Data-Over-Cable Service Interface Specifications

CMAP Architecture Technical Report

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1 SCOPE

1.1 Introduction and Purpose

This Architectural Overview Technical Report is intended to provide an introduction to the Converged Multiservice Access Platform (CMAP) architecture. The CMAP architecture has been specified in an integrated and a modular implementation. This document describes both the integrated and modular architectures and discusses the various CableLabs specifications that contain normative requirements pertaining to the CMAP. In addition, this document describes the architectural entities and interfaces that make up the integrated and modular implementations, as well as the protocols they support. For the modular implementation, this document provides an overview of the operation of Packet Shelf and Access Shelf devices, as well as the interface between them.

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2.1 Reference Acquisition

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- 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.

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3 TERMS AND DEFINITIONS

This document uses the following terms:

Access Shelf	One of the two chassis that make up a Modular CMAP implementation. The Access Shelf is primarily responsible for MPEG processing and access functions (PHY, PON, etc.) normally associated with the CMTS and the Edge QAM.
Advanced Digital Cable™	IP video over DOCSIS
Cable Modem Termination System	A headend component that provides the operator network side termination for the DOCSIS link. A CMTS communicates with a number of Cable Modems to provide data services.
Converged Multiservice Access Platform	A headend component that provides the functionality of a CMTS and an Edge QAM in a single architecture with greater QAM density and overall capacity.
Edge QAM	A head-end or hub device that receives packets of digital video or data from the operator network. It re-packetizes the video or data into an MPEG transport stream and digitally modulates the transport stream onto a downstream RF carrier using QAM.
Ethernet Passive Optical Network	A point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises.
Hybrid Fiber-Coax 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.
NETCONF	An IETF network management protocol that provides mechanisms to manipulate the configuration of a device. NETCONF executes YANG-based XML files containing configuration objects.
Packet Shelf	One of the two chassis that make up a Modular CMAP implementation. The Packet Shelf is responsible for the packet processing functions, such as subscriber management, service flow management, layer-3 routing and higher layer protocol manipulation, as well as Access Shelf command and control.
RF Combiner	Headend equipment that accepts multiple input signals and delivers a single output that is equal in phase and amplitude.
Service Group	A set of channels for a given service (e.g., Video On Demand, High Speed Data) delivered via a number of fiber nodes to corresponding subscribers of that service to a single subscriber device.
YANG	A language used to model data for the NETCONF protocol. A YANG module defines a hierarchy of data which can be used for NETCONF-based operations, including configuration, state data, remote procedure calls (RPCs), and notifications.

4 ABBREVIATIONS AND ACRONYMS

This document uses the following abbreviations:

AAA	Authentication, Authorization, and Accounting
ADC	Advanced Digital Cable
AES	Advanced Encryption Standard
ANCP	Access Node Control Protocol
APC	Angled Physical Contact
AS	Access Shelf
ASM	Any-Source Multicast
AWGN	Additive White Gaussian Noise
BGP	Border Gateway Protocol
BPI	Baseline Privacy Interface
CATV	Cable Television
CBR	Constant Bit Rate
CLI	Command-Line Interface
CM	Cable Modem
CMAP	Converged Multiservice Access Platform
CMTS	Cable Modem Termination System
CPE	Customer Premises Equipment
CSA	Common Scrambling Algorithm
CW	Code Word
DES	Data Encryption Standard
DHCP	Dynamic Host Configuration Protocol
DLC	Downstream Line Card
DNS	Domain Name Server
DPIC	Downstream Physical Interface Card
DSG	DOCSIS Set-Top Gateway
DTI	DOCSIS Timing Interface
ECM	Encryption Control Message
ECMD	ECM Decoder
ECMG	ECM Generator
EPON	Ethernet Passive Optical Network
EQAM	Edge QAM
ERM	Edge Resource Manager
ERMI	Edge Resource Manager Interface
FFT	Fast Fourier Transform
Gbps	Gigabits per second
GigE	Gigabit Ethernet
GRE	Generic Routing Encapsulation

HSD	High-Speed Data
IETF	Internet Engineering Task Force
I-CMAP	Integrated CMAP
IGMP	Internet Group Management Protocol
IPDR	IP Detail Record
IS-IS	Intermediate System To Intermediate System Protocol
L2VPN	Layer 2 Virtual Private Network
LAN	Local Area Network
LDP	Label Distribution Protocol
LSP	Label-Switched Path
MAC	Media Access Control
M-CMAP	Modular CMAP
M-CMTS	Modular CMTS
MCX	Micro Coaxial
MEF	Metro Ethernet Forum
MHz	Megahertz
MIB	Management Information Base
MPLS	Multiprotocol Label Switching
MPTS	Multi-Program Transport Stream
MSO	Multi-System Operator
MVPN	Multicast Virtual Private Network
NNI	Network to Network Interface
NSI	Network-Side Interface
OLT	Optical Line Termination
OOB	Out of Band
OSPF	Open Shortest Path First Protocol
OSS	Operations Support System
OSSI	Operations Support System Interface
OTT VoIP	Over-the-Top Voice over IP
P2MP	Point-to-Multipoint Communication
PASI	Packet to Access Shelf Interface
PCMM	PacketCable Multimedia
PCR	Program Clock Reference
PEG	Public, Education, and Government channels
PHY	Physical Layer
PIC	Physical Interface Card
PIM-DM	Protocol Independent Multicast – Dense Mode
PIM-SM	Protocol Independent Multicast – Sparse Mode
PON	Passive Optical Network
PPM	Parts per Million
PS	Packet Shelf

PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RFI	Radio Frequency Interface
RIP	Routing Information Protocol
RSVP	Resource Reservation Protocol
RSVP-TE	RSVP – Traffic Engineering
SC	Subscriber Connector
SCTE	Society of Cable Telecommunications Engineers
SDV	Switched Digital Video
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SPTS	Single Program Transport Stream
SRM	Session Resource Manager
SSM	Source-Specific Multicast
STB	Set-Top Box
TLS	Transparent LAN Service
TLV	Type Length Value Attribute
UCH	Universal Cable Holder
ULC	Upstream Line Card
UML	Unified Modeling Language
UPIC	Upstream Physical Interface Card
VBR	Variable Bit Rate
VOD	Video on Demand
VoIP	Voice over IP
VLPS	Virtual Private LAN Service
VPN	Virtual Private Network
XML	Extensible Markup Language

5 CMAP ARCHITECTURE GOALS, BENEFITS AND OVERVIEW

5.1 Fundamental Goals of the CMAP

The Converged Multiservice Access Platform (CMAP) is intended to provide a new equipment architecture option for manufacturers to achieve the Edge QAM and CMTS densities that MSOs require in order to address the costs and environmental challenges resulting from the success of narrowcast services. The CMAP leverages existing technologies, including DOCSIS 3.0, Modular Headend Architecture, and current HFC architectures; and also can include newer ones, such as Ethernet optics and EPON.

The CMAP provides an alternative approach to the implementation of converged video and data services described in the Modular Headend Architecture (MHA) Technical Report (i.e., Modular CMTS with Universal Edge QAM). Similar to MHA, the CMAP provides sharing of QAM channels for different narrowcast services, but adds the capability of sharing broadcast QAM channels. The CMAP can be implemented as a single integrated chassis or in two separate devices:

- A Packet Shelf that contains the packet processing functions, such as subscriber management, service flow management, layer-3 routing and higher layer protocol manipulation.
- An Access Shelf that contains the upstream and downstream PHY functions normally associated with the CMTS and the Edge QAM, and nearly all of the DOCSIS MAC.

The key functional goals for CMAP include:

- Flexible use of QAM channels for the various services offered by MSOs, enabling modification to the number of QAMs using MPEG transport stream-based services (e.g., for VOD, SDV, etc.) versus DOCSIS-based services (e.g., HSD, voice, etc.) over time though a single configuration point.
- Individually configurable assignment of QAM channels to various service groups, such that it would be possible to have HSD/voice service groups, VOD service groups, and/or SDV service groups overlap in different ways without requiring that these service groups be identical.
- Efficient implementation of separate sets of QAM channels for narrowcast and broadcast applications, such that QAM channels for narrowcast services can be individually implemented for each RF port, and QAM channels used for broadcast services can be shared among the RF ports in each downstream line card (DLC).
- Simplification of the RF combiner network by providing all QAM channels for all digital services from a single RF port, only leaving certain legacy functions for RF combining.
- Implementation of sophisticated encryption algorithms – both standardized and proprietary (e.g., PowerKEY™, DigiCipher®, etc.) – without requiring special-purpose hardware, such that a CMAP from any vendor can implement the appropriate encryption mechanisms on the platform.
- A transport-agnostic network architecture including implementation of EPON and other access network technologies natively within the CMAP.
- Significant operational improvements, including environmental efficiencies (e.g., reduced space, power consumption, and heat dissipation), implementation of functions such as upstream health monitoring, continuous wave carriers for plant amplifier biasing, and many other operational enhancements.

5.2 CMAP Benefits

Whether implemented in an integrated chassis or in a modular manner, the CMAP provides the following operational benefits.

5.2.1 Service Multiplexing Flexibilities

The CMAP provides efficient implementation of Edge QAM (EQAM) blocks by implementing separate sets of QAM channels for narrowcast and broadcast applications. QAM channels for narrowcast services are individually implemented for each RF port, while QAM channels used for broadcast services are shared among all the RF ports in each downstream line card (DLC). The number of narrowcast and broadcast QAMs supported on each RF port is flexible.

The CMAP provides the ability to map narrowcast and broadcast QAMs in different combinations to specific downstream ports via configuration. The same narrowcast video QAM can be mapped to multiple downstream ports, allowing for overlap of SDV and VOD service groups. This allows an operator to create service groups on a decoupled, service-by-service basis and effectively deal with service group inequalities.

The CMAP can configure any QAM in a given CMAP RF port for DOCSIS or Edge QAM applications. This allows all QAMs for a given service group to be generated from a single RF port.

5.2.2 Bandwidth Capacity and Density Gains

The CMAP is designed to greatly increase the capacity of a single edge device, with a typical integrated CMAP delivering all narrowcast and broadcast services to at least 40 service groups. The CMAP is expected to support 10, 40, and/or 100 GigE interfaces with the ability to support a downstream capacity of over 150 Gbps. On a typical DLC, this traffic will be utilized by up to 12 downstream RF ports. Each port is capable of supporting up to 64 narrowcast QAMs and 96 broadcast QAMs.

5.2.3 High Reliability and Redundancy Capabilities

Given the scope of each RF port providing all services for a given service group, it is important that the operation be highly reliable. Therefore, a CMAP is expected to implement N+1 redundancy for upstream and downstream line cards and 1+1 redundancy of all common equipment.

The CMAP is designed with a “wire once” approach: physical interface cards (PICs) implement the upstream and downstream physical interfaces, allowing replacement of line cards without impact to the cabling. N+1 redundancy allows line card replacement without impacting services for longer than the failover time and without the need to re-wire upstream and downstream connections. This reduces mean time to recovery for the CMAP.

5.2.4 Configuration and Management Simplifications

The CMAP will allow configuration of both CMTS and EQAM functions from the same configuration interface. CMAP configuration will move away from SNMP-based configuration and focus instead on the processing of XML configuration files that hold the configuration details for all services on the CMAP. Traditional command-line interface (CLI) methods of configuration will continue to be supported.

Management of CMTS and EQAM functions are also consolidated on the CMAP. The CMAP implements all MIBs required in the DOCSIS OSSI, as well as appropriate SCTE and IETF MIBs.

5.2.5 Rack-Space and Power Reduction

One of the key benefits of the CMAP is to achieve significant environmental efficiencies. To that end, Figure 5–1 and Figure 5–2 demonstrate an example of the space and power savings achieved by deployment of the CMAP in a typical system.

Figure 5–1 depicts a typical installation in a headend consisting of the various digital services, including broadcast, SDV, VOD, and HSD equipment, plus the corresponding combiner and lasers/receivers.

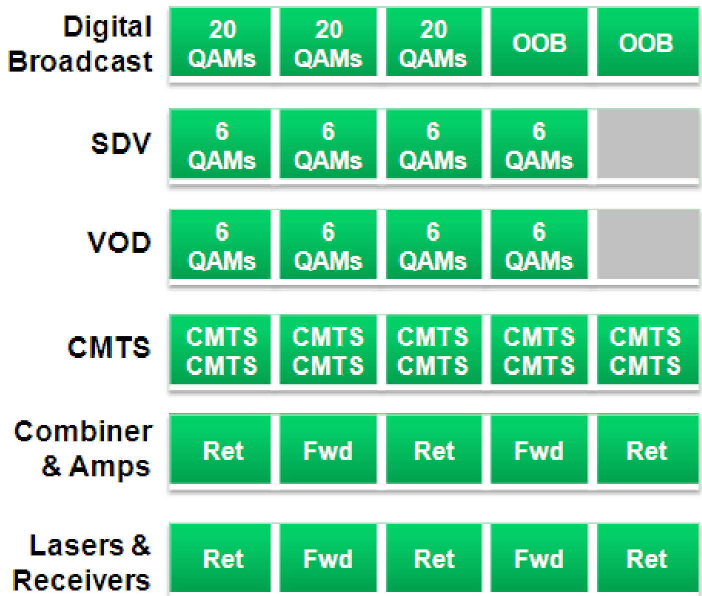

Figure 5–1 - Typical Headend Space Usage

The example shown in Figure 5–1 is intended to serve a typical population, combined in such a way as to result in 160 HSD service groups, and 120 VOD and matching SDV service groups.

