4K Reasons to Accelerate to All-IP

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Abstract

While it may seem like a distant memory, and in retrospect seems hard to fathom, High-Definition (HD) video got off to a very slow and inauspicious start. The adoption cycle was quite long. Obviously display technology, costs at every stage of the content cycle from creation to display, and a very recent massive digital video revolution played a role in the adoption rate. Once the conditions were in place, however, HD took hold and there was no going back.

Fast forward to today, where HD is mature, deployed in scale, and impossible to live without. While an important and profitable component of the operator's business model, there is a resource price to be paid in term of the capacity HD consumes compared to Standard Definition (SD) TV. Operators are regularly adjusting their service mix and introducing technology to increase capacity and make better use of existing capacity to support service evolution. Today's HD falls into this latter category. High Def's maturity, and MPEG-4 encoding's capability present in fielded STBs allows operators to deploy HD content more efficiently.

An HD channel typically has an SD brother in the channel lineup – it's a simulcast. This is not very efficient, but also not terribly penalizing given the relative bandwidth that SD consumes. Now, along comes….4kHD. It's not quite really here, and there will be clear limitations at first. But, it is quite reasonable to expect that 4kHD scales into a mass service within a decade. However, a simulcast approach for current HD channels to be made available in 4kHD would be difficult. The likely option to prepare for 4kHD, in addition to HEVC encoding, is transitioning to an all-IP architecture. Already part of most operator's future plans, 4kHD may be additional inspiration to drive forward with a methodical transition strategy.

This paper will take the reader through an all-IP transition scenario that considers key aspects that an operator must coordinate in phases. Access architecture, bandwidth, encoders, CPE, home architecture, and multicast services represent major balls to be juggled in the transition of services. We will walk through a hypothetical case study based on a typical existing system serving as the Day 0 scenario. We will quantify the CPE situation and migration plans for STB and HSD solutions. We will describe a spectrum management plan with a sensible pace that balances legacy box retirement with capacity demand. And, we will consider how services and capacity tie to network evolution.

An all-IP nirvana has been a future vision for quite some time. With enhanced video and continued HSD speed demand, the future has arrived.

INTRODUCTION

Over the last two decades of service evolution of video, voice, and data, operators have developed in their DNA a keen sense for the planning and implementing growth opportunities at just the right time. MSOs have been a very successful with a pay-as-you grow approach, adopting new technology at the proper point in their lifecycle to deliver on increasingly demanding consumer services. A major enabling component has been access to new HFC capacity, incrementally exploited by pushing fiber deeper, expanding RF bandwidth in the distribution plant, use of WDM in the Optical Distribution Network (ODN) to fuel continued segmentation and services, and migrating all-digital video, or in some cases deploying switched digital video (SDV).

The challenge of continuing to aggressively deliver on new services, which are being introduced more rapidly than ever, and matching the pace of this with network evolution, has never been greater. It is the nature of infrastructure that changing it does not come simply or inexpensively. Various emerging initiatives in Network Function Virtualization (NFV) and Software Defined Networks (SDN) promise to bring some renewed flexibility to evolving the network quickly, but big iron at the edge, connectivity to the home, and CPE are necessarily part of the equation.

The transition to all-IP has been part of most cable operator's thinking for years, and recent service deployment decisions have been weighted towards the recognition of moving towards an IP end state as opposed to adding new capabilities to the legacy digital video, often referred to as the "QAM" ecosystem (confusingly so since cable's IP pipe – DOCSIS – also uses QAM modulation). As new technology draws out the untapped capacity potential of HFC, it will be used to deliver the next generation of HD services, 4KHD, as well as be called upon the support the unquenchable appetite for IP data capacity and speed. Together, they will fuel the final stages of the all-IP transition.

SEEING MORE BANDWIDTH

The appetite for HD is stronger than ever, and it has become a must-have for most video subscribers. However, the lifecycle of HD, which itself carries a large relative bandwidth penalty compared to the longstanding SD services, has only just begun. Cable systems deliver programming in both 720p and 1080i formats today, while 1080p already exists in consumer electronics such as Blu-Ray and gaming consoles. Flat panel televisions continue to become larger and sizes as large as 84" (7 feet!) have been available on the market for a couple of years.

Of course, such screen sizes are able to take advantage of emerging higher resolution HD formats, such as 4K HD. The 4K HD format represents 4x the number of pixels of 1080-column HD. Figure 1 shows the well-understood relationship between resolution, screen size, and viewing distance that governs the practicality of its use as it relates to improved video quality. Note that 4K HD is more than just more pixels. It also enables "better" pixels and potentially increased frame rates in the future.

By the end of this year, it is projected that nearly all majority of TVs sold new will be 4K HD capable. Obviously, they will not be displaying content that has been delivered in 4K HD format right away. Most cable operators utilize and monetize all or most of their spectrum at all times. They regularly manage that spectrum and adjust services, mostly adjusting the video and data service mix. Most of the spectrum is broadcast video spectrum, and it is not practical that "HD 2,0" in the form of 4K HD is delivered on the cable network as a simulcast alongside the existing SD and HD broadcast services.

