The Smart and Seamless Evolution of the HFC Network – Today and Beyond

A Technical Paper prepared for SCTE by

Gustavo Colly
Technical Solutions Sales Engineer
ATX Networks
Buenos Aires, Argentina
+1 (289) 204-7800 Ext 1300
gcolly@atx.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction

As consumer bandwidth requirements continue to grow, cable operators will need to intelligently and cost-efficiently expand network capacity to accommodate future increases in data traffic — especially upstream traffic. Migrating from CAA (Centralized Access Architecture) to DAA (Distributed Access Architecture) architectures, a strategy that most cable service providers are currently pursuing, provides a near-seamless and cost-effective transition. Reallocating spectrum through band splits and the adoption of DOCSIS® 4.0 will play important roles in that effort by taking advantage of the incredible resiliency of cable's HFC network. Depending on the status of the cable operator's HFC network, dropping in RF amplifier modules to fiber nodes and trunk and distribution amplifiers in conjunction with new taps and passives could also provide cable operators with a seamless evolution of their networks. The ubiquity of coaxial connections makes the continued evolution of DOCSIS standards a logical and economical way to continue to bring world-class broadband services to millions of households. Coax is also capable of supporting current gigabit-class services by preserving/reusing most of the existing network infrastructure. The bottom line is that HFC networks can be competitive with symmetrical Gigabit services through DOCSIS 4.0 standards, which will allow the needed expansion of upstream capacity.

This technical paper will highlight best practices and design criteria for managing the evolution of the HFC network, as well as detailing relevant market trends.

2. Traditional Centralized Access Architecture (CAA)

Traditional Centralized Access Architecture (CAA) has been deployed all over the world and is a proven and secure architecture for cable service providers. But it has reached its limits.

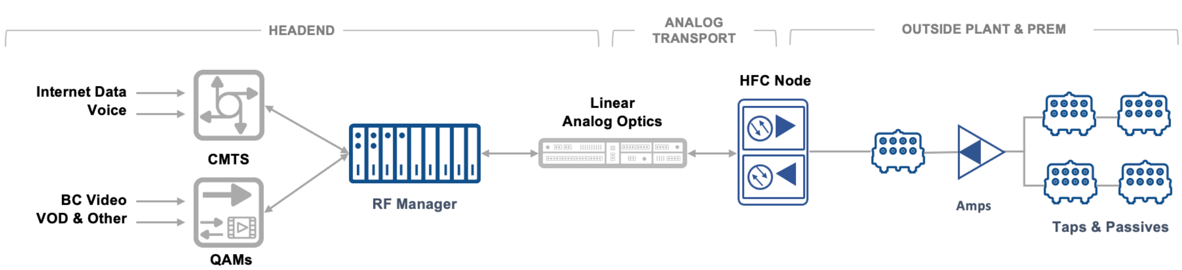


Figure 1 - Centralized Access Architecture (CAA)

In a centralized access architecture, most of the video and data infrastructure remains in the hub or headend location. The main components of it are BC and NC video Edge QAMs, which generate the PHY layer of the video carriers, and the CMTS, which oversees MAC and PHY functions of DOCSIS carriers. CCAP core combines both video and data functions in one device. RF management is used to split/combine the downstream/upstream (DS/US) carriers required by the service group and an optical transmission and reception stage that usually uses linear analog optic technology and oversees the conversion from RF to optical, and vice versa. In the outside plant (OSP), the HFC fiber node connects the fiberoptic cable to the trunk and distribution RF system. It does the same function as the inside plant's (ISP's) optical transmission/reception stage; it converts from an optical signal to an RF signal. OSP taps and passives are being used to distribute RF carriers over the service area with RF amplifiers.

As mentioned earlier, CAA has limits and they are associated with the limitations of CMTS/CCAP cores, Video Edge QAMs, RF Management products and the inside plant's optical platform. Most of this equipment supports up to 1.2GHz in the downstream direction. In terms of upstream direction, its limit is 204MHz, known as the high-split band. These physical limits, in terms of frequency, are determined by DOCSIS 3.1.

