The Switched and Stored Cable Network of 2010

John Carlucci
Chief Network Architect
Time Warner Cable
jcarlucci@mystrotv.com

S.V. Vasudevan
Director and Chief Architect, Cable Video Architectures
Cisco Systems
vasu.vasudevan@cisco.com

Seth Kenvin
Vice President, Strategic Marketing
BigBand Networks
seth.kenvin@bigbandnet.com

Table of Contents

Introduction

Any paper tasked with offering forward-looking predictions has the challenge of serving an interesting cocktail of wishful thinking mixed with educated speculation. To examine the future of services delivered over cable five years hence, one must examine the technologies of the past years that have enabled today's capabilities, and examine the present initiatives that promise to fuel the forthcoming evolution. Numerous technologies and trends can be considered that will play a role in shaping 2010's network. This paper considers how networking and storage technologies are impacting the cable network that we know today by expanding the possibilities of services and content that can be made available from anywhere to anyone. It also projects the trends that these technologies can be expected to enable over the next several years, not only to improve capacity, speed and cost as Moore's Law has accurately predicted, but just as importantly to usher in new breeds of services and delivery endpoints.

A Brief History of Digital Cable

No view of the future of technology can be complete without first considering the contribution of technologies that have enabled today's network. Sometimes it is difficult to conceive that as recently as 15 years ago, all cable networks carried a simple unidirectional broadcast television service consisting of a few dozen analog channels. Important core competencies were largely contained to robust signal transmission. While the digital revolution was commencing, its advances at the time were largely confined to other realms such as desktop computing, enterprise data networking, private branch exchange telephony and audio CDs.

Digitization of the Network for Data and Television

Ubiquitous two-way connectivity in cable networks was predominantly driven by the broadband data and digital television buildouts of the mid 1990s. Cable modem deployments, aided by DOCSIS standardization and a corresponding rapid decline in CPE pricing, caused an explosion in broadband adoption. Suddenly, what seemed like a simple world of analog television had the infrastructure complexities of an IP routed enterprise. Cable plants required careful rebuilds and upgrades to support the RF ingress and egress specifications required for the reliable carriage of two-way digital data. The commercial opportunity of nationwide residential broadband data networking fueled a $75 billion investment in nationwide plant upgrades, with the promise that these upgrades would serve as the physical foundation of a much greater information communications platform.

To support the carriage of traffic to Internet exchange points, metropolitan and wide-area networking technologies needed to be introduced to a cable infrastructure where no digital networking technologies of significance existed before. The predominant transport practices of the time came from the telco world, and consequently technologies like SONET and ATM were used to carry data traffic. These technologies provided reliable transport with predictable isochronous timing and rapid failover, but forced a ring structure into a physical topology that was more suited to a hierarchical tree-based structure. As demands for incremental capacity grew and Ethernet and IP technologies began to dominate in the enterprise space and ride favorably down cost curves, the economics of deployment began to shift to favor the use of Ethernet technologies.

Around the same time, the age of digital cable television was emerging with the creation of a digital television tier, and the deployment of the now-familiar digital set-top box. Digital broadcast technologies brought an instant ten-fold increase in spectral programming capacity, while at the same time providing a more theft-proof signal with digital encryption. A specific economic benefit of digital cable television was its broadcast nature – the same digital signal was transmitted to all households in a given service area. Aside from the requirements for modest two-way interactive TV traffic, digital broadcast television initially did not place great demands on the buildout of the digital IP network. But, two-way networking technologies in the set-top box and client application possibilities provided a foundation for interactive applications that supplemented the core television product. Increasing utilization of digital storage, alongside digital networking, was sparked through application and content servers driving the emerging interactive services. Eventually the demands for IP networking growth would later come from what some describe as digital cable television's "killer app", Video On Demand (VOD).

Storage In The Cable Network - VOD

Today, few can dispute the significance of storage in the digital cable network, as led by its flagship application, VOD. Leveraging the cable infrastructure's differentiating ability to provide robust two-way connectivity, VOD provides a significant service capability over predominantly one-way video delivery technologies such as direct broadcast satellite. While a service like VOD provides a strategic competitive advantage in terms of the overall content portfolio that can be offered with resulting improvement in subscriber satisfaction, VOD also represents a significant commercial opportunity as a standalone service. Incremental revenue opportunities arise in the offering of popular and niche television content with transactional or advertising support, and benefiting consumers (and indirectly, the environment) by allowing users to substitute a drive to the local video store with a few clicks on their set-top box remote control.

