A 10-YEAR RESIDENTIAL BANDWIDTH DEMAND FORECAST AND IMPLICATIONS FOR DELIVERY NETWORKS

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Abstract

Today's Hybrid Fiber Coax (HFC) cable plants provide a cost effective infrastructure for delivery of video, voice and Internet data services to residential customers. Consumers expect Multi-System Operators (MSOs) to continue providing more content and innovative services at competitive prices. What types of service changes are likely to occur over the next 10 years? What are the implications of increased bandwidth consumption to the delivery network? Does Hybrid Fiber Coax (HFC) meet the capacity and future service needs and when do we need Fiber-to-the-Home (FTTH)? What are the value propositions for average consumers? Will there be a "killer app?" How many broadcast channels do we really need, can afford to deliver and can pay to produce? Who wants High-Definition Television (HDTV)?

The answers to these related questions depend not only on technological advances that change economics, but also on consumer expectations and adaptation to new technology. This paper takes a macroscopic approach to estimating demand changes in the following categories:

- *Analog broadcast*
- *Digital video broadcast*
- *HDTV broadcast*
- *Video-on-Demand (VOD)*
- *IP data and services*
- *IP Telephony*

A team of Motorola product engineers, applied researchers and marketing staff developed a forecast to better understand requirements and timing for next generation products. As with all attempts to predict the future, there are dimensions of uncertainty. However, the alternative is to march ahead without any vision of future needs. Industry analyst predictions were useful, but none put the pieces together from a bandwidth perspective. MSOs in North America, Europe and Latin America were consulted for plans and expectations. The forecast was updated and conclusions are presented here.

The bandwidth forecast categories are aggregated to determine RF bandwidth required on HFC nodes. This leads to a possible scenario for HFC node segmentations over the next 10 years.

INTRODUCTION

This paper examines the current state of CATV and broadband services to the home and offers an opinion on changes considered likely to occur over the next 10 years. The primary focus is on the center of the mass market in North America, with some commentary on other regions of the world.

Consumer Adoption of Technology

Before jumping into the forecast, it is helpful to consider, some historical perspectives. We have had over 50 years to develop the TV viewing habits which are engrained in our society. Probe Research[1] analyzed the household adoption of various consumer devices and services. The VCR took about 6 years from introduction to early adopter takeoff and then 10 years before adoption by the late majority. Premium cable service took 12 years from early adopter takeoff to late majority. Some products and services take a generation to become mainstream. The bellwether group is younger consumers, because they are always first to accept new technology. For example, the shortest adoption cycles in the Probe Research[1] study were for two generations of game machines which were targeted at children and teenagers. These each took 4 years from early adopter takeoff to late majority adoption.

FORECASTS BY BANDWIDTH CATEGORY

The bandwidth needs for the major services delivered over cable were considered and a most likely forecast scenario for the next 10 years was developed

Note that, this paper is deliberately colloquial in it's use of the term "bandwidth." In some cases it literally means usage of RF spectrum in the CATV plant. In others, "digital transport capacity" or "bit rate" might be more precise.

Analog Broadcast

At the close of year 2001 76% of US cable plants had a bandwidth of 750 MHz or greater and typically provided 80 channels of analog TV[2]. Analog broadcast service is projected to remain largely unchanged over the next 10 years. This is largely because there are approximately 267 million TV sets in the US, most of which are cable ready and still will be working in 10 years. Without a driving need to reclaim bandwidth, MSOs are likely to add new services in spectrum above 550 MHz.

Although not necessarily to reclaim spectrum, some migration of analog programming to digital is expected by year 2006. Analog scrambled programs are good candidates, since digital cable provides better security and obviates the need for two access control systems. In a typical network, 14 analog channels are expected to migrate to digital, reducing the analog spectrum required from about 500 MHz to 400 MHz by year 2006.

Digital video broadcast

Digital video cable is currently in the mass adoption phase. By the end of year 2001 approximately 18 million digital cable set-top boxes were in use by US subscribers. Systems offering digital video had between 3 and 12 digital Quadrature Amplitude Modulation (QAM) carriers; typical systems had 10. Each QAM carrier provides about 8 to 10 video programs, resulting in 80 to 100 digital channels on a typical system. With VOD services emerging (discussed later) and the cable modems competing for consumers' free time, it is hard to see a case for the addition of many new broadcast channels. A net gain of 36 additional programs is expected over the next 10 years. Some may be unique cable content and some will be digital cable versions of local DTV broadcast that operators opt to carry. Four additional QAM carriers will be added to cable plants, bringing the total number carrying Standard Definition (SD) content (including migration from analog broadcast) to 16 by year 2011.

Interactive TV still coming?

With an installed base of 18 million digital subscribers the business case for interactive TV applications is becoming interesting, despite past industry disappointments. Complicated business relationships and conflicting priorities may have been part of the problem, but the size of the addressable market was a likely factor. Consumer interest in interactive TV exists as evidenced by a growing number of consumers interacting with TV programs using PCs. Beyond our 10-year period, 2-way interactive broadcast content could be the salvation of broadcast services in a world that is otherwise evolving to total content-on-demand.

From a bandwidth perspective, set-top boxes share the 5 MHz – 40 MHz return spectrum with Data Over Cable System Interface Specification (DOCSIS) cable modems. DOCSIS upstream channels typically avoid the band below 20 MHz to avoid ingress noise and to avoid conflicts with other uses (e.g. set-tops and plant monitoring equipment). Most first-generation set-tops are capable of providing real time interactivity using a 256 kbps return modem in the 8 to 15 MHz band. Currently, most set-top return modems are used only for collecting monthly PPV purchases, but they have the potential to do much more. For example using a simple contention protocol with a conservative 10% channel loading, each set-top return channel supports 54 interactive packets per second (payload = 53 bytes). With a channel spacing of 192 kHz, 36 channels are available in the 8 MHz to 15 MHz band, yielding a system capacity of 2,000 interactive packets per second. Both subscriber equipment and sufficient bandwidth are available for real time TV-based interactivity. Successful interactive based businesses are expected to develop involving MSOs and third party application providers.