The linear analog optical solutions often used by the ISP for downstream direction consist of RF-modulated signals that will be amplitude modulated (AM) onto an optical carrier. Several studies demonstrate that 4096 QAM OFDM signals are achievable in the link between TX (ISP) and RX (OSP Node). In the upstream direction, a DFB type of laser was widely deployed in reverse transmitters at fiber nodes and can work with 5-85MHz and 5-204MHz bandwidths. Both upstream bandwidths can achieve 1024 QAM Orthogonal Frequency-Division Multiple Access (OFDMA) signals. Digitizing the upstream optical link of HFC using EDR or Remote PHY can help break the power budget limitations of the analog optical link and go a little farther on QAM constellations used.

CMTS/CCAP Cores used in CAA architectures are based on hardware-specific functionalities that impact capacity in DS and US ports. Current D3.1 cable modems support 32 SC-QAM plus two OFDM blocks. Regarding US support, D3.1 CMs support eight SC-QAM signals along with two 96MHz (max) OFDMA blocks.

In numbers, 32 SC-QAMs plus two OFDM full block (192MHz) with 4096 QAM constellation provides approximately 5Gbps DS capacity (1.9Gbps x 2 + 1.2Gbps = 5Gbps downstream capacity). In US, two OFDMA with 1024 QAM constellation plus four SC-QAMs with 6.4MHz width provides approximately 1.575Gbps upstream capacity.

3. Distributed Access Architecture (DAA)

Distributed Access Architecture (DAA) is an evolution of CAA, where the main functions performed in the headend or hub are relocated to the fiber nodes, closer to the subscriber. Moving these operations from the headend/hub enables MSOs to virtualize operations by using generic computer hardware, which relieves space and cooling constraints of the facilities caused by continued exponential growth in node counts and traffic.

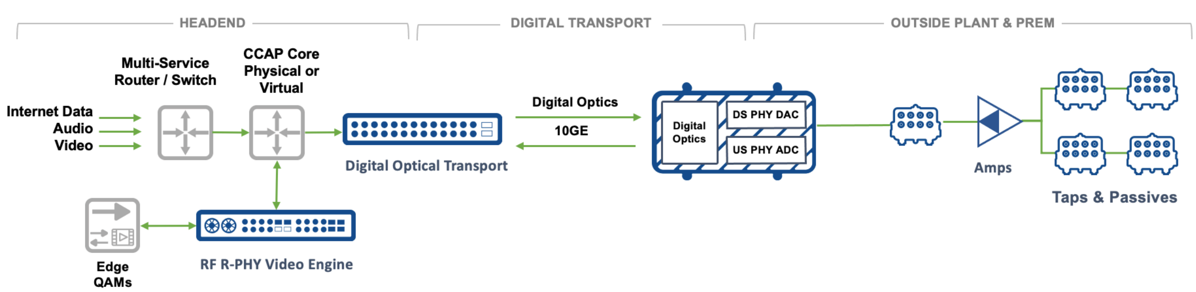


Figure 2 - Distributed Access Architecture (DAA)

The main difference between the two architectures is that the PHY layer of video and data in DAA architectures is now in the fiber node, and a 10Gbps or higher Ethernet fiber link is used to connect all these components, replacing the previous analog optical link. There are two flavors of DAA architectures: R-PHY, which moves the modulation and demodulation to the fiber node and leaves other functionality at the hub or headend, and R-MACPHY, or FMA, that moves the DOCSIS MAC and PHY layers to the fiber node. Both versions are under the Distributed Access Architecture program at CableLabs. All these mentioned differences allow for an improvement in end-of-line (EOL) performance (mainly RxMER), better spectrum efficiency by using higher modulation orders in OFDM/OFDMA blocks and provides flexibility for operators to deploy network functionality. DAA architecture is also the driver for the delivery of 10G symmetrical capacity at the service group level in conjunction with DOCSIS 4.0, which will allow cable operators to achieve 10Gbps speeds downstream and 6Gbps upstream.

4. Envisioning DOCSIS 4.0 (FDD and FDX)

DOCSIS 4.0 technology includes support for Extended Spectrum DOCSIS (ESD), also known as Frequency Division Duplex (FDD), and Full Duplex DOCSIS (FDX) capabilities.