The Evolution of Storage Networking

While VOD clearly has a significant technological component based on storage, consideration also reveals its affinity to switching technologies, as indicated by its targeted distribution of programs to subscribers' specific nodes. In fact, overall implementation of an end-to-end VOD system requires the orchestrated coordination of numerous technologies, including video asset acquisition and distribution, billing system integration, catalog navigation, client application development, session resource management, as well as the streaming of the video itself. Many of these capabilities are in turn storage-oriented as they tend to reside on servers. In parallel, other server-based applications have arisen to enhance DOCSIS services, such as PacketCable Multimedia for quality of service, and call management systems or softswitches to manage VoIP sessions.

Early implementations of VOD streaming servers have experienced a rapid evolution of their own, benefiting from a significant decline in the cost-per-bit for storage, and later with the introduction of memory-based technologies to provide higher-performance streaming capabilities at tactical delivery points in the network.

In the cable network, the emergence of streaming server solutions for VOD preceded the deployment of Ethernet/IP technologies by a few years. Consequently, the first generation VOD servers featured Asynchronous Serial Interface (ASI) outputs or direct QAM outputs, with either option employing a coaxial point-to-point data interface. VOD deployments also featured the more prominent use of narrowcasting and the re-use of cable frequencies on a node or node-group basis, to support the delivery of traffic specific to that node or node-group, and as a side benefit, multiplying the overall bandwidth capacity of the HFC plant.

The lack of cost-effective ASI transport solutions required early VOD servers to be deployed in cable hub locations, where cooling, power and space resources are at a premium. While this practice did use storage extensively, its distribution of servers towards edge facilities was more representative of switching logically than in terms of networking functionality. In fact, it was particularly arduous given use of first-generation servers that required expert administration and did not have the greatest reliability (not surprising with low-MTBF components such as mechanical disk drives). Furthermore, with streaming servers located in hubs, streaming capacity was relegated to hub-based "islands". If a server in "Hub A" was at 99% capacity, and a server at "Hub B" was at 10% capacity, there was no effective means to repurpose the server capacity in Hub B to support the dynamic streaming demands on Hub A. Even worse, a hub's server could face demand greater than its capacity resulting in denied VOD sessions, and consequently frustrated subscribers, thus undermining the benefits of VOD as a service unavailable from competitors.

The next stage of VOD advancement was brought about by greater integration of transport technologies with storage. Transport technologies had been increasingly implemented to carry the VOD server streams over greater distances. This was first achieved through proprietary technologies that carried the ASI signal over a fiber transport technology such as WDM. Later, the ASI interfaces were replaced with Ethernet interfaces. This not only allowed an expensive ASI I/O card in the server to be replaced by a less expensive Ethernet interface, but more importantly allowed the use of metropolitan-area and wide-area Ethernet transport technologies, used widely in enterprise networking, to be used to implement VOD transport solutions. This capability enabled the VOD servers to be migrated from the hubs to the headend; however, early implementations of these solutions relegated the transport links to essentially act as long ASI extension cords. Without a subsequent evolutionary step in the networking infrastructure, the “Hub A/Hub B” problem described above remained, and operators were unable to aggregate streaming capacity across service groups.

The next step in the evolution arrived with the deployment of Ethernet switching/routing technologies in the headend and hubs. With the use of IP switching and routing technologies, any server in the headend could theoretically connect to any narrowcast modulator in the hub sites, enabling greater efficiencies and more attractive economics for VOD stream resource utilization. Incremental system software advances were also required to make these incremental efficiencies possible. In the recent past, much work has been placed in to the area of session resource management. When a VOD session is activated, the VOD asset to be played may exist on one of many streaming servers. Also, the node group served may be reachable with one or more edge QAM modulators. Session resource management requires sophisticated algorithms to enable the optimal selection of all of the resources required to construct a VOD session. Factors such as device load and transport proximity must be dynamically considered when choosing the optimal set of resources. In the future other devices will also be present in the service delivery chain, such as session-based bulk encryptors, and session-based media processors to implement functions such as ad/logo insertion or low-latency rate shaping. With more devices in the delivery chain, the permutations of possible resource selections grow exponentially, and correspondingly the resource selection algorithms must equally grow in sophistication to continue to ensure optimal resource selection.