HDTV broadcast

Broadcasters debuted HDTV in the US in 1998. Consumer adoption of HDTV sets has been slow. Broadcasters offer relatively little of their programming in HD format. HDTV enthusiasts in the US have bought approximately two million HDTVs. The take off point for mass adoption of consumer devices has historically occurred between 10% and 25% adoption[1]. Given there are about 106 million US TV households, HDTV penetration would have to reach at least 11 million units before adoption take off is anticipated. The first barrier is the value proposition. Is the picture quality worth the price of an HDTV? How many consumers viewing a 42 inch screen at normal distances can discern the improvement in HDTV quality relative to DVD or MPEG 2 SD quality? The second issue is scarcity of HD content. DBS and cable MSOs are beginning to address this issue, but only a small fraction of programs are in HD format. D-VHS digital videotape players have recently been introduced at a retail cost of $2000.

In March of 2001, the FCC clarified "Must Carry" rules for digital TV and limited the MSO liability to one "primary video" for each local station. Liabilities aside, some operators have begun to offer HDTV to the enthusiasts on their systems. Rather than carry one HD program using VSB in a 6 MHz channel, most operators are choosing to provide two programs in a single 256 QAM carrier. Since most HDTVs have separate tuners and displays, the cable and broadcast modulation formats can be accommodated by having a decoder for each.

Although mass adoption is not expected in the next few years, increasing amounts of HD content are expected to appear on cable. With two HDTV programs per carrier, systems will begin carrying 4 to 6 HDTV video programs this year. By year 2011, 16 HDTV channels are forecast. The bulk of content will continue to be delivered in SD resolution and channels may even alternate between HD and SD for different programs.

Video-on-Demand (VOD)

Every year for the last few years, VOD seemed poised to put video rental shops out of business. The economics have been proven and deployments are growing, but infrastructure upgrades have taken time and are ongoing. At the start of Year 2002, operators had launched or planned to launch VOD (commercially or in trials) in almost 90 markets[3]. The Time Warner trial of "Subscription HBO" demonstrated strong consumer interest and willingness to pay $9.95 a month for the feature[3]. Subscription VOD provides the capability to pause, resume and rewind broadcast programs. It offers a selection of past programs that can be viewed at the consumer's convenience.

VOD has much more potential than just replacing the video store. Extrapolating subscription models further, MSOs could offer server based Personal Video Recording (PVR) capability. As VOD services gain popularity, MSOs will experiment and identify consumer interest and associated usage patterns to determine which can cost effectively be offered. HDTV VOD might be an interesting proposition. Early HDTV adopters are good candidates for higher priced VOD content.

The estimate of cable plant bandwidth for VOD begins with the take rate of digital subscribers. At the end of year 2002 digital penetrated approximately 17% of HP. Kagan's 2001 annual growth forecast[4] shows digital cable penetration growing to 63% by year 2011. The estimate of simultaneous use during peak hours is 5 % today and forecast to increase to 9 % by year 2011. Combining take rate, simultaneous use and program bandwidth (4 Mbps per program) the bandwidth required per HP is calculated. The assumption is that 100% of digital subscribers are provided VOD service. This may not be the case, but it yields sufficient bandwidth for some likely scenarios. If, for instance, only 50% of digital subscribers take VOD, then the simultaneous use could double to 18 % and we end up with the same aggregate bandwidth demand.

<u>Internet Access</u>

Internet Access is defined to cover "Best Effort" transport of IP packets between a subscriber and Internet Service Provider (ISP). The ISP service could be provided by the cable MSO or by a third party ISP with the MSO providing only access transport services. This is the broadest category and most difficult to forecast because of endless possibilities for new applications. Before talking about growth in user demand, it is necessary to define a starting point. A model bandwidth profile is established that typifies data link performance necessary to user to "satisfy" current users.

Users' key expectations of the broadband Internet are low latency in delivery of web pages and downloads, rapid updates in games and seamless delivery of streaming content. They also expect "always on" service. There is no clear consensus as to the data rate that defines broadband. US MSOs typically limit downstream data rates at 2 Mbsp and upstream at 384 kbps. Customers of those MSOs who do not rate limit can experience 5 Mbps or more. In contrast a large MSO in the United Kingdom offers two levels of service, 128 kbps and 512 kbps. Some believe always-on is the key attraction for English consumers and a data rate of 128 kbps is satisfactory.

Consumer cable Internet access is offered as a "Best Effort" service, usually with rate limits. Some MSOs' service agreements prohibit certain uses such as web server hosting and Virtual Private Networks (VPNs). The vast majority of DOCSIS packets are presently attributable to web surfing. Audio sharing is a significant component of the traffic mix on some systems, with peer-to-peer applications like Morpheus replacing Napster. Email and chat are popular, but messages are too small to significantly affect the overall bandwidth consumption.

Capacity planning for Internet Access services is more complex than that required for broadcast services. Usage is driven by user demand on an instantaneous basis, rather than by a more-or-less constant rate stream of content. Usage demand is bursty, and accurate traffic models of traffic are extremely complex. Interactions between network dynamics and the Transmission Control Protocol's (TCP's) congestion control algorithms affect both network utilization and subscriber-perceived performance. One cannot even talk about "bits per second" without asking "measured over how long a period?" Fortunately, crude approximations are good enough for our purposes.

Actual cable modem usage data was difficult to come by. What information was available varied considerably over time and by MSO. The most common provisioning practice seems to be a gross average. The total usable system capacity is simply divided by a target average capacity per provisioned modem to determine the maximum number of modems on a segment. Operators seem to set target capacity per modem by some combination of rules-of-thumb, customer satisfaction indicators and measurements.

