White Paper

Wireline Networks

Vodafone Network Evolution Paves the Way for Energy Savings

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Executive Summary

Reducing energy consumption is a strategic imperative for multiple service operators (MSOs), both to realize cost efficiencies and to support sustainability initiatives. That drive for efficiency is complicated by shifting subscriber usage models as well as rapidly growing subscriber demands for bandwidth, including in wireline cable networks.

Work-from-home models have put stress on broadband networks, with high levels of bidirectional traffic. The industry is also shifting from a model where content was produced by a few and consumed by millions to one where content is both produced and consumed by millions of users. At the same time, 4K video has become mainstream, and 8K is starting to gain momentum. New media types such as augmented/virtual reality and 360 video are expected to continue and accelerate these trends.

Increased demand unfolds against a background of urgency due to global climate concerns as well as potential supply issues. Geopolitical realities, including the war between Russia and Ukraine, have forced EU member states in particular to find alternate energy providers, significantly raising prices. Shortages in the EU led Germany's Minister of Energy Robert Habeck to implore businesses and consumers alike to be more energy-conscious, asserting "Every kilowatt [saved] helps in this situation."[1] This combination of factors has created an urgent challenge for MSOs in the coming years to handle larger amounts of throughput while using less energy.

Vodafone, in collaboration with Intel, identified a substantial opportunity to reduce energy consumption by modernizing its cable modem termination system (CMTS) implementation. The first stage of this modernization is to virtualize CMTS (vCMTS), transitioning from single-purpose hardware (integrated CMTS, or I-CMTS) to general-purpose servers based on Intel architecture. This current generation vCMTS offers 28% improved power efficiency. Next-generation vCMTS extends that power efficiency to 39% improvement over I-CMTS, using a cloud-native infrastructure.

In concert with energy savings, modernizing the CMTS infrastructure reduces headend rack-space requirements by 28x, while delivering higher network capacity to subscribers and reducing CapEx requirements by more than 40%. These savings are powered by a combination of hardware and software innovation. This paper introduces the architecture created by Vodafone and Intel, presenting test results to quantify its benefits.

Top-Line Results[2]

Introduction of vCMTS saves significantly on energy usage, for sustainability and OpEx savings:

- Current-generation vCMTS is 28% more power efficient than I-CMTS.
- Next-generation vCMTS is 39% more power efficient than I-CMTS.

Savings are also realized in terms of physical infrastructure and CapEx:

- Distributed access architecture plus vCMTS reduces headend rack space by 28x.
- More than 40% CapEx reduction while delivering more capacity.

Additional future savings are expected with forthcoming CPU and software innovation

Reducing Energy Consumption by Evolving CMTS

A broad range of requirements and opportunities add to the urgency of enabling increased power efficiency, as illustrated in Figure 1. The number of watts consumed to handle a given traffic load must be optimized at the same time that traffic volume and diversity are growing dramatically, with relatively flat average revenue per unit. Emerging usages including user-generated video such as Facebook Reels, YouTube Shorts, TikTok videos, IoT and enterprise 5G will compound the benefits of near-term architectural improvements, as data volumes trend even higher.

Intel estimates that energy costs typically comprise 5% to 6% of OpEx, highlighting the potential for financial savings from greater efficiency. In addition to cost considerations, the growing importance of climate sustainability initiatives makes energy efficiency as a corporate goal more compelling still.

Figure 1. Enabling power savings is critical to both operational and strategic requirements.

