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The State of the Art and Evolution of Cable Television and Broadband Technology

Prepared for the City of Seattle, Washington

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1. Executive Summary

Cable broadband technology is currently the primary means of providing broadband services to homes and businesses in most of the United States. Because of its inherent capacity, cable technology will always be able to provide more capacity than commercial wireless solutions and copper telephone lines. Because of its ubiquity, it will be the main pathway for broadband communications for most homes and businesses for the foreseeable future. Cable operators are pursuing several strategies to increase the capacity and performance of cable television infrastructure, and to optimize it for user applications.

There are a number of significant limitations inherent in cable systems relative to fully fiber optic technologies, as well as to communications systems that were designed from the outset to provide Internet-type broadband data services. These include the limitations in total capacity, a physical architecture that is optimized for broadcast communications, and a significant remaining migration path to full end-to-end Internet Protocol (IP) operations.

At the same time, cable system subscribers are using the systems in profoundly new ways that were not envisioned in the design of the systems or the near- to mid-term business plans of the operators. As an example, more users are seeking third-party, "over-the-top" (OTT) programming—streaming video content (both fully produced channels and programs, and consumer-produced media found on YouTube or social media sites)—delivered via a consumer's Internet connection to a television, tablet, smartphone, or other compatible device. The change is technically challenging, because this content comes from outside the cable system and the cable operator's programming arrangements, through external Internet connections, and is growing in a rapid and unpredictable way.

The only way to satisfy this demand is through the cable operator constantly and continuously increasing the IP data capacity and capabilities of the system, and maintaining an open and content-neutral approach to ensuring that users can reach their content and create content, as well as reach the content they might want from the cable provider itself. The cable operator must see that the capacity for both OTT and cable-provider content grows according to the needs and interests of the users. Furthermore, data capacity and capabilities must increase so that cable operators do not face the temptation to favor transport for their own or affiliated content, to the detriment of the OTT content.

The need for growth, juxtaposed against the technical limitations of the cable systems, implies that cable operators nationwide will need to continually update their systems over the next five years and beyond to be able to support new consumer applications and remain competitive with other technologies such as fiber-to-the-premises (FTTP).

It is not possible to fully foresee the evolution of the various hardware and software strategies the cable companies will eventually pursue—just as it is impossible to accurately predict the exact growth of broadband demand. We know with some confidence, however, that the cable industry is seeking to avoid or at least delay the need to replace their networks with fully fiber infrastructure, because the cost of such an upgrade would be extremely high.

The likelihood is that, in the next five to 10 years, cable operators will introduce significant upgrades in electronics (as opposed to wholesale replacement of coax with fiber) such as DOCSIS 3.1 advanced cable modem technology, and will need to continue incremental improvements in the cable physical plant and the headend. Cable operators may reallocate spectrum between upstream and downstream directions to make the capacity more symmetrical. They may also attempt to increase the coaxial cable bandwidth (beyond 860 MHz and 1 GHz).

As cable operators continue down the path to IP convergence, they will develop new applications to meet consumers' demand for multi-screen video (i.e., a seamless ability to watch content on not just televisions, but also tablets, smartphones, and computers), OTT, and improved navigation among the variety of content options available to them.

Cable operators are also broadening their public and subscriber Wi-Fi offerings, as well as seeking ways to utilize their infrastructure to provide additional capacity to commercial wireless carriers (i.e., backhaul from cell sites).

In addition, advancements in video production technology have made the creation of high-quality content for public, educational, and governmental (PEG) channels increasingly cost-effective. The integration of Internet-based video and social networking are also becoming important elements in effectively catering to the needs of the local community.

2. Evolution of Underlying Infrastructure

Among current communications technologies, only fiber has the "off-the-shelf" capacity to support gigabit and higher speeds to the majority of users on a network. At the root of the difference is the difference in the physical capacity of a fiber optic strand, as compared with coaxial cable.

With the cable lengths and components in a typical cable system, coaxial cable is limited to approximately 1 GHz of physical capacity (spectrum), and this capacity is allocated with roughly 20 times as much in the downstream (network to user) as in the upstream (user to network) direction. In contrast, a strand of standard single-mode fiber optic cable in its standard 1310 and 1550 nm communications bands has a theoretical physical capacity in excess of 10,000 GHz,[1] and capacity can be allocated fully symmetrically between upstream and downstream using off-the-shelf technology. Fiber optics are not subject to outside signal interference, can carry signals for longer distances, and do not require amplifiers to boost signals in a metropolitan area broadband network.[2]

An additional limitation arises from the shared nature of cable modem service. Because bandwidth within a neighborhood is shared rather than dedicated, speeds may be significantly decreased by one's neighbors' simultaneous use of their cable modems.

2.1 Infrastructure Upgrades

Comcast operates a hybrid fiber/coaxial (HFC) system in Seattle that is typical of cable systems in major metropolitan areas. The system includes fiber optics to each neighborhood, but is mostly coaxial cable, including some components constructed with the original cable system in the 1970s and 1980s. In order to keep up with increased user demands from Internet and interactive video applications, cable operators continue to incorporate innovations in electronics and upgrade their infrastructure. For example, cable providers have incrementally expanded their fiber optic infrastructure over time, to reach closer to their customers.

[1] Conservative estimate derived from the channel widths of the 1285 to 1330 nm and 1525 to 1575 nm bands in G.652 industry-standard single-mode fiber optics.

[2] Maximum distances depend on specific electronics—10 to 40 km is typical for fiber optic access networks.

Comcast's recent and projected future upgrades have involved changes in equipment, with only incremental changes in the network transmission medium. The upgrades have increased the speeds of operation and capabilities to offer advanced services over the existing HFC plant.

2.1.1 Cable Migration Path

This report describes two potentially complementary evolutionary steps on the horizon for cable infrastructure—the upgrade to DOCSIS 3.1 and the move toward Ethernet PON over Coax. Each can improve the performance and capabilities of the HFC architecture—and each is consistent with the industry's eventual transition to an IP-centric high-capacity network.

Standard IP protocols (software code) govern how the Internet operates, and any communications that travels over the Internet (or Intranets—internal, private networks resembling the Internet). IP communications is organized in packets and travels on a network from its source to destination guided by router devices, which direct the packet based on the address and other information. Because of the efficiency, effectiveness and widespread adoption of IP networking, as well as the ubiquity of the Internet in communications, data, video and voice communications are increasingly becoming IP based and converging toward common IP platforms.

In line with this convergence, cable companies are increasingly using IP technologies in their systems, even in parts not associated with the Internet or the cable modem data service. For example, the backbone video transport (between programmers, centralized cable operator locations, regional system headends and operations centers) is now mostly IP-based.

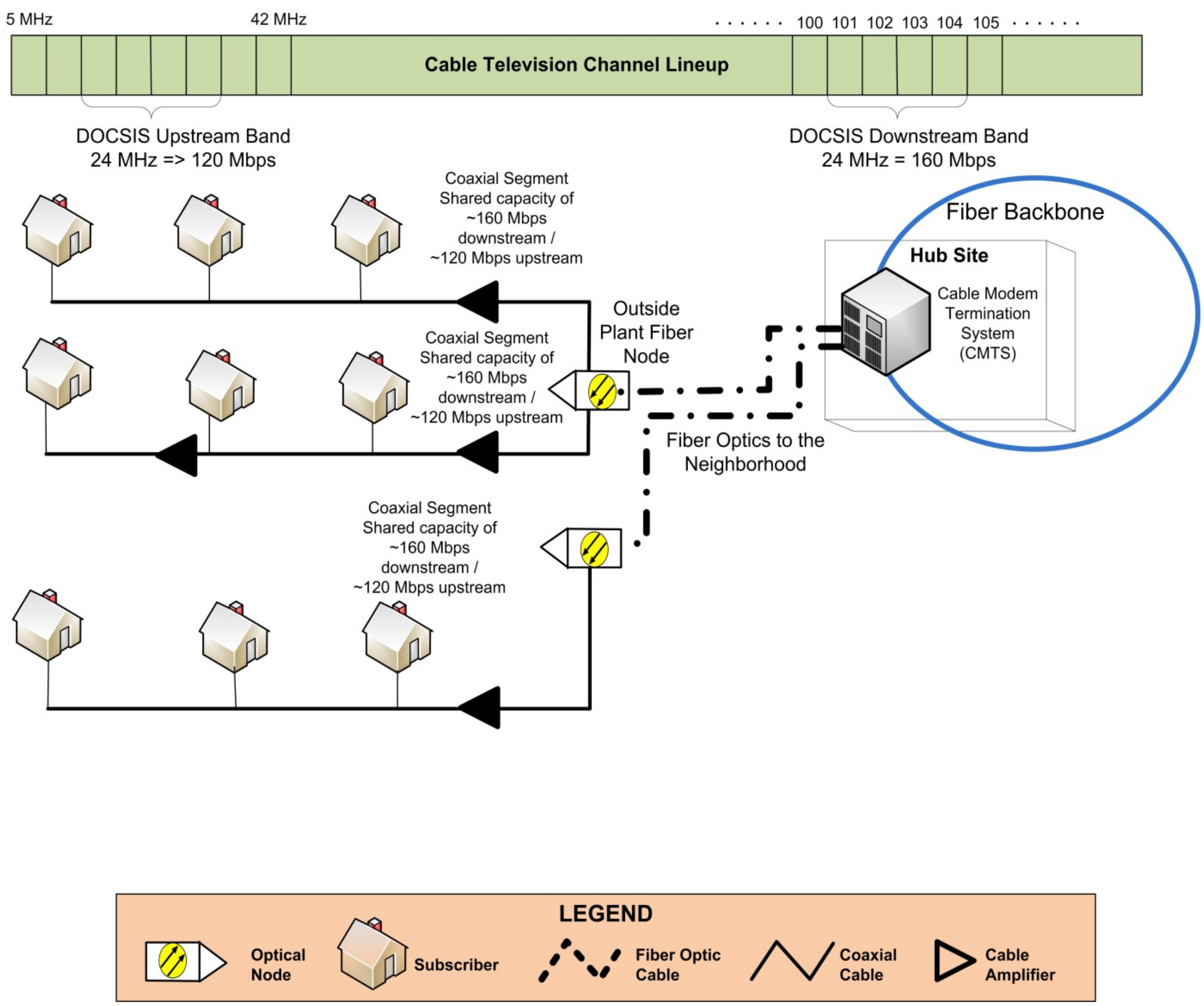
2.1.1.1 Upgrade from DOCSIS 3.0 to DOCSIS 3.1

In Seattle and in most of its systems, Comcast uses the current industry-standard cable technology for data provisioning, known as Data over Cable System Interface Specification version 3.0 (DOCSIS 3.0), first released in 2006.[3] DOCSIS 3.0 makes it possible for cable operators to increase cable modem capacity relative to earlier technologies by bonding multiple channels together. The DOCSIS 3.0 standard requires that cable modems and their associated backbone components be able to bond at least four 6 MHz channels (that is, use at least the same amount of channel spectrum as four analog television channels). With four channels of capacity in each direction, DOCSIS 3.0 provides aggregate speeds of approximately 160 Mbps downstream and 120 Mbps upstream, shared by the

[3] "CableLabs issues DOCSIS 3.0 Specifications enabling 160 Mbps," August 7, 2006, http://www.cablelabs.com/news/pr/2006/06_pr_docsis30_080706.html

users in a segment of the cable system.[4] A cable operator can carry more capacity by bonding more channels, up to the limit of the cable modem termination system installed at the operator headend or hub facility.

