Follow the Yellow Brick Road: From Integrated CCAP or CCAP + Remote PHY to FMA with Remote MACPHY

A Technical Paper prepared for SCTE by

Colin Howlett
Chief Technology Officer
Vecima
771 Vanalman Ave, Victoria, BC, Canada V8Z3B8
+1 (250) 881-6235
colin.howlett@vecima.com

Jeff Finkelstein, Cox Communications
jeff.finkelstein@cox.com

Rex Coldren, Vecima
rex.coldren@vecima.com

Douglas Johnson, Vecima
douglas.johnson@vecima.com

Table of Contents

Title **Page Number**

List of Figures

Title	Page Number

List of Tables

Title	Page Number

1. Introduction

From the early days of cable data services back in the early to mid-1980s until today there has been a continued improvement in supported capabilities by pushing the limits of Hybrid Fiber Coax (HFC) technologies, both in terms of modulation orders and frequencies utilized. Each step has had its fair share of corporate antigens introduced to elicit the desired outcome, and fortunately for the industry an adequate supply of antibodies has generally resulted. Monolithic architectures served their purpose for DOCSIS® head-end equipment by getting equipment deployed and reducing risk associated with rolling out these new technologies.

A monolithic architecture has limitations, primarily in terms of rack space, powering, and environmental requirements. The first part of overcoming these limitations was decomposing the Cable Modem Termination System (CMTS) by adding the use of Edge QAMs as the PHY layer for all downstream spectrum, which also allowed a single device to provide video, voice, and data services. The second piece of the puzzle was moving toward a distributed access architecture (DAA) to push these capabilities closer to the customer and remove analog optics from the deployment equation. The third strategy is moving both the MAC and PHY into the field to simplify the scheduling and timing requirements necessary for services of the future and to eventually the eliminate rack space, powering, and environmental problems of the legacy monolithic architecture.

By moving to a DAA based on a Remote PHY Device (RPD) or a Remote MACPHY Device (RMD) to provide services there are several important considerations. First, the head-end is greatly simplified as a significant portion of the combining network is no longer needed with many services being provided over Ethernet and with the transformation to radio frequency (RF) occurring in the field at the RPD and RMD. Second, the rack space, power, and cooling requirements in the head-end are reduced and potentially eliminated. Third, an all-digital network means that higher order modulations may be used as the Ethernet to RF transition is now within no more than a few thousand feet from the customer.

Transitioning to new technologies is challenging, but we must consider why we should do other than just extending the life of the monolithic architecture as a primary means of service delivery to customers.

- When cost of entry is low, cost to exit is high. The easy technologies to deploy are typically the hardest to move away from when needed.
- Moving to the next generation of a technology is cheaper than trying to keep the previous generation meeting the needs of customers. There comes a point where it is clearly no longer cost effective to keep an existing technology working. When you finally realize that you can be years behind in getting a new technology deployed.
- Changing technology is easy; changing people is hard. Never forget it is the field staff who keep things running and they need to be ready when new things are deployed.
- Everyone has a nice paint job. Most competing technologies look nice and shiny but are mostly similar for 80%-85% of necessary functions.

In this paper we address how we can progress towards a DAA and minimize the risk along the way. Major upgrades are never easy, but with careful planning and training they can be accomplished. One of the biggest challenges in the brave new world of DAA is how to manage new devices without forcing significant changes to OSS/BSS/EMS/NMS software that has been used for decades. To stand up to the challenge, we have been working for the past 8+ years on Remote PHY and the 3+ years on the Flexible MAC Architecture (FMA), which includes Remote MACPHY. Remote PHY and FMA provide standard interfaces both north and southbound of their respective Core network functions to manage DAA devices, removing OSS/BSS/EMS/NMS roadblocks and allowing the journey to DAA to begin.

2. Deployment Motivations for DAA and FMA

With DAA, we're not in Kansas anymore. Getting there may seem as scary as the idea of riding a tornado to land a house on top of a wicked witch. Where we came from was the legacy CMTS and an Edge QAM, a Converged Cable Access Platform (CCAP) and an Edge QAM, and a fully integrated CCAP. Familiar things that will always be a part of us. Where we are going is a land where DAA thrives and where CCAP with Remote PHY support live. And most certainly lots and lots of Munchkins.

In the DAA Land of Oz the Emerald City is where FMA and Remote MACPHY reside, and we must not only get to Oz but journey through it if we want to get to the Emerald City. But first, we need to consider why we might want to go there. Then we need to take a good look around at where we are now. We must consider what we expect to find at our destination and plan for what we need to take with us when we go there. Only then can we start our journey in earnest.

Literally speaking, an operator wanting to get to FMA and Remote MACPHY from where they are today has a lot to consider. What can be reused, what needs to change, and how? What service evolution factors influence how FMA is implemented with Remote MACPHY? How can the legacy approaches co-exist with FMA in a gradual roll-out?

But let's first start with the motivations…

2.1. Why DAA?

Why should we want to go to the DAA Land of Oz in the first place? Let's focus on five areas of interest as illustrated in Figure 1:

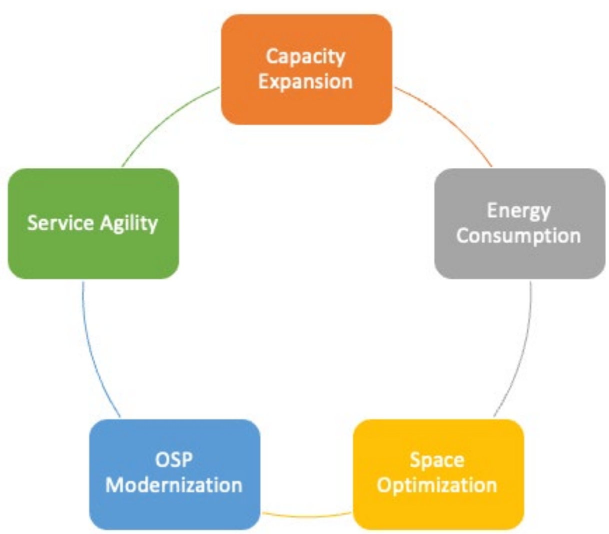

Figure 1 - Benefits of DAA

First, capacity expansion is a critical consideration. As shown in Figure 2, consumer speed tiers continue to scale on an exponential basis with consistent cumulative growth rates. Existing chassis-based CCAP devices that deliver the DOCSIS® and serve 50+ service groups cannot scale to the maximum throughputs needed while at the same time keeping all the RF circuitry within the platform. Hub space, power, and cooling requirements necessary to scale capacity of analog optical transmitters and receivers, the RF combining networks to serve them, and the traditional CCAP devices themselves are too bulky if we continue to shrink service groups to deal with increased capacity needs.

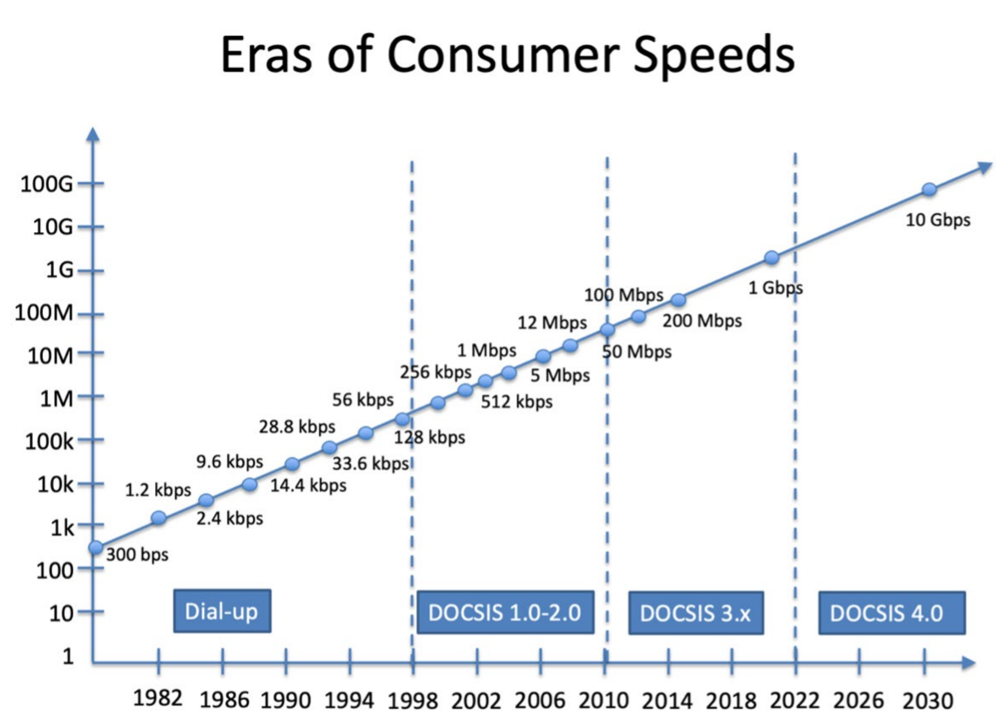

Figure 2 - Consumer Speeds over Time

To avoid regrettable spend on real estate rather than on network infrastructure to serve customer needs, we need to slow and eventually reverse hub space growth and associated increased power and cooling requirements. Remote PHY can help by removing the DOCSIS PHY and RF modulation/demodulation aspects from the CCAP and placing them in the outside plant (OSP). Remote MACPHY can go further by moving all DOCSIS functionality and RF modulation/demodulation to the OSP. Both alternatives can eliminate the need for a hub-based analog combining network and analog optical transmission equipment, replacing them with a Converged Interconnect Network (CIN) of compact Ethernet switches.

Modernizing the OSP by moving from analog optics to digital Ethernet optics increases optical reach, improves performance, and reduces the cost of fine-tuning in the OSP. Moving the RF modulation/ demodulation closer to the subscriber greatly improves RF performance. The combined effects of moving to digital optics and relocating the RF modulation/demodulation close to the subscriber also lead to a cleaner and easier to operate OSP. The movement to all-Ethernet in the OSP optics allows convergence of the network into a CIN with DOCSIS, passive optical networking (PON) for fiber-to-the-home, 4G and 5G wireless Xhaul, and business services all served from a common shared Layer 2/Layer 3 (L2/L3) network.

Finally, DAA is the only path to get to service levels beyond DOCSIS 3.1. DOCSIS 4.0 requires a DAA baseline, whether it be Remote PHY or FMA/Remote MACPHY. You can get to the DAA Land of Oz from Kansas, but you can't get to DOCSIS 4.0 from Kansas without first taking a trip through Oz.

2.2. Why FMA? Why Remote MACPHY?

Once we're in the Land of Oz, why would we want to go all the way to the Emerald City? The answer is, that's where FMA and Remote MACPHY are.

FMA has standardized the Remote MACPHY architecture, which has been deployed globally in pre-standard implementations. Standardization allows RMDs from multiple vendors to work in the same operator network by interoperating with a single management entity and provides the operator with protection from the risks of being locked into single-vendor solutions.