It is estimated that YE 2001 a provisioned gross average bit rate of 21 kbps per subscriber was needed to achieve subscriber satisfaction. For example, DOCSIS with 256 QAM modulation in the downstream provides a data rate of approximately 38 Mbps (ignoring overhead). In typical traffic engineering practice, links are provisioned so as to be loaded to 50% of their raw capacity (as averaged over the busiest 15 minute interval of the day); this yields 19 Mbps usable capacity on a DOCSIS downstream carrier. This can be divided by 21 kbps per modem to support approximately 900 modems. If take rate for cable modems is 10% of HP, a single downstream carrier could support nodes totaling 9000 HP. Many systems have been provisioned at approximately this capacity.

For bursty traffic, gross averages are somewhat misleading in provisioning and measurement. From the consumer's perspective, the broadband experience is defined by the approximate peak data rate seen by a receiver during a burst (taking into account TCP congestion control, buffering in the network and packet loss). This makes peak data rate at busy hour a good target service objective. Since service economics depend upon large statistical gains, a simple on-off traffic model is employed as an approximation, and duty cycle (on/off ratio) is used for a provisioning metric. Capacity is provisioned as the usable system capacity divided by product of number of modems, estimated percentage of active users at busy hour, target peak rate and duty cycle. For purposes of this model, it is estimated that at YE 2001, 50% of subscribers are active at busy hour, with a 3.5% duty cycle, and that a satisfactory broadband experience requires a peak rate of about 1.2 Mbps. Fortunately, the long term average model is convertible to the peak burst model by dividing the average provisioned capacity by the product of busy hour percent active and duty cycle. Thus, in terms of our YE 2001 estimates, 21 kbps/(0.5 activity ratio * 0.035 duty cycle) = 1.2 Mbps.

In trying to forecast per-subscriber usage growth, trends in various applications were considered. For example, increases have been noted in streaming media objects in web pages, "post-Napster" peer-to-peer file exchange applications like Morpheus, broadband multiplayer games on the X-Box and (starting in the summer) Playstation 2, consumer-to-consumer exchange of digital video clips and snapshots. Distributed computing programs such as Search for the Extraterrestrial (SETI) encourage users to donate CPU power and bandwidth when they are not using their computers. This blurs the lines between active and in-active users. Chat programs are moving to offer audio and video clips that would boost the size of a message by at least a couple of orders of magnitude. Other trends suggest more web based applications and web based personal data storage.

That said, it was rapidly realized that by looking for "killer apps", one could not see the forest for the trees. The real power of the Internet is in providing a communications substrate that enables innovation and rapid deployment of new and previously unimagined applications that in themselves become "killer apps". None of us truly has the prescience either to pick winners and losers among the applications that are now emerging, or to predict the emergence and traffic characteristics of applications that have yet to emerge.

Instead, our forecast extrapolates from historical experience in the Internet[5] and from Moore's law in allied technologies such as microprocessor computing power and memory density. This leads to an exponential growth model (or, to be more accurate, a logistical growth model which is indistinguishable from exponential growth in the near term). The 10-year forecast, therefore is for consumption to grow at 50% per year. Specifically, peak rate grows at 25% per year, and duty cycle at 20% per year. In practice, actual growth is not expected to be closely fitted to these growth curves, but it is expected to be a good fit over time with appropriate smoothing. Thus, by YE 2011, average active users will demand a peak rate of 11 Mbps, and a duty cycle of 22%.

As for upstream from the home to the network, the peak rate is expected to increase from 200 kbps to about 3.2 Mbps in year 2011. Average upstream consumption increases from 7 kbps to 700 kbps. Upstream bandwidth increases more than downstream due to the expectation that rate asymmetry (the ratio of downstream to upstream rates) will decrease from 6:1 to 3.5:1.

Technology savvy users will seek to push the envelope of what can be done with their broadband connections. Such subscribers can create a "tragedy of the commons" by taking unfair shares of the system capacity and ruining the broadband experience for others. MSOs can treat this as a threat, and put service agreement restrictions and mechanisms in place to keep problematic applications out of the network. Alternatively, they can treat it as an opportunity and put tiered service agreements and mechanisms in place to maximize total subscriber satisfaction and revenue. DOCSIS 1.1 and PacketCable offer architectures and protocols needed to coordinate QoS mechanisms for dynamic and provisioned service flows. However, the specific mechanisms are, to the extent possible, left to implementers. Even for "Best Effort" service, stronger or weaker CMTS implementations can greatly affect fairness and performance, both as seen by individual users and as seen by the MSO. Advanced CMTS features such as per flow queuing, longest queue push-out, hierarchical scheduling with rate guarantees, and fine-grained flow classification can ensure fairness and isolation of service flows within a service class, performance to service level agreements and performance of delay sensitive applications.

Considering all the forces at work, consumers will demand and broadband providers will have to deliver more bandwidth per user each year. With broadband service prices relatively flat, technology and economics need to continue to drive cost per bit down, thus keeping the business healthy.

Streaming high quality IP audio and video

Leveraging the QoS capabilities of DOCSIS 1.1, MSOs are uniquely positioned to offer high quality subscription audio and video streaming services. There is a segment of the population that is happy to listen to audio and watch video on their PC, but mass-market penetration of streaming will likely wait until solutions are in place to move the content into the entertainment center and other places within the home. Lacking solid QoS guarantees, entertainment quality video and audio cannot be delivered reliably enough to satisfy paying consumers.

Streaming audio bandwidth demands are modest (see service example in the next section) for DOCSIS downstream data rates and devices exist to move the audio from a PC to where consumers want to listen. For example, Motorola offers a wireless product called SimpleFi that links the PC to home stereo systems. A transmitter unit plugs into the USB connector of a computer and transmits streaming audio over a 2.4 GHz link. A user-friendly device with a IR remote control connects to RCA jacks on a stereo amplifier. A menu allows user to select between streamed Internet audio and stored personal audio files on their PC.