Considering typical CMTS and Edge QAM equipment available today, this service group configuration would require about 10 CMTS chassis and about 4 racks for VOD and SDV, each containing 6 Edge QAM chassis configured for 64 QAM channels, each at a density of 4 QAM channels per RF port. The digital broadcast lineup is composed of 60 individual QAM channels, plus the corresponding out-of-band equipment.

Figure 5–2 depicts the analogous installation when considering the deployment of equivalent CMAP equipment.

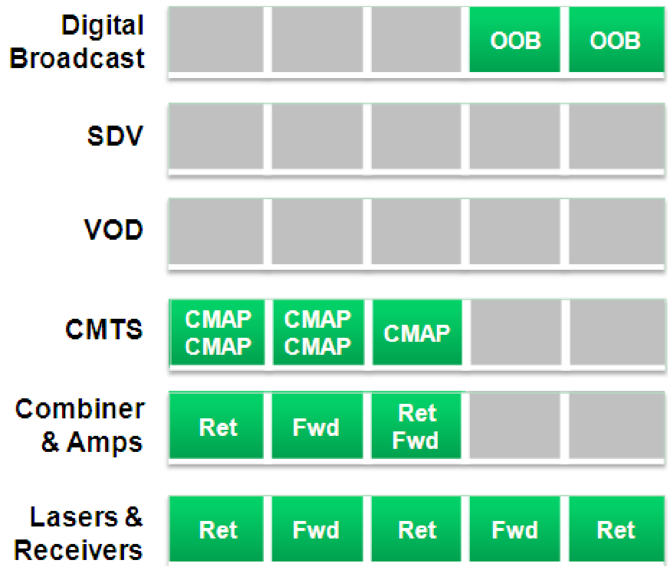

Figure 5–2 - CMAP Deployment Space Usage

Figure 5–2 shows the following:

- Given that the CMAP chassis would have twice the density of a typical CMTS, only half the number of CMAP chassis are required (compared to CMTS chassis), resulting in equivalent space savings.
- Additionally, the CMAP chassis, in its basic implementation, includes all the necessary QAM channels for supporting the VOD and SDV services. Therefore, no additional equipment is needed to support these functions, resulting in significant additional space savings.
- Given that the CMAP also supports sufficient broadcast QAM channels, the space previously allocated to the broadcast equipment is no longer needed, further contributing to space savings.
- Finally, it is estimated that half of the space allocated to the combiner network would be saved, resulting in even further space savings.

With all this taken into account, as much as half of the space previously required is needed for deploying the CMAP. Moreover, given that the CMAP can serve twice as many narrowcast QAM channels as the previous architecture could, the depicted CMAP scenario actually results in even greater space savings, providing twice as much capacity in half the space.

In addition, a cursory analysis of the difference in power consumption, assuming typical power draw for existing equipment and the expected power consumption for the CMAP, yields an estimated power savings of greater than 50%. And, this is taking into account the use of 32 QAM channels in the CMAP, or 2 times the capacity indicated in the original typical deployment.

With the decrease in equipment and power necessary to support this density of QAMs, the amount of heat generated by the equipment is also reduced, resulting in cooling savings in the headend.

5.2.6 RF Combining Simplifications

Deployment of the CMAP simplifies the RF combiner network by providing all QAM channels for all digital services from a single RF port, only leaving certain legacy functions for RF combining. Rather than having to rewire the physical plant to make service group changes, the QAM content of a downstream RF port can be changed via the CMAP configuration interface. Downstream of the CMAP, legacy out-of-band, analog channels, and maintenance streams (balance, sweep) are the only things that need to be combined into the CMAP output.

5.3 Supported Services in CMAP

This section discusses the various services supported by the CMAP on an HFC system. Some of these services can also be supported by a CMAP for an EPON deployment.

5.3.1 Video EQAM Services

Video services supported by the CMAP include digital video services that are supported today by existing broadcast and narrowcast Edge QAMs (EQAMs). These services include digital video delivered as: 1) broadcast digital video; 2) switched digital video; and 3) video on demand. The CMAP is not intended to support modulation of analog video. Analog video signals are combined external to the CMAP with the output digital QAM signals of the CMAP prior to the input into the downstream fiber optic transmitter.

5.3.1.1 Broadcast Digital Video

Broadcast digital video services refer to the programming delivered in a channel lineup to subscribers in common, as opposed to just a particular subscriber or to a particular node. Sometimes, broadcast video services are referred to as linear broadcast services because of the time-linear nature of the broadcast, whereby the programming operates on a regular schedule that is not under the control of the viewers themselves (e.g., no native ability to pause, rewind, or fast-forward the program).

Broadcast digital video services are typically delivered to the hub site in “pre-packaged” multiplexes (a “broadcast lineup”) that require minimal processing beyond local encryption, modulation, and upconversion.

The broadcast digital video services typically contain retransmission of over-the-air broadcast channels as well as programming supplied from various programmers delivered by satellite to a cable headend. Certain broadcast digital video services may also require local digital program insertion for advertisements targeted for particular ad zones, but the CMAP is not required to perform or support local ad insertion. Some broadcast lineups may require basic MPEG-2 “add/drop” type multiplexing to accommodate local public, education, and government (PEG) channels. For PEG channels, the CMAP is required to multiplex one or more SPTSs into an existing MPTS and perform MPEG table management (e.g., Program Association Table, Program Map Table).

Although digital music services delivered over a CATV system are principally audio services, they are also included here as a broadcast digital video service, since the programming usually includes accompanying still pictures or video in the background along with descriptions of the musical track and artist.

5.3.1.2 Switched Digital Video

Switched digital video (SDV) is classified as a narrowcast video service, as opposed to a broadcast service. Although the SDV content is delivered in common to multiple subscribers, the target subscribers are only those of a particular SDV service group that corresponds to the SDV QAM channels delivered to one or more fiber nodes. SDV transmits channel programs to only those service groups where there is a subscriber viewing the channel. Bi-directional data transmission is a key element to the support of SDV since STBs that are SDV-capable will indicate that they are tuned to, or are tuning to, a particular channel.

With an SDV service, the system delivers to viewers programs that operate on a regular schedule and are not under the control of viewers. Thus, in that sense, SDV is a linear video service.

Broadcast video services and SDV services can coexist on the channel lineup transmitted on a given node. Programming considerations, analysis of viewership of particular programs, and available downstream frequency channels feed into decisions about which particular programs to include on downstream QAMs delivering SDV.

5.3.1.3 Video on Demand

A video on demand (VOD) service is defined as a video service delivered to a specific subscriber, generally in response to a real-time request for pre-packaged MPEG content. Thus, VOD is a narrowcast video service. VOD requires interaction between the subscriber STB and the program control system across a bi-directional CATV system. In addition, VOD typically means that the user has the ability to make a video selection and have control over its playback (e.g., pause, rewind, fast forward). In this sense, VOD is not a linear video service.

5.3.2 DOCSIS Services

Services enabled by the CMAP and other equipment supporting the interfaces specified in the various DOCSIS specifications include:

- high-speed data (HSD)
- PacketCable voice over IP (VoIP)
- Transparent LAN Service (TLS) over DOCSIS L2VPN
- IP video over DOCSIS (hereafter referred to as Advanced Digital Cable (ADC) Services)

These services are discussed in the following sections (hereafter referred to as Advanced Digital Cable™ (ADC) Services).

5.3.2.1 High-Speed Data

Interfaces for cable modems (CMs) and cable modem termination systems (CMTSs) have been defined in the DOCSIS specifications. Multiple generations of DOCSIS specifications exist in support of high-speed data services. The DOCSIS 1.0 specifications provide basic broadband Internet connectivity for one or more devices in the home. Among other things, they include the ability to rate-limit (cap) a particular customer's data rate to a cable operator selected value. The DOCSIS 1.1 specifications provide improved operational flexibility, security, and quality-of-service (QoS) features that support high-quality digital voice, interactive gaming, and commercial service level agreements (SLAs). The DOCSIS 2.0 specifications include increased upstream reliability and throughput for symmetric services. The DOCSIS 3.0 specifications provide a number of enhancements, most notably channel bonding, support for IPv6, and support for Advanced Digital Cable (ADC) services. Channel bonding provides cable operators with a flexible way to significantly increase speeds to customers, with compliant devices supporting up to at least 160 Mbps in the downstream and 120 Mbps in the upstream. The DOCSIS 3.0 specifications also provide a platform for the evolution of the cable video business into ADC services.

The CMAP platform fully incorporates the functionality of DOCSIS 3.0 CMTSs – which includes backward compatibility for all previous DOCSIS generations – but with a much higher density.

5.3.2.2 PacketCable VoIP

The VoIP service discussed in this section refers to VoIP as provided by equipment supporting the interfaces specified in various PacketCable specifications. In this context, PacketCable VoIP provides a voice service that has voice quality, call features, and reliability that is expected from a primary line telephony service. Therefore, so-called over-the-top (OTT) VoIP services are not included in this category and can be considered as one of many applications that can be delivered under an HSD service. In addition to containing all the functionality of PacketCable 1.0, PacketCable 1.5 extends the PacketCable residential voice capability with capabilities such as fax and modem support, analog trunking for PBXs, and Session Initiation Protocol (SIP) for session management within and among PacketCable networks.

At a very high level, the PacketCable 1.5 architecture contains three networks: the DOCSIS HFC Access Network, the Managed IP Network, and the PSTN. The CMTS provides connectivity between the DOCSIS HFC Access Network and the Managed IP Network. Both the Signaling Gateway and the Media Gateway provide connectivity between the Managed IP Network and the PSTN. In the CMAP architecture, the CMAP performs the CMTS functions that are involved in support of PacketCable functionality today.

5.3.2.3 Transparent LAN Service

The Transparent LAN Service (TLS) discussed in this section refers to the functionality defined in the DOCSIS L2VPN specification. TLS is also sometimes referred to as a "Metro Ethernet" or "Carrier Ethernet" service as specified by the Metro Ethernet Forum (MEF). TLS allows businesses to extend their Layer 2 Ethernet networks (LANs) across the connectivity cloud of a core network which could be by itself an Ethernet, IP, or MPLS network.

The DOCSIS L2VPN specification defines functionality required for the CM and CMTS to support TLS. It defines the CM interface providing TLS service on the subscriber side, and the CMTS interfaces on the core network connection side as well as the DOCSIS RF interface. The required functions reuse a lot of existing DOCSIS functionality and provide some necessary extensions. The DOCSIS L2VPN specification defines support for both point-to-point Ethernet connections (E-LINE type of service in MEF terminology) and multipoint-to-multipoint Ethernet connections (E-LAN type of service in MEF). It also provides support for non-multiplexed services (EPL – Ethernet Private Line) as well as services multiplexed on one CM port (EVPL – Ethernet Virtual Private Line). It has a robust support for QoS enforcement /guarantees and security/encryption for this type of business services.

In the CMAP architecture, the CMAP performs the CMTS functions as defined by the L2VPN specification. In particular, it performs necessary per-L2VPN flow packet encapsulation on the NSI, QoS enforcement, downstream encryption and other functions.

5.3.2.4 Advanced Digital Cable Service

One of the services that the CMAP is expected to support is Advanced Digital Cable Service. As previously noted, in this document the term Advanced Digital Cable (ADC) service is used to refer to an IP video over DOCSIS service as supported by a CMAP.

ADC traffic has certain characteristics that can make the handling of that traffic by the CMAP less resource intensive. For example, ADC traffic flows have the following fundamental characteristics:

- **Large Packets:** ADC traffic consists predominantly of large packets on the order of 1300 to 1500 bytes. In order to sustain a given data rate, the CMAP needs to forward fewer packets per second than it otherwise would if the traffic flow consisted of small packets.
- **Long Sessions:** ADC sessions are generally long-lasting in comparison to internet sessions. Long duration sessions have the effect of minimizing session and flow setup and teardown overhead in the CMAP. Typical session duration is expected to be greater than 10 minutes.
- **Lower number of sessions:** ADC sessions are generally high bitrate sessions in comparison to internet sessions. High bitrate sessions require a lower number of sessions per QAM. Typical number of ADC sessions per QAM is expected to be lower than 40.