Figure 1: DOCSIS 3.0



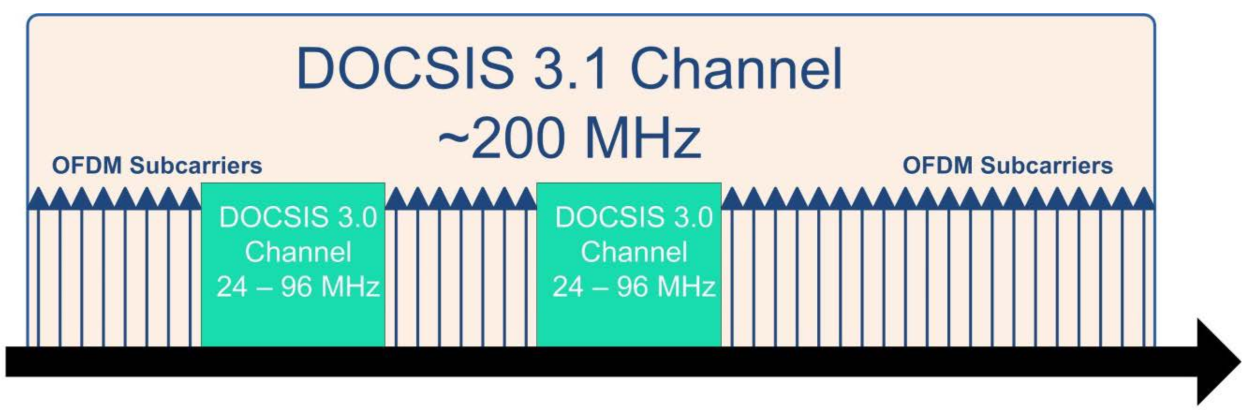
The cable industry is now actively developing the DOCSIS 3.1 standard, which will make it possible to:

[4] Segment (or node) sizes depend on the specific cable system, but are typically a few hundred homes or businesses. Typical cable industry practice is to reduce the segment size or add channel capacity when the peak utilization reaches a particular threshold. This is typically done in a case-by-case, incremental way, for the part of the cable system with the need.

- Aggregate the available capacity on the system into larger, more usable blocks rather than 6 MHz analog television channel blocks,
- Increase the capacity and flexibility of the system, and
- Create an architecture more consistent with migrating the non-IP traffic (i.e., TV channels) to an IP format.

DOCSIS 3.1 is an evolution of DOCSIS 3.0 that uses a technique called the Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme,[5] which is also used by technologies such as DSL, LTE, WiMAX, and Wi-Fi. The OFDM scheme spreads aggregated IP traffic over a number of much smaller "channels," or subcarriers, that are between 10 KHz and 50 KHz wide; these small channels are "orthogonal" to each other in the sense that they can be efficiently placed into much larger spectrum blocks than the 6 MHz blocks currently used by TV channels without interfering with each other in spite of less guard spacing between them. Thus, more information can be transmitted by using larger channels that contain data subcarriers with characteristics that can mitigate the loss of data (or signal attenuation) during transmission.

Figure 2: Representation of OFDM Channel



[5] A modulation scheme spreads data on a carrier signal by using different combinations of the amplitude and/or phase of the carrier signal.

DOCSIS 3.1 will also be able to implement higher-order data encoding rates, namely 4096-QAM in place of the existing 256-QAM,[6] using advanced OFDM-based electronics as discussed and by incorporating better error correction techniques (such as Forward Error Correction (FEC) and Low Density Parity Check (LDPC)), which will in turn make data transmission more spectrally efficient i.e. more data (bps) within the limited amount spectrum (Hz).

DOCSIS 3.1 also proposes to include electronics to reallocate the spectrum balance between upstream and downstream directions, so that a larger amount of spectrum can be allocated to upstream traffic, better supporting interactive applications. Reallocating the balance between the downstream and upstream directions will require modification or replacement of many components in the outside plant of the cable system.

The cable industry claims that DOCSIS 3.1 will provide 10 Gbps downstream capacity and 1 Gbps upstream. This will not be possible for most actual cable systems—a typical system with 860 MHz capacity might have the first 200 MHz to 250 MHz assigned to upstream, leaving 600 MHz to 650 MHz for downstream.[7] Even with 10 bps/Hz efficiency, the actual capacity for a shared node area would be closer to 6 Gbps than 10 Gbps, and the capacity, of course, will be shared among a few hundred users.

With appropriate planning and node segmentation, it should be possible for cable operators using DOCSIS 3.1 to consistently, simultaneously deliver more than 100 Mbps downstream and 25 Mbps upstream to customers and to fully migrate the television system to IP technology, if desired.[8]

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[6] The number "X" in the X-QAM modulation refers to the number of possible combinations in the modulation scheme—the combinations of distinct types of changes in amplitude and/or phase in a signal. More speed requires higher-order modulation schemes, but higher-order schemes are more sophisticated to design and build and more sensitive to noise and imperfections in the signal. In the most commonly used scheme in a cable system, 256-QAM, there are 256 combinations changes in amplitude or phase. 256 is also 2^8, and 256 combinations can be depicted mathematically in the full range of combinations of eight digits of "0" or "1." In a 256-QAM (2^8-QAM) channel of a given bandwidth, the theoretical capacity is [channel width in bps] x 8. Assuming use of a typical 6 MHz analog television channel, the theoretical channel capacity is 6 Mbps x 8 = 48 Mbps. With four channels, this becomes 192 Mbps. There is typically communications overhead and interference, so the real aggregate capacity is lower. If a cable operator is able to use 4096-QAM (which requires a less noisy environment than current cable systems), the theoretical capacity for the 6 MHz channel becomes 6 Mbps x 12 = 72 Mbps, or 296 Mbps for four channels.

[7] The Comcast cable system in Seattle, as well as almost all other cable systems in the U.S., have less than 50 MHz of bandwidth in the upstream direction.

[8] "Docsis 3.1 Targets 10-Gig Downstream," *Lightreading*, October 18, 2012, http://www.lightreading.com/docsis/docsis-31-targets-10gig-downstream/240135193.

On the other hand, expansion of downstream spectrum to 1.2 GHz and maybe up to 1.7 GHz for greater capacity are also being considered,[9] but this is still under evaluation and would require significant changes in network hardware. It is also important to note that higher-order QAM, such as 4096-QAM, will likely require improvement in the quality of the cables in the system and replacement of drop cables to subscriber residences.[10]

DOCSIS 3.1 is designed to be backward-compatible to DOCSIS 3.0, but a customer will need a DOCSIS 3.1 modem to have DOCSIS 3.1 speeds. [11] The deployment of DOCSIS 3.1 on Comcast's networks is planned to begin in late 2014 or early 2015.[12]

2.1.1.2 Ethernet PON over Coax (EPoC) Architecture

One possibility being considered by the cable industry for next-generation cable architecture, beyond simply upgrading DOCSIS on cable systems, is to reconfigure the cable system to operate with new electronics architecture resembling the passive optical network (PON) architecture used by many fiber-to-the-premises (FTTP) operators. Again, the upgrade would enable the cable operator to obtain more capacity and make the system more compatible with full IP data and video applications, and would be a way to make progress without wholesale replacement of the coaxial cable with fiber.

The FTTP PON architecture consists of a series of unpowered optical splitters that are used to provide access to multiple premises over fiber optic cable alone, as opposed to a hybrid fiber/coax network. There are two main components in a PON—the OLT (Optical Line Terminal) and ONU (Optical Network Unit), which are similar to the CMTS and cable modem, respectively.

The cable-TV PON architecture standard proposed by the IEEE is called Ethernet PON over Coax (EPoC). EPoC could potentially provide 10 Gbps speeds over the existing hybrid fiber/coaxial (HFC)

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[9] "An evolutionary approach to Gigabit-class DOCSIS," *CED Magazine*, July 5,2012, http://www.cedmagazine.com/articles/2012/07/an-evolutionary-approach-to-gigabit-class-docsis

[10] "EXAMINATION OF SPECTRAL LIMITATIONS IN HFC PLANTS," Leo Montreuil, Rich Prodan, IEEE EPoC PHY Study Group, July, 2012 Meeting Material, July 17-18 San Diego, CA, http://www.ieee802.org/3/epoc/public/jul12/montreuil_01a_0712.pdf

[11] "ARRIS Proposals for the Next Generation- Cable Access Network," *IAMU Broadband Conference*, April 10, 2013, http://www.iamu.org/documents/filelibrary/broadband_images__docs/2013_broadband_conference/BentonDOCSIS_3_D10CAA25B6946.pdf

[12] "Cable Show 2013:CTOs say DOCSIS 3.1 will save Cable's Upstream," *Multichannel News,* June 10 2013, http://www.multichannel.com/technology/cable-show-2013-ctos-say-docsis-31-will-save-cable%E2%80%99s-upstream/143819

architecture and further delay the need for cable operators to extend fiber. EPoC standards are currently in development and are scheduled to be complete by 2015.[13]

EPoC uses the same headend/hub optical equipment and user electronics as an FTTP operator, but with the existing cable-TV system sitting-in between these components. At the locations of the current cable-TV neighborhood node,[14] there would be a new device that would convert the communications on the fiber to separate Ethernet communications streams over the coaxial cable to each premises. The user would access the EPoC system with a device resembling the FTTP PON ONT user electronics, but with an RF coaxial network interface. The user would receive a fully IP Ethernet service, similar to what a user of an FTTP network would receive, but of course would still be constrained by the bandwidth limitations of the coaxial cable.

EPoC is conceived to coexist with other cable services, so a cable operator could transition gracefully to it while still providing traditional DOCSIS and digital television services over other parts of the channel spectrum.

The advantage of EPoC, relative to the current cable system, is that, once operational, it would allow a cable operator to virtually provide a dedicated IP Ethernet connection to each customer in a more efficient and direct way than using DOCSIS cable modems, and would allow cable operators and FTTP operators to be in the same marketplace for headend, hub and user premises equipment and take advantage of the economies of scale.