Hi QoS Audio Streaming

As an example bandwidth demand scenario, assume that 128 kbps is sufficient for high quality audio. Most people find that MP3 encoding at 128 kbps has acceptable sound quality. One could argue for a higher or lower data rate, but audio codecs are still improving, and it is unlikely that 128 kbps will be too low a rate in the future[6]. For provisioning estimates, assume the service is rolled out in year 2002 with a take rate of 2% HP. A successful service might grow to a saturation penetration of 20% HP by 2005. Assume the extreme case where each subscriber stream is on 100% of the time, hence maximum plant bandwidth requirement is 128 kbps x 20% take = 25.6 kbps/HP.

VOD over IP

VOD can be streamed over the Internet using IP and DOCSIS, but end-to-end QoS mechanisms are required to support continuous data rates in the range of 2 Mbps to 4 Mbps. At these rates, audio and video quality is competitive to that offered over MPEG 2 multi-program transport streams to set-top boxes.

The previous section on VOD forecasted VOD bandwidth and accounts for both delivery methods. The number of viewers in the home is the same regardless of the video delivery method. Some VOD service will likely migrate to IP delivery, but there are too many uncertain factors to predict how much and when.

PC based multimedia decoders (Windows Media Player, RealPlayer, QuickTime, and ultimately MPEG4) are widely used to deliver low resolution, low rate VOD over “Best Effort” Internet access service. The Internet Access forecast accounts for this type of VOD.

IP Telephony

Plans to rollout IP telephony in North America stalled as the economy faltered mid year 2000. PacketCable has had time to refine standards and equipment manufactures have had time to test and mature designs. Rollouts of IP telephony are expected to begin gradually late this year. Where offered, IP telephony is estimated to grow from a 2% penetration in year 2002 to about a 30% HP penetration by year 2011. Subscribers are expected to purchase an average of 1.5 IP telephony lines initially tending toward 2.0 in the later years. Penetration estimates take into account the likelihood that Voice-over-DSL will emerge as a second line telephony competitor to cable, and also take into account substitution competition from cell phones. The forecast for an eventual 30% penetration, assumes that MSOs will offer price competitive service.

For calculating bandwidth, a data rate of 100 kbps full duplex per call is assumed. The short packet size required to minimize voice latency adds considerable DOCSIS overhead. This assumption may be slightly low if only G.711 (64 kbps PCM CODEC) is deployed, but high if any other CODECs allowed by PacketCable are used. Typical traffic engineering practice allocates 0.1375 Erlangs per residential subscriber line and allocates enough trunks to ensure a call blocking probability a less than 1%. In populations of 60 to 150 lines, the number of required trunks can be approximated as 20% the number of lines. The node segmentation model (described later) tends to maintain the number of lines within this range. These assumptions allow comparison of telephony bandwidth requirements to other data service components on a HP basis.

SUMMING THE BANDWIDTH DEMANDS

In the next sections demands for IP delivered data and VOD are totaled. The aggregate amount determines node size. The average user consumption is multiplied by projected take rates to normalize data requirements to bits per home passed (HP). A user demand driven node segmentation example is presented.

Downstream to the home

The four downstream components that are destined for individual subscribers are:

- Internet Access
- Hi-QoS Audio Streaming
- IP Telephony
- VOD.

The graph in Figure 1 provides a sense of the growth in bandwidth demand. This result is a combination of increased per-user consumption and a growth in user population. Note that VOD is a significant factor in the near term, but levels out and eventually Internet Access dominates. Hi-QoS Audio and IP telephony are never relatively significant components because by the time subscriber take rates become significantly large, VOD and Internet Access have grown much larger. Figure 2 zooms in on the forecast out to Year 2006 and highlights the VOD growth in the near term. Figure 3 takes out VOD to better show the relative growth in data components delivered over IP. Note that in figure 3 the starting point for Internet Access is 4.2 kbps per HP.

Upstream from the Home

Upstream demand from the home has two components, IP Telephony and Internet Access. The graph in figure 4 shows the growth in demand. Note that upstream data grows even faster than downstream due to the trend toward more symmetrical applications

