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## Next Generation CMTS – An Architectural Discussion

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## Introduction

Modular CMTS (M-CMTS) defined how to separate the downstream Edge QAMs (EQAMs) from the CMTS to permit the EQAMs to be shared between MPEG Video services and DOCSIS® services. NG M-CMTS (Next Generation M-CMTS) takes the architecture one step further by separating the upstreams from the CMTS. This architecture would transform the CMTS into a combination of a Packet Shelf consisting of a generic router and a PHY Shelf consisting of an RF gateway with the downstream and upstream RF electronics.

This paper will explore what the NG M-CMTS architecture might look like and what the various options are. The paper also explores the various architectural issues as well as the various marketing issues surrounding NG M-CMTS.

### **What is the Customer's Problems to be Solved?**

The following is a collection of problem statements from Cable Operators:

- 1) How can we continue to offer price-competitive high-speed services that compare favorably or exceed Telco VDSL2 and even FTTX solutions while maintaining the investments in operational experience and capital outlay in HFC network over the next 10+ years?
- 2) How can we scale the CMTS in such a way as to improve both cost from a service and/or per customer perspective, but also achieve certain management cost enhancements (operational, management)?
- 3) How can we deploy a modularized CMTS without losing reliability or availability, or increasing the time to repair?
- 4) What CMTS architectures could provide a more orderly migration path from current DOCSIS protocols to future protocols (that might operate directly over fiber)?
- 5) What, if anything, can be done to reduce the costs for the complete system in comparison with traditional I-CMTS designs assuming a given number of customers and service classes?
- 6) How might CMTS architectures evolve to incorporate increasingly convergent service offerings and the increasing importance of commercial services revenue?

## **Relating the CMTS Evolution with the DOCSIS Evolution**

I-CMTS addresses the implementation of DOCSIS 1.0, DOCSIS 1.1, and DOCSIS 2.0 for a data and voice environment.

M-CMTS introduces a separate universal EQAM. The universal EQAM permits HFC bandwidth to be shared between DOCSIS and MPEG-TS Video services. The universal EQAM also helps drive down the cost of the DOCSIS downstream channel.

NG M-CMTS is the natural evolution of M-CMTS where all the RF PHY circuitry is removed from the CMTS into a separate chassis. NG M-CMTS is addressing the additional scaling requirements introduced with DOCSIS 3.0 in addition to supporting the original goals of M-CMTS.

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## Review of Current Architectures

### Definition of DOCSIS CMTS Building Blocks

For the sake of analysis and discussion, this White Paper is defining a set of CMTS building blocks. Each building block represents a set of functionality that is of particular importance to the NG M-CMTS architecture.

**Network Processor**

The Network Processor performs layer 3 functions such as packet classification, rate shaping, queuing, quality of service (QoS), forwarding/switching/routing, filtering, flow verification, etc.

**NP MA**

The Network Processor Management Agent is the layer 3 configuration that has been extracted from the DOCSIS State Machine

**DS MAC Framer**

The DS MAC Framer includes all elements in the downstream data path related to packet formatting including the DOCSIS headers, segment headers, and BPI. It may also include segmentation and queuing engines.

**US MAC Framer**

The US MAC Framer includes all elements in the upstream data path related to packet formatting including termination of the DOCSIS headers, fragmentation, concatenation, segment re-assembly, and Baseline Privacy Interface (BPI).

**US MAC Scheduler**

The US MAC Scheduler manages the upstream bandwidth. Its inputs include data request messages and Ranging Request messages from the Cable Modem (CM). Its outputs include MAP messages, and Ranging Response messages.

**DOCSIS MA**

The DOCSIS MA (Management Agent) includes the DOCSIS MAC management message state machines (except for messages handled by the US MAC Scheduler), DOCSIS configuration file database (DB), subscriber DB, CMTS interface DB, HFC topology DB, etc.

**DS PHY**

The DS PHY contains the QAM modulator and upconverter. Its output is the DOCSIS RF Interface (DRFI).



The US PHY contains the burst demodulator.

When these CMTS building blocks get broken apart into separate chassis, they get combined with additional building blocks from the Modular CMTS architecture such as a DEPI framer. For simplicity, the M-CMTS building blocks are not included in the following architectural diagrams. Rather, the M-CMTS architecture building blocks are inferred by the mention in the diagrams of the M-CMTS protocol,

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## Integrated CMTS (I-CMTS)

### Architecture

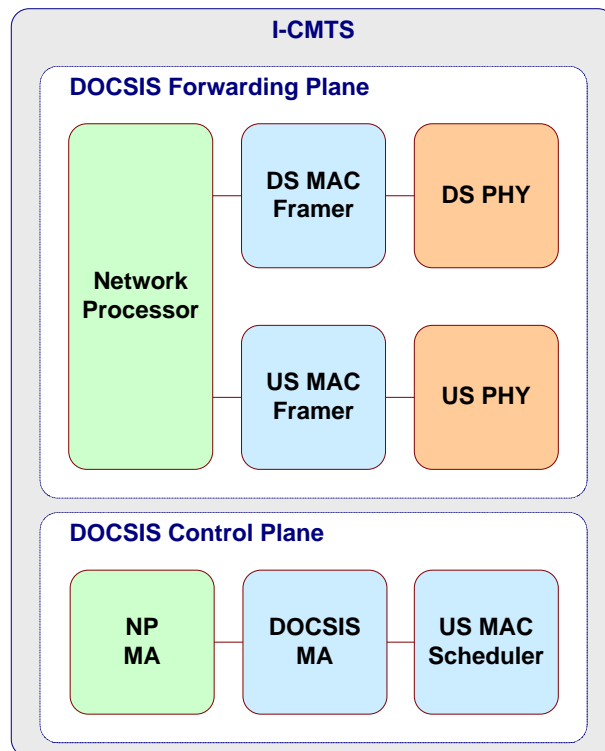


Figure 1: I-CMTS Architecture

### Discussion

The I-CMTS has all of its building blocks contained within one chassis. That chassis could be a pizza box chassis with all components on one card, or a larger chassis with multiple line cards.

## Next Generation CMTS -- An Architectural Discussion

In a traditional I-CMTS with multiple line cards, the downstream and upstream MAC and PHY were located within the same line card. Typical downstream-to-upstream ratios are 1x6 and 1x4 which expand to common card ratios such as 2x8, 2x12, and 5x20. Base ratios from new line cards are approaching 1x2 and 1x1.

Packet processing can be either centralized in the chassis or distributed to each line card. The upstream packet scheduler is generally located on the line card.

### Pros

*Simplicity:* The advantage of having all the DOCSIS building blocks on the same line card was simplicity. Co-location of the downstream and upstream was often a requirement of earlier DOCSIS MAC chip sets. Wiring was simple. Because the DOCSIS MAC domain could be entirely contained within the line card, writing code was simpler. Deployment and basic interconnection to fiber nodes was also simple if the deployment matched the downstream-to-upstream ratio of the line card. Management of one platform is simpler than managing multiple platforms. Finally, troubleshooting a fixed config on one line card was simple.

*Chassis Efficiency:* All-in-one line cards generally have simpler fail-over domains. One line card in a CMTS can protect all other line cards. For example, a 10 slot system could support nine active cards and one standby card. This is known as a N+1 fail-over domain.

*High Availability:* Proper design for high availability (HA) can result in meeting the goal of 99.999% availability for the CMTS. With all components in a single chassis, DOCSIS failure detection and recovery is limited to that one chassis. This may become significantly more challenging when a DOCSIS failure is spread over multiple chassis.

### Cons

*Fixed ratios:* The main disadvantage of the classic combination line cards was the resulting MAC domain had a fixed ratio of downstreams and upstreams. If the deployment scenario required a different ratio, then either downstream or upstream resources became stranded. For example, line cards with 1x4 ratios that get deployed as 1x2 have 50% of their upstream ports unused.

The fixed ratios become more of an issue with deploying channel bonding in DOCSIS 3.0. Downstream bonding groups in DOCSIS 3.0 could be 3, 4, 8 channels, or any number in between. Upstream bonding could be 2, 3, or 4 channels. The upstream might even need to support four channels for bonding plus a few extra channels to support legacy modems. Downstream bonding might get deployed before upstream bonding. This results in a large number of downstream-to-upstream ratios that may change quickly with time.

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## Next Generation CMTS -- An Architectural Discussion

*Technology Transition:* The challenge with separate US and DS line cards is the transition to new technology. In general, new MAC chips are required. Also, the CMTS backplane must synchronize the DOCSIS clock and timestamp between line cards. MAC domains are now spread across line cards which may have both implementation impact and operational impact.

*Universal Services:* QAM modulators embedded in CMTS chassis at this point in time are not re-usable for standard video over MPEG-TS services. They are dedicated DOCSIS QAMs. To be able to support video, the QAM channels in a CMTS would have to be redesigned to support video, and would have to be able to compete with the video EQAM for price.

*Growth in QAM Technology:* Downstream QAM technology is on an extremely aggressive growth curve. QAM density is roughly doubling in density and halving in price every 1.5 to 2 years. This is driven in large part by the EQAM market. One very real disadvantage of locating downstream QAM technology within a CMTS is that such implementations will not keep up with the aggressive price/density changes that EQAMs are experiencing. The EQAM market is driven by the video market which at this point requires at least 4x the number of QAM modulators than the data market.

*Chassis Inefficiency:* RF resources can take up a large amount of chassis space. It is possible that large packet processing engines may be under-utilized when located in the same board or chassis as the RF components. For example, one Packet Processing ASIC chip set might be capable of supporting 10 Gbps of throughput. At 40 Mbps per QAM Channel, that is the equivalent of 240 QAM Channels. Each QAM Channel requires a QAM, an upconverter, a power amplifier, and supporting filtering. This would indicate that a Network Processor would be under-utilized if it was not in a chassis-based system with at least 240 QAM channels. This is well above what any CMTS on the market is providing today.

### **Observations**

The I-CMTS architecture in its various forms has done a great job of supporting the DOCSIS CMTS market for the first 10 years of DOCSIS deployments. It was what the market needed and what technology could provide.

I-CMTS is probably best suited to the low-to-medium density markets which generally have fewer variations in configurations. Accommodating various DOCSIS 3.0 bonding scenarios where the number of upstreams/downstreams grows beyond a few to 4, 6, 8 or more will probably be the breaking point for most I-CMTS architectures.

I-CMTS is also not applicable to the emerging universal QAM environment where QAM modulators are shared between DOCSIS and MPEG-TS Video.

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## NG I-CMTS

### Architecture

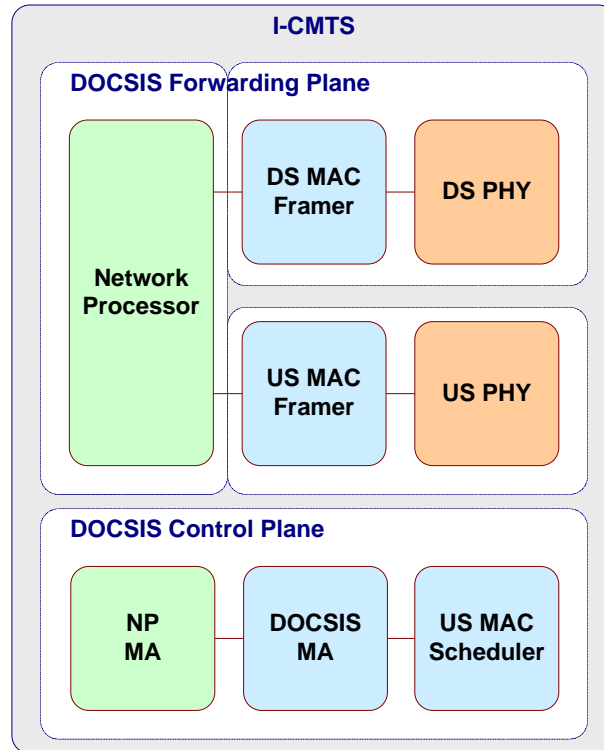


Figure 2: NG I-CMTS Architecture

### Discussion

In more recent CMTS designs, the DS MAC and DS PHY may be located on one line card while the US MAC and US PHY may be located on another line card. Other variations also exist where a downstream line card supplements another line card that contains both upstreams and downstreams. Depending upon the desired feature sets (typically DOCSIS 2.0 vs. DOCSIS 3.0), the downstream channels on the I-CMTS line card may not be used.