These characteristics of ADC traffic flows might allow a CMAP to be more cost-effectively sized with respect to the performance capabilities of a system than a system that is sized for full DOCSIS traffic of various sized packets on all data QAMs.

5.4 Integrated CMAP Architecture

Two reference architectures are provided in this section: one showing the digital video delivery infrastructure, and the other showing the high-speed data infrastructure. The CMAP was designed to fully support both types of services simultaneously.

5.4.1 CMAP MPEG Video Headend Reference Architecture

Cable headends acquire video from various sources to be provided to the subscriber via the access network. In Figure 5–3, the dotted lines represent the video data while the remainder of the diagram represents control elements or flows within the MPEG video system.

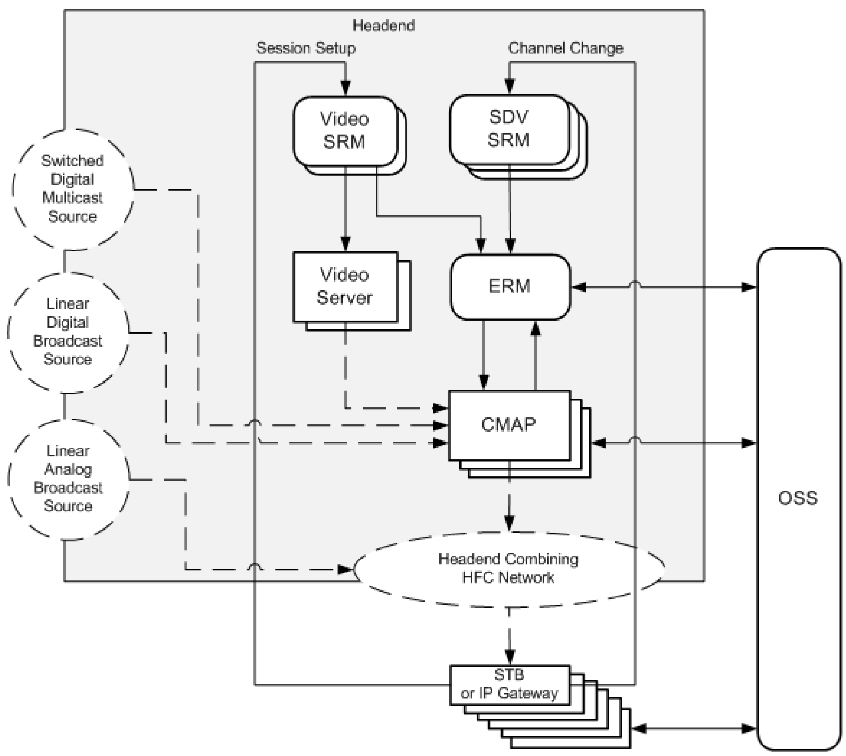

Figure 5–3 - CMAP Video Headend Reference Architecture

The CMAP has one or more ingress interfaces and multiple RF QAM outputs. The CMAP accepts input MPEG SPTSs or MPTSs transported via UDP/IP (multicast or unicast) over Ethernet, and multiplexes these input programs into an output MPTS that is then modulated and transmitted out one of the QAM RF outputs.

Digital video that is not broadcast continuously to service groups is controlled by the interaction of a service-specific client application on the STB, signaling to service-specific session resource managers (SRM) to request receipt of a video stream. When the STB client requests a stream, the SRM must acquire the necessary resources that allow the stream to be transported from source to destination. When the CMAP is first deployed, it is expected that VOD streams will be delivered as unicast, constant bit rate (CBR) SPTSs. The CMAP will be directed to route them to a particular QAM port and RF frequency, either via a UDP port mapping scheme, where the UDP port defines the RF port and frequency, or under the control of the Edge Resource Manager (ERM). In either case, the CMAP will be required to multiplex incoming SPTSs into MPTSs, and perform QAM modulation, up-conversion, and in some cases encryption. Variable bit rate (VBR) SPTSs may be supported in future releases.

Typical SDV architectures involve a centralized pre-processing of linear video streams into CBR SPTSs, a process known as “clamping”. The SPTSs are then routed to a network encryption device that applies appropriate content security and multicasts the streams onto the network. An SDV SRM will have knowledge of the SPTS multicast groups that correspond to each service and will communicate this to the ERM. When a STB client sends a request to the network to view a particular service, the CMAP that is able to reach that STB client will be instructed by the ERM to join the multicast of that service and route it to a particular QAM. Therefore, the requirement on the CMAP is to respond to the ERM request and multiplex the encrypted SPTS into a transport stream with additional SPTSs and perform QAM modulation and upconversion.

Linear digital broadcast video is routed to the CMAP in “pre-packaged” multiplexes (a “broadcast lineup”) that require minimal processing beyond local CA encryption, modulation, and upconversion. Each downstream line card on the CMAP will support at least a single broadcast lineup, sharing it among the service groups the line card serves. The CMAP can have multiple broadcast lineups per line card which are distributed across the service groups that the line card serves.

The ERM functional component is used to manage the use of transport bandwidth on the HFC network – the QAM channel and associated downstream frequency – out of the CMAP. The SRM uses the ERM to find a CMAP RF output having sufficient bandwidth and connectivity to the STB service group (serving area). In order to acquire the necessary RF/QAM bandwidth and CMAP resources needed to transport the stream to the service group, the SRM requests an ERM component function to allocate the bandwidth to the session manager. The ERM component provisions the CMAP to prepare it to receive the stream and direct it to the appropriate RF output using the allocated MPEG program number. The ERM can be either a controller interface outside of the CMAP or can be implemented internally to the CMAP.

The STB receives the QAM channel by tuning to the proper frequency, and can decode a single MPEG program from the MPTS. The STB is also responsible for providing the decoded A/V stream to the subscriber output device (i.e., monitor or TV) for presentation.

5.4.2 CMAP Data Reference Architecture

The CMAP performs all DOCSIS functions in the way that a traditional CMTS platform does. In addition, PON can be deployed on the CMAP to manage commercial HSD traffic. The following diagram, Figure 5–4, illustrates how HSD streams flow through the CMAP and the network to DOCSIS and PON devices and back.

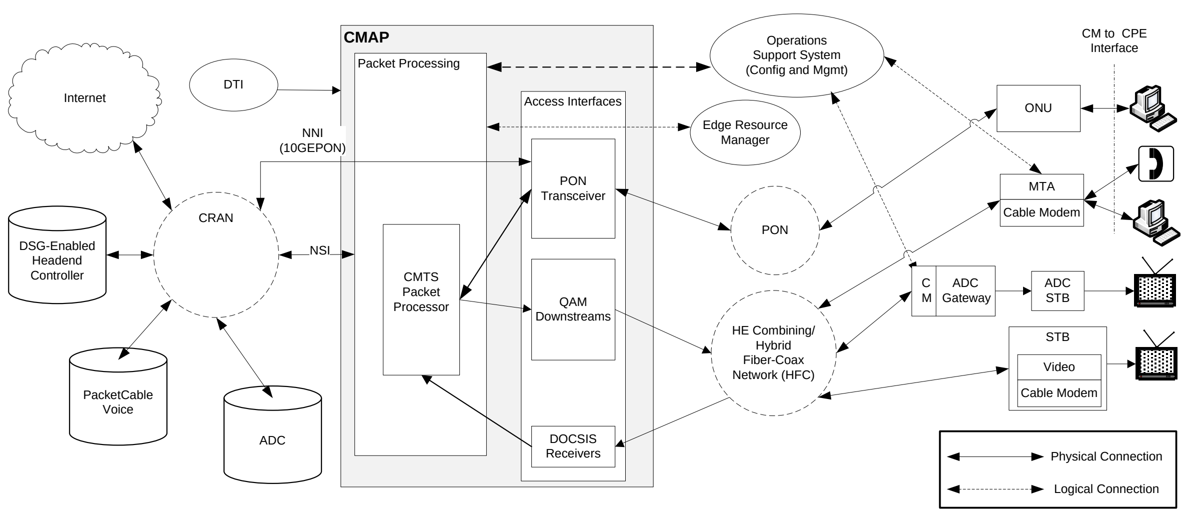

Figure 5–4 - CMAP Data Reference Architecture

The CMAP receives internet content, IP video, PacketCable voice data, and [DSG] data through the network side interface (NSI) from a converged regional access network (CRAN), consisting of at least 160 Gbps of data on one or more physical interfaces. Individual NNI may be provided for HSD business services using a 10GEPON interface.

The CMAP performs all of the MAC-layer functionality and all the initialization and operational DOCSIS-related processes. The MAC-layer functionality includes all signaling functions, downstream bandwidth scheduling, and DOCSIS framing. The CMAP creates the DOCSIS QAMs for the service groups the CMAP serves, and these QAMs are modulated and output as either downstream QAMs on the downstream line cards in the CMAP, or QPSK on the downstream PON interfaces.

The CMAP will deliver data and voice per the DOCSIS 3.0 and PacketCable 1.5 or PacketCable Multimedia (PCMM) specifications.

The ERM functions in a similar way to the MPEG video session setup: to acquire the necessary RF/QAM bandwidth and the CMAP resources to transport the stream to the service group.

The outputs of the CMAP are combined with legacy OOB data (and possibly legacy analog video) in the headend combining network and are distributed through the HFC network or PON network, where they are received by the following devices:

- MTA/CM: Provides PacketCable voice services and DOCSIS HSD for telephony and personal computing applications.
- ONU: Terminates the PON traffic for business services applications.
- ADC Gateway/CM: Receives video via IP protocol for ingestion by ADC set-top boxes.
- Set-Top Boxes: native QAM video and command and control data (either through DOCSIS or legacy out-of-band).

Upstream DOCSIS HSD and PacketCable voice traffic travel through the HFC or EPON and are received by either QAM upstream receivers or PON transceivers.

A DTI Server may be used to provide a common clock reference to synchronize to other TDM clock domains.

5.5 Modular CMAP Architecture

This section presents two architectural views of the Modular CMAP (M-CMAP). The first is a functional architecture that describes the physical separation of the M-CMAP components and the responsibilities of each. The second presents an architectural view of the M-CMAP in the headend, showing the flow of data and video, as well as interaction with other headend devices.

5.5.1 Modular CMAP Functional Architecture

An M-CMAP is the result of the decomposition of an Integrated CMAP (I-CMAP), whereby packet processing is segregated logically and physically from the real-time critical, access-specific processing. The M-CMAP is implemented as two separate “shelves”:

- A Packet Shelf
- An Access Shelf

The Packet Shelf is responsible for interfacing with Operational Support Systems on behalf of Access Shelves. Additionally the Packet Shelf is responsible for packet processing, service flows, and fine-grained quality of service. The Access Shelf insulates the Packet Shelf from access-specific technology such as HFC, PON, or

Wireless. In the case of HFC the DOCSIS MAC is self contained in the Access Shelf. An HFC-based Access Shelf will also perform functions found in a Universal Edge QAM.

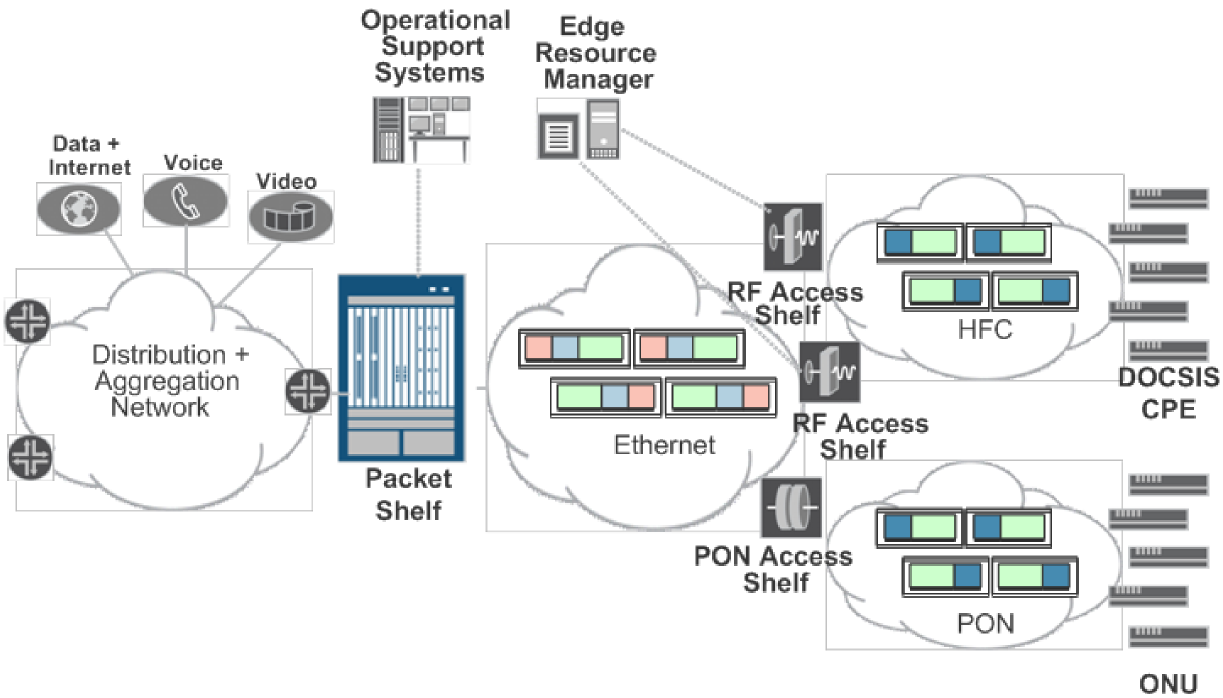

Figure 5–5 - Modular Implementation

5.5.1.1 Packet Shelf Functionality

The Packet Shelf has common functions that are self-contained without regard to the type of Access Shelf connected to it. These common functions include, but are not limited to:

