SWITCHED UNICAST VIA EDGE STATISTICAL MULTIPLEXING

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Abstract

Competitive HDTV offerings compel Cable Operators to make plans for 100+ HD Broadcast channels and 10% HD-VOD service (peak capacity), as well as devise innovative in on-demand and Time Shifted television services. Unfortunately, the current networks are unable to carry the load. The various bandwidth enhancement options are capital intensive, disruptive to existing infrastructure and, for the most part, don't provide sufficient bandwidth. This study analyzes SDV Unicast and Edge Statistical Multiplexing (StatMux), concluding that it is the most cost-effective and least disruptive method for handling the HDTV bandwidth explosion.

HDTV-driven Bandwidth Explosion

HDTV is beginning to permeate mainstream America. Currently in over 19 million US homes, i.e. at 17% current penetration, HDTV is projected to climb to 81% by 2010, according to Kagan Research. Unlike the historic migration from analog to digital TV, whereby some percentage of the subscriber base continued to access both formats, it has been recently observed that a significant portion of HD tuners are tuned almost exclusively to HD content, indicating that once exposed to HDTV, some consumers become disenchanted with SDTV.

Concurrently, HD-DVD and Blu-ray are making their debut in the retail market, increasing the demand for HD content and raising the video quality bar. HD-DVDs offer a stunning viewing experience at average bit rates (VBR) of up to 20Mbps using H.264 compression.

Video providers are unfolding their HDTV deployment plans: EchoStar carries 30 National HDTV channels, plus locals, planning on rapid growth. DirecTV plans to carry 60-100 HD by year's end, with new satellites providing capacity for 150 national and over 1,000 local HD channels. Verizon FiOS carry 20 HD channels, claiming "best video quality". AT&T U-Verse plans to offer 25 HDTV channels.

It is apparent that the new competitive landscape for acquiring and retaining premium subscribers is centered on HDTV content. Cable operators must make plans for 100 HDTV broadcast channels and improved HD-VOD service.

VOD has established itself as a useful "weapon" in this contest. There are 28 million VOD-capable homes in U.S, with over 3 billion streams served in 2006, and a steady increase in adoption, usage and ARPU. TWC's "Start Over" service has been observed to increase the on-demand usage by 25%, and additional Time-Shifted TV services are emerging. Playlist and dynamic ad insertion techniques are being tested to enable a further increase in on-demand content and profitability.

However, the spectral occupancy of the combined SD-VOD, HD-VOD and HD Broadcast services is identified as a key limiting factor.

Bandwidth Expansion Options

How much bandwidth will be actually needed? Over the next couple of years, to keep up with competition, cable operators might be required to provide 100 HD Broadcast channels, 8-10% peak capacity HD-

VOD service and up to 25% SD-VOD service, to account for the increase in VOD library content, better movie release windows, ad-supported content and Time-Shifted TV offerings. Advanced high-quality encoders and new post-encoding techniques will enable multiplexing of three HD streams per QAM channel (3:1) at good quality. A straightforward estimate indicates that the operators will require 33 6MHz slots or about 200MHz to provide 100 HD channels. On-demand usage will call for minimizing the Service Group (SG) size at the fiber node, down to about 500 digital tuners per SG. It is estimated that at 20% HD penetration and 10% HD-VOD service, each SG must supply 10 HD-VOD concurrent streams. SD-VOD usage of up to 25% implies 125 SD-VOD stream capacity. Together with HD-VOD, a total of (10 x 4 + 125) / 10 = 17 QAM channels per SG. This is 13 more VOD QAM channels relative to the currently deployed 4 channels per SG! Altogether, HDTV digital broadcast and VOD expansion will further require about 40-50 additional 6MHz slots, or 240-300 MHz.

The primary question is whether it is even physically feasible to provision the required bandwidth. The second question in line concerns the economics: cost per subscriber per 6MHz slot.

In principle there are several bandwidth expansion options. We first consider a costly plant upgrade from 750MHz to 860MHz plant – unfortunately such an upgrade barely provides an additional 100MHz bandwidth, hardly addressing the requisite capacity enhancement. Node split is again expensive and only doubles the Switched tier but not the Broadcast tier, freeing at most two to six (2-6) 6MHz slots.

Other bandwidth expansion options involve massive CPE upgrades. However, these options are too disruptive, too expensive, and entail a certain amount of churn. In particular, analog tier reclamation requires many additional expensive STBs and high installation costs. Moreover, even when the STBs are burdened on the cable operator's balance sheets, it has been observed that such upgrades encounter significant resistance from certain subscribers. Unlike the HDTV experience recounted earlier, some people do prefer analog (and no set-top) over digital SDTV. Similar problems arise upon considering upgrades to H.264, denser QAM, and 1GHz, all of which require STB replacement and expensive installation at the subscribers' premises. There are other options such as spectrum overlay, FTTH and dense home base decoder, which do not entail STB upgrades, however those require expensive plant upgrades and/or expensive CPE home gateways, and even higher subscribers premises installation expenses.

