Bell Labs Consulting

An economic analysis of distributed access architectures: The next major cable transformation

White Paper

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Introduction

Cable access networks are on the cusp of a major transformation driven by an insatiable consumer appetite for multimedia and over the top (OTT) content, social media, learning and communication. This hunger is fueled by the increasing digitization of everything and the automation of the world around us, both of which are enhancing human experiences and forever changing our lives. Satisfying this appetite, and doing it cost-effectively, requires a foundational transformation in cable access network architectures. This transformation will provide the capacity and performance needed to realize these enhanced human experiences and needs.

The use of Distributed Access Architectures (DAAs) is one of the concepts transforming the future of cable networks. This degree of change has not been seen since the late 1980s or early 1990s when fiber began to play a prominent role in access. We are moving from today's network, which provides asymmetrical multi-Mbps capacity, to one defined by multi-Gbps capacity and, ultimately, to one of hyper-scaled symmetrical multi-Gbps capacity. DAA also delivers these speeds at lower CAPEX and OPEX than is achievable with today's networks.

In this paper, we present an overview of the cardinal drivers and technologies shaping future cable networks. We then present an analysis of three DAA architectures[1] comparing their use of space and consumption of energy to the conventional Integrated Converged Cable Access Platform (I-CCAP)[2] architecture. We also compare the CAPEX and OPEX of two of the architectures. The DAA architectures are compared to a CCAP variant with a core RPD (remote physical device), and two virtual versions of the Cable Modem Termination System (vCMTS), one with RPD and, the other, with a remote media access layer (MAC) and physical layer (PHY), referred to as RMD.

The three DAA architectures are:

1. CCAP Core + Remote PHY (CCAP Core RPD)
2. Virtual CMTS + Remote PHY (vCMTS RPD)
3. Virtual CMTS + Remote MACPHY (vCMTS RMD)

We demonstrate that the vCMTS RMD architecture provides the greatest savings in hub space (83%), and the greatest hub energy consumption reduction (89%), over I-CCAP. We also find that vCMTS RMD provides 12 percent CAPEX savings and 32 percent OPEX savings over vCMTS RPD. Finally, we determine that the number of power supplies required in the outside plant (OSP) is comparable for all solutions analyzed.

1 - Further defined in Section 4.
2 - Further defined in Section 4.

The early days of cable access

A radical transformation in hybrid fiber-coaxial (HFC) networks has occurred over the last several decades. Originally intended for broadcast television distribution, HFC networks were designed to serve thousands of households passed (HHP) per fiber node. In the downstream (DS) direction, many amplifiers (potentially dozens) in series on the coax (N[3] + many[4]) were used to amplify the radio frequency (RF) signals between the fiber node locations and consumers. Service group[5] sizes were enormous, covering many fiber-node serving areas and HHP.

As new applications emerged to serve the need for more effective communication, HFC began to include bi-directional voice and data services provided by proprietary vendor solutions. These new services were delivered on the same basic HFC network used for video, with the addition of an upstream (US) set of channels for bi-directional communication. The Data Over Cable System Interface Specification (DOCSIS®) 1.0[6] defined and introduced the technology and interfaces required for the first multi-vendor interoperable specification for low bit-rate bandwidth cable data services. Voice eventually shifted away from proprietary solutions to those based on CableLabs®' PacketCable™[7] specifications.

As consumer demand for higher peak rates and higher usage increased, new versions of asymmetrical DOCSIS[8] were defined (DOCSIS 1.1, 2.0, 3.0) that enabled increased bandwidth, improved spectral efficiency, increased network capacity and enhanced quality of service (QoS) mechanisms. In order to improve spatial capacity through spectrum reuse, fiber was pushed deeper into the network thereby reducing the number of HHP per fiber node (400–500 is a typical range today).[9] Service groups were made smaller[10] over time to reduce the number of consumers sharing limited cable plant spectrum and DOCSIS-based plant capacity, thus increasing per-consumer average bandwidths. In this process, the average number of amplifiers in series on the coax cable has also been reduced from the original N + many to a much smaller number of N + x, (i.e., x=6, 5, 4) in many deployments.

