

Looming Challenges and Potential Solutions for Future Distributed CCAP Architecture Systems

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Introduction

The Cable Industry is entering an exciting new era that will offer Multiple System Operators (MSOs) many options for evolving their Hybrid Fiber--Coax (HFC) network architectures. Fig. 1 is a taxonomy of selections that may be available to MSOs in the future.

They will be able to pick from higher--density Centralized Access Architectures that use traditional connectivity (such as Head-end I-CCAPs). They will also be able to pick from many evolving Distributed Access Architectures (DAAs), including DOCSIS/EQAM--oriented Distributed CCAP Architectures (DCAs). This paper will focus on the analysis of three sub-classes of DCAs (shown in green within Fig. 1), including:

- Remote MACPHY w/ EQAM in the Node (aka Remote CCAP in [RMPH])
- Remote MACPHY w/o EQAM in the Node (aka Remote CMTS in [RMPH])
- Remote PHY w/ EQAM in the CCAP Core

These three approaches have received much attention in committee activities by MSOs and vendors for the past two years. The authors have been involved in Standards Groups and design activities surrounding all three approaches, so an attempt will be made to fairly compare the approaches within this paper. Due to space constraints, the other variants will not be discussed within the paper.

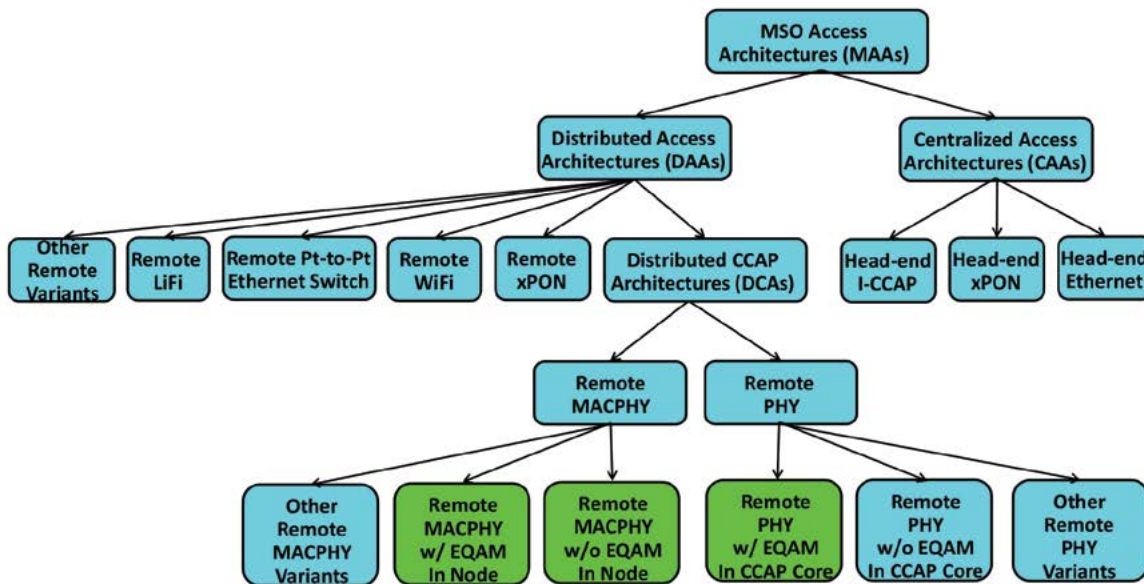


Figure 1 – Taxonomy of Potential MSO Access Architectures (w/ 3 Focus Areas in Green)

DCAs are an entirely new class of architecture for providing Broadband Digital Services (such as High--Speed Data, Video, and Voice). These DCA architectures propose moving some (or most) of the CCAP functionality (including PHY and/or MAC processing sub-systems) into the Fiber Nodes that exist within the Outside Plant. They therefore require the use of Ethernet-based or Passive Optical Network (PON)--based Digital Optics (instead of Analog Optics) for transmissions across the fiber in the HFC plant. DCAs offer many potential benefits to MSOs, including:

- a) reducing the required space and power requirements in the Head-end
- b) increasing the number of simultaneous lambdas that can be wavelength--division-multiplexed on a single fiber (for support of future node-splits)
- c) circumventing nonlinear optical noise effects and increasing the End-Of-Line Signal-to-Noise Ratios (SNRs) and increasing the corresponding spectral efficiencies of DOCSIS 3.1 transport.

Each MSO will need to determine if/when these benefits warrant the cost of the change to DCA architectures. Studies [EMME] have shown that item (c) only yields a 5-30% improvement in downstream spectral efficiencies, so that benefit may not be as important as the others if annual traffic growth rates are ~50%. But the other two benefits are critical to many MSOs. To capitalize on these benefits DCAs will likely be deployed in some MSO markets where the cost of “touching” the node is justified by the benefits, whereas higher-density Head-end I-CCAP systems will likely continue to be deployed in other MSO markets where the above issues are not as problematic. This will lead to a likely bifurcation of the CCAP market in the future (Fig. 2). Current guestimates indicate that Head-end I-CCAPs will likely dominate the future market, but this is still uncertain.

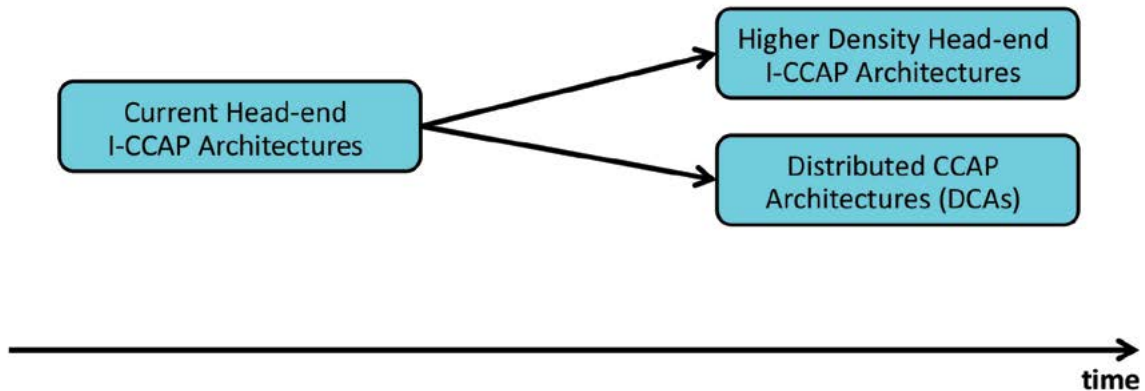


Figure 2 – Future Bifurcation of the CCAP Market

High-level Descriptions of the Three DCA Approaches

A typical Head-end and Outside Plant architecture of today is illustrated in Fig. 3. There are many sub-systems within the Head-end/Hub of this architecture, including back-office servers and management systems (on the left), Converged Cable Access Platforms (CCAPs) with CMTS and EQAM functionality (in the middle), Amplitude-Modulated (AM) Optical Transceivers (also in the middle), and OOB Transceivers used to communicate with legacy set-top boxes (also in the middle). The optical fiber emanating from the Head-end/Hub is routed to an Analog Fiber Node (on the right) where the optical signals are converted back to electrical signals on coax and then routed to subscriber homes.