Switched Digital Video

A promising bandwidth expansion option is Switched Digital Video. The primary architectural alternatives for SDV are multicast and unicast. While multiple subscribers can share a multicast stream, a unicast stream is unique to each subscriber. Unicast SDV enables more personalized media services, included virtually limitless content offerings and highly targeted ads, closely resembling Internet content delivery in its ability to target specific content to specific consumers. Most importantly, Standard Definition SDV Unicast can eventually include the entire SDTV Broadcast tier, freeing up a lot of spectral space for HDTV Broadcast and HD-VOD.

SD Multicast

A typical deployment of Standard Definition SDV Multicast involves an SDV pool of 120-150 SDTV channels over 8 QAM channels. In a Broadcast tier, assuming good-quality encoding, post-encoding and

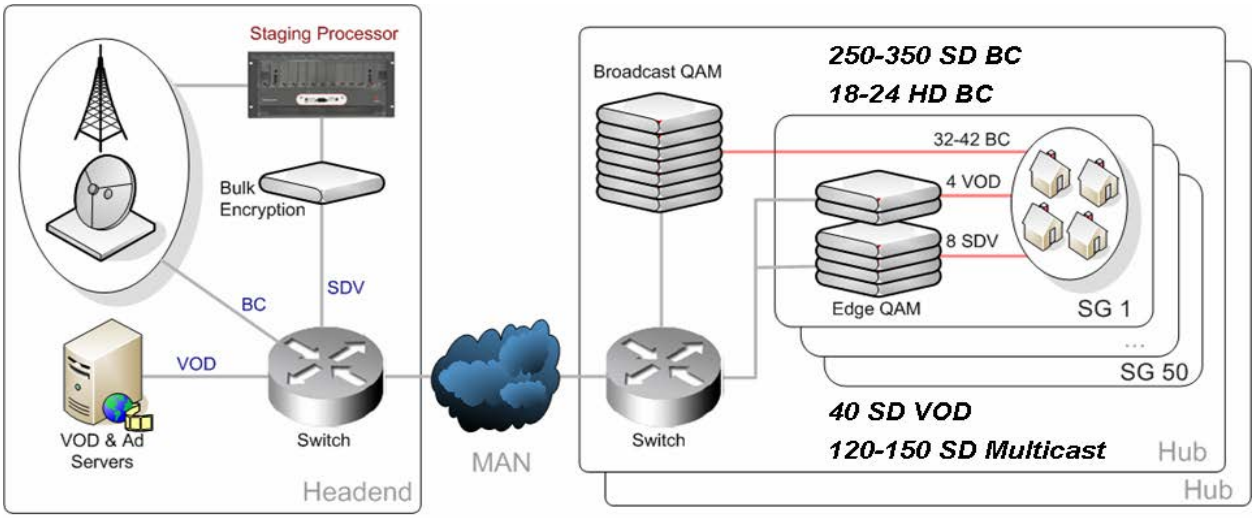


Figure 1: Today's typical network architecture with SD Multicast

StatMux technologies, it would be possible to multiplex 15 SDTV streams per QAM channel (15:1) at today's typical SDTV quality. This means that 120-150 SDTV channels in the Broadcast tier would occupy 8-10 QAM channels. Equivalently stated, Standard Definition SDV Multicast savings, in the way it is deployed today, would only amount to, at best, 2 QAM channels. By adopting a more aggressive content-to-capacity ratio (sometimes referred as concentration ratio) it might be possible to save a few more QAM channels, but this is hardly sufficient. Following is typical network architecture with Standard Definition SDV Multicast.

The network architecture illustrated in Figure 1 provides 4 VOD QAM channels, 8 SDV Multicast channels and 32-42 Broadcast QAM channels depending on analog tier size (72-80 channels typically) and the plant bandwidth (750MHz or 860MHz). Assume typical Service Groups (SG) of 500-1000 homes-passed and 500 tuners, 400 of which are SD, and 100 HD at 20% HD penetration. Under these assumptions, the architecture of Figure 1 is able to provision 400-450 SDTV Broadcast channels, around 20 HDTV Broadcast Channels, only 8% SD-VOD service and no HD-VOD service.

SD Unicast & Edge StatMux

Standard Definition SDV Unicast (SD Unicast), combined with advanced Edge StatMux technology can address the bandwidth issue in a cost-effective way and provide a non-disruptive migration. SD Unicast, powered with Edge StatMux capability, provides: (i) limitless SDTV content, 100+ HD Broadcast channels and 8-10% HD-VOD service without adding a single QAM device while laying the groundwork for a robust future bandwidth optimization roadmap; (ii) significantly improved video quality enabling more effective competition with less constrained media such as HD-DVD/Blu-Ray and Verizon FiOS; (iii) a technology path to truly personalized ad insertion; and (iv) an improved overall user experience, in particular instantaneous channel change support.

