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How to deliver QAM video in a DAA world

A Technical Paper prepared for SCTE•ISBE by

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Introduction

Cable operators are transitioning to Distributed Access Architectures (DAAs) in response to the dramatic increase in High-Speed Data (HSD) traffic on their networks. As cable operators begin planning the introduction of DAA into their networks, one of the critical decisions they need to make is how they will deliver video.

If an operator is not immediately migrating to an all-IP video implementation, they must continue to support Quadrature Amplitude Modulation (QAM) video, which also consumes significant capacity and spectrum. The good news is that a Flexible MAC Architecture (FMA) implementation of DAA enables a variety of options for carrying QAM video regardless of whether the architecture used is Remote PHY (R-PHY), Remote MACPHY (R-MACPHY), or a combination of both.

In this paper, we will address the factors an operator should consider in making the DAA video delivery decision and outline several flexible DAA QAM video delivery options, and discuss their pros and cons.

Content

1. A quick recap on DAA

A DAA distributes specific functions of the Converged Cable Access Platform (CCAP) to other parts of the network. There are several different approaches to DAA. However, with the standardization of FMA, the two predominant approaches are:

R-PHY: Pushes certain DOCSIS MAC functions as well as the DOCSIS PHY and Video PHY to the optical node, creating a Remote PHY Device (RPD). Doing so digitizes the hub-to-node connection and significantly improves signal quality to the end customer.

R-MACPHY: Instantiates an RPD with the DOCSIS Core/virtual CMTS (vCMTS) running locally in the node instead of in the headend, creating a Remote MACPHY Device (RMD). R-MACPHY delivers all the benefits of R-PHY, but also enables huge headend space and overall system power advantages by eliminating the need for a DOCSIS Core /vCMTS in the headend. Additionally, by keeping the DOCSIS components together, R-MACPHY avoids the tight coupling and timing challenges of R-PHY and minimizes latency and jitter concerns for efficient support of capabilities like Low Latency DOCSIS (LLD) and Mobile Backhaul (MBH) over DOCSIS.

2. Challenges of delivering QAM video in DAA

In a traditional cable network, broadcast and narrowcast digital video streams are converted into QAM-modulated RF signals either in the headend or hub. This process is done in either a standalone Edge QAM (EQAM) or a CCAP. The resultant video QAM/RF signals are combined with DOCSIS HSD QAM/RF signals and transmitted over analog fiber to Hybrid Fiber-coaxial (HFC) nodes for delivery to subscribers.

With DAA, the QAM modulation and RF upconversion are moved to an RPD or RMD in the outside plant (OSP), digitizing the connectivity to the node. That means an EQAM or CCAP with RF output cannot connect over the now-digital link to the node. Thus, an operator must make adjustments to their existing video network as they adopt DAA. This challenge of QAM video delivery is the same regardless of whether the DAA approach used is R-PHY or R-MACPHY.

3. Important considerations

As cable architects design their DAA networks, they must consider how their existing video network is laid out, what video services they currently offer, and how they envision evolving their video network. In this section, we discuss the leading factors to which cable architects must pay attention including:

⇒ How is the broadcast video network laid out?
⇒ How is the narrowcast video network laid out?
⇒ How is the video encryption set up?
⇒ How does the set-top box (STB)-control flow through the network?
⇒ Is there analog video in the network?

3.1. How is the broadcast video network laid out?

Most broadcast functions are centralized in a traditional cable network, but there are variations in the broadcast network based on the location of the broadcast QAMs and presence of local broadcast channels. The three most common scenarios are:

1. Broadcast QAMs in the hub: This is a common scenario where most broadcast functions are centralized, but the broadcast QAMs are located in the hub.
2. Centralized broadcast: In this scenario, all the broadcast functions, including the QAMs, are centralized with analog super-trunks connecting the broadcast QAMs in the central location all the way to the node.
3. Local broadcast: Here the broadcast QAMs for local channels are located in the hub while all other broadcast QAMs are centralized.

DAA provides options to support all of the broadcast scenarios discussed above. With DAA, the operators can choose to keep their broadcast QAMs as-is in the hub. However, with the QAM function moved to an RPD or RMD in the OSP, it is most natural to centralize the broadcast services.

3.2. How is the narrowcast video network laid out?

Narrowcast services are designed to serve a group of homes in a neighborhood, and hence the narrowcast QAMs are naturally suited to be placed in hubs close to the neighborhood. Video on Demand (VoD) and Switched Digital Video (SDV) are the two predominant narrowcast services.