4.1. Frequency Division Duplex (FDD) DOCSIS

FDD mode of operation uses spectrum dedicated to upstream transmission and separate spectrum dedicated to downstream transmission. FDD DOCSIS increases the upper end of upstream spectrum to 684MHz, while the maximum downstream frequency increases to approximately 1.8GHz.

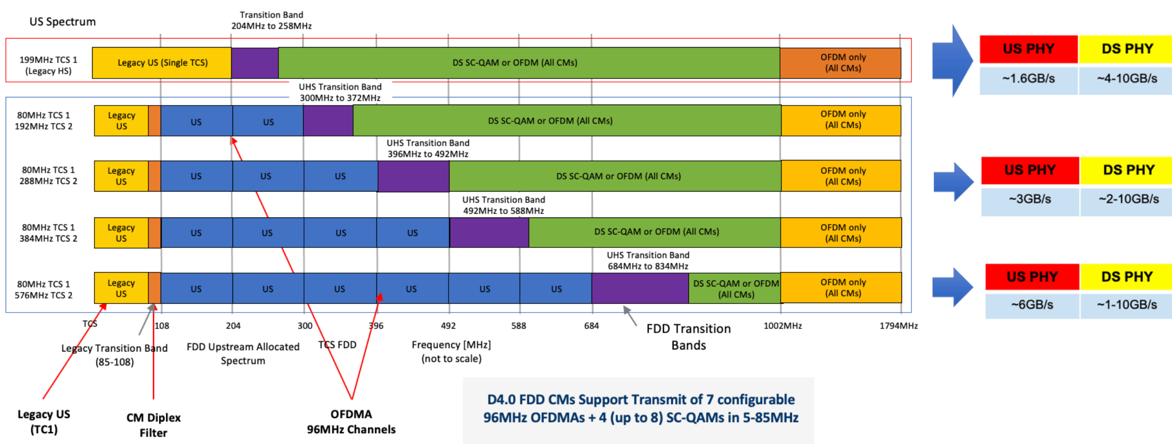


Figure 3 - Frequency Division Duplex (FDD) Spectrum

As shown in Figure 3, depending on the split allocation used, MSOs can get from 1.6Gbps (High-Split) up to 6Gbps (Ultra-High Split 684MHz) upstream provisioned capacity. In the downstream, 1 to 10Gbps can be achieved based on the combination of SC-QAMs with OFDM blocks.

4.2. Full Duplex (FDX) DOCSIS

The FDX specifications were created to provide service providers with the ability to increase the offered upstream speeds without sacrificing the valuable downstream spectrum. This is done by overlapping the US and DS spectrum from 108-684MHz, also known as FDX US/DS overlap band.

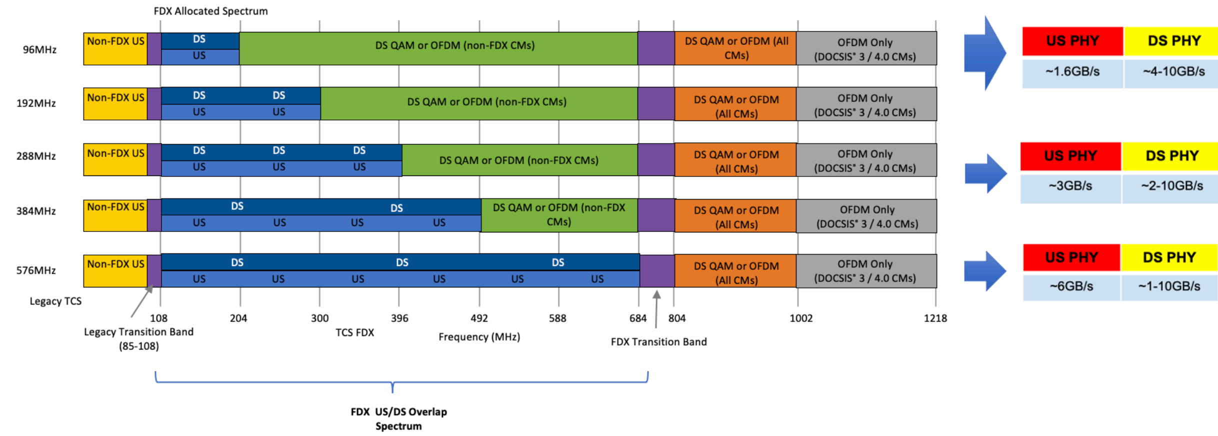


Figure 4 - Full Duplex (FDX) DOCSIS

FDX relies on echo cancellation functionality, which is performed in the fiber node. Echo cancellation is needed because the fiber node is using the same spectrum for simultaneous DS transmissions and US receptions.