However, it is important to note that there is no magic or free lunch in the EPoC architecture—if the coaxial portion of the cable system is not upgraded to fiber, the customers on the network are still constrained by the physical capacity of that part of the system, even if a more efficient architecture sits on top. And, as cable operators push for spectral efficiency (bits per Hz) through more demanding modulation schemes, the communications becomes even more sensitive to imperfections in the cable plant, requiring the cable operator to replace the drop cables to the

[13] " EPoC: Is Ethernet over Coax the Next Big Step?," *Broadband Technology Report,* December 14,2011, http://btreport.net/2011/12/epoc-is-ethernet-over-coax-the-next-big-step/

[14] The node is the device in the HFC cable system that sits in each neighborhood, between the fiber and coaxial portions of the cable system. The placement of the node determines the coaxial segment size of the cable system, and therefore is the one of the most important parameters in determining the capacity and speed that a customer is provided on the system.

home[15] or perform other costly work on the outside cable plant. The claimed 10 Gbps speed is still an aggregated 10 Gbps, shared by all the users on a segment of the cable system. The per-user speeds will depend on the amount of fiber optics in the system. If the cable operator does not expand fiber, the likely speeds are, as in the case of DOCSIS 3.1, in the 100 Mbps downstream and 25 Mbps upstream range.

2.2 Internet Protocol (IP) Migration and Convergence

As discussed in Section 2.1, transition to an all-IP platform is a scalable and cost-effective strategy in the long run, allowing the operator to reduce ongoing costs, increase economies of scale with other network, communications, and media industries, and operate a more uniform and scalable network. For example, after the transition of video from separate digital video channels to the IP data (cable modem) network, there would not need to be a separate set of video transport equipment in the headend or hubs, nor a set of dedicated video channels. The transport equipment and the spectrum would become uniform and converged to a single IP platform. Thereafter, network upgrades could be carried out solely based on the evolution of high-speed networking architecture, independent of video processing capabilities.

2.2.1 Converged Cable Access Platform (CCAP)

The cable industry sees the Converged Cable Access Platform (CCAP) as the next step on the road to an all-IP-based content delivery model for most cable operators in the United States, including Comcast. CCAP represents CableLabs'[16] consolidation of two separate data and video convergence projects—the Converged Multiservice Access Platform (CMAP) initiative led by Comcast and the Converged Edge Service Access Router (CESAR) project by Time Warner Cable. [17]

CCAP is designed to merge the hardware for DOCSIS IP data and digital video channels (also known as Quadrature Amplitude Modulation (QAM) video) into one platform. Cable networks now assign distinct blocks of available bandwidth to different types of services—such as video on demand

[15] "EXAMINATION OF SPECTRAL LIMITATIONS IN HFC PLANTS," Leo Montreuil, Rich Prodan, IEEE EPoC PHY Study Group, July, 2012 Meeting Material, July 17-18 San Diego, CA, http://www.ieee802.org/3/epoc/public/jul12/montreuil_01a_0712.pdf

[16] Cable Television Labs (CableLabs) is a non-profit research and development consortium founded in 1988 which pursues advancements in cable telecommunications technologies and its integration by the cable industry. http://www.cablelabs.com/about/overview/

[17] "CableLabs Updates Technical Report on Converged Cable Access Platform," June 14, 2011, http://www.cablelabs.com/news/pr/2011/11_pr_ccap_061411.html

(VoD), high-definition TV (HDTV), and Switched Digital Video. The current technique of assigning bandwidth is relatively fixed, and requires planning and effort to reallocate when customer demand or technologies change. CCAP is a converged IP platform that allows more dynamic provisioning of bandwidth adapting to users' demand for a particular type of service.

Because many separate components of the video and data/voice platforms will be consolidated, operators will require less headend space and power. At the same time, the network will become more scalable and flexible—to support the future demand for data and advanced video services, including over-the-top (OTT) video accessed from third parties over the cable modem system.

The transport portion of the cable headend or hub, facing the cable system, typically consists of 1) the Cable Modem Termination System (CMTS), which is the headend/hub component of the IP cable modem network, and 2) QAM modulators that insert the digital video into the cable system (Figure 3).

By integrating the functions of the CMTS and QAM modulators into a single architecture (Figure 4), CCAP will reduce the number of interfaces (RF ports) and associated combining hardware that cable operators need to support a greater variety of video content and access devices.

Figure 3: Typical Headend

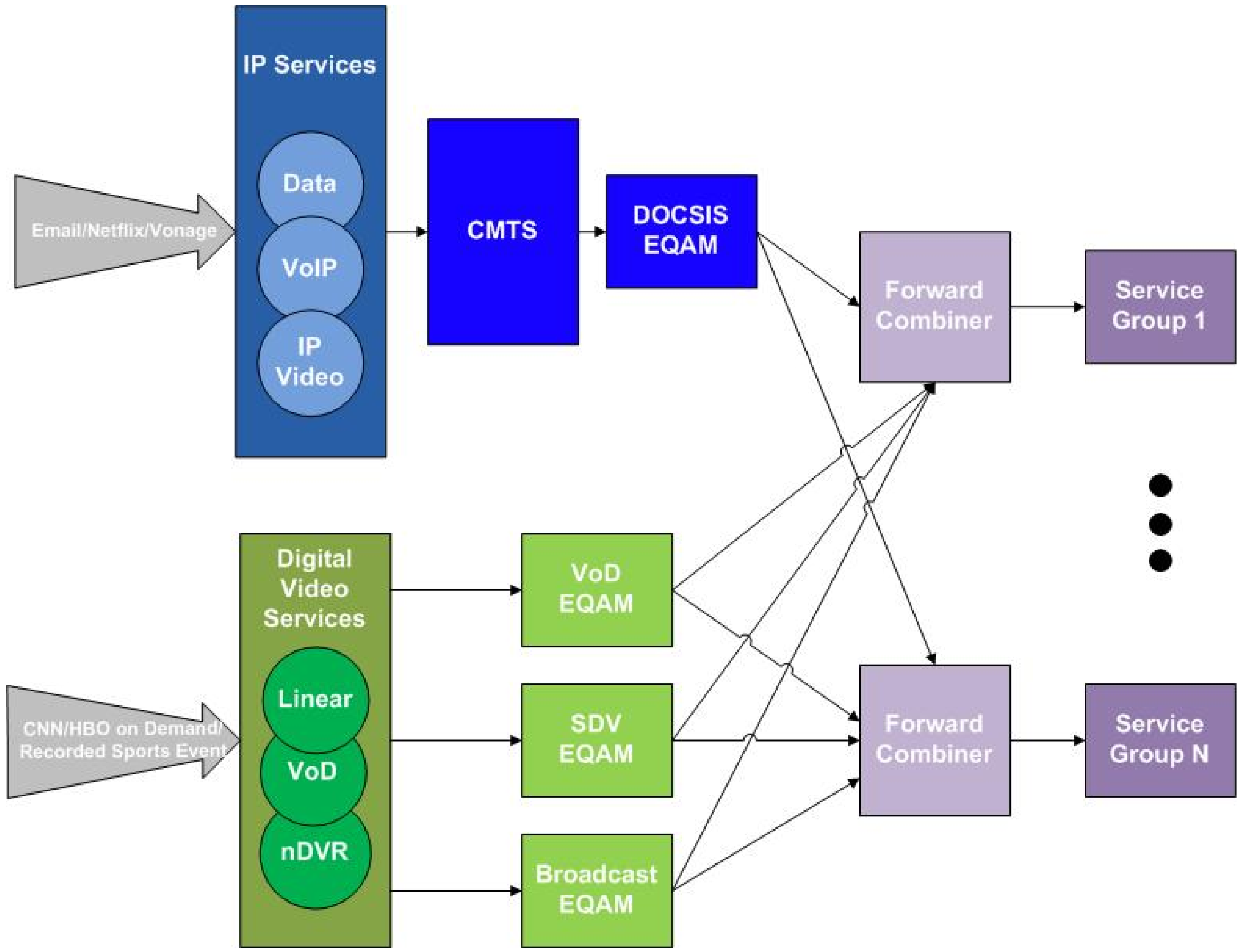
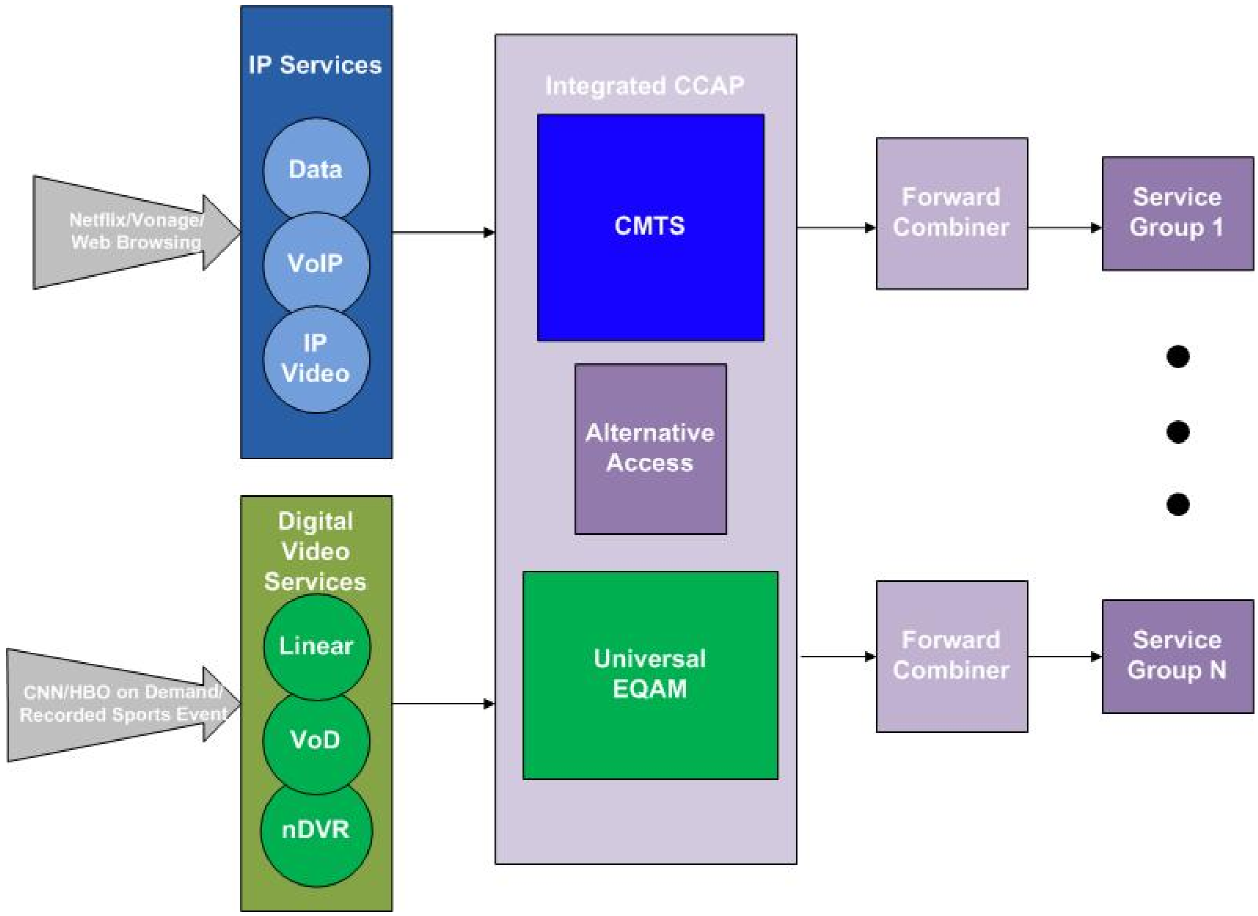


Figure 4: Headend with CCAP



Comcast has reportedly completed an operational readiness trial of the CCAP architecture in the northeast United States and is entering a pilot deployment phase that is expected to begin in the second half of 2013.[18] The full deployment of CCAP is scheduled to begin after the test period and planned to be deployed by market area in an incremental manner.