3 - N=(fiber) Node

4 - N + many, N + X are outside plant (OSP) architectures denoting the number of amplifiers in series beyond the fiber node.

5 - A service group is a defined area that receives a set of services sharing the same resources. Service groups are established based on the serving areas of one or more fiber nodes.

6 - DOCSIS defined specifications are 1.0, 1.1, 2.0, and 3.1; see www.cablelabs.com.

7 - CableLabs PacketCable-defined specifications are 1.0, 1.5, and 2.0; see www.cablelabs.com.

8 - DOCSIS 1.0, 1.1, 2.0, 3.0 and 3.1 are asymmetrical definitions, with much higher downstream bandwidths than upstream bandwidths.

9 - This number varies by service provider and is provided as an average number.

10 - In the past, many nodes were served by a single service group.

The inevitable shift to DAA

DAA is a fundamental component of the Bell Labs Future X vision [1] that will deliver a massive value transformation to MSOs and consumers. This vision includes an essential set of new technological capabilities and critical 'digital network needs' defined by the Future X vision. In summary, they are:

- Seemingly infinite, hyper-capacity and 100x growth over the next decade
- Unlimited on-demand capacity for any application or service
- Tera-hyper-scaling of end-to-end networks supporting trillions of connected systems, processes, objects and automata.

MSOs need to meet these digital network needs with a network that delivers increased capacity, greater flexibility and reduced complexity with increased efficiency and reusability — all at a reduced cost. They need to radically simplify operations and facilitate rapid service deployment with flexible business models.

These requirements lead to three major access architecture imperatives:

- **Capacity expansion:** the increase of cable plant capacity to provide bandwidth to satisfy customer demand
- **Energy consumption and space optimization:** the need to reduce energy and space crunches at hubs caused by inefficient scaling of current architectures
- **OSP modernization:** the need to reduce OPEX and optimize the plant to take advantage of modern digital fiber, higher spectral efficiency and highly scalable capacity.

Capacity expansion

DOCSIS 3.1[11] further increases capacity through improvements in a number of areas, including spectral efficiency based on multi-carrier modulations, increased US spectrum (and capacity) via mid- and high-spectrum splits, and increased aggregate US/DS spectrum to 1.2 GHz. MSOs continue to push fiber deeper through physical node splitting and node relocation where needed. This is resulting in even smaller node sizes — often well below 400 HHP per fiber node serving area.

Increasing the number of serving groups per node can further reduce the number of households passed per serving group. Depending on the DOCSIS 3.1 requirements[12] implemented, I-CCAP[13] platform configurations and the architectural changes made, HFC transformations can enable hyper-scaling and hyper-capacity of Gbps-plus DS and several hundred Mbps US services. DAA architectures will further facilitate DOCSIS 3.1 capacity expansion by pushing fiber deeper and moving the node closer to the consumer where needed.

Full duplex (FDX) DOCSIS, currently under definition,[14] will provide symmetrical multi-Gbps data speeds on existing coax. FDX will require an N+0[15] architecture, as FDX signals cannot be passed through existing amplifiers. Fiber will be brought within 100–300 meters of consumers, and a maximum of several tens of consumers will be served from each node. Using 1.2 GHz of spectrum, FDX will theoretically provide 10 Gbps symmetrical bandwidth.[16] Longer-term, fiber can be driven to the last coax drop tap, within tens of meters of four to six consumers, exploiting spectrum above 1.2 GHz. DAA architectures will enable this transformation and tapping spectrum beyond 1.2 GHz.

11 - www.cablelabs.com
12 - For example, US/DS mid-split or high split, plant spectrum and channel aggregation.
13 - I-CCAP is currently being used by MSOs to host and deploy DOCSIS 3.0 and D3.1 technologies.
14 - Being defined by CableLabs, its member companies and vendors.
15 - Node deployed at the last amplifier location.
16 - FDX will initially operate over a reduced spectrum, enabling sub-10 Gbps symmetrical service rates.