5. Outside Plant Architectures

New outside plant architectures will need to support FDD or FDX technologies with the aim of preserving, as much as possible, RF amplifier spacing and taps and passives distribution.

5.1. OSP used with FDD

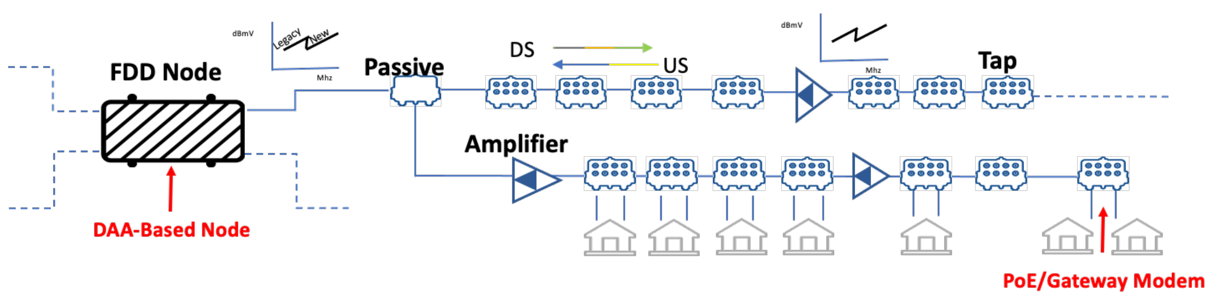
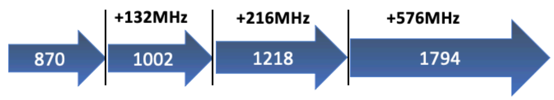


Figure 5 - OSP FDD Architecture

Fundamentally, the OSP Architecture to support DOCSIS 4.0 FDD needs to support N+X architectures and a range of US/DS split bands from 85MHz to 684MHz in upstream spectrums and from 105MHz to 1794MHz in downstream spectrums. It will be driven by the required US capacity, which will determine the US/DS diplexers needed to configure impacted fiber nodes and RF amplifiers. Maintaining “legacy” DS slopes and levels will help to minimize impacts in the OSP. OSP engineers must consider the Total Composite Power (TCP) of their systems to determine if one tilt/level or two levels must be used.

5.1.1. Bandwidth Migration vs Gain & TCP

TCP, which is also shorthand to Total Power, is the combined power of all signals in a given frequency range — for instance, the downstream. It is a concern because excessive total power is what overdrives RF hybrids, lasers, set-tops boxes, modems and other devices.



System Amplifier Gain/Level

1.0 to 1.8GHz Migration	1002	1218	1794			
Step down @1.2G (dB)	N/A	N/A	6.0			
Virtual tilt (dB)			20.0			
TCP	60.6	65.6	69.2	Gain w/Internal Cable Profile Tilt		
	Amplifier Output Level (dBmV)			1002	1218	1794
1794MHz			50.0			49
1221MHz			42.6			42.8
1215MHz		49.0	48.5		48	42.8
999MHz	44.0	46.0	45.7	43.0	45.7	40.3
837MHz	41.6	43.1	43.6	41.2	44	38.2
609MHz	38.0	39.5	40.6	38.5	40.9	35.0
495MHz	36.5	37.7	39.1	37.1	39.2	33.2
261MHz	33.0	34.0	36.0	32	33	29.0

Figure 6 - Bandwidth Migration vs Gain and TCP

RF hybrid technology has been supported in the past by increasing gain and RF levels from 870MHz, 1002MHz and 1218MHz, extending the RF levels. That was until the jump to 1.8GHz. A 1.8GHz amplifier equipped with the newest RF hybrid can support around 69dBmV TCP in the output port. This TCP value will dictate the new system design rules of cable operators.