Before moving to DAA, operators must consider how their narrowcast Single Program Transport Streams (SPTS) are multiplexed and mapped to their QAMs. Today, such a mapping is done in one of three ways:

1. ERM-managed – ISA: In this mode, the narrowcast SPTS sessions are multiplexed and mapped to video QAMs by an Interactive Services Architecture (ISA)-based Edge Resource Manager. ISA architecture is implemented by multiple operators in North America.
2. ERM-managed – NGOD: In this mode, the narrowcast SPTS sessions are multiplexed and mapped to video QAMs by an NGOD-based Edge Resource Manager. Comcast is one of the primary operators using NGOD architecture.
3. Table-based mapping: In this mode, the VOD SPTS sessions are multiplexed and mapped to video QAMs using a pre-defined IP/UDP scheme. This scheme is used only for VOD and is prevalent in regions outside North America.

With DAA, operators need to ensure that the option they select for delivering QAM video supports the existing method for multiplexing the narrowcast services.

Furthermore, with the QAM function moved to the RPD or RMD under DAA, the operators have the option to centralize their narrowcast video network. In order to do so, the operators must ensure their network meets the following conditions:

- The ad-splicing system used for narrowcast services must be centralized along with the narrowcast video.
- There must be sufficient capacity in the fiber connecting the headend to the hubs to accommodate full line-rate narrowcast MPTS traffic.

3.3. How is the video encryption set up?

In North America, the two primary forms of encryption used for QAM video are Cisco PowerKEY and Motorola DigiCipher. In Europe and other parts of the world, DVB CAS is the predominant encryption method. Today, operators use one of three architectures for their video encryption:

1. Proprietary edge encryption: Proprietary encryption of the video services occurs in the video QAM device, either EQAM or CCAP. Proprietary encryption limits the choice of vendor.

2. Standards-based edge encryption: Standards-based encryption of the video services is done in the video QAM device. Standards-based encryption enables an interoperable eco-system.

3. Bulk encryption: The video is bulk-encrypted, or pre-encrypted, before flowing toward the video QAM device, whether EQAM or CCAP. Bulk-encryption provides operators more network flexibility and vendor choice.

DAA provides options to support any of these approaches. However, as operators adopt DAA, they are encouraged to implement either bulk-encryption or standards-based encryption as it enables an interoperable eco-system, provides greater network stability, and enables the centralization and consolidation of the video services.

3.4. How does the STB-control flow through the network?

Cable operator networks are used to transmit the interactive guide and other control signals for video QAM STB operation. Operators use either a dedicated out-of-band (OOB) network for STB-control traffic, or they deliver the STB-control messages using in-band video or via DOCSIS.

1. Separate OOB network:

   In this design, out-of-band protocols are used to control STB operation. Vendor-specific headend equipment uses the OOB path to manage the STBs in the field. An OOB modulator modulates the control signals originating from various headend equipment into QPSK RF signals. The modulated OOB RF signals are combined with the DOCSIS and video QAM RF services in the RF combiner. OOB consumes very little bandwidth, but is essential for the operations on the QAM-based STB.

   The OOB concept is most prevalent in North America. There are two central OOB systems deployed by operators in America:

SCTE 55-1: This is the legacy Motorola/CommScope system that multiplexes and modulates MPEG over IP/UDP streams received from the legacy Motorola headend in the downstream direction, and in the upstream direction, demodulates signals received from STB and packetizes into ATM-like cells over IP/UDP for further transmission (Aloha system).

SCTE 55-2: This is the Scientific Atlanta/Cisco system that performs a similar function as SCTE 55-1, but between a Cisco headend and QAM STB using an ATM transport.

The challenge with OOB support is that existing OOB gear in the headend relies on an RF combining network. In DAA, the RF combining network is eliminated, and hence, an alternative solution is required. Furthermore, when operators design their DAA network, they need to accommodate the fact that OOB typically uses two-way communication. DAAs offer various options for delivering OOB over the same digital transport infrastructure used to provide HSD and video services.

2. In-band video or via DOCSIS:

In this design, the STB-control traffic is delivered either via in-band video or via DOCSIS. The STB-control in a broadcast setup flows in-band through the broadcast video. The STB-control in a narrowcast setup flows via the DOCSIS path, except for the encryption control which flows through the narrowcast video path.

Since there are no OOB signals used for STB-control in this scheme, there are no special requirements to handle STB messaging under DAA. The same solution used to deliver video services in DAA can also handle the STB-control traffic.