These approaches can be thought of as a Next Generation Integrated CMTS (NG I-CMTS). The NG I-CMTS becomes comparable under certain circumstances to the NG M-CMTS which, as we will see later, also has separate downstream and upstream line cards.

Packet processing again can be centralized or distributed.

## Pros

*Configurable Ratios:* Different ratios of downstreams-to-upstreams can be achieved by changing the mix of line cards.

## Cons

*Two N+1 Redundancy Groups:* With a traditional I-CMTS, some manufacturers can use one protect line card to backup the remaining working line cards. Now that there are two line card types, two backup cards are needed. Also the RF Switch complex (either internal or external) must support two N+1 redundancy groups. This reduces slot efficiency which reduces the number of ports available and thus the number of subscribers than can be supported. For example, the 10-slot system in the previous example would now have eight active cards and two standby cards. This is 11% less efficient than a 9+1 redundancy group.

Separate downstream and upstream line cards are not infinitely configurable. Instead, they have a finite number of combinations that are practical. For example, in an 10-slot system, the common choice of {DS Group, US Group} is {4+1, 4+1}. The next choice is {3+1, 5+1} or {5+1, 3+1}. The last combination of {1+1, 6+1} or {6+1, 1+1} is usually too extreme. There can still be a mismatch between the number of downstreams and upstreams used for fiber node connectivity versus what comes with a particular line card configuration, although the amount of stranded ports is usually less than the combination cards.

For chassis upgrades from combo cards to separate cards, ultimately more slot space is required which may require more chasses.

For new installations, the flexibility that separate downstream and upstream line cards provide can outweigh the lower density. Of course, if the CMTS already required more than one redundancy groups due to other reasons (such as RF losses in the switching network), then this might not be an issue.

*Dedicated QAM Channels:* Since the downstream QAM PHY is located in the CMTS, it is not a multi-vendor solution. As a result, this may not have the best price point for the customer.

*No Shared Services:* There is a much greater chance that the downstream QAM Channels will be DOCSIS only and will not support MPEG-TS Video. While this may not be much of a concern while QAM channel density is around two to four channels per physical port, it becomes a much larger issue when QAM technology is eight or more channels per physical port. As QAM density increases, there is a higher probability with I-CMTS that QAM channels will go unused when the number of DOCSIS QAM Channels deployed on a plant does not exactly equal the number of channels on a DOCSIS CMTS port.

### **Observations**

NG I-CMTS is more flexible than I-CMTS and is a welcomed improvement. NG I-CMTS should begin to address the needs of DOCSIS 3.0.

NG I-CMTS is still less flexible than M-CMTS, however, due primarily to a single vendor solution for QAM Channels and lack of MPEG-TS Video integration. The NG I-CMTS also does not take any advantage of external network processing resources that are located in the Edge Router.

Also, adding downstream channels to an existing CMTS may actually be more efficient with a M-CMTS retrofit than with a NG I-CMTS retrofit. A NG I-CMTS retrofit may require the addition of more RF line cards in order to handle the newer downstream channels. If there are no empty slots in the CMTS, then more CMTS chassis are required. M-CMTS upgrades utilize external RF components, so the impact to the CMTS chassis is only from the downstream MAC component which may be easier to fit into the chassis.

## Modular CMTS

### Architecture

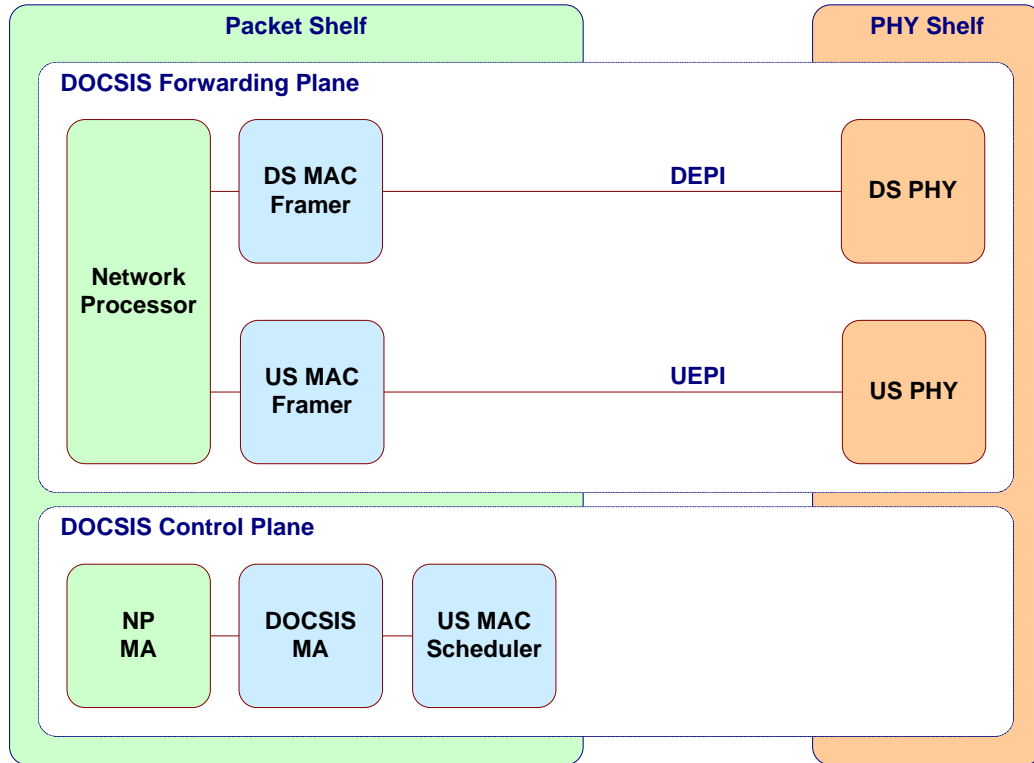


Figure 3: M-CMTS Architecture

### Discussion

The Modular CMTS architecture removed the downstream QAMs from the CMTS and placed them into a universal EQAM chassis. The universal EQAM will support DOCSIS data/voice/video or MPEG Transport Stream (MPEG-TS) video. Thus, the QAM modulators become a shared resource.

The CMTS without the downstream QAM carriers becomes known as the M-CMTS Core. The link between the M-CMTS Core and the EQAM is DEPI (Downstream External PHY Interface). DEPI is a L2TPv3 based pseudowire with two choices of sub-layer protocols: D-MPT (DOCSIS over MPEG-TS) and PSP (Packet Streaming Protocol). [1]

The philosophy of the M-CMTS architecture was to take the least amount of DOCSIS hardware and the least amount of DOCSIS software (in this case, none) with the

largest amount of common functionality between MPEG-TS video and DOCSIS. The common elements were basically MPEG-TS and timing.

### **Pros**

*Cost:* By removing the QAM modulators from the CMTS and retargeting the EQAM technology from video to DOCSIS, the goal is to produce a lower cost downstream path. Lower prices per channel for EQAMs come with increased channel density. In order to efficiently invest in QAM technology for deployment, EQAMs must be shared across services.

*Scalability:* In general, more bandwidth is required for DOCSIS in order to provide higher speed services. EQAMs are getting much denser very quickly. This is a good match.

*Configurable Ratios:* Since the EQAM is separate and can be added in increments, different ratios of downstream to upstream PHYs can be achieved. The ultimate flexibility depends upon the design of the M-CMTS Core and if it permits downstream MAC channels to be added independent of upstream channels.

*Shared Services:* The EQAM represents a bandwidth gateway between the provider's backbone and the HFC plant. EQAMs literally convert MHz to Mbps. EQAMs convert a natural resource – in this case HFC plant spectrum – into a finished product – in this case IP/Ethernet ports – which can now be used by a multitude of applications and services.

The current services include VOD (Video on Demand), SDV (Switched Digital Video), Digital Broadcast, and IP/DOCSIS-based data/voice/video. One well designed set of universal EQAMs can support all of these services. A Universal EQAM which combines the different services also permits far better statistical multiplexing gains and better usage of precious HFC spectrum. Furthermore, the service infra-structure can change over time or geographical location without a change in the RF plant connectivity. This is a huge benefit which becomes more apparent as QAM density increases.

For example, QAM Modulator technology in newer EQAM products is four or eight QAM channels per port. If services were not shared, then the only efficient configuration available would be eight QAM Channels for VOD, eight QAM channels for SDV, and 8 QAM channels for DOCSIS. The example gets more extreme at 16 channels per port.

*Dynamic Service Allocation:* The use of M-CMTS is the first step into the separation of resources from applications for dynamic resource allocation. In this case, an EQAM is the shared resource that applications such as VOD, SDV and DOCSIS can dynamically request via a Universal Edge Resource Manager(UERM).

Once a pool of QAM channels supports shared services, the assignment of the number of QAM channels to each service type can be changed on a time of day or on a usage-based service through the use of a UERM. This further reduces the total number of QAMs needed.

Figure 4 shows a QAM sharing architecture where EQAMs are shared in a DOCSIS and MPEG Video environment.

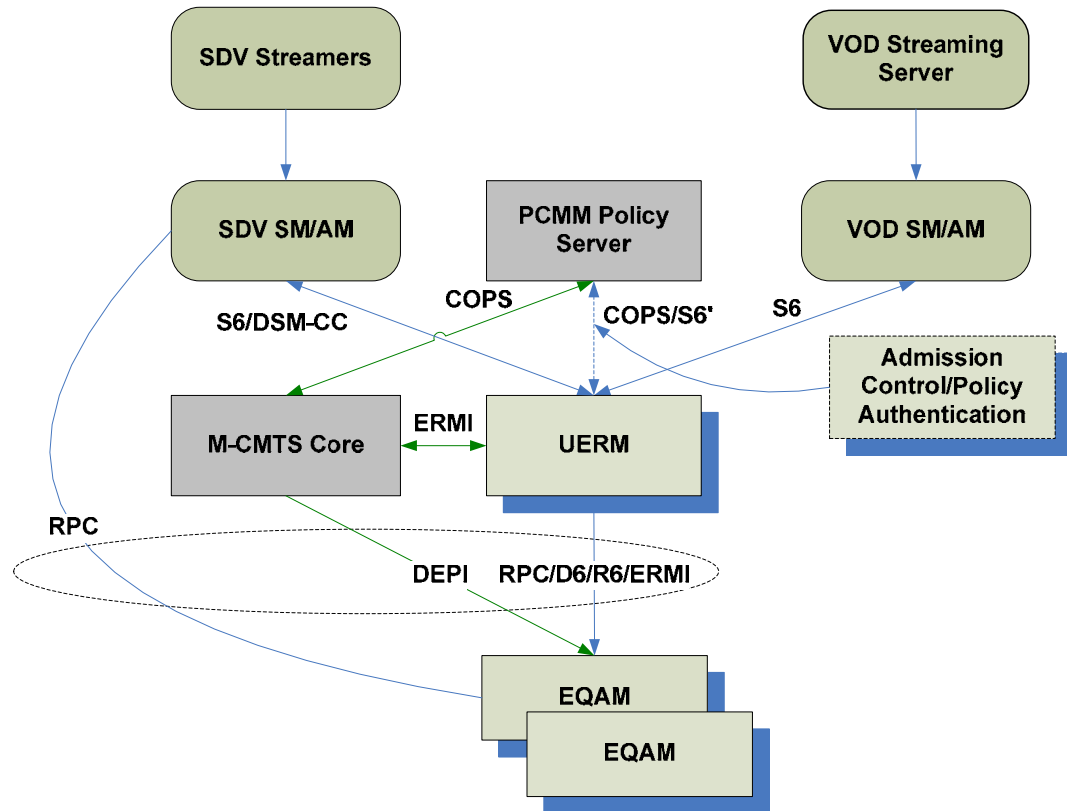


Figure 4: QAM Sharing Architecture

**Cons**

*Management:* From a strictly CMTS perspective, there are now at least two chassis to manage rather than one chassis. The automated provisioning included in the M-CMTS Downstream External PHY Interface (DEPI) alleviates most of this issue, but it is still more work than an I-CMTS. It is worth noting that the EQAMs already exist in the network and are already being managed. This has to be expanded now from purely MPEG-TS video to include DOCSIS.