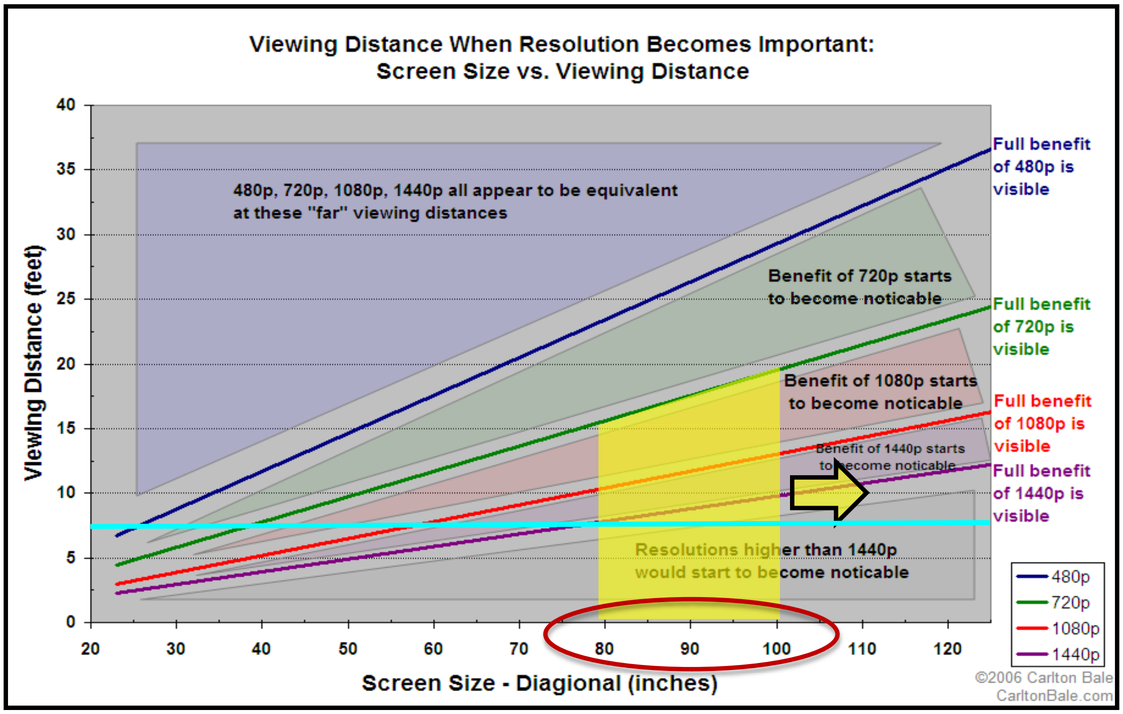

Figure 1 – Screen Size, Viewing Distance, and Spatial Resolution [1]

For example, a 750 MHz system may have 300 SD channels and 150 HD channels. Using MPEG-2 encoding, the spectrum allocated to these channels as broadcast would be about 85 slots – 60 for HD and 25 for SD – for a total of 115. The remaining spectrum can be allocated to On-Demand (VOD) or data services (DOCSIS).

With 300 SD and 150 HD, let's assume half again (75 channels) would be 4K HD broadcasts. Based on Table 1 below [2], those 75 programs would need another 75 spectrum slots encoded as MPEG-4. A 750 MHz system has about 116 spectrum slots in total, so the notion of a simulcast broadcast using MPEG-4 of 4K HD is clearly not in the cards.

Less Filling

MPEG-4 codecs are valuable and mature tools for operators to manage HFC spectrum as HD content and OTT video services continue to grow. However, as was obvious in the 4K HD calculation, MPEG-4 efficiency gains do not offset the resolution increase due to pixel count alone.

MPEG-4 is, of course, not the latest encoding standard to draw on – that would be High Efficiency Video Coding (HEVC), or H.265. HEVC has been successfully shown to achieve its objective of 50% less average bandwidth compared to MPEG-4. It is fair enough to expect that the emergence of HEVC should undoubtedly be turned toward the 4K HD service, and in this case 38 spectrum slots are necessary to support such a broadcast. Not available typically, but we are in a much closer realm of possibility with a combined set of practical set of tools for network evolution, as we shall see.

In addition to linear services, there would be an expected increase in VOD due to 4K HD content being part of the library, roughly doubling the VOD allocation.

Table 1 – Video Streaming Rates [2]

Resolution		Digital Compression Method and Bit Rate		
Resolution Terms	Frame Size / Scanning System / Frame Rate	MPEG2	H.264	HEVC
SDTV	480 / i / 30	3.7 Mbps	2 Mbps	1 Mbps
HDTV	720 / p / 30	6 Mbps	3 Mbps	1.5 Mbps
HDTV	720 / p / 60 (or 1080 / i /60)	12 Mbps	6 Mbps	3 Mbps
HDTV	1080 / p / 60	20 Mbps	10 Mbps	5 Mbps
4K UHDTV	4Kx2K / p / 60	80 Mbps	40 Mbps	20 Mbps
8K UHDTV	8Kx4K/ p / 60	320 Mbps	160 Mbps	80 Mbps

How would 38+ more spectrum slots be possible? Several technology tools similar to those that operators have developed in the past when capacity expansion was required can be exploited towards this goal. In particular in this case, Fiber Deep, which provides new standard spectrum and also expanded DOCSIS 3.1 spectrum, and DOCSIS 3.1 itself, which provides more "effective" spectrum slots, could provide a path to this broadcast 4K HD support.

However, while 4K HD is a step function of new capacity on a relatively full network, video is not the only thing growing in the cable network these days. Wise operators are preparing for all projected service evolutions. And, thinking of video through only the lens of video channels is also no longer sufficient – it now blends with IP data, which has been governed by a persistently aggressive Compound Annual Growth Rate (CAGR).

PERSISTENT AGGRESSIVE CAGR (PACAGR)

Figure 2 captures the breadth of services and applications now common in today's residential service portfolio. The "triple play" has been a valuable bundle, offering an attractive combination of customer satisfaction as well as sound business strategy and opportunity for the operator.

Figure 2 – Residential IP-Based Services Continue to Expand [10]

The IP data component of the triple play has driven many of the new growth applications. Having delivered on the initial game-changer of high-speed web browsing, broadband data service rapidly evolved into the rich content and ubiquity of access we assume today. Operators invested in increasing capacity and speed year after year, as demand grew and applications became more sophisticated.