- Terminate the DOCSIS OSSI
- Provide an SNMP manager for querying the Packet Shelf and any subtended Access Shelves
- Provide a configuration interface for the Packet Shelf and any subtended Access Shelves
- Manage IP subscribers and CPE devices
- Support L2 and L3 VPNs, along with various IP-based and MPLS-based routing protocols
- Support L2VPN packet encapsulation and forwarding
- Provide common Packet to Access Shelf Interface (PASI) management, control and data planes
- IP/MPLS QoS, shaping and scheduling
- PacketCable and PCMM Support
- Cable broadband intercept and/or PacketCable electronic surveillance functions
- Provide deep packet inspection functionality

5.5.1.2 Access Shelf Functionality

Since each Access Shelf type is access-specific, there is very little that is common across Access Shelves. Access Shelves can be access-technology-specific, only supporting one access medium such as HFC; or they can be hybrid, supporting more than a single access method, such as HFC and PON. The following is a list of common functions found on every Access Shelf type:

- Terminating common PASI management, control and data planes
- Providing access to SNMP MIBs for attributes under the control of the Access Shelf
- Processing Access Shelf configuration objects in response to a configuration request from the Packet Shelf
- Generating Syslog messages/SNMP traps to the operator's OSS

The other functions found on Access Shelves are access-specific. For example, an HFC Access Shelf will contain the DOCSIS MAC, MPEG processing, QAM processing, and DOCSIS upstream receiver functionality including QAM demodulation. In addition, the HFC Access Shelf will perform the following non-exhaustive list of functions:

- Cable modem ranging
- Modulation and demodulation
- DOCSIS timing
- Upstream bandwidth allocations and scheduling
- Framing and sequencing of downstream data
- Bonded channel scheduling

5.5.2 Modular CMAP Data/Video Architecture

The flow of data traffic and video traffic in the M-CMAP is very similar to the flow for the I-CMAP, the difference being the physical separation of the Packet Shelf and its subtended Access Shelves. Multicast and unicast streams enter the Packet Shelf via an NSI interface using the same protocols as are used in the integrated instance. These streams are then routed via a Route/Switch Engine within the Packet Shelf to the appropriate Access Shelf via the PASI Adapter Interface.

The Access Shelf receives these streams via its own PASI Adapter Interface, implemented as an NSI or NNI where they are processed and possibly replicated on the downstream line card (DLC) and directed to the appropriate downstream port (RF or PON) for transmission across the access network.

The ERM and OSS interact with both the Packet Shelf and the Access Shelf, performing the same functions as they do for the integrated CMAP.

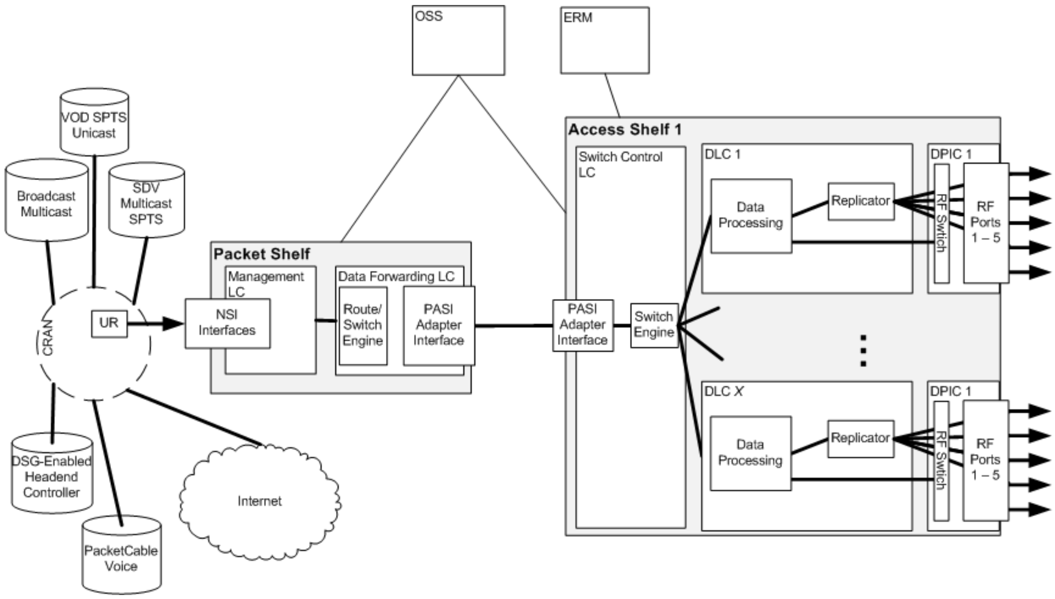

Figure 5–6 - Video and Data Flow in the M-CMAP

6 SUMMARY OF DOCSIS SPECIFICATIONS AND APPLICABILITY

6.1 DOCSIS 3.0 Specifications

The following sections describe which DOCSIS 3.0 specifications are required for the CMAP, and the extent to which they apply.

6.1.1 MAC and Upper Layer Protocols Interface ([MULPI]) Specification v3.0

The [MULPI] specification defines the MAC layer protocols of DOCSIS 3.0 as well as the requirements for upper layer protocols (e.g., IP, DHCP, etc.). The CMAP is required to meet all CMTS requirements specified therein.

6.1.2 Physical Layer ([PHY]) Specification v3.0

The [PHY] specification defines the upstream physical layer requirements for hybrid fiber-coax systems that the CMAP must support. The CMAP is required to meet all of the requirements specified therein. In addition, the CMAP is also designed to be compatible with the European market. For a European CMAP, adherence to Annex B of [PHY] is required.

6.1.3 DOCSIS Security ([SEC]) Specification v3.0

The [SEC] specification defines security services for DOCSIS communications, providing the operator with the ability to secure the provisioning process of cable modems (CM) and protect cable modem users by encrypting traffic flows between the CM and the cable modem termination system; in this case, the CMAP. The CMAP is required to meet all CMTS requirements specified therein.

6.1.4 Operations Support System Interface ([OSSI]) Specification v3.0

The [OSSI] specification defines the DOCSIS management interfaces and protocols for CMTS. Although the CMAP inherits some of the requirements of the [OSSI] specification, others are not mandated. The following sections summarize CMAP adherence to the [OSSI] specification.

6.1.4.1 SNMP Requirements

The SNMP requirements of the CMAP are based upon the requirements specified in [OSSI], but the CMAP does not implement all SNMP requirements specified therein. The CMAP is required to support SNMP v1 and v2, as well as at least 10 SNMP community strings with controlled access via access lists. The CMAP primarily diverges from the [OSSI] specification in its configuration methods. The CMAP is not required to implement SNMP as a configuration protocol; instead, the CMAP is configured through the processing of XML configuration files, the structure of which is defined in YANG instance modules. The [OSSI] specification will be updated to include the XML-based configuration method.

6.1.4.2 OSSI MIBs

All read-only MIB objects in the [OSSI] specification are implemented for status and performance monitoring, but the read-write and read-create MIB objects are not mandatory for the CMAP. The non-mandatory status of SNMP for configuration allows these write/create MIB objects to be excluded.

6.1.4.3 Event Reporting

The CMAP must support all standard event reporting mechanisms defined in section 8 of the [OSSI] specification.

6.1.4.4 IPDR

The CMAP is required to meet all IPDR requirements specified in the [OSSI] specification. The CMAP is also required to support all IPDR service definitions defined in the [OSSI] specification.

6.1.4.5 Object Model Definitions

The following OSSI object model definitions are implemented in the CMAP unchanged.

Table 6–1 - Unchanged OSSI Objects

FiberNodeCfg	CmtsCmEaeExclusion	ProfileSessionRule
CmtsCertRevocationList	LogTriggersCfg	StaticSessionRule
SavCfgList	LogGlobal	DefGrpSvcClass
CmtsServerCfg	Grp	DocsIfCmtsMpodulationTable
CmtsSavControl	Base	ChFnCfg
CmtsOnlineCertStatusProtocol	FilterGrp	ServiceClass
CmtsCertificate	Ctrl	CmtsEventNotif
CmtsEncrypt	Profiles	CmtsEventCtrl

The following OSSI object model definitions are implemented in the CMAP, but with alterations.

Table 6–2 - Altered OSSI Objects

Object	Attribute Changed
CmtsGrpCfg	The RowStatus attribute is not used.
CmtsGrpEncryptCfg	The RowStatus attribute is not used.
CmtsGrpQosCfg	The RowStatus attribute is not used.
CmtsGrpPhsCfg	The RowStatus attribute is not used.

6.2 Downstream RF Interface ([DRFI]) Specification

The [DRFI] specification defines the downstream radio frequency interface for EQAMs and CMTS; as such, the requirements specified in [DRFI] are required for the CMAP. While all [DRFI] specification requirements must be met by the CMAP, the CMAP does diverge from the [DRFI] specification in the following areas:

- Spectrum coverage: The CMAP requires support for the optional frequency range extension to 1002 MHz (1006 MHz for the European Technology Option), as defined in the [DRFI] specification.
- Frequency accuracy: The CMAP requires a frequency accuracy of equal to or better than 5 ppm, 10 year aging over time and temperature.
- Port-to-port isolation: The CMAP requires a minimum port-to-port isolation of ≥70 dB from 50 MHz to 550MHz and ≥65 dB from 550 MHz to 1002 MHz.
- Frequency shift: The CMAP requires:
  - Carriers must not sweep across bands.
  - Ports must be muted when changing frequency.
  - Port output cannot be restored until the RF output is at the correct frequency and is stable.
- Output level adjustment: The [DRFI] specification contains general language regarding how the system should behave while changing output levels, which is required for the CMAP.

6.3 DOCSIS Set-Top Gateway ([DSG]) Specification

The [DSG] specification defines an interface and associated protocol that introduces additional requirements on a DOCSIS CMTS and DOCSIS CMs to support the configuration and transport of a class of service known as "Out-Of-Band (OOB) messaging" between a set-top controller (or application servers) and the customer premises equipment (CPE). The CMAP is required to meet all CMTS requirements in the [DSG] specification.

6.4 Edge Resource Management Interface ([ERMI]) Specification

The [ERMI] specification defines interfaces that are used by EQAMs, ERMs, and M-CMTS Cores. While the CMAP does not require that all of [ERMI] be supported, because the CMAP will interface with ERMs to dynamically control video and possibly DOCSIS QAMs, the following interfaces specified in [ERMI] are required:

- Registration interface to the ERM (ERMI-1)
- Control interface to the ERM (ERMI-2)

In addition to these interfaces, the CMAP is also required to implement switched digital video (SDV) as defined in the [ERMI] specification.

6.5 Layer 2 VPN ([L2VPN]) Specification

The [L2VPN] specification describes requirements for both CMTSs and CMs in order to implement a DOCSIS Layer-2 Virtual Private Network. The L2VPN feature allows cable operators to offer a Layer 2 Transparent LAN Service (TLS) to commercial enterprises. The CMAP is required to meet all CMTS L2VPN requirements and implement all relevant read-only L2VPN MIB objects. The CMAP is not required to implement L2VPN read-write and read-create MIB objects.

6.6 TDM Emulation Interface ([TEI]) Specification

The [TEI] specification defines a method for cable operators to deliver T1, E1 and NxDS0 emulation services that meet or exceed the quality requirement of applications that use such services. Implementation of TDM emulation is preferred for the CMAP, but no [TEI] specification requirements are mandatory.

6.7 DOCSIS Timing Interface ([DTI]) Specification

The [DTI] specification defines the timing interfaces required for the DOCSIS M-CMTS architecture. While the CMAP must support stratum 3 clock accuracies, it is not required to implement the timing interface as specified in the [DTI] specification, although [DTI] is an acceptable implementation. If a DOCSIS timing interface is not implemented, then the external timing interface is required to support a method to lock itself to the internal DOCSIS clock to ensure traceability of the clock to the TDM hierarchy.