*Wiring:* Downstream and upstream connections go to two separate chassis, each of which must have its own RF Switch redundancy strategy. It is not at all uncommon

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with head end equipment at a Cable Provider to have separate chassis for downstreams and upstreams.

*Protocol Complexity:* Additional protocols are needed. DEPI which is an extension of L2TPv3; ERMI (Edge Resource Management Interface) for management of the QAMs.

### **Observations**

The M-CMTS architecture is positioned to provide better management of RF Plant downstream bandwidth by the sharing of MPEG-TS Video and DOCSIS services within a universal EQAM. In doing so, the EQAM should provide an overall lower cost per downstream for the CMTS.

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## Next Generation M-CMTS Architectural Choices

This section introduces the Next Generation M-CMTS. The first part defines the problem that is trying to be solved. The next part presents four solutions and lists the PROs and CONs of each. The final section compares the NG M-CMTS system to other similar systems in the industry such as DSL and WiMAX.

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### NG M-CMTS Vision

#### Architecture

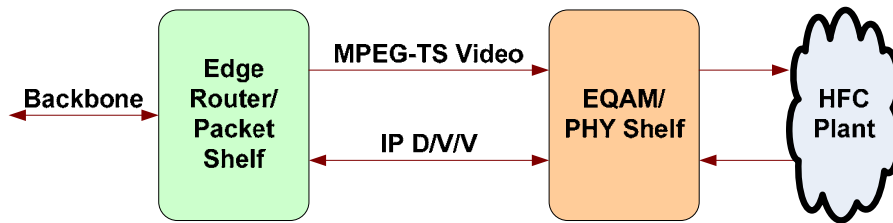


Figure 5: NG M-CMTS Vision

For convenience, this white paper defines a NG M-CMTS system as consisting of a Packet Shelf and a PHY Shelf. The Packet Shelf is based upon a generic Edge Router (a router that is subscriber aware). The Packet Shelf handles all the layer 3 functions. The Packet Shelf connects to the PHY Shelf through Ethernet and may do so directly or through a layer 2 or layer 3 network. The Packet Shelf may or may not be co-located with the PHY Shelf.

The PHY Shelf is an RF Gateway that connects from Ethernet to the HFC Plant. The PHY Shelf handles all layer 1 functions. It is one or more chassis that together include the universal EQAM in the downstream, the DOCSIS burst demodulators in the upstream, and may include an RF Switch complex for RF line card redundancy.

The next section lists the objectives that the NG M-CMTS architecture is trying to achieve. The following sections then explain some of the fundamental assumptions that NG M-CMTS architecture makes.

#### NG M-CMTS Objectives

NG M-CMTS takes the M-CMTS to the next level of disaggregation. In doing so, NG M-CMTS is trying to achieve the following objectives:

- Disaggregate the upstream from the M-CMTS Core to enable scaling of the upstream in the same modular fashion as was done with the downstream.

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- Allow the complete physical separation of the M-CMTS Core from the RF interfaces to reduce space requirements at the edge of the network. This has already become a critical concern to MSOs as VOD needs have grown, SDV equipment is deployed, and additional DOCSIS equipment is needed to support bonding.
- Enable scaling of the M-CMTS Core in a completely separate manner from the RF interfaces. This becomes critical as the need for additional upstream and downstream channels may otherwise dictate growth in CMTS needs by a factor of two, three or more in an inefficient manner. (Refer to the section "System Sizing" on page 42 for more detail)
- Expand the functionality of the interfaces to the RF components of the CMTS to allow for redundant links to one or more M-CMTS Core components of the CMTS (Refer to the section "High Availability" on page 38 for more detail)
- Permit the direct interface between the RF components of the CMTS and other components of the MSO network to enable DOCSIS and non-DOCSIS traffic to traverse the RF components of the CMTS (refer to Figure 4: QAM Sharing Architecture on page 16.)

### Impact of DOCSIS 3.0

The first assumption is the impact of DOCSIS 3.0.

DOCSIS 3.0 defines a DOCSIS Service Group (SG). A Service Group is a group of fiber nodes that share the same downstream and upstream spectral resources. Any bandwidth used by a subscriber on one fiber node within a SG will impact a user on the other fiber node in the same SG (It gets more complex than that, but this basic view is sufficient for this white paper). The long-term goal of the Cable industry is to get to one fiber node per service group, and then to reduce the number of households passed (HHP) per service group. This will greatly increase the amount of bandwidth a CMTS will have to provide.

At the same time, DOCSIS 3.0 introduces bonding technologies which combine multiple QAM channels together into one large pipe. Bonding is a key technology that will permit the migration of DOCSIS services from a typical 6 Mbps down, 500 kbps up to 100 Mbps down and 10 Mbps up. When the market is ready, DOCSIS 3.0 could deliver Gigabit service to a customer in the downstream and 100 Mbps service in the upstream.

As service providers enable higher tiered data services, the number of subs per interface goes down and the M-CMTS allows you to serve more nodes per CMTS. The added benefit of M-CMTS is to add more downstream and upstream carriers/QAMs per service group to provide more capacity to existing customers and

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minimize node splits while at the same time enabling DOCSIS 3.0-based bonding on those channels for DOCSIS 3.0 modems.

Instead of one or two downstream and upstreams per service group, DOCSIS 3.0 might start with 4 or 8 downstream QAM channels and 4 or 6 upstream QAM channels. It will grow over time from there.

### **Impact of Different Technology Trends**

The second assumption is that there is a difference in the technology trends of each of the primary technology components.

The goal of NG M-CMTS is to position the various technology components of a CMTS so that they can best scale to meet the demands of DOCSIS 3.0. The critical primary technology components are:

- 1) The Downstream PHY
- 2) The Upstream PHY
- 3) The Network Processor

The Downstream PHY technology consists of a QAM Modulator and an upconverter. That technology is radically changing, fueled by demand from the MPEG-TS Video market along with the conversion of what was once a difficult analog technology into something that is now a CMOS ASIC-based design using Direct Digital Synthesis (DDS) techniques which can digitally construct a spectrum. The output of the ASIC goes directly to some filters and a power amp before going to the HFC plant. This technology is rapidly changing. The industry is likely to see a doubling of density every two-to-three years for quite a while.

The Upstream PHY technology consists of a QAM Modulator. This technology is far more stable than the downstream technology. The technology is already in digital and ASIC form. The limiting factor in the upstream direction is the HFC plant bandwidth. Upstream bonding will double the number of upstream channels needed. DOCSIS 3.0 defines an extended upstream spectrum up to 88 MHz. Should this happen, another doubling of the upstream can be expected. All this will happen at a slower rate than the downstream expansion.

The Network Processor industry is a tough one. There are not many Network Processors to choose from. A Network Processor is a specialized chip that processes IP packets and is capable of extensive efficient header manipulation and complex packet queuing (technically, there is usually a separate traffic manager chip that works in conjunction with the packet processor to achieve the complex queuing). These chips are typically power hungry, tack up lots of space, and operate at rates much higher than the bandwidth of DOCSIS PHY chips that may be packed onto the

## Next Generation CMTS -- An Architectural Discussion

same line card. The Network Processor industry is being driven independently by the move to 10GE and eventually 100GE interface cards.

The DOCSIS MAC technology is important, but is a secondary concern. The main scaling challenges the DOCSIS MAC faces are:

- 1) How many DOCSIS MAC framers can fit into one FPGA or ASIC?
- 2) How many DOCSIS upstream channels can be scheduled by one CPU?
- 3) How much processing power and memory is required for DOCSIS subscriber management?

The various solutions examined in this section focus on separation of the three primary technologies and different placement of the DOCSIS MAC technology to try and achieve different trade-offs. By separating the downstream PHY, the upstream PHY, and the packet processor, the overall CMTS system will be able to better enable a distribution of new components rather than making all components grow together in parallel when they don't need to.

Rather than having the fast technology cycle of one component held up by a slower technology cycle of another component, they can grow somewhat independently. This will all help to account for the upcoming explosion in downstream and upstream ports per service group.

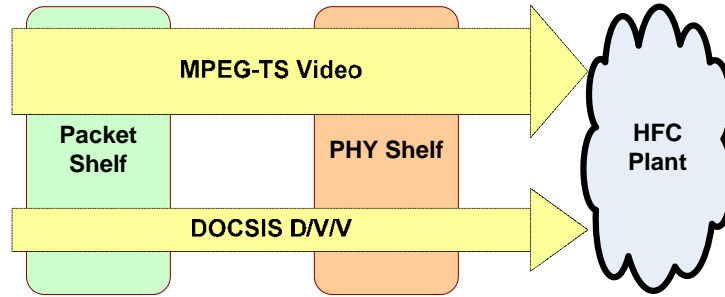
### **Impact of the Intelligent Network**

The third assumption is that an Edge Router exists behind the CMTS and that that Edge Router function can be migrated to include L3 subscriber management. This would mean that the Edge Router has enough memory to handle per subscriber level information and packet processing capability to manage as much as 100,000 or more flows (for example).

The fourth assumption is the RF gateway technology as exemplified by the universal EQAM will continue to evolve and will be capable of absorbing the DOCSIS upstream PHY either within the same chassis or as a companion chassis.

The fifth assumption is that if the previous two assumptions are true, a separate CMTS chassis is not needed, and that the DOCSIS functionality can be absorbed into the Edge Router and the RF gateway. This is a critical assumption. If one of these two chassis does not exist, then the CMTS functionality cannot be absorbed.

## Impact of MPEG Transport (MPEG-TS) Video Deployment



**Figure 6: Converged MPEG-TS Video and DOCSIS Architecture**

The sixth assumption is that the combination of the Edge Router and the RF gateway will manage both MPEG-TS Video traffic and DOCSIS traffic. This is important as MPEG-TS Video currently occupies the greater share of network resources (such as bandwidth). As such, MPEG-TS Video brings the Edge Router and RF gateway into existence and helps justify the large scaling of each machine in a much earlier time frame than DOCSIS could do alone.

### Summary

Here is a re-statement of the six assumptions that form part of the NG M-CMTS vision.