The Remote MACPHY architecture is a step forward architecturally from Remote PHY. Eliminating the split DOCSIS architecture removes the tight coupling and synchronization requirements from the Core network element and the OSP devices. The "Core network element" in Remote MACPHY is a software management function that only needs to support device and subscriber management, not DOCSIS MAC and upper layer functions such as the DOCSIS upstream and downstream schedulers. It also does not need to deal with the DOCSIS data plane at all as FMA disaggregates the data plane and management planes into separate elements. With this disaggregation and decoupling comes several benefits:

- Simpler Interoperability – Interoperability for Remote MACPHY will be simpler relative to split DOCSIS Remote PHY interoperability, which has been and continues to be cumbersome due to the tight coupling of MAC and PHY between CCAP Core and RPD.
- Latency – DOCSIS latency of request/grant cycles between Cable Modem (CM) and DOCSIS MAC function is contained within the RF network between RMD and subscriber in Remote MACPHY. This provides optimal support by eliminating the delay between CCAP Core and RPD given the Remote MACPHY scheduler is co-located with the MAC and PHY layers in the same device.
- Simplified CIN – Remote MACPHY's CIN is simplified. Traffic engineering for DOCSIS data traffic can easily be provided in a native Ethernet/IP network, whereas it cannot in Remote PHY since data traffic is encapsulated in L2 tunnels. There is also no need to design the CIN to hairpin data traffic through a purpose-built Core element in Remote MACPHY and the need for precise phase and frequency synchronization between MAC and PHY from RPD using IEEE 1588 Precision Time Protocol (PTP) is not necessary for DOCSIS support as the MAC and PHY are co-located. Since long-term cable networks will likely run video over IP (i.e., DOCSIS) the Remote MACPHY approach can minimize or eliminate the need for PTP.
- Reduced hub space, cooling, power – Remote MACPHY enables the minimum requirements in hub space, cooling, and power of any of the DOCSIS alternatives. The "Core network elements" are COTS servers for management and control functions rather than chassis-based systems that pass hundreds of Gigabits of data plane traffic. These COTS servers can be located anywhere in the network and do not need to be near the OSP devices.
- Optimized virtualization of management/data plane – Remote MACPHY and FMA were designed to maximize virtualization opportunities for operators by cleanly separating the management and control functions from the data plane functions. The simplified CIN of Remote MACPHY plays nicely in a virtualized architecture by maximizing native transport virtualization opportunities as well.

There are plenty of reasons to want to go to the DAA Land of Oz, and there certainly are incentives enough to take a stroll toward the Emerald City once we are there.

3. Current Deployment Architectures

Before we can begin our trip to the Emerald City, it is important to understand where we are starting from so that we can plan our journey and know what to take with us. We first must document what is included and how the system functions are realized in existing centralized access architectures for DOCSIS and QAM video.

3.1. Pre-DAA

In Kansas we have a centralized access network with lots of splitting and combining and analog optics. We have legacy CMTS and an Edge QAM, a CCAP and an Edge QAM, and a fully integrated CCAP. The state-of-the-art in Kansas is the fully integrated CCAP.

The fully integrated CCAP includes a routing engine, cable control plane and subscriber management functionality. It also brings together DOCSIS and QAM video functionality and has the analog RF ports which connect to a splitting and combining network and then to analog optical transmission gear. In practice only narrowcast video is provided through the integrated CCAP. In many cases, broadcast video is processed external to the CCAP and needs to be combined in the combining network separately. Also not included in the integrated CCAP is video out-of-band processing, which is provided by special hub and head-end gear that connects over RF into the splitting and combining network. Figure 3 illustrates the fully integrated CCAP.

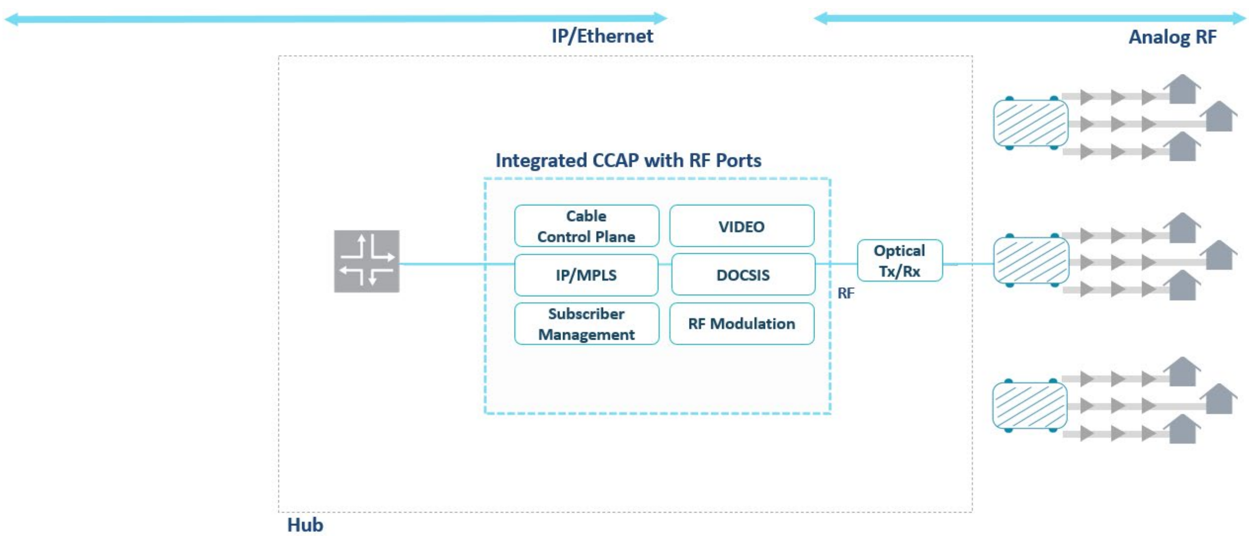

Figure 3 – Integrated CCAP

The RF access network in this environment starts in the hub. It includes the splitting and combining network and analog optical transmission gear. Analog fiber nodes are deployed in the OSP to perform RF optical/electrical conversion. The serious OSP operations maintenance activities begin back at the hub.

The difference between the integrated CCAP architecture and other RF-based hub equipment is typically in the video. A CMTS provides only DOCSIS functionality and is far less dense than a CCAP. A non-integrated CCAP is analogous to a dense CMTS. Narrowcast video is provided in both cases by a separate Edge QAM. Video out-of-band in all cases uses special gear which must be combined in the RF domain.

3.2. DAA with Remote PHY

In Oz we have a distributed access network, DAA, which provides us both Remote PHY and Remote MACPHY. Due to existence of legacy CCAP deployments a first DAA step for many operators was to convert their “big iron” chassis-based CCAPs to support Remote PHY.

In the chassis-based Remote PHY environment are most of the same things provided in the integrated CCAP. This includes a routing engine, cable control plane and subscriber management functionality. It also brings DOCSIS functionality but does not have analog RF ports, a splitting and combining network, or analog optical transmission gear. Those are replaced with Ethernet-based digital optics and a stack of Ethernet switches.

The RF line cards of the integrated CCAP are replaced with Ethernet-based Remote PHY line cards. These line cards perform upper layer DOCSIS and DOCSIS MAC functions. The DOCSIS PHY and RF modulation/demodulation are moved to the OSP in the RPD, typically in a fiber node form factor. This split DOCSIS is achieved via a complex set of Remote PHY requirement specifications provided by CableLabs®. Precision timing is required at both the Core network element and RPD to support DOCSIS.

Narrowcast video that was provided through the integrated CCAP cannot be supported as it was before. RF video of all types in DAA needs to be packetized and sent over the CIN. For this purpose, specialty elements called Video Cores and Traffic Engines are added to the architecture to provide packetized RF video which is then modulated at the RPD and delivered to the traditional video end devices. Legacy video out-of-band needs to be treated in a similar manner by what is dubbed an Out-of-band Core.

Figure 4 illustrates the integrated CCAP Remote PHY architecture.

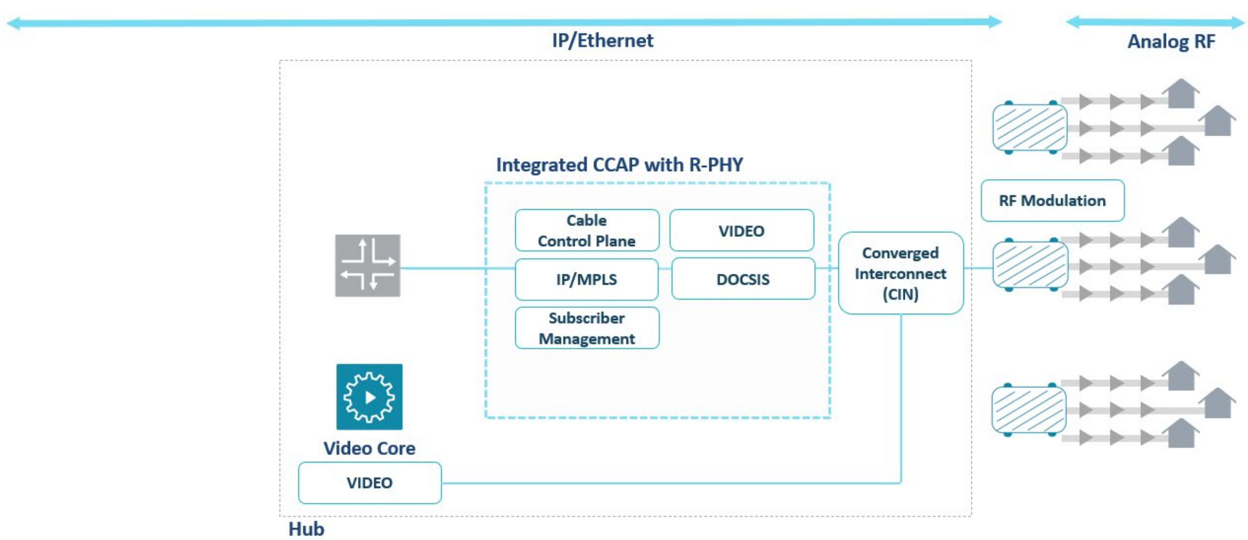

Figure 4 – Remote PHY Architecture

The RF access network in this environment starts in the Remote PHY node in the OSP. The serious OSP maintenance activities begin at the Remote PHY node, which is a significant DAA improvement versus the centralized access architecture.

4. Future Deployment Architecture – DAA with FMA

4.1. Overview

As much fun as the trip might be, getting to FMA does not literally require a tornado flight to the DAA Land of Oz nor a lengthy journey on foot to the Emerald City. Simply put, it is an evolutionary step that builds upon the successful foundation of DOCSIS, CMTS, integrated CCAP, and Remote PHY.

The key benefit of a DAA deployment is to converge the data plane packet interfaces across a range of access technologies on common and well-understood Ethernet/IP technologies. This allows operators to reap the benefits of DOCSIS and deep RF signal modulation/demodulation in their coax network, while also leveraging common high-volume packet-switching products on the fiber part of the access network.

FMA is a set of standards that further improves on DAA concepts by decoupling the management plane and data plane components of a traditional integrated CCAP, allowing each concern to be treated and deployed separately. The data plane can be optimized for throughput, latency, and uptime, while the management plane can be optimized for scale, agility, and velocity.

FMA defines three primary new components:

- MAC Manager (MM) – A management plane functional component that aggregates many MAC Network Elements into a single, unified controller. It provides backwards compatible OSSI interfaces to legacy Multiple System Operator (MSO) backoffice technologies.
- MAC Network Element (MAC-NE) – A physical device containing a DOCSIS MAC and DOCSIS PHY. It is expected, but not required, to be housed within an OSP Node enclosure. The MAC-NE embodied currently in FMA is the RMD. We refer to the FMA MAC-NE as an RMD throughout the paper.
- PacketCable Aggregator (PAG) – An aggregation functional component which bridges between existing PacketCable infrastructure and a population of deployed MAC-NE/RMDs.