6.8 Video Stream Interface ([EQAM VSI]) Specification

The [EQAM VSI] specification defines the data plane requirements for receiving, processing, and transmitting MPEG transport streams in EQAMs. The CMAP implements all requirements in the [EQAM VSI] specification, with the following exceptions:

- Section 9 – Encryption and Encryption Interface: The CMAP is implemented with its own content protection mechanisms, described in further detail in Section 7.2, Content Protection of this report. The CMAP Encryptor is also required to support payload input and payload output, as defined in VSI.
- Section 12 – Input and Output monitoring: The CMAP implements robust MPEG transport stream monitoring.

6.9 Summary of DOCSIS Specification Applicability

The following table summarizes the level of adherence the CMAP must have to the DOCSIS specification.

Table 6–3 - DOCSIS Specification Adherence

	Specification										
Device	**MULPI**	**PHY**	**SEC**	**OSSI**	**DRFI**	**DSG**	**ERMI**	**L2VPN**	**TEI**	**DTI**	**VSI**
I-CMAP	M	M	M	P*	M	M	P	M	O	O	P
M-CMAP PS	M		P	P		M	P	M		O	
M-CMAP AS	M	M	P	P	M	M			O	O	P
ERM							M				

M = Mandatory
P = Partially Required
O = Optional

* The changes detailed in Section 6.1.4 will be made to the [OSSI] specification, allowing certification.

7 CMAP FEATURES AND CAPABILITIES

7.1 Service Multiplexing Capabilities

7.1.1 CMAP Service Groups

For the purposes of the CMAP, a service group is defined as a set of channels in a given service delivered via some number of fiber nodes to the corresponding subscribers of that service, provided by one or more CMAP ports. One of the concepts tied in with service groups is the reachability of certain signals from the CMAP to fiber nodes to the subscribers on those nodes, and likewise, the reachability of return path signals from fiber nodes to the CMAP. Thus, a service group is defined as a set of channels to or from a set of subscribers.

A downstream service group has traditionally been defined as a set of downstream channels carrying a particular service that reaches a specific set of optical nodes. The sizes of the service group for each service on the network, in terms of fiber nodes or actual subscribers, may be independent of each other. For the discussion below, it is assumed that the output of one port on the downstream line card (DLC) is associated to one fiber node. In addition, the number of channels provided for a particular service on each node differs for various service types available to subscribers.

The notion of a service group is important to understand some of the key functions of the CMAP. The following sections provide an overview of the different types of service groups and how they relate to each other.

7.1.1.1 Broadcast Service Groups

A broadcast service group consists of linear digital broadcast video channels corresponding to an advertising zone or a channel lineup with local or regional PEG channels. A broadcast service group typically spans more than one port on a DLC, possibly spans all ports on a DLC, and may even cross multiple DLCs.

7.1.1.2 Switched Digital Video Narrowcast Service Groups

An SDV service group consists of a number of downstream QAM carriers that are configured for video services for switched digital video applications. The SDV service group is a configured element of the CMAP and may span more than one RF port on a DLC.

7.1.1.3 VOD Narrowcast Service Groups

A VOD service group consists of a number of downstream QAM carriers that are configured for video services for video on demand. A VOD service group may be configured to be smaller than a DOCSIS service group, due to frequency re-use configurations and the number of QAMs needed for a specific serving area. The VOD service group may span more than one RF port on a DLC.

7.1.1.4 DOCSIS Narrowcast Service Groups

A DOCSIS downstream service group today is typically configured to be comprised of one to four optical nodes, depending on node size, service penetration, and data traffic load. There is some expectation (not necessarily a rule) that a DOCSIS service group would correspond to one port on a DLC.

7.2 Content Protection

The CMAP is designed to accept incoming transport streams that have had encryption applied to keep them protected as they traverse the network of the MSO, remove that network encryption, and then, based on the encryption mode specified for the content, apply the appropriate conditional access (CA) encryption for downstream transmission. The CMAP Decryptor and CMAP Encryptor are the two core functions of the CMAP, daisy-chained as shown in Figure 7–1, to dynamically process a large portion of the input payload, according to the requirements of each content protection session.

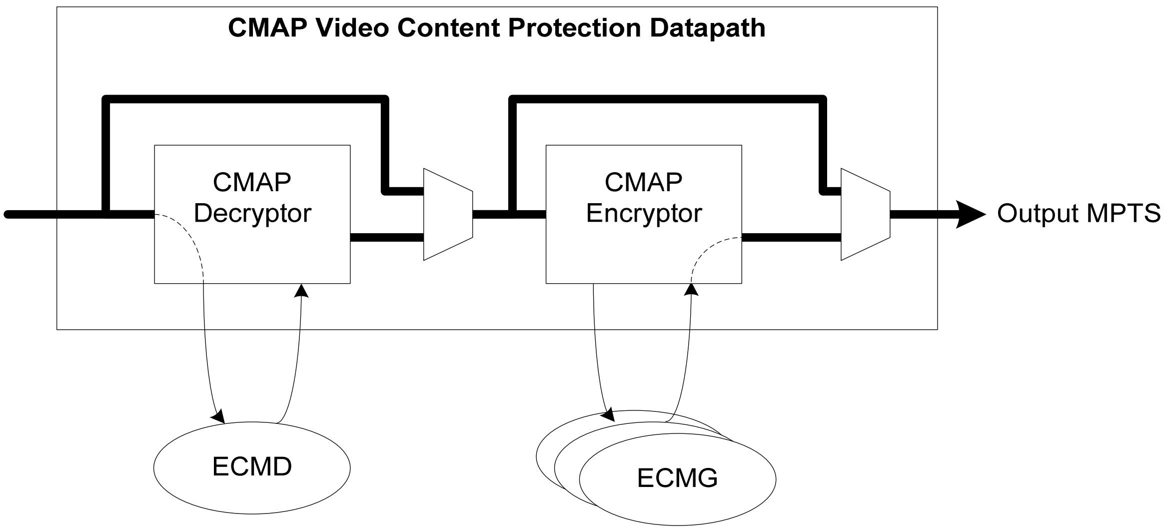

Figure 7–1 - CMAP Video Content Protection Overview

The CMAP content protection data path is designed to support all of the decryption and encryption needs for the following existing and future video cable services:

- Video on demand
- Switched digital video
- Linear Digital Broadcast

The CMAP Decryptor and CMAP Encryptor functionally reside on the downstream line card.

7.2.1 Network Decryption

The CMAP Decryptor component works in association with one external ECM decoder (ECMD) to remove the encryption layer used to secure the content distribution within the operator inner network. The control words and copy control information are retrieved from the incoming ECM to allow decrypting the associated payload, if required. The CMAP Decryptor supports 128-bit AES decryption.

7.2.2 Access Encryption

The CMAP Encryptor component works in association with one or more external ECM generators (ECMG) to apply the encryption layer required to secure the content distribution to the subscriber CPE devices. In Simulcrypt operation, the Encryptor provides the same control word and access criteria to all ECMGs, which in return generate their matching ECMs. In non-Simulcrypt operation, the Encryptor receives both control words and ECMs from the selected ECMG, based on the provided access criteria.

The CMAP Encryptor supports both DigiCipher and PowerKey conditional access systems, with support for the following encryption algorithms:

- DES
- CSA
- 128-bit AES

7.3 QAM Replication

In order to simplify integration of the CMAP into existing systems, the CMAP is expected to implement a QAM replication feature. The purpose of this feature is to allow an operator to create service groups on a decoupled, service-by-service basis. This will provide the ability to replicate narrowcast video (SDV and VOD) QAMs across multiple ports on a given line card (not necessarily across all of the line cards in the chassis).

To effectively deal with service group inequalities, the CMAP will share a given set of SDV or VOD QAMs to other ports on the line card to form service groups with unique sets of HSD QAMs.

This is illustrated in the Figure 7–2; note that each DLC port has a unique HSD group of QAMs (not depicted).

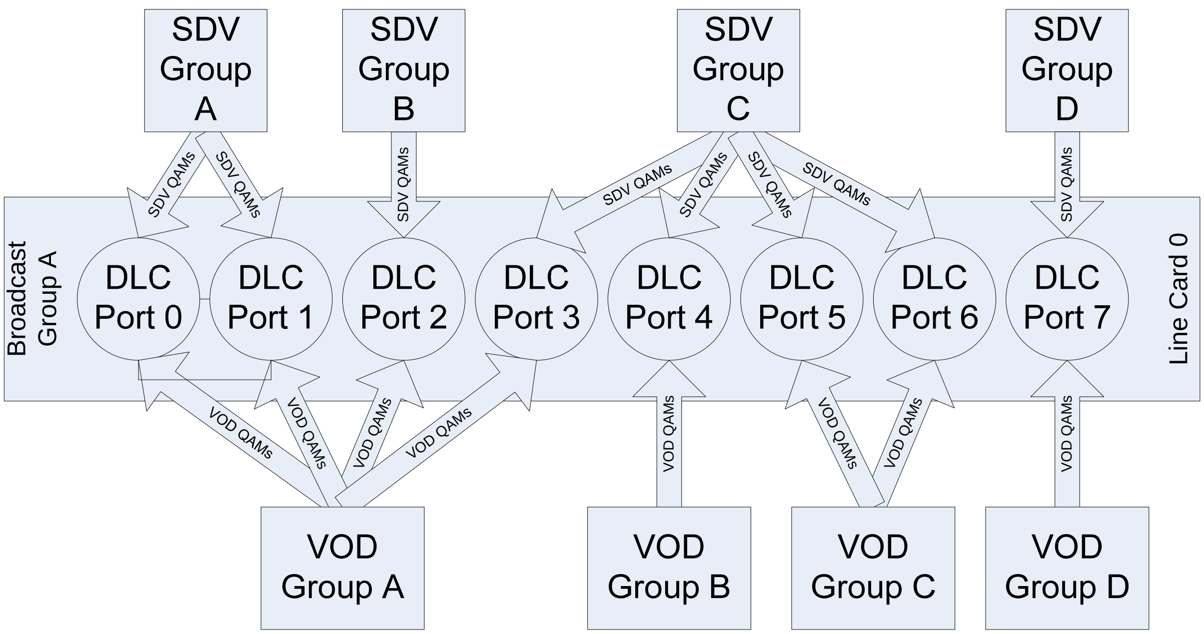

Figure 7–2 - QAM Replication

Note that the SDV and VOD QAMs are not necessarily coupled, but can be combined in various SDV/VOD pairs. In this illustration, each service group has a unique set of HSD QAMs.

The CMAP will be capable of replicating the contents of all narrowcast QAMs configured for native MPEG transport stream video services (e.g., VOD or SDV), and those configured for DOCSIS services, to a minimum of 3 other QAMs operating at the same frequency on other ports on the same DLC. The replication can be done to any ports on the same DLC and to any ports on different DLCs.

7.4 Spectrum Surveillance

Due to the nature of the CMAP system and its targeted services, the CMAP is placed at a critical location within the MSO's network. As the primary bridge between the back-office network and the HFC plant, the CMAP is responsible for transmitting and receiving all of the signals on the HFC plant for MPEG-TS SDV, MPEG-TS VOD, MPEG-TS Broadcast, DOCSIS High-Speed Data, DOCSIS VoIP, and ADC Services. Many of these services require a fully-operational DOCSIS connection in the HFC return path for both data transport and for signaling/messaging transport.

To ensure the quality of the upstream, the CMAP is expected to be capable of monitoring the upstream return path to help identify:

- any return path RF issues that might negatively impact the performance of DOCSIS upstream channels, or
- proprietary signaling/messaging signals propagating in the upstream direction.

This upstream surveillance monitoring will provide the MSO with up-to-date information on the RF quality of all of the upstream channels being used, and all of the upstream spectrum that is currently unused (in case the MSO decides to utilize that spectrum for new upstream channels in the future). This upstream surveillance data will provide spectral information in the form of Fast Fourier Transform (FFT) outputs that could be used to quantify the magnitude of the Additive White Gaussian Noise (AWGN) on the upstream HFC plant, as well as the magnitude of ingress noise and impulse (burst) noise that might be present on the upstream HFC plant.

The CMAP will permit the MSO to monitor the upstream spectrum without interrupting the transmission of DOCSIS data that is being simultaneously transmitted in the upstream direction. In addition, the CMAP will permit the MSO to periodically schedule "quiet times" in the DOCSIS upstream channels to permit the RF noise to be successfully measured within the spectrum of each DOCSIS upstream channel. To ensure ease of use, the MSO will be allowed to enable or disable this CMAP Spectrum Surveillance feature using simple configuration commands.

7.5 Configuration Management Features

The CMAP combines the functionality of an Edge QAM with a CMTS into a single platform designed to reduce operational costs and provide network flexibility. In order to provide operators the simplest path to deployment of CMAP with existing OSS systems, the goal for configuration and management of the CMAP is to treat the configuration of these very distinct platforms in a consolidated fashion.

This section will provide an overview of the various aspects of configuring a CMAP chassis including background on the choice of object modeling language chosen and a discussion of the various object models and their constructs.