Many of today's applications take advantage of these ever-increasing network capabilities. Expectations have become gradually raised, and supporting more sophisticated and bandwidth-hungry applications seamlessly is a customer requirement. Key examples include online gaming, Over-the-top (OTT) streaming video (i.e. Netflix), file sharing applications, telecommuting, the exploding use of image and video-centric social media, and access to on-demand programming on all screens, anywhere in the home.

Recently, operators have branched out into whole home services such security, home control and automation, and even energy management. Unlike the prior media/entertainment-centric applications described, these services deliver completely new value to operators and customers. Currently deployed applications are perhaps the tip of the iceberg as the "Internet of

Things" (IoT) possibilities emerge. As envisioned in Figure 3, new service growth opportunities unrelated to typical media-centric and telecommunications services are vast, with promising new categories already underway on or the horizon in telemedicine, health, and wellness.

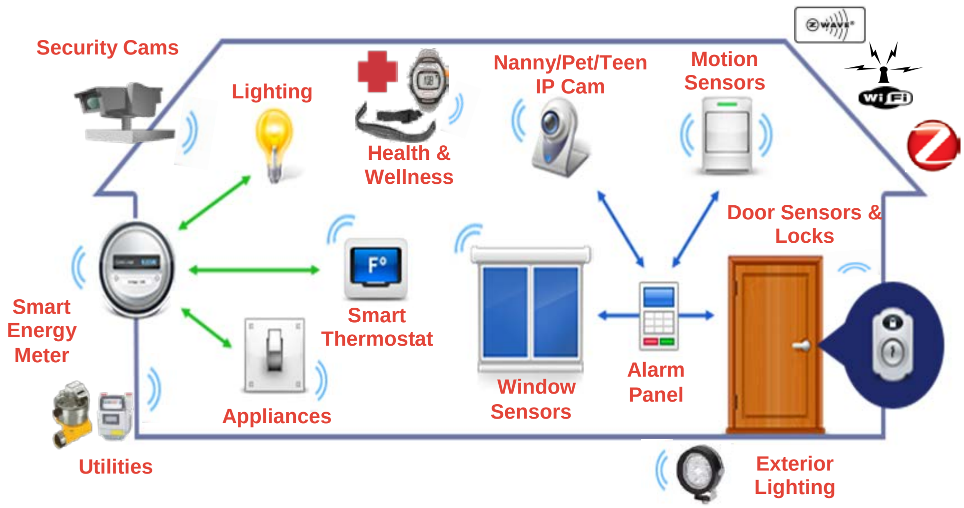

Figure 3 – The Emerging Area of Whole Home Services [10]

All of the above promise to keep PACAGR racing steadily ahead, and perhaps (gulp!) accelerating as we move beyond media delivery, which has finite practical limits of human consumption [3]. And, as noted above, the media consumption component itself continues to grow with the introduction of 4K HD, which in part has to do with the fact that there is room in the human experience for improved video quality – we have not yet achieved the "looking through a pane of glass" experience. Because of this, it remains important to account for these emerging video formats when we analyze long-term capacity management. Herein, that focus is on 4K HD, but higher resolution, 8K HD, formats also exist and could play a future role.

On the bandwidth asset side of the ledger, there is vast, untapped capacity in the HFC architecture. However, it is not infinite. The competing phenomenon of growth and HFC capacity can be observed using the Capacity Management Timeline approach, as shown in Figure 4. This approach represents a simple a tool that allows operators to understand the impacts of PACAGR to HFC resources.

Figure 4 is a basic example using the common 50% CAGR trend on a particular serving group. A 16-channel DOCSIS 3.0 spectrum allocation, operating at half of total capacity (there is runway for growth), follows the red trajectory which compounds at 50% YoY – doubling roughly every 21 months. As the trajectory climbs, node splits occur in 2016 and 2021.

Video and data service evolution occurs in parallel with architecture evolution, and the most daunting of the service evolution steps is the all-IP Transformation. However, this is a an essential transition for the long term, maximizing capacity, simplifying operations, as well as enhancing service flexibility, breadth, and velocity. The path to an IP network nirvana is a complex balance of new services arriving, old services phasing out, and architecture evolutions introduced nimbly.

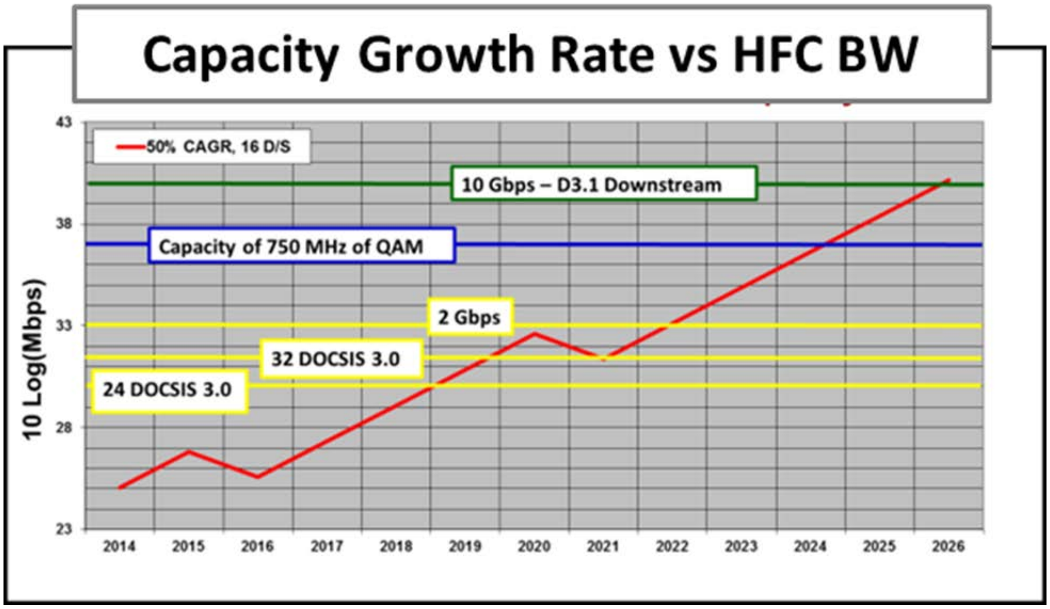

Figure 4 – Capacity Management Timeline Approach: PACAGR vs HFC Capacity [4]

