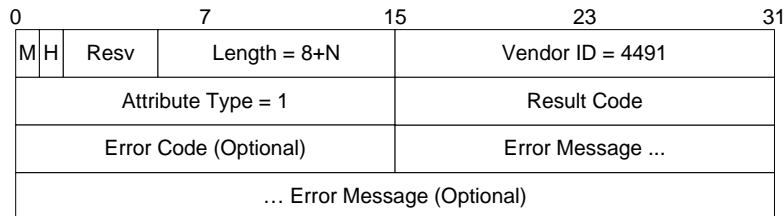### 7.7.2   DEPI Session Specific AVPs

The AVP types defined specifically for DEPI are shown in Table 7-9. The range of Attribute Types from 0-99 is reserved for DEPI Session Specific AVPs. These AVPs are only used in L2TP session messages. Note that several AVPs defined for DEPI have been deprecated from use in the R-PHY protocol. The CCAP-Core MUST NOT transmit deprecated AVPs. The RPD MUST NOT transmit deprecated AVPs.

Table 7-9 - DEPI Defined Session Specific AVPs

Attribute Type	Description
0	Reserved
1	DEPI Result Code
2	DEPI Resource Allocation Request
3	DEPI Resource Allocation Reply
4	DEPI Local MTU
5	Deprecated (DOCSIS SYNC Control)
6	Deprecated (EQAM Capability Bits)
7	DEPI Remote MTU
8	DEPI Local UDP Port
9	Deprecated (DPR Session Type)
10	Deprecated (DPR Session Status)
11	DEPI Remote Multicast Join
12	DEPI Remote Multicast Leave
13	DEPI Multicast Capability
14	Upstream

7.7.2.1   *DEPI Result and Error Code (CDN, SLI)*

Figure 7–32 shows the DEPI Result and Error Code AVP.

0			7	15	23	31
M	H	Resv	Length = 8+N		Vendor ID = 4491	
Attribute Type = 1					Result Code	
Error Code (Optional)					Error Message ...	
… Error Message (Optional)						

Figure 7–32 - DEPI Result and Error Code AVP

Table 7-10 - DEPI Result and Error Code AVP Details

Field	Description
M	1 bit. Mandatory bit. MUST be set to 0.
Length	10 bits. 8 bytes plus any additional bytes required for the Error Code and Error Message.
Attribute Type	2 bytes. Set to 1.
Result Code	2 bytes. Mandatory field. The values are as follows:

	Result Code	Result Description
	0	Session not established - Bad DEPI AVP Reference
	1	Session not established - Bad PHY AVP Request
	2	Session not established or disconnected for the reason indicated in Error Code.

Field	Description
Error Code	2 bytes. This field is optional. One cause of Error Code 0 is if the RPD does not have the values of M and N configured for the QAM Channel Symbol Rate. The values are as follows:

	Error Code	Error Description
	0	Device is not yet ready or configured properly.
	1	Attempt to modify a locked PHY parameter.
	2	Attempt to modify PHY Parameter failed – out of range value.
	3	Requested PSP Flow PHB-IDs not supported.
	4	Incorrect pseudowire type used in session.

Field	Description
Error Message	Variable length. This field is optional.

The format of the fields of this AVP are identical to the corresponding fields in the standard L2TPv3 result and error code AVP except that the Vendor ID field has the value of 4491 rather than 0. The Result and Error Codes for this AVP are unique to [DEPI], and are in addition to the standard Result and Error codes listed in Section 7.7.1.2.

7.7.2.2   DEPI Resource Allocation Request (ICRQ)

Figure 7–33 shows the DEPI Resource Allocation Request AVP.

0	7	15	23	31
M H	Resv	Length = 6+N	Vendor ID = 4491	
Attribute Type = 2		X X	PHB ID 1 X X	PHB ID N
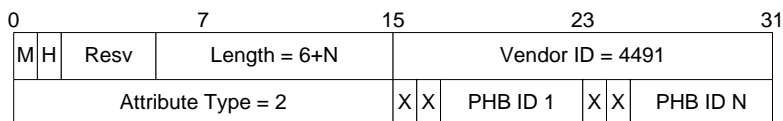
Figure 7–33 - DEPI Resource Allocation Request AVP

Table 7-11 - DEPI Resource Allocation Request AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. 6 bytes plus one additional byte for each flow that is requested.
Attribute Type	2 bytes. Set to 2.
PHB-ID	6 bits. Per Hop Behavior Identifier being requested by the CCAP-Core for the RPD packet scheduler. Per hop behavior identifiers are defined in the "Per Hop Behavior Usage" section of [R-PHY].

A CCAP-Core includes this AVP in an ICRQ for pseudowires with downstream sublayer data packets, as indicated in Table 7-7.This includes both PSP and non-PSP pseudowire types with downstream sublayer data. Each byte in the attribute payload represents a request for one unique downstream flow. Each request contains a PHB-ID that selects the per-hop behavior in the RPD, i.e., how it schedules packets from the flow relative to other flows in the same session (if any).

In a DEPI Resource Allocation Request AVP, the CCAP-Core MAY request more than one downstream flow only for the pseudowire types PSP and PSP-OFDM. In a DEPI Resource Allocation Request AVP with more than one downstream flow, the CCAP-Core MAY request the same PHB-ID for more than one flow. For all pseudowire types other than PSP and PSP-OFDM, the CCAP-Core MUST request a single downstream flow.
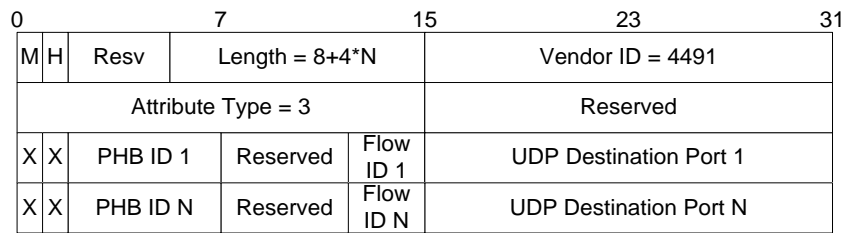
The RPD signals as GCP capabilities the maximum number of PSP flows it supports per PSP session and the set of PHB-IDs it supports for its downstream packet scheduler. The CCAP-Core MUST NOT request more PSP flows than the RPD advertises it is capable of supporting. The CCAP-Core MUST NOT request a PHB-ID for a downstream flow that is not advertised as supported by the RPD in a GCP capability.

If an RPD receives a DEPI Resource Allocation Request AVP with a PHB-ID that it has not advertised as supported, the RPD MUST tear down the session with CDN.

7.7.2.3   DEPI Resource Allocation Reply (ICRP)

This AVP is signaled by the RPD in an ICRP to inform the CCAP-Core of the flow IDs and UDP Destination Ports it has assigned for downstream data packets on each flow of the session, as requested by the CCAP-Core for PHB-IDs signaled in a DEPI Resource Allocation Request.

Figure 7–34 shows the DEPI Resource Allocation Reply AVP.

0			7		15	23	31
M	H	Resv	Length = 8+4*N			Vendor ID = 4491	
Attribute Type = 3						Reserved	
X	X	PHB ID 1	Reserved		Flow ID 1	UDP Destination Port 1	
X	X	PHB ID N	Reserved		Flow ID N	UDP Destination Port N	

Figure 7–34 - DEPI Resource Allocation Reply AVP

Table 7-12 - DEPI Resource Allocation Reply AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. 6 bytes plus one additional byte for each flow that is requested.
Attribute Type	2 bytes. Set to 3.
PHB-ID	6 bits. Per Hop Behavior Identifier being requested by the CCAP-Core. Per hop behavior identifiers are defined in the "Per Hop Behavior Usage" section of [R-PHY].
Flow ID	3 bits. This is the flow ID assigned by the RPD. The flow ID is unique within a session.
UDP Dest Port	2 bytes. When using UDP Headers, this is the UDP Destination Port number selected by the RPD for incoming downstream L2TPv3 data transport packets containing segments of the identified flow. When not using UDP Headers, this field is reserved; the RPD MUST set it to 0 and the CCAP-Core MUST ignore the value.

In the DEPI Resource Allocation Reply AVP, the RPD MUST assign one downstream flow to Flow ID 0 because S-BFD does not signal a flow ID in its sublayer header and its IP (and optional UDP) encapsulation are as specified for flow ID 0.

In the DEPI Resource Allocation Reply AVP, the RPD MUST specify the downstream flows in the same order as the DEPI Resource Allocation Request because more than one downstream flow ID may have the same PHB-ID.

A CCAP-Core MUST tear down a session for which the RPD does not reply with all requested flows in its DEPI Resource Allocation Reply AVP and in the same order. Note that this operation differs from that described for M-CMTS in [DEPI], which permitted partial allocation of requested downstream flows.

7.7.2.4   *DEPI Local MTU (ICRQ)*

Figure 7–35 shows the DEPI Local MTU AVP.

M	H	Resv	Length = 8	Vendor ID = 4491
		Attribute Type = 4		DEPI Local MTU

0   *7*   *15*   *23*   *31*
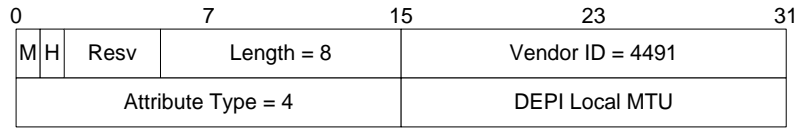
Figure 7–35 - DEPI Local MTU AVP

Table 7-13 - DEPI Local MTU AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. Set to 8.
Attribute Type	2 bytes. Set to 4.
DEPI Local MTU	2 bytes. In the ICRQ message, this is the MTU (Maximum Transmission Unit) that the CCAP-Core can receive from the RPD on the CIN interface.

The MTU is the Layer 3 payload of a Layer 2 frame. For R-DEPI, the MTU includes the L2TPv3 header and payload and the IP header, but does not include the Ethernet Header or the CRC. For example, a 1518-byte Ethernet frame (1522 bytes if VLAN tags are present) would support an MTU of 1500 bytes.