- 1) The increased bandwidth and variability of service group sizes change as a result of DOCSIS 3.0.
- 2) The primary CMTS components (packet processor, downstream PHY, upstream PHY) each have different technology improvement cycles.
- 3) The Edge Router can perform high concentrations of subscriber management.
- 4) The PHY Shelf can evolve from an EQAM to an RF Gateway which includes upstream PHYs and downstream PHYs, or it will be okay to have separate US PHY Shelves.
- 5) The combination of the Edge Router (Packet Shelf) and the RF Gateway (PHY Shelf) can absorb the CMTS functionality.
- 6) The Edge Router and RF Gateway will manage both MPEG-TS video and DOCSIS IP data/voice/video.

## NG M-CMTS Option 1 - Remote US PHY

### Architecture

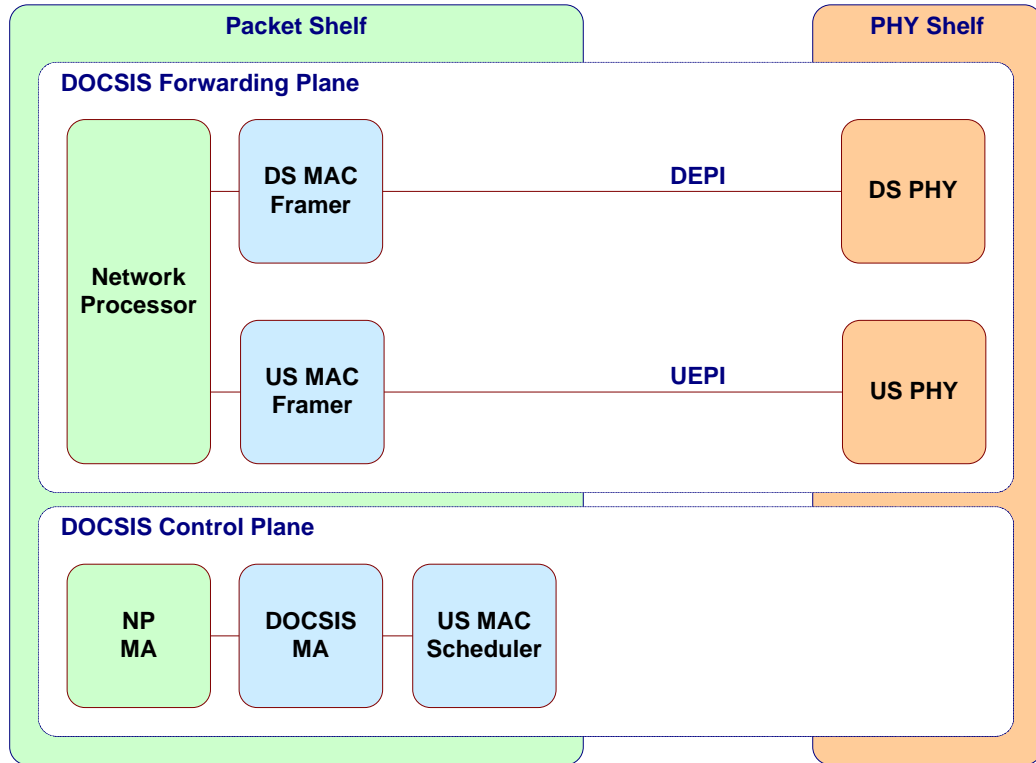


Figure 7: NG M-CMTS Option 1 Architecture

### Discussion

In option 1, the US PHY is removed from the CMTS chassis and placed either in the same chassis as the DS QAM modulator or in its own chassis. Interconnectivity is done with Ethernet. As such, Option 1 is attempting to achieve the same goals as the M-CMTS in extracting the least amount of DOCSIS hardware and the least amount DOCSIS software into a separate chassis.

The Modular CMTS upstream interface, unofficially referred to as “UEPI” (pronounced *you-eppie*) is very much like DEPI. It is a PSP (Packet Streaming Protocol) L2TPv3-based pseudowire. UEPI connects each logical channel in the upstream PHY to a matching channel in the Upstream MAC Framer with an L2TPv3 session. UEPI signaling allows the M-CMTS Core to configure the RF parameters of the Upstream PHY Shelf in the same manner the DEPI permits the Downstream PHY Shelf to be configured.

## Pros

*Simplicity:* This is about as simple an implementation as could be achieved. All CMTS software is preserved in the Packet Shelf.

## Cons

*US Throughput Performance:* Since the US scheduler is located in the Packet Shelf, the Packet Shelf and the PHY Shelves must be co-located and interconnected with high-speed, low-latency Ethernet connections so that the delay introduced by the UEPI architecture does not significantly impact the DOCSIS request-grant delay.

*US Scheduler Scalability:* The US Scheduler is a CPU intensive activity. As the number of upstreams to be scheduled increases, more and more CPU cycles are required. To support the scheduling of the number of upstream channels that a Packet Shelf may have to support would require multiple CPU cores. It is hard to scale the US scheduling when the CPU is a centralized resource, especially when a generic solution might have to design for the worst case number of upstream channels.

## Observations

There is a market need, at least for a certain percentage of the market, to be able to locate the Packet Shelf at a different location than the PHY Shelf. A typical example would be if the Packet Shelf was a large router which then serviced multiple PHY shelves located in multiple smaller hub sites.

As such, Option 1 is not a complete solution for all deployment situations. It may be useful for early isolated deployments, but not as an only solution. Option 2 addresses the limitations of option 1.

## NG M-CMTS Option 2 - Remote US PHY and Scheduler

### Architecture

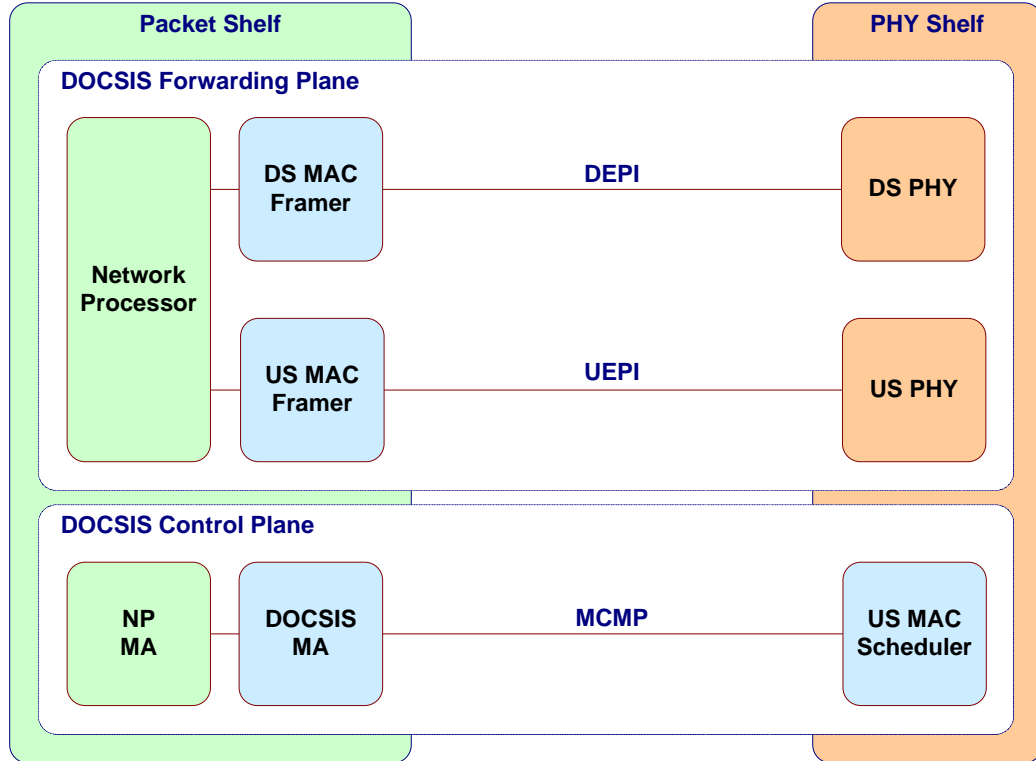


Figure 8: NG M-CMTS Option 2 Architecture

### Discussion

In option 2, the US PHY plus the US scheduler are moved to the US PHY Shelf. This addresses the limitation that Option 1 had. Thus, Option 2 achieves the goal of extracting the least amount of DOCSIS hardware and the least amount DOCSIS software into a separate chassis to arrive at a working solution.

Option 2 does require a new software interface between the Packet Shelf and the PHY Shelf. While UEPI could set up and tear down connections, a second software interface is required in the management and control plane to program the US MAC Scheduler. This interface is denoted in this White Paper with the generic acronym MCMP (M-CMTS Management Protocol).

There is also the issue of MAPs. The Upstream MAC Scheduler was placed in the PHY Shelf so that Requests could be received locally and that MAPs could be generated and derived to the downstream locally. This now means that the QAM Channel in the downstream PHY must receive content from two sources: payload

## Next Generation CMTS -- An Architectural Discussion

packets from the Network Processor and packets containing MAPs from the upstream PHY Shelf.

DEPI currently only allows one connection per QAM Channel. This is because DEPI does not use closed-loop flow control. Instead, it is the responsibility of the sending entity to rate-limit its output to always be less than the payload of the QAM Channel.

To accommodate the delivery of MAPs, two DEPI connections would be permitted to terminate on one QAM Channel. The simplest approach to flow control would be to configure a fixed amount of bandwidth to each flow, and each source rate shapes to that flow. For example, MAPs may be allowed 2 Mbps. The upstream scheduler would never send more than 2 Mbps, subject to a negotiated burst profile. The Packet Shelf would also limit its traffic to the remaining QAM Channel capacity (approximately 36.5 Mbps). Care must be taken not to count the DEPI overhead which would not be put onto a downstream QAM Channel.

### Pros

*Centralized Software Model:* This model is attractive for an existing CMTS that already has centralized software and wants the least amount of changes to its existing software model.

*Simple PHY Shelf:* This model is also attractive to US PHY manufacturers who have access to the layer 1 aspects of DOCSIS but who do not have access to the more complicated software models that a DOCSIS CMTS requires.

### Cons

*Software Partitioning:* The scheduler is an integral part of the upstream software design. Removing the scheduler and still being able to offer all the advanced services that the DOCSIS upstream requires may involve quite a bit of database replication between the Packet Shelf and the PHY Shelf. Adding to that complexity is that fact that there may be multiple databases in implementation and most of them are dynamically changing. Thus, additional software may be required just to verify that the databases on each side remain in sync. Thus, the technical challenge for this particular repartitioning should not be underestimated.

*Change to DEPI:* To allow two sessions per QAM Channel instead of just one. One session would be for content from the Packet Shelf, while the other session would be from the Upstream PHY Shelf. Since the sources are different, this would also require two L2TPv3 Control Connections.

Since DEPI does not have flow control, the simplest solution is to have each session configured to a portion of the QAM payload bandwidth. Each source would rate shape the traffic to not exceed this bandwidth limit. The sum of the MAP bandwidth

limit and the data bandwidth limit would be less than the payload bandwidth of the QAM Channel in order to prevent QAM overflow.

For example, MAP traffic on a QAM which might have to describe four different upstreams may require 2 Mbps. The Upstream PHY Shelf would generate MAP traffic with a burst profile that would not exceed 2 Mbps. Note, to prevent delaying MAPs, it is the MAP calculation and generation that needs to be spread out, rather than the delivery of the MAP messages.

If the QAM Payload was say 38 Mbps, then the Packet Shelf would be configured to deliver  $38 \text{ Mbps} - 2 \text{ Mbps} - 0.5 \text{ Mbps} = 35.5 \text{ Mbps}$ . The extra 0.5 Mbps is an example of headroom that should be allowed so that the QAM buffer does not overflow.

While not an optimal approach, this is inevitable with NG M-CMTS systems.