LAST MILES AND MILES

Typical deeper fiber HFC migration has been shown to be a valuable tool for providing continued lifespan runway for video evolution such as HD and OTT, as well as non-video IP data traffic growth [5]. The use of node splitting reaches its final phase when the last active feeding the home becomes a fiber optic node. This architecture goes by various names – Passive Coax, Fiber-to-the-Last-Active (FTLA), or N+0, and the names are not used to refer to the same thing across the industry. Figure 5 illustrates this commonly used multi-phased migration strategy to segmenting a serving area [4].

An "N+0" strategy often involves more than just exchanging amplifiers for nodes, which can be an inefficient way to create a logical N+0. A more strategic implementation optimizes the node placement for reach, balancing the optimal reach with the re-use of existing infrastructure.

Three main benefits of N+0 are:

1) Small serving groups; more average capacity per HHP
2) Opportunity to exploit new coaxial bandwidth; over 60% more downstream and more than doubling of the upstream
3) Higher performance (higher SNR) channel

Figure 5 – Service Area Segmentation using Common Node Splitting [4]

The latter two are related to DOCSIS 3.1, which enables 10 Gbps of downstream capacity by enabling use of more spectrum, and by making use of more bandwidth efficient modulation profiles (4096-QAM, possibly higher). DOCSIS 3.1 modernizes the core technology, primarily updating the forward error correction (FEC) and introducing the use of OFDM. N+0 also leaves operators a stone's throw from FTTP.

Figure 6 compares today's 256-QAM modulation with 4096-QAM as enabled by DOCSIS 3.1 [6].

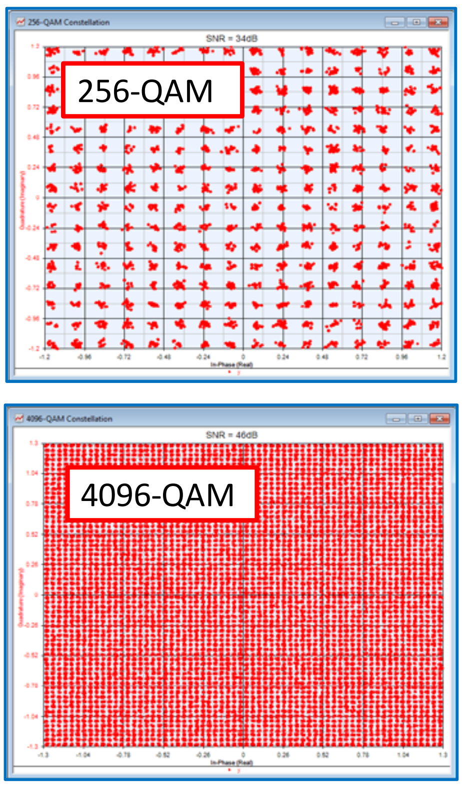

Figure 6 – Comparing Maximum Modulation Profiles of DOCSIS 3.0 and DOCSIS 3.1 [6]

Figure 7 on the following page captures the broad essence of the N+0 or "Fiber Deep" architecture [4].

IP HOME – A HALFWAY HOUSE

IP video access in the customer home and onto customer devices occurs with OTT services as well as MSO-managed services, with operators developing apps for second screens that connect to their networks to authenticate devices and enforce content rights. Traditional STBs will remain in the field for some time. However, as part of the IP transition, as they are removed there is no longer an intent to replace them with a more sophisticated version integrated into the QAM ecosystem.

Hybrid gateways, IP gateways, and IP client STBs, operated from the cloud, is the realm of the majority of new "STB" development. As this transition takes place, both QAM and IP networks (DOCSIS, MoCA™) will be running simultaneously on the coax in the home, as will WiFi™, of course. We are "half-way" to the IP conversion in the home. However, this hybrid state is common during the technology phase of any transition.

Traditional HFC allows for placement of CPE anywhere in the home that a coaxial outlet is located. However, in the case of HFC spectrum re-allocation, spectrum expansion, or even future FTTP extension, a network demarcation point may be established at the point of entry. In this sense, it is a natural "two box" system of network termination device plus in-home CPE.

A whole-home hybrid architecture that utilizes MoCA™ and WiFi™ to deliver video over IP on the Home LAN while passing through QAM is as shown in Figure 8 [10].

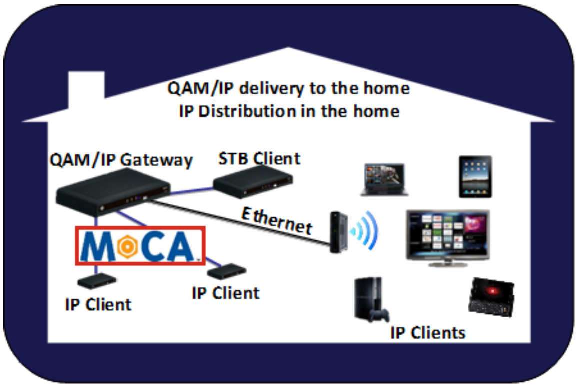

Figure 8 – Cable Home LAN Today [10]

With current HFC, MoCA™ bands are implemented that do not overlap with the spectrum used by current services, because today's CPE terminate the HFC access network inside the home. The Home coaxial LAN, as stated, is part IP – there is an IP Home LAN, but it is a shared resource with conventional QAM signals today.