3.5. Is there analog video in the network?

Operators are phasing out the analog video from their networks, but it still exists in many parts of Latin America, Asia, and Europe. Some operators have a limited amount of analog video content which they are planning to phase out in the next couple of years. Other operators have a significant amount of analog video content which they may retain for a longer duration.

Today, analog video is combined with narrowcast and broadcast QAM services in the hub. As operators transition to DAA, it is an excellent opportunity for them phase out analog video, but it is not compulsory. DAA provides both short- and long-term solutions to handle analog video depending on the number of analog video channels, and thereby provides operators the flexibility and freedom to phase out analog video when they prefer.

4. Options for delivering QAM video

DAA provides different flexible options to deliver QAM video.

4.1. Option 1: Use Analog Overlay

The simplest option for delivering QAM video in DAA is to use an Analog Overlay. This approach delivers all the existing video-related services, including broadcast QAM video, narrowcast QAM video, analog video, and STB-control, using existing analog fiber infrastructure overlaid on top of the digital link carrying HSD services. The video services can be delivered on a separate analog fiber, or on a dedicated wavelength using wavelength-division multiplexing (WDM), all the way to the DAA node where the optical-to-electrical conversion occurs.

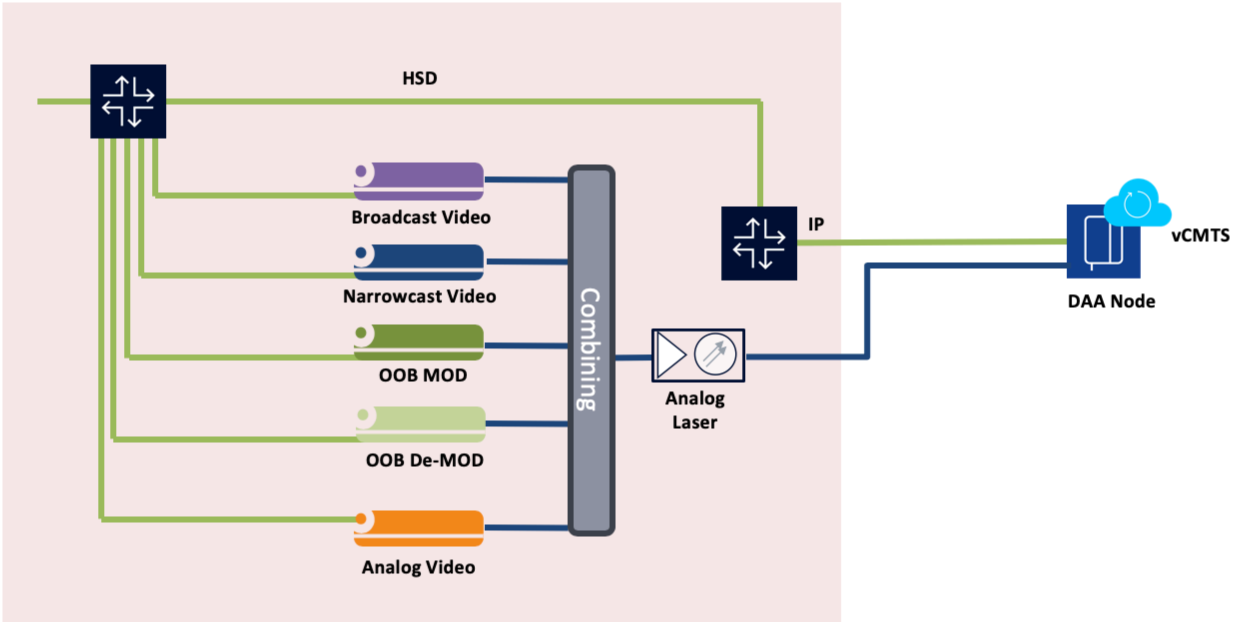

Figure 1 - Option1: Analog Overlay

The Analog Overlay is the simplest option as there is no change to the existing video and OOB infrastructure. This option supports the entire line up of analog video and supports most "corner case" scenarios. However, this option provides the least benefits as it:

- Limits how far the nodes can be placed from the hub
- Does not eliminate RF in the headend-to-node connection
- Might require two fiber connections to the node

By fundamentally maintaining two networks, operators incur the highest operating cost by using this option.