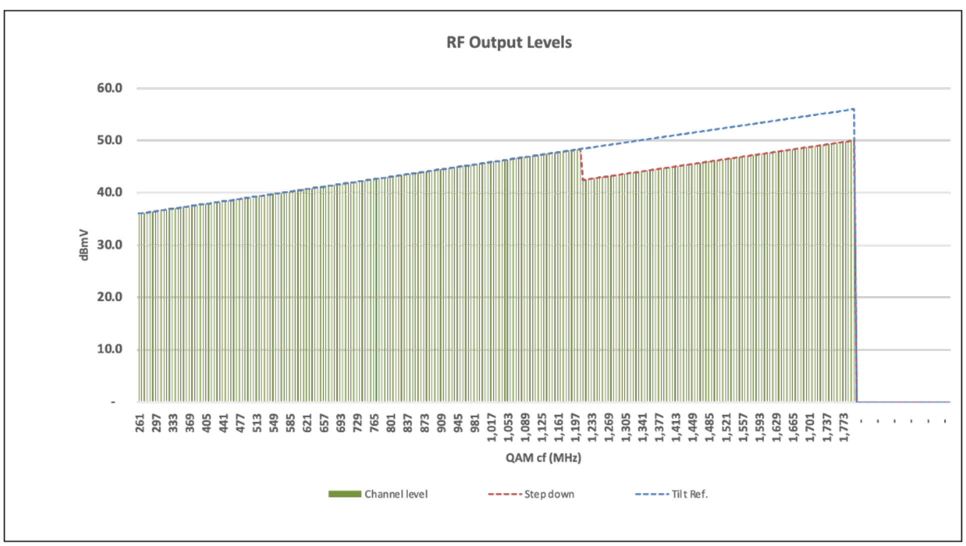


Figure 7 - FDD 1.8GHz RF Output Levels

As an example, Figure 7 shows the RF output levels suggested to use with new 1.8GHz RF amplifier technologies. In this high-split example, legacy levels from 258MHz to 1218MHz were preserved as they are in operation, and levels above 1218MHz to 1794MHz are 6dB lower.

New RF amplifiers incorporate electronic control of RF levels, which supports the auto alignment of the attenuation and equalization at its various stages. They also support 1.2GHz and 1.8GHz modes to ease the transition to 1.8GHz and to support the actual implementations.

5.2. OSP used with FDX

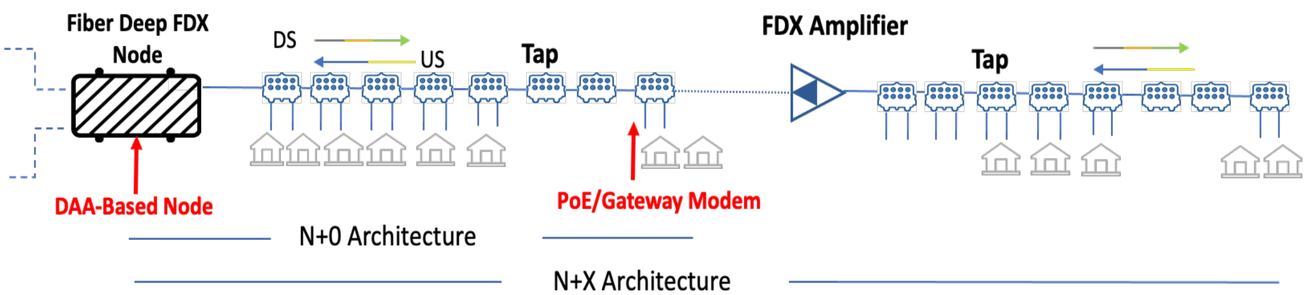


Figure 8 - OSP FDX Architecture

As mentioned previously, FDX is one of two DOCSIS 4.0 flavors available to cable operators. FDX runs DS/US in the same spectrum allocation of 1.2GHz that DOCSIS 3.1 networks use today. It originally was compatible with N+0 architectures, but due to its cost, cable service providers interested in this technology are looking to deploy FDX in N+1 or up to N+4 architectures. FDX will preserve 1.2GHz taps and passives distribution. But it will require a new generation of both fiber nodes and RF amplifiers equipped with echo cancellation capabilities.