With the network terminated at the point of entry, the entire coaxial infrastructure in the home can be allocated to the IP Home LAN, and lower MoCA bands, and higher in-home speed and capacity are enabled. Of course, to make this a practical reality, existing QAM digital video services and STBs must be removed from the network. The "pass through" of legacy services shown in Figure 8 must be eliminated. In other words, this architecture is well-suited to the end-state of the all-IP transition.

In many ways, the implementation and turning on of IP-based video services is the easier part – the more difficult and complex part of the IP Transition is the business-driven aspect of retiring legacy QAM video.

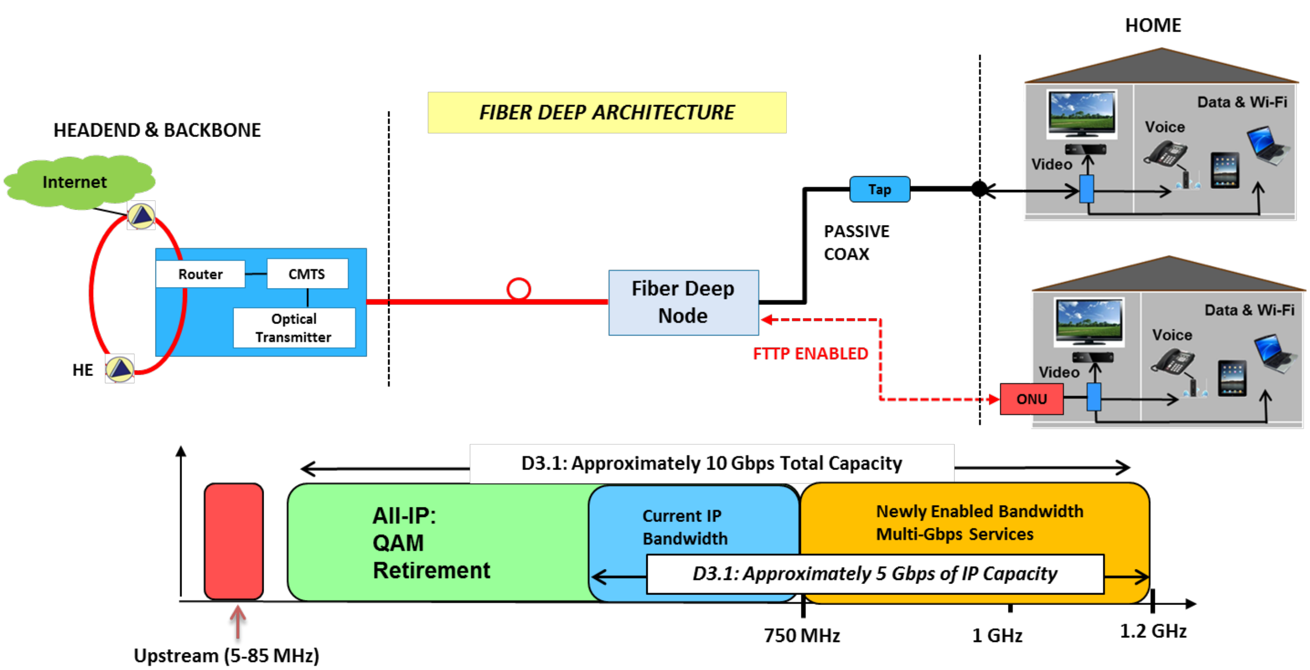

Figure 7 – The Essence of the N+0 or "Fiber Deep" Architecture

IPTV IN THE ACCESS NETWORK: THE LAST FRONTIER

The reasons for cable to migrate to IP for video, or IPTV, are numerous and varied, and have been the subject of many industry papers in the past, and we will not delve into them here. Some key ones are listed below:

- Multi-screen video – IP Devices and Home LANs
- Access to content anywhere
- Blending video with other services (Social media, merchandising, targeted ads)
- Cost efficiencies of single unified network operations
- Leveraging of the global development and equipment ecosystem
- Access agnostic for similar IP-based systems structured on OSI principles
- Software-based digital content rights and management (DRM)
- Flexibility of IP traffic engineering at the edge
- Standard remote management tools

When the network is all-IP, content and transport will have no limiting relationships. Video service is abstracted from access architecture, and the network is consolidated around a single unified delivery system.

The transition to an all-IP network is an end-to-end effort. However, the "transition" largely left to take place is almost exclusively in the access network, as epitomized by Figure 9 [10]. Video gets to distribution hubs and Headends using IP/Ethernet delivery. Behind the access network edge right up to the EdgeQAM or CMTS, IP/Ethernet is the dominant transport and hardware implementation. Broadcast and narrowcast video is delivered to the edge in this format, whereupon it makes its way onto the HFC network as MPEG-TS only.