Energy consumption and space optimization

Many cable hubs are already under duress for space and energy consumption due to the volume of new equipment that has been installed to meet the extensive capacity and bandwidth growth that has occurred in recent years. As the hunger for bandwidth continues to increase, further scaling of capacity and equipment demands additional energy and space in these same cable hubs. DAA solves this problem by moving key functions out of the hub and into DAA nodes located in the OSP where they are locally powered.

OSP modernization

We predict a continuation in the push to a much-preferred, all-digital, broader spectrum network with new products based on modern silicon. It will be triggered by three factors: continued expansion of multi-Gbps asymmetrical bandwidth, the introduction of symmetrical bandwidth, and the need to reduce access network CAPEX and OPEX (space, energy). With DAA, analog fiber[17] is replaced by digital fiber, providing a multitude of advantages [5] including:

- Use of higher-order quadrature amplitude modulation (QAM) achieving greater spectral efficiency
- Traversing longer distances
- Multiplexing of more optical wavelengths
- Use of lower-cost, industry-standards-based optics (Ethernet-based)
- Reduced maintenance costs
- Improved reliability.

17 - Analog transmission is used today on the fiber between a cable hub and a fiber node. This is commonly referred to as analog fiber. DAA requires replacing analog transmission with digital technology. This is commonly referred to as digital fiber.

NOKIA

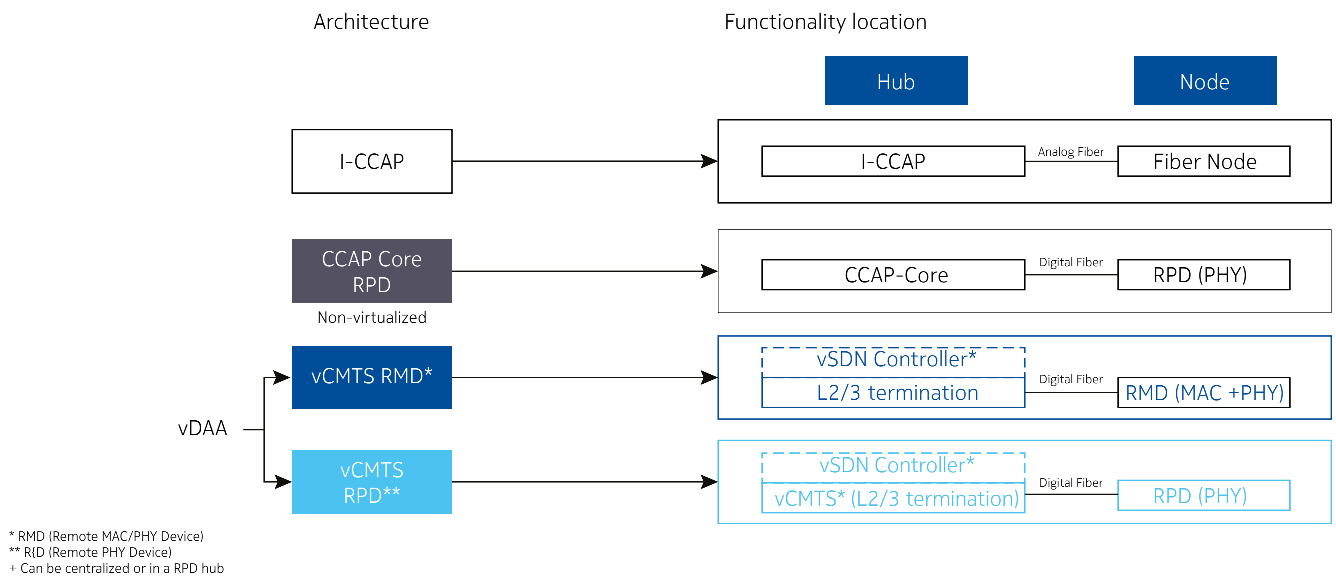
DAA defined

DAA is widely accepted by the industry as the approach to accomplish the transformations described earlier. DAA shifts key functions typically performed by cable-specific headend hardware to other discrete devices in the network. Vendors, MSOs and CableLabs have defined three primary DAA architectures (refer to figure 1):

- CCAP Core RPD[18] is a non-virtualized CCAP core containing the DOCSIS 3.1 MAC function with the PHY function in a remote node connected to the hub via digital fiber
- vCMTS RPD is a virtualized CMTS (vCMTS) function running the DOCSIS 3.1 MAC on an off-the-shelf server in a hub or centralized location with the PHY function in a remote node connected to the hub via digital fiber
- vCMTS RMD[19] is a system running DOCSIS 3.1 MAC integrated with the PHY functions in a remote node connected to a hub via digital fiber.