6. Residential Drops — Today and Tomorrow

At the customer premise, a significant change, especially in LATAM locals, is the migration from a wired to a wireless home network in which most home devices are connected to a coaxial cable network to a wireless home network.

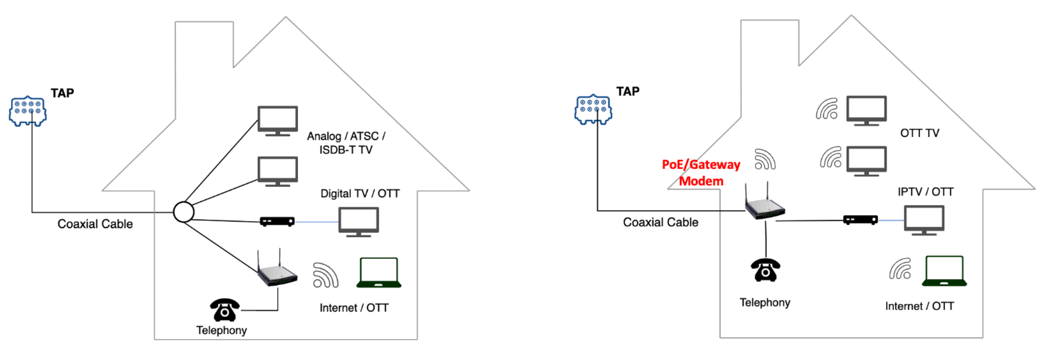


Figure 9 - Residential Drops — Today and Tomorrow

In this environment, a DOCSIS 4.0 modem will be a point of entry (PoE) device, making it the sole hybrid fiber-coaxial (HFC)-terminating device in the household. This PoE gateway incorporates WIFI 6E and WIFI mesh capabilities to support the coverage requested inside the home. Additionally, there will be no need for a splitter network to feed other boxes, such as set-top boxes, and in many instances also the cabling inside the unit.

7. New Requirements on Powering the Network

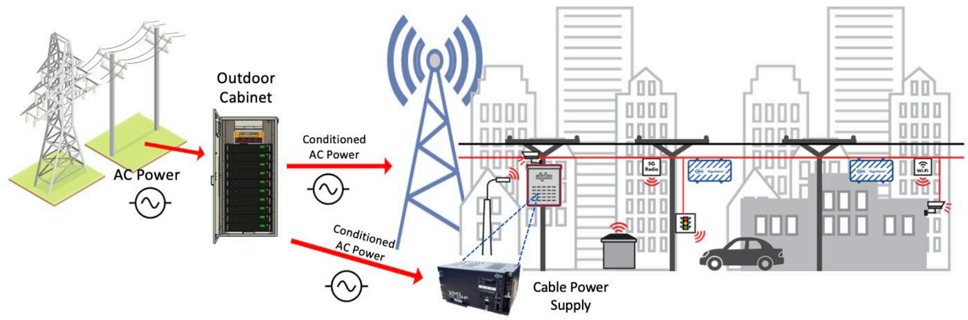


Figure 10 - New Requirements on Powering the Network

Power has become an increasing concern due to the increase in power requirements by modern technologies, as well as the growing need for power to be reliable. Power outages can have disastrous effects, shutting down critical services such as water, energy, communications, transportation and other types of infrastructure. Energy Storage Systems play a big part in establishing a reliable power source.

DAA architectures require the distribution of network components (like RPDs, RMDs, Small Cells, WIFI Access Points, etc.), putting increased power strains on the network. The impact of a power outage in a DAA architecture is more severe and longer lasting than in a CAA architecture. As an example, the booting time of an RPD is a few minutes, which is the time required for all video and data services to be restored. For that reason alone, MSOs have an increasing need for reliable power systems in the OSP.