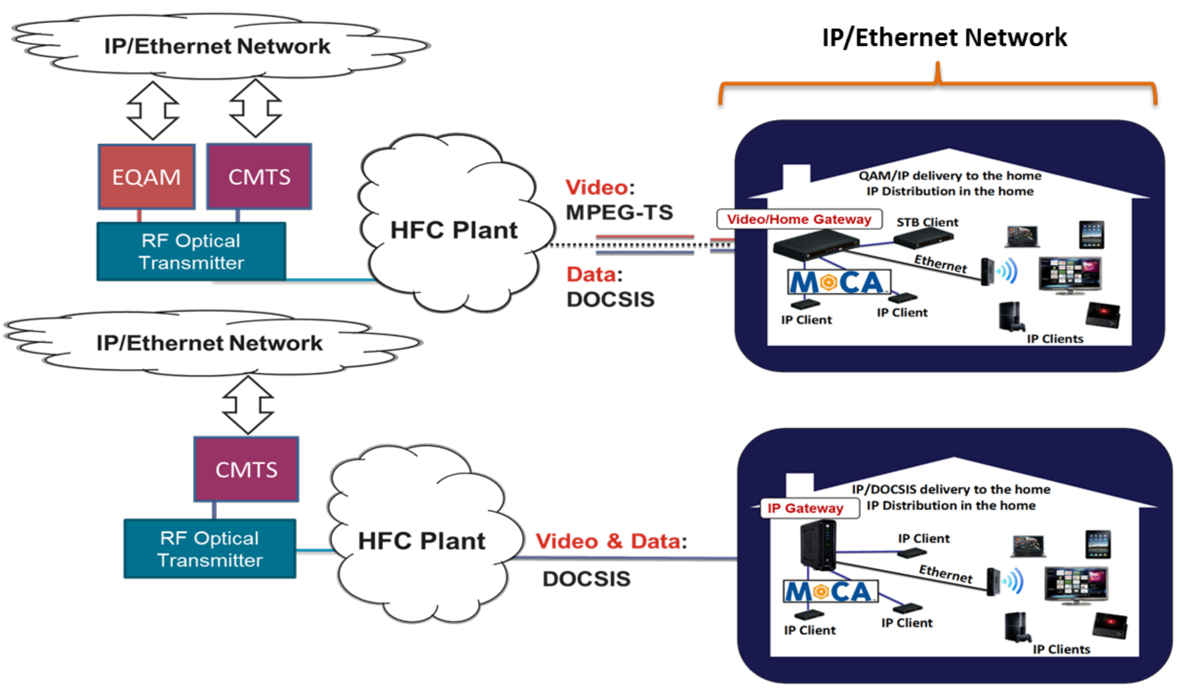

Figure 9 – End-to-End IP – Most Work Remains in the Access Network [10]

In the HFC access network, the IP transition has two major implications. First, the transition of all content to IP eventually enables the potential to eliminate legacy analog and QAM carriers. There will be a period of simulcast of existing video services and IP-based content, but the maximum benefits of the IP transition occur when all legacy spectrum is recovered and freed up for use as IP capacity.

A second implication of the all-IP conversion is the ability to distribute video over any other IP-based transport mechanism – in particular other RF (Wi-Fi™, MoCA), Ethernet, and future FTTP, such as Ethernet PON (EPON).

IP Video – Multicast, Multiplexing & Variable Bit Rates

IP video over DOCSIS 3.0 or DOCSIS 3.1 makes available techniques that provide valuable efficiencies over tradition broadcast QAM – multicast and wideband IP traffic multiplexing gains.

Legacy QAM architectures squeeze a fixed number of video signals in a 6 MHz QAM slot with the help of video statistical multiplexing to make the most of the roughly 40 Mbps per slot. IP Video can be implemented using variable, adaptive bit rates, over bonded DOCSIS 3.0 channels or wider DOCSIS 3.1 spectrum. IPTV over 16 bonded DOCSIS 3.0 channels, for example, is a resource pool of 640 Mbps.

Various analysis have estimated the incremental efficiency associated with wider spectrum and natural IP traffic multiplexing [8]. Bonding, coupled with more streams per QAM of MPEG-4 or HEVC benefits from the law of large numbers, reducing average bandwidth. Many independent streams over *much* more pipe capacity results in effective self-averaging.

Based on simulations and observations of the prior analysis, we use an 80% scaling as the bandwidth required for VBR-based channel bonded DOCSIS 3.0 video in comparison to single carrier QAM transport.

A second valuable benefit is the use of IP Multicast, which means that only when a program is asked for is it put onto the network, in contrast to broadcast channels. Others in the service group access the same multicast stream when they tune to the program, saving access bandwidth.

Trends have been moving towards more unicast for many years and for many reasons:

- Time-Shifting
- 2nd Screen viewing
- Smaller service groups
- Targeted advertising
- Voluminous on-demand offerings

Nonetheless, the most popular programs and channels tend to always benefit from multicast for even shrinking service groups at prime time, although the number of channels this applies to can be surprisingly small – the top 20-30 in the lineup, for example. In IP, of course, we are streaming programs, not channels, which is another layer of granularity and potential for dynamic flexibility.

Figure 10 is an example of the type of analysis showing the dependency of IP multicast to number of concurrent users and content mix. Note that this analysis is based on MPEG-2 video encoding. Since the analysis of Figure 10 in [9], MPEG-4 has become mature and is expected to be the dominant compression format initially for IPTV.

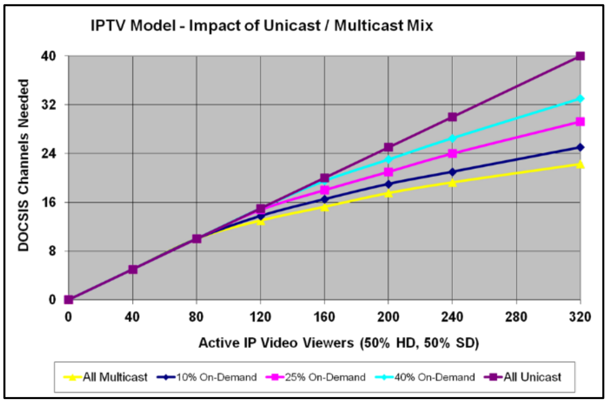

Figure 10 –IP Multicast Efficiency Analysis [9]

An important premise of determining IP Video capacity needs is to recognize that ultimately what matters is the number of eyeballs at primetime. The rest is just mathematical scaling. Customers are agnostic to delivery method and what is underneath the hood.

A WALK IN "IP" PARK

Figure 11 pulls together a possible transitional spectrum map integrating the items we have discussed herein and more. While the approach is to incrementally evolve services and technology in phases such as the eight steps in Figure 11 below, recognizing the impracticality of a straight "cutover" in most cases, the steps shown are still relatively coarse. The primary focusing was to introduce impacts of key technology components while having a reasonable number of permutations, but enough to create a useful timeline of guidance with the chart.