Asset Positioning and Streaming Server Disaggregation

The early deployments of VOD revealed traffic usage patterns that seem intuitively obvious now. An exaggerated version of the famous “80/20 rule” quickly emerged in describing the popularity of VOD titles; 10% of the VOD titles could be selected as much as 90% of the time. Therefore, it would follow that if a VOD server were placed in the hub, or perhaps a more diminutive version of the server that carried 10% of the streaming capacity, then 90% of the transport capacity required for VOD could be saved. Correspondingly, the ability to centrally consolidate 90% of VOD storage resources represents an attractive deployment scenario from an administration and maintenance standpoint. This deployment model makes the assumption that the most popular VOD titles are propagated to the smaller server through some means. An evolution of more sophisticated asset management has emerged to allow the dynamic measurement of asset usage, and to enable these measurements to effect a change in the dynamic asset population of servers. The use of these techniques has led to even greater efficiencies of storage and networking resources required for VOD deployment.

Another observation was made regarding the 90/10 rule. If indeed 10% of the content was being streamed 90% of the time, then a great demand would be placed on a fixed number of content assets. With disk-based server technology, the server performance would ultimately be limited by the rotational speed of the server’s disks.

Subsequent generations of VOD servers would ultimately recognize this fact and begin to employ the use of memory-based technologies. Dynamic memory (or DRAM), while much more expensive per bit than its disk-based counterpart, has retrieval speeds that are orders of magnitude higher than disks. Through the use of an appropriate blend of memory-based storage and disk-based storage, streaming throughputs and efficiencies are higher than ever.

PVRs – The Living Room VOD Server

Former FCC Chairman Michael Powell caused a mild controversy in 2003 when he declared his TiVo Personal Video Recorder (PVR) to be "God's machine". Though his choice of words were perhaps misplaced, it is difficult to misplace his enthusiasm for the technology. The satellite industry picked up on this potential quickly, leveraging PVRs as the alternative to VOD. Since then the cable industry has responded, realizing that in fact PVR usage is highly complementary to VOD and in combination can further elevate the personalization of television services.

PVR usage has experienced rapid rates of adoption by the public and has single-handedly changed the nature of television viewership by bringing a non-linear element to broadcast television viewing experiences, perhaps obsoleting (or at least diminishing) the notion of a "prime time" viewing window. The placement of storage capacity in the home not only marks the beginning of the end for VHS tapes, but also brings its own share of controversy with its hyperefficient commercial-skipping capabilities.

In addition to the home-based PVR, a networking parallel promises to emerge. Recent launches of "start over" offerings allow subscribers to go back to the beginning of programs already in progress. Pending determination of marketing desirability and potentially some further deliberations with content owners, complete "network PVR" capabilities could enable subscribers to leverage the storage scale and switching sophistication of the cable network for access to any recent programming from any provider, and not just the episodes that happen to be saved on their home PVRs.

Storage and Switching Hit Broadcasting

While VOD services have been the poster children for the potential of storage and switching in cable networks, these technologies have extended to the industry's bread-and-butter broadcasting services as well. In fact, local ad insertion could be argued to pre-date VOD in its implementation of ad asset storage. And as this practice has gone digital, the resulting efficiencies are beginning to make the practice viable on practically any broadcast network. As switching functionality has entered the mix, new possibilities have emerged. These include zoning in which multiple digital ads can be spliced into the same broadcast program, with each ad distributed to the regions of greatest interest for subscribers (and correspondingly greatest attractiveness for advertisers). With cable industry consolidation to larger operators more dominant in large geographic areas, this zoning of digital advertising is increasingly relevant because many systems are otherwise too large for the participation of small advertisers.

Another powerful recent illustration of storage and switching impacting broadcast television is the onset of switched digital broadcast. In this service, storage on both set-top boxes and in the network is utilized, as in VOD. A thin client application signals a server of the subscriber's interest in a particular program, and the server determines how that program should be dynamically provisioned. This dynamic provisioning of programming only in direct response to subscriber demand is already revealing substantial bandwidth savings, and promises to expand the slate of cable programming offerings. Switched digital broadcast can also integrate with other storage and switching technologies to further enhance subscriber experiences with new functionality as described later in this paper.