4.2. Option 2: Add a Video Adapter in front of the video QAMs

The Video Adapter alternative requires minimal changes to the network for video delivery, enabling an operator to primarily focus on data delivery as they transition to a DAA. The Video Adapter allows the operator to keep their existing video QAM assets as they are in the headend or hub; the operator simply adds a Video Adapter downstream of the EQAM or CCAP video QAMs. The Video Adapter demodulates the Multi-Program Transport Stream (MPTS) over RF from the video QAMs and outputs digital MPTS either in RTP or DEPI (L2TP signaling) format. The video can then be delivered over the same digital link as the HSD to the node, where the original QAM/RF signal is re-created for transmission to the STB. The Video Adapter supports 1588 PTP to synchronize with the node where the QAM/RF upconversion occurs.

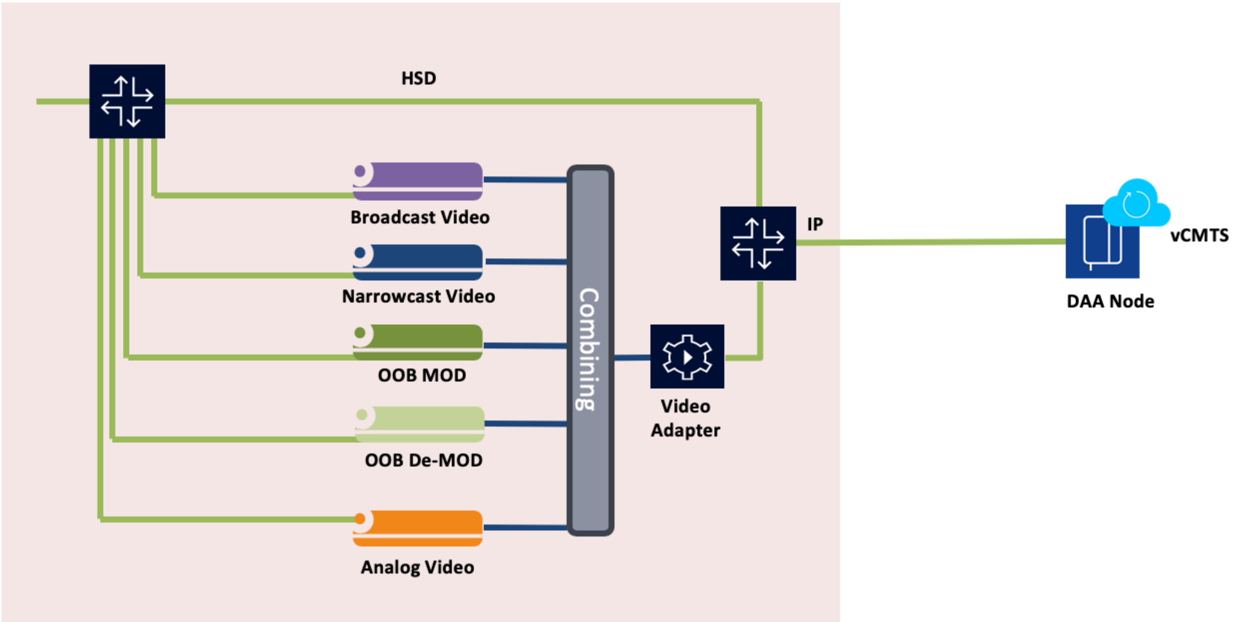

Figure 2 - Option2: DAA Video Adapter

To deliver OOB in DAA, the Video Adapter applies the Narrowband Digital Forward (NDF) and Narrowband Digital Return (NDR) concept to handle both SCTE 55-1 and SCTE 55-2 signals. A Video Adapter with NDF samples and digitizes the QPSK/RF signals coming from the OOB modulator for transmission over the converged interconnect network (CIN) to the remote node. The node then re-creates the original QPSK/RF downstream signal for transmission to the STB. In the reverse direction, the NDR on the node samples and digitizes QPSK/RF signals coming from the STB for transmission over the CIN to the Video Adapter, which then re-creates the original QPSK/RF upstream signal. The NDR/NDF approach is defined by the CableLabs R-PHY OOB (R-OOB) architecture.

The Video Adapter applies the Wideband Digital Forward (WDF) technique to deliver analog video in-band using the same digital link to the node used for other services. WDF functionality must also be enabled in the DAA node to support analog video.

By using a Video Adapter, operators need not change their existing video and OOB infrastructure as they transition to DAA. The Video Adapter can be used for all services including broadcast, narrowcast, and OOB, and can work with any vendors' equipment. The Video Adapter also supports most analog video and "corner case" scenarios. Using a Video Adapter can be a transitional step before adopting longer-term video options explained later in this paper. However, this option could also serve as a longer-term solution.