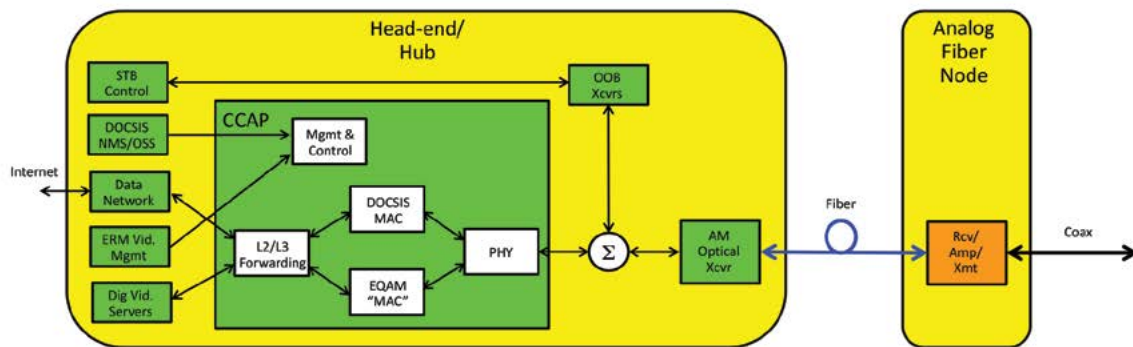


Figure 3 – Typical Head-end & Outside Plant Architecture

Within the CCAP (in the Head-end/Hub), there are many sub--systems, including Management & Control, L2/L3 Forwarding, DOCSIS Media Access Control (MAC), EQAM “MAC,” and the Physical (PHY) Interface. Each of these sub-systems performs an essential function. Management & Control is responsible for orchestrating activities within the CCAP. L2/L3 Forwarding is responsible for steering packets within the CCAP. DOCSIS MAC is responsible for filtering, encrypting, scheduling and reformatting headers on Ethernet/Internet Protocol (IP) packets for transmission across the HFC plant. EQAM “MAC” is responsible for multiplexing of video streams, encryption, packet de-jittering, clock reference correction, and table modifications. The PHY is responsible for Error Correction, encoding groups of bits from packets into super--imposed sine waves (or vice versa), up-converting

(or down-converting) those sine waves to higher (lower) frequencies, and amplifying those up-converted sine waves prior to launching them onto a coax towards the Optical Transceiver and the Outside Plant.

DCAs propose chopping up many of these CCAP sub-system functions and moving some from the Head-end to the Fiber Node. Because there are many ways to chop up the sub-systems within the CCAP, many different approaches have been proposed for DCA operations. Different people use different labels for the various types of proposed DCA systems, and the nomenclature is still evolving (and confusing). The paper will focus on three types of DCAs and will utilize the labels and definitions from the sub-sections below.

Remote MACPHY with EQAM in the Node

The first type of DCA that will be studied is the Remote MACPHY w/ EQAM in the Node. [EMME] This architecture is also sometimes known as a Remote CCAP architecture (although the version assumed in this paper requires Control and Management functions to exist in the Head-end for configuring and provisioning the Remote CCAP Fiber Node). A potential evolutionary path using this flavor of DCA is illustrated in Fig. 4.

The Remote MACPHY w/ EQAM in the Node DCA proposes to chop up the CCAP sub-systems as illustrated in Fig. 4(a). The red, dashed "cut--line" shows where the CCAP is disassembled. The CCAP functions to the right of the cut-line are moved out of the Head-end and into the Fiber Node, and they are then connected to the Head-end via Ethernet or PON links. As seen in the figure, this particular DCA instantiation moves all of the PHY, all of the DOCSIS MAC, all of the EQAM "MAC," part of the L2/L3

Forwarding, part of the Management and Control, and part of the OOB Transceivers into the Fiber Node. The CCAP piece-parts remaining in the Head-end include part of the L2/L3 Forwarding and part of the Management and Control. The initial resulting architecture is illustrated in Fig. 4(b). The CCAP piece-parts remaining in the Head-end are shown to be implemented in a typical L2/L3 Switch/Router and in a Virtualized Management and Control application that can be operated on a COTS server. (Note: This Virtualized Management and Control sub-system can be housed in the Head-end, as shown in the figure. However, it can also be housed in a remote data center or even in a third-party hosted environment, allowing it to capitalize on elasticity as it can be scheduled on the server processor cores along with many other applications).

Everything else from the CCAP has been transported down to the Fiber Node, including DOCSIS MAC, EQAM "MAC," PHY, part of the L2/L3 Forwarding, and part of the Management and Control.

In Fig. 4(b), it is assumed that many MSOs may choose to keep the Bcast Video EQAM functionality in the head-end to minimize change and continue to capitalize on that already-deployed equipment, so the Bcast Video EQAM would feed an AM Optical Transceiver that yields an overlay lambda (shown in red) that could be placed on the fiber along with the Ethernet/PON lambda (shown in dark blue) that is also on the fiber. This overlay lambda would have to be separated from the Ethernet/PON lambda at the Fiber Node, converted to the electrical domain, and then combined into the RF output from the other CCAP circuitry that was moved into the Fiber Node.

Fig. 4(c) is similar to Fig. 4(b), but it shows a futuristic point in time when MSOs may have decided to eliminate their head-end Bcast Video EQAMs and let all of the Bcast video be processed by the CCAP components in the Fiber Node. This eliminates the need for the overlay lambda shown in Fig. 4(b). It also eliminates the need for all AM Optical Transceivers in the system.

Some MSOs have indicated an interest in eventually migrating the CCAP MAC functionality into Virtualized Servers in the Head--end. The value of this approach is still being debated (as will be discussed below), but if this approach is pursued, then Fig. 4(d) illustrates how the MAC functionality could be virtualized in the Head--end. This would obviously require the use of "connections" between the MAC in the virtualized Head-- end and the PHY in the Fiber Node-- the DEPI, UEPI, GCP, OOB, and IEEE 1588 Precision Timing Protocol (1588) specifications would provide a convenient solution to utilize.

Thus, DEPI, UEPI, GCP, and 1588 functions would need to be added to the Fiber Node in order to accommodate this final transition. But fortunately, the processing resources that are freed up by the elimination of MAC functionality in the Fiber Node can conveniently be re--purposed and utilized for the DEPI, UEPI, GCP, and 1588 functions that would be needed for this transition towards virtualizing the MAC (see Fig. 4(d)). In the end, the resulting system shown in Fig. 4(d) operates as a Remote PHY system. This indicates that the

Remote MACPHY w/ EQAM in the Node is a flexible architecture that can evolve to support many long-term evolutionary visions held by MSOs. (Note: It is also possible for Remote MACPHY systems to virtualize different pieces of the CCAP than Remote PHY systems. For example, an MSO could choose to only virtualize the Management and Control sub-systems and the Upper-Layer MAC functions such as QoS, Classification, and Filtering. This is one of the potential benefits of Remote MACPHY systems).