7.7.2.5   *DEPI Remote MTU Max Payload (ICRP)*

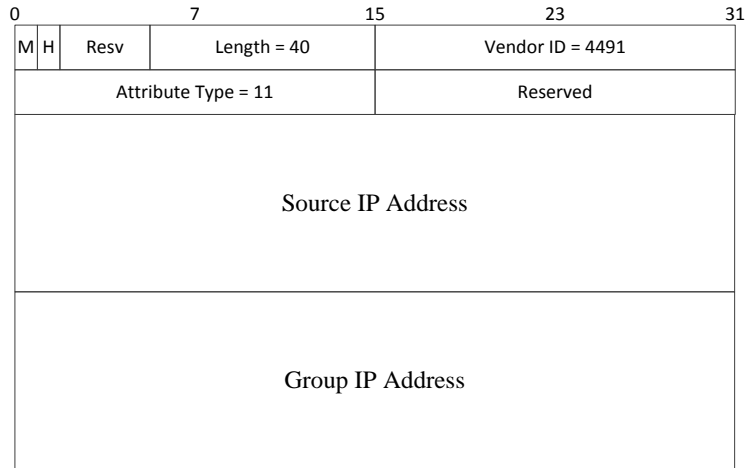Figure 7–36 shows the DEPI Remote MTU Max Payload AVP.

M	H	Resv	Length = 8	Vendor ID = 4491
		Attribute Type = 7		DEPI Remote MTU

0   *7*   *15*   *23*   *31*
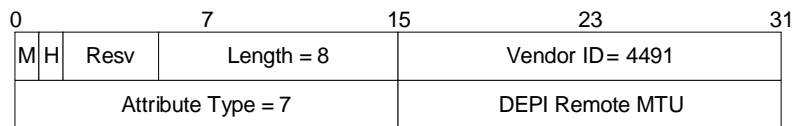
Figure 7–36 - DEPI Remote MTU Max Payload AVP

Table 7-14 - DEPI Local MTU Max Payload AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. Set to 8.
Attribute Type	2 bytes. Set to 7.
DEPI Remote MTU	2 bytes. In the ICRP message, this is the MTU that the RPD can receive from the CCAP-Core on the CIN interface. The MTU is the Layer 3 payload of a Layer 2 frame.

7.7.2.6   DEPI Remote Multicast Join

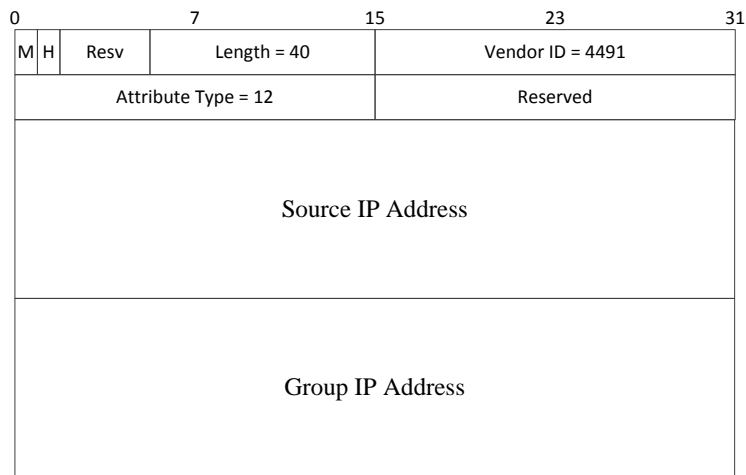Figure 7–37 shows the DEPI Remote Multicast Join AVP.

0			7	15	23	31
M	H	Resv	Length = 40		Vendor ID = 4491	
Attribute Type = 11				Reserved		
Source IP Address						
Group IP Address						

Figure 7–37 - DEPI Remote Multicast Join AVP

Table 7-15 - DEPI Remote Multicast Join AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. Set to 40.
Attribute Type	2 bytes. Set to 11.
Source IP Address	16 bytes. This field signals the Source IP address of the multicast stream the RPD should join.
Group IP Address	16 bytes. This field signals the Group (Destination) IP address of the multicast stream the RPD should join.

7.7.2.7   DEPI Remote Multicast Leave

Figure 7–38 shows the DEPI Remote Multicast Leave AVP.

0			7	15	23	31
M	H	Resv	Length = 40		Vendor ID = 4491	
Attribute Type = 12				Reserved		
Source IP Address						
Group IP Address						

Figure 7–38 - DEPI Remote Multicast Leave AVP

Table 7-16 - DEPI Remote Multicast Leave AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. Set to 40.
Attribute Type	2 bytes. Set to12.
Source IP Address	16 bytes. This field signals the Source IP address of the multicast stream the RPD should leave.
Group IP Address	16 bytes. This field signals the Group (Destination) IP address of the multicast stream the RPD should leave.

The CCAP-Core SHOULD signal the same Source and Group IP address in the DEPI Remote Multicast Leave AVP as was signaled in the DEPI Remote Multicast Join AVP for this session. In case the RPD receives DEPI Remote Multicast Leave AVP with Source and/or Group IP address that do not match the address(es) sent via the DEPI Remote Multicast Join AVP, the RPD should handle it as though a Leave was received for the multicast stream associated with that session.

7.7.2.8   DEPI Multicast Capability (SCCRQ, SCCRP)

Figure 7–39 shows the DEPI Multicast Capability AVP.

0		7		15		23		31
M	H	Resv	Length = 8			Vendor ID = 4491		
Attribute Type = 13					C	Reserved		
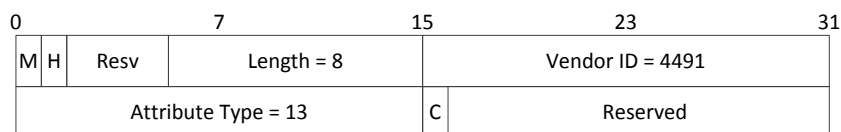
Figure 7–39 - DEPI Multicast Capability AVP

Table 7-17 - DEPI Multicast Capability AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. Set to 8.
Attribute Type	2 bytes. Set to 13.
C	DEPI Multicast Capability. When set to '1' the sender of the AVP supports DEPI Multicast signaling on downstream sessions.

DEPI Multicast Capability AVP indicates the ability of the CCAP-Core or of the RPD to support the multicast operation, including the signaling of multicast session Ids assigned by the CCAP-Core.
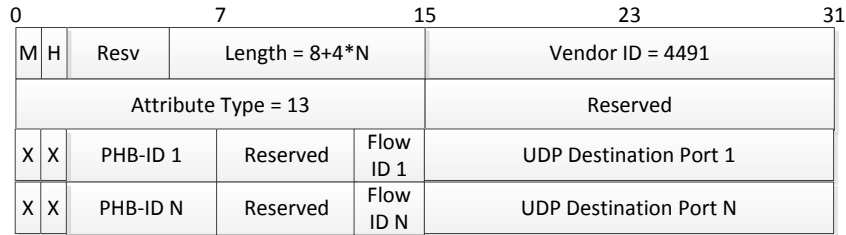
The CCAP-Core MUST support the DEPI Multicast Capability AVP. The RPD MUST support the DEPI Multicast Capability AVP.

The CCAP-Core SHOULD set the value of the C bit to "1" in the DEPI Multicast Capability AVP. The RPD MUST set the value of the C bit to "1" in the DEPI Multicast Capability AVP.

7.7.2.9   Upstream Flow (ICRP)

This AVP is signaled by the CCAP-Core in an ICRQ to inform the RPD of DSCPs and UDP Destination ports of data packets for each upstream flow in the session.

Figure 7–40 shows the Upstream Flow AVP.

0		7		15	23	31
M	H	Resv	Length = 8+4*N		Vendor ID = 4491	
Attribute Type = 13					Reserved	
X	X	PHB-ID 1	Reserved	Flow ID 1	UDP Destination Port 1	
X	X	PHB-ID N	Reserved	Flow ID N	UDP Destination Port N	

Figure 7–40 - Upstream Flow AVP

Table 7-18 - Upstream Flow AVP Details

Field	Description
M	1 bit. The Mandatory bit MUST be set to a 1.
Length	10 bits. 8 bytes plus 4 additional bytes for each flow that is described.
Attribute Type	2 bytes. Set to 13.
PHBID	6 bits. Per Hop Behavior Identifier that equals the 6-bit DSCP with which the RPD transmits L2TPv3 data packets for the flow.
Flow ID	3 bits. This is an upstream flow ID assigned by the CCAP-Core. The flow ID is unique within a session.
UDP Dest Port	2 bytes. This is the UDP Destination Port number selected by the CCAP-Core for incoming upstream L2TPv3 data transport packets containing segments of the identified flow. If L2TPv3 has been configured to not use UDP headers, the UDP Destination Port field is reserved; it MUST be set to all 0 by the CCAP-Core and MUST be ignored by the RPD.

7.7.3   QAM Channel PHY AVPs
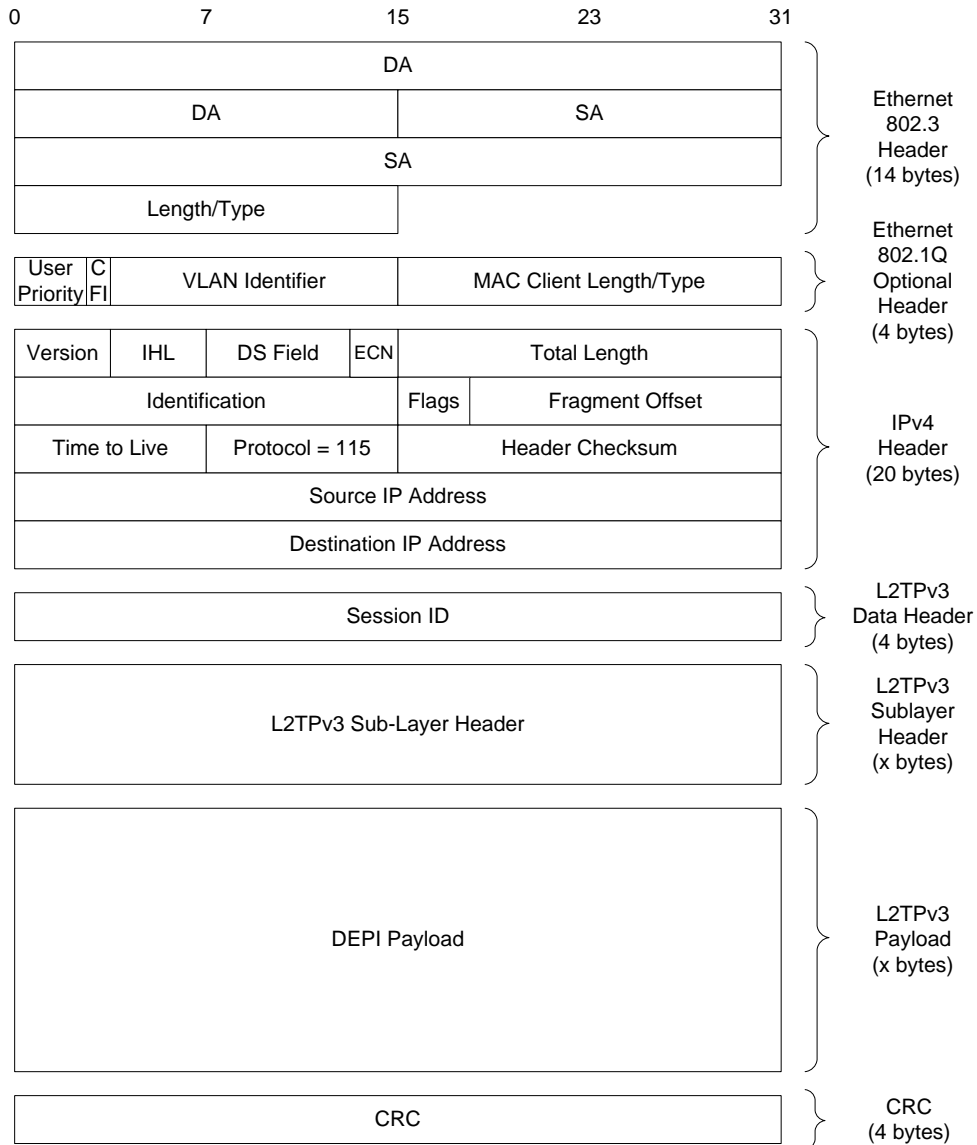
The QAM Channel Physical Layer specific AVP types initially defined in [DEPI] have been deprecated from use in the R-PHY protocol.