2.2.2 Migration from IPv4 to IPv6 Protocol

The Internet is in the process of migrating from the IPv4 to the IPv6 protocol. The migration includes several improvements in the operation of the Internet. One of the most notable is the

[18] "Major Cable Players rally around CCAP," *LightReading*, March 21, 2013, http://www.lightreading.com/head-ends/major-cable-players-rally-around-ccap/240151312, http://www.lightreading.com/document.asp?doc_id=694587

increase in available device addresses, from approximately four billion to 3×10^{38} addresses. IPv6 also incorporates other enhancements to IP networking, such as better support for mobility, multicasting, security, and greater network efficiency; it is being adopted across all elements of the Internet, such as equipment vendors, ISPs, and websites.

Comcast has begun offering a home networking/automation solution and a business Ethernet service with IPv6. As of the writing of this report, it is providing "dual-stack" cable modems in some markets, including Oregon and southwest Washington.[19] Dual stack means that modems get IPv6 and IPv4 addresses and can use both protocols.

Customers with access to IPv6 can connect IPv6-aware devices and applications through their Comcast cable modem connection and no longer need to use network address translation (NAT) software and hardware to share the single IP address from Comcast among multiple devices and applications; each device can have its own address, can be fully connected, and (if desired) can be visible to outside networks. One way to think of removing NAT is that it is the IP equivalent of moving from a world of cumbersome telephone systems with a main number and switchboard extension (e.g., 216-555-0000 extension 4422) to one where each individual has a unique direct number (e.g., 216-555-4422). Devices and applications that will particularly benefit from IPv6 include interactive video, gaming and home automation, because NAT (and other IPv4 work-arounds to share limited address space) makes connecting multiple devices and users more complex to configure, and IPv6 will eliminate that complexity and improve performance. With IPv6, each device and user can potentially be easily found, similar to how a phone is reached by dialing its phone number from anywhere in the world.

Comcast's support of services based on IPv6 across the network in co-existence with IPv4 is expected to be complete in 2013 and will likely be expanded as the Internet ecosystem evolves.

2.2.3 IP Transport of Video on Demand (VoD)

The popularity of video on demand (VoD) continues to increase, both in the content provided by the cable operator and for over-the-top[20] video provided by third parties and viewed using the cable modem system. In Comcast's current system, the backbone network delivers the requested content

[19] Comcast IPv6 Information Center, http://www.comcast6.net/, accessed August 18, 2013.
[20] Details in Section 3.2.1

from a central server (or, potentially from a cached location in the headend or hub) and sends it to a QAM modulator to reach a specific user's set-top box.

With the introduction of the X1 and X2 set-top devices, Comcast can begin to migrate its VoD service to the IP network, essentially streaming it to the set-top box from the headend or hub DOCSIS CMTS. This change will enable the migration of VoD from the video portion of the cable system into the data platform. While the migration will increase the utilization of the DOCSIS cable modem platform, the change will also be able to provide the benefits and long-term economies of IP convergence, as well as more functionality for both Comcast and the customer, such as the opportunity to view and manage both IP-originated content (e.g., YouTube) and Comcast video-on-demand on the same home platform, and to draw on all of the viewing for targeting personalized advertising at the viewer. Personalized advertising is scheduled to be available in Comcast systems throughout the United States by the end of 2014.[21]

2.2.4 Multicasting—IP Transport of Video Channels

Traditional Internet video can waste capacity, especially in a "channel" video environment, because it sets up a new stream from the source to each viewer. Even if many people are watching the same program at the same time, a separate copy is streamed all the way from the server (or source) to the user. Multicasting is a method of transmitting data to multiple destinations by a single transmission operation in an IP network.

Using multicasting, a cable operator can send a program to multiple viewers in a more efficient way. A multicast-aware network sends only a single copy of the program (known as a multicast stream) from the server or source through the various network routers through the network (in this case, through the cable modem system). When a viewer selects the program, the viewer's device (set-top converter or computer) connects to the multicast stream. The stream exists only once on the network, so even if the viewer and many neighbors are viewing the same stream, there is only one copy being sent through the network.

[21] "Comcast to Widen World of Addressable Ads," *Multichannel News*, http://www.multichannel.com/cable-operators/comcast-widen-world-addressable-ads/142214, accessed October 3, 2013.

Figure 5: Unicast IP Network Carries Multiple Copies of Single Video Channel

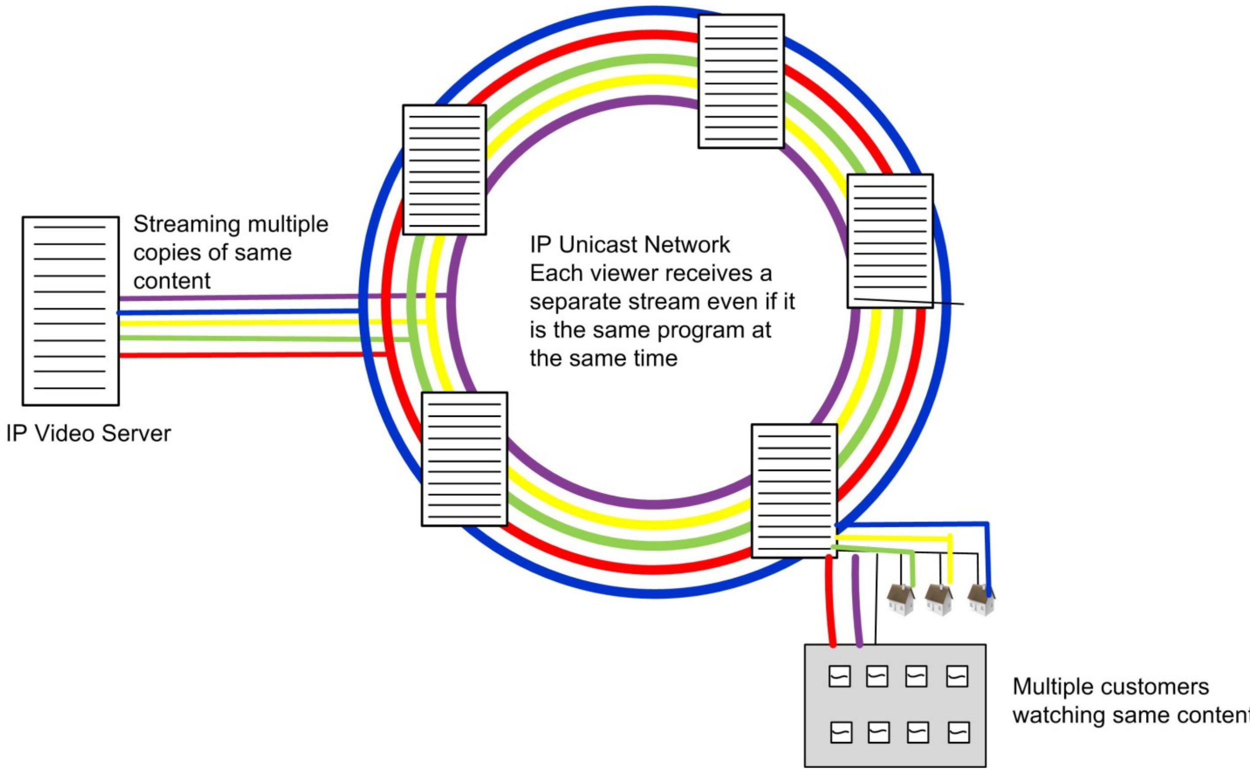
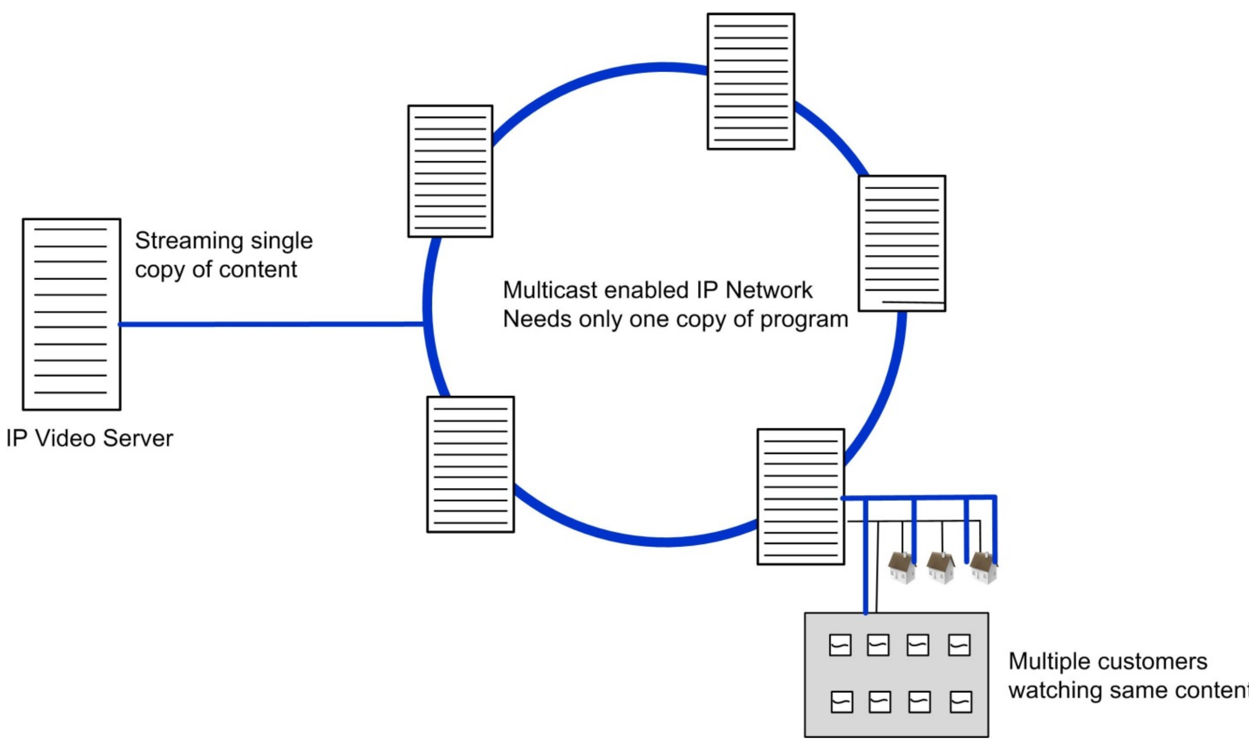


Figure 6: Multicast IP Network Carries Single Copy of Single Video Channel



Multicast is a feature that was optional in IPv4 but standard in IPv6. As multicast-capable and multicast-aware routers and set-top converters become standard, the cable operator can consider migrating all video programming to IP, and not just video-on-demand, as multicast provides a means to carry traditional channels over IP without wasting the backbone capacity.