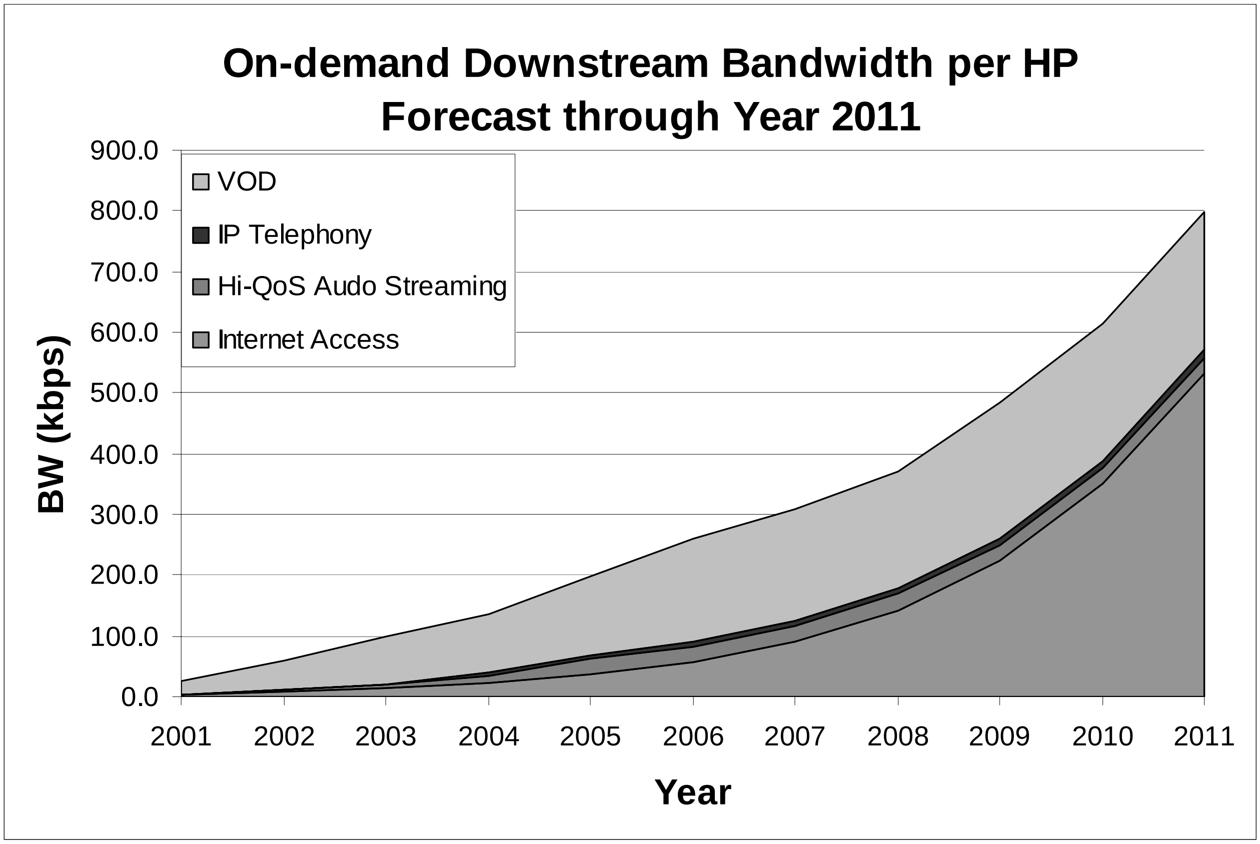

Figure 1

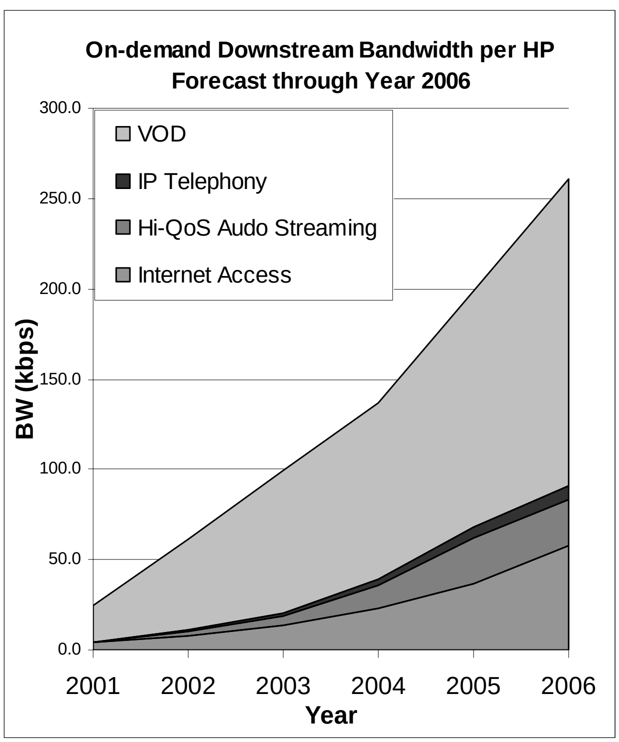

Figure 2

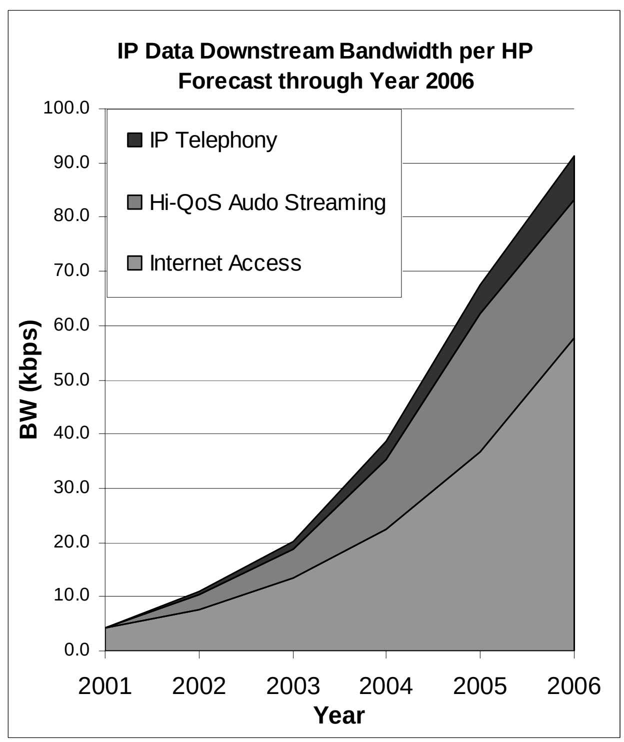

Figure 3

HFC node segmentation example

HFC cable plants deliver optical signals to "nodes", where signals are converted to radio frequencies (RF) and delivered to residences over coax. A tree and branch structure of two-way amplifies and splitters strives to provide each customer with a consistent signal quality. This tree structure also functions to collect upstream data transmitted back from each residence to the headend. The challenge for upstream operation is to overcome the ingress noise that gets funneled up the tree structure from every extremity. Noise is reduced as node size is reduced. As node size is reduced, DOCSIS cable modems can operate at higher symbol rates and higher order modulations. The chart below is a guideline that can be used to determine the upstream aggregate data rate capacity based on node size.