The Storage and Networking Infrastructure of 2010

Given the progress made in the last five years the development of the digital cable networking storage infrastructure of, the following assertions can be made about what to expect in the next five years.

Infrastructure Enhancements

The cable infrastructure represents the storage, networking, end devices, and signaling software that form the underpinning of all past, present and future service offerings. Over time the trend has been towards ever more synergistic integration of these technologies to realize each one's best attributes. The groundwork is laid for an infrastructure continuously upgrading for five years and more, which can be expected to yield the following capabilities in 2010.

More Raw Capacity

Will storage or networking dominate in 2010? The answer is yes. In 2010, expect more capacity everywhere, as Moore's law continues to pay its yearly dividend. Moore's law for storage (known as "Kryder's law") has storage capacities accelerating at an even faster rate. Storage capacity will allow for the proliferation of massive content libraries that are readily accessible. Inside a decade and a half (from 1990 to 2005), hard disks have increased their capacity 1000-fold, a rate that Gordon Moore himself has called "flabbergasting"[1]. Expect more layers of storage hierarchy to develop in the VOD service chain, with volumes of "long tail" content in nationally centralized servers that cover an MSO's entire nationwide footprint.

Accompanying this increase in storage will be a corresponding increase in networking capacity. 10 Gigabit Ethernet interfaces will be as common as Gigabit Ethernet interfaces are today. These storage and throughput gains are not limited to the headend and hub – similar enhancements can be expected in the home, and in mobile devices.

[1] "Kryder's Law", Scientific American, August 2005.

It is intriguing to conceptualize what new applications might be enabled by such high bandwidth levels. History teaches that when bandwidth is availed, there is a well established tendency for entrepreneurial providers and eager consumers to find a way to fill it. Already there are experiments in academic and research centers with video at even higher quality levels than HDTV consuming several times the bandwidth. Extend such considerations to such possibilities as panoramic perspective and three dimensional elements, and what might have been recently considered to be enough bandwidth for all anticipated services becomes reminiscent of IBM founder Thomas Watson predicting an eventual worldwide market potential of five computers.

Wideband IP Delivery

In 2010, DOCSIS 3.0 will have long since been ratified, and wideband DOCSIS modems bonding as many as 16 downstream channels or more will provide unprecedented data transfer speeds to the home. Cable operators are marketing speed tiers of up to 10 Mbps in the cable network of 2006 – before 2010 one can expect to have access to a data tier offering 100Mbps, with even greater burst speeds.

An interesting trend of three price/performance curves will take shape over the next five years. Wideband DOCSIS has demonstrated that download speeds are expected to dramatically increase shortly. Corresponding increases in storage capacity are expected in the few years as well. This further lowers the cost barrier of placing storage in CPE devices such as PVRs. However, due to advances in media processing, the required bandwidth of a digital television or a VOD stream is expected to decline by 50% with the introduction of advanced codecs. With 100Mbps download speeds, a 1.5Mbps VOD title can be downloaded at 67 times its streaming rate. Compare this to 2006, where a 4Mbps MPEG-2 VOD title can be downloaded at only two times its streaming rate. If it is possible to download a two hour movie into a PVR cache in 90 seconds, what does this portend for streaming versus downloaded video? Alternatively, higher access speeds could support live streaming of content at new, higher quality levels, as referenced above.

Fat, Invisible Pipes in the Home

While 802.11g wireless LANs have achieved speeds of up to 54Mbps, 2010 will witness a ten-fold increase in these speeds with the adoption of 802.11n, a new wireless standard currently in the drafting process.

In January 2004, the IEEE announced that it had formed a new 802.11 Task Group (TGn) to develop a new amendment to the 802.11 standard for local area wireless networks. The real data throughput is estimated to reach a theoretical 540Mbps, which should be up to 10 times faster than 802.11a or 802.11g, and nearly 40 times faster than 802.11b. It is projected that 802.11n will also offer a better operating distance than current networks.