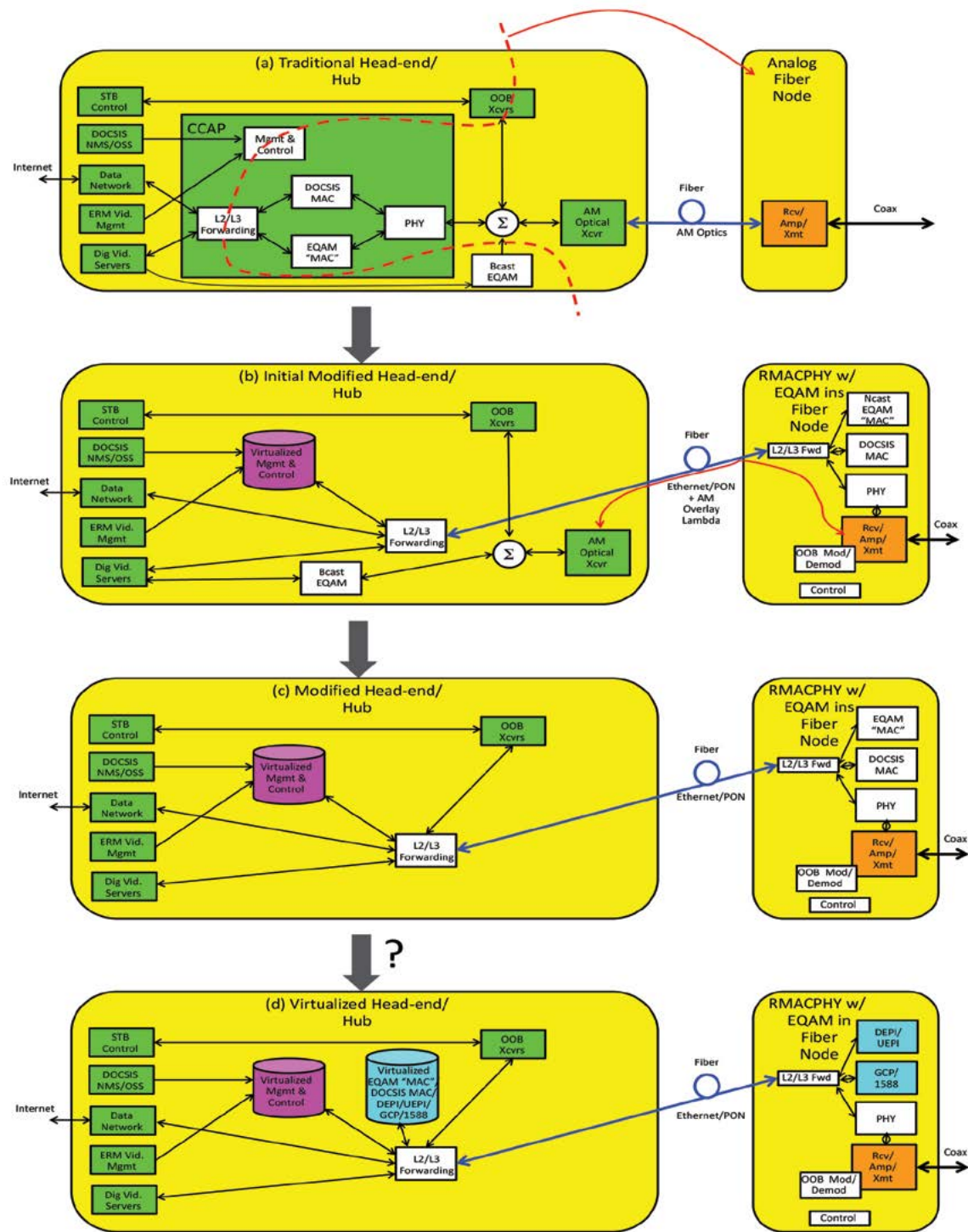


Figure 4 – Possible Evolution w/ Remote MACPHY w/ EQAM in the Node

Remote MACPHY without EQAM in the Node

The second type of DCA that will be studied is the Remote MACPHY w/o EQAM in the Node. [PARI] This architecture is also sometimes known as a Remote CMTS architecture. A potential evolutionary path using this flavor of DCA is illustrated in Fig. 5.

The Remote MACPHY w/o EQAM in the Node DCA proposes to chop up the CCAP sub-systems as illustrated in Fig. 5(a). The red, dashed “cut-line” shows where the CCAP is disassembled. The CCAP functions to the right of the cut-line are moved out of the Head--end and into the Fiber Node, and they are then connected to the Head--end via Ethernet or PON links. As seen in the figure, this particular DCA instantiation moves all of the PHY, all of the DOCSIS MAC, part of the L2/L3 Forwarding, part of the Management and Control, and part of the OOB Transceivers into the Fiber Node. The

CCAP piece-parts remaining in the Head-end include the EQAM “MAC,” part of the L2/L3 Forwarding, and part of the Management and Control. The initial resulting architecture is illustrated in Fig. 5(b). The CCAP piece-parts remaining in the Head-end are shown to be implemented in a typical L2/L3 Switch/Router and in a Virtualized Management and Control application that can be operated on a COTS server. This architecture also requires a modified EQAM to exist in the Head-end. (Note: The modified EQAM (sometimes called an “EtherQAM”) must output MAC-processed Ethernet packets instead of RF signals, and the MAC-processed Ethernet packets would be transmitted to the PHY in the Fiber Node). Everything else from the CCAP has been transported down to the Fiber Node, including DOCSIS MAC, PHY, part of the L2/L3 Forwarding, and part of the Management and Control.

In Fig. 5(b), it is assumed that many MSOs may choose to keep the Bcast Video EQAM functionality in the Head-end to minimize change and continue to capitalize on that already-deployed equipment, so the Bcast Video EQAM would feed an AM Optical Transceiver that yields an overlay lambda (shown in red) that could be placed on the fiber along with the Ethernet/PON lambda (shown in dark blue) that is also on the fiber. This overlay lambda would have to be separated from the Ethernet/PON lambda at the Fiber Node, converted to the electrical domain, and then combined into the RF output from the other CCAP circuitry that was moved into the Fiber Node.

Fig. 5(c) is similar to Fig. 5(b), but it shows a futuristic point in time when MSOs may have decided to eliminate their head-end Bcast Video EQAMs and let all of the Bcast video be processed by the EQAM “MAC” components in the Head-end. This eliminates the need for the overlay lambda shown in Fig. 5(b). It also eliminates the need for all AM Optical Transceivers in the system.

For MSOs who wish to eventually migrate their CCAP MAC functionality into Virtualized Servers in the futuristic Head-end, Fig. 5(d) illustrates how this can be done. This would obviously require the use of “connections” between the MAC in the virtualized Head-end and the PHY in the Fiber Node--the DEPI, UEPI, GCP, OOB, and 1588 specifications would again provide a convenient solution to utilize. Thus, DEPI, UEPI, GCP, and 1588 functions would need to be added to the Fiber Node in order to accommodate this final transition. But fortunately, the processing resources that are freed up by the elimination of the DOCSIS MAC functionality in the Fiber Node can conveniently be re-purposed and utilized for the DEPI, UEPI, GCP, and 1588 functions that would be needed for this transition towards virtualizing the MAC (see the light blue sub-systems in Fig. 5(d)). In the end, the resulting system shown in Fig. 5(d) operates as a Remote PHY system. This indicates that the Remote MACPHY w/o EQAM in the Node is also a flexible architecture that can evolve to support many long--term evolutionary visions held by MSOs. (Note: As stated in the previous section, it is also possible for Remote MACPHY systems to virtualize different pieces of the CCAP than Remote PHY systems. For example, an MSO could choose to only virtualize the Management and Control sub-systems and the Upper-Layer MAC functions such as QoS, Classification, and Filtering. This is one of the potential benefits of Remote MACPHY systems).