Node Size Homes Passed	Carrier BW (MHz)	Modulation	Number Carriers	Throughput (Mbps)
2000	1.6	QPSK	8	20
500	3.2	QPSK	8	40
125	3.2	16 QAM	8	80

Using this guideline with the forecast a scenario was developed for node segmentation driven by upstream traffic demand. The graph in figure 5 shows a system beginning with a 2000 Home Passed (HP) node and the actual number of HPs that could be supported based on upstream traffic demand. Before the "max node size" curve drops below the number of HPs on the segment, the node is segmented into 4 smaller nodes. The "DS carriers" graph in figure 5 shows the number of downstream DOCSIS carriers that are needed to complement the upstream traffic. In year 2003, the 2000 HP node is segmented to 500 HP in both forward and reverse directions. In year 2007 only the reverse direction is segmented from 500 HP to 125 HP. By choosing to leave the downstream node size at 500 HP, more carriers are required but equipment cost is saved. This configuration supports expected traffic requirements through year 2011.

THE TOTAL PLANT BANDWIDTH PICTURE

Combining broadcast and non-broadcast components an overall bandwidth loading picture was developed. Based on node size the aggregate requirements for non-broadcast traffic is calculated and fit into an integer number of 6 MHz QAM carriers. The cable plant spectrum usage chart in Figure 6 shows how the requirements stack up. It can be see there is spare capacity in HFC plants built out to at least 750 MHz. Although the primary factor driving node size is upstream data, the downstream is segmented simultaneously from 2000 HP to 500 HP. Note figure 6 shows a reduction for DOCSIS and VOD, but subscriber demand is actually increasing. Downstream carriers are added to satisfy downstream demand through year 2011.

A likely scenario has been presented for the typical advanced cable plant. It should be noted that upscale neighborhoods could easily demand much higher amounts of non-broadcast components. Some North American nodes are reported to have had cable modem take rates in excess of 50% HP. Also, there are systems that would like to provide more broadcast channels. Needs include serving multi-lingual and ethnic populations with international programming and lots of HDTV, eventually. 870 MHz plants offer significantly more bandwidth insurance for unplanned demand than 750 MHz. The top of the Figure 6 stops at 870 MHz to provide a relative picture of spare capacity. Current prices for 870 MHz node equipment are a small premium over 750 MHz, hence, a small price for insurance.