7.5.1 CMAP Configuration Management

7.5.1.1 YANG Data Modeling Language and XML Background

The configuration of a CMAP chassis can be accomplished using a variety of methods such as via a command-line interface or through file-based processing. Underlying these configuration methods is a common configuration object model which defines the parameters that are to be configured. For the purposes of the CMAP, the configuration object modeling language is UML and the configuration data modeling language used is YANG.

YANG is a data modeling language for the NETCONF network configuration protocol that has been developed within the IETF to allow for modeling of configuration data, network element state and network events (see [YANG]). For purposes of the integrated CMAP, only the configuration data modeling portion of YANG is utilized. In addition, while NETCONF is typically used for the execution of a YANG-based XML file, the use of NETCONF is not required for the integrated CMAP. The Modular CMAP Packet Shelf will use NETCONF protocol for configuring its subtended Access Shelves.

The CMAP YANG configuration data model is the basis for the creation of the XML file which will be used to configure the CMAP. The CMAP will parse the entire YANG-based XML configuration file and process the configuration objects which are present in the file. Internal processing of configuration objects specified in the CMAP configuration file is vendor-specific.

7.5.1.2 Configuration and Management Object Models

A CMAP Configuration and Management Object Model has been developed in UML to define the elements (objects) and their parameters (attributes) that will need to be represented in the YANG configuration data model and eventually, the XML configuration file. Each object can be defined to have the following attributes:

- Name
- Type (integer, string, etc.)
- Access (read, read-write, etc,)
- Constraints (restrictions on the value)
- Units (dBmV, Hz, etc.)
- Default Value

The object model also defines the associations between objects.

One example of a CMAP object is the Downstream RF Port. The Downstream RF Port has its own attributes such as number (1…N where N is the number of ports on a line card), Administrative State (the status of the port), RF Mute and Channel Power. The Downstream RF Port is also defined to be associated with a particular Downstream Line Card object and a set of Downstream Channel objects; these associations define the location of the Downstream RF Port in the chassis and the particulars of the QAM channels that will be carried on the Downstream RF Port.

7.5.1.3 Configuration Data Model

The CMAP YANG configuration data model is constructed in a tree format using modules and sub-modules. The CMAP YANG configuration data model can be used by a YANG validation tool to generate the XML schema used for the configuration file or the CMAP can validate the configuration file directly against the YANG configuration data model.

The CMAP YANG configuration object model defines a single top-level module called cmap.yang which represents the master file for all CMAP objects. The cmap.yang module is composed of five underlying sub-modules. These sub-modules are described briefly below.

- **cmap-hardware.yang:** This sub-module represents the physical hardware that comprises the CMAP. Contained within this sub-module are the configuration details regarding the chassis type (I-CMAP, Packet Shelf, Access Shelf), chassis location and the physical line card, physical port, and logical channel configuration information.
- **cmap-video-session.yang:** This sub-module defines information related to the “EQAM” portion of the CMAP. This includes information such as video session configuration (ERM location, etc.), encryption configuration (CA algorithm, ECMG location, etc.), video diagnostic interface configuration, and MPTS pass-through.
- **cmap-docsis.yang:** This sub module defines the “CMTS” parameters of the CMAP. These include MAC domain configuration, QOS configuration, BPI configuration, load balancing, subscriber management configuration, and multicast configuration.

- **cmap-network.yang:** This sub-module contains information regarding configuration of network components of the CMAP. These include time-server configuration, Syslog server configuration, IPDR configuration, AAA configuration, DNS configuration, RIPv2 configuration, and network interface configuration.
- **cmap-global-types.yang:** This sub-module is different than the other sub-modules defined by the cmap.yang module. This sub-module does not actually contain configuration information for specific elements; it represents the definition of reusable objects for the CMAP, such as Modulation Annex, and the "path" (referred to as a "leafref" in YANG terms) to reference those objects via their associations.

7.5.1.4 CMAP Configuration File Processing

The CMAP is configured via the execution of an XML configuration file that is transferred to the file system on the I-CMAP (or on the Packet Shelf in the M-CMAP). The CMAP parses the entire XML configuration file and processes the configuration objects represented in the file as a sequence of individual element operations. Individual element operations can succeed or fail; the CMAP will log unsuccessful operations.

Before a configuration file is applied to the CMAP, the CMAP performs several checks against the file, such as verifying that the configuration file is well-formed XML and that it validates against its schema. If the configuration file does not pass these checks, the CMAP will reject the file. The CMAP can also reject individual objects within the configuration file. In all rejection cases, the CMAP will log the rejection as an error.

An XML configuration file can contain any explicit "merge", "replace", or "delete" operation values at various nodes within the configuration tree included within the file. In this manner, a valid file may contain merge operations for one branch of the tree, replace operations for another portion, and delete operations for yet another branch. The CMAP supports partial configuration, allowing the CMAP to not process objects that it either does not understand or that have invalid parameters, while continuing to process the objects that have no issues.

7.5.2 PON Configuration: DOCSIS Provisioning of EPON

Cable operators have recognized the value of including alternative access technologies into their network topology. This has included exploration and deployment of various wireless and passive optical solutions. The common characteristic for all of these alternative access technologies is that they have uncommon OSS models. Specifically, they do not look nor feel like a DOCSIS-oriented system to the operator that is responsible for deploying and managing services provided by this new technology. As such, there is value in mediating the interaction between these new access technologies and existing back-office tools, processes, and operator expectations.

The DOCSIS Provisioning of EPON (DPoE) specification provides a service overlay of the DOCSIS and CMTS management framework on an IEEE 802.3ah/av EPON network. DPoE systems rely on the EPON MAC and PHY and the upper-layer DOCSIS protocols defined by CableLabs. The DOCSIS MAC and PHY do not apply.

7.5.2.1 The DOCSIS and DPoE Networks

The following diagram summarizes the primary systems and elements involved in a typical HFC-based DOCSIS network. For brevity, only a sample of the back-office systems used to provision, manage, authorize, and control the network are included.

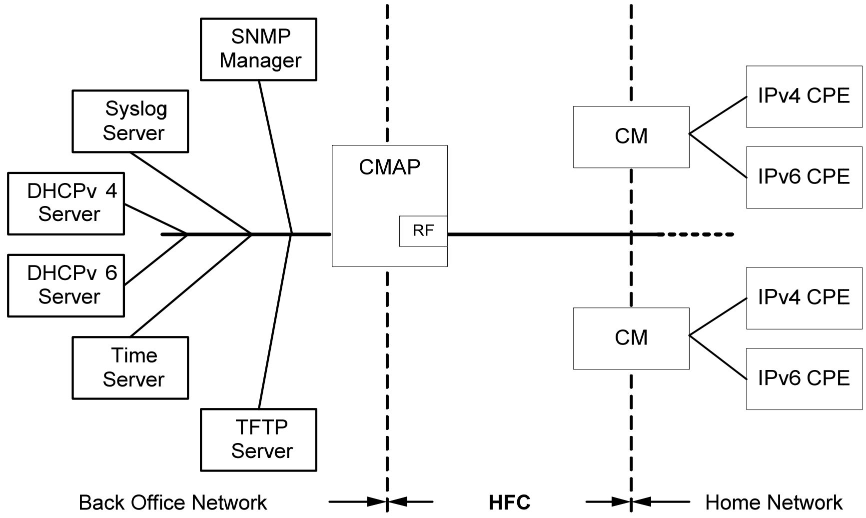

Figure 7–3 - DOCSIS 3.0 HFC Network Using CMAP

The DPoE specification defines a system that is analogous to a CMTS. The DPoE System need not be a single device, but instead could be a collection of devices that includes an OLT, router, and DOCSIS emulation system. Collectively, these separate devices would be referred to as the DPoE System. The DPoE System provides the logical interfaces and protocol translations necessary to integrate EPON devices into the DOCSIS OSSI framework. This permits operators to take advantage of standard EPON functionality while retaining their investment in back office operations and systems, leaving CPE unchanged.

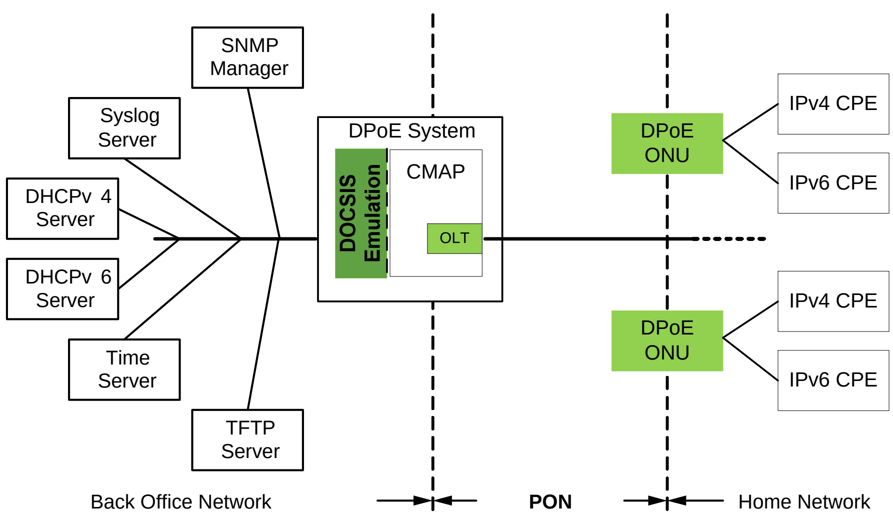

Figure 7–4 - DPoE Network using CMAP

7.5.2.2 DPoE Provisioning and Management

Interfaces and systems for managing DPoE devices may be provided through a DOCSIS Emulation module either running on the CMAP itself or running on an external server. Requirements for these interfaces are specified by the DPoE OSSI specification to provide Provisioning and Management support for the network. As shown in Figure 7–

5, requirements for the CMTS and CM MIBs are provided via the DPoE system by proxying for the OLT components on the CMAP line cards and the remote ONU devices.

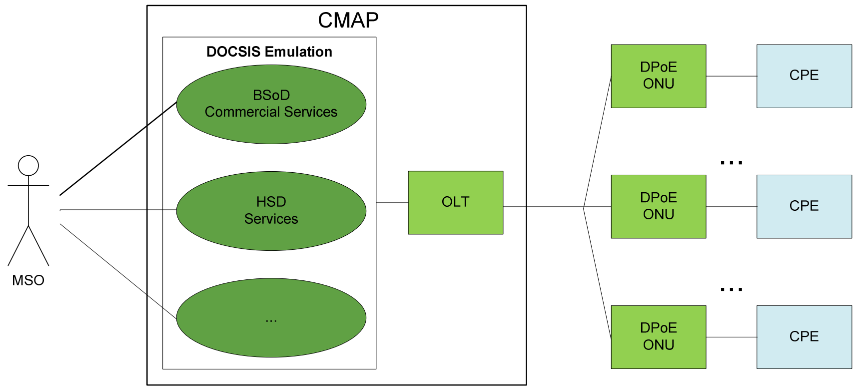

Figure 7–5 - Operator Interfaces to EPON Access Network

7.5.2.3 Provisioning and Management of OLT Devices

As CMAP is providing the functionality of the DPoE System, the OLT and associated PON interfaces are managed in a similar fashion to DOCSIS RF interfaces. Logical DOCSIS constructs, such as MAC domains, are implemented on top of the physical EPON interfaces. Relevant CMTS MIBs and DOCSIS CLI operations are mapped to their EPON equivalents to maintain the look-and-feel and, more importantly, the functionality expected of a DOCSIS RF interface.

7.5.2.4 CM Provisioning and Management of ONU

With the exception of the EPON-specific MAC and PHY, the initialization and subsequent management of the DPoE ONU is the same as a DOCSIS CM. The following diagram in Figure 7–6 highlights the relevant aspects of ONU initialization as a DOCSIS CM.