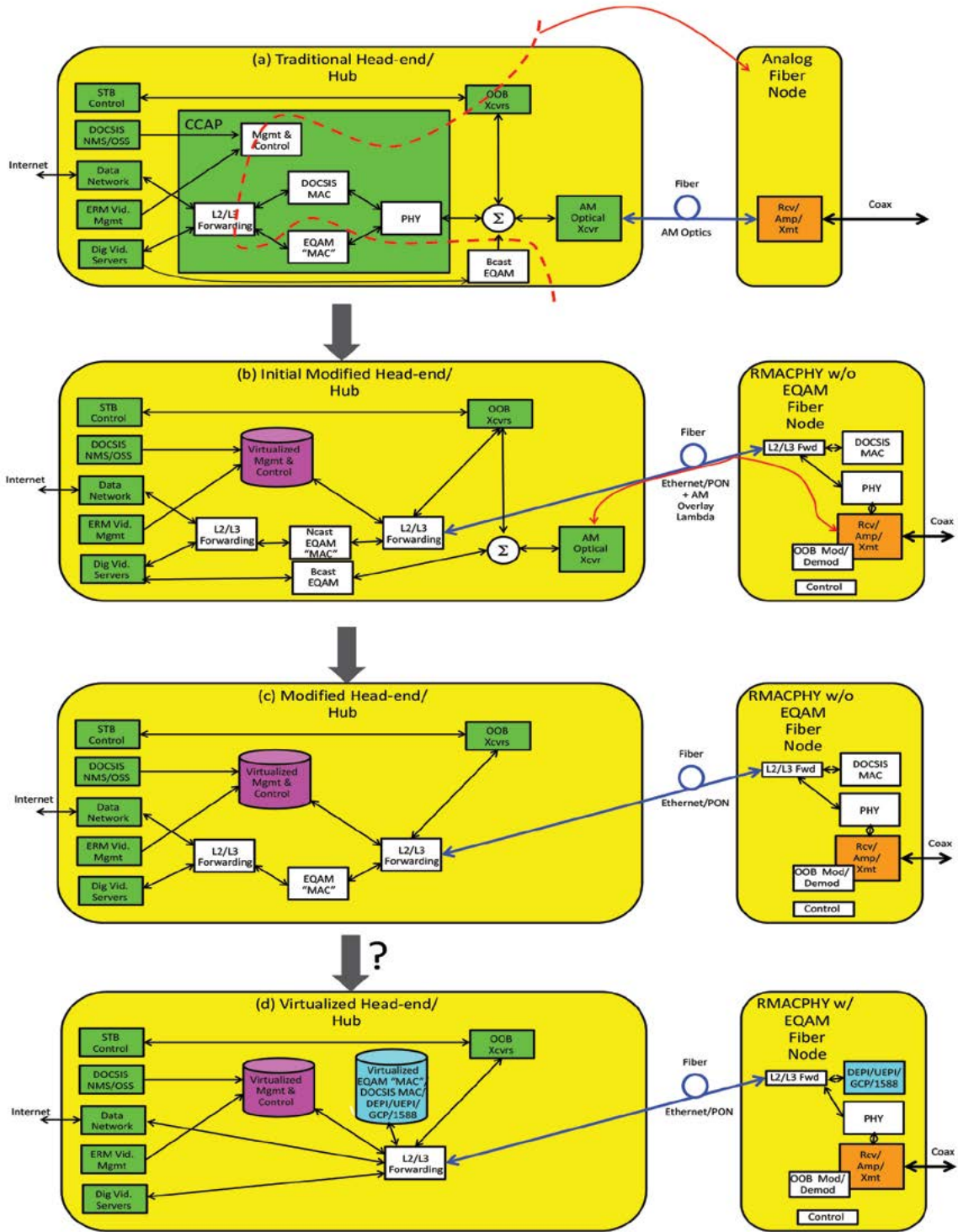


Figure 5 – Possible Evolution w/ Remote MACPHY w/o EQAM in the Node

Remote PHY with EQAM in the CCAP Core

The third type of DCA that will be studied is the Remote PHY w/ EQAM in the CCAP Core. [CHAP] This architecture is sometimes simply referred to as the Remote PHY architecture, although there are other variants of Remote PHY architectures that separate the EQAM functionality from the CCAP Core. (Note: Many people in the industry incorrectly refer to the generic DCA class of architectures as Remote PHY architectures. The authors recommend against this use of the term, because Remote PHY is simply one sub-class of the overall DCA class of architectures). A potential evolutionary path using this flavor of DCA is illustrated in Fig. 6.

The Remote MAC w/ EQAM in the CCAP Core DCA proposes to chop up the CCAP sub-systems as illustrated in Fig. 6(a). The red, dashed “cut-line” shows where the CCAP is disassembled. The CCAP functions to the right of the cut-line are moved out of the Head-end and into the Fiber Node, and they are then connected to the Head-end via Ethernet or PON links. As seen in the figure, this particular DCA instantiation moves all of the PHY, part of the L2/L3 Forwarding, part of the Management and Control, and part of the OOB Transceivers into the Fiber Node. It also requires the addition of new functions in both the CCAP Core and the Remote PHY Fiber Node to support DEPI, UEPI, GCP, OOB, and 1588 functionality, so all of those functions are also contained in the Fiber Node. The CCAP piece-parts remaining in the Head-end include the DOCSIS MAC, the EQAM “MAC,” part of the L2/L3 Forwarding, part of the Management and Control, and the newly-required sub-systems for DEPI, UEPI, GCP, and 1588 functionality. The initial resulting architecture is illustrated in Fig. 6(b) where the newly-required sub-systems are illustrated in light blue. The CCAP piece-parts remaining in the Head-end are shown to be implemented in a typical L2/L3 Switch/Router and in a Virtualized Management and Control application that can be operated on a COTS server. This architecture also requires a CCAP Core to exist in the Head-end. The CCAP Core is a networking element that resembles a CCAP, but it only does not have any PHY Processing functions. The CCAP Core can serve as the overall system controller for the Remote PHY system, and all of the data and control messages passed from the CCAP Core to the Remote PHY Fiber Node would pass through L2TPv3-based tunnels defined by DEPI and UEPI or TCP/UDP connections defined by GCP. As seen in the figure, the Fiber Node will only contain the PHY, part of the L2/L3 Forwarding, part of the Management and Control, and the newly-required DEPI, UEPI, GCP, OOB, and 1588 sub-systems.

In Fig. 6(b), it is assumed that many MSOs may choose to keep the Bcast Video EQAM functionality in the Head-end to minimize change and continue to capitalize on that already-deployed equipment, so the Bcast Video EQAM would feed an AM Optical Transceiver that yields an overlay lambda (shown in red) that could be placed on the fiber along with the Ethernet/PON lambda (shown in dark blue) that is also on the fiber. This overlay lambda would have to be separated from the Ethernet/PON lambda at the Fiber Node, converted to the electrical domain, and then combined into the RF output from the other CCAP circuitry that was moved into the Fiber Node.

Fig. 6(c) is similar to Fig. 6(b), but it shows a futuristic point in time when MSOs may have decided to eliminate their Head-end Bcast Video EQAMs and let all of the Bcast video be processed by the EQAM “MAC” components in the CCAP Core. This eliminates the need for the overlay lambda shown in Fig. 6(b). It also eliminates the need for all AM Optical Transceivers in the system.

For MSOs who wish to eventually migrate their CCAP MAC functionality into Virtualized Servers in the futuristic Head-end, Fig. 6(d) illustrates how this can be done. This would obviously require the use of “connections” between the MAC in the virtualized Head-end and the PHY in the Fiber Node—the DEPI, UEPI, GCP, OOB, and 1588 specifications would again provide a convenient solution to utilize. These DEPI, UEPI, GCP, OOB, and 1588 functions would already exist in the Remote PHY Fiber Node. But CCAP Core functions in the Head-end would have to be shut down and replaced by the COTS servers where the virtualized MAC would reside (see Fig. 6(d)). The resulting system shown in Fig. 6(d) is still a Remote PHY system, but it has been virtualized. This indicates that the Remote PHY w/ EQAM in the CCAP Core is also a flexible architecture that can evolve to support many long-term evolutionary visions held by MSOs.