The downside of the Video Adapter option is that it requires additional equipment in the headend or hub. Also, for OOB application, the distance limitation between the STBs in the field and the OOB gear as specified in SCTE 55-2 still applies.

4.3. Option 3: Add DEPI to existing video QAMs

Another option to evolve video QAMs to DAA is to modify the existing EQAM or CCAP video QAMs to send out MPTS via DEPI using L2TP signaling instead of QAM/RF signals. This option ensures an all-digital path to the node in the outside plant. It would require the video QAM vendor to add new hardware and/or software that supports the delivery of legacy video via DEPI. The QAM vendor may also need to add 1588 PTP functionality for synchronization with the node. The synchronization is essential to ensure the video chassis outputs MPTS packets at the same rate as the QAM modulation inside the node. In some markets, the QAM vendor may offer the option of sending MPTS over IP/RTP in addition to the DEPI.

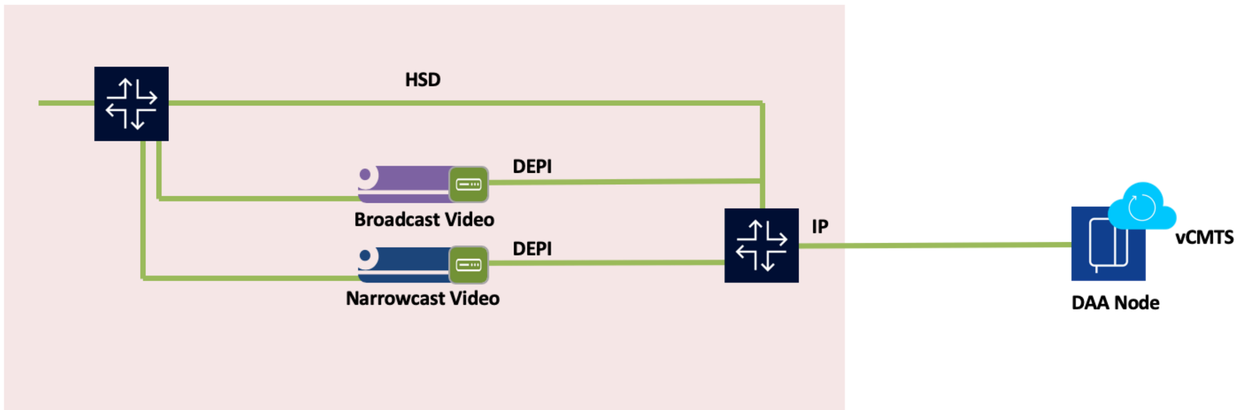

Figure 3 - Option 3: Add DEPI to existing video QAMs

Modifying existing QAMs to add DEPI is an option that does not require additional separate equipment in the headend. However, it does require modifications to the existing video QAM gear to adapt to DAA. Thus the viability of this option depends on the specific QAM equipment in use and support from that equipment vendor.

4.4. Option 4: Deliver QAM video through a Video Core

As discussed earlier, a DAA moves the QAM/RF functions to the node in the outside plant. The remaining core functions for video are described as a Video Core, which is an auxiliary core as defined by the CableLabs FMA standard. In essence, a Video Core performs all the functions of an EQAM except for the modulation and PHY, which are done in the DAA node. The broadcast and narrowcast SPTS that were previously flowing into the EQAM now stream into a purpose-built Video Core instead. The Video Core multiplexes the streams and transports MPTS streams over IP/DEPI to the DAA node in the neighborhood.

The essential functions of a Video Core include:

- MPTS re-multiplexing
- PCR re-stamping/de-jitter
- Program (PSI) manipulation
- DEPI encapsulation
- 1588 timing
- Dynamic setup/teardown of narrowcast video services
- Edge encryption

The video QAMs in an EQAM or CCAP perform all of these functions today with the exception of the DEPI encapsulation and 1588 timing, which are requirements specific to a Video Core.