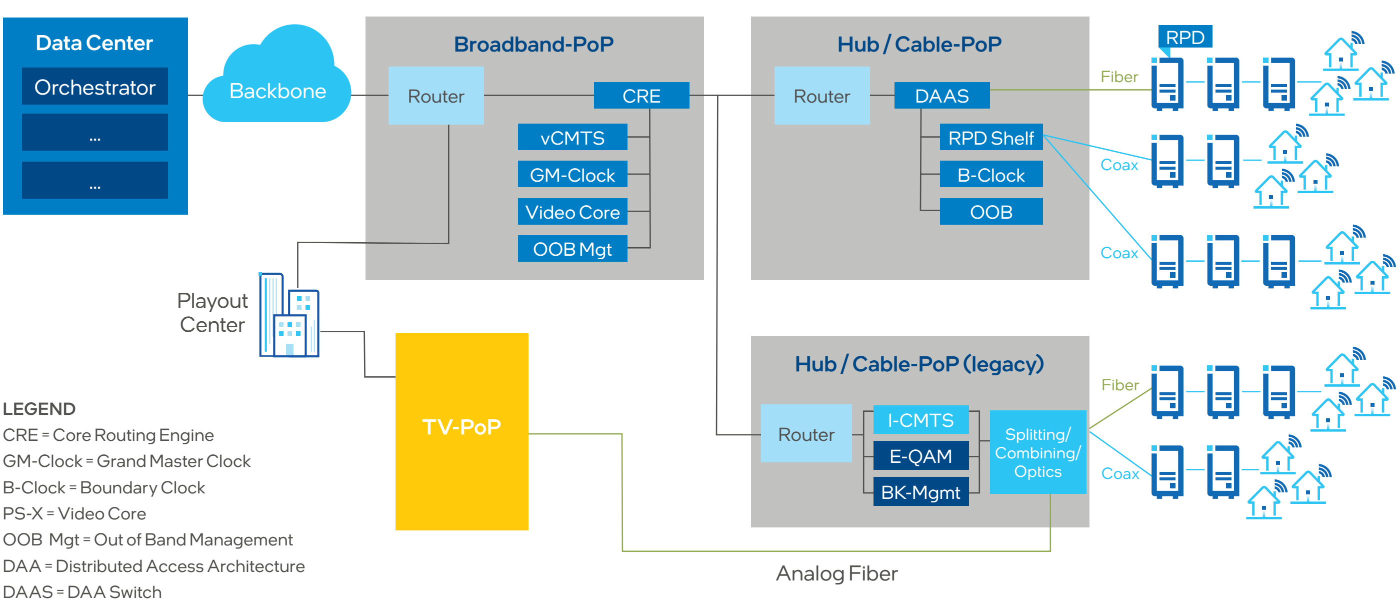

Figure 2. Vodafone DCA architecture overview.

Vodafone identified a significant opportunity to realize energy savings through evolution of its CMTS infrastructure. Working in collaboration with Intel and equipment manufacturers, Vodafone developed a Distributed Cable Architecture (DCA)[4] for deployment alongside its legacy I-CMTS, as illustrated in Figure 2. The transition to the new architecture can therefore be gradual, with new capacity being brought online using the new approach as older equipment reaches end of service, or, for example, when segments get split to reduce the number of concurrent subscribers per segment.

The distributed nature of the architecture includes the disaggregation of the physical (PHY) layer from the media access control (MAC) layer and distributing them as well as the I-CMTS layer-3 routing functionality across the network to separate locations. This aspect of the design enables those functions to scale independently of each other, in addition to being placed individually. Removing the RF elements from the headend and pushing digital-to-RF conversion closer to the subscriber adds further to the solution's efficiency.

Evolving from Monolithic to Cloud-Native CMTS

Vodafone's modernization program for its CMTS infrastructure includes two phases of transition that successively improve on its legacy implementation:

- **Legacy I-CMTS** is the single-purpose appliance chassis approach, which is costly to purchase and operate, and lacks flexibility in its deployment location and functionality.
- **Current-generation vCMTS** is based on the CableLabs DOCSIS MHAv2 specification, which implements a remote PHY architecture to separate compute from the physical generation of the signal. This architecture uses Intel architecture-based servers with an appliance-like model.
- **Next-generation vCMTS** is a cloud-native approach using Kubernetes and containerization of CMTS functions, which enables greater agility and cost-efficiency in concert with broader digital transformation efforts underway elsewhere in the organization.

The lower-right box in Figure 2, labeled "Hub / Cable-PoP (legacy)," represents the solution based on I-CMTS. Here, IP traffic enters the I-CMTS from the left, and RF exits to the right. In addition, the setup includes Edge Quadrature Amplitude Modulation (E-QAM) appliances for channel generation and distribution in the broadcast and video-on-demand domains, as well as Breitbandkabel (BK) management devices to control amplifiers and other equipment. Television signals come from a playout center where channel lineups are prepared and transmitted over analog laser connections to be combined with the rest of the signal for distribution.