These three architectures stand in marked contrast to I-CCAP, the baseline centralized architecture being deployed today, with integrated MAC and PHY functions located at the cable hub and connected to a remote fiber node via analog fiber.

Figure 1: Distributed access reference architectures



18 - Remote PHY Device (RPD) architectural details can be found in reference [2]
19 - RMD (Remote MAC/PHY) architectural details can be found in reference [4]

Quantifying the economic benefits of DAA

Reference architectures

We modeled CCAP Core RPD, vCMTS RPD and vCMTS RMD to compare them to I-CCAP on space utilization and energy consumption. We also modeled and compared vCMTS RPD and vCMTS RMD on CAPEX and OPEX. Our analysis includes equipment required to deploy each of the DAA architectures and I-CCAP from the hub to the node, including off-the-shelf servers, switches, routers, video equipment and racks. We found significant differences in how these architectures compare across all metrics: space utilization, energy consumption, CAPEX and OPEX.

For illustration purposes, figures 2 and 3 show the vCMTS RPD and vCMTS RMD DAAs that we modeled. [20] Figure 2 illustrates all the essential elements needed if the DAA is realized by implementing the vCMTS function at the hub. CMTS and video functions are hosted in general purpose servers. Switching functions are packaged together in a leaf-spine-like configuration inside a rack. This integral unit is referred to as a vCMTS RPD pod, and it connects various RPD nodes via digital fibers.

Figure 2: vCMTS RPD reference deployment configuration

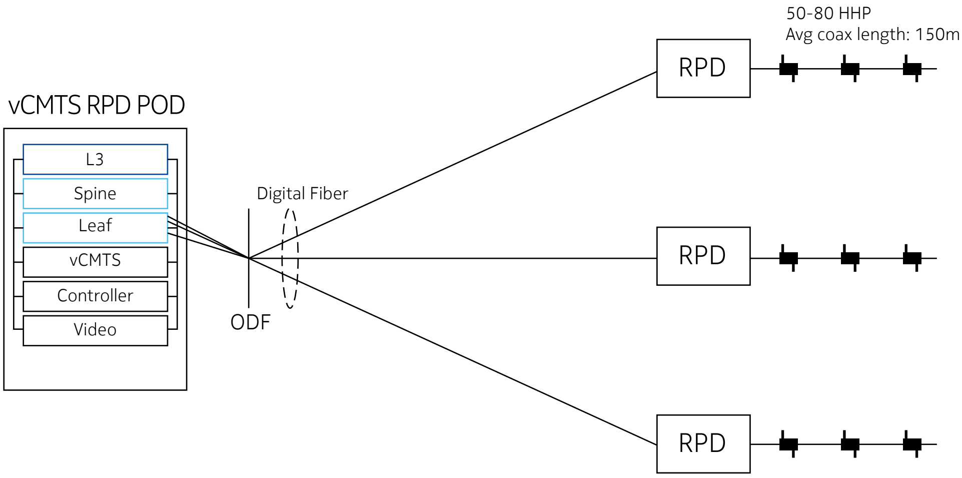
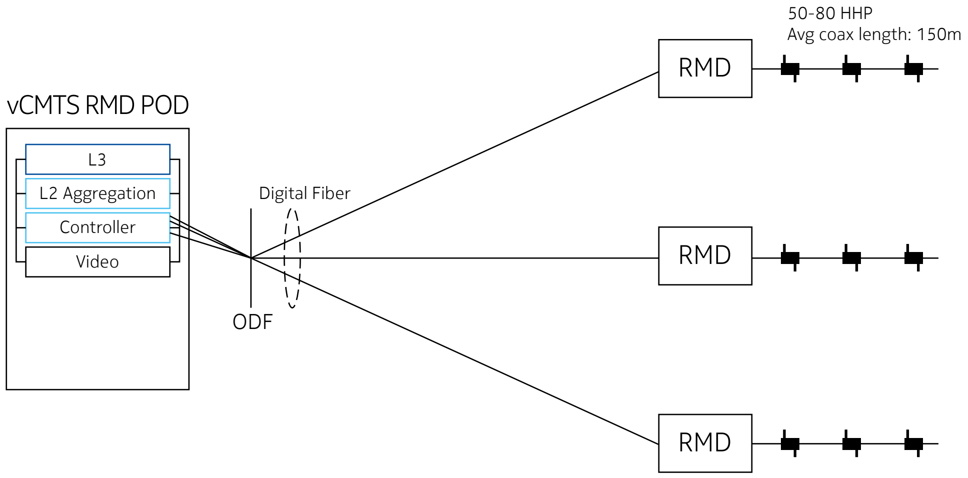