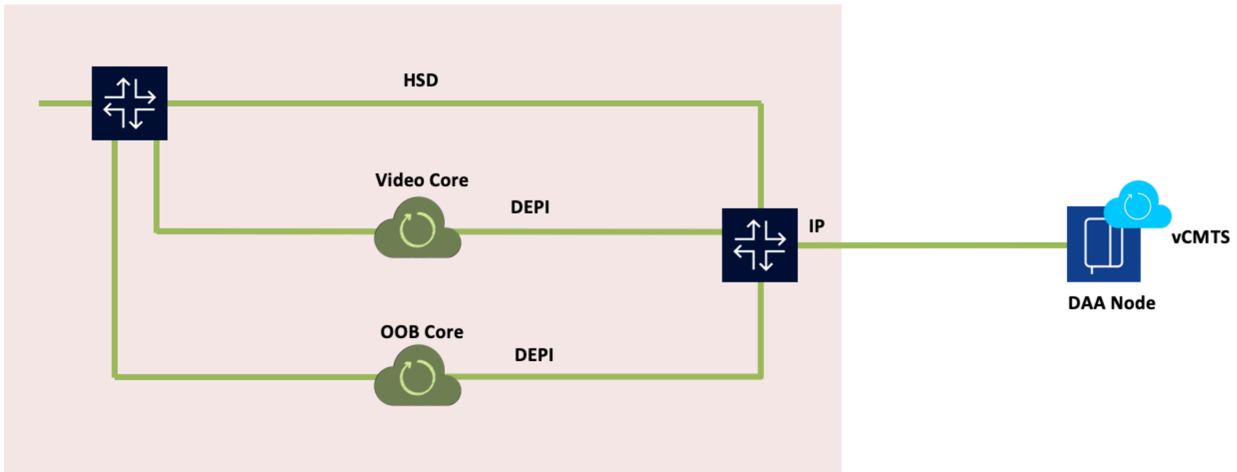

Figure 4 - Option 4: Video Core

Virtual Video Core

An essential aspect of a Video Core is that it is purpose-built. Thus, there is an excellent opportunity to maximize efficiency by constructing it as a software-based or virtualized Video Core. The distributed nature of a software-based Video Core makes it a perfect candidate to be placed in containers or virtual machines and launched as a cloud-native solution. Virtualizing the Video Core has multiple benefits, including:

- Runs on off-the-shelf servers rather than more expensive, purpose-built equipment
- Reduces the video footprint in the headend and hub, delivering significant space and power savings
- Enables centralization of broadcast and narrowcast video services
- Allows hub consolidation by eliminating the need for any video gear in the hub
- Enables orchestration of the virtual Video Core to simplify network configuration, increasing network agility and service velocity
- Can run alongside other virtualized cores in any location

A Video Core allows operators to phase out their current video assets and sets the stage for evolution to a future-proof, all-IP, all-digital network. Virtualization really makes it easy for the operator to make the transition to an all-IP solution, making a Video Core the most optimal, longer-term option.

OOB Core

An OOB Core is another auxiliary core used to handle the OOB application. The OOB Core functions are defined by the CableLabs R-PHY OOB (R-OOB) architecture. In R-OOB, the existing OOB modulator is either replaced or modified to send the OOB downstream signal as MPEG transport streams or ATM cells encapsulated over DEPI, and the existing demodulator is either replaced or modified to decapsulate upstream ARPD datagrams or ATM cells carried over UEPI. The modulation and demodulation functions move to the DAA node in the outside plant. This approach is applicable for both SCTE 55-1 and SCTE-55-2 with a caveat. The SCTE 55-2 OOB system relies on ATM transport and has stringent, low latency timing requirements which, if not met, can cause the STBs to go offline. Hence, some OOB MAC implementation is required in the DAA node to prevent the STBs from going offline. The R-OOB approach resolves the distance limitation challenges and is a better suited long-term approach for handling OOB in DAA.

4.5. What does the FMA standard say?

The FMA standard, currently in development at CableLabs, provides a common framework for video regardless of the selected DAA implementation. The FMA defines auxiliary cores such as the Video Core and the OOB Core to handle video and OOB applications. These auxiliary cores function the same way in both the R-PHY and R-MACPHY FMA alternatives.

The FMA reuses the OOB and video requirements defined in the R-PHY standard. The FMA includes a Video Core that utilizes the Generic Control Protocol (GCP) to manage the resources on both the RPD and RMD. The FMA also supports the concept of a Video Engine, where the FMA MAC Manager is primarily responsible for managing the video QAMs in any DAA implementation, and thereby limits the role of the Video Cores to simple traffic engines with no significant management responsibility. A Video Engine is essentially a Video Core without GCP.

4.6. Comparing the options

In summary, there are a number of options available to the cable operators to deliver QAM video in a DAA network. The approaches include short-term alternatives requiring minimal network alteration as well as long-term more efficient options. An operator's selection will be influenced by their current QAM video network set up, their network centralization plans, and their all-IP video evolution strategy.