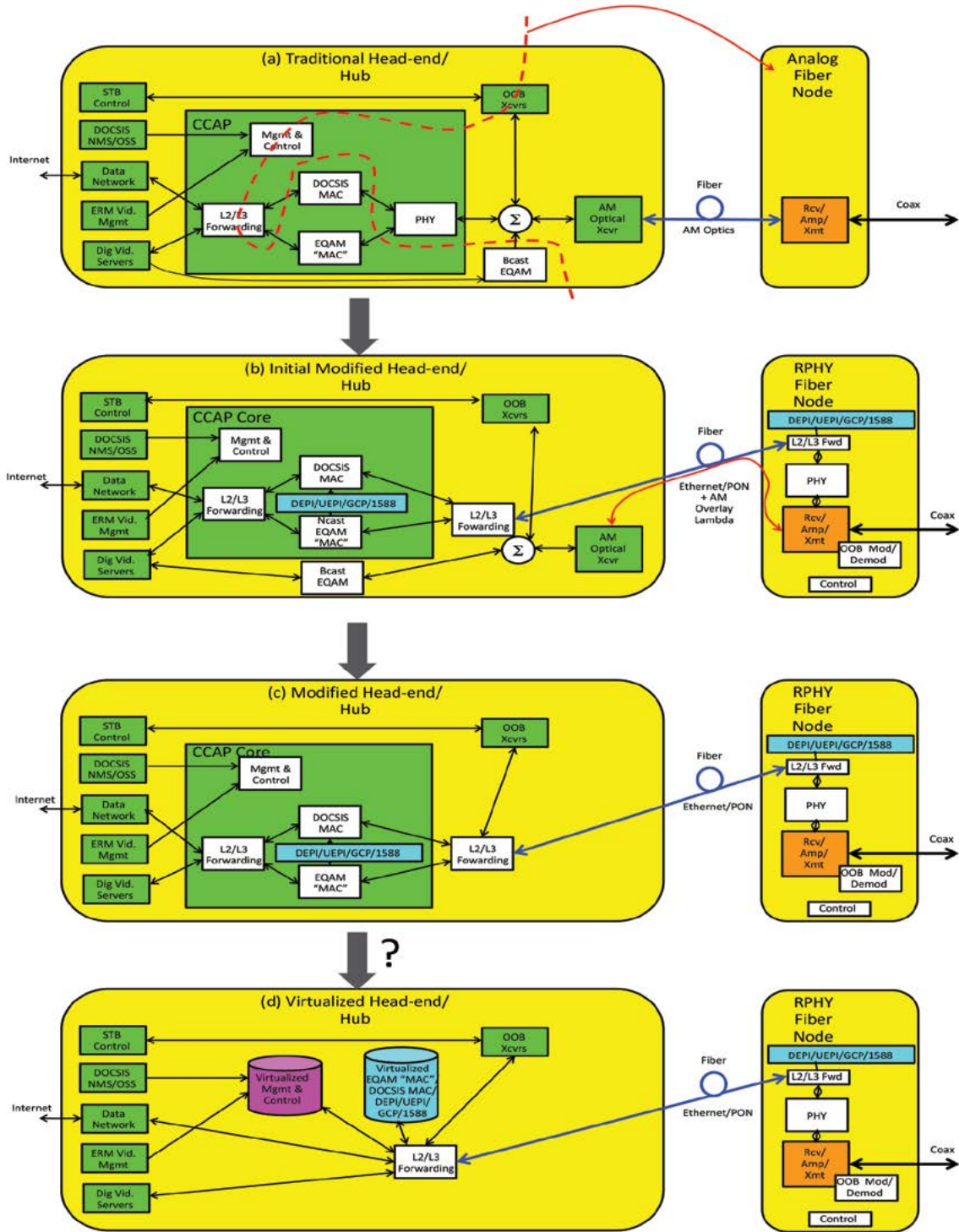


Figure 6 – Possible Evolution w/ Remote PHY w/ EQAM in the CCAP Core

Comparisons of the Three DCA Approaches

There are obvious differences between the three DCA approaches described in the previous sections. In particular, each moves more or less functionality from the CCAP in the Head--end/Hub out to the Fiber Node. Remote MACPHY w/ EQAM in the Node proposes to move the most amount of CCAP functionality into the Fiber Node. Remote PHY w/ EQAM in the CCAP Core proposes to move the least amount of CCAP functionality into the Fiber Node. Remote MACPHY w/o EQAM in the Node is somewhere in between.

These different approaches will yield different characteristics for each solution. Each approach will have its own unique set of advantages and disadvantages. The paper will attempt to analyze these advantages and disadvantages in a fair and unbiased fashion within this section. To give a clue to the conclusions, none of the approaches are perfect-- nor are any of the approaches entirely bad.

The authors have identified many different system--level attributes that are considered to be important by different MSOs. The list in this paper includes twenty--six attributes that various MSOs or vendors have indicated as being important in deciding which DCA approach is most appropriate. The list of important attributes includes many attributes that are being addressed by the standards groups as well as those that are outside the scope of the standards groups. Different MSOs are weighing different attributes differently. Attributes important to one MSO may be entirely unimportant to another MSO. So it is important to consider all of them.

The twenty--six attributes have been divided into four categories: Operational Cost Management, Operational Ease Of Use, Infrastructure Compatibility, and Design Simplicity. Due to space limits, each category and its associated attributes will be briefly covered below, and rationale for scores will be given. For each attribute, a score ranging from 1 (very bad) to 5 (excellent) will describe how well each of the three DCA approaches handles the particular attribute. In particular, the scores might be described as shown below:

1 – Very bad

2 – Bad

3 – Average

4 – Good

5 – Excellent

It is recognized that these scores are highly subjective and that others would undoubtedly assign different scores to the attributes. One reason for this subjectivity is that different designs may lead to different conclusions. The authors cannot make the claim to have looked at every possible design for the various systems. As a result, readers are advised to consider the reasons for the scores (and not the scores themselves) when comparing different DCA technologies-- the readers can then create their own subjective scores based on the given rationale, and the readers can also apply their own weightings to the importance of the different attributes.

Operational Cost Management Attributes

Managing costs is critical to the success of MSO operations, so many of the questions on different DCA architectures coming from MSOs are related to cost. The attributes below are related to Operational Cost Management.

Head-end Costs

The cost in the Head--end will likely scale with the number of required boxes needed to provide service to a given number of Service Groups. From the descriptions above, it is clear that Remote MACPHY w/ EQAM in the Node will require the lowest Head--end cost investment for service. Remote MACPHY w/o EQAM in the Node will require the next lowest Head--end cost investment for service. Remote PHY w/ EQAM in the CCAP Core will require the highest Head--end cost investment for service. As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

Node Costs

The cost in the Node will likely scale with the number of components needed to provide service to a single Node. From the descriptions above, it is clear that Remote MACPHY w/ EQAM in the Node will require the highest Node cost investment. Remote MACPHY w/o EQAM in the Node will require the next highest Node cost investment. Remote PHY w/ EQAM in the CCAP Core will require the lowest Node cost investment. As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 3
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Total System Costs

Total cost is a critically important attribute to most MSOs. As one ponders the cost of the various solutions, it is clear that the actual processing that must be done is similar in all approaches. DOCSIS packets need to pass through CMTS functions, video packets need to pass through EQAM functions, and all packets must eventually pass through PHY functions.

The authors can recall a time in the past when great debates occurred over whether I-CMTS or M-CMTS systems would be more cost--effective. The authors (at that time) believed that moving Downstream PHY functions out of the CMTS and into an EQAM was just playing a "shell game" with the overall system costs, and that the total costs of the two solutions would likely remain very similar. Based on product pricing of the I-CMTS products and M-CMTS products over the past ten years, that belief seems to have been validated.

In the new debates over the different DCA architectures that are occurring now, the authors are still driven to the same conclusion--moving functionality from point A to point B does not significantly change the cost of that functionality. It is just a shell game with the overall system costs. As a result, the authors expect that all three of the DCA architectures will likely have similar cost structures in the future.

There may be a few variations that may force solutions with more functionality in the Node to have slightly higher costs. These variations include:

- 1) Higher temperature (and higher cost) parts may be necessary for Node--based designs since air cooling is not easily permitted
- 2) Sharing of circuitry (such as Power Supplies or multi--core processors used to support more Service Groups) can sometimes lead to lower costs... that sharing is easier to accomplish in Head--end equipment than in Node equipment

All of the DCA approaches may therefore experience slightly higher per--Service Group costs than the costs of a typical I-CCAP system. These variations are expected to be relatively small, but it does lead us to slightly lower the scores of all three of the DCA approaches. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 4

Head-end Power Consumption

The power consumed in the Head-end will scale with the number of required boxes needed to provide service. From the descriptions above, it is clear that Remote MACPHY w/ EQAM in the Node will require the lowest Head-end power (since little functionality is left in the Head-end). Remote MACPHY w/o EQAM in the Node will require the next lowest Head--end power. Remote PHY w/ EQAM in the CCAP Core will require the highest Head--end power (since CCAP Cores still remain in the head-end). As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