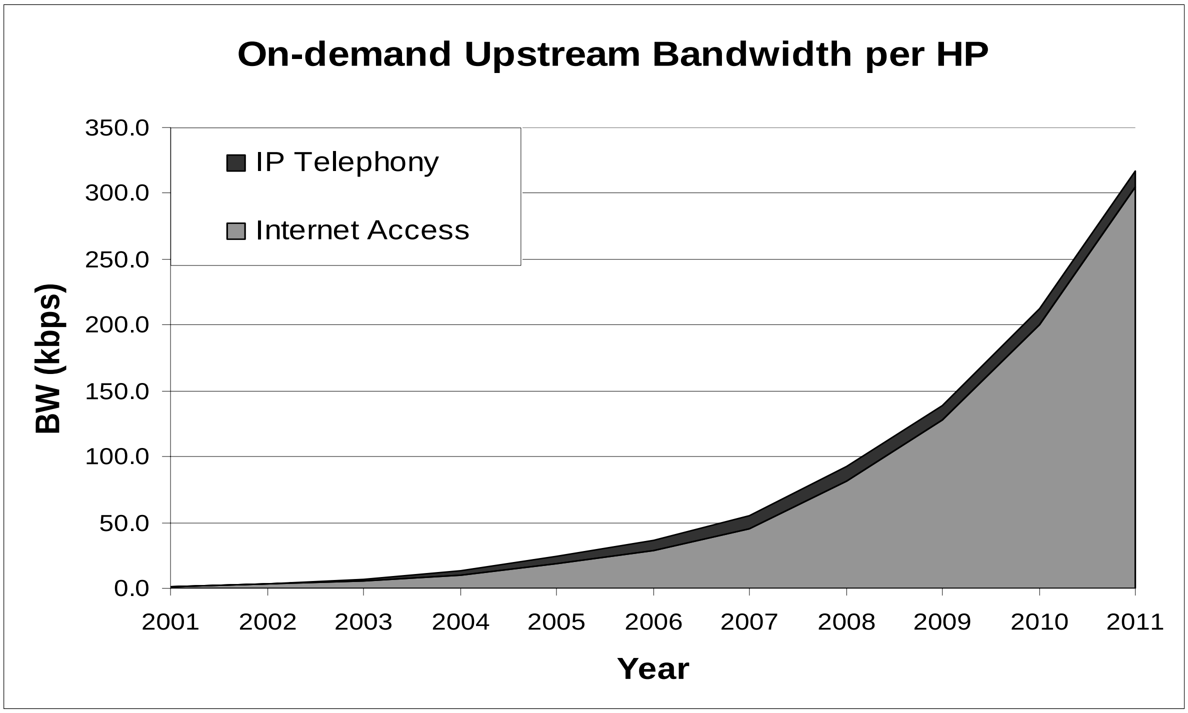

Figure 4

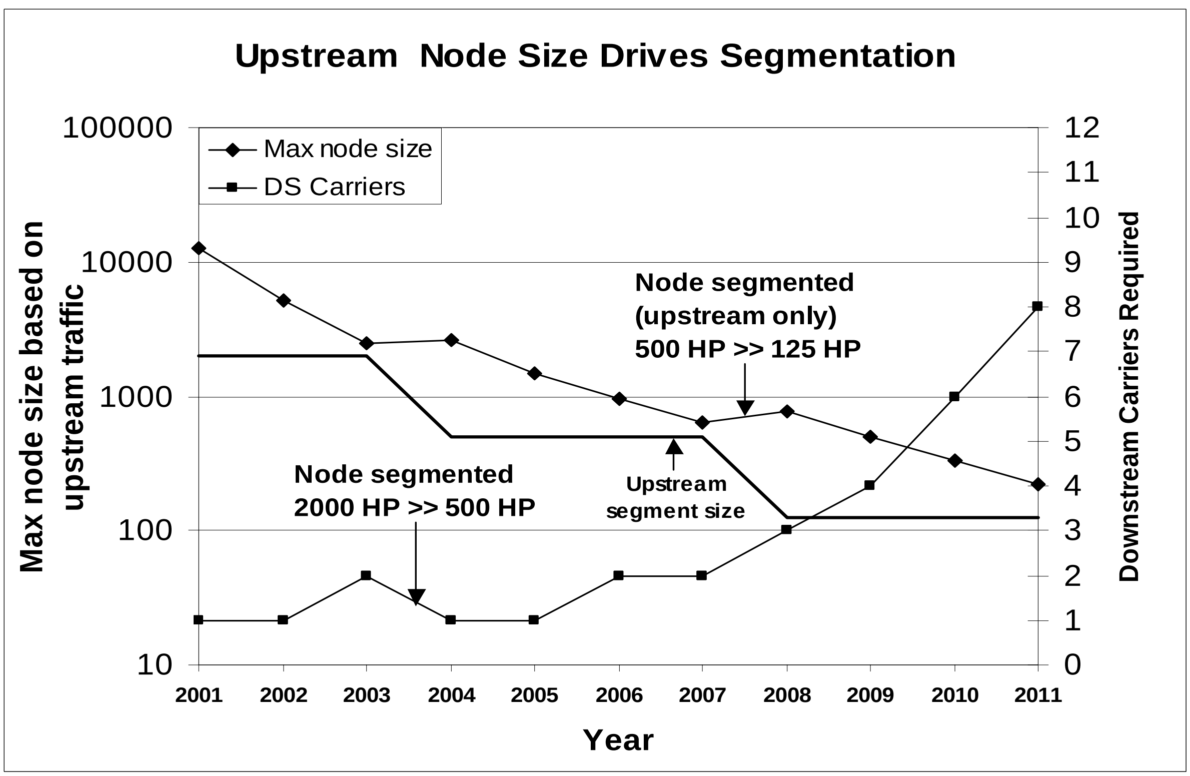

Figure 5

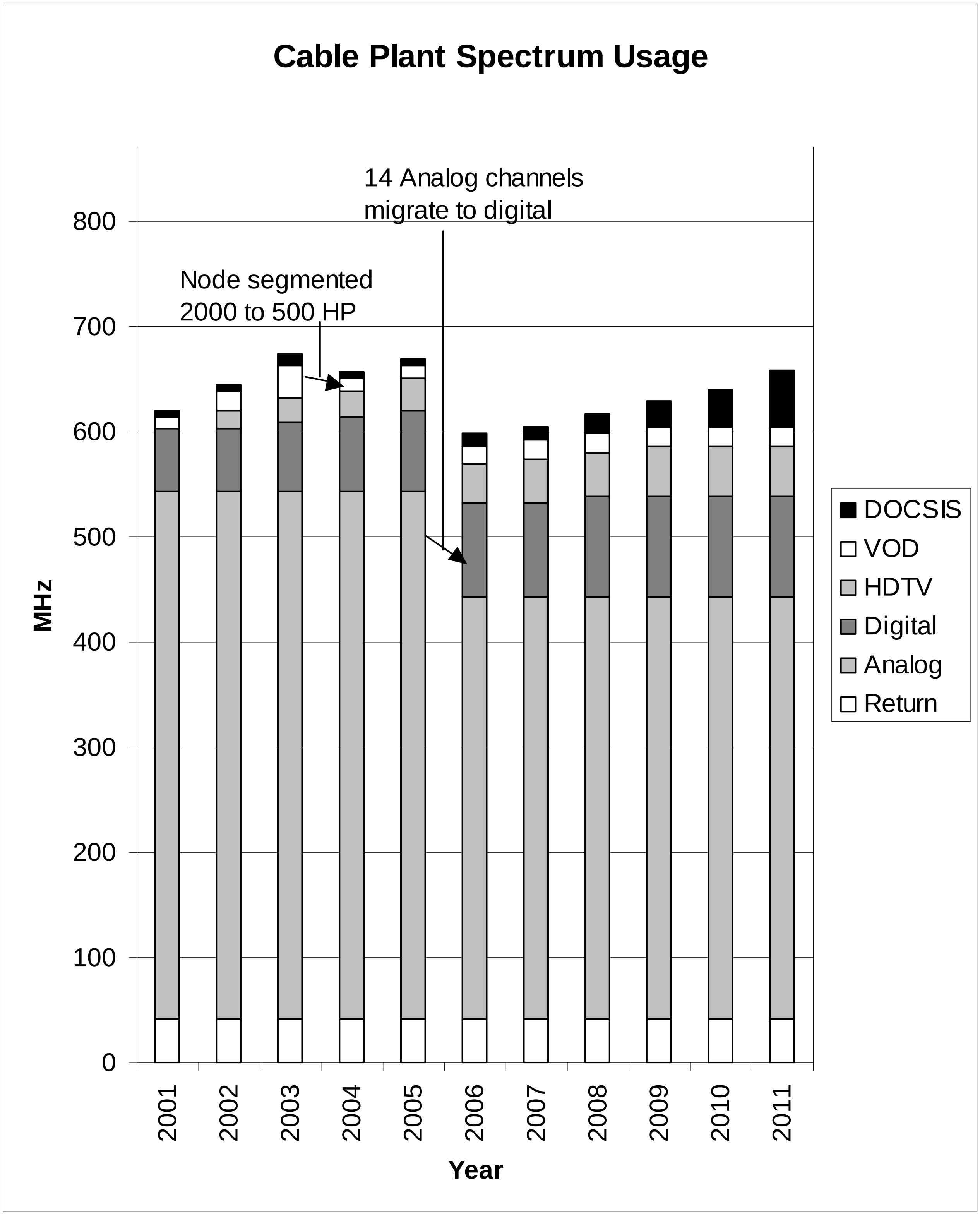
Cable Plant Spectrum Usage
14 Analog channels
migrate to digital
Node segmented
2000 to 500 HP
800
700
600
500
400
300
200
100
0
MHz
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Year
DOCSIS
VOD
HDTV
Digital
Analog
Return