FMA optionally reuses some Remote PHY components:

- Video Cores and Traffic Engines – FMA is compatible with the Remote PHY legacy video infrastructure.
- Out-of-Band – FMA is compatible with Remote PHY SCTE 55-1, 55-2, and Narrowband Digital Forward/Narrowband Digital Return (NDF/NDR) Remote Out-of-band (R-OOB) solutions.
- PTP – FMA is compatible with Remote PHY PTP profiles.

The FMA architecture is illustrated in Figure 5.

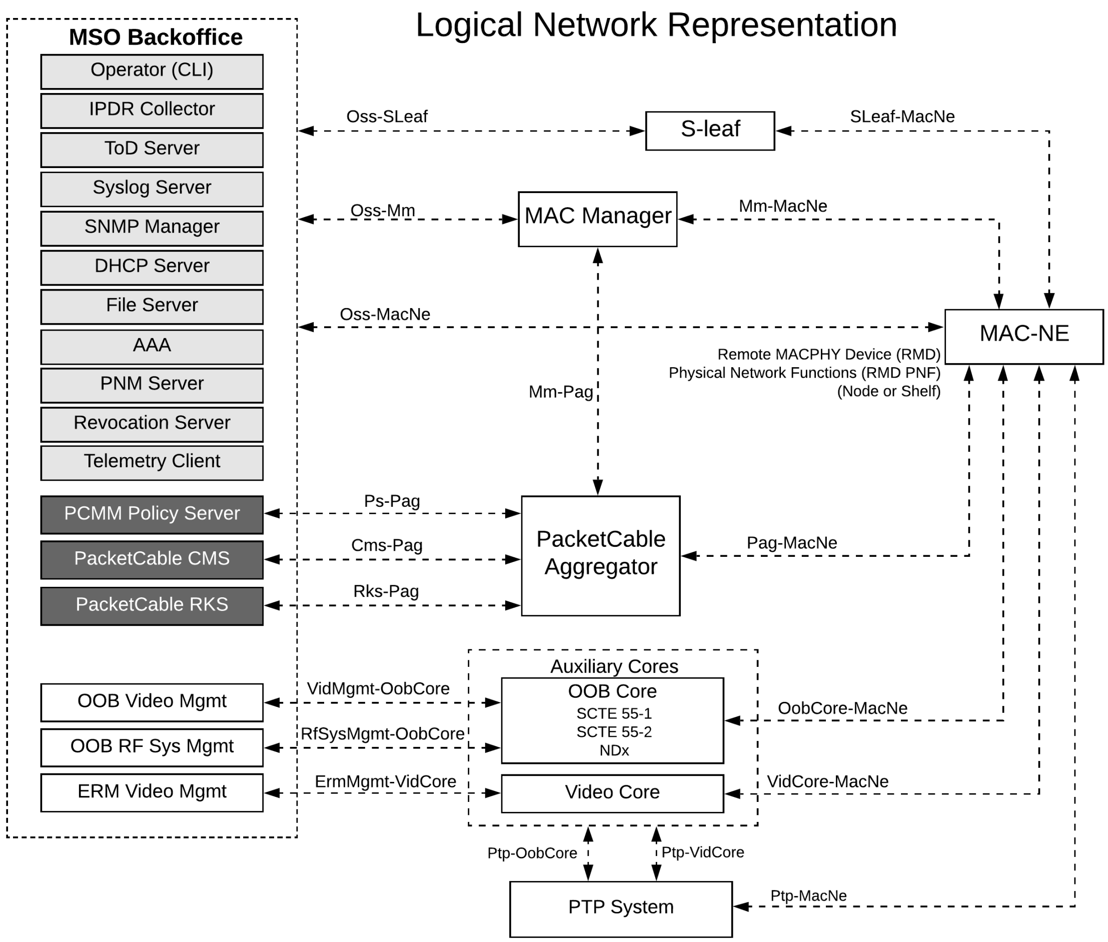

Figure 5 – CableLabs® Flexible MAC Architecture

In FMA, each interface is named by specifying both ends of the interface. A few key interfaces within the specification are:

- Oss-Mm – OSS to MAC Manager. A backwards compatible interface with existing MSO backoffice interfaces (e.g., SNMP), realized on the MAC Manager.
- Mm-MacNe – MAC Manager to MAC-NE. A new API, defined in YANG modules, between the MAC Manager and the MAC-NE to command, control, and monitor MAC-NEs. Mm-MacNe is commonly referred to as the MAC Management Interface (MMI).
- Pag-MacNe – PAG to MAC-NE. A new API, defined in Google Protocol Buffers, to command-and-control PacketCable functionality on the MAC-NE. Pag-MacNe is commonly referred to as the PacketCable Aggregator Interface (PAI).
- SLeaf-MacNe – CIN Secure Leaf to MAC-NE. A data plane interface between the first-hop aggregation points in the CIN and the MAC-NE.

Like Remote PHY, FMA places the full-spectrum RF generation and reception in a remote location, such as a node enclosure deployed in the OSP. This allows FMA to realize the same RF signal quality benefits as Remote PHY in improving Modulation Error Rate (MER) and allowing for higher modulation rates in channel plans. Unlike Remote PHY, which tunnels DOCSIS packets over IP to/from a packet-processing

CCAP/DOCSIS Core, FMA terminates DOCSIS in the remote device and provides raw customer bearer traffic directly in Ethernet/IP packets to the first-hop aggregation device. This removes the need for a CCAP/DOCSIS Core in the architecture and enables per-packet-processing and routing to occur in standard switch and router products. This allows operators to access the larger switching market and bundle switch and router cores into higher volume products. Further, because FMA provides standard Ethernet/IP packets at the SLeaf-MacNe interface, FMA is converging with other access technologies on common and proven packet interfaces.

4.2. Management Considerations

In FMA, the MAC Manager acts as the management plane entity which aggregates configuration and operational status of many individual RMDs into a single functional entity. The MAC Manager does not participate in data plane packet handling, a function that is housed completely within the RMD. However, the MAC Manager has larger-scope visibility and intelligence, and the ability to dynamically adjust the behavioral parameters of the distributed RMD packet-processing entities.

The MAC Manager provides an OSSI compatible interface to existing MSO backoffice systems. This enables a backwards compatible transition from CMTS/CCAP deployments into FMA deployments. SNMP, IPDR, and Command Line Interface (CLI) for the RMD population is all realized in the MAC Manager for all subtended RMDs. DHCP and TFTP snooping/intercept is implemented in the RMDs and learned services are provided to the MAC Manager for operational management over the MMI.

The FMA-OSSI specification extends the existing CCAP-OSSI with new object models to manage the subtended RMDs. Streaming telemetry is expected to be added in future phases to allow metrics to be streamed directly from the RMDs or from the MAC Manager to telemetry collectors in the cable operator backoffice.

From a management perspective, transitioning to FMA from an existing CMTS/CCAP with or without RPDs is straightforward. MAC Managers will likely be available as software-only deliverables (virtual machines or container clusters) or may be available in ready-to-deploy server appliances as well. After launching/installing the MAC Manager and giving it an IP address in a routable network, the MAC Manager would be ready to be used.

Like the approach used in the Remote PHY architecture, in FMA the MAC Manager requires L3 connectivity to any RMDs that it will be managing. Also like the approach used in Remote PHY, the RMD learns the network address of the MAC Manager via DHCP options. This discovery mechanism has the RMDs announce their presence to the MAC Manager using addresses provided over DHCP, either via IPv4 or IPv6, to the RMDs. RMDs support discovery of MAC Managers via DNS, IPv4, or IPv6 address. The DNS mechanism is new in FMA and is not supported in Remote PHY. It provides a clear path to virtualized MAC Manager solutions. When deploying container-based solutions into an orchestrator, such as Kuberenetes, the favored approach is through dynamic IPv6 addressing of container instances. Using MAC Manager discovery through DNS eases the deployment of container-based MAC Managers and helps bridge the dynamically orchestrated container environment to the statically deployed RMD environment.

Existing MSO backoffice implementations continue to operate when moving to a MAC Manager and RMD based deployment, while new functionality such as new FMA-OSSI object models, can be layered into existing operational tooling to gain better visibility to the RMD status directly.

4.3. Data Plane Considerations

4.3.1. DAA Advantages

In FMA full spectrum RF is generated at the RMD, just as is done in Remote PHY at the RPD. In CMTS and integrated CCAP, full spectrum RF is generated in the head-end/hub. This relocation of full spectrum RF generation has multiple benefits, including moving from analog modulation (AM) to digital-optics in the HFC fiber plant, improved fiber redundancy, and improved modulation orders in the HFC plant.

Converting the legacy HFC AM fiber to instead carry digital-optical signals represents one of the single most important aspects of moving to a DAA in both Remote PHY and Remote MACPHY deployments. Removing optical AM modulation of RF signals in HFC fiber removes the errors introduced by optical losses such as clipping and optical noise. Digital optics in SFP module form-factors are more robust, enable higher throughput, and make better use of optical wavelengths. Digital optics carry Ethernet/IP packets in a point-to-point connection between the CIN and the OSP Node enclosure housing the RPD and RMD modules. When deployed with DWDM the fiber cable is shared with other point-to-point SFP pairs at unique wavelengths.

In DAA, on one end of the SFP pair is an aggregation switch or router in a Hub or Headend aggregation point. On the other end is an individual RMD or RPD device. Redundancy of this point-to-point link can be handled passively at the optical/Layer 1 or actively at L2 by deploying two SFP pairs with unique fibers or wavelengths between the CIN and a single RPD/RMD, and then configuring active redundancy in the RPD/RMD software. In FMA, active redundancy is standardized using 802.3ad Link Aggregation Group (LAG) and Link Aggregation Control Protocol (LACP).

DAA moves full-spectrum RF generation into the OSP. This supports improved spectral density with higher modulation orders and better MER on the RF portion of the network, which no longer includes the AM optics. All that remains to impact modulation order and MER is the coaxial distance between the DAA node and the CM. This creates an opportunity to greatly improve modulation profile configurations in DAA versus legacy CMTS and integrated CCAP architectures.

The DAA data plane is clearly superior to legacy architectures for the reasons previously mentioned. Within DAA there is however a data plane divergence between Remote PHY and Remote MACPHY to consider. In Remote PHY the MAC continues to be based in a centralized component through integrated CCAP chassis line-card upgrades or transitioning to a virtual Core architecture. DOCSIS packets are opaquely tunneled across the CIN. In Remote MACPHY the MAC is deployed along with the PHY in the RMD. This makes subscriber bearer traffic more readily available at the first-hop Ethernet switch or router. The Remote PHY choice supports integrated CCAP chassis reuse through line-card upgrades. The Remote MACPHY choice enables early routing and maximizes CIN convergence with other applications such as PON, 4G and 5G wireless Xhaul, and business services.

4.3.2. Remote MACPHY Data Plane

Figure 6 illustrates the Remote MACPHY data plane logical architecture. Upstream, the RMD uses digital-optical modules to provide connectivity back to the aggregation network in a hub/headend location. Commonly, this link would be 10G SFP+ DWDM LR modules, though FMA isn't prescriptive on the digital backhaul. The optical interface of the RMD carries subscriber bearer traffic over Ethernet/IP which in the upstream direction has already been BPI+ decrypted and reassembled. FMA RMD uses MACsec L2 encryption technology between the first-hop aggregation device and the RMD to ensure subscriber traffic is encrypted while transiting the OSP fiber links.