Figure 3 illustrates an architectural configuration for realizing vCMTS with the MAC and PHY terminated by the vCMTS with the DOCSIS MAC and the PHY functions implemented in a remote RMD node. A vCMTS RMD pod also hosts the video, networking and management functions, but not the DOCSIS MAC.

20 - I-CCAP and CCAP Core RPD are not illustrated.

Figure 3: vCMTS RMD reference deployment configuration

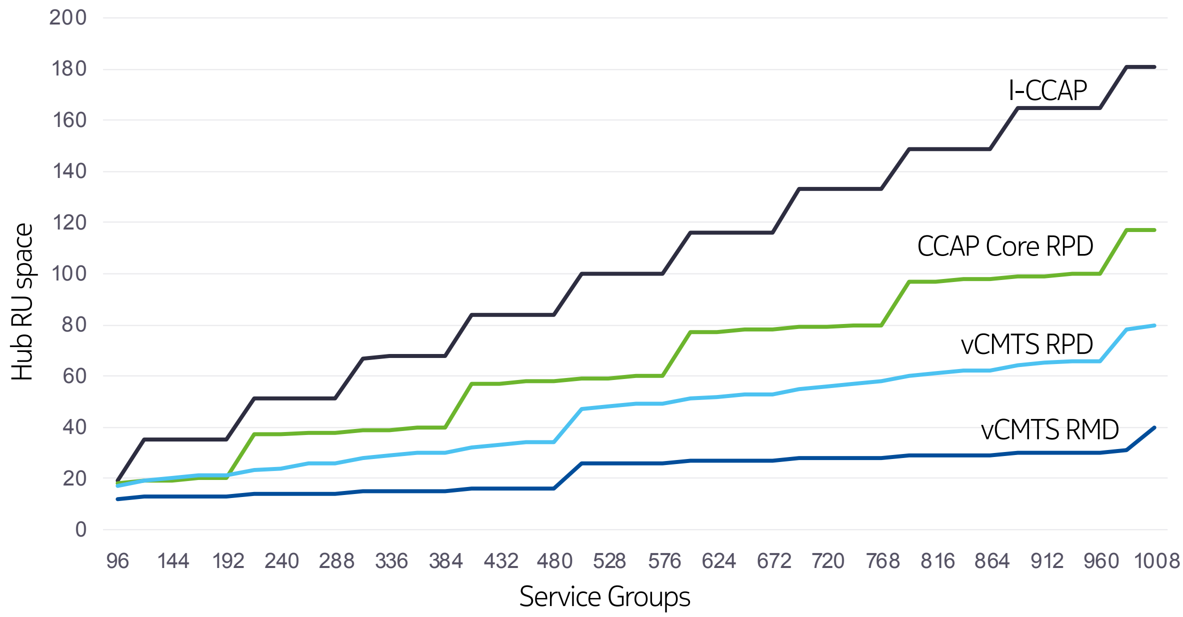


Both architecture configurations will support digital fibers to the remote nodes at any suitable N+x. Both configurations realize the same amount of spectral efficiency and available bandwidth to each service group. However, there are differences in the amount of hardware, space and energy needed by each configuration in the hub as well as the OSP. Appendix A identifies our key modeling assumptions.