We describe the steps introduced in Figure 11 below.

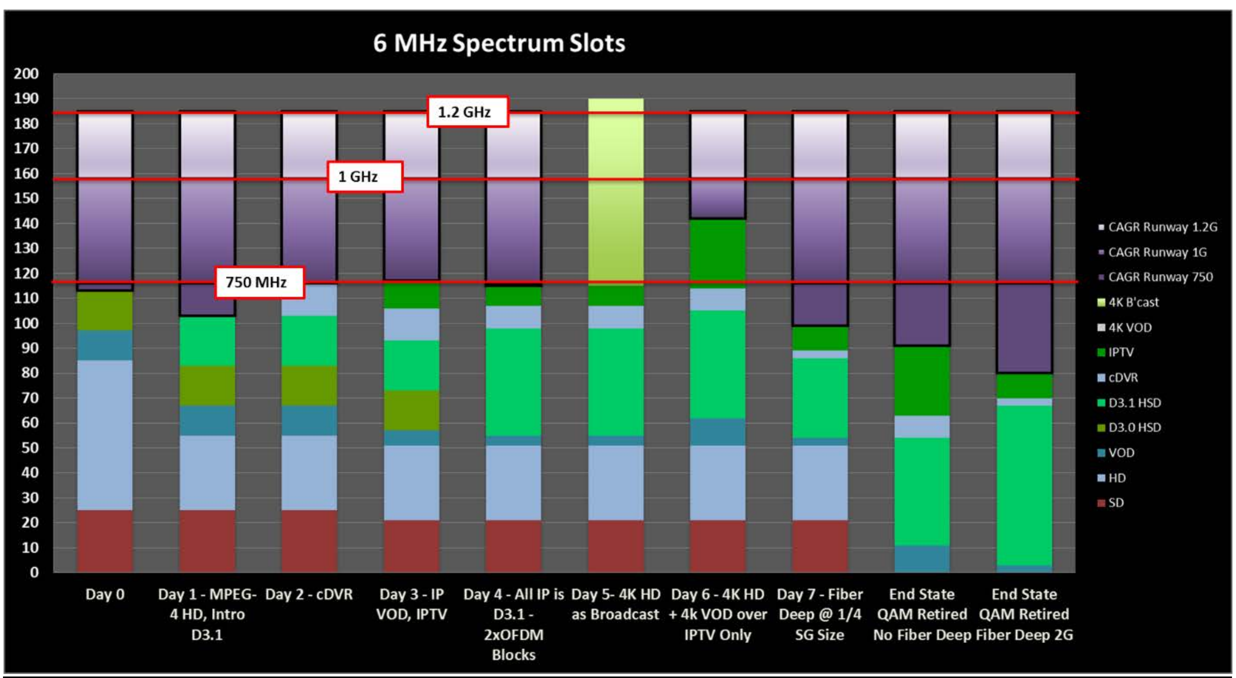

Figure 11 – Spectrum Transition Example Involving 4KHD, IPTV, Fiber Deep, and D3.1

Day Zero:

An HD channel typically has an SD brother in the channel lineup – it's a simulcast. This is not very efficient, but also not terribly penalizing given the modest relative bandwidth that the SD consumes.

As a starting point, we assume 300 SD and 150 HD channels of broadcast, 12 channels dedicated to VOD, and 16 channels for DOCSIS 3.0. It is apparent already (and not surprisingly) that this lineup consumes most of a 750 MHz HFC plant. All of the spectrum is being monetized for services.

Day 1: MPEG-4, DOCSIS 3.1

The introduction of a substantial chunk of spectrum for DOCSIS 3.1 is shown occurring using spectrum mined from transitioning HD to MPEG-4 for HD content.

Some of the spectrum reclaimed from the QAM pool is used to introduce DOCSIS 3.1 and enable Gigabit data service.

Note that the fact that DOCSIS 3.1 uses the 6 MHz spectrum slots more efficiently is embedded in the accounting of Figure 11 throughout all steps that incorporate DOCSIS 3.1

Day 2: Cloud DVR

Cloud DVR is an emerging service that continues the MSO move to IP-based video service. The impacts of cDVR can be projected mathematically based on available data on DVR penetration, video consumption behaviors, and content type.

We will assume an initial recorded viewing percentage at 33% based on [11]. We use 60% video services penetration, 70% peak busy hour (pbh) usage, 1.5 streams per home time-shiftable, and the 33% concurrency of recorded consumption.

We also assume *all* DVR customers have exchanged local storage service for cDVR service. Again, this transition will occur in phases in practice.

Day 3: IP VOD, IPTV

The move of VOD to IP VOD has occurred in this phase. Again, this will happen in phases, but in Figure 11 we show only all-QAM and all-IP cases, with the assumption of equivalent eyeballs meaning an efficiency improvement for IP VOD due to MPEG-4 encoding basis.

In addition, IPTV using IP Multicast is activated as a simulcast service using Figure 10 as a guide for required DOCSIS channels.

To remain contained in a 750 MHz network, the slots allocated to SD services was reduced. The reduction shown is about 16% on average, so more efficient use of existing compression may be sufficient. Of course, a full 50% is obtainable if desired with investment for the SD tier as well.

Day 4: Release 1 of DOCSIS 3.1

Use of DOCSIS 3.1 expands to the two full OFDM blocks per the initial capability requirements. DOCSIS 3.0 equipment has been replaced (again, a phased transition in practice).

Day 5: Intro to 4KHD

We consider the case of introducing 4KHD as a simulcast/broadcast, using HEVC compression.

Day 6: IP 4KHD

We remove broadcast 4KHD, and implement 4K VOD and linear as IP only using HEVC encoding.

Day 7: Fiber Deep

A Fiber Deep architecture (N+0) is considered. The architecture guidelines for Fiber Deep cap the maximum serving group size at 128 hhp.