Work remains to develop silicon that economically realizes this breakthrough in wireless functionality, but the ramifications on home networking and whole-house media distribution are self-evident. Robust networking technologies in the home add yet another dimension to the overall service delivery network. With the abundant gains of switching and storage extended to the home, standardization and industry development initiatives such as CableHome are further armed with a stronger base infrastructure to enhance the quality of existing services or contemplate new services that were previously not possible or practically feasible.

Thinking Outside the (Set-Top) Box

2010 will witness the delivery of media content to a variety of devices besides the set-top boxes we know today. The ubiquitous support of IP networking will allow content to be readily repurposed and delivered to the device of all sorts. These will include (but are certainly not limited to) PCs, home media servers, video phones, automotive media devices, and handheld devices.

The release of the Playstation PSP and the 2005 iPod, both which support MPEG-4 part 10 playback, will spark a flurry of creativity about what content is best suited for playback on these devices. This surge in creativity will bear fruit in 2010. “Vodcasts” will be as much a part of the 2010 vernacular as “podcasts” are in the 2006 vernacular.

Adoption of new, empowered consumer devices may seem threatening to a network-based industry like cable, but really all elements of increasing device and service diversity create opportunity. Overall such trends call for greater intelligence and functionality from the infrastructure in order to interface with the hybrid end-user environment, and situation of storage right at the CPE creates yet another storage tier to manage and by which to further optimize asset location. Cable operators can balance across titles residing on the network for on-line consumption and others that are streamed off-line to subscribers for later consumption, possibly doing so by utilizing network resources at off-peak moments. This only enhances the positioning of cable service provision, a competitive imperative.

The Applications and Services of 2010

The preceding section talked about infrastructure. Services and applications are built on a base layer of a solid and robust infrastructure. With the vast advances expected in the cable and home infrastructures, a wide array of services, some familiar, some previously not conceivable, will be enabled in the network of 2010.

Worldwide Linear and Non-Linear Content

In 2010, network PVR will be ubiquitously deployed. It will blend with a switched digital infrastructure to allow seamless linear and non-linear access to an infinite source of programming content. Network PVR will not replace PVRs in the home; they can be more seen as an alternate implementation, and in some scenarios can be seen as working cooperatively. In fact, the telecom industry is getting a jump on such concepts by leapfrogging to an architecture of a few “super headend” facilities servicing the entire country in their video service launches.

2010 will witness the maturation of the content delivery networking (CDN), which will make traditional satellite-based methods of programming delivery seem obsolete. By 2010, every major MSO will have a robust terrestrial IP network with direct fiber connections into their networks from programming providers. Dish farms outside of headends as we currently know them will seem antiquated.

While much attention will be paid to the distribution efficiencies of this new CDN, even more value can be expected to be extracted from the contribution capabilities of this CDN. The advances of networking technologies will be shared worldwide. The 11 O’clock news or some niche sports event on the other side of the world will be encoded for storage shortly after its broadcast. This content can be broadcasted anywhere live, and within minutes be made available on a video server or PVR of a paid subscriber halfway around the world.

Content contribution will not be limited to commercial production alone. Viewers will be able to publish and subscribe to a camcorder video of the family reunion they had the misfortune of missing, just as readily as they would access a top 10 Hollywood movie on demand. This is yet another opportunity for cable operators to fight competitive pressures of commoditization by being more service-oriented for subscribers, such as uploading/storage capabilities to network-based server capacity extended to subscribers. This too would leverage switching and storage technologies including the separation of memory writing from streaming in the headends for the server space availed to subscribers.

Targeted Advertising

The continued penetration of VOD, switched digital broadcast, and network PVR all suggest a more narrowcast-oriented delivery model. The economics and logistics of narrowcast stream deployment may not be quite ready to support a “PID for every home” model in 2010, but the statistics of real subscriber usage demonstrated by switched digital broadcast will make it feel that way. Since a narrowcast delivery model implies a one-to-one orientation of connectivity from source content to end device, this fact will provide fertile ground for the rollout of targeted advertising.

Targeted advertising systems will use a combination of preconfigured demographic information and subscriber viewing patterns to provide a set of advertising to end devices that is useful to the consumer and respectful of privacy concerns. Media processing advances will allow the seamless splicing of content, be it real-time, stored, or switched. The proliferation of network PVR will further allow the selection of ads to not only be a function of user demographics, but additionally a function of time of day and/or any supplemental business rules that the operator may wish to assert. With more targeted ads reaching the consumer, and more eye-catching spots produced by a resurgence in the ad production industry, ad-skipping will be a function that will still be available to the end user, but less often exercised. In fact, such advertising that is more interesting to subscribers and more attractive for sponsors could lead to bolstered viewer interest and attention.