Node Power Consumption

The power consumed in the Node will likely scale with the number of components needed to provide service to a single Node. From the descriptions above, it is clear that Remote MACPHY w/ EQAM in the Node will require the highest power (since it has more functions and more associated components in the Node). Remote MACPHY w/o EQAM in the Node will require the next highest power. Remote PHY w/ EQAM in the CCAP Core will require the lowest power (since it has less functions and less associated components in the Node). The required power difference between the Remote PHY w/ EQAM in the CCAP Core and the Remote MACPHY w/ EQAM in the Node varies depending on the technology used and the system design. It also will decrease as new, lower-power technologies are developed in the future. Using today's technology in several analyzed designs, the power difference per Service Group within the Node may range from 5-10 W. As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 3
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Total Power Consumption

Total power consumption is a critically important attribute to most MSOs. As one ponders the power consumed by the various solutions, it is clear that the actual processing that must be done is similar in all approaches. Thus, it is expected that the total power (Head-end power plus Node power) associated with the different approaches would be quite similar for all DCA architectures. It is possible that there would be more I-squared--R losses in delivering power to the Nodes, but that depends on the distances from power distribution points. We will ignore this effect in the analysis. As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 5

Head-end Rack-space

The rack-space consumed in the Head--end will scale with the number of required boxes needed to provide service. From the descriptions above, it is clear that Remote MACPHY w/ EQAM in the Node will require the lowest rack-space (since little functionality is left in the Head-end). Remote MACPHY w/o EQAM in the Node will require the next lowest Head-end rack-space. Remote PHY w/ EQAM in the CCAP Core will require the highest Head-end rack-space (since CCAP Cores still remain in the head-end). As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

Size of Vendor Eco-system

Many MSOs have a desire to have a large vendor eco--system to help ensure good product pricing and a strong availability of back--up suppliers. The vendor eco--system must reach a critical mass of three or more vendors before these goals can be achieved. More than three vendors can be viewed as a slight benefit to MSOs, but the Cable Industry oftentimes has a difficult time economically supporting a large number of vendors within a single product space. As a result, the number of vendors for a particular product space is usually limited to three to five vendors. Bifurcating the market across many different DCA architectures and having different MSOs buying from different architecture pools could put a strain on the vendor community, because vendors will be forced to focus on one DCA architecture (and live with lower revenues) or will be forced to do development on all of the selected DCA architectures to give themselves the chance of selling into the total market.

If a bifurcated market does come to exist, then some of the DCA architectures might be able to attract more vendors than other DCA architectures. Architectures that split up the functionality into smaller piece-parts can lower the bar on vendor involvement and permit more vendors to initially compete for the market. As a result, Remote PHY w/ EQAM in the CCAP Core may permit more vendors (both CCAP Core vendors and Node vendors) to participate (at least in the early days of the market). Remote MACPHY w/o EQAM similarly could permit more vendors (both EtherQAM vendors and Node vendors) to participate (at least in the early days of the market). However, the authors believe that EQAM vendors of the past may not whole-heartedly embrace the idea of adding a new Ethernet feature to already-deployed EQAMs. In addition, over time, the larger competition from a larger vendor eco-system may force some vendors to drop out of the market and all three DCA architectures may end up with the same number of final vendors (probably three to five). Because of these dynamics, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Ability to Share Deployed MAC Functionality between Service Groups

There is a flexibility benefit to the Remote PHY w/ EQAM in CCAP Core architecture, because the MAC functionality within the Head-end's CCAP Core can be sub-divided and steered to any number of Service Groups. Thus, MAC functionality is not wasted. MAC processing that supports ten Service Groups today may be re-steered to support a single Service Group in the future. This flexibility is indeed a benefit that is offered by the Remote PHY approach.

However, it must be pointed out that most (if not all) CCAP vendors will typically future-proof their designs by adding more functionality than is needed into any system that is deployed into the field. This practice is expected by most MSOs, because they expect the CCAP equipment to scale up and last in the field for many years to come. Thus, most CCAP vendors place extra MAC (and PHY) functionality in their equipment and charge the MSOs only for the MAC (and PHY) functionality that is enabled. More MAC functionality can then be enabled in the future when the MSO purchases a software license that upgrades the system capacity.

This practice tends to diminish the benefits of having the flexibility of the MAC functionality in the CCAP Core. If MSOs only pay for that which they enable and if they can enable as much bandwidth capacity as they desire at any point in time, then the value of the MAC flexibility is lost. Remote MACPHY systems will likely be deployed with sufficient MAC processing to support the expected needs for a decade or more, and MSOs will likely only be paying for the MAC functionality that they enable at any given time. Thus, the value of the MAC sharing is quite small. Because of these dynamics, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Operational Ease of Use Attributes

Decreasing the operational complexities of systems is very helpful to MSO operations, so many of the questions on different DCA architectures coming from MSOs are related to Operational Ease of Use. The attributes below are also related to Operational Ease of Use.

Ease of Troubleshooting

Troubleshooting is an important MSO activity that must be able to be done with speed and efficacy. Restoring a faulty system to a healthy and sane state of operation is critical to ensure high Quality of Experience levels for subscribers. In the opinions of the authors, having a single vendor to go to for assistance when a serious problem develops can help to expedite the solution process. Having multiple vendors splitting the functionality and responsibility between one another can lead to confusion, excuses, finger-pointing, and delays. Remote PHY w/ EQAM in the CCAP Core and Remote MACPHY w/o EQAM in the Node produce system architectures that require both Head-end and Node equipment that could be designed by different vendors. Remote PHY w/ EQAM in the CCAP Core has the largest number of new interfaces that the vendors will need to accommodate, so it probably will experience the largest number of complications. Remote MACPHY w/o EQAM in the Node will only require vendors to design to the new video interfaces. Remote MACPHY w/ EQAM in the Node places all of the functionality (except for some Management and Control) into the Node, so it is (by definition) designed by a single vendor. As a result, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

Ability to Select Best-in-Breed from MAC Cores and Nodes

Some MSOs would prefer to be able to purchase their Networking (ex: CCAP Core) equipment from their favorite Networking vendors and would prefer to be able to purchase their Outside Plant (ex: Node) equipment from their favorite Outside Plant vendor. The organizational structures and decision-making processes inside of many MSOs may become disrupted if this long-standing procedure were to be altered. Thus, solutions that keep the CCAP Core functionality separated from the Node functionality might be preferred by these MSOs (if they opt to have no changes in their organizational structure). Since Remote PHY w/ EQAM in the CCAP Core permits this approach, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 3
- Remote MACPHY w/o EQAM in the Node: 3
- Remote PHY w/ EQAM in the CCAP Core: 5

Bricking of Node Software Loads

Some MSOs have indicated a concern with DCA architectures that might require a larger number of software loads to be downloaded to the Node than was typical in the past.

The concern is that the Nodes will be susceptible to “bricking” if the software download is unsuccessful. The concern is also related to the fact that a truck--roll is now required to restore the operational state of the Node, and subscribers would be experiencing longer outage times than they would have if the failed software download was aimed at a sub-- system in the Head--end. This has led some MSOs to believe that Remote PHY w/ EQAM in the CCAP Core would experience bricking in the Node much less frequently than the other DCA architectures, because new software loads to the Node would only occur when the PHY changes. And it is correctly assumed that MAC software (which is stored in the Node for Remote MACPHY systems) change more often than PHY software (which is the only software stored in the Node for Remote PHY systems).