8 DEPI FORWARDING PLANE

8.1 L2TPv3 Transport Packet Format

8.1.1 Data Message Format without UDP

Figure 8–1 shows the format of the L2TPv3 data packet outer encapsulation (without UDP headers).

Figure 8–1 - L2TPv3 Data Packet Outer Encapsulation (without UDP)

8.1.2   Data Message with a UDP Header

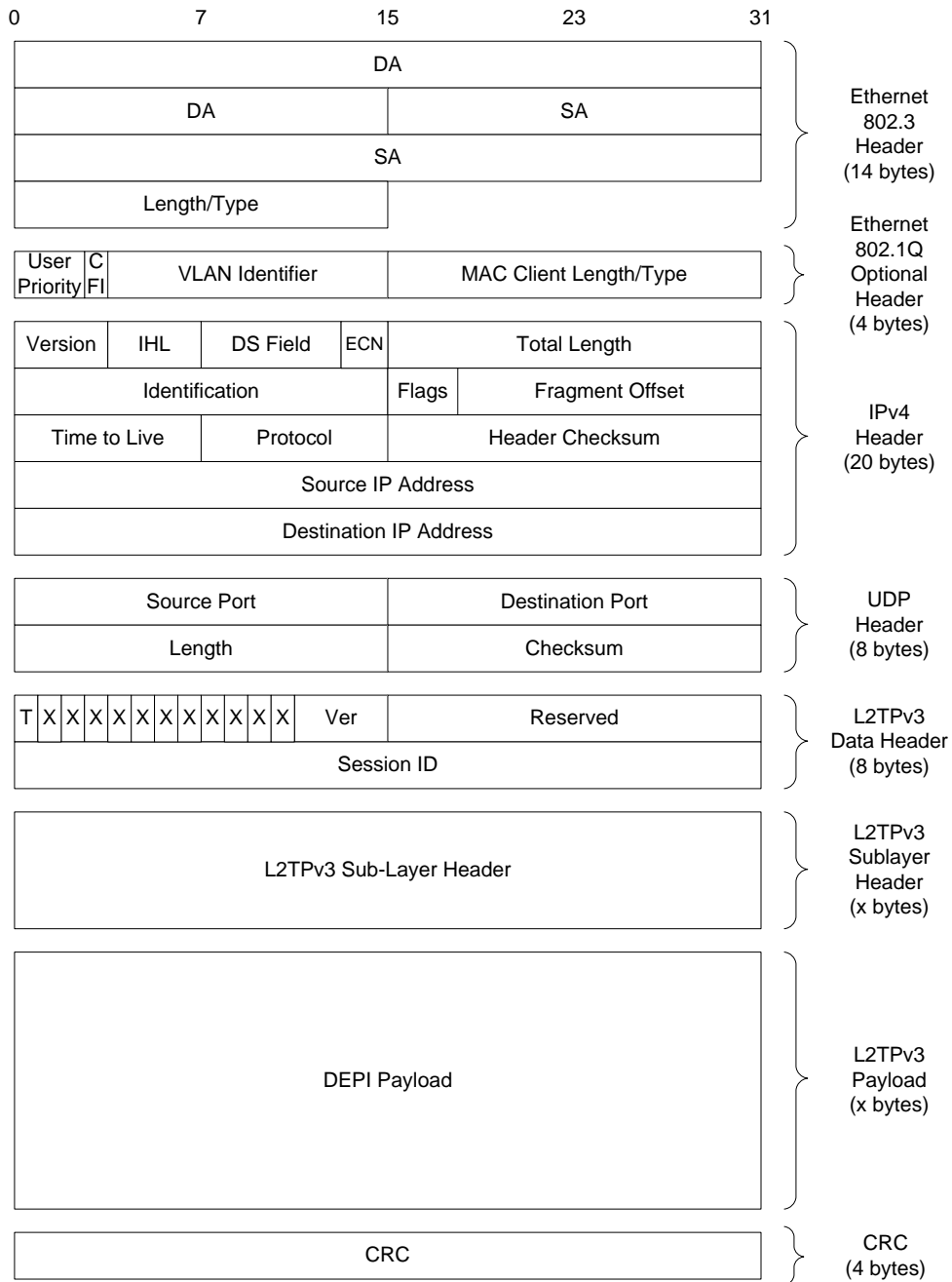Figure 8–2 shows the format of the L2TPv3 data packet with a UDP Header.

Figure 8–2 - L2TPv3 Data Packet Outer Encapsulation with UDP Header

8.1.3   Specific Headers for Data Messages

8.1.3.1   L2TPv3 Data Header

The L2TPv3 Data Header is not used in R-DEPI because data packets with L2TPv3 over IP do not require an L2TPv3 Data Header.

8.1.3.2   *L2TPv3 DEPI Sublayer Header*

DEPI supports three main pseudowire types. The first type, known as D-MPT, is used for transporting MPEG packets. The second type, known as MCM, is a variation of the D-MPT type. MCM allows transport of MPEG packet belonging to multiple QAM channels in a single DEPI packet. The third type, known as PSP, is used for transporting DOCSIS frames. Each pseudowire type has a unique L2TPv3 DEPI sublayer header format. The fields of these sublayer headers are defined in Sections 8.2 and 8.3. Additionally, both pseudowire types support a latency measurement sublayer header, the fields of which are defined in Section 8.4.1.

The CCAP-Core MUST use the appropriate DEPI sublayer header for the pseudowire type of the DEPI session.

The RPD MUST accept packets from the CCAP-Core that contain the appropriate DEPI sublayer header for the negotiated pseudowire type. The RPD MUST send a CDN message to tear down a session in which packets are received with the wrong pseudowire type. The RPD MUST ignore packets received that do not comply with these L2TPv3 DEPI sublayer header definitions.

8.1.3.3   *DEPI Payload*

The payload contains one or more segments. In D-MPT mode and in MCM mode, each segment is a 188 byte MPEG packet. In PSP mode, a segment contains either a full DOCSIS frame or a partial DOCSIS frame or data intended for the PLC channel.

8.2   DOCSIS MPT Sublayer Header

Figure 8–3 shows the format of the DOCSIS MPT Sublayer header and payload.
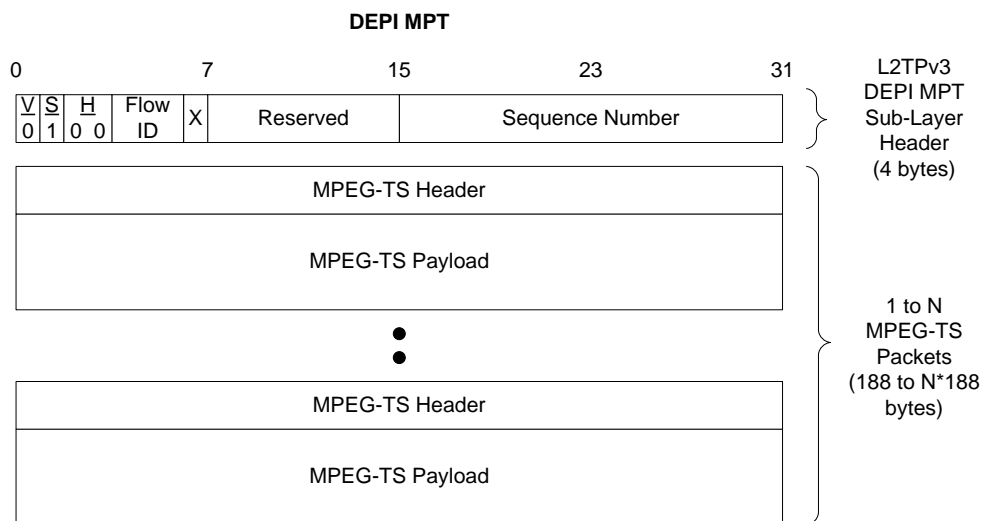
Figure 8–3 - DOCSIS MPT Sublayer Header and Payload

Table 8-1 - Header Format for MPT Sublayer Header and Payload

Field	Description
V	1 bit. VCCV bit. Set to 0. Reserved for compatibility with [RFC 5085].
S	1 bit. Sequence bit. Set to 1 to indicate that the sequence number field is valid. Set to 0 to indicate that the sequence field is not valid.
H	2 bits. Extended Header bits. Set to '00' to indicate a DEPI sublayer header that matches the current active pseudowire type (either D-MPT or PSP).
X	1 bit. Reserved bit. Set to all zeroes at the transmitter, ignored at the receiver.
Flow ID	3 bits. Flow Identifier.
Reserved	1 byte. Reserved field. Set to all zeroes at the transmitter, ignored at the receiver.

Field	Description
Seq Num	2 bytes. Sequence Number. The sequence number increments by one for each data packet sent, and may be used by the receiver to detect packet loss. The initial value of the sequence number SHOULD be random (unpredictable).

The CCAP-Core MUST NOT put null bytes between the UDP header and the first MPEG-TS header or between consecutive MPEG-TS packets. The CCAP-Core MUST support all bits in the MPT sublayer header.

The RPD MUST accept 1–7 MPEG-TS packets in an L2TPv3 payload when the path MTU is 1500 bytes in length. The length of an Ethernet frame containing seven MPEG-TS packets with L2TPv3 with a D-MPT L2TPv3 sublayer, and an IPv4, [IEEE 802.1q] header is 1378 bytes. If the RPD, the CCAP-Core, and the network between them all allow larger MTU sizes, the CCAP-Core MAY increase the total number of MPEG-TS packets transmitted per L2TPv3 packet.