### **Observations**

Option 2 mirrors DEPI and leverages the DEPI interface work. However, the system architecture and software implementation considerations are more important than re-using an interface specification.

Option 2 in theory permits a simple upstream PHY shelf which could be made by non-CMTS companies at potentially a lower price point. The reality is that the market for an US PHY Shelf is significantly smaller than the EQAM market and will thus attract fewer manufacturers.

Option 2 leaves the bulk of the DOCSIS code in the Packet Shelf which is intended to be a high-end router. That might not be the best place to put the DOCSIS code if the high-end router is a mission critical resource for the network, or if the router is made by a company that does not specialize in CMTS software.

All of these reasons take us to Option #3.

## NG M-CMTS Option 3 - Remote US MAC

### Architecture

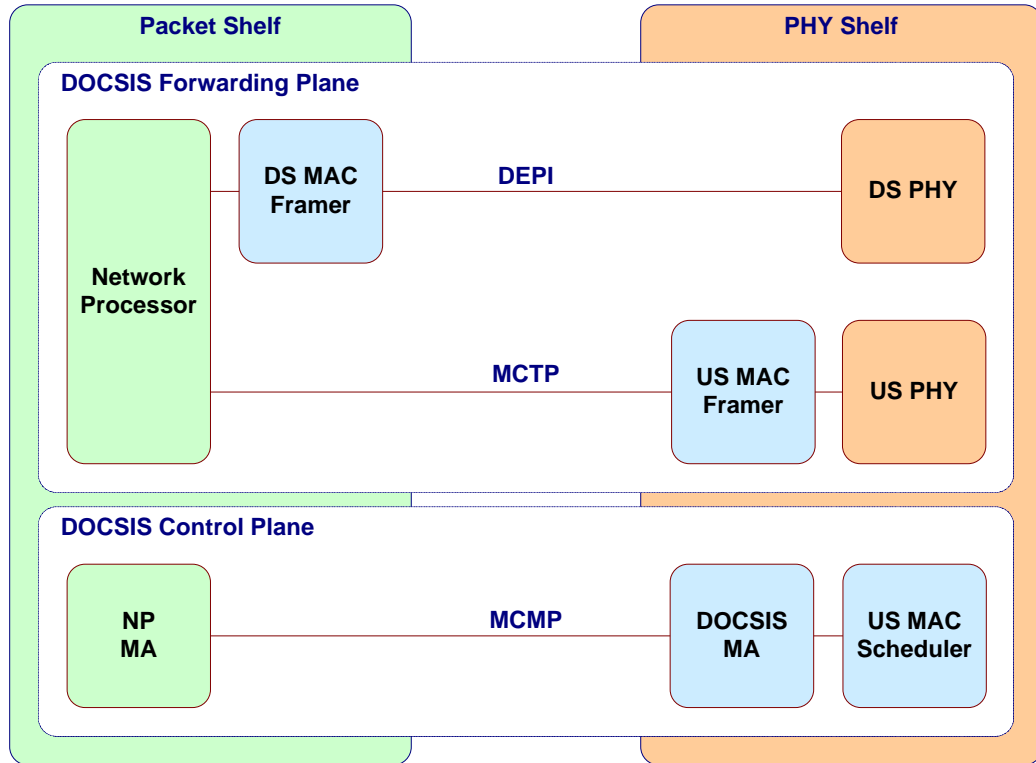


Figure 9: NG M-CMTS Option 3 Architecture

### Discussion

In option #3, the DOCSIS MA, the US MAC Framer, the US Scheduler, and the US PHY are all relocated to the US PHY Shelf. The US Shelf virtually inherits all the complexities and specifics of CMTS behavior. The US MAC Framer is now located in the US PHY Shelf. Because of this, the output of the US PHY shelf is whole IP packets. While this is different from UEPI, a pseudowire or equivalent interface will still be needed so that packets can be tagged with a flow identifier. This new interface is denoted for the moment as MCTP (M-CMTS Tunneling Protocol).

### Pros

*Simpler Router Model:* The big win here is that the central Packet Shelf could be implemented with a generic router. If the Upstream PHY Shelf and the M-CMTS Management Protocol (MCMP) protocol were designed appropriately, the US PHY

## Next Generation CMTS -- An Architectural Discussion

Shelf could convert from DOCSIS signaling semantics to more generic router semantics.

The Edge Router would still have to be subscriber aware. Even if all the DOCSIS complexities could be contained in the US PHY Shelf, there is still an operation need to be able to query and troubleshoot individual service flows on both machines.

*Simple EQAM Model:* The same downstream approach as M-CMTS is used with minor changes. One change will be for the EQAM to be able to receive MAPs from the Upstream Shelf and data from the Packet Shelf. Currently, DEPI only accepts content from a single source.

### Cons

*Complicated US PHY Shelf Model:* The complexity of the entire DOCSIS CMTS system is housed in the US PHY Shelf. The DOCSIS MA on the US PHY shelf drives all the other system components. The interface to the Packet Shelf is as close to generic IP functionality as possible.

*Asymmetrical System Architecture:* The downstream model and upstream model is completely different. The DS MAC is in the Packet Shelf while the US MAC is in the PHY Shelf. Further, the software that controls the DS PHY Shelf is actually in the US PHY Shelf!

### Observations

This is not a purist architecture. Rather, it is an architecture that is driven by completely different goals in the downstream and upstream direction.

In the downstream, the DS PHY Shelf (EQAM) has to be extremely inexpensive, be shared with MPEG-TS Video, scale to larger and larger numbers of channels, and has to keep pace with a fast-changing QAM technology.

In the upstream, the US PHY Shelf cost, while always important, is secondary to the DS PHY Shelf and the Packet Shelf costs. Scaling is generally limited to four-to-six channels per upstream (due to limited HFC Plant bandwidth), and the technology is very stable.

It is also driven by technology. The US PHY just does not separate from the CMTS as easily as the DS PHY did.

It is driven by history. The DS separation and design are established. New products have been built and are entering the market.

It is driven by priorities. The highest priority was optimization of the DS Packet Shelf (EQAM). The next priority was the optimization of the Packet Shelf. The last priority was the US PHY Shelf.

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## NG M-CMTS Option 4 - Remote MAC

### Architecture

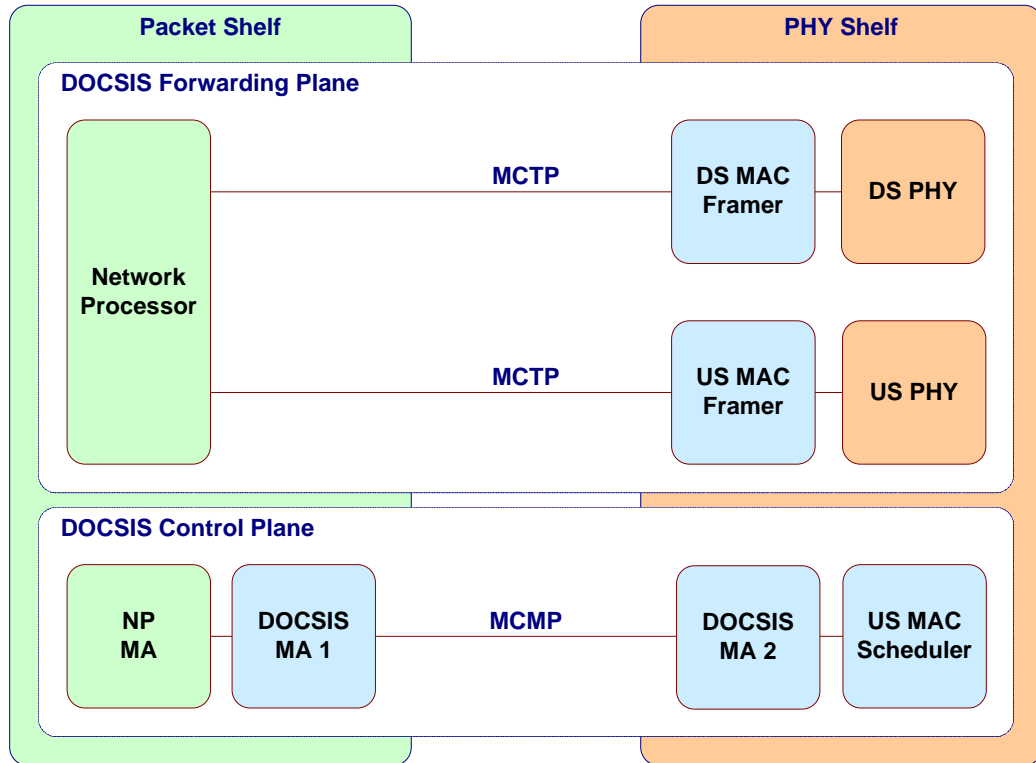


Figure 10: NG M-CMTS Option 4 Architecture

### Discussion

What if? What if there was a blank sheet of paper? What if there was no CMTS core to port or existing platforms to be leveraged? What might such a solution look like? What have others in similar circumstances done?

Option 4 puts both the downstream MAC Framer and the upstream MAC Framer in the PHY Shelf. This approach reasons that the primary goal is to separate the Layer 1 PHY and Layer 3 Packet Processing entities and that the Layer 2 framer is negotiable.

The downstream MAC framer consists primarily of the DOCSIS header formatting, Baseline Privacy Plus (BPI+), and Payload Header Suppression (PHS). The presumption in Option 4 is still that the Packet Shelf is doing all layer 3 downstream

## Next Generation CMTS -- An Architectural Discussion

functions such as classification, quality of service including rate-shaping, load balancing (DCC), and bonding. Pushing these functions into the EQAM would be yet another level of EQAM sophistication.

The DOCSIS MA may be separated between the two chassis. Potential variations of this model may exist where the DOCSIS MA could live entirely in the Packet Shelf or the PHY Shelf.

Other architectures in industry that might parallel Option 4 are DSL (Digital Subscriber Line) and WiMAX. However, as discussed in a later section, neither technology directly solves the problem that NG M-CMTS is trying to solve.

### Pros

*Symmetrical Data Paths:* With both the downstream and upstream MAC Framer in the PHY Shelf, the upstream and downstream data paths would be consistent. The new M-CMTS data plane interface (MCP) could probably be defined to work in either direction. The software structure on the upstream and downstream PHY Shelves may continue to be unsymmetrical, so it is a limited win.

### Cons

*Incompatible with DEPI:* Moving the MAC to the downstream chassis would change the definition of what an EQAM is. This could derail the last three years of development work in getting universal EQAMs to market.

### Observations

This does appear to be a more symmetrical architecture. However, if the split of the DOCSIS MA converged between Option 3 and Option 4 to the same solution (very possible), then the only difference is the location of the DS MAC framer. Since the downstream direction is defined already, products are built, and the downstream is not fundamentally broken, then it is very hard to justify changing it for purist purposes.

There is a school of thought that if the downstream DOCSIS Framer was in the EQAM, and the content transmitted were something simple such as only CBR video flows, the M-CMTS Core would not be needed and could be bypassed. An entire separate white paper on the pros and cons could be written on this premise. In summary, it is an approach driven by cost. To be practical, as the Packet Shelf scales upwards in connectivity, to the tune of 100s or 1000s of channels, the cost per channel of the Packet Shelf will become low enough that bypassing the Packet Shelf is more trouble than it's worth.