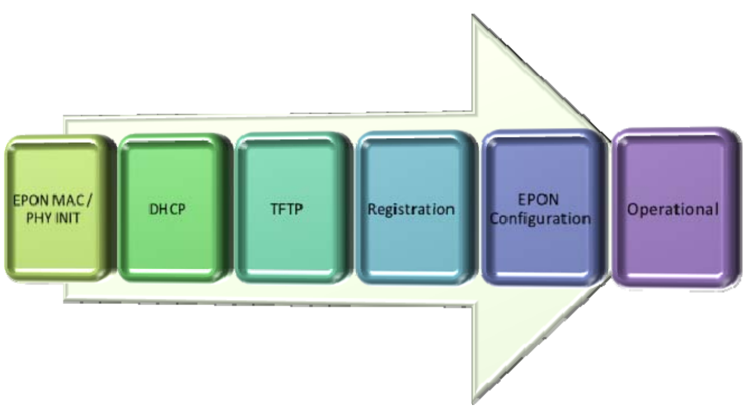

Figure 7–6 - DPoE ONU Initialization as a DOCSIS CM

These steps can be summarized by the following sequence:

1. DPoE ONU Initialization
    a. The DPoE ONU powers on and performs self-diagnostics.
    b. The DPoE ONU executes the normal EPON PHY and MAC layer initialization sequence to attach to the EPON network.
    c. The discovery of the DPoE ONU by the OLT on the CMAP is communicated to the DOCSIS Emulation module.
    d. The physical ONU is now represented as a "virtual" CM (vCM) in the DOCSIS Emulation module and appears as a CM in all applicable CMTS DOCSIS MIBs and CLI commands.
2. CM IP Application Initialization
    a. The vCM uses DHCP to obtain an IP Address for the virtual CM on behalf of the ONU.
    b. The vCM then performs a TFTP file transfer to obtain the DOCSIS provisioning file corresponding to the ONU's MAC Address.
3. CM Registration and EPON Configuration
    a. The vCM parses, verifies, and authorizes the services as provisioned in the CM configuration file.
    b. The configurations of the OLT and ONU are modified to reflect the provisioned DOCSIS services.
4. "CM" Is Operational
    a. The DPoE ONU is now operational and manageable via SNMP as a DOCSIS CM via the unique IP address provided by the DHCP Server.

7.6 Protocol Support

This section provides an overview of protocol support by the CMAP with respect to IP version, virtual private networks, routing, and multicast.

7.6.1 IP Versions

The CMAP supports IPv4 and IPv6 for both unicast and multicast traffic. The CMAP has the ability to forward traffic to both IPv4 and IPv6 devices.

7.6.2 VPN

The CMAP is expected to support the following VPN-related RFCs:

- VPLS using BGP for auto-discovery and signaling, as specified in [RFC 4761]
- BGP/MPLS IP VPNs, as specified in [RFC 4364]
- The framework for L2VPNs, as specified in [RFC 4664]
- LDP, as specified in [RFC 5036]
- Extensions to RSVP for LSP tunnels, as specified in [RFC 3209]
- Exclude routes extension to RSVP, as specified in [RFC 4874]
- Node behavior upon originating and receiving RSVP path error messages, as specified in [RFC 5711]

7.6.2.1 MPLS

Major applications of MPLS are telecommunications traffic engineering and MPLS VPN. In the context of MPLS VPNs, the CMAP is expected to support the following MPLS RFCs:

- Encoding of attributes for MPLS LSP Establishment, as specified in [RFC 5420]
- Encapsulation MPLS in IP or GRE, as specified in [RFC 4023]
- Encapsulation methods for transport of Ethernet over MPLS networks, as specified in [RFC 4448]
- Encoding of attributes for MPLS LSP establishment, as specified in [RFC 4420]

7.6.2.2 Multicast VPN (MVPN)

MVPN is a technology to deploy multicast service in an existing VPN or as part of a transport infrastructure. Multicast data is transmitted between private networks over a VPN infrastructure by encapsulating the original multicast packets.

The CMAP is expected to support the following MVPN-related functionality:

- Intra-AS Multicast VPN (MVPN) membership discovery via BGP MCAST-VPN address family
- BGP C-multicast route exchange when the provider-edge – customer-edge (PE-CE) protocol is PIM-SM (SSM), PIM-SM (ASM), PIM-DM or IGMP
- IP/GRE based inclusive Provider tunnels (P-tunnels) signaled by PIM-SM (ASM)
- IP/GRE-based inclusive P-tunnels signaled by PIM-SM (SSM)
- MPLS inclusive P-tunnels signaled by RSVP-TE P2MP LSPs
- MPLS selective P-tunnels signaled by RSVP-TE P2MP LSPs

7.6.3 Routing

The CMAP is expected to support the following routing protocols:

- RIPv2 on the access side as specified in [RFC 2453]
- IS-IS, as specified in [RFC 5303]
- OSPFv2 as specified in [RFC 2328] and [RFC 5709].
- BGPv4, as specified in [RFC 4724].

7.6.4 Multicast

The CMAP is expected to support Protocol Independent Multicast-Sparse Mode (PIM-SM) with SSM extensions, as specified in [RFC 4601]. In addition, the CMAP has the ability to join multiple IP multicast groups with PIM-SM.

On the access interfaces (DOCSIS, PON, etc.), the CMAP supports Internet Group Management Protocol version 3 (IGMPv3) with SSM extensions [RFC 3376] and also IGMPv2. When the CMAP receives an IGMPv3 join request on an access interface for a specific multicast source and group, the CMAP uses the PIM-SM protocol to join that multicast flow, if needed. The CMAP can allow support of IGMPv2 and IGMPv3 joins from the same access interface.

The CMAP is expected to support joining at least 4096 multicast groups.

7.6.5 Modular CMAP: Packet to Access Shelf Interface (PASI) Protocols

In a Modular CMAP, the Packet Shelf and the Access Shelf interact through the Packet to Access Shelf Interface (PASI). PASI has three different planes, as shown in Figure 7–7:

- Management plane conveying management information between the shelves
- Control plane signaling for information between the shelves
- Data plane encapsulation method to transport packets between shelves

Each plane has a specific purpose and uses a particular protocol(s). Protocols were chosen to re-use industry standard protocols and to avoid creating any new protocols that would be PASI-specific and would need to be standardized.

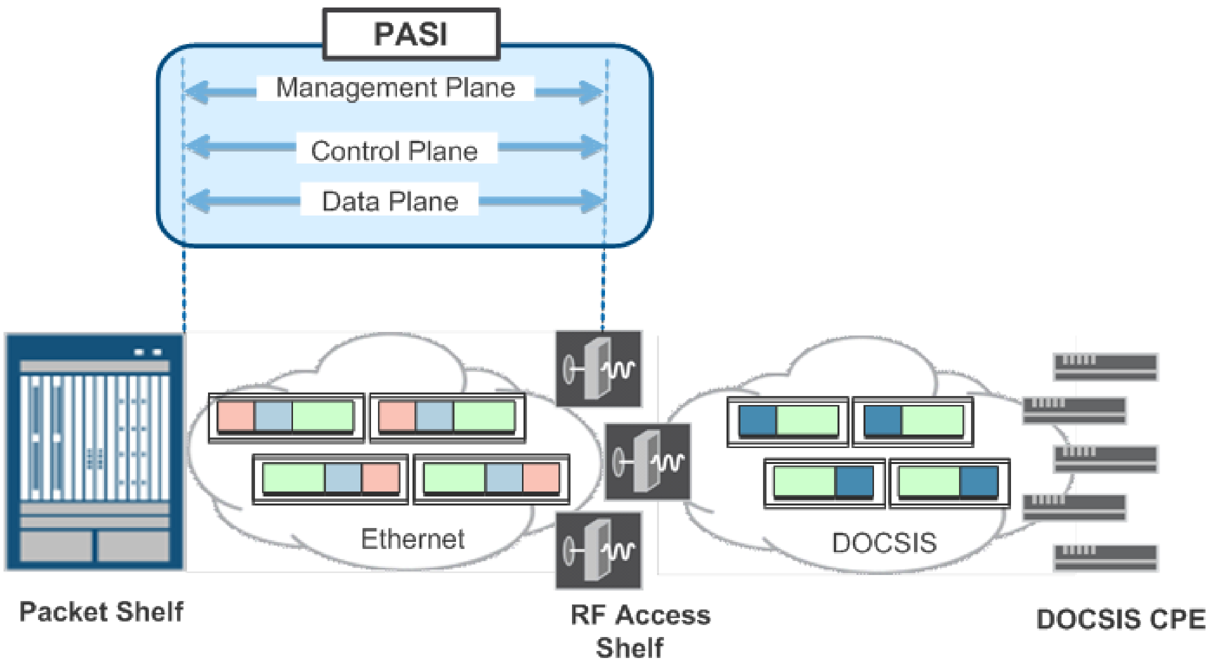

Figure 7–7 - PASI Planes

These planes and their protocols are discussed in the following sections.

7.6.5.1 PASI Management Plane

The PASI Management plane uses the SNMP protocol for management requests. When SNMP queries are sent to Packet Shelf for particular attributes that are found on its subtended Access Shelves, the Packet Shelf will use an SNMP proxy function to forward the query to the appropriate Access Shelves. Each Access Shelf will send the results of these queries back to the Packet Shelf; the Packet Shelf is responsible for aggregating the results of the queries on behalf of all of its subtended Access Shelves. The Packet Shelf will then respond to the SNMP request from the operational support system with all of this information.

In the case of configuration requests, the Packet Shelf will take configuration requests that are specific to an Access Shelf and proxy them to the Access Shelf via the NETCONF protocol. The Access Shelf will respond to Packet Shelf via NETCONF, and then the Packet Shelf will respond back to the requesting operational support system.

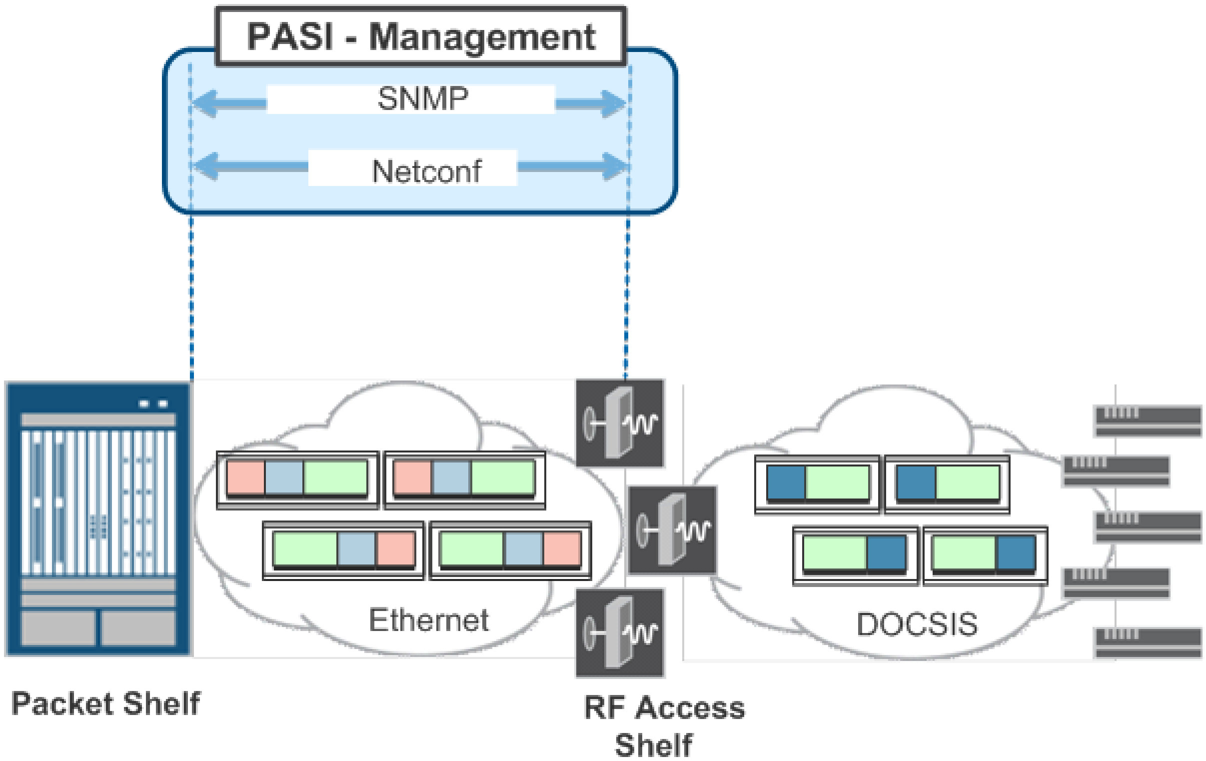

Figure 7–8 - PASI Management Plane

7.6.5.2 PASI Control Plane

The PASI Control Plane uses the ANCP protocol. This protocol is a real time protocol used to communicate information between the PS and the AS. For example, when a modem ranges, the PS needs to be notified of this event. The AS will notify the PS via ANCP by encoding its information in Type Length Value attributes (TLVs). The AS will also communicate changes in RF plant performance and bonding configuration via ANCP in order to adjust the scheduling and QOS capabilities on the PS.