The CCAP-Core MAY insert null MPEG packets into the D-MPT or MCM stream for a DOCSIS SC-QAM channel. A null MPEG packet is 188 bytes in length with a reserved PID value of 0x1FFF as defined in [ISO 13818-1]. The RPD MAY discard these null MPEG packets. The RPD is only required to support one flow for D-MPT or MCM mode.

## 8.3   DOCSIS DEPI Multi-channel MPEG (MCM) L2TPv3 Sublayer Header Format

The MCM L2TPv3 Sublayer Header is shown in Figure 8–4. The MCM Sublayer Header carries multiple channels inside an IP frame (unlike the DEPI D-MPT mode where each IP frame carried the same channel). The MCM Sublayer packet takes advantage of recent industry changes to carry 2000 byte Ethernet frames. This allows the MCM DEPI packet to carry up to 10 MPEG-TS packets.

The "H" bits in the Sublayer first double word partially define the type of sublayer header. In D-MPT, PSP, and MCM mode, the Control Plane sets bits to identify the packet content.

Table 8-2 - Sublayer "H" Bits Decode Table

Original DEPI vs. DEPI-MCM	Sublayer H Bits	Direct Decode of "H" Bits	L2TPv3 Control Plane Control
Orig DEPI	2'B00	DEPI sublayer header that matches the current active pseudowire type (either D-MPT or PSP).	L2TPv3 Control Plane sets up pseudowire choice of D-MPT or PSP.
Add-on to Orig DEPI	same = 2'B00	Reuses existing DEPI H bits of 2'B00.	Downstream PHY Module In-Band Control Plane selects new MCM Pseudowire type.
Orig DEPI	2'B01	DEPI Latency Measurement (DLM) Sublayer Header	No control over DLM packets.
Orig DEPI	2'B10 & 2'B11	Not defined	NA

DEPI-MCM (2000byte pkt)
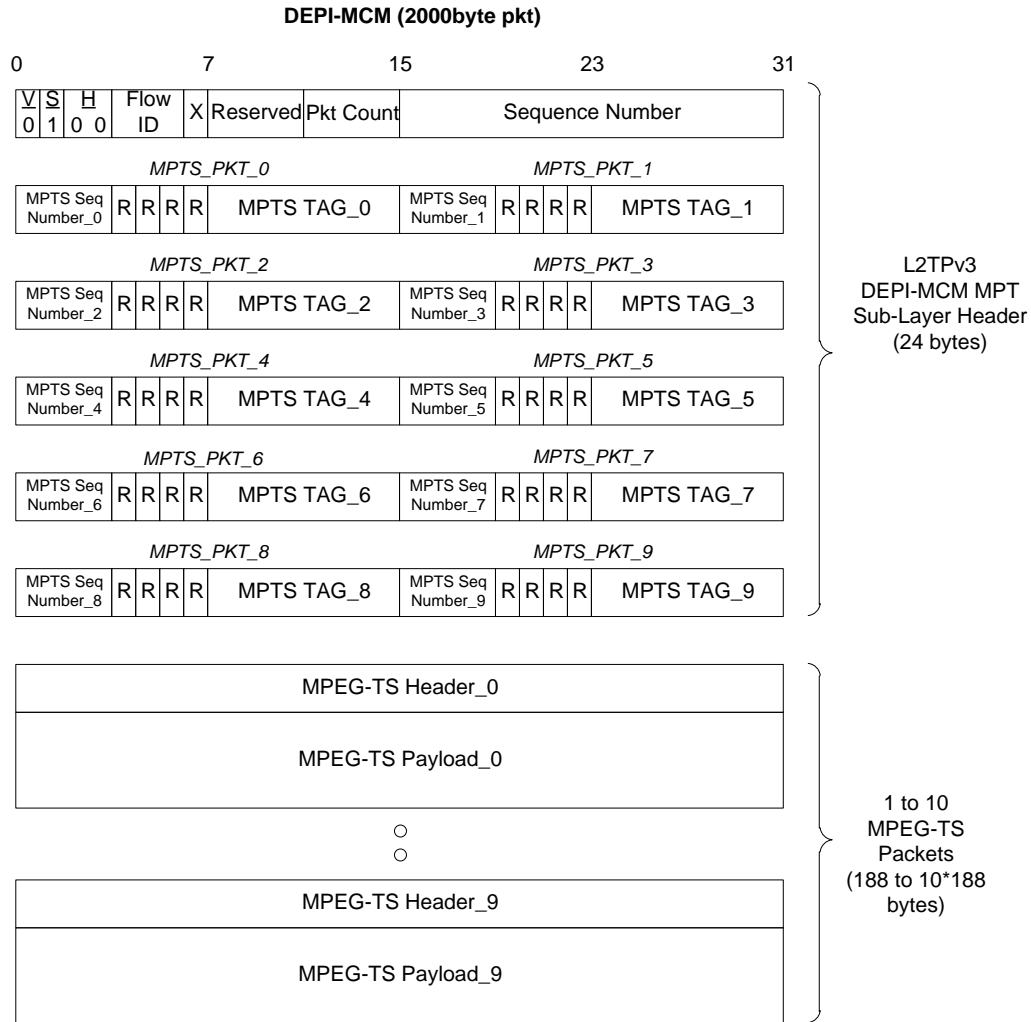
Figure 8–4 - MCM Sublayer Header and Payload

Table 8-3 - L2TPv3 MCM Sublayer Header and Payload Format

Field	Description
V	1 bit. VCCV bit. Set to 0. Reserved for compatibility with [RFC 5085].
S	1 bit. Sequence bit. Set to 1 to indicate that the sequence number field is valid. Set to 0 to indicate that the sequence field is not valid.
H	2 bits. Extended Header bits. Set to '00' exactly the same as existing DEPI; the In-Band Ethernet Control Plane chooses MCM Sublayer to indicate an MCM sublayer header is being used to move multiple channels of MPEG in the same IP Frame.
X	1 bit. Reserved bit. Set to all zeroes at the transmitter, ignored at the receiver.
Flow ID	3 bits. Flow Identifier.
Reserved	4 bits. Reserved field. Set to all zeroes at the transmitter, ignored at the receiver.
Packet Count	4 bits. Packet Count is the number of MPEG-TS packets in the L2TPv3 payload. Set to 4'h0=reserved, 4'h1=1pkt, 4'h2=2pkts….4'hA=10pkts, 4'hB>4'hF=reserved. Packet Count also indicates which MPTS TAGs and MPTS Sequence Number fields are valid.
Seq Num	2 bytes. Sequence Number. The sequence number increments by one for each data packet sent, and may be used by the receiver to detect packet loss. The initial value of the sequence number SHOULD be random (unpredictable). The sequence number can be used to track lost IP frames.

Field	Description
MPTS TAG	1 byte. MPTS Tag. The MPTS Tag provides a pointer to the RPD's MPEG-TS Stream Processing Resource (SPR). The MCM IP frame carries multiple MPEG-TS packets all directed at different MPEG-TS processing engines and QAM channels. The value of the Packet Count field defines how many MPTS tags are valid.
MPTS Sequence Number	4 bits. MPTS Sequence Number. The MPTS Sequence Number provides per-channel tracking information for the RPD. The RPD receives MPTS TAGs and MPTS Sequence Numbers, these two entities allow the RPD to count per-channel the MPEG-TS packets as they enter the RPD. The RPD will have the capability to replace per-channel MPEG-TS packets with MPEG NULL packets.

The new L2TPv3 MCM sublayer header has been defined so the R-PHY protocol can carry multiple channels of data in the same IP frame. It consists of a 4-byte-long subheader and 20-byte-long MPTS TAG and Sequence Number array. This array contains attributes associated with MPEG frames carried in the L2TPv3 payload. The array is fixed in size and supports up to 10 MPEG-TS packets. The value of the Packet Count field indicates which entries in the array are valid. For example, if the Packet Count field contains a value of 8, the first eight entries in the array are valid. The remaining, invalid entries in the array, are transmitted as zeroes and ignored upon reception.

The L2TPv3 Sequence Number is helpful for tracking possible lost and/or out-of-order IP frames. The MPTS Sequence Number helps in dynamically correcting channel-specific MPEG packets. The combination of the L2TPv3 Sequence Number and the MPTS Sequence Number allow for error-recovery accounting in the event an IP frame with varied channel-specific data is lost.

8.4 PSP Sublayer Header

8.4.1 PSP Legacy Sublayer Header

Figure 8–5 shows the format of the DEPI Legacy PSP Sublayer header and payload which was defined in the MHAv1 DEPI specification.
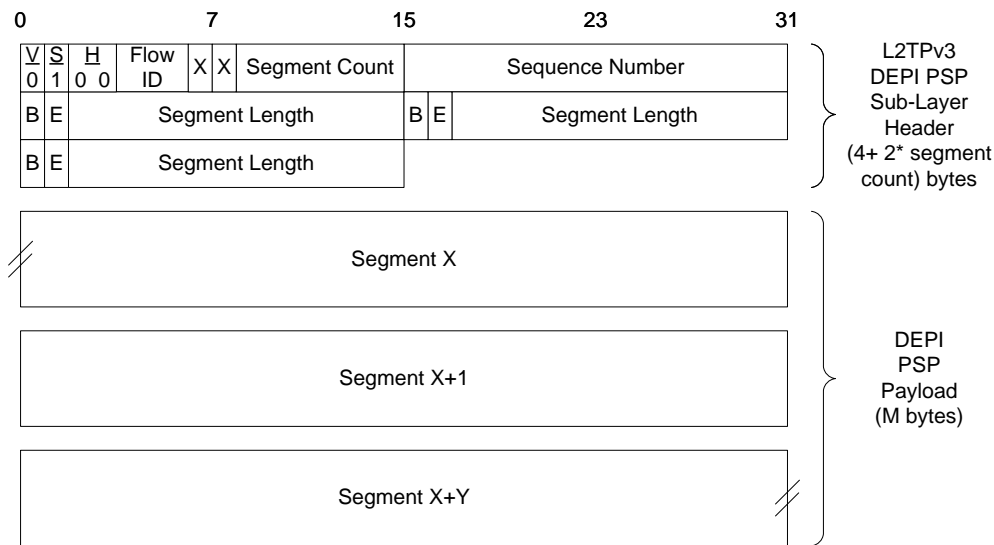
Figure 8–5 - DEPI Legacy PSP Sublayer Header and Payload

Table 8-4 - DEPI Legacy PSP Sublayer Header and Payload Format Details

Field	Description
V	1 bit. VCCV bit. Set to 0. Reserved for compatibility with [RFC 5085].
S	1 bit. Sequence bit. Set to 1 to indicate that the sequence number field is valid. Set to 0 to indicate that the sequence field is not valid.
H	2 bits. Extended Header bits. Set to '00' to indicate a DEPI sublayer header which matches the current active pseudowire type (either D-MPT or PSP).
X	1 bit. Reserved bit. Set to all zeros at the transmitter, ignored at the receiver.
Flow ID	3 bits. Flow Identifier.
Segment Count	7 bits. This is the number of segments in the DEPI PSP Payload, and this is also the number of 2 byte entries in the PSP Segment Table.
Seq Num	2 bytes. Sequence Number. The sequence number increments by one for each data packet sent, and may be used by the receiver to detect packet loss. The initial value of the sequence number SHOULD be random (unpredictable).
B	Begin bit. 1 bit. Set to a 1 to indicate that the PSP Frame contains the beginning of a DOCSIS frame. Otherwise, set to 0.
E	End bit. 1 bit. Set to a 1 to indicate that the PSP Frame contains the end of a DOCSIS frame. Otherwise, set to 0.
Segment Length	14 bits. Length of DEPI segment in bytes.