## Comparison to DSL Architecture

### Architecture

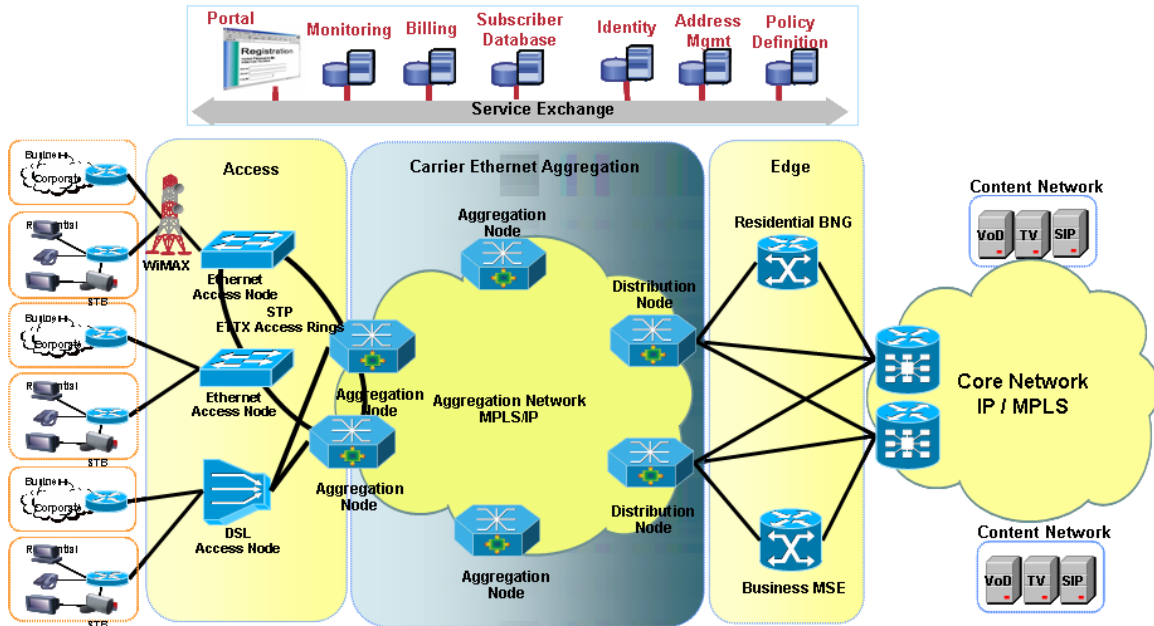


Figure 11: DSL and WiMax Architectures

### Discussion

The first model that is interesting to observe is the Digital Subscriber Line (DSL) model. DSL has a chassis called a Digital Subscriber Line Access Multiplexer (DSLAM) that contains a MAC and PHY for the upstream and downstream. All the intelligence is in a second box called a Broadband Remote Access Server (BRAS). The BRAS is where all the L2 sessions terminate (usually PPPoE), RADIUS AAA functions and IP addressing, protocol filtering (in many cases) are assigned to user equipment (UE)/customer premise equipment (CPE), plus QoS and other functions.

The DSLAM is a relatively simple, dense, and inexpensive device. The BRAS is complicated, not inexpensive, and is a specialized box. It is not a generic router. Due to DSL's point to point nature, QoS and all other functions that are equivalent to the DOCSIS MA would be centrally located.

### Observations

DSL is quite different than DOCSIS in its layer 1 and layer 2. For one thing, since the DSL PHY is point to point, there is not need for an upstream scheduler in the DSLAM and hence no need for a distributed subscriber management. The BRAS performs

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some similar functions that a CMTS might, although typically with different protocols. The core functions within the BRAS that drive the protocols might be reusable from a code or infrastructure view point.

Thus, the DSL model is interesting, but may not directly applicable.

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## Comparison to WiMAX Architecture

### Architecture

See Figure 11: DSL and WiMax Architectures on page 32.

### Discussion

The second model that is interesting to observe is WiMAX. WiMAX is a new point to multi-point wireless technology. The forwarding plane and control plane of WiMAX have been derived from DOCSIS 1.1. Again the MAC and PHY are located in the WiMAX Base Station. Because WiMAX must react quickly to the needs of the user, QoS, including downstream classification and rate shaping is also located in the Base Station. Remotely behind the Base Station is an Access Service Network (ASN) which handles session and subscriber management functions.

### Observations

The WiMAX model is intriguing at first. If WiMAX started from DOCSIS 1.1 and built from there, why not re-use the WiMAX model for NG M-CMTS? It sounds tempting, but the details are enlightening.

WiMAX has defined an interface called R1 between the Base Station and the ASN. In practice, though, each WiMAX vendor is using their own R1 proprietary, unpublished interface definition, a practice which is actually allowed by the WiMAX specifications. There is also a lot of additional work that has gone into the WiMAX specifications that is unique for the wireless environment. While it may be an interesting model to study, it may be easier to start from scratch than to remove the wireless specific functions.

WiMAX also has the downstream QoS in the Base Station, the analogy to the Packet Shelf. To do so in Modular CMTS would require moving the Network Processor to the PHY Shelf. This defeats the goal of what M-CMTS is trying to achieve. It is worth noting that a WiMAX base station typically only supports four to twelve QAMs, and can cost \$20K or more. This is not the scale that NG M-CMTS requires.

## System Analysis

Once the correct architecture is chosen, then the next challenge is to build the right product for the right market that solves a real customer problem. This section takes a look at a variety of deployment scenarios that influence the correct choice of product.

## Deployment Flexibility

### Deployment Scenarios

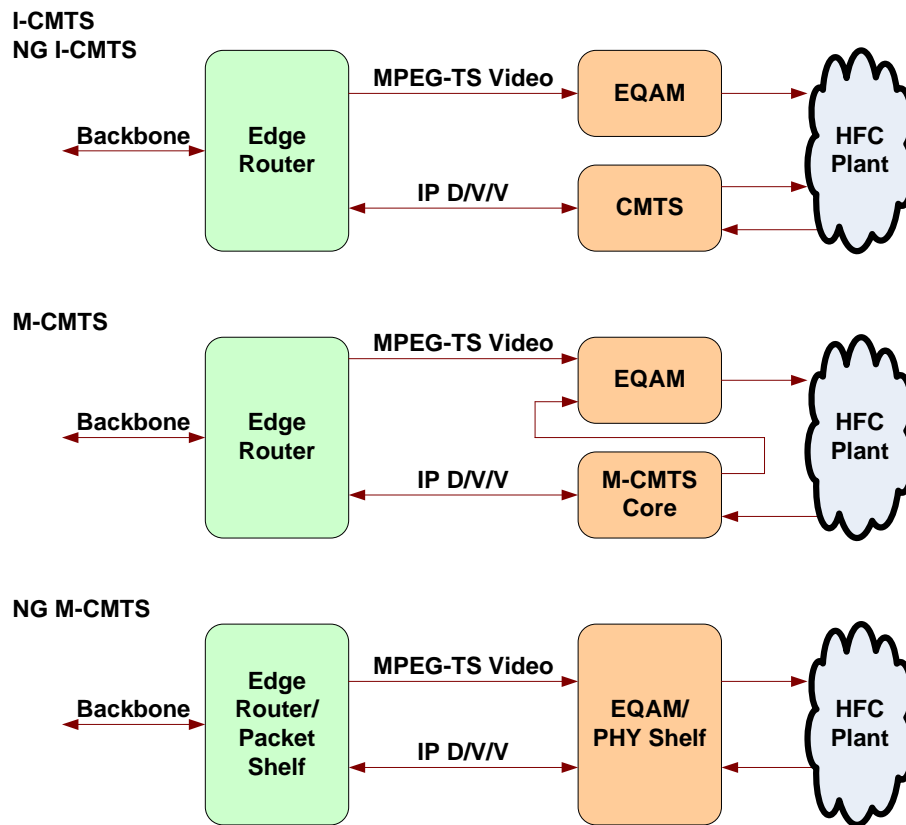


Figure 12: Summary of CMTS Architectures

### Discussion

The deployment scenarios for MPEG-TS Video and IP data/voice/video (D/V/V) for each of the CMTS architectures is shown in Figure 12. For simplicity, only the common data path components are shown. Control elements are not shown. Also, for a given Edge Router or Packet Shelf, there will likely always be more than one EQAM/CMTS/PHY Shelf, even though only one is shown.

## Next Generation CMTS -- An Architectural Discussion

I-CMTS is a stand-alone, self contained CMTS. It contains all PHY, MAC, and packet processing components required for its operations. Behind it sits a generic Edge Router. In the early days of DOCSIS, it was hoped that the CMTS could be a simple bridge and that the Edge Router would manage all routing and layer 3 functions. In practice, the CMTS now handles far more detailed layer 3 operations than the Edge Router does. The Edge Router's main task is to run more complex routing algorithms such as a BGP. Other than knowing the IP address, the Edge Router today is generally unaware that it has a DOCSIS CMTS connected to it.

MPEG-TS Video is delivered over UDP/IP through the Edge Router to the EQAM. Many variations on this theme exist, including completely separate independent networks for the MPEG-TS Video and IP D/V/V services. However, going forward, with the consolidation of the video and data networks, a common Edge Router should be the goal.

M-CMTS re-arranges the functionality of the CMTS and EQAM by moving the downstream QAM modulators out of the CMTS and into the EQAM, making the EQAM a universal EQAM capable of handling all downstream services.

NG M-CMTS further re-arranges the functionality of the CMTS and Edge Router by removing the downstream and upstream packet processing out of the CMTS and replacing it with the functionality already in the Edge Router. This simplifies the CMTS further and reduces it to an upstream PHY Shelf. In some implementations, the upstream PHY shelf will get combined with the EQAM functionality into a common PHY Shelf or RF Gateway. This will actually reduce the different types of boxes to be managed from three to two.

### Observations

Can the market really support all three architectures? Can any one CMTS vendor really support all three architectures, complete with feature parity and timely release of new hardware technologies such as faster processors and denser QAMS? Will NG M-CMTS replace M-CMTS? Is there still room for I-CMTS?

As stated earlier in the I-CMTS analysis, I-CMTS will probably stay around for a long time in the low end of the market where density is not important, where integration with video is not important, and where DOCSIS 3.0 can be handled with an isolated set of DS to US ratios (4x4 for example).

M-CMTS has the ability to service a large portion of the market. Because of the density of M-CMTS products, M-CMTS may be better suited to medium-to-large scale markets where a diverse set of DS to US ratios are required and where a universal QAM technology that handles both MPEG-TS and DOCSIS data/voice/video (D/V/V) would be needed.

NG M-CMTS seems like the next generation of M-CMTS. If the industry decides to pursue NG M-CMTS, it would make sense to replace the M-CMTS for new applications.

Ironically, while M-CMTS can be supported out of the current generation of CMTSs by converting the CMTS to a CMTS Core, migrating a CMTS to NG M-CMTS requires converting the CMTS into an US PHY Shelf instead of an M-CMTS Core! Those are two very different scenarios from an implementer's viewpoint.

Will it make sense to migrate deployed M-CMTS systems to NG M-CMTS? If the systems are not migrated that means that the M-CMTS system has to be supported indefinitely. Migrating the systems means that something that is working and deployed has to be changed.

This, of course, is the classic trade-off. There has to be a really compelling feature to upgrade an installed platform. Something significant like new features or increased density. In any case, deployment plans for NG M-CMTS should be evaluated as to what role deployed I-CMTS and M-CMTS systems should or should not play.