Table 1 - Comparing the options for DAA QAM video delivery

DAA options for QAM video	When to use it?	Pros	Cons
Analog Overlay	• Support analog video • “Corner case” scenarios	• No change to existing video infrastructure • No change to existing OOB infrastructure • Supports all analog video and “corner case” scenarios	• Highest operating cost – essentially maintaining two networks • Least benefit – limits distance, does not eliminate RF in headend-to-node connection, requires two fiber connections to node
Video Adapter	• Keep existing video and OOB infrastructure as-is	• No change to existing video infrastructure	• Additional equipment required in the headend/hub

DAA options for QAM video	When to use it?	Pros	Cons
	• Near-term IP video migration	• No change to existing OOB infrastructure • Supports most analog video and “corner case” scenarios • Single IP (digital) link to the node	• Need to make sure Video Adapter densities align with EQAM locations
Add DEPI to existing video QAMs	• Mainstream video QAMs support DEPI	• Leverage existing video infrastructure • No additional boxes (e.g., video adapter) required • Single IP (digital) link to the node • Likely “Video Core” ready	• Does not support OOB • Existing QAM equipment requires modification
Video Core	• “Cap & grow” existing video infrastructure • Centralize and virtualize the video infrastructure	• Replace or “cap & grow” existing video infrastructure • Purpose-built appliance or virtualized solution	• Requires replacing existing video QAM assets • Requires building separate video and OOB core

4.7. Example DAA QAM video deployment scenarios

We have discussed some of the network considerations to which cable operators must pay attention when designing their DAA network. We have also reviewed the various QAM video delivery options for DAA. We now present a couple of example deployment scenarios.

1. Example deployment – Scenario 1: DEPI EQAM and Video Adapter

In this example, narrowcast video is delivered by modifying the existing video QAMs to add DEPI functionality. The encryption of the video services is done inside the video QAM device, which is managed by an ERM. Broadcast video, OOB and in some cases analog video are delivered using a Video Adapter. All the QAM video equipment resides in the hub.

In this scenario, the existing video and OOB infrastructure is either leveraged or retained as-is. This is a possible scenario for most/many deployments in North America.

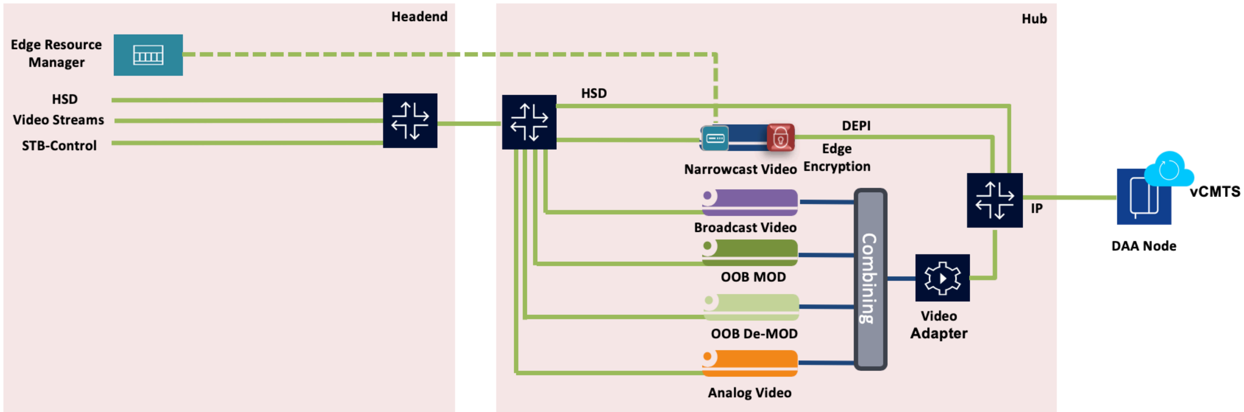

Figure 5 - Example deployment – Scenario 1: DEPI EQAM and Video Adapter

2. Example deployment – Scenario 2: Video Cores

In this example, a Video Core replaces the existing broadcast and narrowcast video QAMs. The video streams are either bulk-encrypted or pre-encrypted before reaching the Video Core, and a table-based mapping scheme is used by the Video Core to multiplex the incoming VOD SPTS streams. The STB-Control traffic is delivered in-band through video and via DOCSIS. Finally, an Analog Overlay is used to deliver the analog video. This is a possible scenario for DAA deployments in Europe.