2.3 Other Evolution of Cable-Related Infrastructure

2.3.1 Migration from MPEG-2 to MPEG-4 and Higher Compression Standards

Video compression is a powerful tool that can carry high-quality video over a relatively low-rate data link. Compression is part of almost all digital video systems. HDTV and SDTV digital video use compression, as does most video streamed over the Internet.

Compression takes advantage of the amount of repetition and symmetry within a single image, and the stability of video over time. Without compression, full-motion, high-quality video requires over 100 Mbps. With compression, the same quality video can be provided using only a few Mbps. Cable operators compress video with a codec device at the headend or programming source.

Cable operators typically use Moving Picture Experts Group-2 (MPEG-2) standards for the programming stream from the system to the cable set-top converters. MPEG-2 has been the standard on Comcast systems since the introduction of digital video on cable system. Using MPEG-2, the cable operator can select the level of compression based on available capacity, the demand of the video signal (sports and movies have more motion than other programming, so compression can be more noticeable), and tolerance for the artifacts of video compression, such as picture freezing or pixilation. Comcast typically places two to three HDTV signals in a 6 MHz channel block.

Migrating to more advanced compression has the advantage of freeing up bandwidth for more programming and cable modem capacity. Ideally, increasing compression is done in a judicious manner, where the benefits are achieved through faster and better hardware and software, not simply by crudely "dialing up" the compression on existing systems. Most CODECs have variable compression ratios, but selecting too high a ratio can result in freezing and blocking of the picture, and washed out color.

MPEG-4 (also known as H.264), is one means of increasing compression without sacrificing picture quality. H.264 was completed in 2004 and is now utilized in Blu-ray and high-definition DVD (HD DVD) and on HDTV programming on Verizon FiOS; it provides about twice the compression ratio of the previous version (MPEG-2). Many existing devices, including set-top converters, are not MPEG-4 compatible, so Comcast cannot offer MPEG-4 (or any other higher compression) unless the subscriber has a compatible converter.

The availability of greater processing power and parallel computing architectures has led to the establishment of a successor for H.264 video compression—the H.265 standard, which is also known as High Efficiency Video Coding (HEVC). H.265 is primarily envisioned for the next generations of ultra-high-definition video, as well as mobile video content and applications where only software upgrades are needed to decode HEVC.

H.265 carries out compression in a different manner from H.264. Instead of using a grid of small squares to segment a picture for compression, H.265 utilizes a variety of shapes that more efficiently segment and store information about changes across a picture. This scheme will offer significant savings in bandwidth over its predecessor and ultimately reduce the costs associated with transmission; H.265 is capable of providing better quality video at around 50 percent of the bit rate of H.264.

2.3.2 Ultra High Definition Television (UHDTV)

H.265 and other recent advancements in video encoding have facilitated the next phase in consumer video: Ultra High Definition Television (UHDTV). UHDTV improves picture resolution from 1280 x 720 /1920 x 1080 pixels (HDTV) to 7680 x 4320 pixels. UHDTV comes in two flavors, 4k (also called UHDTV1) with 2160 pixels and 8k (UHDTV2) at 4320 pixels. This means that UHDTV at the lower 4k resolution has about four times the pixels of HDTV, while 8k would boost it to 16 times. Therefore, even though this technology uses high compression ratios, implementing 4K and 8K technologies will significantly increase the demand for bandwidth on the system.

UHDTV will easily be able to translate into the mobile space due to the more efficient processors and software integration capabilities on new phones. However, the full scope of this technology will only be realized on larger screens. UHDTV will provide viewers with 60 degrees of field of view, which is almost double what is available today with HDTV, thus portraying a greater amount of detail and better zooming capabilities. It also decreases the viewing distance needed to convey a noticeable difference in picture quality, hence promoting the use of larger displays in smaller areas to provide a more immersive experience.

An important potential application of UHDTV could be the development of glasses-free 3DTV. This might be facilitated by UHDTV's large number of additional pixels, which could present the different display angles required for 3D viewing.

At the NCTA's *The Cable Show 2013*, Comcast CEO Brian L. Roberts demonstrated the first public U.S.-based transmission of 4K Ultra HD video.[22] The UHDTV displays currently available on the market have access to only a limited amount of 4k programming content; the rest is upconverted HD content. The high bandwidth transmission methods to make 4k content accessible to the public will not be readily available until 2014 at the earliest.

2.3.3 Evolution of Set-Top Boxes

Since the 1980s, set-top boxes (STBs) have been an integral part of the television ecosystem as a means for accessing video programming signals from cable, satellite, or IP sources and delivering them to televisions. Within the cable industry, STBs, which are typically proprietary leased equipment, act as gateways performing the functions of user authentication, digital rights management, and the decryption of video channels.

Over the course of the past few decades, cable television programming has evolved from being primarily one-directional analog channels to an all-digital environment that consists of a mix of digital QAM and two-way IP-based communications. With the launch of digital TV channels, HD content, and interactive programming, new proprietary gateways and adapters such as digital transport adapters (DTAs) and their HD-equivalent, HD-DTAs, are needed to interconnect TV sets for viewing subscription-based content. The costs associated with the purchase/renting and powering requirements of this equipment have caused a considerable amount of dissatisfaction among many subscribers.

In 1998, in order to resolve this issue, the Federal Communications Commission (FCC) promoted the development and adoption[23] of standards-based embedded technology for televisions and STBs, namely CableCard/tru2way in place of a cable provider's leased STB. However, various

[22]"Comcast demonstrates the future of broadband speed and 4k Ultra HD Video," Comcast Corp., Jun 11,2013, http://corporate.comcast.com/news-information/news-feed/comcast-demonstrates-the-future-of-broadband-speed-and-4k-ultra-hd-video

[23] "First FCC Report and Order: Commercial Availability of Navigation Devices," FCC, June 06,1998, http://transition.fcc.gov/Bureaus/Cable/Orders/1998/fcc98116.pdf

complexities in implementation, additional expenditure by the cable operators, and several other factors led the cable industry to resist adopting the technology.

A replacement technology called AllVid was proposed to create a competitive market for network-agnostic gateways and adapters in 2010.[24] By this time, there was a proliferation of IP-based video content (also known as over-the-top, or OTT) providers such as Netflix, Amazon Instant, and Hulu, as well as primarily IP-based retail media gateways and digital video recorders (DVR) such as Apple TV, Xbox 360, Roku, Boxee, and TiVo. The AllVid hardware was meant to serve as a universal adapter and navigation device for all types of video content from a variety of sources, including cable, satellite, and IP-based platforms. Subsequently, the cable industry tried to discourage the FCC's new initiative,[25] claiming that the rising number of IP-based video-capable retails devices had supplanted the need for standards-based hardware. At the time of this writing there seems to be limited development toward a platform (such as AllVid) that would eliminate the need for consumers to purchase/lease additional equipment from cable operators.

New STBs recently introduced by cable operators can deliver video content from cable operators both to televisions and IP-based user electronics (such as tablet computers or PCs) by converting encrypted QAM cable channels to IP video provided through Wi-Fi or Ethernet[26,27]—indicating that a strategy of collaboration is being pursued between cable operators and independent retailers. Also, the latest STBs offered by Comcast (the X1 and X2) have cloud-based[28] user interfaces and remote video storage mechanisms that move much of the complex computational processing and data caching space from the consumers' hardware to the network—potentially reducing consumer power consumption from approximately 25 watts to approximately 15 watts.[29]

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[24] "All about the FCCs AllVid," *LightReading, April 23,2010,* http://www.lightreading.com/dvrs/all-about-the-fccs-allvid/240118222

[25]" NCTA to FCC: Call Off AllVid," *LightReading*, January 26,2011 http://www.lightreading.com/blog/internet-video/ncta-to-fcc-call-off-allvid/240128956?queryText=allvid

[26]" New DTA will extend Cable TV to Retail Devices," *LightReading*, March 11,2013http://www.lightreading.com/internet-video/new-dta-will-extend-cable-tv-to-retail-devices/240150431?queryText=allvid

[27]"Comcast begins to connect Boxees cloud DVR," *Multichannel News,* April 11, 2013, http://www.multichannel.com/cable-operators/comcast-begins-connect-boxees-cloud-dvr/142668

[28] Cloud Computing is a broad term used to depict software or services delivered over a network (typically the Internet).The processing capabilities and data storage servers are located remotely on a pool of computing resources.

[29] EnergyStar Set Top Box Qualified Product List, http://www.energystar.gov/ia/products/prod_lists/set_top_boxes_prod_list.pdf, accessed October 3, 2013.

3. *Evolution of Applications and Video Content Presentation*

Along with enhancements to the underlying medium of content delivery, there have been improvements in applications and services that contribute to the overall consumer viewing experience. These are diverse items, but they collectively point to increasingly interactive IP communications over the cable system—communications that are likely to continue to grow.

In terms of the cable system, these enhancements are each likely to 1) increase utilization of the cable system capacity, 2) increase the use of IP-based communications, relative to the traditional QAM digital video fixed "channels," 3) increase the use of narrowcast content, relative to traditional broadcast communications, and 4) increase the use of *continuous* streaming media content, relative to highly-variable download communications (such as e-mail or traditional point-and-click Web downloading).