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## Vendor Flexibility

### Deployment Scenarios

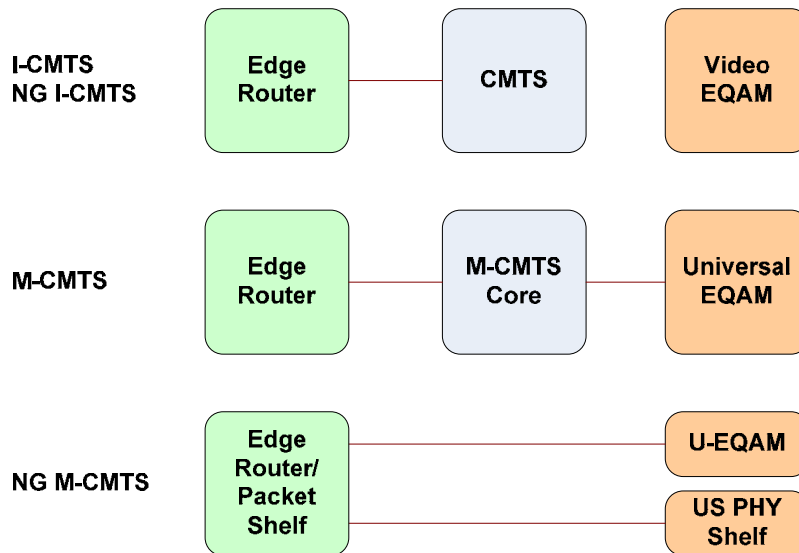


Figure 13: Vendor Flexibility

### Discussion

One of the reasons quoted for deploying NG M-CMTS has been the ability to mix and match CMTS components from the best-in-class vendors. Figure 13 shows the

basic configuration of the three proposed CMTS architectures. The NG M-CMTS implementation is shown with a separate DS PHY Shelf (the EQAM) and upstream PHY Shelf. This discussion is independent of physical location of the devices or if there are additional network elements such as aggregations switches.

### Observations

I-CMTS provides complete independence between the Edge Router, the Video EQAM, and the CMTS. Thus, there is complete freedom to choose the CMTS and the Edge Router from different vendors. The same is true for the EQAM, although it is not part of the solution at this point.

M-CMTS keeps the same number of boxes, but rearranges the functionality of the EQAM and CMTS to make more efficient use of the EQAM.

The difference is that the DOCSIS QAMs may now be purchased from an EQAM vendor rather than the CMTS vendor. While this seems like a tangible benefit, it is interesting to note that all the CMTS vendors are now also becoming universal EQAM vendors. Perhaps it is the MPEG-TS Video market that will ultimately benefit from a competitive perspective.

A CMTS is a complex device. The belief is that by disaggregating it into pieces, each piece will be easier to build and thus will permit more competition. This is certainly true with the EQAM. By removing the complex layer 3 network processing from the CMTS and putting it into a platform like an Edge Router which specializes in this kind of functionality, it may not expand the choices of vendors for Edge Routers, but it may expand the choices of vendors for the PHY Shelf.

The challenge for equipment developers will be to ensure that the increase in operational complexity from managing separate components does not overshadow the benefits outlined in this paper.

NG M-CMTS eliminates the separate CMTS chassis and focuses the functionality into the Edge Router and a PHY Shelf. It should be noted that if the US PHY shelf is implemented in a separate chassis from the EQAMs, then the same number of chassis still exist, and it is just the functionality of the CMTS and Edge Router chassis that was redefined. CMTS functionality now exists in all two or three chassis.

The NG M-CMTS specifications will have to be very well defined to permit complete independence of vendors. Beyond the specifications, there are operational considerations. There is the issue of how management tasks are coordinated, including the gathering of statistics and command line interfaces (CLI), by which a multi-vendor solution would be complicated.

Who is the solutions provider in such best-in-class, multi-vendor environments? In other words, when the system doesn't work, which of the multiple vendors will step

up and fix it? Can it be assumed that whoever provides the Packet Shelf “certifies” or otherwise validates that the selection of a PHY Shelf will operate seamlessly?

A multi-vendor environment may have its benefits, but it also introduces its own challenges. These are challenges that the NG M-CMTS architecture would need to address. While this appears a daunting task, architectures such as PacketCable have set precedence by integrating more boxes and more vendors together than this.

A simpler test can be applied to the NG M-CMTS architecture. What if all the components were from the same vendor? That would take care of the solution provider, CLI, and management issues. However, would that vendor be able to produce a system that was better than a traditional CMTS? The answer would have to be yes if NG M-CMTS is to be considered a viable solution.

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## High Availability

### Deployment Scenario

#### Case A: Small System Redundancy



#### Case B: Large System Redundancy

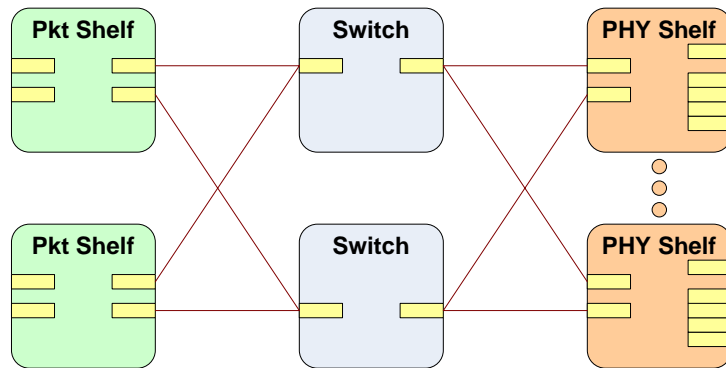


Figure 14: High Availability Architecture

### Discussion

High Availability (HA) is the name given to the task of ensuring that a platform or a system will remain operational as much as possible. A typical measure of HA is the

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percentage of uptime. A system that has the classic five 9's of reliability would be a system that would be operational 99.999% of the time. This equates to less than 5.26 minutes of downtime per year.

To achieve this goal, one of the techniques used is component redundancy. A typical I-CMTS in 2008 will have the following internal redundancy groups:

- N+1 RF line card (one or more)
- 1+1 Ethernet WAN card
- 1+1 switching engine line card
- 1+1 power supply

An Edge Router behind a CMTS typically also has internal redundancy. Specifically, it will have the following internal redundancy groups:

- 1+1 Ethernet cards toward the CMTS
- 1+1 Ethernet line cards toward the backbone
- 1+1 switching engine line card
- 1+1 power supply

An Edge Router takes this one step further. For large systems, in addition to being internally redundant, the entire Edge Router is often duplicated in the network. This provides diverse routing for the network and protects not only the platform from failing, but also if there is a link failure between platforms.

The requirements for the PHY Shelf that will implement component redundancy for HA can be derived from current examples as follows:

- N+1 DS RF line card
- N+1 US RF line card
- 1+1 Ethernet WAN card
- 1+1 DTI card
- 1+1 switching engine line card
- 1+1 power supply

The requirements for the Packet Shelf to implement component redundancy for HA can be derived from current examples as follows:

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- 1+1 Ethernet line cards toward the PHY Shelf
- 1+1 Ethernet line cards toward the backbone
- 1+1 switching engine line card
- 1+1 power supply

These components are illustrated in Figure 14. The PHY Shelf has N+1 line card Redundancy on the HFC side and 1+1 redundancy on the CIN (Converged Interconnect Network) side. The Packet Shelf has redundant line cards for the CIN and for the backbone. The redundant switching card, DTI (DOCSIS Timing Interface) card, power supplies are not shown.

In scenario A, a small system is shown with full redundancy. In scenario B, a large system is shown. In this large system, the Packet Shelf may not be co-located and may have to go through one or more IP/Ethernet hops (L3 or L2 switches/routers) to connect to the PHY Shelf. The CIN may also aggregate or disaggregate GE and 10GE connections between the Packet Shelf and PHY Shelf.

Now, the big question: Should the entire Packet Shelf be redundant, just as Edge Routers are today? Before accepting this as a conclusion, is there some fundamental practical product requirement that can be used to justify this decision? Is there a product requirement or metric that can be modified over time, one that can be used to decide when to duplicate the Packet Shelf and when not to?

To establish a threshold for when box-to-box redundancy is needed, we look to the density of DOCSIS Service Flows. What is the maximum number of Service Flows that a Cable Operator will put through one chassis before they become concerned about large network outages?

In a typical large CMTS deployment in 2008, a CMTS might handle 20,000 Services Flows. When DSG (DOCSIS Set-top Gateway) STBs are added to the deployment, upwards of 50,000 DOCSIS Service Flows may exist on a single CMTS. However, the additional DSG Service Flows go to the same service as the original 20,000 Service Flows. Further, if DSG was interrupted due to a CMTS component failure, the STBs they serve would continue to run. (The MTTR (Mean Time To Repair) of the CMTS is typically 4 hours for a manned hub site. STBs can tolerate this long an outage.) Thus, it is the core 20K non-DSG data/voice/video service flows that need to be considered as a first priority.

Another common deployment metric is 1,000 service flows per downstream. As DOCSIS moves towards bonding with multiple downstreams, the metric will change to 1000 service flows per Service Group (SG). Each SG will have multiple downstreams. This reflects that the same amount of customers are getting more bandwidth; not that more bandwidth generates more customers.

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20,000 Service Flows at 1,000 Service Flows per Service Group equates to 20 Service Groups. At 1,000 HHP (households passed) per Service Group, that would be 20,000 HHP. Add in a  $\pm 100\%$  margin for deployment variations, then a Packet Shelf would need to be duplicated if it served more than say 40,000 HHP. This is just a metric. There may be other factors, such as VoIP requirements, SLA requirements, etc, that may cause this number to be higher or lower.

### Observations

Edge Routers today typically aggregate multiple CMTSs together and thus easily exceed 40,000 HHP in coverage. They are also typically deployed as pairs. If a Packet Shelf is indeed the Edge Router with a DOCSIS MAC blade, then the Packet Shelf will really be a pair of Packet Shelves.

This has several implications. First, and foremost, is technical complexity. The DOCSIS state in the Packet Shelf has to be redundant not only within the Packet Shelf, but between Packet Shelves. That is a double layer of protection which is challenging in implementation. This is all the more reason to keep the Packet Shelf implementation streamlined and less DOCSIS aware. Fortunately, state redundancy between Edge Routers is already a network feature for other network protocols. Thus, there is a framework to leverage from and upon which to build.

The next implication is footprint and cost. Two boxes cost twice as much as one box and take twice the rack space. The answer has to be that the cost and footprint has already been spent on the Edge Router, and that the additional functionality of the Packet Shelf is a replacement of a previous line card. Specifically, the Ethernet line card that was servicing the CMTS now becomes a Modular CMTS Ethernet line card servicing a PHY Shelf.

Implementing a good, solid redundancy scheme that actually increases up-time rather than contributing to down-time is non-trivial and should not be under estimated.

The cost and complexity of one large NG M-CMTS system has to be compared to the cost and complexity of many smaller systems. If a NG M-CMTS System has to have box-to-box redundancy due to its size, and that causes the solution to be too costly or too complex, then NG M-CMTS may be a non-starter.

## System Sizing

### Deployment Scenario

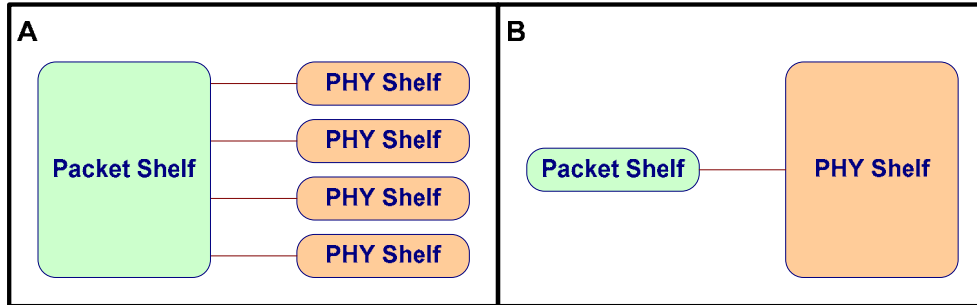


Figure 15: Matching PHY Shelves to Packet Shelves

### Discussion

So how large should the Packet Shelf and PHY Shelf be? Really big? Really small? How big are the hub sites they will service? Really big? Really small? Is there one solution for all cases?