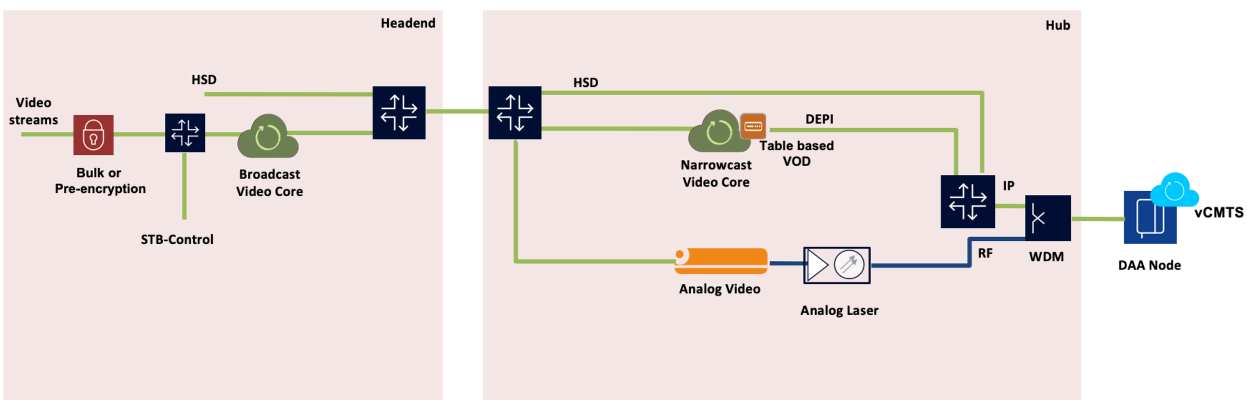

Figure 6 - Example deployment – Scenario 2: Video Cores

5. Evolution to IP video

Most operators began their migration to IP video sometime back. The following three questions will help an operator gauge how prepared they are to move to IP video:

1. How much of the broadcast and narrowcast content is available on IP video?
2. How much of the IP video content is available on the "big screen"?
3. Where are you in the roll-out of IP-based STBs?

Broadly speaking, cable operators aspire to deliver all of their video services over IP. However, very few are there yet. The reality is that most operators say "QAM video will be in their network for at least the next 5 to 10 years."

There are different paths operators can follow in their evolution to all-IP video:

Option 1: Operators can go to all-IP video in conjunction with their DAA transition.
Option 2: Operators can go to DAA with a simple interim QAM video delivery option (e.g., Video Adapter) before a near- or mid-term evolution to all-IP video.
Option 3: Operators can go to DAA using a Video Core as a mid- or long-term stepping stone to all-IP video.

Most operators will pursue option 2 or 3, continuing to support some legacy QAM video in DAA as they gradually transition to all-IP video.

Conclusion

Consumers around the globe are increasingly consuming video via the Internet. This has resulted in an exponential growth of high-speed data traffic, presenting a capacity challenge to cable operators. Most operators will ultimately deliver all of their video over IP. However, this migration will be gradual. In the meantime, operators must increase their networks' data capacity.

DAA is widely accepted as the best solution for ever-greater capacity requirements. Not only does it efficiently accommodate the increased HSD traffic, but it also provides multiple flexible options for operators to accommodate the QAM video in their network as they migrate to all-IP. Operators can deliver QAM video in a DAA by adopting one of four options:

1. Keep their existing video QAM assets as they are and use an Analog Overlay approach;
2. Keep their existing video QAM assets as they are and add a Video Adapter in front of the video QAM;
3. Modify their existing video QAM assets by adding DEPI functionality; or
4. Retire existing video QAM assets and deliver QAM video through a Video Core.

The question of how to distribute QAM video in a DAA network has been thoroughly addressed and should not cause concern or delay an operator's decision to move to DAA.

By applying a distributed architecture and digitizing the network all the way from the headend to the node in the neighborhood, a DAA lays the perfect foundation for evolving to all-IP video. With IP transport as a baseline, operators have a clear path to an all-IP video solution by making minimal changes in the headend and swapping out the QAM-based STBs with IP-based STBs. DAA provides a clear stepping-stone to an all-IP video solution.

Abbreviations

CCAP	Converged Cable Access Platform
DAA	Distributed Access Architectures
DOCSIS	Data-Over-Cable Service Interface Specifications
EQAM	Edge QAM
FMA	Flexible MAC Architecture
HSD	high-speed data
ISA	Interactive Services Architecture
LLD	Low Latency DOCSIS

MBH	mobile backhaul
NGOD	Next Generation On Demand
OSP	outside plant
QAM	quadrature amplitude modulation
R-PHY	Remote PHY
R-MACPHY	Remote MACPHY
RPD	Remote PHY Device
RMD	Remote MACPHY Device
SDV	switched digital video
VoD	video on demand

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