End States

Both nominal service group size and a Fiber Deep architecture (N+0) are considered as the legacy QAM services are retired.

7 BUSY DAYS – SUMMARY

The *Day 0* state points out the obvious, using the 750 MHz network assumption – operators wisely use nearly all of the spectrum at their disposal for revenue-generating services.

Day 1 makes clear an important and oft-overlooked component of HFC capacity management. That is, while PACAGR garners all of the headlines, the industry has hardly stopped innovating in the video compression space. Since the deployment on a wide scale digital video over cable using MPEG-2 compression, a full two generations of MPEG compression have been completed and become deployable. The vast majority of non-IP based digital cable spectrum is still MPEG-2 based. Obviously there is a STB dependency that makes rapid changeover difficult, but a carefully managed changeover is quite reasonable and underway with many MSOs.

Day 1 indicates the effect of MPEG-4 on the HD broadcast spectrum only. Some of the reclaimed spectrum of the 50% HD savings is allocated to deploy DOCSIS 3.1 with enough capacity that bonded DOCSIS 3.0 and DOCSIS 3.1 channel achieve Gigabit data services.

Note that the net of MPEG-4 conversion and DOCSIS 3.1 introduction is an *increase* in spare spectrum, largely because DOCSIS 3.0 already existed and is providing a good percentage of the total capacity needed to support 1 Gbps.

In *Day 2*, we can see that the spare spectrum set aside is sufficient (not accidentally!) to enable Cloud DVR services (cDVR) at 100% penetration of DVRs. The service is assumed supported over DOCSIS 3.0, as the initial production of these DVRs it is assumed occurred in the DOCSIS 3.0 era (i.e. now)

By *Day 3*, we assume the transition of VOD to all-IP has occurred. Viewing behaviors are assumed held constant, and the IP version benefits from the use of MPEG-4. The introduction of IPTV occurs, based upon analysis as shown in Figure 10 for multicast gain and channel count required (spectrum).

As mentioned, the SD tier was reduced in order to make enough room for linear IPTV service. This can be a sacrifice of SD content, perhaps acceptable this many years down the road, squeezing better efficiency out of existing MPEG-2 compression, or of course MPEG-4 encoding is available for the SD tier if the investment is worthwhile to be made on SD services by this stage.

In *Day 4*, all of the IP services – HSD, cDVR, IPTV, VOD are over DOCSIS 3.1 only. The added spectrum efficiency of DOCSIS 3.1 allows all of these to consume less total spectrum.

However, HSD capacity growth and speed requirements are expected to continue as these phases (years) go by. All of the freed up spectrum is given to DOCSIS 3.1. The total number of DOCSIS 3.1 is increased to allow for the two full OFDM blocks of 192 MHz to be deployed. This now just fits within the 750 MHz envelope (again, not by accident!).

On *Day 5*, we can see the extreme scenario of the 4KHD dilemma. It displays the "what if" a broadcast simulcast of 4KHD (over HEVC) sat alongside SD and HD content. This does not make much sense to consider, and there is likely no one with such a plan. Figure 11 simply makes this abundantly clear.

On *Day 6*, however, we begin to see a pixel of light at the end of the 4KHD tunnel when we deploy 4KHD linear video and VOD over IP. While we have stepped over the 750 MHz boundary, we are comfortably within the 1 GHz boundary of existing HFC equipment and infrastructure with well-understood upgrade cost and logistics.

Alternatively, we have the *Day 7* approach to HFC evolution involving Fiber Deep as shown in Figures 5 and 7. The assumption of Fiber Deep in this case is a service group reduction by a factor of four, effecting the number of channel required for all narrowcast (unicast or multicast) services. This can be calculated. Note that spectrum allocation associated with a peak speed requirement (in this case, a 1G assumption).must still be maintained despite shrinking service groups and less total capacity utilized.

As can be seen in Figure 11, each of the evolutions of Day 6 (1 GHz upgrade) and Day 7 (Fiber Deep) are possible solutions to 4KHD capacity management. It is straightforward to show that the broadcast 4KHD case does not fit within 750 MHz when "Fiber Deep" is implemented. However, Fiber Deep in the form of N+0 and strictly NO amplifiers is inherently a 1 GHz architecture based upon a new Fiber Deep node. In this case the 4KHD broadcast is actually supported. So, HFC could support a 4KHD broadcast if necessary.

However, given that the IP transition is in process, just as 4KHD comes to life alongside HEVC, and given the much higher spectrum efficiency possible deploying over IP and with DOCSIS 3.1, it is understandable how we can look at 4KHD as a logical stimuli to the movement of video on the network to exclusively IP-based

End State makes the correlation between the scaling of 4KHD content and service, and the IP transition, abundantly clear. In this case –Fiber Deep or no Fiber Deep, retiring QAM spectrum and clearing its use for IP only services, delivered over maximally efficient DOCSIS 3.1 is the HFC Network Nirvana.

Note also that in this final state, which is assumed to be some years away, a D3.1 spectrum allocation supportive of 2G speeds is included, still comfortably.

End State – No Fiber Deep – make a pretty compelling case as to why the transition to IPTV includes the technology evolution of full video services over IP, but also the retirement of legacy video services, eventually eliminating broadcast/simulcast spectrum inefficiency. Ultimately, this simply makes the network traffic completely correlated with customer demand, which is significantly skewed today because of broadcast video services.

CONCLUSION

Cable operators are well underway in their transition to all-IP. However, it is along road. Behind the edge, throughout the home, and onto second screens are all mature aspects of IP video for cable operator (non-OTT) programming as well as OTT itself. This paper hopefully described some of the key puzzle pieces, and shows an example instructive pathway – a mix of technology and service evolutions – that can serve as coarse guidance of the "how-to" of IP transition management.

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