Neither RPD nor the CCAP-Core uses the legacy DEPI PSP Sublayer header format. The legacy DEPI PSP Sublayer header format is provided in this document for historical reference purposes only. Additional details can be found in [DEPI].
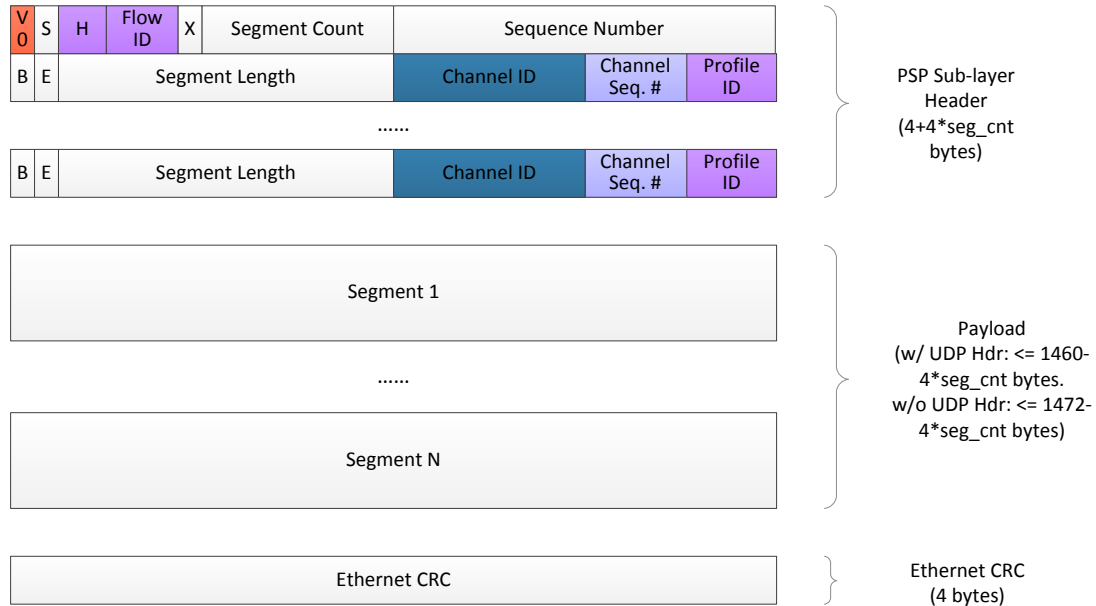
8.4.2   PSP Sublayer Header

The Packet Streaming Protocol (PSP) can take a series of DOCSIS frames, assemble them into a stream of back-to-back DOCSIS frames, and then split that stream up into PSP PDUs. In doing so, the first and last DOCSIS frames of a PSP PDU may be split into segments across PSP PDUs. DOCSIS frames that are not the first or last frame in a PSP PDU will not be split.

A DOCSIS frame may be split into more than two segments and therefore may be spread across more than two PSP PDUs. PSP segments can also carry Message Blocks for the PLC sub-channel of the OFDM channel. This specification defines two types of segments: DOCSIS PDU Segments and PLC Message Block Segments. While PSP supports segmentation of DOCSIS PDUs, PLC Message Blocks cannot be segmented.

The Segment Table provides information on the contents of each of the subsequent PSP frames. This includes signifying if the frame is the beginning, middle, end, or comprises an entire DOCSIS frame.

The main format difference between the DEPI Legacy PSP Sublayer header and the PSP Sublayer header defined in this specification is the expansion of the segment table from 16-bits to 32-bits. 32-bit long entries of the segment table carry additional information such as channel identifier, per channel sequence number, and OFDM profile information.

Figure 8–6 shows the unified format of the DEPI PSP Sublayer header that is utilized for carrying data intended for downstream SC-QAM channels, OFDM channels, and the PLC sub-channels of the OFDM channels.

Figure 8–6 - DEPI PSP Sublayer Header and Payload

Table 8-5 - DEPI PSP Sublayer Header and Payload Format Details

Field	Description
V	1 bit. VCCV bit. Set to 0. Reserved for compatibility with [RFC 5085].
S	1 bit. Sequence bit. Set to 1 to indicate that the sequence number field is valid. Set to 0 to indicate that the sequence field is not valid.
H	2 bits. Extended Header bits. Set to '00' to indicate a DEPI sublayer header that matches the current active pseudowire type.
Flow ID	3 bits. Flow ID. Allows for multiple flows per session.
X	1 bit. Reserved bit. Set to all zeroes at the transmitter, ignored at the receiver.
Segment Count	7 bits. This is the number of segments in the DEPI PSP payload, and this is also the number of 4 byte entries in the PSP segment table.
Seq Num	2 bytes. Sequence Number. The sequence number increments by one for each data packet sent, and MAY be used by the receiver to detect packet loss. The initial value of the sequence number SHOULD be random (unpredictable).
B	Begin bit. 1 bit. The interpretation of the "B" bit depends on the type of the segment. For DOCSIS PDU Segments, the "B" bit is set to 1 to indicate that the PSP segment contains the beginning of a DOCSIS frame. Otherwise, set to 0. For PLC Message Block Segments, the value of the "B" bit indicates the presence of the prepended 32-bit timestamp to the message block located within the segment payload. In such case (if the "B" bit is set to 1), then the PLC Message Block in the segment is prepended with a 32-bit timestamp. If the "B" bit is set to 0, the segment contains a PLC Message Block and no timestamp.
E	End bit. 1 bit. For DOCSIS PDU Segments the "E" bit is set to 1 to indicate that the PSP frame contains the end of a DOCSIS frame. Otherwise, set to 0. For PLC Message Block Segments the usage of the "E" is undefined. The sender transmits the "E" bit as 0, and the receiver ignores it.
Segment Length	14 bits. Length of DEPI segment in bytes.

| Field	Description
Channel ID	9 bits. An identifier of the downstream channel or the PLC sub-channel to which a particular segment belongs. The CCAP-Core provides the mapping between downstream channels in the RPD and Channel IDs used in the segment table via L2TPv3 control plane protocol. The sender MUST set the Channel ID in every entry of the segment table. Note that while the size of the Channel ID field permits effective identification and multiplexing of data from up to 256 channels, this specification imposes additional restrictions on how many and which channels can be grouped in a single session. Additional detail can be found in Section 8.4.3.2.
Channel Seq. Num	4 bits. Per channel sequence number. The sequence number is incremented by the sender (CCAP-Core) for each segment of a particular channel. This field can be used by the receiver (the RPD) in the reassembly process to detect lost segments.
Profile ID	4 bits. The interpretation of the Profile ID field depends on the type of the segment and the channel type it is associated with. For DOCSIS PDU Segments carrying data intended for SC-QAM channels, the sender transmits this field as "0000". This field is ignored by the receiver. For DOCSIS PDU Segments carrying data for OFDM channels, this field indicates the OFDM Profile ID of a downstream packet. The Profile ID field is valid in the first segment of a DOCSIS PDU (if the "B" bit is set.to '). If the "B" bit is set to 0, the sender transmits the profile field as '0000' and the receiver ignores it. For segments associated with an OFDM PLC sub-channel, the lowest bit of this field is referred to as the Segment Type or "T" bit. The three most significant bits of this field are transmitted as '000' by the CCAP-Core and ignored by the RPD. If the "T" bit is set to 0 this indicates DOCSIS PDU Segment type. If the "T" bit is set to 1 this indicates PLC Message Block Segment type.

When transmitting a DOCSIS PDU for OFDM data channels, the CCAP-Core MUST specify the OFDM profile ID in the first segment of the PDU.

When transmitting a DOCSIS PDU for OFDM data channels, the CCAP-Core MUST set the Profile ID to '000' in all but the first segment of the PDU.

When transmitting a DOCSIS PDU for SC-QAM data channels, the CCAP-Core MUST set the Profile ID to '0000' in all segments.

8.4.3 Interpretation of PSP Sublayer Header for PLC Sub-channel

Figure 8–7 shows an example of the DEPI PSP Sublayer header and payload with segments intended for a PLC sub-channel. The PSP header format allows the transport of DOCSIS PDUs for transmission on the message channel of the PLC as well as for the transport of PLC Message Blocks.
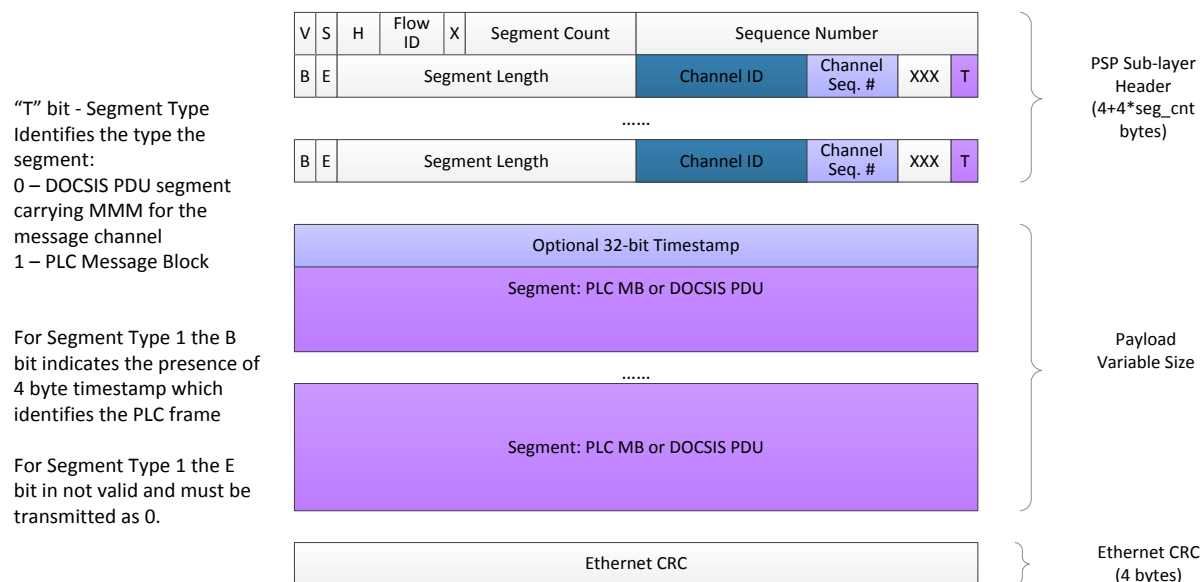
Figure 8–7 - Use of DEPI PSP Sublayer Header for PLC Sub-channel

The Profile ID field in the segment header includes a Segment Type "T" bit that allows the receiver to differentiate segments carrying DOCSIS PDU segments from segments carrying PLC Message Blocks. When the "T" bit is set to 1, the segment carries a complete PLC Message Block including a space for a 24-bit CRC message block. The CCAP-Core does not initialize the CRC field in the message block and typically fills it with null bytes. The RPD is responsible for computing and insertion of the 24-bit CRC. Any of the transported message blocks can be preceded by a 32-bit DOCSIS timestamp. The presence of the timestamp is indicated when both the "T" bit is set to 1 and the "B" bit is set to 1 in the segment table.