The "Broadband-PoP" box in the figure illustrates the distributed architecture, notably the Harmonic CableOS server based on Intel® Xeon® Scalable processors, which handles DOCSIS processing. A significant advantage of this approach is that the DOCSIS core can be placed flexibly, either in a local PoP or hub site, or in the case of space-constrained PoP sites, further upstream in the broadband PoPs or even at more centralized data centers. The Broadband-PoP also includes grandmaster clocks for synchronization among network elements, Harmonic ProStream X to create video channel lineups per region and other servers running spectrum analysis tools. These elements are connected using routers to the IP network on the headend side.

The "Hub / Cable-PoP" box in Figure 2 shows that in the distributed architecture, only a distributed access architecture switch (DAAS) is needed, in contrast with the heavy equipment associated with I-CMTS. This 1RU 48-port switch is uplinked to the backbone and downlinked with digital fiber to the remote PHY devices (RPDs) that generate RF electrical output for the distribution network. In this conception, the RPDs and the DOCSIS core combine to provide functionality equivalent to the I-CMTS in the legacy implementation. The RPD shelf provides an alternate distribution model for coax segments that are directly connected to the hub site. A boundary clock to synchronize the RPDs and narrowband digital forward/return (NDF/NDR) digitization for out-of-band (OOB) signals used in management and related functions complete the hub network design.

Note: To help ensure simplicity and repeatability, the power analysis in this paper does not include video transmission. Complete migration to DCA from legacy systems would be expected to yield greater benefit than what is described here.

Efficiency Gains from Successive CMTS Generations[5]

The efficiency benefits of Vodafone's CMTS evolution emerge over many vectors, as shown in Table 1. In place of the I-CMTS appliance, the current-generation vCMTS cluster implements eight general-purpose servers, connected together with core routing engine (CRE) switches to provide a one-by-one redundancy scheme, with four active servers and four on passive standby. The next-generation cluster uses a more sophisticated redundancy approach, with three subclusters of three servers each in which all three servers are active and each provides failover for the others. The architecture uses 48-port distribution switches that are each populated with traffic for 40 distribution groups, requiring three switches per current-generation cluster or five switches per next-generation cluster.

Table 1. Overview of I-CMTS and vCMTS systems.[2]

	I-CMTS	Current-Generation vCMTS Cluster: ▪ 8 servers ▪ 2 CRE switches ▪ 3 distribution switches	Next-Generation vCMTS Cluster: ▪ 9 servers ▪ 2 CRE switches ▪ 5 distribution switches
Service Groups (1DS:2US)	40	120	180
Total Throughput (DS/US)	100/15 Gbps	240/20 Gbps	504/147 Gbps
Power Consumed E2E	6.835 watts	14.770 watts	18.851 watts
Watts per Gbps	59 watts	57 W (-4%)	29 W (-51%)
Rack Space CMTS	14 RU	10 RU	11 RU
Rack Space RF/Optics/OOB	145 RU	7 RU	11 RU
Rack Units per Service Group	3.98	0.14 (-96%)	0.12 (-97%)

Throughput increases dramatically with the successive generations of architecture, from 100 Gbps downstream with I-CMTS to 240 Gbps and 504 Gbps respectively with the vCMTS architectures. The accompanying power consumption increases are proportionally smaller, dropping somewhat from 59 watts per Gbps with I-CMTS to 57 watts per Gbps with current-generation vCMTS, then more dramatically to just 29 watts per Gbps with next-generation vCMTS. Rack space savings associated with eliminating the analog optics used by I-CMTS are likewise dramatic, reducing the rack units required per service group by between 96% and 97%.

The financial impact of these shifts is summarized in Figure 3. The transition from I-CMTS to current-generation vCMTS is shown to save 42% in CapEx and 28% in OpEx. Those advantages are compounded by the transition to Vodafone's cloud-native next-generation CMTS architecture, to yield an overall advantage of 46% CapEx and 39% OpEx savings compared to I-CMTS.