Downstream, the RMD outputs RF which could be provided to a launch amplifier and further extended with line amplifiers in N+X or N+0 plant designs before reaching the taps and customer premise. FMA supports full spectrum up to 1.2 GHz DOCSIS 3.1 and 1.8 GHz DOCSIS 4.0, but plant upgrades from existing upper frequencies are not explicitly required by RMD deployments. The cable-plant coax/RF return is also terminated in the RMD with link processing and packet-reassembly occurring in the RMD.

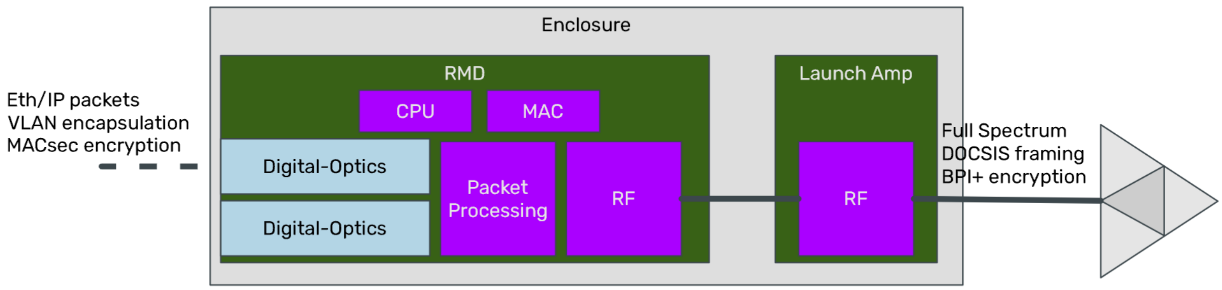

Figure 6 – Logical RMD Architecture

The RMD implements the DOCSIS MULPI and PHY specifications as a L2 CMTS. Remote MACPHY terminates the DOCSIS network in the RMD, a key difference compared to Remote PHY. The DOCSIS MAC is contained within the RMD and both downstream and upstream packet scheduling is managed within the RMD itself.

In Remote MACPHY no additional DOCSIS-specific packet-processing components, physical or virtual, exist in the network. All bearer traffic transiting into or out of the RMD are transparent native Ethernet/IP packets handled by standard switching and routing solutions. Hub and headend space are consequently significantly reduced since no additional compute equipment specific to DOCSIS packet processing is required. The amount of switching equipment needed in the CIN may also be reduced in FMA compared to Remote PHY because the DOCSIS traffic is no longer opaquely tunneled to a packet-processing entity for DOCSIS-specific processing, which can cause the bearer traffic to transit twice across the CIN due to hair pinning to reach the packet-processing entity.

When compared to an integrated CCAP deployment the FMA architecture decomposes the monolithic chassis into composite parts and places functionality into best-fit locations. Access-technology specific functionality moves to the edge closer to the customer and is contained in its optimal location. Packet aggregation at L2 is placed within first-hop aggregation switches and readily capable of horizontal scaling. L3 routing is decoupled from L2 aggregation to allow it to be more centrally deployed and managed.

This architecture can be seen to be very similar to a traditional Broadband Network Gateway (BNG) used with L2 PON devices or in telco copper access with digital subscriber line access multiplexers (DSLAM). Shifting routing to a BNG-like implementation with L2 in the RMD allows for easier convergence for operators deploying a mix of HFC and fiber-to-the-home.

The Remote MACPHY architecture functional decomposition between CIN functions and RMD functions is illustrated in Figure 7.

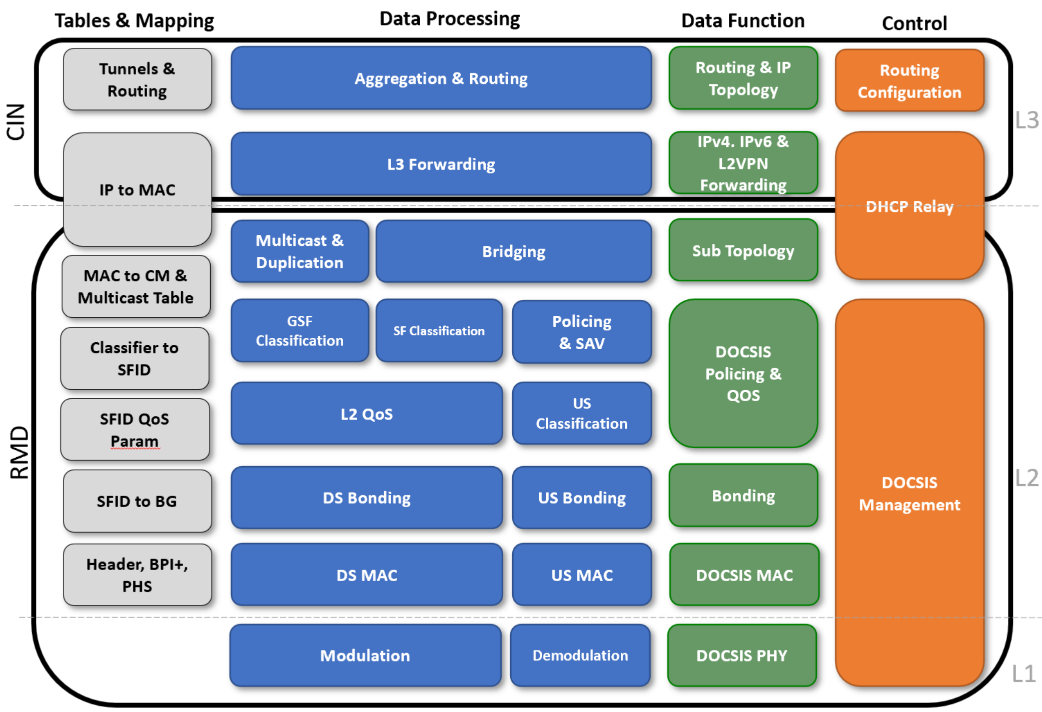

Figure 7 – Remote MACPHY Functional Decomposition

4.3.3. CIN Considerations

FMA outlines one example of CIN design, that of a Spine-and-Leaf illustrated in Figure 8, but does not mandate that type of network layout.

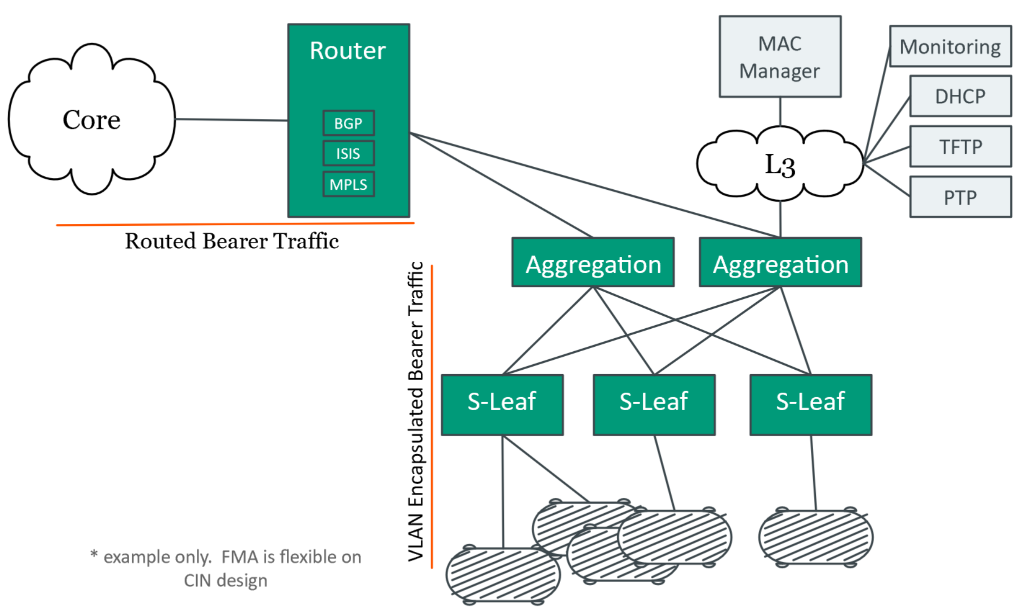

Figure 8 - Spine-and-Leaf CIN

An FMA based DAA does presuppose certain functions are handled within a CIN of any design though. MACsec, DHCP relay, and routing of both are required, as are separation of management and subscriber traffic are supported. The RMD handles certain DOCSIS-specific network functions: DHCP intercept (add/remove DHCP options), TFTP intercept, Source Address Verification (SAV), MAC learning, and cable bundles via VLANs. As such, routing at the first hop networking device is an equally valid topology for FMA.

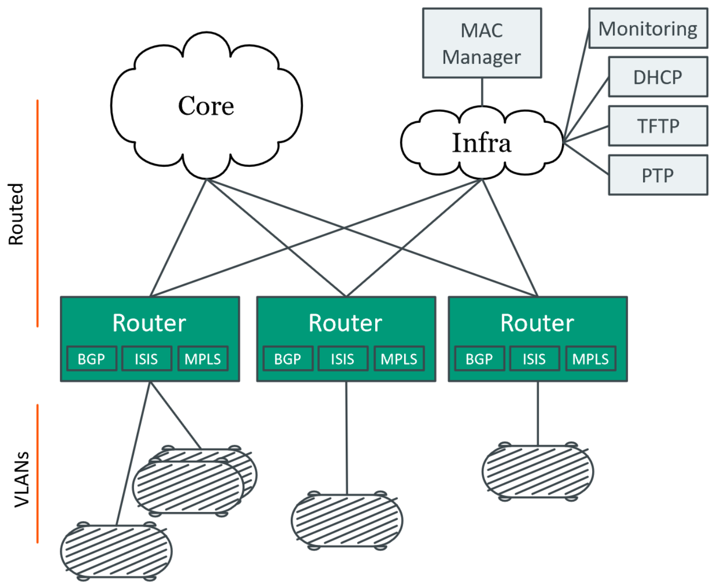

Figure 9 - Flat Network CIN

Spine-and-Leaf can be attractive in designs were high aggregation and oversubscription is expected, though FMA doesn't expect to see large east-west traffic patterns which mutes some of the benefits of this type of CIN. Flat designs are attractive to reduce VLAN stretching and in deployments with high north-south traffic patterns but may result in more routing entities to manage as the network horizontally scales. Operators may want to explore hybrid or other CIN topologies as well.

4.4. PacketCable

4.4.1. PacketCable Overview

PacketCable 1.5 Dynamic Quality of Service (DQoS), PacketCable Multimedia (PCMM) and PacketCable Event Messages (PCEM) are all supported transparently in FMA by the combination of the MAC Manager and PAG applications and the collection of RMDs within their scope. FMA makes the distributed access system appear to the legacy PacketCable backoffice systems as a CMTS or integrated CCAP, greatly simplifying the transition to FMA from legacy systems.