For the sake of analysis, two size categories are presumed. A small chassis would typically be a fixed-configuration pizza box with a height of 1U or 2U (U = Rack Unit = 1.75"). A large chassis would have replaceable line cards and may be on the order of 10U to 20U. Further, it is presumed that the NG M-CMTS PHY Shelf contains both downstream and upstream QAM channels in the same chassis or in two separate chassis.

Bandwidth follows chassis size, although a Packet Shelf typically has significantly more bandwidth than a PHY Shelf for a given size. For example, with 2008 technologies, a small PHY Shelf might be 2-4 Gbps while a large PHY Shelf may be 10-40 Gbps. A small Packet Shelf may be 10 Gbps while a large packet shelf could easily be 80 Gbps or more in bandwidth.

### Observations

*Scenario A – One-to-Many:* This scenario is anticipated as the general scenario mainly due to the fact that Packet Shelves are denser in bandwidth than PHY Shelves. For large hub sites, this configuration with the Packet Shelf and the PHY Shelf co-located can be setup to support the hub site. For small hub sites, the PHY Shelf can be located at the hub site while the Packet Shelf can be located centrally at the Head End. In this scenario, the PHY Shelf can be any size it needs to be.

This is very significant. This means that NG M-CMTS can really be used in virtually any deployment scenario. In fact, it is more flexible than M-CMTS to the extent that

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the PHY Shelf is more compact than the M-CMTS Core plus EQAM. This could easily provide a 50% rack savings which in turn permits more room for EQAMs.

*Scenario B – One-to-One:* Presuming that a Packet Shelf has much higher Bandwidth per RU than a PHY Shelf, this scenario is for the case where one large PHY Shelf plus one small Packet Shelf come together to create a replacement system for an I-CMTS. In this role, the Packet Shelf may be acting separate from the Edge Router and be more dedicated to CMTS functionality.

This is an interesting scenario. It provides a way to take the NG M-CMTS technology down-market to address the market that would have been left to I-CMTS only systems.

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## CAPEX

CAPEX (Capital Expenditures) refers to the onetime cost of purchasing the equipment.

### Which Approach is Cheaper?

As more nodes and service groups are served per chassis and the number of subscribers per interface goes down with higher rate of speed for each tier, a M-CMTS architecture will be substantially cheaper than an I-CMTS solution. Current pricing structures and densities do not show a substantial savings between an M-CMTS and high-density I-CMTS solution. M-CMTS is still very much in the early stages of deployment, and downstream densities are still low. They both reduce the current downstream cost to 1/3 of what it was in the old 1x4 MAC Domain I-CMTS solution.

By 2009 and beyond, more downstream channels per service group are required in order to meet peak speed requirements of DOCSIS 3.0 speeds and to meet average peak bandwidth requirements for non-bonded customers and that would mean support for more downstream channels per chassis. In that scenario, M-CMTS will be significantly less than the current cost of an I-CMTS solution.

What about system upgrades? If the downstream density of a CMTS system needs to be increased, a M-CMTS system should have a better chance of a lower cost upgrade since the QAM components are separate. Further, EQAM densities will be doubling every two years for the next decade while the rest of the system will not be. Modularity better facilitates this upgrade cycle.

### Integration of the Edge Router

If you look at the scaling of an I-CMTS and a M-CMTS solution to meet the high bandwidth consumption of next generation web streaming traffic, scaling a M-

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CMTS core, which could be a high bandwidth router with a pool of EQAM resource will be substantially cheaper than scaling an I-CMTS chassis.

### **Integration of IP Video Function**

As QAM sharing with video is achieved at RF port level or at a Carrier level, then the cost of the Edge resources will be shared across multiple services. This will mean an overall reduction of the cost of deploying the IP video and DOCSIS services.

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## **OPEX**

OPEX (Operational Expenditures) refers to the ongoing cost of running the equipment.

### **Manageability of multiple devices**

From an OPEX perspective, there is an added cost of managing a M-CMTS core chassis and an EQAM. But, as UERM and dynamic EQAM discovery schemes are implemented in the cable network, most of the configurations and management of the M-CMTS core and EQAM will be dynamic and transparent.

### **Command Line Interface (CLI)**

NG M-CMTS systems are likely to be comprised of one Packet Shelf (with a redundant Packet Shelf) connected to many PHY Shelves. The PHY Shelves will either be co-located or remotely located at remote hub sites. This creates one CMTS system.

Which box manages this CMTS system? Which box will the operator enter in CLI to configure the system? Is it the Packet Shelf, the PHY Shelves, or both? Much of this depends upon the Option chosen for NG M-CMTS. In NG M-CMTS Options 1 and 2, the bulk of the CLI will be centralized. The PHY Shelves will have local CLI for PHY configuration. However, all that configuration can also be done remotely with DEPI and UEPI. In NG M-CMTS Options 3 and 4, the task is split. Most of the DOCSIS related tasks will be associated with the PHY Shelf with a mirror of the tasks on the Packet Shelf. Basic system troubleshooting will mandate traceability of flows between the system components.

## Conclusion

The traditional I-CMTS started the DOCSIS revolution. It was the only solution for the first 10 years. It will likely continue to live on for some time, although it may move to more of a market niche product as Modular CMTS technology comes in at the high end and works its way down.

The M-CMTS solution promises to create value. M-CMTS creates a system that expands scalability, creates a lower cost point for downstream transmission, and creates a common HFC interface for MPEG-TS Video and DOCSIS. As of 2008, much of this value is still yet to be realized as M-CMTS systems are not fully deployed yet.

The success of NG M-CMTS seems to be related to how well it, as a solution, can blend with the environment and improve upon M-CMTS. Where as M-CMTS consists of an Edge Router, an M-CMTS Core, and an Edge QAM, the NG M-CMTS system has the capability of overlaying on an upgraded Edge Router and an upgraded EQAM.

The other interesting promise of NG M-CMTS is its ability to create one large virtual CMTS that spans multiple sites, rather than many smaller CMTSs at each site. If this can decrease OPEX for the Cable Operator, then NG M-CMTS has even further value.

One thing is for certain. It is generally hard for any one manufacturer to be able to provide all three solutions – I-CMTS, M-CMTS, NG M-CMTS – simultaneously with full feature parity. Some choices and priority calls have to be made by the DOCSIS community.

From a technical viewpoint, there are technical solutions which can be made to work. The market need and the business case for NG M-CMTS needs to be well understood by vendors and Cable Operators alike. Then we, as a community, can decide if we move forward with implementing NG M-CMTS and, if so, when.

## Acronyms and Abbreviations

AAA:	Authentication, Authorization and Accounting
ASIC:	Application-Specific Integrated Circuit
ASN:	Access Service Network
BGP:	Border Gateway Protocol
BPI:	Baseline Privacy Interface
BRAS:	Broadband Remote Access Server
CAPEX:	Capital Expenditure
CBR:	Constant Bit Rate
CIN:	Converged Interconnect Network
CLI:	Command Line Interface
CM:	Cable Modem
CMOS:	Complimentary Metal-Oxide Semiconductor
CMTS:	Cable Modem Termination System
COPS:	Common Open Policy Server
CPE:	Customer Premise Equipment
DDS:	Direct Digital Synthesis
DEPI:	Downstream External PHY Interface
D-MPT:	DOCSIS over MPEG Transport Stream
DOCSIS:	Data over Cable Service Interface Specifications
DRFI:	DOCSIS RF Interface
DS MAC:	Downstream Media Access Control
DSG:	DOCSIS Set-Top Gateway
DSL:	Digital Subscriber Line
DSLAM:	Digital Subscriber Line Access Multiplexer
DTI:	DOCSIS Timing Interface
D/V/V:	Data/Voice/Video
EQAM:	Edge QAM
ERM:	Edge Resource Manager
ERMI:	Edge Resource Management Interface
FPGA:	Field Programmable Gate-Array

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FTTx:	Fiber to the (endpoint)
GE:	Gigabit Ethernet
HA:	High Availability
HFC:	Hybrid Fiber Coax
HHP:	Households Passed
IP:	Internet Protocol
I-CMTS:	Integrated CMTS
L2TPv3:	Layer 2 Tunneling Protocol version 3
MA:	Management Agent
MAC:	Media Access Control
MCMP:	M-CMTS Management Protocol
MCTP:	M-CMTS Tunneling Protocol
M-CMTS:	Modular CMTS
MPEG:	Moving Pictures Experts Group
MPEG-TS:	MPEG Transport Stream
MSO:	Multiple System Operator
NG:	Next Generation
NP:	Network Processor
NP MA:	Network Processor Management Agent
OPEX:	Operational Expenditure
PCMM:	PacketCable™ Multimedia
PHS:	Payload Header Suppression
PHY:	Physical
PPPoE:	Point-to-Point Protocol over Ethernet
PSP:	Packet Streaming Protocol
QAM:	Quadrature Amplitude Modulation
QoS:	Quality of Service
RADIUS:	Remote Authentication Dial In User Service
RPC:	Remote Procedure Call
SDV:	Switched Digital Video
SG:	Service Group
SM/AM:	Statistical Multiplier/ Access Multiplexer

STB:	Set-Top Box
U:	Rack Unit
UDP:	User Datagram Protocol
UE:	User Equipment
UEPI:	Upstream External PHY Interface
UERM:	Universal Edge Resource Manager
US MAC:	Upstream Media Access Control
VDOC:	Video over DOCSIS
VDSL:	Very high speed Digital Subscriber Line
VOD:	Video on Demand
WAN:	Wide Area Network
WiMAX:	Worldwide Interoperability for Microwave Access

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## About the Author



John T. Chapman is currently a Cisco Fellow and the Chief Architect for the Cable Business Unit at Cisco Systems in San Jose, California. As a founding member of the Cisco Cable BU, John has made significant contributions to Cisco and the cable industry through his pioneering work in DOCSIS and development of key technologies and concepts critical to the deployment of IP services over HFC plants. Included in these achievements are being the primary author of significant portions of the DOCSIS specifications

These including DCC, UGS, UGS-AD, PHS for DOCSIS 1.1; originating and authoring DOCSIS Set-top Gateway (DSG); originating the downstream and upstream channel bonding concepts which evolved into DOCSIS 3.0; and originating DEPI and DTI for Modular CMTS. John has also published a number of ground breaking whitepapers on Multimedia Traffic Engineering (MMTE), DSG, QoS, and high availability and is a respected and frequently requested speaker at industry events.

John graduated from the University of Alberta in Canada with a Bachelor in Science of Electrical Engineering in 1984. John began his formal career designing voice line, trunk, and ISDN cards for ROLM/IBM/Siemens and joined Cisco Systems in 1989. At Cisco, before joining the Cable BU in 1996, he was responsible for the development of HSSI (High-Speed Serial Interface) which is now an ANSI and ITU-T standard (V.12). Later projects included the industry's first ISDN BRI router, the design of the multi-protocol Smart Serial interfaces and HDLC ASICs used across the Cisco router product line, and co-architecting the VIP card in the Cisco 7500 product line.

John has over 50 patents issued or pending in a variety of technologies including telephony, VoIP, wide area networking, and broadband access for HFC cable networks. In his spare time, John enjoys spending time with his wife and two daughters. John is a 6<sup>th</sup> Degree Black Belt Master in Tae Kwon Do and enjoys white water canoeing and skiing.

Previous papers by John may be found at <http://www.johntchapman.com>.

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<sup>1</sup> DEPI: Downstream External PHY Interface Specification, Feb 23, 2007, CableLabs