Open Standards Programmability for Power Savings

The transition to general-purpose servers based on Intel architecture offers programmability for software-enabled power efficiencies. A particular opportunity rests on adjusting core CPU frequencies using P-states and C-states, so the power usage on individual servers can be dialed up and down based on dynamic traffic load requirements. Intel estimates that data plane traffic accounts for roughly 60% of the cable access infrastructure, all of which today runs constantly at full utilization due to software configuration limitations.

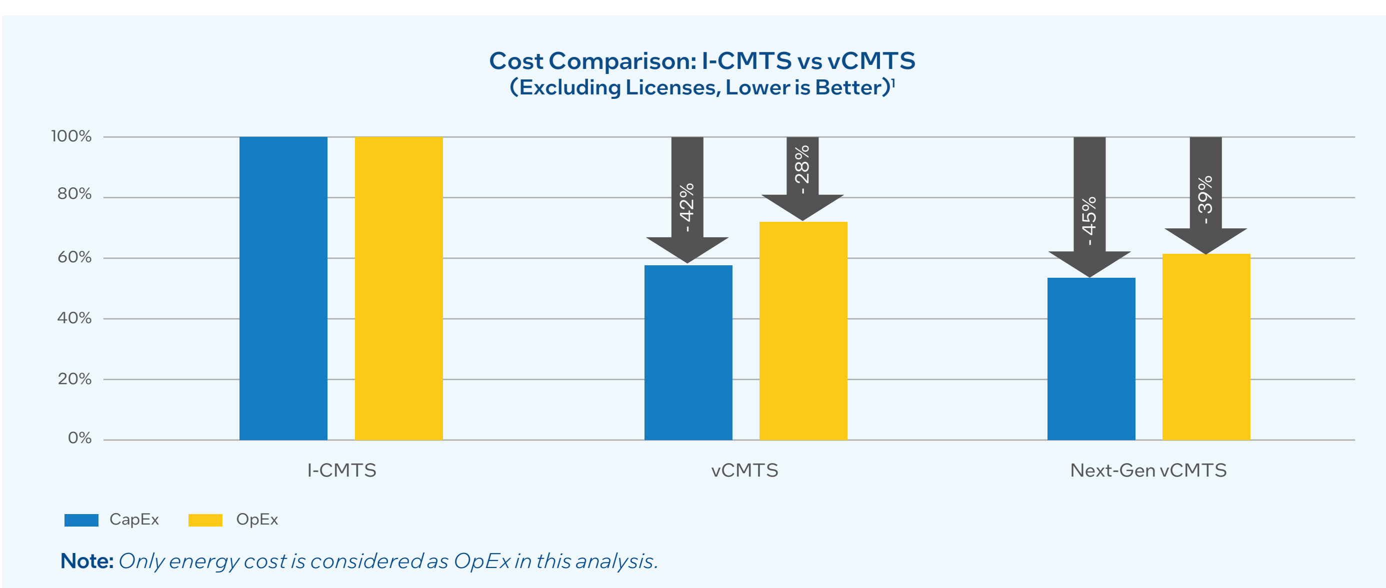

Figure 3. Comparing CapEx and OpEx (energy) across CMTS architectures.[2]

Figure 4 shows a traffic pattern over a 24-hour period, to illustrate the opportunity for energy savings from adjusting the CPU frequency in response to load. The "default frequency" bars represent the typical state where processors run at full frequency and power 24 hours per day, regardless of the changing traffic levels on the network, which are represented by the "traffic" bars. The "adjusted frequency" line shows the potential for software-based P-state control to reduce processor frequency (and corresponding energy consumption) during periods of reduced traffic.