Space utilization modeling results

Figure 4 illustrates that vCMTS-based approaches strongly outperform CCAP-based approaches. With vCMTS RMD, remote placement of MAC and PHY functions provides significant rack unit savings over I-CCAP and all other DAA approaches. At 1,000 service groups, vCMTS RMD requires less than one-half the rack space of vCMTS RPD, about one-third the rack space of CCAP Core RPD, and about one-fifth the rack space of I-CCAP. In addition, the more gradual rise of the vCMTS RMD line reflects its ability to scale more efficiently than other DAA solutions. vCMTS approaches also scale more granularly, allowing the MSO to 'pay as it grows'.

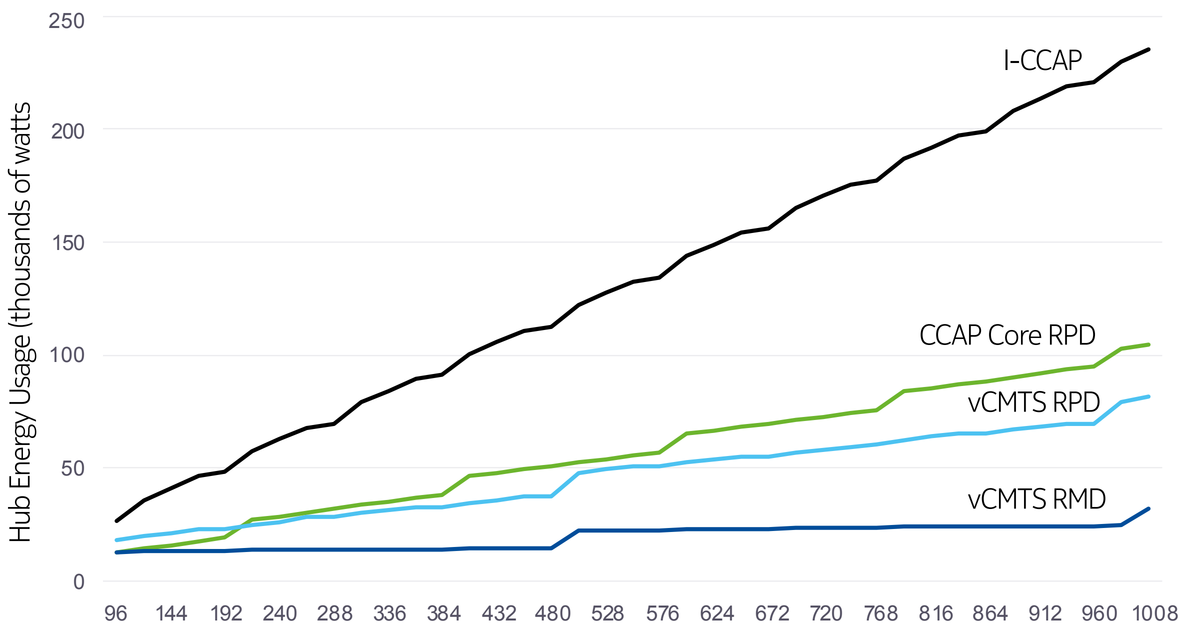
Figure 4: Rack space at hub site comparison for serving up to 1,000 service groups