8.4.3.1   Rules for Transport of PLC Data

A single PSP session and even a single PSP flow can be used to transport a mix of DOCSIS PDUs for the OFDM data channel and the PLC sub-channel as well as PLC message blocks for a single OFDM channel. The CCAP-Core is bound by the requirements of [MULPIv3.1] in the selection of DOCSIS message types that can be sent on the PLC sub-channel.

The CCAP-Core can use PSP sessions to transport Trigger and EM Message Blocks as well as any other message blocks that will be defined in the future. Timestamp message blocks are generated locally by the RPD.

When the 32-bit Timestamp field is prepended to a PLC Message Block, its value communicates to the downstream RPD the time when the message block is to be transmitted. The CCAP-Core MUST insert the timestamp value with enough accuracy to uniquely identify the PLC frame in which the message block will be sent. The CCAP-Core MUST send any message blocks that are preceded by the timestamp with time advance equivalent to the duration of 1–20 PLC frames to account for DEPI transmission path delays and necessary processing time in the downstream RPD. A RPD MAY discard message blocks with a timestamp outside of the advance time window equivalent to 1–20 PLC frame durations.

The CCAP-Core MUST send Trigger Message Blocks in the order in which they are to be transmitted. The CCAP-Core MAY send Trigger Message Blocks with or without a prepended timestamp. When the timestamp is not prepended, the downstream RPD autonomously decides into which PLC frame to insert the Trigger message block.

The CCAP-Core MUST transmit EM Message Blocks in the order in which they are to be transmitted on the PLC. If the CCAP-Core sends more than one EM Message Block scheduled for transmission in the same PLC frame, the downstream RPD MUST transmit EM Message Blocks in the same order in which they have been received.

The CCAP-Core MUST limit the volume of data sent on the PLC pseudowire to match the traffic rate supported by the PLC. This requirement is defined to prevent excessive buffering on the downstream RPD.

8.4.3.2   PSP Requirements and Use Rules

The RPD MUST support signaling and operation with at minimum four PSP flows per session. The RPD MAY support up to eight PSP flows per session.

The PSP pseudowire header format includes an 8 bit Channel ID field, which allows effective identification and multiplexing of up to 256 channels or PLC sub-channels in a single session. Requiring support for arbitrary combinations of channels in a single session would complicate the implementation of the RPD. For this reason this specification only mandates support for two combinations of channel types in a single L2TPv3 session. The support for other channel type combinations is not expressly prohibited. Their definition and methods of signaling are outside of the scope of this specification.

The RPD MUST support a single PSP session with 1–32 SC-QAM channels mapped to the same downstream RF port of the RPD.

The CCAP-Core MUST support a single PSP session with one SC-QAM channel.

The CCAP-Core MAY support a single PSP session with more than one SC-QAM channel mapped to the same downstream RF port of the RPD.

The RPD MUST support a single PSP session with exactly one OFDM data channel and one PLC sub-channel of the same OFDM channel.

The CCAP-Core MUST support a single PSP session with exactly one OFDM data channel and one PLC sub-channel of the same OFDM channel.

To minimize DEPI overhead; a single PSP frame can transport multiple DOCSIS frames with different OFDM profiles. For example, a single DEPI packet can include a segment with a DOCSIS MDD message intended for transmission on profile "A" and a segment with a DOCSIS data PDU intended for transmission on profile "C". Similarly, a single PSP frame can transport multiple DOCSIS frames with different Channel IDs.

PSP pseudowires are intended to be implemented with a single segmentation and reassembly (SAR) context for each PSP flow. Within a single PSP flow, the CCAP-Core MUST complete the transmission of all PSP segments of a DOCSIS frame before transmitting the first segment of another DOCSIS PDU even if it belongs to a different OFDM profile or a different channel.

8.5   Optional Headers

The DEPI protocol supports optional VLAN [IEEE 802.1q] and MPLS headers. An example of a complete DEPI packet, including VLAN and MPLS headers, is shown in Figure 8–8.
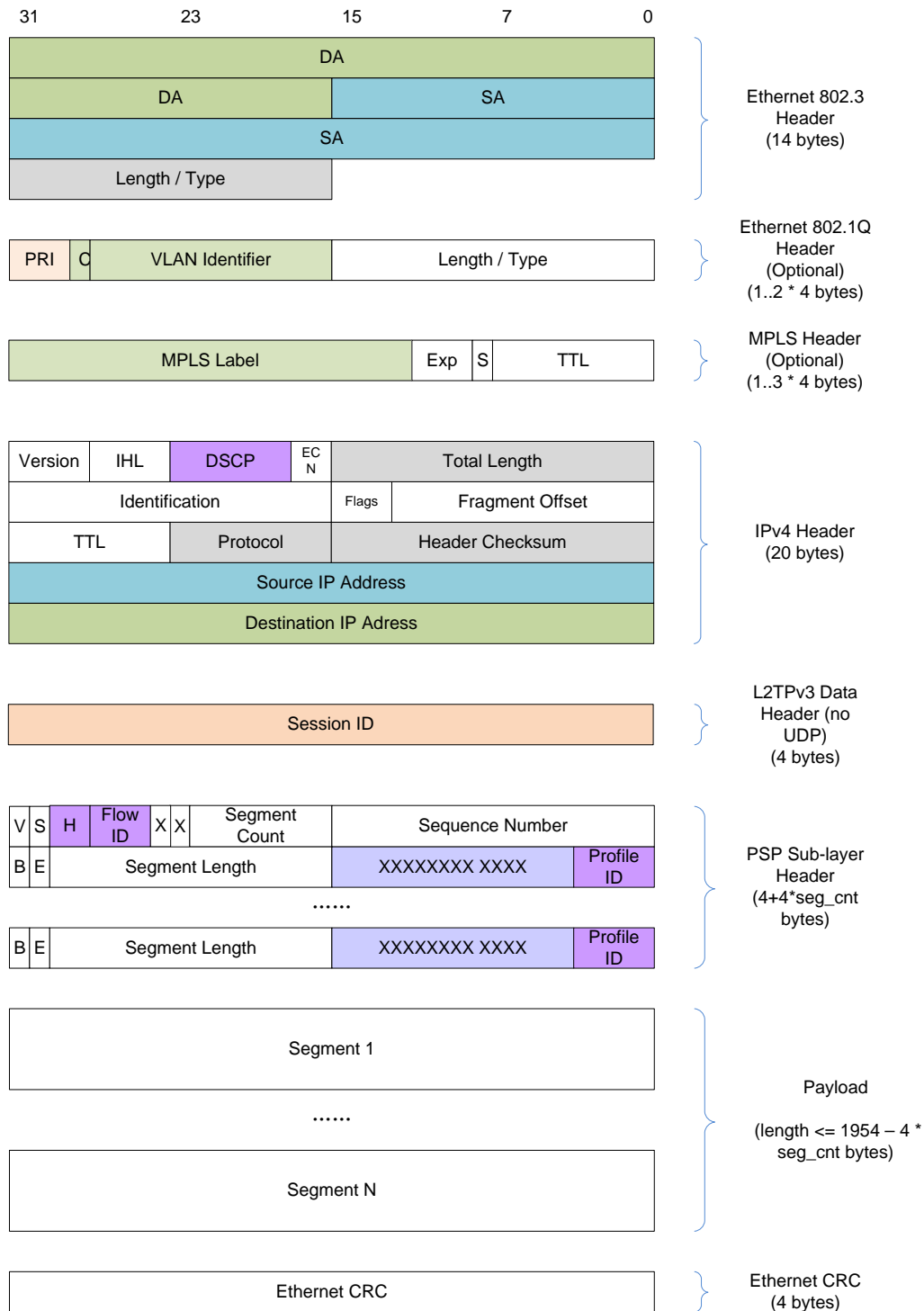

Figure 8–8 - Example of a Complete DEPI Packet Format (IPv4) with Extras

The specific requirements for support of VLAN and MPLS headers by the CCAP-Core and the RPD are [TBD].

8.6   DEPI Latency Measurement (DLM) Sublayer Header

The DEPI Latency Measurement (DLM) Sublayer Header is used by the CCAP-Core and the RPD to measure the delay and latency of the CIN on DOCSIS channels. This measurement is important because the transition network has the potential to affect the latency budgets already established in [RFIv2.0] for legacy DOCSIS 1.x and 2.0 devices.