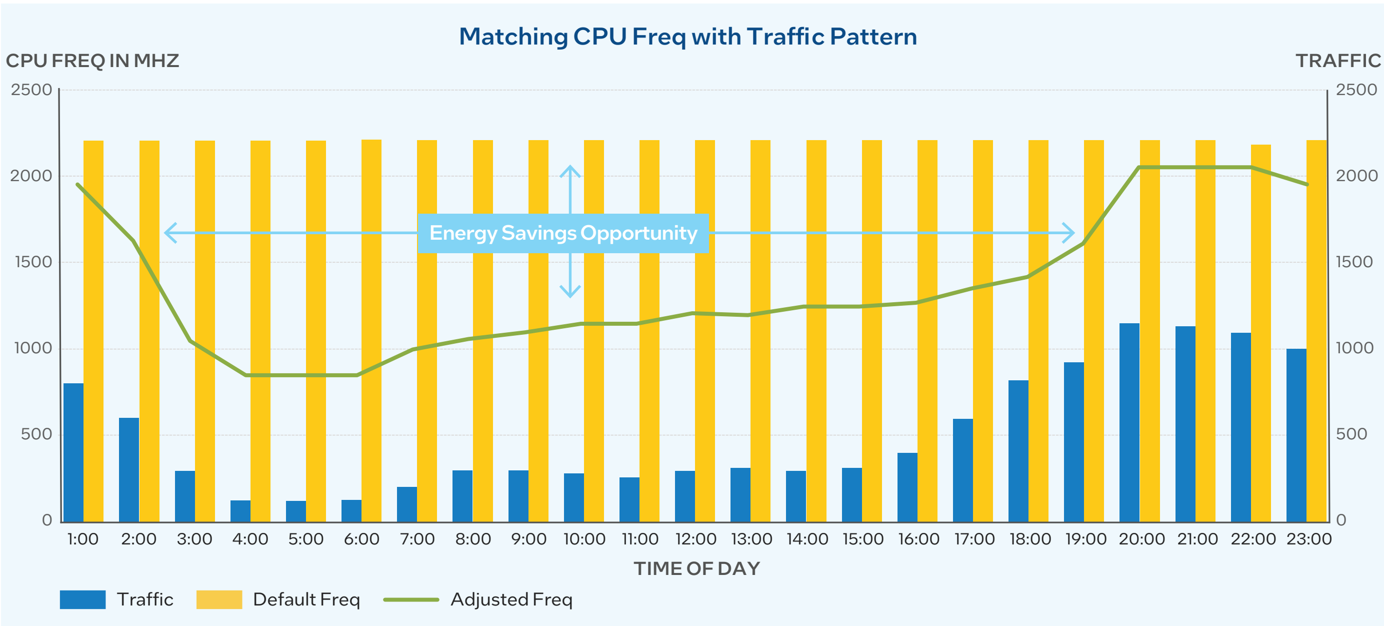

Figure 4. Using P-states to reduce vCMTS data plane power.

Software-based approaches to power management are an active area of research at Vodafone, Intel and elsewhere. Telemetry-aware analytics models are showing promise at predicting traffic levels based on past and current traffic patterns, potentially creating proactive policy that fine-tunes power states using prediction. The potential of software enablement also extends beyond current hardware features and capabilities to emerging ones on Intel's platform roadmap. For example, enhanced power management capabilities of 4th Gen Intel Xeon Scalable processors dramatically reduce the transition time required to recover from deeper power states, making the system more responsive while allowing for the use of more aggressive power policies.

Conclusion

Vodafone's modernization of its CMTS infrastructure demonstrates a pattern for MSOs as they innovate to meet the financial and sustainability challenges of the immediate future. The transition from monolithic single-purpose equipment to distributed general-purpose servers based on Intel architecture is generational. It holds the key to dramatic improvements in energy consumption while meeting customers' unbounded demands for bandwidth. With these developments, Intel is helping Vodafone realize its climate goals for a more sustainable future, as a positive agent for change.

[1] https://twitter.com/BMWK/status/1537159838412816385.

[2] Light Reading Webinar "Cable Goes Green": How Vodafone Cable Network Evolution drives Energy reduction. Date March 23, 2023. https://www.lightreading.com/webinar.asp?webinar_id=2185 Intel does not control third party data.

[3] Intel estimate.

[4] Vodafone uses the term "distributed cable architecture" as a specific instance of the broader industry term "distributed access architecture."

[5] Power consumption figures for all devices in hub sites are multiplied by a Power Usage Efficiency (PUE) factor as part of these calculations. PUE is defined as (total energy consumption per site)/(energy consumption of network equipment). This adjustment reflects energy use such as HVAC, lighting, security, safety, etc. The average PUE for Vodafone is 1.60, as specified in the company's sustainable business report from 2019.

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