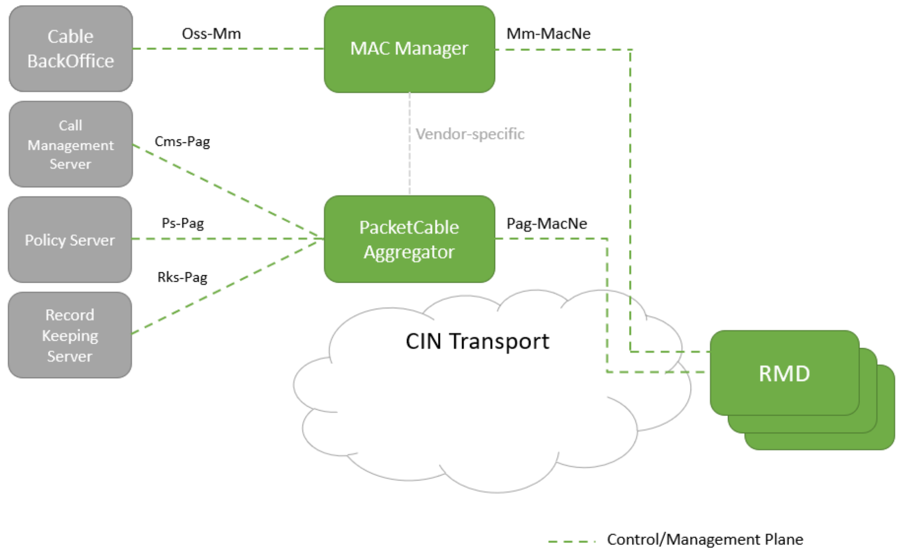

Figure 10 – FMA PacketCable Architecture

The MAC Manager supports MSO backoffice provisioning of PacketCable on the FMA System via the Oss-Mm interface. The PAG enables DQoS via Call Management Servers (CMS) for IP packet-based voice telephony and PCMM via Policy Servers for IP packet-based multimedia applications by providing the necessary COPS-based Cms-Pag control interfaces to these legacy functional entities. The PAG also supports PCEM delivery to Record Keeping Servers (RKS) for accounting purposes via the associated RADIUS-based Rks-Pag event reporting interfaces. The MAC Manager and PAG are software-based applications in the FMA System. They interact in a vendor implementation-specific manner.

The RMDs provide finite state machine operations required of the CMTS in PacketCable specifications. However, RMDs need only communicate with their PAG rather than connecting with one or more CMS, Policy Server and RKS functional entities. This simplifies RMD operations by moving most connectivity management to a central location, the PAG. It also efficiently scales the FMA System by keeping the number of legacy functional entity connections on par with a CMTS or CCAP sized system.

4.4.2. PacketCable Provisioning

Existing CCAP PacketCable provisioning parameters are available in FMA, as specified in CCAP-OSSI and FMA-OSSI. In FMA the Oss-Mm is implemented on the MAC Manager.

The MAC Manager is responsible for provisioning the PAG with its PacketCable parameters. After the PAG receives its PacketCable provisioning it connects to the legacy PacketCable backoffice functional entities. PacketCable DQoS specifies requirements for connecting the PAG with a CMS. PCMM specifies requirements for connecting the PAG with a Policy Server. Both PacketCable DQoS and PCMM specify COPS-based protocols which run over TCP connections. When it is provisioned for event message reporting, the PAG reports PCEM to the RKS via a RADIUS-based protocol which runs over UDP. The RKS destination is not provisioned by the MAC Manager but is signaled dynamically to the PAG in PacketCable DQoS and PCMM control signaling.

When new RMDs come online, they are configured and provisioned by the MAC Manager over the MMI (Mm-MacNe). The MAC Manager is responsible for provisioning the RMD with its PAG address and its PacketCable parameters. The RMD connects to its provisioned PAG over the PAI (Pag-MacNe), which runs on top of TLS. The PAI supports the complete message set that is specified in PacketCable. It is based on messages defined using Google Protocol Buffers (GPB), which is supported by tooling and automatic source code generation that greatly enhances interoperability.

4.4.3. PacketCable 1.5 Operation

In PacketCable 1.5, the CMS is the call control entity responsible for enabling packet-based voice over IP telephony over a DOCSIS access network. A CMS signals end-to-end to CMs with embedded multimedia terminal adapters (E-MTAs) using the Network-based Call Signaling (NCS) protocol for call processing control. Functionality such as relaying on-hook and off-hook conditions, applying dial tone, collecting digits, and ringing phones are all communicated to and from the CMS via NCS signaling. The PAG and RMD do not participate in end-to-end NCS signaling.

The CMS also controls DOCSIS access network quality of service (QoS) via DQoS signaling. In legacy environments, DQoS runs between the CMS and CMTS or CCAP, opening and closing QoS “Gates” on the access network. In FMA, DQoS operates between the CMS and PAG, which translates COPS-based messages to and from the corresponding PAI messages sent and received over the PAI between the PAG and RMD. The Gate Control operations signaled by a CMS are implemented in the finite state machines of the RMD.

When PCEM is supported, the RMD will generate QoS-related events over the PAI to the PAG. The PAG relays the events to the RKS over the PCEM Rks-Pag RADIUS interface. The PAG does real time event message relay and controls batch processing of events as well. It also manages RKS redundancy with the Primary and Secondary RKS. Event message controls are provisioned on the PAG by the MAC Manager and provided by the CMS in its DQoS messages to the PAG.

4.4.4. PacketCable Multimedia Operation

In PCMM, the Policy Server is the QoS control entity responsible for enabling QoS for PacketCable 2.0 voice telephony and various multimedia applications over a DOCSIS access network. The Policy Server or Application Manager associated with the Policy Server signals end-to-end with end user CPE and applications in an application-specific manner. The PAG and RMD do not participate in end-to-end application-specific signaling.

The Policy Server also controls DOCSIS access network QoS for these applications using PCMM signaling. In legacy environments, PCMM runs between the Policy Server and CMTS or CCAP, opening and closing QoS “Gates” on the access network. In FMA, PCMM operates between the Policy Sever and PAG, which translates COPS-based messages to and from the corresponding PAI messages sent and received over the PAI between the PAG and RMD. The Gate Control operations signaled by a Policy Server are implemented in the finite state machines of the RMD.

When PCEM is supported, the RMD will generate QoS-related events over the PAI to the PAG. The PAG relays the events to the RKS over the PCEM Rks-Pag RADIUS interface. The PAG does real time event message relay and controls batch processing of events as well. It also manages RKS redundancy with the Primary and Secondary RKS. Event message controls are provisioned on the PAG by the MAC Manager and provided by the Policy Server in its PCMM messages to the PAG.

4.5. Lawful Intercept

4.5.1. Lawful Intercept Overview

FMA provides full support for Lawful Intercept. The MSO interface point to Law Enforcement Agencies (LEA) requiring intercept of traffic within the cable operator network is referred to as Mediation Device, or alternatively the Delivery Function. The Mediation Device touches several network entities in the cable operator network to provision Taps on those devices and to collect mirrored traffic and certain traffic-related metadata. The Mediation Device is not specific to FMA. It is inherited from the legacy CMTS and CCAP Lawful Intercept architectures.

The FMA architecture provides alternatives which operators can leverage based upon the functionality present in their networks and the desired method of delivering intercepted traffic to the Mediation Device.

- For PacketCable 1.5 Electronic Surveillance, which supports intercept of PacketCable 1.5 voice traffic, the combination of PAG and RMD enable the functionality that is provided by the CMTS and CCAP in legacy systems.
- For broadband High-Speed Data (HSD) intercepts, the combination of MAC Manager and RMD enable the functionality that is provided by the CMTS and CCAP in legacy systems.
- Alternatively, for broadband HSD intercepts the operator may choose a convergence strategy where routers located above the access networks serve as the focal point for intercepting traffic over disparate access technologies such as HFC, PON and wireless.

These mechanisms are all supported in FMA. The details of each mechanism are provided in the sections which follow.

4.5.2. PacketCable 1.5 Voice Lawful Intercept

In PacketCable 1.5, the CMS is the call control entity responsible for enabling packet-based voice over IP telephony over a DOCSIS access network. The CMS also controls DOCSIS access network QoS using PacketCable 1.5 DQoS signaling. In this environment, requirements for supporting Lawful Intercept have been specified in the PacketCable 1.5 Electronic Surveillance specification.

Intercept Taps are provisioned by the Mediation Device on the CMS. The CMS signals that intercepts are required on a call-by-call basis via electronic surveillance parameters in PacketCable 1.5 DQoS messages, which are sent to the RMD by way of the PAG. If PCEM event messages are to be reported as part of the intercept, the PAG makes note of this and serves as a mirroring point for these events when they are reported to it by the RMD. In this case the PAG mirrors the events toward the Mediation Device.

The RMD implements the voice traffic mirroring point. It mirrors intercepted voice traffic to the Mediation Device as indicated in the DQoS electronic surveillance parameters on a call-by-call basis.

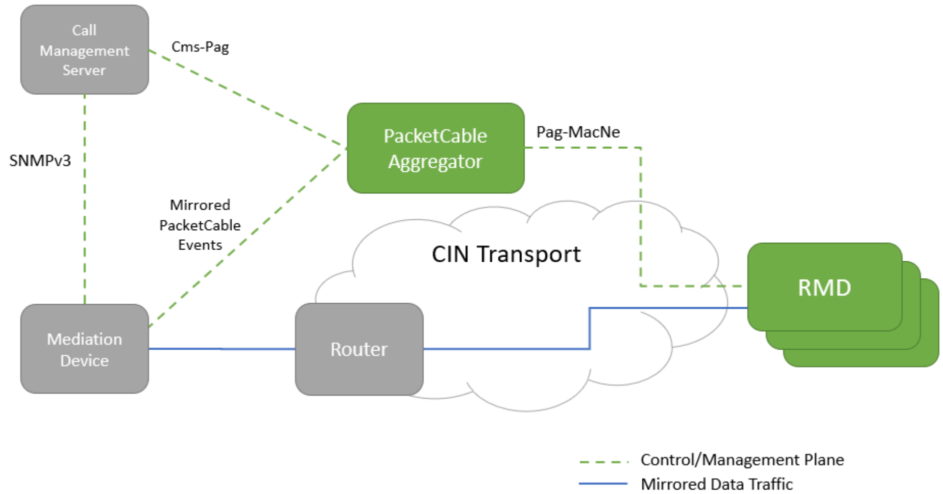

Figure 11 – FMA PacketCable Lawful Intercept Architecture

4.5.3. FMA-specific High Speed Data Lawful Intercept

Broadband HSD traffic on the cable network is also subject to Lawful Intercept. When an HSD Tap is provisioned, the traffic to be intercepted is specified in an FMA Tap MIB that unifies various Tap MIBS which exist in the industry to provision Taps on CMTS and CCAP devices. The FMA Tap MIB provides commonly used parameters and eliminates those parameters that the industry has not found to be relevant.

Intercept Taps are provisioned by the Mediation Device on the MAC Manager via SNMPv3 and the new FMA Tap MIB. The MAC Manager in turn provisions the Tap on the RMD over the MMI. These taps are persistent, unlike the call-by-call Taps used in PacketCable 1.5 Electronic Surveillance.

The RMD implements the HSD traffic mirroring point. It mirrors intercepted data traffic to the Mediation Device as configured by the MAC Manager over the MMI.