To perform this measurement, a packet is sent using the DEPI Latency Measurement Sublayer Header (shown in Figure 8–9) to which the receiver responds. This sublayer header is designed to be used with any active L2TPv3 session between the CCAP-Core and the RPD. It may be used with MPT, MCM, and PSP pseudowire types. It is anticipated that this particular message exchange may occur between hardware mechanisms at either end of the DEPI interface.
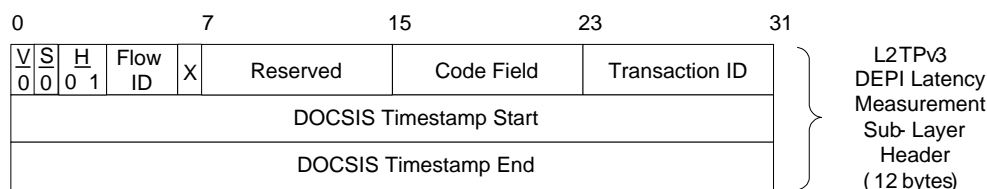
Figure 8–9 - DEPI Latency Measurement (DLM) Sublayer Header

Table 8-6 - DEPI Latency Measurement (DLM) Sublayer Header Details

Field	Description
V	1 bit. VCCV bit. Set to 0. Reserved for compatibility with [RFC 5085].
S	1 bit. Sequence bit. Set to 0.
H	2 bits. Extended Header bits. Set to '01' to indicate the presence of the latency measurement sublayer header.
X	1 bit. Reserved bit. Set to all zeroes at the transmitter, ignored at the receiver.
Flow ID	3 bits. Flow Identifier.
Reserved	1 byte. Reserved field. Set to all zeroes at the transmitter, ignored at the receiver.
Code Field	1 byte. The permitted values are described below: 0 = A DLM-EI-RQ (DLM EQAM Ingress Request) packet originated by the CCAP-Core requesting a measurement to be made at a reference point adjacent to the DEPI ingress port of the RPD. 1 = A DLM-EI-RP (DLM EQAM Ingress Reply) packet originated by the RPD with a Timestamp End value calculated at a reference point adjacent to the DEPI ingress port of the RPD. 2 = A DLM-EE-RQ (DLM EQAM Egress Request) packet originated by the CCAP-Core requesting a measurement to be made at a reference point adjacent to the DEPI egress port of the RPD. 3 = A DLM-EE-RP (DLM EQAM Egress Reply) packet originated by the RPD with a Timestamp End value calculated at a reference point adjacent to the DEPI egress port of the RPD. Values 4–255 are reserved.
Transaction ID	1 byte. This is a unique ID assigned by the sender and returned by receiver. The transaction ID is unique for each transaction.
DOCSIS Timestamp Start	4 bytes. Timestamp sent by sender.
DOCSIS Timestamp End	4 bytes. Timestamp existing at the receiver.

The CCAP-Core MUST support the sending of a DLM-EI-RQ packet and the receiving of a DLM-EI-RP packet on DEPI flows corresponding to DOCSIS channels. The CCAP-Core MAY support the sending of a DLM-EE-RQ packet and the receiving of a DLM-EE-RP packet on DEPI flows corresponding to DOCSIS channels. The CCAP-Core MUST send the DLM packet to the RPD on an existing R-DEPI session flow (either PSP, MCM, or D-MPT). The CCAP-Core MUST set the proper DSCP values for the DLM packet based on the R-DEPI session being measured. The CCAP-Core MUST provide a configuration mechanism to set the sampling interval through the Network Management Method defined in the [R-OSSI].

The CCAP-Core MUST report delta measurements that exceed a configured threshold through the Network Management Method defined in [R-OSSI]. The CCAP-Core MUST NOT send a DLM-EI-RQ or DLM-EE-RQ packet to a particular DEPI session, if there is already a DLM-EI-RQ or DLM-EE-RQ outstanding for that session, or if a DOCSIS frame on that flow has been segmented and the complete DOCSIS frame has not been sent. The CCAP-Core MUST place the current [DTI] 32-bit timestamp value in the DOCSIS Timestamp Start field of the message. The CCAP-Core SHOULD use a timestamp value that is accurate to within 100 µs of the current timestamp as derived from [R-DTI].

The RPD MUST support the receiving of a DLM-EI-RQ packet and the sending of a DLM-EI-RP packet. The RPD MAY support the receiving of a DLM-EE-RQ packet and the sending of a DLM-EE-RP packet. The RPD MUST support the use of the DLM packet within any active DEPI session corresponding to a DOCSIS channel. The RPD is not required to support more than one concurrent latency measurement per session. The RPD MUST ensure that the timestamp value inserted in the DOCSIS Timestamp End field is accurate to within 100 µs of the current timestamp used for SYNC insertion and/or correction or Timestamp Message Block insertion on OFDM channels.

For DLM-EI-RQ packets, the RPD MUST perform the timestamp insertion prior to queuing the DEPI frame on the D-MPT or PSP QoS queues. For DLM-EE-RQ packets, if supported, the RPD MUST perform the timestamp insertion at the point where the SYNC message is originated; this is discussed in Section 6.1.3.2. The RPD MUST send the completed Latency Measurement Packet back to the CCAP-Core that originated the measurement request, and do so within the RPD DLM Timeout value specified in Annex A.

An RPD that does not support a DLM-EE-RQ packet MUST silently discard the DLM packet without generating a DLM-EE-RP response packet.

8.7   DEPI Multicast Packet Header Format

The packet headers for the DEPI multicast packet are identical to the headers shown for the DEPI unicast packet in Figure 8–1. The only difference is that the source and destination IP address represent the Source and Group address of the multicast stream, and the Ethernet Destination address is also multicast instead of unicast.

8.8   CCAP-Core Output Rate

It is possible that if the CCAP-Core was to send packets at a data rate which exactly equaled the payload rate of the downstream QAM and those packets were subject to jitter, the RPD would insert an MPEG-TS null byte. Once the packets from the CCAP-Core arrived, there would be an output queue delay that would equal the worst case jitter present at the DEPI input of the RPD. That queuing delay would not be removed until the input to the RPD was interrupted and the internal queue was drained. Furthermore, the rate at which this delay is removed is related to the amount of jitter the input stream has, the peak input rate, and the maximum burst size of the input stream.

Unlike SC-QAM channels, the downstream OFDM channel defined by DOCSIS 3.1 does not have a single measureable output rate. The actual output rate of a channel depends on a number of factors such as the proportion of the traffic sent to each of the defined profiles and the effectiveness of the PMD encoding. When more data is sent on the downstream profiles with higher effective modulation rates, the channel output rate increases. When more data is sent on downstream profiles with lower effective modulation rates, the channel output rate decreases.

The effective rate of a channel increases when the codeword encoder is able to assemble more full-length FEC codewords. While the CCAP-Core is able to estimate the channel output rate based on the current traffic mix, it has no visibility into the PMD encoding process in the RPD device.

To prevent persistent buildup of buffers in the RPD, the CCAP-Core MUST limit the output rate of the aggregate payload of all DEPI flows that are destined to the same DOCSIS downstream channel within an RPD. The CCAP-

Core MUST support OSSI-configurable de-rating of the aggregate DEPI payload to DOCSIS downstream channels with a default of 99% and a range of 90–99% with a granularity of one percent.

For all DOCSIS DEPI payload types, the CCAP-Core MUST limit its burst of payload output at the CIN interface to a maximum of 1.5 ms of the estimated RF payload output rate. The value of 1.5 ms was chosen to exceed the RF transmission time of three (3) 1522-byte Packet PDUs at the slowest SC-QAM RF modulation rate of QAM-64. Any such burst is absorbed in the RPD jitter buffer as specified in Section 8.8.1.

For video and NDF DEPI payloads, the CCAP-Core MUST maintain output with a deviation of no more than 1.0 ms ahead or behind the RF output rate of the payload.

The CCAP-Core MAY provide vendor-specific configuration to increase the maximum DEPI payload burst.

The CCAP-Core MUST be able to rate limit the aggregate of all DEPI flows, including any null MPEG packets that the CCAP-Core may have inserted, that are destined to the same downstream channel within an RPD. The peak rate of this aggregate MUST be configurable to be a percentage of the nominal or estimated downstream channel payload rate. The burst size of this aggregate MUST be configurable. The default burst size of the aggregate MUST be the equivalent of three frames per DEPI session. (For a frame size of 1522 bytes, this is 4566 bytes.)

8.8.1   Downstream Output Buffer History

The RPD samples the aggregate depth of its output buffers every 1 ms and stores the measurements in a circular buffer containing one thousand samples, thus providing buffer occupancy history for the last one second interval. In cases where the RPD maintains multiple output queues per channel, the RPD records the sum of the measured individual queue depths for all output queues for a particular channel. The CCAP-Core can read the content of the measurement history buffer via GCP at any time. Based on this information, the CCAP-Core can analyze such issues as latency and jitter, and optimize the channel output rate.

While the RPD measures the actual buffer occupancy in bytes, to minimize internal storage requirements and the volume of data exchanged via GCP, the buffer occupancy measurement samples are normalized to 8-bit values, where 0 represents an empty buffer and 255 represents a full buffer. For this purpose, the CCAP-Core provides a normalization factor for each channel computed from the channel output rate and the output buffer depth. The method for calculation of the normalization factor is explained in the following examples.

Example 1:

For SC-QAM channels with an output rate of 38.8 Mbps, the maximum buffer depth, as measured in bytes can be calculated as:

$D = (8 \text{ [msec]} * 38.8 \text{ [Mbps]})/ 8 \text{ [B/b]} = 38.8 \text{ [kB]}$

Scaling factor: $N = D/256 = 38.8 \text{ [kB]} / 256 = 151 \text{ [B]}$

Example 2:

For an OFDM channel with a maximum output of 1 Gbps, the buffer depth can be calculated as:

$D = (8 \text{ [msec]} * 1 \text{ [Gbps]})/ 8 \text{ [B/b]} = 1 \text{ [MB]}$

Scaling factor: $N = D / 256 = 1 \text{ [MB]} / 256 = 3.9 \text{ [kB]}$

Example 3:

For an MPEG video channel with an output rate of 38.8 Mbps, the maximum buffer depth, as measured in bytes can be calculated as:

$D = (10 \text{ [msec]} * 38.8 \text{ [Mbps]}) / 8 \text{ [B/b]} = 48.5 \text{ [kB]}$

Scaling factor: $N = D/256 = 48.5 \text{ [kB]} / 256 = 189 \text{ [B]}$

The RPD MUST support Output Buffer Occupancy history for downstream DOCSIS channels, MPEG video channels, and NDF channels.

8.8.2   Downstream Buffer Depth Monitoring Alerts

The CCAP can instruct the RPD to actively monitor the depth of its downstream queues and alert the CCAP-Core via GCP if the average buffer depth for a particular channel exceeds a programmed threshold. This mechanism is designed to ensure that the buffer buildup issues within the RPD can be discovered in a timely manner so that the CCAP-Core can correct them before buffers overflow and channel data is lost.

The CCAP enables Downstream Buffer Alerts by sending the RPD a Buffer Alert Threshold (BAT) value and a smoothing factor "α" for a selected channel via GCP. Upon reception of the BAT value, the RPD starts computing the exponential moving average (EMA) of the aggregate output buffer for the channel, sampling the buffer depth every millisecond. When the computed value of the buffer depth EMA exceeds the BAT value, the RPD notifies the CCAP-Core a single time that the threshold has been exceeded.