3.1 Multi-Screen Video

Most U.S. cable subscribers view content on a variety of stationary and mobile screens, including computers, TVs, smartphones, tablets, and game consoles. TVs still dominate the landscape for multimedia entertainment—however, more often than not, consumers are also simultaneously using another device.[30] This has created an immense need for seamless "multi-screen viewing" across consumer equipment. To offer this, however, 1) each video has to be converted (or transcoded) into formats and resolutions that would be compatible with the different devices, and 2) a consistent user interface, such as a website or home media gateway, needs to be present.

The demand for multi-screen video led to the implementation of the concept of "TV Everywhere" across the industry. Launched in 2009 by Comcast,[31] TV Everywhere means that subscribers can receive the same content on their TVs and other multimedia devices. Most recently, in order to improve the multi-screen usage experience, Comcast introduced the "Home Pass," which enabled

[30] "The New Multi-Screen World Study," Google Research Study, August 2012, http://www.google.com/think/research-studies/the-new-multi-screen-world-study.html

[31] "Comcast TV Everywhere scorecard:1.5B and counting," *CED Magazine*, September 14, 2012, http://www.cedmagazine.com/blogs/2012/09/comcast-tv-everywhere-scorecard-15b-and-counting

the automatic authentication of subscribers on various devices within a home (over their Wi-Fi network).[32]

3.2 Over-the-Top (OTT) Programming

Over-the-top (OTT) programming typically refers to streaming content delivered via a consumer's Internet connection on a compatible device. Consumers' ubiquitous access to broadband networks and their increasing use of multiple Internet-connected devices has led to OTT being considered a disruptive technology for video-based entertainment. The OTT market, which includes providers like Netflix, Hulu, Amazon Instant, and iTunes, is expected to grow from about $3 billion in 2011 to $15 billion, by 2016.[33]

In order to provision content, OTT services obtain the rights to distribute premium TV and movie content, then transform it into IP data packets that are transmitted over the Internet to a display platform such as a TV, tablet, or smartphone. Consumers view the content through a Web-based portal (i.e., a browser) or an IP streaming device (e.g., Google Chromecast, Roku, Apple TV, Xbox 360 or Internet-enabled TV/Smart TV).

The key difference in the delivery of OTT video content to consumers compared to other data traffic is the requirement of high Quality of Service (QoS). QoS prioritizes the delivery of video packets over other data where uninterrupted delivery is not as critical, which ultimately translates to a high quality viewing experience for customers.

OTT providers typically have to utilize cable operators' DOCSIS-based IP bandwidth to reach many of their end users. At the same time, they are a major threat to the cable television programming, provided by the very same cable operators, due to their low-cost offerings. As a result of this, many cable operators have introduced their own OTT video services to reach beyond the constraints of their TV-oriented platforms and to facilitate multi-screen delivery.[34]

While the nature of OTT video lends itself nicely to VoD, time-shifted programming, and sleek user interfaces, OTT providers have limited control over the IP transport of content to users, which can

[32] "Comcast Makes Home Pass*," LightReading*, July 5 2013, http://www.lightreading.com/document.asp?doc_id=703307

[33] "Over-the-Top-Video – "First to Scale Wins," Arthur D Little, 2012 http://www.adlittle.com/downloads/tx_adlreports/TIME_2012_OTT_Video_v2.pdf

[34] "Cable operators embrace over the top," *FierceCable*, July 2,2013, http://www.fiercecable.com/special-reports/cable-operators-embrace-over-top-video-studios-thwart-netflix-hulu-options

cause strains on network bandwidth due to the unpredictable nature of video demand. Cable operators have recently experimented with bandwidth caps,[35] which would reduce subscribers' ability to access streaming video content. It is also technically possible for cable operators to prioritize their own traffic over OTT video streams, dial down capacity used by OTT on the system, or stop individual OTT streams or downloads.

Some cable operators have attempted to manage OTT on their networks by incorporating the caching of OTT video content from third-party providers (e.g., Netflix) in their data centers in order to improve QoS and reduce congestion on the cable provider's backbone network. This serves as a means for improving the quality of OTT video for video hosted in the data center.

3.3 Navigation and Program Guides

Customer interfaces to access video content from cable networks will increasingly be hosted on the network (cloud) to offer intuitive, agile user experiences that are similar to Web-based interfaces. For instance, navigation and program guides for set-top boxes (STBs) are being enhanced to be simpler to use, intuitive, and attractive as compared to the older frameworks (which are limited to grids with channels on the left and timings on the right).

"Cloud-based STBs" (such as the Comcast X1 and X2) facilitate the migration to an all-IP service delivery model and can swiftly adopt new services without expensive hardware replacements. Cloud migration and its accompanying efficiencies can help cable operators offer new services, including:

- A customized viewer front-end, including recommendations based on the preferences of each individual user within a household
- The support of applications (apps) from different vendors, including home automation and security
- Greater integration of content from the Web (including social media, search engines, and review data)

[35]"Comcast tests new usage based internet tier in Fresno," *Multichannel News*, August 1, 2013http://www.multichannel.com/distribution/comcast-test-new-usage-based-internet-tier-fresno/144718

- The ability to deliver media on multiple devices (multi-screen video) with the encoding/decoding taking place on the network

- Motion-, gesture-, and voice-activated remote control

A key enabler for cloud-based dynamic user interface platforms is Hypertext Markup Language 5 (HTML5)—the latest version of the HTML programming language used in the display and layout of items on a webpage. The use of HTML5 creates the consistent interface across the Web and for access to video and gaming applications from cable providers. It is a non-proprietary platform that has been optimized for the delivery of multimedia without the use of plug-ins, thus ensuring faster loading and playback times. HTML5 has been developed with features that are suited for low power requirements, which will contribute to its utilization across mobile IP-connected devices. HTML5 is already being widely adopted as an alternative to Adobe Flash by cable providers, though the specification has not yet been finalized.

3.4 Network Digital Video Recorder (nDVR)

In the past several years, DVRs have enabled consumers to watch time-shifted content, allowing them to view TV programming based on their convenience rather than on the schedules set by television networks. However, the need to expand DVR storage capacity and the high costs of the associated customer equipment created challenges for cable TV service providers. Many viewers also want the ability to watch their desired content anywhere, anytime, and on any device.

The ability to store DVR content on the cable operator's network (or "in the cloud") provides a future-proof resolution for these issues, because operators can easily add storage capacity and upgrade functionalities in the cloud.

Network DVRs (nDVRs) eliminate the need for devices with larger hard drive space and potentially additional power requirements. Subscribers ultimately benefit by having much greater capacity without being tied to one device or delivery location. However, there will likely be higher pricing for service tiers with greater storage capacity. Largely for protection of digital rights, additional limitations on the functionalities will be present, such as allowing subscribers to record only a predetermined amount of content. This content may also be automatically deleted after a preset expiration date.

Network DVRs have been launched in several European and Asian countries, and a number of U.S. cable operators, including Comcast, are rolling out this application. Comcast reports that it expects to introduce a "network DVR" service along with the X2 platform, which will enable customers to have DVR functionality with video content stored on Comcast servers, and not simply within the DVR itself.

3.5 Advanced/Dynamic Advertising

The rise in multi-screen video viewership, VoD, and network DVR (nDVR) devices has changed the consumer advertising market.[36,37] Newer advertising methods based on customer profiles and preferences, and interactive advertising (such as responding via remote control), are a better fit for today's multimedia programming landscape, and are in line with approaches used by social media providers, search engines, and elsewhere on the Internet.[38]

With dynamic advertising, for example, ads can be prompted to play based on customer requests and can utilize the customers' feedback to provide additional information. Similar to the personalized advertising model adopted by Google on the Web, personalized multimedia advertisements could be displayed for cable viewers based on the type of video being streamed. On the other hand, the ability of consumers to easily skip ads on traditional DVRs has created the need to somehow insert marketing and advertising within programming content, such as with graphics overlays. It is yet to be seen if cloud-based nDVRs will maintain the functionality to skip over advertisements.

3.6 Integration of Wireless Communications

With the improvement of the quality and speed of wireless communications, the public has become accustomed to accessing Internet services over wireless technologies, either on a communications link managed by a wireless service provider (i.e., a cellular data plan), on local infrastructure typically managed at a home or business (i.e., a Wi-Fi hotspot), or through a mixture of those two approaches (e.g., a hotspot operated by a service provider, municipality, landlord, or homeowners association).

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[36] "What changing TV habits mean for advertisers," *Business Insider*, May 29,2013, http://www.businessinsider.com/what-changing-tv-habits-mean-for-advertisers-2013-5

[37] "Cross Screen-Engagement Study," Microsoft Advertising, March 2013, http://advertising.microsoft.com/en-us/cl/1932/cross-screen-research-report

[38] "Advertising and Interactive services," CableLabs, http://www.cablelabs.com/advancedadvertising/

The ability to deliver cable TV content to consumer devices anywhere, at any time, is highly dependent on the evolution of wireless technologies. Nationwide, cellular service providers operate a mixture of third-generation (3G) and emerging fourth-generation (4G) wireless technologies.[39] As of June 2013, the latest 4G LTE (Long Term Evolution) technologies have been rolled out by every major U.S carrier, creating an environment for better access to streaming video. In the near term, the challenges for wireless carriers are for greater capacity, extending network coverage, and efficiently utilizing the limited amount of wireless spectrum. Cable operators are well positioned to mitigate some of these issues with their extensive hybrid fiber/coaxial (HFC) infrastructure and Wi-Fi capabilities. As described in the following section, they have recently been pursuing synergies with wireless carriers by exploring ways to utilize and extend each other's communication networks.