This is an important attribute to address. The probability of “bricking” is a function of the Maintenance sub-system within any design. A well-designed Maintenance system should be able to easily survive a failed software download. Well-known tricks of the trade should be applied to help ensure that is the case. These tricks can include:

- 1) Maintaining one or more local, back--up software loads that were known to have worked in the past
- 2) Implementing watchdog timers to identify when lock--ups have occurred
- 3) Maintaining counters to determine when repeat attempts are failing catastrophically
- 4) Establishing processes to periodically try again after catastrophic failures
- 5) Providing more than one path back to the Head--end servers
- 6) Providing watchdog--timed messaging back to the Head--end Management and Control system that would identify a failure in the Node and initiate a truck-roll (while the system can still be operational on a back--up software load)

When implemented appropriately, the Maintenance system will permit the DCA system to continue providing service even if a software download is disrupted. Because the authors are strong believers in the power of a good Maintenance system, it is believed that there is little reason for the concerns registered by some MSOs. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Ease of Interoperability

Systems that have many interfaces between products from different vendors can sometimes suffer from interoperability issues. Even with available specifications, different interpretations can lead to issues that delay product deployments for a long time. Remote PHY has many more new interfaces being defined (ex: DEPI, UEPI, GCP) than the other approaches. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 3

Head-end Consolidation Support

Some MSOs are looking at consolidating their Head--ends and managing their networks from a single centralized location. This could require longer distances (hundreds of miles) between the Head--ends and the subscriber Cable Modems. Since the DOCSIS 3.1 currently limits the distance between the MAC and the Cable Modem to be no more than fifty miles. Remote PHY w/ EQAM in the CCAP Core (with the MAC in the distant Head-end) would support the required distances only with modifications to scheduling algorithms. These modifications are under study, but may have some negative effects on channel utilization levels. Remote MACPHY systems (with the DOCSIS MAC in the Node) would support the required distances without any modification. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 4

Node Boot-up Time

Node boot-up time consists of many components including loading software, loading hardware, and acquiring configuration information. For Remote PHY systems that separate the MAC and the PHY, 1588 timing must also be stabilized before full operation is permitted. Depending on the design, 1588 timing sync could take several minutes.

This could increase overall boot-up time. Since Remote MACPHY systems do not require 1588 to operate, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 4

Node Availability

Node availability (Mean Time Between Failures) is a function of the amount of hardware in the system and the amount of software in the system. For the hardware component, Remote MACPHY w/ EQAM in the Node requires more hardware than Remote MACPHY w/o EQAM in the Node, and Remote PHY w/ EQAM in the CCAP Core requires the least hardware. However, early-stage designs indicate that the primary difference between the different designs is a few cores in a multi-core processor. Calculations on hardware Mean Time Between Failure for the different designs therefore indicate only slight differences. Similarly, the software of Remote MACPHY w/ EQAM in the Node is slightly larger than the software of the Remote MACPHY w/o EQAM in the Node, and Remote PHY w/ EQAM in the CCAP Core requires the least amount of software in the Node. But all of them experience worse Mean Time Between Failures than traditional Nodes. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4.25
- Remote MACPHY w/o EQAM in the Node: 4.5
- Remote PHY w/ EQAM in the CCAP Core: 4.75

Security

All three of the DCA architectures can provide security using similar techniques. As an example, MACSec is a likely candidate for securing the fibers between the Head-end and the Node for all architectures. IPSec is also a likely candidate for securing multi-hop fibers between the Head-end and the Node for all of the architectures. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 5

Box-level Simplicity

It is more difficult to manage many boxes than it is to manage a few boxes. All of the proposed DCA architectures require a Node. But each one requires a different number of boxes in the Head-end. From the descriptions above, it is clear the Remote MACPHY w/ EQAM in the Node requires less boxes in the Head-end than Remote MACPHY w/o EQAM in the Node. Remote PHY w/ EQAM in the CCAP Core requires the most boxes in the Head-end. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

Infrastructure Compatibility

DCA architectures must fit into an existing Head-end and Outside Plant infrastructure. How well it fits can determine whether a particular architecture is appropriate or not. The attributes below are related to Infrastructure Compatibility.

Harmonization with Other “Last-Hop” Technologies

Many MSOs plan to offer many types of services in the future, including DOCSIS, xPON, WiFi, DSL, and G.Fast. All of these technologies could be implemented using Media Converter boxes deployed in the neighborhood of the subscribers. In most cases, the MAC and the PHY for the technology resides near the last hop interface that the MAC and PHY are managing. However, Remote PHY w/ EQAM in the CCAP Core is a one-off technology whose implementation is quite different from the implementation of all of the other technologies (see Fig. 7). Some MSOs would prefer to have all of their services offered in a similar fashion. In addition, one can argue that a transition from one technology to another (ex: DOCSIS to xPON) may be simplified if the locations of the MAC and PHY are similar for the two technologies. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 3

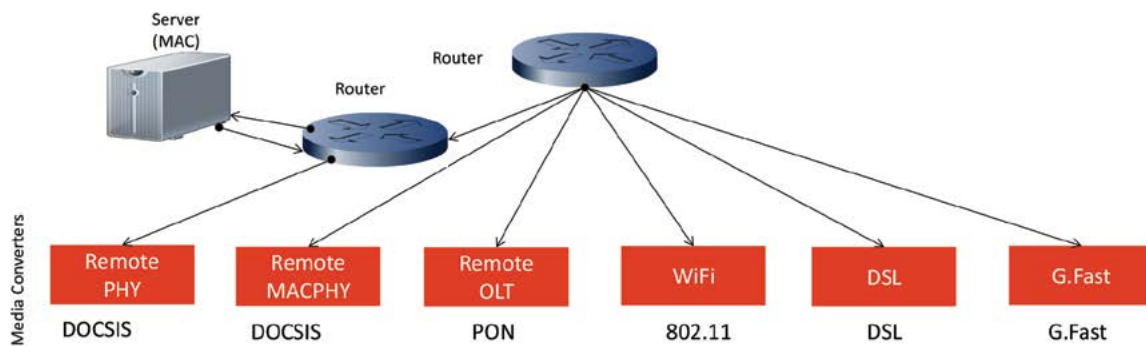


Figure 7 – Connections for Various Last-Hop Access Technologies

Video Encryption Compatibility

Traditional Digital Video Encryption is an important part of any video service. Several techniques are utilized, including Bulk Encryption and Edge-based Encryption performed in the EQAMs or CCAPs. Remote MACPHY w/ EQAM in the Node proposes to perform the EQAM and CCAP functionality in the Node. As a result, any MSO who prefers Edge-based Encryption would (by definition) be performing that encryption in the Node for a Remote MACPHY w/ EQAM in the Node system. The other two approaches would perform the Edge-based Encryption in Head-end boxes. This leads to a dilemma for MSOs who prefer Edge-based Encryption and utilize Remote MACPHY w/ EQAM in the Node, because the video passing over the fiber between the Head-end and the Node would contain unencrypted video. There are two solutions to this problem:

- 1) Pre-encrypt the data for transport across the fiber and then un-encrypt the data before re-encrypting at the Edge-based Encryption engine
- 2) Convert to Bulk Encryption.

These techniques add complexity to the MSO network. In addition, MSOs may incur extra costs by having to re-purchase video encryption licenses for each of the Remote MACPHY Nodes if they had already purchased them in their Head-end equipment. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 3
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 5

Provisioning/Configuration/Management Simplicity

Managing the Nodes in a DCA system is important. All three of the DCA systems provide good ways to manage the Nodes. Remote PHY systems manage from the CCAP Core, whereas Remote MACPHY systems permit the Nodes to be managed by virtualized Management and Control applications. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 5

Virtualization Compatibility

Some MSOs are trying to determine whether it makes sense to virtualize the MAC functionality. Other MSOs expect that they will never follow that path because it lacks harmonization with their other last-hop access technologies (see above). For MSOs who choose to follow this path, it was shown above that all of the DCA approaches can eventually be evolved into a virtualized environment. However, less changes are required to transition from the Remote PHY solution than from either of the Remote MACPHY solutions, because the Remote MACPHY solutions must add DEPI and UEPI and GCP functionality when the virtualized system is deployed. However, it is also interesting that the Remote MACPHY solutions will move towards virtualization of their Management and Control functions earlier than Remote PHY (since virtualized management is required for Remote MACPHY systems). Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Design Simplicity

Some MSOs hope to begin deploying DCA architectures in the next few years. To accommodate these desires, the designs that vendors must implement should be simpler. The attributes below are related to Design Simplicity.