Figure 6

Everything-on-Demand – An Extreme Bandwidth Demand Example

Suppose an MSO wanted to offer all content "on-demand" plus maintain basic analog TV services. A quick calculation will show how this is still possible with a 750 MHz plant! Assume a nominal 500 HP node for the example and that 60% take everything-on-demand service. This is 300 subscribers. With an estimate 2.5 TV sets per home, at most 300 x 2.5= 750 individual streams are required for non-blocking service. The actual number required would be lower due to statistical gains. Dividing by 9 programs per digital carrier we determine that 84 channels are required. The band from 50 to 750 MHz supports (112) 6 MHz channels. Allocating 2 channels for DOCSIS downstream carriers still leaves 26 channels for basic analog service.

In this scenario all digital video content is delivered in 4 Mbps MPEG program streams to each TV. The headend provides broadcast programs either through digital switching or through the VOD server. All digital users have the option of watching live programs or pausing and replaying with an arbitrary time shift. They can choose from a library of stored content that may be included in a subscription or purchase on demand.

It has been shown HFC bandwidth is sufficient for this service. The real questions are how much the remaining infrastructure to support such services will cost and whether consumers are ready and willing to pay enough to justify those costs. The headend equipment would be very different and more complex than today's broadcast equipment. Emerging VOD offerings and PVRs will should begin to whet consumers appetite for this type of service.

Fiber to the Home (FTTH)

Beyond year 2011 MSOs will have to decide between pushing HFC capacity further or re-trenching to bring fiber to the home. Capital costs for FTTH are expected to become competitive for green fields deployments well with the 10 year forecast period. Fiber cable costs are competitive with coax today. Tools and techniques are improving that dramatically reduce the time to make splices. The biggest cost hurdle is the residential and field opto-electronics and the headend infrastructure. If analog TV is to be delivered in addition to digital services, the optics cost is higher for both plant and residential equipment. If only digital television is delivered, then set-tops are required for all TVs and an infrastructure like that described in the everything-on-demand scenario is required. It is not clear which of these options will be optimum, but it seems that voice, video and data services are needed to recover costs of building FTTH. FTTH is considered the "end game" since it offers enormous bandwidth to the home. The fiber itself is expected to last over 40 years, and more capacity requires only headend and subscriber equipment upgrades. Fiber-to-the-curb or fiber-to-the-building (FTTB) for multi-dwelling housing units offers an intermediate more cost effective step towards FTTH. FTTB solutions are expected to be cost competitive in the next few years.

International comparisons to North America

Penetration of Direct-to-Home (DTH) satellite video services in Europe is much higher than in North America but digital cable lags. Europe is impossible to completely generalize as situations vary greatly from country to country. From a recent, but limited sampling of European operators it was noted most are just beginning to upgrade plants beyond 550 MHz and deploying RF return capability.

Analog offerings are often less than 40 channels (as compared with 80 in typical US systems). There is interest in moving toward digital cable TV, but little interest in HDTV. Some believe that because PAL & SECAM offer superior resolution to NTSC, HDTV is less necessary. Services using Euro-DOCSIS are expected to expand, but deployments will be paced by plant upgrades

South America tends to have limited analog content and one-way plants of less than 550 MHz. Little change is expected in the near term due to limited capital for upgrades.

Asia-Pacific with the exception of a few countries tends to lag in all dimensions of service offerings. South Korea is one exception where cable modems and DSL are highly penetrated. Japan is planning aggressive deployments of fiber, but the economic model seems unclear.

Conclusion

The first 50 years of cable were about providing more signals and better picture quality. The next 50 will be about data services. In 10 years the number of bits pouring into the home will be over 50 times the amount delivered today. Rich interactive multimedia video will be commonplace. HDTV will succeed as one of the many services. Telephony will become a rounding error in the traffic analysis. This growth has been shown to be easily supported by continuous upgrades to the HFC infrastructure. Capacity estimates are conservative based on current technology. Much more can be squeezed out of HFC, if and when needed. The critical issue for MSOs will be monitoring usage and keeping ahead with provisioning. A good understanding of what users are doing and how the applications consume bandwidth is essential to anticipating changes in demand. Evolving to more sophisticated service metering will ensure customer satisfaction and QoS based services present a wealth of revenue opportunities.

MSOs will continually be faced with capital investment trade-offs between infrastructure upgrade costs vs. how much excess capacity to install. The node segmentation example divides nodes by four in years 2003 and 2007. Smaller divisions would result in more frequent upgrades, higher labor cost and more disruptions. Larger divisions would incur larger spending and excess capacity would represent a waste of capital employed. Legacy equipment will tend to make upgrade trade-offs more complex and optimum timing will vary. It is hoped that this forecast is helpful to long term planners.

Fiber optic technology is expected to advance at a rapid rate. Breakthroughs in performance and manufacturing cost are potentially disruptive to the scenario presented. If end-to-end costs for delivering bits over the Internet were to drop dramatically and Internet backbone latency and packet loss were considerably reduced an entirely new set of bandwidth intensive applications and businesses could emerge. With delivery costs tending toward distance insensitivity, independent businesses could cost effectively serve a geography disperse customer base.

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