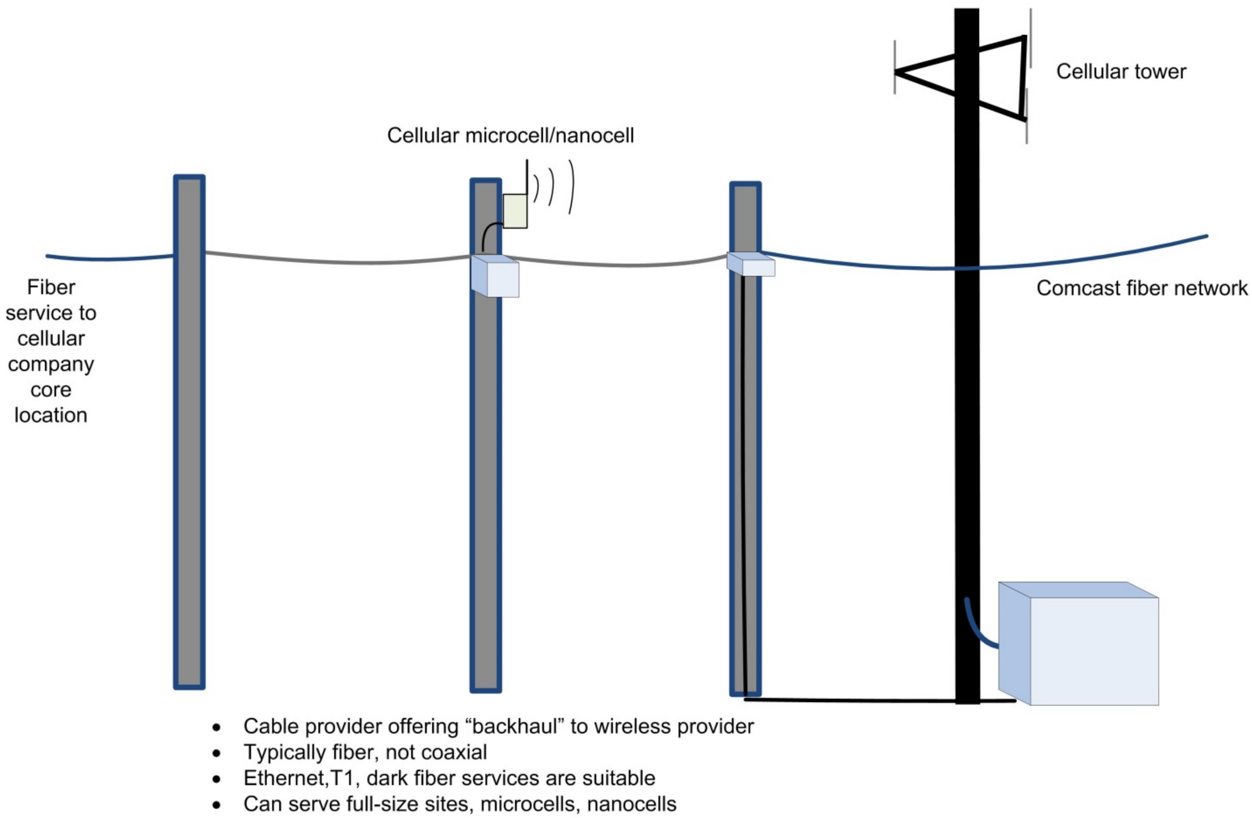
3.6.1 Mobile Backhaul

One area for greater collaboration between cable and wireless carrier networks is the provision of backhaul from cell sites to core network locations. In a carrier wireless network, cell towers are typically connected (backhauled) to the wired telecommunication network through low-bandwidth circuits. Given the fact that cable operators have infrastructure that is spread out in a pattern that can easily reach cell towers, a relatively small investment in upgrading the fiber portion of cable operator networks for robust Metro Ethernet services will equip them with capabilities for mobile backhaul.[40]

[39] The strict definition of 4G from the International Telecommunications Union (ITU) was originally limited to networks capable of peak speeds of 100 Mbps to 1+ Gbps depending on the user environment; according to that definition, 4G technologies are not yet deployed. In practice, a number of existing technologies (e.g., LTE Revision 8, WiMAX) are called 4G by the carriers that provide them and represent a speed increase over 3G technologies as well as a difference of architecture—more like a data cloud than a cellular telephone network overlaid with data services. Furthermore, a transition technology called HSPA+, an outgrowth of 3G GSM technology (previously considered a 3G or 3.5G technology, with less capability than LTE or WiMAX), has been marketed as "4G" by certain carriers—so the definition of 4G is now fairly diluted. The ITU and other expert groups have more or less accepted this.

[40] "Mobile backhaul opportunity knocks for cable operators," *CED Magazine*, Feb 28, 2011, http://www.cedmagazine.com/articles/2011/02/mobile-backhaul%3A-opportunity-knocks-for-cable-operators

Figure 7: Cable Operator Providing Fiber Backhaul to Cell Sites and Micro/Nanocells



Additionally, the coaxial portion of the cable system (as well as customer premises) may be suitable for small "picocell" devices—miniature cell sites resembling Wi-Fi hotspots that can connect a handful of wireless users to a carrier, typically for indoor locations with poor wireless coverage.

3.6.2 Partnerships with Wireless Carriers

In addition to the greater speeds available on the latest LTE networks, wireless carriers can also promote the usage of video streaming on mobile devices (such as smartphones and tablets) by implementing functionalities that optimize the broadcast of premium TV content on the wireless network. A technique called Evolved Multimedia Broadcast Multicast Service (eMBMS) along with the implementation of new adaptive streaming protocols (in place of buffering) and High Efficiency Video Coding (HEVC) enables the spectrum to be utilized more efficiently for the provision of TV content by wireless carriers. Verizon Wireless is already providing an NFL Mobile Service that delivers a separate session to each individual user (i.e., unicasting), but eMBMS will enable the broadcasting of live video similar to how TV signals are delivered.[41]

Some cable companies such as Comcast are also offering customers a "Quad Play" of Internet, voice, cable, and wireless services (by reselling wireless phone services). This strategy also provides another portal for extending the reach of cable television and associated services.

3.6.3 Wireless Services by Cable Provider

Wi-Fi enables the delivery of content to multiple TVs, tablets, PCs, and smartphones without the limits of cabling. Cable providers have been offering wireless Internet services for several years through Wi-Fi routers connected to DOCSIS-based cable modems. Comcast and other video content providers are now increasingly pursuing ways to offer wireless transmission of video content on home networks as well as on large-scale roaming networks. Theoretically, Wi-Fi may also enable a provider to offer some of its services from its cable plant to a home or business without installing a cable into the premises.

3.6.3.1 *Residential Wireless Services—Wi-Fi and New Technologies*

Wi-Fi or Wireless Local Area Network (WLAN) technology is based on the IEEE 802.11 standard. WLANs have been able to provide greater bandwidth over the course of their evolution and may potentially create a completely wire-free future for connectivity within the home.

One of the latest versions of the 802.11 standard, 802.11ac, positions WLANs to target the exponential wireless market growth expected over the next few years by offering speeds of up to 1.3 Gbps[42]—doubling that of the current 802.11n standard. The new standard (operating only in the 5 GHz band as opposed to both the 5 GHz and 2.4 GHz bands) has various design enhancements, including:

- Increase in channel sizes up to 160 MHz from a maximum of 40 MHz in 802.11n
- Use of higher modulation and coding schemes such as 256 QAM (an improvement over 64 QAM)

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[41] "Verizon's McAdam Sees Broadcast Video over LTE in 2014,"*Multichannel News*, Jan 8,2013 http://www.multichannel.com/telco-tv/ces-verizons-mcadam-sees-broadcast-video-over-lte-2014/141109

[42] "802.11ac:The fifth Generation of Wi-Fi Technical White Paper," Technical White Paper, Cisco Systems, August 2012

- Greater number of multiple input, multiple output (MIMO) antenna streams (i.e., eight antenna streams instead of four) separated spatially in a manner that improves data rates and performance

- Use of multi-user MIMO, which supports simultaneous transmission to multiple clients, thus more effectively utilizing channel bandwidth

The Wi-Fi Alliance, a trade association that ensures the interoperability of equipment from different vendors, had recently approved 802.11ac technology on various new devices. The relatively faster adoption of this new technology has become a necessary step in order to support the pervasive bandwidth being demanded by mobile applications and the increasing number of devices per user. Backward-compatibility to older standards and 2.4 GHz equipment will be a feature that will be present on most devices for the foreseeable future.

Another standard—802.11ad—which will offer functionalities closer to peer-to-peer (P2P) applications has been in development by the IEEE committee to enable the use of the 60 GHz band of radio spectrum. It has the capability to transfer up to 7 Gbps.[43] This technology is more suited for high capacity, line-of-sight links (such as in-room wireless connection) and has the potential to be a highly effective way to communicate between content delivery mediums and user screens—similar to how an HDMI cable or docking station would work, but at greater distances.

3.6.3.2 Roaming Wi-Fi Networks

Cable providers have been able to broaden their wireless service footprints by creating a nationwide roaming Wi-Fi network. Comcast has expanded its Wi-Fi hotspot network, "Xfinity WiFi," to several densely populated areas within its service region to provide wireless Internet access to both subscribers (at no additional charge) and non-subscribers (at a pay-per-time-block rate), although as of the date of this report it is not available in Seattle. Comcast and four other cable companies—Time Warner Cable, Cox Communications, Cablevision, and Bright House Networks—have collaborated to create a Wi-Fi roaming network across the United States, named "CableWiFi." This network allows cable subscribers to access the Internet within the coverage of

[43] "Amendments in IEEE 802.11ad enable Multi-gigabit throughput and groundbreaking capacity," IEEE Standards Association, 8 January, 2013, http://standards.ieee.org/news/2013/802.11ad.html

150,000 hotspots (as of June 2013) belonging to any of the cable providers in more than a dozen major cities.[44]

In June 2013, Comcast launched a "homespot" network[45] that sets up an additional sub-network on the Wi-Fi gateways deployed in individual customer premises that is accessible to all Comcast subscribers. This model has already been demonstrated in Europe and has the potential to provide millions of hotspots across Comcast's service footprint, enabling roaming access to video and data content.

The expansion of roaming Wi-Fi networks either collaboratively (e.g., CableWiFi) or by individual cable providers (e.g., Comcast's homespot) does not appear to create bandwidth bottlenecks on cable operator networks at the moment. Rather, the networks create benefit to cellular wireless carriers, which have a new avenue to relieve their network congestion by offloading their data services to cable operator's public Wi-Fi networks. At the same time, wireless subscribers can also direct their traffic to Wi-Fi networks whenever possible to avoid the data caps set by cellular providers. In both cases, MSOs benefit by 1) obtaining a greater penetration in the wireless broadband market and 2) the creation of a smooth transition in the TV viewing experience outside of their coverage area.

[44] "CableWiFi Alliance triples to 150,000 hotspots," *USA Today*, June 10, 2013, http://www.usatoday.com/story/tech/2013/06/10/cablewifi-expands/2408829/

[45] "Comcast unveils plans for millions of Xfinity WiFi Hotspots," press release, Comcast Corp., June 10, 2013, http://corporate.comcast.com/news-information/news-feed/comcast-unveils-plans-for-millions-of-xfinity-wifi-hotspots-through-its-home-based-neighborhood-hotspot-initiative-2

4. Evolution of Video Production

A typical public, educational, and governmental (PEG) production studio for a large suburban community consists of a variety of equipment—including cameras, editing systems, lighting, media storage, playback systems, studio sets, video streaming platforms, and networking equipment—ranging in price from $500,000 to $1. 5 million, not including the cost of the building space. While the electronics required for a studio varies widely, electronic components typically have five- to seven-year replacement cycles. Over a 15-year period, capital replacement costs would likely be between $3 million and $5 million.