Energy consumption modeling results

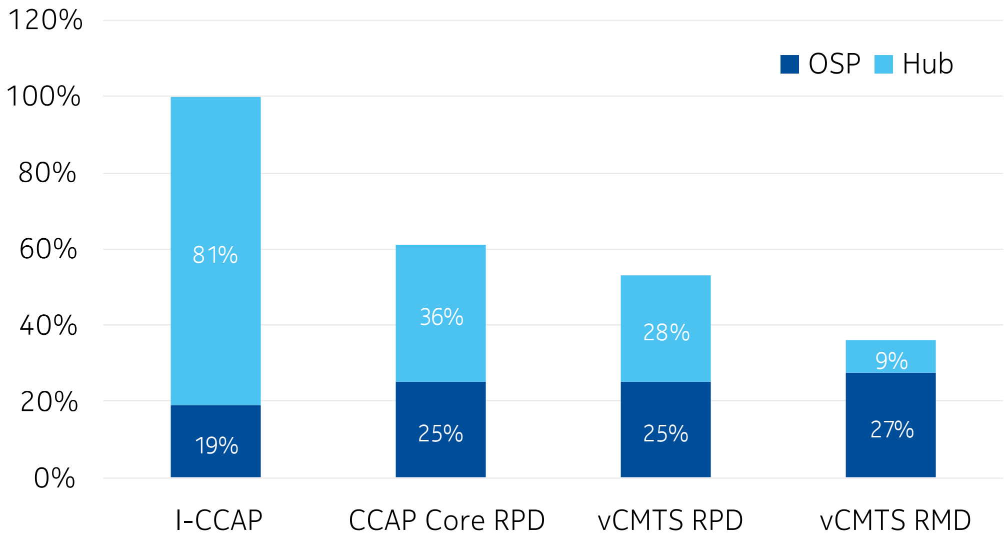
Figure 5 illustrates that all DAA architectures reduce hub energy consumption over I-CCAP due to the distribution of key functions. vCMTS RMD requires mainly an SDN controller function at the hub, and distributing both the MAC and PHY functions to remote nodes reduces energy consumption in the hub by approximately 89 percent over I-CCAP.

Figure 5: Energy consumption at hub site relative to I-CCAP



We also modeled the OSP and, we found that the OSP with vCMTS RMD node consumes approximately 9 percent more energy than the OSP with vCMTS RPD node. However, when including the energy consumed in the hub, the overall energy consumed by the vCMTS RMD architecture, as shown in figure 6, is 32 percent lower than the vCMTS RPD architecture for 1,000 service groups. We also found that the number of power supplies required is comparable for all solutions, even though the RMD nodes consume marginally more power than RPD or traditional fiber nodes.