Overall Design Complexity

Design complexity is a complex topic. Depending on viewpoints and starting points, one could argue that any approach is more or less complex. If the starting point for a vendor is a M-CMTS system, then Remote PHY w/ EQAM in the CCAP Core is probably less complex, because much of the DEPI code is already available and can be ported. If the starting point for a vendor is an I-CCAP system, then either Remote MACPHY system is probably less complex, because much of the I-CCAP code is already available and can be ported. For new entrants into the vendor space, it is probably true that Remote MACPHY systems are slightly simpler than Remote PHY systems, because they add DEPI and UEPI and GCP requirements to the other functions that are already contained in Remote MACPHY systems. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 4

Spec Completeness

The lack of finalized specs can delay product deliveries. Interfaces within the Remote MACPHY systems are (for the most part) based on the already-existing CCAP specs. The only new interfaces that may need to be defined are the interfaces between the Node and the virtualized Management and Control sub-system in the Head-end. Remote PHY specs are beginning to approach a final stage, but they are not completely finalized at this point. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 4
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 3

MAC/PHY Timing Interactions

The addition of any additional interfaces within a system can increase its time-to-market window. Remote MACPHY systems do not require any new specs or interfaces to define the timing information exchanged between the MAC functionality and PHY functionality. However, Remote PHY systems do require a new spec and interface (1588) to be defined between the MAC functionality in the Head-end and the PHY functionality in the Node. This leads to a slight increase in complexity for the Remote PHY system. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 5
- Remote MACPHY w/o EQAM in the Node: 5
- Remote PHY w/ EQAM in the CCAP Core: 4

Ability to Fit in Small Nodes

Node designs with less functionality and lower power requirements can sometimes be made to fit in smaller-sized Nodes than designs with more functionality and higher power requirements. As was described above, Remote MACPHY w/ EQAM in the Node consumes the most power. Remote MACPHY w/o EQAM in the Node consumes slightly less power. Remote PHY w/ EQAM in the CCAP Core consumes the least amount of power and may be able to fit in smaller Nodes than the others. Thus, scores will be assigned as shown below:

- Remote MACPHY w/ EQAM in the Node: 3
- Remote MACPHY w/o EQAM in the Node: 4
- Remote PHY w/ EQAM in the CCAP Core: 5

Conclusion

Three different Distributed CCAP Architectures (DCAs) were studied within this paper. Those architectures included:

- Remote MACPHY w/ EQAM in the Node
- Remote MACPHY w/o EQAM in the Node
- Remote PHY w/ EQAM in the CCAP Core

It was shown that the differences in these three diverse architectures lead to many different advantages and disadvantages. These advantages and disadvantages were rated for many different attributes. The attributes covered four categories, including:

- 1) Operational Cost Management
- 2) Operational Ease of Use
- 3) Infrastructure Compatibility
- 4) Design Simplicity.

The resulting scores for the attributes within each of these four categories are characterized in the entries shown in Table 1.

Attribute	Remote MACPHY w/ EQAM in the Node	Remote MACPHY w/o EQAM in theNode	Remote PHY w/ EQAM in CCAP Core
Head--end Costs	5	4	3
Node Costs	3	4	5
Total System Costs	4	4	4
Head--end Power Consumption	5	4	3
Node Power Consumption	3	4	5
Total Power Consumption	5	5	5
Head-end Rack--space	5	4	3
Size of Vendor Eco-system	4	4	5
Ability to Share Deployed MAC Functionality between Service Groups	4	4	5
Ease of Trouble-shooting	5	4	3
Ability to Select Best-in-Breed from CCAP Cores and Nodes	3	3	5
Bricking of Node Software Loads	4	4	5
Ease of Interoperability	5	5	3
Head-end Consolidation Support	5	5	4
Node Boot-up Time	5	5	4
Node Availability	4.25	4.5	4.75
Security	5	5	5
Box--level Simplicity	5	4	3
Harmonization with Other "Last-Hop" Technologies	5	5	3
Video Encryption Compatibility	3	3	5
Prov/Config/Mgmt Simplicity	5	5	5
Virtualization Compatibility	4	4	5
Overall Design Complexity	5	5	4
Spec Completeness	4	4	3
MAC/PHY Timing Interactions	5	5	4
Ability to Fit in Small Nodes	3	4	5

Table 1 – Attribute Scores for Different DCAs

It might also be interesting to look at the strengths and weaknesses for each of the three different DCAs under study.

Remote MACPHY w/ EQAM in the Node has the following strengths (scores of 5):

- Head-end costs
- Head-end power consumption
- Total power consumption
- Head-end rack--space
- Ease of troubleshooting
- Ease of interoperability
- Head-end consolidation support
- Node boot-up time
- Security
- Box-level simplicity
- Harmonization with other “last-hop” technologies
- Prov/Conf/Mgmt simplicity
- Overall design complexity
- MAC/PHY interactions

Remote MACPHY w/ EQAM in the Node has the following weaknesses (scores of 3 or less):

- Node costs
- Node power consumption
- Ability to select best--in--breed from CCAP Cores and Nodes
- Video encryption compatibility
- Ability to fit in small nodes

Remote MACPHY w/o EQAM in the Node has the following strengths (scores of 5):

- Total power consumption
- Ease of interoperability
- Head-end consolidation support
- Node boot-up time
- Security
- Harmonization with other “last-hop” technologies
- Video encryption compatibility
- Prov/Conf/Mgmt simplicity
- Overall design complexity
- MAC/PHY interactions

Remote MACPHY w/o EQAM in the Node has the following weaknesses (scores of 3 or less):

- Ability to select best-in-breed from CCAP Cores and Nodes

Remote PHY w/ EQAM in the CCAP Core has the following strengths (scores of 5):

- Node costs
- Node power consumption
- Total power consumption
- Size of vendor eco-system
- Ability to select best-in-breed from CCAP Cores and Nodes
- Bricking of Node software loads
- Security
- Video encryption compatibility
- Prov/Conf/Mgmt simplicity
- Virtualization compatibility
- Ability to fit in small Nodes

Remote PHY w/ EQAM in the CCAP Core has the following weaknesses (scores of 3 or less):

- Head-end costs
- Head-end power consumption
- Head-end rack-space
- Ease of troubleshooting
- Ease of interoperability
- Box-level simplicity
- Harmonization with other “last-hop” technologies
- Spec completeness

Readers should recognize that the scores are subjective and should only be considered as rough guidelines. The relative distance between scores and the reasons for the scores (described within the paper) are much more important than the scores themselves.

It should also be noted that different MSOs will assign different levels of importance and different weightings to each of the attributes, so the resulting take-aways from this study may very well vary from MSO to MSO.

One other interesting note is that none of the DCA approaches is perfect and that none of the DCA approaches is terrible. In fact, all of the scores shown in the table have values of 3 or higher, which are all fair to excellent scores.

The results from this paper should be useful as MSOs begin to select their DCA paths into the future.

Abbreviations

1588	IEEE 1588 Precision Timing Protocol (PTP)	I-CCAP	Integrated Converged Cable Access Platform
AM	Amplitude--modulated	HFC	Hybrid fiber-coax
Bcast	broadcast	L2/L3	Layer 2 and Layer 3
bps	bits per second	MAC	Media Access Control interface
CCAP	Converged Cable Access Platform	MACPHY	DCA instantiation that places both MAC & PHY in the Node
CMTS	Cable Modem Termination System	MSO	Multiple system operator
COTS	Commercial Off The Shelf	Ncast	narrowcast
DAA	Distributed access architecture	OOB	Out Of Band
DCA	Distributed CCAP architecture	PHY	Physical interface
DEPI	Downstream External PHY Interface	PON	Passive Optical Network
DOCSIS	Data over cable service interface specification	PTP	Precision Timing Protocol
EQAM	Edge Quadrature Amplitude Modulator	RF	Radio frequency
FEC	Forward error correction	UEPI	Upstream External PHY Interface
GCP	Generic Control Protocol	W	Watt
IEEE	Institute of Electrical and Electronics Engineers	SCTE	Society of Cable Telecommunications Engineers

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