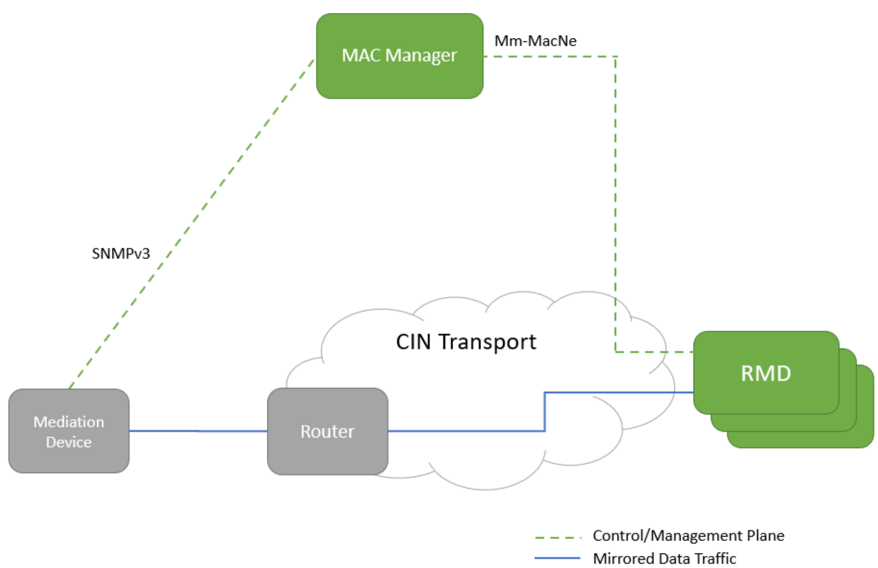

Figure 12 – FMA High Speed Data Lawful Intercept Architecture

4.5.4. Converged Access High Speed Data Lawful Intercept

Broadband HSD traffic is subject to Lawful Intercept regardless of the access technology. Operators with more than one access technology in their network may be wise to consider an architecture where Taps can be done at a common point in the network, such as in a router at a level above the access network. This is an architecture that is independent of access technology. Therefore, while such an architecture would also support FMA HSD traffic intercept, it does not impact the FMA System.

Intercept Taps are provisioned by the Mediation Device on the router via one of the industry-supported Tap MIBs. These taps are persistent.

The router implements the HSD traffic mirroring point. It mirrors data traffic to the Mediation Device as configured by the Mediation Device.

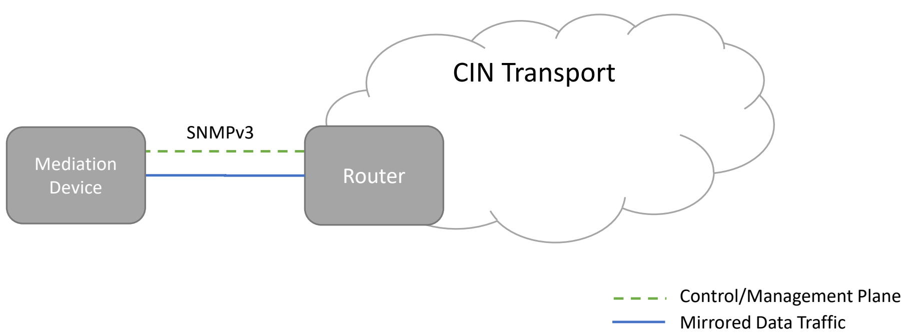

Figure 13 – Converged Access High Speed Data Lawful Intercept Architecture

4.6. Remote PHY Reuse – QAM Video, OOB, and Plant Maintenance

FMA specifications include the idea of eventually incorporating a mixture of flexible MAC (the “FM” in FMA) devices or MAC-NEs under a single umbrella architecture. This could possibly include a CCAP Core configured and monitored by a MAC Manager, or even a Remote MAC Core (RMC) that contains the DOCSIS MAC but feeds subtended RPDs.

There has also been focus on reusing components from the original Remote PHY specifications where possible so that these can be shared between different MAC-NE implementations, potentially in the same market area. This includes three main functions: QAM video operation, set-top box (STB) and other out-of-band (OOB) signals, and signals needed for plant maintenance.

In all cases the same protocols, Generic Control Plane (GCP), Remote Downstream External PHY Interface (R-DEPI), Remote Upstream External PHY Interface (R-UEPI), and Remote Out-of-Band (R-OOB) are used by FMA so the associated centralized components, the Auxiliary Cores, supporting these functions do not need modification to serve all forms of MAC-NE in an FMA System.

Auxiliary Core operation in FMA relies on the same mechanisms as Remote PHY, with the exception that the MAC Manager configures all the Auxiliary Core information on the RMD before the RMD can start GCP operation. The MAC Manager does not need to interact with Auxiliary Core except to be able to configure the core details in the RMD.

4.6.1. QAM Video

DAA QAM video implementations have evolved as Remote PHY systems have moved into scaled deployment and the unique needs of operators are being addressed. [QAMVideoDAA] provides an excellent summary of the options available and considerations in those Video Cores and Traffic Engines. Figure 14 summarizes options generally available and being deployed by operators for QAM video in any DAA environment, whether it be Remote PHY or Remote MACPHY.

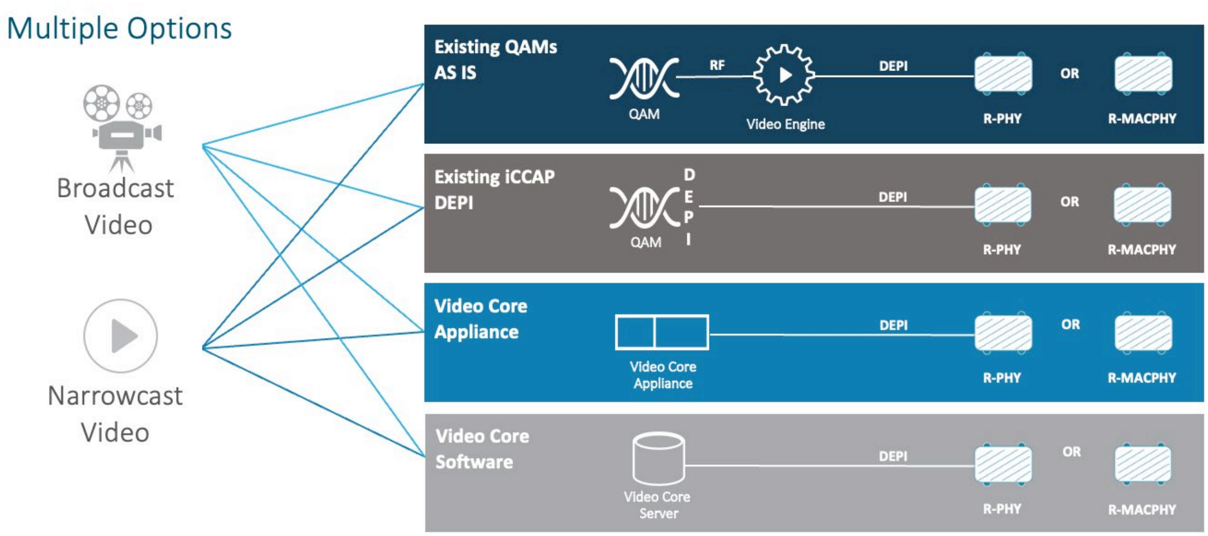

Figure 14 - QAM Video Implementation Options

4.6.1.1. Edge QAM and Traffic/Video Engine

Operators can leave existing Edge QAMs in place and deploy large scale QAM demodulators to convert pre-encrypted, full rate QAM, multi-program transport streams (MPTS) with NULL packets into R-DEPI format for transport to the RPD or RMD. This solution is also referred to as a Traffic Engine, which means a device that supports the QAM video data plane only, leaving Auxiliary Core operation to configure the video channels to other components. The MAC Manager can support video configuration of Traffic Engines on the RMD through the MMI as a static pseudowire.

4.6.1.2. Fully Integrated CCAP

Many operators have existing integrated CCAP solutions that support all their QAM video needs for analog node deployments. Some integrated CCAP solutions may also support R-DEPI out for Remote PHY operation and Auxiliary Core operation. These solutions can provide DAA QAM video for RPDs and RMDs alike.

4.6.1.3. Standalone Video Core

A third alternative is a Standalone Video Core appliance or software solution that contains both traditional Edge QAM functions (narrowcast video control plane, single program transport stream (SPTS) to MPTS multiplexing, encryption) and provides an R-DEPI output compatible with any RPD or RMD solution. These Video Cores may support both Traffic Engine for video data plane and Auxiliary Core for

GCP control or may just act as the Traffic Engine and support configuration using the MAC Manager with static pseudowire objects specified over the MMI.

4.6.2. Out-of-Band

QAM video deployments in HFC with traditional STBs require a way to provide authorization, encryption messaging, and software update capability for those STBs. Options for the transport of this traffic includes:

- DOCSIS 1.0-3.1 – No specific functionality is required in the FMA system to accommodate.
- DOCSIS Set-Top Gateway (DSG) – The RMD operates as a DSG Agent. An additional accommodation of adding NAT64 to the DSG Server in the network and a DSG Agent in the RMD is required if the operator chooses to deploy in an IPv6-only environment. This functionality is unique to FMA and not reused from Remote PHY.
- SCTE 55-1 – ALOHA protocol, typically used with Motorola conditional access.
- SCTE 55-2 – DAVIC protocol, typically used with Scientific Atlanta conditional access.

Similar to QAM video, SCTE 55-1 and SCTE 55-2 in FMA reuses implementations already supported in Remote PHY. Figure 15 illustrates these options – NDF/NDR or direct OOB operation using an OOB Core.

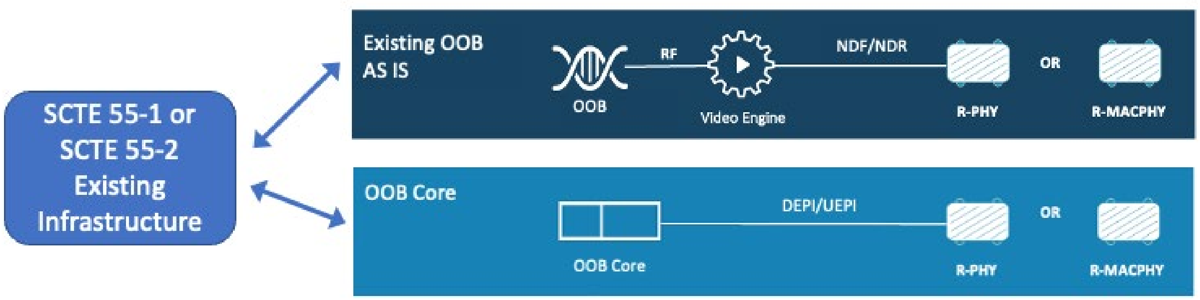

Figure 15 – Out-of-Band Implementation Options

4.6.2.1. NDF/NDR

NDF digitizes narrowband signals from the existing RF-based SCTE 55-1 and 55-2 systems with a centrally located Video Engine component which then transports the digitized signal using R-DEPI to the RPD/RMD where it is regenerated and transmitted to the STB.

NDR digitizes narrowband return signals from the STB in the RPD/RMD and transports them back to the Video Engine component using R-UEPI. The Video Engine regenerates those signals and transmits them back to the existing 55-1 or 55-2 RF systems.

SCTE 55-1 is tolerant to jitter and latency, so NDF/NDR operation is robust in many different deployment architectures.

The SCTE 55-2 protocol requires fast acknowledgements (under 3ms) of received STB transmissions. As a result, SCTE 55-2 operation using NDF/NDR requires shorter distances between the Video Engine and

RPD/RMD, as well as tight control of round-trip network latency. This general DAA constraint applies to both RPD and RMD systems.

4.6.2.2. Direct SCTE 55 Operation

In direct operation mode, centralized components are added which replace or augment the existing RF-based systems in place for SCTE 55-1 and SCTE 55-2.