ITV

Targeted advertising demonstrates the advantages of using storage assets for application logic and not just content retention, and will pave the way for a more general trend of content personalization. The narrowcast delivery trend will not only mean that video programming will be individualized, but adjunct data supporting the video can also be personalized. A user watching the morning news will see a ticker of personal topics of interest. A fan watching a sports game will see a ticker of his/her fantasy team's scores and statistics. It is even conceivable for logo-based advertising to emerge as a supplemental skip-proof means of revenue generation.

Interactive TV possibilities are fascinating to contemplate and could include next generation karaoke in which viewers can play any instrumental or vocal role in music videos; portfolio management games for simulated daytrading integrated with financial programs; extension of the Wiki concept for users to share their own comment bubbles with others attached to reality shows; and an ultimate advancement of video games in which subscribers can almost literally step into live major-league sporting events as a player.

These applications will be more rapidly developed and deployed through the assistance of OCAP standardization. Providing a powerful, portable standards-based development platform on the network's established storage and switching foundations will invite a new wave of interactive TV application development that was previously not achievable with the more rigid development environments presented on legacy set-top platforms.

IPTV

In 2006, IPTV will be a word whispered with concern among cable executives in conference corridors, as it will be strongly associated with the rollouts of incumbent telephone operators. In 2010 IPTV will be another delivery vehicle for cable, and could even emerge as the overall direction of the industry.

Advances in wideband DOCSIS leveraging the M-CMTS architecture which enables inexpensive downstream data transport, will enable the cost-effective deployment of IP set top boxes in the cable network. Other compatible devices could range from IP-cable-ready TVs to inherently IP-based PCs to handheld and mobile devices. Robust and mature IP multicast technologies will be used to deliver individualized programming. All of the technologies that the telco competition believes will distinguish them from their competition can and will be just as readily available to cable subscribers as well. With the analog tuner technology removed from the set-top, and further advances in silicon integration, the dream of a $35 set-top box will be realized.

Portable Services

The notion of presence will play a strong role in the network of 2010. If a cable subscriber travels on a business trip, she still remains a cable subscriber. Subscriber identification and authentication schemes, combined with IP streaming delivery technologies, will allow the business traveler to watch a hometown sports game, the local news, or even a stored PVR program from their laptop, or perhaps and alternate media device that has yet to be conceived and created in the next 5 years. In fact the industry must develop such service innovations given that the technology industry is currently seeing start-ups emerge for exactly such purposes. What's next is practically unbounded.

Summary: Back to Earth

The authors have a late confession to make with regards to the aforementioned predictions. Our view of the network of 2010 is less of a representation of the world that *will* be and more a representation of the would that *should* or *could* be. Much diligent engineering effort stands between 2006 and 2010.

Downloadable CAS and digital rights management needs to deploy and mature, to enable the secure and portable distribution of protected content. Advanced codecs need to emerge in the market, both on the headend and CPE platforms. Wireless and in-home networking technologies need to mature and search technologies need to be innovated and integrated to allow easy navigation of the vast amount of forthcoming content. OCAP needs to be deployed en masse. Wideband DOCSIS and Modular CMTS solutions need to be standardized, developed and deployed. MSOs need to complete the buildouts of their nationwide core and regional IP networks. Provisioning and back-office systems need a major upgrade to support the easy and flexible scaling of service types. Cost curves need to continue to attractively decline to support prudent capital buildouts. Correspondingly, consumer digital TV and broadband penetration needs to maintain a healthy growth rate to provide a strong foundation for the development of new services.

And a lot of software needs to be written and debugged.

Overall, the benefits of switching and storage, combined with traditional cable strengths, give great reason for optimism with ongoing initiatives. The network that lies on the other side of the next few years hopefully serves as an inspiration to press on with this challenging work, as it has the power to enrich the financial and strategic positions of the operators who deploy it, as well as the vendors who construct it, and most significantly, has the potential to powerfully and positively impact the subscribers who use and enjoy it.