Upon reception of an alert, the CCAP-Core takes a corrective action; it reduces the channel output rate by a fraction. The CCAP-Core determines the size of the rate reduction step. This specification recommends that the reduction step size to be at minimum one half of one percent of the current channel rate.

After the CCAP-Core takes a corrective action, it can re-enable buffer depth monitoring in the RPD by sending the BAT value again. Such an approach, which requires the CCAP-Core to consecutively reset the alert function after reception of an alert, is intended to ensure that the RPD does not flood the CCAP-Core with a large number of alerts.

The RPD calculates the buffer depth EMA using the following equation:

$$A_t = \alpha * D_t + (1 - \alpha) A_{t-1}$$

Where:

A_t – current average, A_{t-1} – previous sample average

D – a normalized buffer depth (see Section 8.8.1 for the description of the normalization)

α – a smoothing factor, $\alpha = 1/2^N$, N is a parameter configured by the CCAP-Core via GCP

The RPD SHOULD support Downstream Buffer Depth Monitoring Alerts for OFDM channels.

The RPD MAY support Downstream Buffer Depth Monitoring Alerts for SC-QAM DOCSIS channels.

The RPD MAY support Downstream Buffer Depth Monitoring Alerts for NDF channels.

The CCAP-Core SHOULD support Downstream Buffer Depth Monitoring Alerts for OFDM channels.

The CCAP-Core MAY support Downstream Buffer Depth Monitoring Alerts for SC-QAM DOCSIS channels.

The CCAP-Core MAY support Downstream Buffer Depth Monitoring Alerts for NDR channels.

8.9   Bidirectional Forwarding Detection

Bidirectional Forwarding Detection (BFD) is the widely adopted IETF standard (see [RFC 5580]) that allows the two endpoints to monitor the reachability over a link or a network by both ends periodically sending "hello" packets to each other. It is an efficient and generic hello/keep-alive protocol that is used by many applications, and plays a key role in fast convergence and traffic redirection to achieve necessary SLA requirements of applications.

[RFC 5085] describes Connectivity Verification (CV) types using Bidirectional Forwarding Detection (BFD) with Virtual Circuit Connectivity Verification (VCCV). VCCV provides a control channel that is associated with an L2TPv3 pseudowire (PW), as well as the corresponding operations and management functions such as connectivity verification to be used over that control channel. Embedding VCCV information within the pseudowire permits the CV function to be handled by the same hardware components that are involved in processing the tunneled data.

Recently, the IETF focused on several aspects of BFD in order to further improve scalability and efficiency, to expand failure detection coverage and to allow BFD usage for more scenarios. These efforts resulted in creation of Seamless BFD (S-BFD) described in [S-BFD-BASE] and related IETF drafts.

The RPD MUST support S-BFD responder functionality as specified in [S-BFD-BASE] and related L2TPv3 extensions specified in [S-BFD-VCCV] and [S-BFD-DSR-L2TP].

The RPD MUST support the ability to respond to S-BFD requests with a minimum rate of 100 responses per second under normal operational conditions.

Figure 8–10 shows the format of a BFD packet with a UDP header and the BFD Sublayer header.
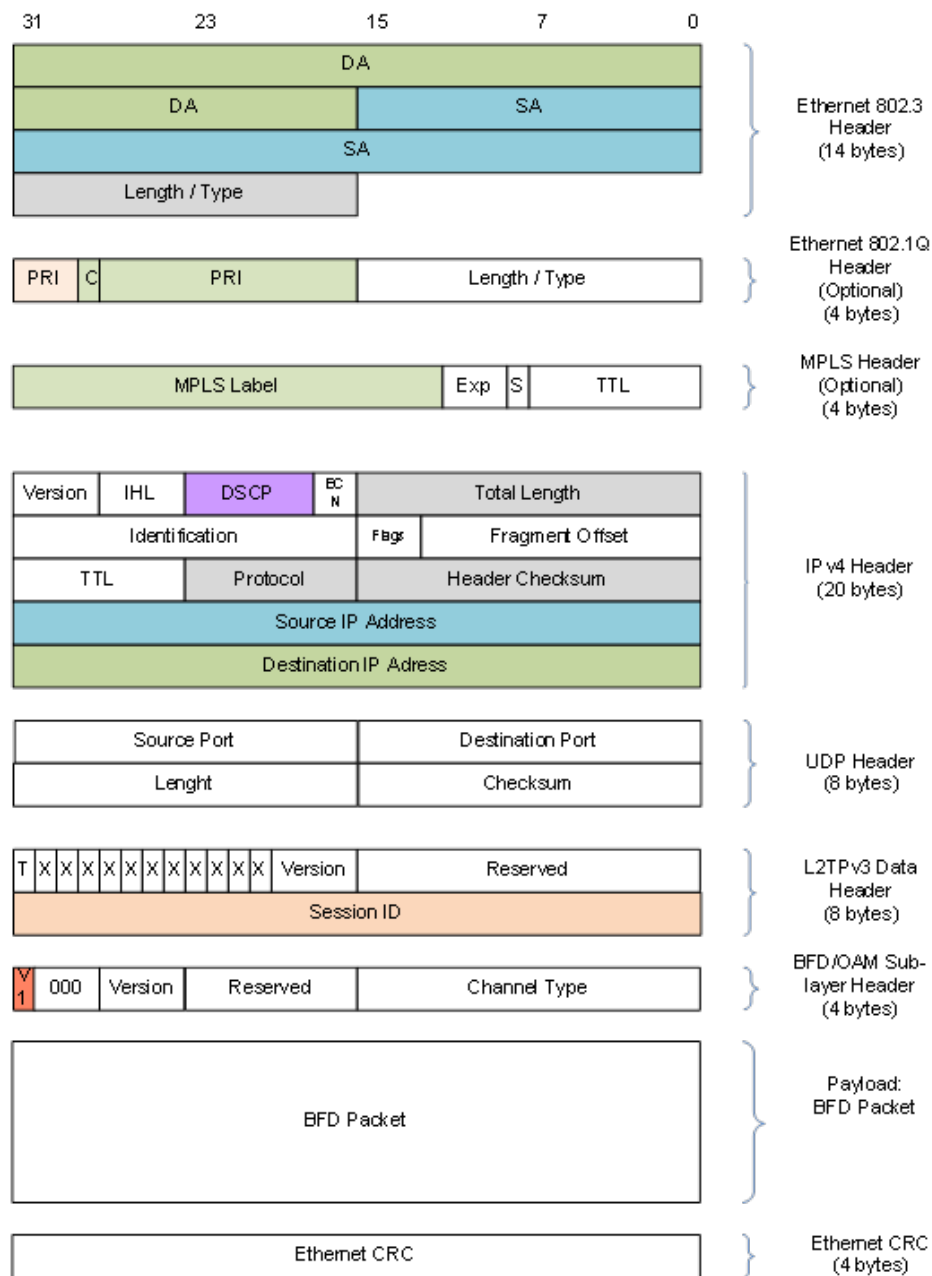
Figure 8–10 - BFD Sublayer (with UDP)

8.10 IPv6 Support

The MHAv2 [DEPI] protocol supports both IPv4 and IPv6 network layer addressing. The RPD MUST support DEPI transport with IPv4 and IPv6 headers. The CCAP-Core MUST support DEPI transport with IPv4 and IPv6 headers.

Additional considerations for processing of IPv6 extension headers are critical for IPv6 standard compliance and for supporting future capabilities of the RPD. Segment routing is one of the technologies considered for addressing QoS challenges in future SDN-managed access networks. The following requirements have been crafted in anticipation of deployment of segment routing over IPv6 in the CIN environment.

The Segment Routing impact on the RPD is fairly limited. The RPD does not need to understand the semantics of Source Routing. The RPD appends IPv6 extension headers to transmitted DEPI data packets or removes or bypasses those headers in received DEPI data packets.

In the ingress direction, the RPD's DEPI receiver MUST be able to process received packets with IPv6 extension headers up to 176 bytes long. The extension header length of 176 bytes was calculated based on the assumption that the longest Segment Routing extension header will contain a segment routing chain of 6 segments.

This specification does not define requirements for the interpretation or processing of the content of the extension headers with the exception for identification of the Hop-by-Hop header. The RPD's DEPI receiver MUST "punt" all packets with "Hop-by-Hop" extension headers to the RPD software for further processing.

The DEPI receiver in the RPD MUST be able to locate the L2TPv3 header in a packet based on traversing of the IPv6 extension header chain, as the RPD may have no prior knowledge of header size in the received packets.

In the egress direction, the DEPI transmitter in the RPD MUST be able to insert IPv6 extension headers up to 176 bytes long into transmitted DEPI packets. The number of unique IPv6 extension headers per RPD is limited to 4 per each CCAP-Core the RPD communicates with.

The RPD SHOULD be capable to update the inserted extension headers (or the entire packet headers) atomically, that is without disrupting the flow of data packets. The RPD MUST minimize the disruption to the flow of transmitted data packets when the IPv6 headers are updated.

The method by which the RPD receives IPv6 headers to be inserted into transmitted DEPI packets will be defined in future revisions of R-PHY specifications.

Annex A   Parameters and Constants (Normative)

Table A-1 - Parameters and Constants

System	Name	Time Reference	Minimum Value	Default Value	Maximum Value
CCAP-Core, RPD	SYNC Interval	Nominal time between transmission of SYNC messages.			200 ms
CCAP-Core, RPD	HELLO Timer	L2TPv3 section 4.4		60 sec	
CCAP-Core, RPD	Control Message Timeout	L2TPv3 section 4.2	First attempt: 1 sec, then second attempt 2 sec, then third attempt: 4 sec, then each additional attempt: 8 sec.		
CCAP-Core, RPD	Control Message Retry Count	L2TPv3 section 4.2			10
CCAP-Core, RPD	StopCCN Timeout	L2TPv3 section 3.3.2	31 sec		
RPD	EQAM DLM Timer	Time between receipt and retransmission of a DLM packet.			100 ms

Annex B   DOCS-IF-M-CMTS-MIB (Normative)

OSS Updates will be incorporated into the [R-OSSI] specification.

Annex C   Format and Content for Event, SYSLOG, and SNMP Notification (Normative)

Updates will likely be incorporated into the [R-OSSI] specification.

Annex D   DEPI Path Redundancy (Normative)

The MHAv2 updates to DEPI Path Redundancy will be addressed in a future revision.

Appendix I   DEPI and DOCSIS System Performance (Informative)

This appendix will be updated in a future revision.

Appendix II   Acknowledgements

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Sangeeta Ramakrishnan	Cisco	George Hart	Rogers
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