For SCTE 55-1, downstream Moving Picture Experts Group (MPEG) transport packets from existing control components are R-DEPI encapsulated by a centralized 55-1 OOB Core function and subsequently decapsulated and modulated onto SCTE 55-1 OOB RF channel(s) at the RPD/RMD. Upstream ATM-like cells are R-UEPI encapsulated at the RPD/RMD and subsequently decapsulated at the 55-1 OOB Core, which groups together multiple RPD/RMDs to look like a single legacy RF component to minimize issues with scale of the existing control components.

The centralized 55-1 OOB Core function can be implemented as:

- Part of the CCAP Principal Core in Remote PHY – Extra functions are integrated within an Integrated CCAP Core already serving DOCSIS and QAM video.
- An Auxiliary Core in Remote PHY and FMA – A single element contains both data plane transport over R-DEPI and configuration of RMD/RPD using GCP.
- A Traffic Engine in Remote PHY and FMA – A data plane only element based on static pseudowires, with configuration coming from the Principal Core using GCP in Remote PHY or the MAC Manager using MMI in FMA.

For SCTE 55-2, existing centralized RF-based control components are replaced by functions in the RPD/RMD and a centralized 55-2 OOB Controller. The 55-2 OOB Controller acts as an Auxiliary Core, containing the full 55-2 MAC and connecting to the video backoffice. The 55-2 OOB Controller encapsulates downstream packets in R-DEPI format and transmits them to the RPD/RMD, which performs R-DEPI decapsulation and RF modulation. In the upstream the RPD/RMD demodulates RF, encapsulates as packets in R-UEPI format and transmits to the 55-2 OOB Controller. The RPD/RMD must also perform some lower layer MAC functions such as upstream acknowledgement insertion. Lower layer MAC functions for 55-2 are included in the RPD/RMD to ensure tight ACK turnaround times can be met with long distances and higher jitter between the OOB Controller and RPD/RMD.

4.6.3. Plant Maintenance

Reliable operation of the HFC system requires support of the operational tools used by field technicians to setup and monitor critical RF OSP conditions. Each of these tools for FMA RMD operation leverages the systems already deployed widely for Remote PHY:

- Downstream and upstream sweep – Sweep provides ongoing validation of proper signal levels across the entire downstream and upstream bands to detect excessive cable loss and impairments between the node (RPD/RMD), amplifier cascade, passives and CMs in the plant. Available options for sweep operation in Remote PHY are reused for FMA and are described in R-OOB Appendix III.
- Upstream spectrum capture – Capture of the upstream spectrum as part of overall proactive network maintenance (PNM) provides significant benefit to operators to understand sources of upstream packet errors due to persistent or intermittent noise and ingress. Upstream spectrum

capture operation for Remote PHY is reused for FMA and is described in R-UEPI sections 8.2.8 and 8.2.9.

- Leakage detection – Regulators mandate that cable operators ensure the cable plant does not "leak" RF energy into frequency bands that may be susceptible to interference (e.g., aeronautical communication frequencies or spectrum used by licensed mobile wireless systems). Identifying and repairing faults as part of PNM leakage detection activity also reduces errors due to ingress interference from those other uses. R-OOB Appendix IV and Section 9 describe operation of downstream leakage detection. In the future, High Split systems where upstream OFDMA signals will operate in the aeronautical frequency band on potentially licensed mobile wireless frequencies will require additional support, which has recently been added into CableLabs® DOCSIS specifications. See [LeakageHighSplit] for details on the specifications and High Split leakage detection solutions. It should be noted that all High Split leakage detection solutions in the specifications are applicable to both Remote PHY and FMA RMD deployments.

5. FMA Migration Considerations

As operators begin their journey toward the Emerald City to enable the deployment of FMA with RMD, it will be important to know what they should take with them. If their journey started with legacy systems in Kansas, a transition to DAA is required. If their journey began with Remote PHY, a DAA starting point is already in place. In either case it is important to understand the similarities between Remote PHY and FMA standards and components as well as where they diverge. Knowing this can help operators identify common operational benefits where Remote PHY and FMA may coexist and understand the changes required if transitioning deployments from Remote PHY to FMA with RMD.

Table 1 summarizes the reuse opportunities for each of the steps.

Table 1 - FMA Migration and Remote PHY Reuse

FMA Migration Step	Remote PHY Architecture and Component Reuse
Fiber node change	Yes
OSP analog to digital optics change	Yes
CIN - L2 RMD aggregation layer	Yes
CIN - 802.1X RMD port authentication	Yes
CIN – MACsec encryption	No – MACsec not used in Remote PHY with BPI+ applied at CCAP Core
CIN – DHCP for RMD	Yes
CIN - Synchronization (PTP/SyncE)	Yes, but PTP only needed in FMA for delivering precision time services such as Mobile Xhaul
CIN – L2/L3 termination	No – largest area of divergence
QAM video and STB OOB support	Yes
Plant maintenance tool updates	Yes
MAC Manager addition	No – Remote PHY pCore/vCore management possible with MAC Manager in future FMA phases

5.1. Migration Steps with Remote PHY Reuse

The FMA network migration steps listed below all have significant reuse of Remote PHY architecture and components.

5.1.1. Fiber Node Change

An analog fiber node is swapped for a Remote MACPHY node or a new Remote MACPHY node is deployed instead of splitting an existing analog node.

Remote MACPHY node installs in the OSP are effectively the same as Remote PHY conversions by migrating to nodes with digital Ethernet optics capability.

5.1.2. OSP Analog to Digital Optics Change

The traditional OSP analog fiber distribution and associated wavelength division multiplexing (WDM) equipment is converted to digital optics with appropriate pluggable Ethernet transceivers. Outdoor mux/demux are installed as needed to match the wavelength and fiber planning.

Remote MACPHY OSP digital-optical fiber conversion is the same as Remote PHY and, in fact, investments in digital conversion for Remote PHY can be reused for Remote MACPHY deployments.

5.1.3. CIN - L2 Remote MACPHY Aggregation Layer

The new digital Ethernet optics and associated Remote MACPHY node are connected into a L2 aggregation network as the node-facing part of the CIN.

The L2 aggregation CIN network is very similar between Remote PHY and Remote MACPHY with the exception of some considerations for segmenting offered services into VLANs that is available in Remote MACPHY.

5.1.4. CIN - 802.1X Remote MACPHY Node Port Authentication

The L2 CIN is provisioned to support 802.1X mutual authentication for network access control.

802.1X operation is very similar between Remote PHY and Remote MACPHY as a way to ensure there is no unauthorized access into the CIN L2 aggregation layer.

5.1.5. CIN – DHCP for Remote MACPHY

A DHCP server, IPv4 or IPv6, is configured to serve RMDs and provide the MAC Manager network location via IP address or DNS name.

RMD boot and DHCP mechanisms are based on the initialization and operation of RPDs.

5.1.6. CIN – Synchronization (PTP/SyncE)

As an optional step, IEEE 1588 PTP Grandmasters (GMs) are added and connected to the CIN if needed for precision time services such as Mobile xHaul. Network elements in the CIN between GM and RMD are provisioned as Boundary Clocks or Transparent Clocks as needed to meet precision timing performance requirements. SyncE network clock synchronization may also be added as needed to meet precision timing performance requirements.

In contrast with Remote MACPHY, Remote PHY networks cannot operate without PTP phase and frequency synchronization, which is required between the CCAP Core and RPD for DOCSIS scheduling. While Remote MACPHY does support R-DTI requirements from Remote PHY, PTP is only needed in

FMA for delivering precision time services such as synchronization for small cells or mobile Xhaul. Depending on implementation in any deployed Remote PHY equipment, coexistence of Remote MACPHY and Remote PHY in the same network may also require the use of PTP for frequency synchronization for synchronous QAM video or NDF/NDR solutions.

5.1.7. QAM Video and STB OOB Support

QAM video and STB OOB support are added in the network using Video Engine(s), Traffic Engines and Auxiliary Cores using whichever best fits the operator video backend and STB infrastructure. The MAC Manager directly configures static pseudowires on the RMD or directs the RMD towards the Auxiliary Core(s) for further configuration.

QAM video and Remote PHY R-OOB functions (55-1, 55-2, NDF/NDR) are all directly reused in FMA.

5.1.8. Plant Maintenance Tool Updates

Updated versions of plant maintenance operational tools for sweep, spectrum capture, and leakage detection are installed and configured, with the RMD provisioned for working with these tools through the MAC Manager as needed.

Plant maintenance tools used in the network are the same for Remote PHY or FMA.

5.2. Migration Steps Divergent from Remote PHY

The FMA network migration steps listed below all diverge from the Remote PHY architecture and do not reuse components from Remote PHY.

5.2.1. CIN – MACsec Encryption

FMA/Remote MACPHY adds configurable MACsec encryption in the L2 aggregation layer for operators who choose to encrypt all traffic in the OSP network segment(s).

Remote PHY encrypts user traffic with BPI+ from the CM through the RPD and CIN to the CCAP Core, so MACsec encryption is not required for bearer traffic. Remote PHY does not mandate encryption for non-bearer traffic such as management and control signaling between the Core and RPD, or for certain types of signaling between back-office and CM, such as DHCP and TFTP.

A CIN which converges PON access along with HFC will generally require MACsec for the same reasons as FMA with Remote MACPHY since the PON layer terminates at the OLT or Remote OLT.

5.2.2. CIN – L2/L3 Termination

A router is configured to route bearer traffic from the RMD to the Core network through the CIN.

The largest divergence between Remote PHY and FMA is the decoupling of L3 routing from DOCSIS packet processing. In FMA there is no centralized DOCSIS packet processing engine terminating an L2TPv3 tunnel containing DOCSIS frames and providing a L3 CMTS northbound router for the customer traffic. Rather, the RMD terminates the DOCSIS frames and acts as a L2 CMTS northbound toward the aggregation network. L2 packet flows are aggregated at a standard L3 router to provide routing into the operator core network. Customer bearer traffic is directly accessible for aggregation, switching, and routing at the first-hop switch or router which can be selected from a range of readily available switch and router vendors. Traffic engineering of natively transported traffic in an FMA CIN is a considerable upside of the architecture.

5.2.3. MAC Manager Addition

A MAC Manager is deployed and configured with IP routable connectivity between the RMD network location and the MAC Manager, with provisioning for the associated RMD(s) configured on the MAC Manager.

No MAC Manager is present in current Remote PHY systems but the "Flexible MAC" part of FMA can be utilized to manage pCore/vCore MAC-NEs in future FMA phases once that operation is standardized. In this way, the Remote PHY portion of the network can eventually be brought under one FMA umbrella.

6. Other Architecture Considerations

There are several other important architecture considerations between traditional integrated CCAP, CCAP + Remote PHY, and FMA with Remote MACPHY deployments.

6.1. CIN Latency

Scheduling upstream traffic on a DOCSIS access network relies on a request and grant cycle between the CM requesting bandwidth and the entity scheduling minislots against those requests.

Both Remote MACPHY and traditional integrated CCAP co-locate the MAC and PHY components so there is no additional delay added to each request and grant in the protocol. No CIN impact on DOCSIS request/grant cycle latency is present in FMA with RMD. In addition, as shown in [FMACloud], latency between the MAC Manager and RMD is not a critical consideration for system operation since no data plane functions exist between MAC Manager and RMD.