Innovations in video production technology have made the creation and dissemination of high-quality video content much easier and more accessible—and in many cases more cost-effective—than in previous decades. Public, educational, and governmental (PEG) access television channels have greater opportunities to make an impact in their communities through the adoption of these improvements to production and transmission.

4.1 Changes in Programming Production

4.1.1 Cost-Effective Programming Techniques

As technology has become a greater component of today's video production world, adequately trained staffing is required across a range of production disciplines to achieve the mission of either a single PEG production facility or the PEG access program as a whole. It is critical that staff is properly trained in newer technologies and that technical support is provided to maintain and operate these systems. Due to better usability, it is possible to conduct cross training of personnel (such as teaching producers the skills for computerized editing of their own content). New sources for staff members who may already have some of the requisite cross-training can also be tapped—including, perhaps, staff and students of educational institutions such as high schools and colleges. Greater affordability and ease of use of new high-quality video production technology such as Web-based video production methods has also made it possible for almost anyone to produce programming content that can convey issues of general interest to individual communities (i.e., citizen journalism).

Professional-grade content programming can increasingly be created outside of the studio and integrated to channel programming via various transport technologies. The content generated across multiple locations by the use of sophisticated, remotely controlled cameras and prewired facilities can be consolidated efficiently over high-bandwidth networks. There is a clear trend toward producing on a virtual studio (i.e., using “green screen” technology to allow operators to create virtual backdrops and sets, which enable them to use one studio space and have it appear unique for each program produced). Greater adoption of the concept of remote/virtual sets leads to the use of smaller spaces than those traditionally required for studio facilities, which in turn leads to lower operating expenses.

On the other hand, with PEG operators migrating to digital environments, the need for content storage has increased. A centralized media storage solution that could manage, maintain, and archive content would prove more cost-effective than each operator implementing its own media storage solutions. It would also facilitate the exchange of content between operators and result in greater capacity and less equipment (which may increase reliability).

In summary, technology evolution has made feasible a reduction in the dependency on human resources and the transition to less expensive professional-quality equipment.

4.1.2 Latest Production Environments

Cable TV’s transition to an all-digital system creates new opportunities to expand the quality, visibility, and access to PEG programming. The broadcast transition to high definition (HD) has occurred rapidly over the past few years, with cable operators increasing the number of HD channels available to subscribers. In addition, video on demand (VoD) and live streaming services such as YouTube, Netflix, and Hulu also support HD video. As viewing habits continue to change, subscribers will expect all video content to be provided in HD. In order to accommodate subscribers, the PEG operators must proceed with upgrading their production capabilities. Continuing to provide PEG channels only in standard definition (SD) will essentially isolate the channels and limit viewership. Production in HDTV will likely be replaced by 4k Ultra High Definition Television (UHDTV) in the future, similar to how HDTV migrated from SD. The replacement of SD shooting, editing, playback, video storage, and digital audio equipment with HD equipment is a necessary step to maintain the standards of the latest television production environments.

Lately, VoD access to PEG programming has become particularly important. Much of the PEG programming is not live, so content is currently aired based solely on the decision of the programming managers. Since PEG programs frequently contain information that remains current for a long time, it is a natural fit for the VoD environment. As with any television content, PEG content would be more accessible to a wider audience if it were available for viewing whenever a resident wants to watch it. The use of different platforms for content delivery in addition to traditional playback on cable channels (such as uploading to Internet websites, streaming to mobile devices, and using services such as YouTube, iTunes, and Blip) also lends to this model.

4.2 Portable Technologies

Facilitating live coverage of events requires two critical elements: portable video production equipment and network connectivity. Following the typical trend across the electronics industry, videography and transmission equipment have become easy to use and more lightweight, enabling greater portability. (The equipment can now be housed in one or two small cases that fit in the back of a vehicle.)

The emergence of all-in-one live production equipment such as the Sony Anycast and NewTek TriCaster, ranging in price from $10,000 to $20,000, makes filming and editing very flexible—and eliminates the need for separate professional live streaming devices such as a video switcher, streaming encoder, video recorder, audio mixer, and storage device. These devices also have interfaces to connect to studios through high-speed connections and various options to provide live video feeds at locations where a wired connection is not feasible, such as through public wireless access points and LTE modems. The combination of advanced, less-expensive camera technology and faster network connectivity mean that portable live equipment is an effective complement to the equipment in fixed PEG production studios.

4.3 New Approaches to Local Programming

Techniques for optimizing local programming that would increase viewership and community interaction include:

- The provision of high-bandwidth Internet, perhaps through the city's internal fiber network, and widely available wireless broadband access. Central media storage and other systems such as playback and automation are some of the many future PEG systems and applications that will rely on a robust network infrastructure.

- Greater social media integration that can promote awareness about available local PEG content and serve as an effective means for feedback from the community. For example, greater visibility and promotion of Twitter feeds that notify the community about show timings and associated online videos, as well as the Facebook pages of relevant channels which can be used to garner reactions and comments from the public.

- Access to the electronic programming guide (EPG) via a connection that allows the PEG operators to export their programming schedules from their automation systems to the EPG system The EPG still remains a critical tool for alerting viewers of the content on the channels and facilitating recording of programs on digital video recorders (DVRs). Without an EPG, subscribers will only know when a program is on by memorizing the schedule or through traditional channel surfing, which is an increasingly outdated mode of television watching.[46] While the use of social media and other marketing tools can help alert viewers to the programming schedule, the EPG should also be used. PEG operators would need to provide information about all of their programming, to ensure that the on-screen guide is useful for residents.

- The distribution of citizen-generated content that is procured through Web-based technologies and interfaces. Regularly scheduled training classes for studio production, field production, and editing will facilitate greater participation from the community.

- The use of more and improved two-way video applications such as Skype and Google Hangouts will foster more interaction and drive greater interest in PEG programming.

- The support and enhancement of portable video production equipment such as mobile production vehicles and other remote production field kits to minimize the set-up time and staff needed to facilitate remote productions. This will also require upgrading common PEG resources, including the mobile production vehicle and the channel transport system, to HD.

[46] Instead of traditional channel surfing, viewers increasingly rely on "surf" the EPG to find programming. PEG operators who do not have access to the EPG are missing out on this viewing audience.

Appendix A: Glossary of Terms

Asymmetric	Data service with more capacity in the downstream (network to user) direction than the upstream (user to network) direction. Asymmetric services are often less costly to deploy and, because many uses of the Internet are heavier in the downstream direction, asymmetric services can suit the needs of many types of users. Asymmetric services are less well-suited to users who host data, who use many interactive multimedia applications, or who frequently upload large files.
Bandwidth	Available range of frequencies (or number of channels) over a cable or over the air. Bandwidth is typically measured in the frequency range available (kHz or MHz).
Backhaul	The transport of telecommunications network traffic from the outer edge of the network back to the central core. A common example is wireless backhaul, which is the connection from a wireless base station or tower to the wireless network core.
CableCard	A device that is provided by the cable service provider or embedded in a retail device (e.g., television monitor) that allows access to digital cable services and maintains signal security without having to use a cable provider's set-top-box.
CCAP	Converged Cable Access Platform – Integration of the data and video portion of the cable architecture into one platform.
CODEC	EnCOder-DECoder, converts between different types of video streams. A CODEC provides video in a known format, such as MPEG-2 or H.264.
Compression	Reduction in the size of a video stream by computer processing, which takes advantage of symmetry and repetition in images and the stillness of a video picture over time. Widely available compression algorithms reduce the size of video by factors of tens or hundreds.
DOCSIS 3.X	The latest version of a Data Over Cable Service Interface Specification telecommunication standard that enables the transmission of high-speed

	IP-based data and voice over the cable network and provides interoperability between devices of different manufacturers. Like Wi-Fi and Ethernet, DOCSIS made it possible to build less-expensive mass-produced devices.
Ethernet	The name of the technology invented by the Xerox Corporation for a 10 Mbps shared resources LAN, subsequently incorporated into Institute of Electrical and Electronics Engineers standard IEEE 802.3. Ethernet, like Wi-Fi, is a widely adopted standard that creates interoperability between different vendor devices and a widely adopted technical approach to networking. Almost all wired computer network interfaces are Ethernet, and Ethernet is now a typical interface on a digital television.
Headend	A cable system operator's central cable TV facility, which receives satellite and off-air video feeds and inserts signals into the cable system. The headend also includes data and voice switching and administrative services.
HFC	Hybrid Fiber Coax – A standard cable TV architecture in which the backbone network is fiber optic cable and the last-mile access network is coaxial cable. HFC is a scalable architecture, in which capacity can be increased by building fiber closer to users.
HDTV	High-Definition Television – Video/images of higher resolution than standard definition (SD), resulting in enhanced picture quality. Common HDTV signal resolutions are 1920 x 1080 and 1280 x 720.
Hub	Key facilities on a network that are served by the network backbone. Typically hubs are connected to each other and the headend over redundant fiber paths.
IP	Internet Protocol – A set of networking standards and an addressing scheme which emerged with the Internet and is also frequently used in private networks.
MHz	Megahertz – Unit of measuring frequency and bandwidth. One MHz is one million cycles per second. AM radio is between 0.54 and 1.6 MHz; FM radio

is between 88 and 108 MHz; and over-the-air television frequencies range between 54 and 700 MHz.

Modem — MOdulator-DEModulator, typically providing an interface between a cable (telephone, cable TV, or fiber optic) and data terminal equipment.

MPEG — Motion Picture Experts Group – A video standard for full-motion entertainment quality television. Most cable television uses the MPEG-2 standard.

Node — A component in a Hybrid Fiber Coaxial network that converts between optical and electrical signals and resides at the boundary between the fiber optic cable and coaxial cable. Since the capacity of fiber optics is much greater than coaxial cable, a cable system with optical service nodes serving fewer subscribers provides greater capacity for interactive services.

PEG — Public, Educational, and Governmental programming. PEG channels, studios, and equipment are provided in cable franchise agreements. Public access is typically operated by a nonprofit entity or by the cable operator and is intended to provide members of the public with the ability to produce and broadcast television programs. Educational channels are operated by schools or higher education institutions. Government channels are operated by local governments and typically air public meetings and government information.

QAM — Quadrature Amplitude Modulation – The presentation of data on a carrier signal in a cable or over the air by using different combinations of its phase and amplitude. QAM is the technique used on cable systems for digital video and cable modem services. It makes it possible for a cable system to carry six (64-QAM), eight (256-QAM), or 10 (1024-QAM) Mbps of data for each MHz of frequency used.

Spectral Efficiency — A measure of the efficiency of data transmission over bandwidth (or spectrum), which determines the amount of useful information per unit of spectrum (devoid of error correction and other parameters aiding smooth transmission). It is usually measured in bps/Hz.