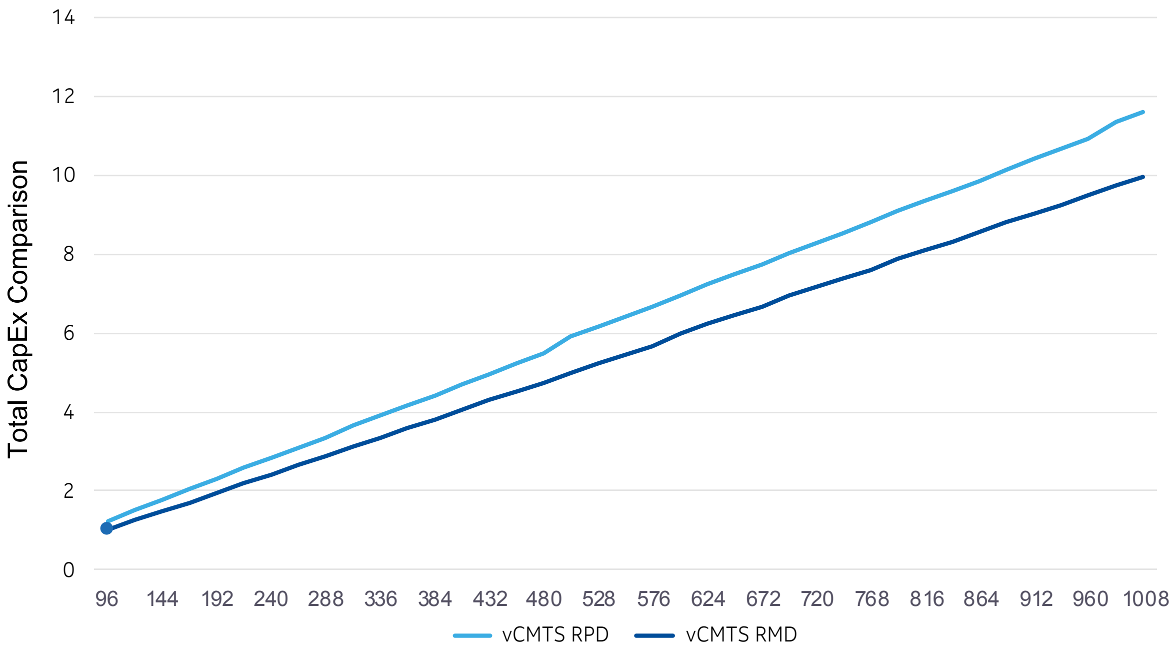
Figure 6: Total energy consumption



CAPEX modeling results

We compared the CAPEX of vCMTS RPD and vCMTS RMD, as illustrated in figure 7. Because competitive pricing of CCAP-Core RPD is highly dependent on existing vendor-customer pricing deals, with the virtualized solutions, we maintained CAPEX cost parity per service group. CAPEX includes hub and OSP equipment, including power supply and remote node, as well as licensing costs. The costs for licensing and OSP equipment are comparable in both use vCMTS RPD and vCMTS RMD solutions. It is self-evident from the higher power and space required for CCAP-Core RPD that, from a cost perspective, the virtualized solutions far outperform CCAP-based solutions. Furthermore, vCMTS RMD has lower CAPEX requirements than vCMTS RPD due to efficient equipment scaling and reduced equipment at the hub, as previously explained.

Figure 7: Normalized CAPEX comparison of a 1,000 SG N+0 network



Conclusion

In the above, we have shown that vCMTS RPD and vCMTS RMD reduce hub space and hub energy consumption when compared to traditional I-CCAP deployments. As well as CAPEX savings, vCMTS RMD provides the greatest OPEX savings in hub space and hub energy consumption. It consumes only slightly more OSP energy than vCMTS RPD, but less total energy. Although, these space and energy savings are an interplay of many factors, our results are representative of the typical needs and benefits for larger hubs.

Bell Labs Consulting can help MSOs assess various DAAs, technologies and specific deployment configurations to determine the optimal investment and roadmap.

Appendix A: Key modeling assumptions

Several hundred assumptions are included in our models. Below we identify only those assumptions that have the greatest impact on the results.

Assumptions common to all architectures:

- 50K HHP coverage by hub
- 30K consumers served/hub
- 42 Rack Unit (RU) rack size
- 2 service groups per remote node.

I-CCAP specific assumptions:

- 16 RU chassis with a density of 96 service groups.

CCAP Core RPD specific assumptions:

- 16 RU chassis with a density of 192 service groups.

Assumptions common to all vCMTS architectures:

- 600 watt 1RU COTS compute server trays
- Video servers of similar capability.

vCMTS specific RPD assumptions:

- 32 service groups per server tray
- 20 server trays per POD hosting vCMTS function – no redundancy.

Controller assumptions:

- 500 service groups per server tray for controller (1+1 configuration[21]).

References

[1] The Future X Network, A Bell Labs Perspective Book, Version Date: 20150910.

[2] "Distributed CCAP Architectures Overview Technical Report," CM-TR-DCA-V01-150908.

[3] Data-Over-Cable Service Interface Specifications, DCA - MHAv2, Modular Headend Architecture v2 Technical Report, CM-TR-MHAv2-V01-150615.

[4] Data Over Cable Service Interface Specifications, DCA – Remote MACPHY Technical Report, CM-TR-R-MACPHY-V01-150730.

[5] Data-Over-Cable Service Interface Specifications, MHAv2, Modular Headend Architecture v2 Technical Report, CM-TR-MHAv2-D01-140829.

21 - One active, one standby.

Acronyms

ASIC	Application-Specific Integrated Circuit
CAPEX	Capital Expenses
CCAP	Converged Cable Access Platform
CMTS	Cable Modem Termination System
DAA	Distributed Access Architecture
DOCSIS	Data Over Cable System Interface Specification
DS	Downstream
FDX	Full Duplex
Gbps	Gigabit per second
HFC	Hybrid Fiber-Coax
I-CCAP	Integrated Converged Cable Access Platform
MAC	Media Access Control layer
Mbps	Megabit per second
MSO	Multiple System Operator
OPEX	Operational Expenses
OSP	Outside Plant
OTT	Over The Top
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency
RMD	Remote MAC and PHY Device
RPD	Remote PHY Device
SG	Service Group
US	Upstream
vCMTS	Virtual CMTS

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