In Remote PHY the MAC and PHY are in separate devices separated by a CIN of one or more hops. CIN latency and jitter between the CCAP Core MAC and RPD PHY add to request and grant cycle, thereby lengthening the time for CM bandwidth requests to be served and increasing upstream latency. The impact is dependent on the distance and delay within the CIN as well as the DOCSIS MAP interval. Centralization of the CCAP Core exacerbates the problem by extending the distance, delay and probability of jitter, so careful consideration of where CCAP Cores are placed is needed in Remote PHY systems.

6.2. Deployment Granularity

In traditional integrated CCAP and CCAP + Remote PHY deployments, space and power targets for hub-based equipment have resulted in high density chassis which serve tens to hundreds of service groups in a single element. This tends to result in a natural bundling and a deployment architecture where only the largest geographic areas get the latest high density chassis features and capabilities. CCAP + Remote PHY deployments can help with this by centralizing the CCAP Core to share over a large geographic area but then the CIN latency impacts of section 6.1 can result in degraded upstream latency.

In contrast, the latency tolerance of the disaggregated MAC Manager and RMD in FMA allows for service groups to be added one RMD at a time, with operational efficiency by using a centralized MAC Manager which can be deployed 1000s of kilometers away. This makes RMD with FMA well suited to rural and other low-density locations, or as a way to boost capacity in targeted locations within a larger urban center while continuing to use integrated CCAP or CCAP + Remote PHY.

7. Conclusion

We know why we want to go to the DAA Land of Oz and, once there, why we want to go to the Emerald City. There's a clear path to the Emerald City once in Oz, and that path as not as scary as it would seem since we can take along plenty of familiar friends for support.

This paper has presented a comprehensive discussion of the considerations for migration of HFC delivered services from traditional integrated CCAP or CCAP + Remote PHY architectures to FMA with Remote MACPHY. Significant reuse of architecture and network components between Remote PHY and FMA allows operators deploying FMA with Remote MACPHY to:

- Obtain the well understood and proven benefits of DAA
    - Converged digital Ethernet optics
    - Improved end of line RF performance for greater capacity
    - Improved field operations through intelligent nodes
- Apply the lessons learned by the industry during Remote PHY deployment in an FMA deployment
- Support coexistence of Remote PHY and FMA with Remote MACPHY within the operator network
- Support a graceful migration from Remote PHY to FMA with Remote MACPHY

Some areas will be different between Remote PHY and FMA for operators – this isn't Kansas anymore – but these offer a pathway to the future of cable operator access networks:

- Disaggregation of the management and data planes through the FMA MAC Manager
- Access network abstraction through the FMA MAC Manager
- A common L2 architecture similar to PON for convergence on the overall access network L2/L3 topology

The near future is sure to be very active in FMA with standards activities moving from specification writing to product implementation, interoperability events happening to demonstrate the multi-vendor capability of FMA, and the upcoming industry movement towards DOCSIS 4.0 which requires DAA nodes for deployment.

Abbreviations

AAA	Authentication, Authorization, Accounting
AM	Analog Modulation
BG	Bonding Group
BGP	Border Gateway Protocol
BNG	Broadband Network Gateway
BPI	Baseline Privacy Interface
BSS	Business Support System
CCAP	Converged Cable Access Platform
CIN	Converged Interconnect Network
CLI	Command Line Interface
CM	Cable Modem
CMS	Call Management Server
Cms-Pag	CMS to PAG interface
CMTS	Cable Modem Termination System
COPS	Common Open Policy Server
COTS	Commercial of the Shelf
CPU	Central Processing Unit
DAA	Distributed Access Architecture
DAVIC	Digital Audio Video Council
DEPI	DOCSIS External PHY Interface
DHCP	Dynamic Host Control Protocol
DNS	Domain Name Server
DOCSIS	Data Over Cable System Interface Specification
DQoS	Dynamic Quality of Service
DSG	DOCSIS Set-Top Gateway
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense Wavelength Division Multiplex
EMS	Element Management System
E-MTA	Embedded Multimedia Terminal Adapter
ERM	Edge Resource Manager
FMA	Flexible MAC Architecture
GCP	Generic Control Protocol
GHz	Giga Hertz
GM	Grandmaster
GPB	Google Protocol Buffers
HFC	Hybrid Fiber Coax
HSD	High Speed Data
IPDR	IP Detail Record
IP	Internet Protocol
IPv4	IP version 4
IPv6	IP version 6
ISIS	Intermediate System to Intermediate System
LACP	Link Aggregation Control Protocol
LAG	Link Aggregation Group
LEA	Law Enforcement Agency
LR	Long Range

L2	Layer 2
L2VPN	L2 Virtual Private Network
L3	Layer 3
MAC	Media Access Control
MAC-NE	MAC Network Element
MACsec	MAC Security
MER	Modulation Error Rate
MIB	Management Information Base
MM	MAC Manager
MMI	MAC Management Interface
Mm-MacNe	MM to MAC-NE interface
MPEG	Moving Picture Experts Group
MPLS	Multi-Protocol Label Switching
MPTS	Multi-Program Transport Stream
MSO	Multiple Systems Operator
MULPI	MAC and Upper Layer Protocol Interface
NCS	Network-based Call Signaling
NDF	Narrowband Digital Forward
NDR	Narrowband Digital Return
NMS	Network Management System
N+x	Node plus x
N+0	Node plus 0 (zero)
OOB	Out of Band
OSP	Outside Plant
OSS	Operations Support System
OSSI	OSS Interface
Oss-Mm	OSS to MM interface
PAG	PacketCable Aggregator
Pag-MacNe	PAG to MAC-NE interface
PAI	PacketCable Aggregator Interface
PCEM	PacketCable Event Messages
PCMM	PacketCable Multimedia
PHS	Payload Header Suppression
PHY	Physical Layer
PNM	Proactive Network Maintenance
PON	Passive Optical Network
PS	Policy Server
Ps-Pag	PS to PAG Interface
PTP	Precision Time Protocol
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RADIUS	Remote Access Dial-Up Server
R-DEPI	Remote DEPI
RF	Radio Frequency
RKS	Record Keeping Server
Rks-Pag	RKS to PAG interface
RMC	Remote MAC Core
RMD	Remote MAC Device

R-OOB	Remote OOB
RPD	Remote PHY Device
SAV	Source Address Verification
SCTE	Society of Cable Telecommunications Engineers
SF	Service Flow
SFID	SF Identifier
SFP	Single Formfactor Pluggable
SLeaf	Secure Leaf
SLeaf-MacNe	SLeaf to MAC-NE interface
SNMP	Simple Network Management Protocol
SNMPv3	SNMP version 3
SPTS	Single Program Transport Stream
TCP	Transmission Control Protocol
TFTP	Trivial File Transfer Protocol
TLS	Transport Layer Security
ToD	Time of Day
UDP	User Datagram Protocol
VLAN	Virtual Local Access Network
WDM	Wavelength Division Multiplex
Xhaul	Cross-haul
YANG	Yet Another Next Generation

Bibliography & References

[FMACloud] *FMA in the Cloud*, D. Johnson, J. Thompson; 2021 Fall Technical Forum.

[LeakageHighSplit] *Leakage Detection in a High Split World,* R. Coldren, M. Cooper, G. Tresness; 2021 Fall Technical Forum.

[QAMVideoDAA] *Delivering QAM Video in Distributed Access Architectures,* C. Howlett, D. Johnson, K. Meisen; 2019 Fall Technical Forum; https://www.nctatechnicalpapers.com/Paper/2019/2019-delivering-qam-video-in-distributed-access-architectures

DOCSIS® Flexible MAC Architecture System Specification, CM-SP-FMA-SYS-I02-210526, May 26, 2021, Cable Television Laboratories, Inc.

DOCSIS® Flexible MAC Architecture MAC Manager Interface Specification, CM-SP-FMA-MMI-I02-210526, May 26, 2021, Cable Television Laboratories, Inc.

Flexible MAC Architecture, YANG Modules, http://mibs.cablelabs.com/YANG/DOCSIS/FMA

DOCSIS® Flexible MAC Architecture PacketCable Aggregator Interface Specification, CM-SP-FMA-PAI-I01-200930, September 30, 2020, Cable Television Laboratories, Inc.

Flexible MAC Architecture, Google Protocol Buffers, http://mibs.cablelabs.com/GPB/DOCSIS/FMA/

DOCSIS® Flexible MAC Architecture OSS Interface Specification, CM-SP-FMA-OSSI-D03-210630, June 30, 2021, Cable Television Laboratories, Inc.

DOCSIS® MHAv2 Remote PHY Specification, CM-SP-R-PHY-I16-210804, August 4, 2021, Cable Television Laboratories, Inc.

DOCSIS® MHAv2 Remote PHY OSS Interface Specification, CM-SP-R-OSSI-I16-210903, September 3, 2021, Cable Television Laboratories, Inc.

DOCSIS® MHAv2 Remote PHY Downstream External PHY Interface Specification, CM-SP-R-DEPI-I16-210804, August 4, 2021, Cable Television Laboratories, Inc.

DOCSIS® MHAv2 Remote PHY Upstream External PHY Interface Specification, CM-SP-R-UEPI-I13-201207, December 7, 2020, Cable Television Laboratories, Inc.

DOCSIS® MHAv2 Generic Control Plane Specification, CM-SP-GCP-I05-200323, March 23, 2020, Cable Television Laboratories, Inc

DOCSIS® MHAv2 Remote DOCSIS Timing Interface Specification, CM-SP-R-DTI-I08-200323, March 23, 2020, Cable Television Laboratories, Inc

DOCSIS® MHAv2 Remote Out-of-Band Specification, CM-SP-R-OOB-I12-200323, March 23, 2020, Cable Television Laboratories, Inc

DOCSIS® 4.0 Physical Layer Specification, CM-SP-PHYv4.0-I04-210826, August 26, 2021, Cable Television Laboratories, Inc.

DOCSIS® 4.0 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv4.0-I04-210826, August 26, 2021, Cable Television Laboratories, Inc.

DOCSIS® 4.0 CCAP Operations Support System Interface Specification, CM-SP-CCAP-OSSIv4.0-I04-210521, May 21, 2021, Cable Television Laboratories, Inc.

DOCSIS® 3.1 Physical Layer Specification, CM-SP-PHYv3.1-I18-210125, January 25, 2021, Cable Television Laboratories, Inc.

DOCSIS® 3.1 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv3.1-I21-201020, October 20, 2020, Cable Television Laboratories, Inc.

DOCSIS® 3.1 CCAP Operations Support System Interface Specification, CM-SP-CCAP-OSSIv3.1-I21-210716, July 16, 2021, Cable Television Laboratories, Inc.

PacketCable™ 1.5 Specifications Dynamic Quality-of-Service, PKT-SP-DQOS1.5-C01-191120, November 20, 2019, Cable Television Laboratories, Inc.

PacketCable™ 1.5 Specifications Event Messages, PKT-SP-EM1.5-C01-191120, November 20, 2019, Cable Television Laboratories, Inc.

PacketCable™ 1.5 Specifications Electronic Surveillance, PKT-SP-ESP1.5-C01-191120, November 20, 2019, Cable Television Laboratories, Inc.

PacketCable™ 2.0 Specifications Electronic Surveillance Intra-Network Specification, PKT-SP-ES-INF-C01-140314, March 14, 2014, Cable Television Laboratories, Inc.

PacketCable™ Specification Multimedia Specification, PKT-SP-MM-C01-191120, November 20, 2019, Cable Television Laboratories, Inc.