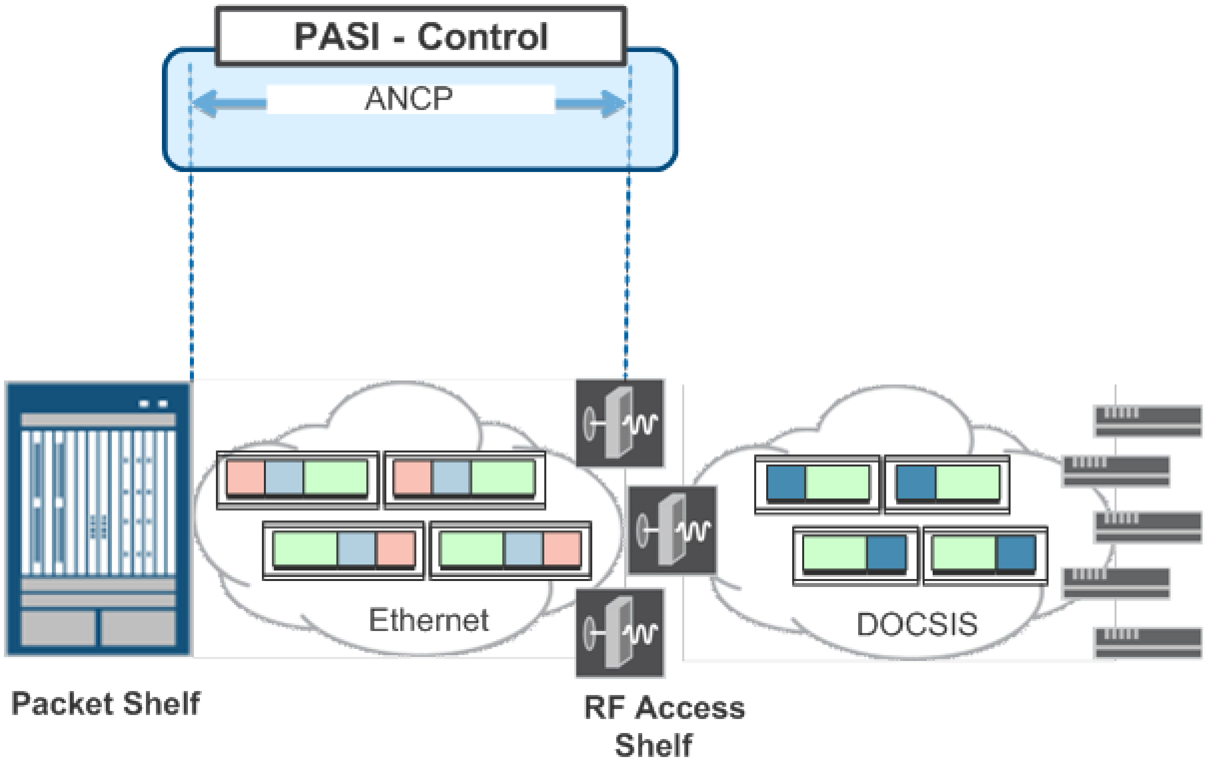

Figure 7–9 - PASI Control Plane

7.6.5.3 PASI Data Plane

The PASI Data Plane protocols used for fast-path communication between PS and AS can be broken down into two separate types.

First is for packet steering to allow packets to be directed from the PS to the AS and back. The M-CMAP will use a basic Ethernet Frame with an IEEE 802.1Q VLAN tag. This is used when the PS and AS are not directly connected and there are intermediate network nodes that need to forward the packet to the appropriate AS or PS. This selection was made to take advantage of Metro Ethernet deployments and the ubiquity of Ethernet in networks today.

The second aspect of the PASI Data Plane is encoding of Service Flow ID into a packet that will reuse the MPLS standard. The M-CMAP will not modify how the EXP, S bit, or TTL fields of the MPLS packet are used for PASI; these fields will continue to be used in a standard way. With PASI, the PS will add a two-label MPLS header to the packets along with Ethernet header with VLAN and the AS will remove both (the two MPLS labels and Ethernet header with VLAN) before forwarding it into the HFC/DOCSIS network. The AS, when transmitting upstream traffic toward the PS, adds the two MPLS labels and Ethernet header with VLAN. The PS will remove these before transmitting it upstream toward IP/MPLS aggregation network.

This particular solution was selected as to leverage existing forwarding capability on Edge routers and enable Access Shelves to take advantage of available industry silicon.

8 CMAP IMPLEMENTATIONS

8.1 CMAP Interface Options

8.1.1 Hybrid-Fiber Coax Interfaces

The CMAP is expected to implement upstream and downstream RF interfaces on separate downstream and upstream physical interface cards (PICs). This separation of PICs allows upstream and downstream capacity to be changed independently. The CMAP could be implemented with a combined PIC, a card that has both upstream and downstream interfaces, but this is not expected to be a typical configuration.

8.1.1.1 Downstream RF Interfaces

The CMAP is expected to support a downstream RF interface ratio of one downstream RF port per downstream service group. A standard integrated CMAP is expected to support a minimum of 40 – 60 downstream service groups (with 60 being the preferred minimum), and downstream physical interface cards (DPICs) are expected to support a minimum of 8 downstream RF ports.

Each downstream RF port supports the following edge-to-edge frequency ranges for North American devices:

- 54 – 1002 MHz
- 108 – 1002 MHz

The North American channel width is specified as 6 MHz.

For European devices, each downstream RF port supports an edge-to-edge frequency range of 86 – 1006 MHz, with a channel width of 8 MHz.

In addition, a single downstream RF port is expected to be capable of supporting up to 158 QAMs of any type. Each port will typically support 32 – 64 narrowcast QAMs and up to 96 broadcast QAMs.

The preferred implementation of a downstream RF interface is in the form of an F-connector, but ganged 75 Ohm MCX interfaces in a universal cable holder (UCH) could also be implemented. All RF interfaces are expected to be located at the rear of the chassis.

8.1.1.2 Upstream RF Interfaces

The CMAP is expected to support an upstream RF interface ratio of one upstream RF port per upstream service group. The CMAP is expected to support at least 80 – 120 upstream service groups (with 120 being the preferred minimum), and upstream physical interface cards (UPICs) are expected to support at least 16 upstream RF ports.

Each upstream RF port supports the following edge-to-edge frequency ranges for North American devices:

- 5 – 54 MHz
- 5 – 85 MHz

For European devices, each upstream RF port supports an edge-to-edge frequency range of 5 – 65 MHz, as specified in Annex B of [PHY].

Both European and North American devices support channel widths of 1.6, 3.2, and 6.4 MHz. They are also expected to support between 4 – 6 DOCSIS RF upstream channels per RF port.

The preferred implementation of an upstream RF interface is in the form of ganged 75 Ohm MCX interfaces in a UCH, but an F-connector can also be implemented. All RF interfaces are expected to be located at the rear of the chassis.

8.1.2 Passive Optical Network (PON) Interfaces

Fiber access represents one method of offering higher bandwidth to subscribers. Increasing bandwidth may be required to meet the increasing data demands of business customers. PON minimizes investment in the access infrastructure while delivering more bandwidth and greater service flexibility. It is the least costly method of constructing fiber to the subscriber and it has the service control and flexibility to offer any business or consumer service.

8.1.2.1 Split Ratios and Customers Served

The PON split ratio for CMAP is expected to be 128:1. Each I-CMAP chassis is expected to support at least 16 active PON interfaces, and 24 or more is preferable. Two RF service groups should be served by each PON interface. This suggests a density of approximately 128 business customers per 1000 residential customers.

In PON networks distance and subscriber density are inversely correlated. For example, the CMAP is expected to support 128 business customers on a PON at a distance up to 5km, up to 64 customers at 10km, up to 32 customers at 20km, 16 customers at 30km, 8 customers at 40km, and up to 4 customers at a distance of 50km.

8.1.2.2 PON Redundancy

The CMAP chassis is expected to support N+1 PON redundancy. Other redundant configurations are possible as well. High availability and reliability are critical to enterprise business services and will be an important option when diversely routed fiber is available to the subscriber.

8.1.2.3 PON Connectors

PON line cards should support SFP-type connectors. This form factor allows for maximum flexibility for wavelength and port selection. A maximum 8 degree angle cut is for SC/APC polish is preferred. SC/PV is also an option.

8.1.3 Network Side Interface

The CMAP receives Internet content, IP video, PacketCable voice data, and DSG data through the Network Side Interface (NSI), which would consist of at least 160 Gbps of data on one or more physical interfaces in order to support a fully loaded chassis. The I-CMAP will be expected to implement multiple, redundant NSIs on the Switch Routing line card; the Packet Shelf will be expected to implement them on the Management line card. These interfaces should be deployed with standards-based pluggable optics. While initially deploying 10 GbE interfaces, CMAP deployments are expected to migrate to 100 GbE interfaces as the technology matures. 10 GbE interfaces should comply with [IEEE 802.3ae] and 100 GbE interfaces should comply with [IEEE 802.3ba]. Each NSI port should support untagged IEEE 802.3 Ethernet encapsulation. Individual Network-to-Network Interfaces (NNIs) may be provided for HSD business services using a 10GEPON interface.

8.2 Platform Implementation Options

As with the existing CMTS architectures, a CMAP device can be implemented in an integrated or modular manner. For the integrated CMAP (I-CMAP), all functions are implemented in a single chassis. In the second, CMAP functions are divided between a Packet Shelf (PS) and an Access Shelf (AS), as follows:

- The PS implements packet-processing functions, such as subscriber management, service flow management, layer-3 routing and higher layer protocol manipulation, and other such functions.

- The AS implements all the upstream and downstream PHY functions normally associated with the CMTS and the Edge QAM, video program stream edge manipulation (e.g., multi-program transport stream creation, PCR restamping, etc.), and as much of the DOCSIS MAC as needed to support both upstream and downstream flows. A documented interface between the PS and the AS (Packet to Access Shelf Interface or PASI) is defined to enable interoperability between AS and PS vendors. EPON versions of the Access Shelf are also supported.

These implementations are described in the following sections.

8.2.1.1 I-CMAP Deployment Alternatives

The integrated CMAP chassis may be deployed in a full-sized chassis, designed to support a minimum of 40 downstream service groups. A typical full-size I-CMAP will support 60 or more downstream service groups. The I-CMAP could also be implemented in a smaller chassis, supporting at least 16 service groups.

8.2.2 Modular CMAP Chassis

The Modular implementation of the CMAP is provided by two devices: a Packet Shelf (PS) and an Access Shelf (AS). The PS and AS are used together to provide the same functionality that is found in the I-CMAP implementation. The Modular implementation also provides additional location flexibility of the shelves and the integration of traditional edge routing functionality.

The Packet Shelf is designed to support a minimum of eight Access Shelves and 160 downstream service groups (preferred implementations will support 12 Access Shelves and 240 downstream service groups).

The Access Shelf is designed to support as few as 20 downstream service groups, allowing support for smaller headends and hub sites.

8.2.2.1 Modular CMAP Deployment Alternatives

The Modular CMAP solution can be deployed in any location that an Integrated CMAP makes sense. But there are some additional deployment options that Modular architecture allows. For example, the modular solution allows for AS and PS to be positioned in the network in different parts of network.

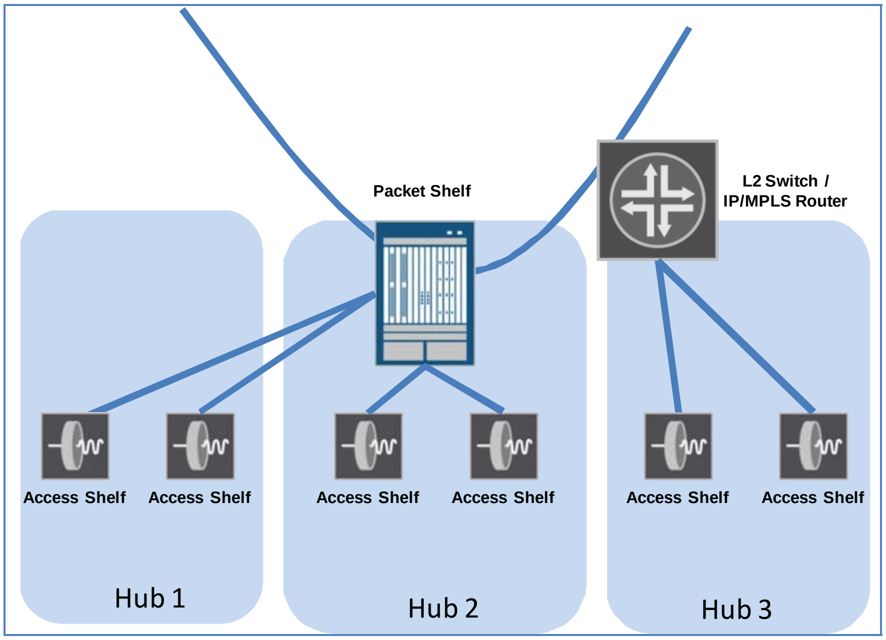

Figure 8–1 - Access Shelf Deployments

As shown in Figure 8–1, the Access Shelves in Hub 1 are remote to the PS at Hub 2. They are interconnected via Point to Point fiber. In the Hub 2 case, the PS and AS are co-located. With Hub 3, the PS and AS are not in same location; they are connected across a Metro Ethernet aggregation network or IP/MPLS network. As illustrated, a modular architecture has a high degree of deployment flexibility.

Appendix I Acknowledgements

We wish to thank the members of the Comcast CMAP Specification Team for their efforts toward creating this report, with special acknowledgement going to the following contributors:

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