8. Industry Transition from CAA to DAA

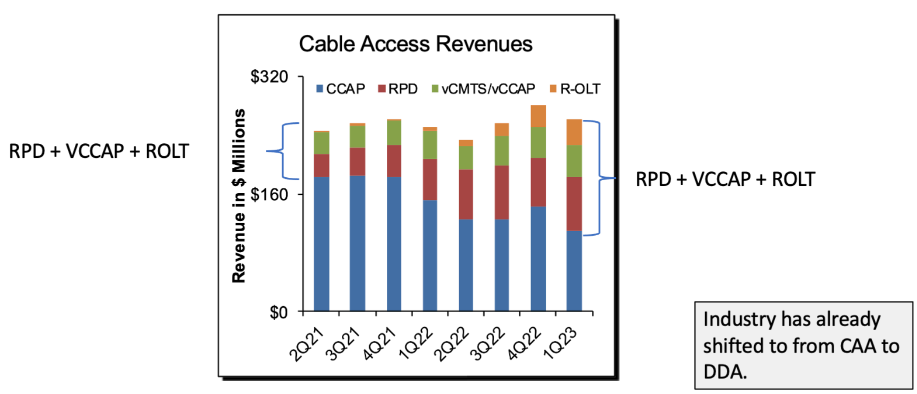


Figure 11 - Cable Access Revenues

An analysis of the cable broadband market over the past few years indicates that the industry has already shifted from CAA to DAA architectures. It was driven mainly by required band splits, which rely on an increase in DAA deployments, particularly the growth of RPDs.

9. Conclusion

Cable industry innovation, such as the latest release of DOCSIS standards, will enable cable service providers to reach the 10G era of symmetrical multigigabit services, empowering cable operators to meet the increasing bandwidth demands of residential and business subscribers. In terms of architecture, DAA will play a key role in this evolution in conjunction with FDD and FDX technologies. Industry stakeholders are aligned with this evolution and market transition, concentrating R&D, product development and network design and adoption on the continued evolution of the HFC network.

Abbreviations

AM	amplitude modulation
BC	broadcast
CAA	centralized access architecture
CCAP	converged cable access platform
CM	cable modem
CMTS	cable modem termination system
DAA	distributed access architecture
DFB	distributed feedback laser
DOCSIS	data over cable service interface specification
DS	downstream
EDR	enhanced digital return
EOL	end of line
FMA	flexible MAC architecture
HFC	hybrid fiber coaxial
Hz	hertz
ISP	inside plant
MAC	media access control
MSO	multiple system operator
NC	narrowcast
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OSP	outside plant
PHY	physical layer
PoE	point of entry
QAM	quadrature amplitude modulation
R-MACPHY	remote MACPHY device
R-PHY	remote PHY
RF	radio frequency
RMD	remote MACPHY device
ROLT	remote OLT
RPD	remote PHY device
RX	receiver
RxMER	receive modulation error ratio
SC-QAM	single carrier QAM
SCTE	Society of Cable Telecommunications Engineers
TCP	total composite power
TX	transmitter
US	upstream
VCCAP	virtualized cable convergence access platform
WIFI	wireless fidelity

Bibliography & References

[Jay Lee/ATX Networks]. (2020, June 24). *A new era of HFC evolution* [Webinar Video]. ATX. https://atx.com/company/news/webinar-the-2050-project-a-new-era-of-hfc-evolution/

Whitley, M. & Whittlesey, P. (2023). [1.8GHz Amplifier System Design Specifications]. ATX Networks.

He, Z., Skrobko, J., Zhang, Q. & Zhang, W. (2016). *The capacity of analog optics in DOCSIS 3.1 HFC networks*. Cisco Systems. https://www.nctatechnicalpapers.com/Paper/2016/2016-the-capacity-of-analog-optics-in-docsis-3-1-hfc-networks

Downey, John J. (2017). *Downstream early lessons learned*. Cisco Systems. https://www.nctatechnicalpapers.com/Paper/2017/2017-docsis-3-1-downstream-early-lessons-learned

Downey, John J. (2020). *The power of distributed access architectures (DAA)*. *Benefits of digital fiber along with remote-PHY*. Cisco Systems. https://www.nctatechnicalpapers.com/Paper/2020/2020-the-power-of-distributed-access-architectures

(2023). [Broadband Access Report]. Dell'Oro Group.