In the proposed network diagram illustrated in Figure 2 below, a dense Edge StatMux either replaces the IP Switch for VOD and SDV or is positioned immediately downstream from the IP Switch. The Edge StatMux module receives SPTS/UDP/IP signaling from the VOD Servers and over Multi

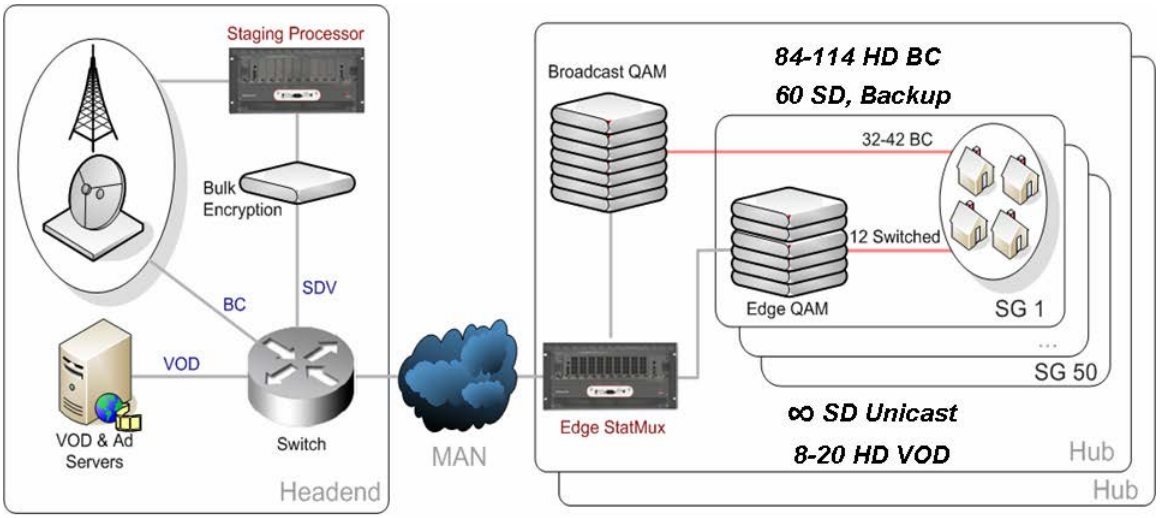


Figure 2: Network architecture with SD Unicast and Edge StatMux

cast IP (for the Switched and Broadcast tiers). The Edge StatMux outputs MPTS/UDP/IP to the QAM devices, and optionally locally multiplexes the Broadcast tier as well as providing local ad insertion and the ability to move content dynamically between Switched and Broadcast tiers. The Edge StatMux is connected in a one-to-one correspondence with the QAM channels at the QAM device, together forming the so-called "Edge QAM." An Edge Resource Manager (ERM) or a Global Session Resource Manager (GSRM) communicates directly with the Edge StatMux in such a deployment, instead of communicating with the QAM device, for the purpose of signaling channel changes.

Edge StatMux Requirements

The following list describes the essential set of performance requirements and features to be supported by an Edge StatMux, under the proposed solution:

1. **Price**. The benefits of an Edge StatMux are multiple: substantial savings in QAM device capital expenditures; freeing up of 6MHz spectrum slots; significant improvement in video quality (to be further discussed below); enabling personalized/targeted ad insertion; instantaneous channel change; easy migration to Switched Unicast; and enabling content mobilization between Broadcast and Switched tiers. Notwithstanding these benefits, in order to actually provide a scalable solution, the bottom line should be that the Edge StatMux price be below that of the conventional QAM evolving price, on a per stream basis.

2. **Video Quality**. Under peak usage, the Edge StatMux must provision at least 15 SD streams or 3 HD streams per QAM channel, at the common video quality acceptable for these services today. However, in VOD and Standard Definition SDV Unicast, most of the QAM channels are under-utilized most of the time. At least 99% of time, the video quality threshold can be significantly exceeded. During the brief times of peak usage, the quality should nevertheless be preserved at a minimum threshold. The system should then comprise QoS mechanisms ensuring uniform video quality under all conditions (detailed below).

3. **Density**. A single platform should support an entire hub of 50 or more Service Groups, i.e., at least 600-1000 QAM channels. The real estate utilization of hub's rack should not be increased as a result of deploying the new devices. The size of the platform should approximate the size of the QAM devices being replaced, and not to exceed 5-6 rack units.

4. **IP Switching**. The Edge StatMux must support standard 1GbE fiber or copper interfaces, and 10GbE in the future. It must perform non-blocking IP Multicast duplications, and supply a 2:1 IP unicast input to output ratio for ad insertion and VOD StatMux compression.

5. **Reliability**. The Edge StatMux platform must be Carrier-Grade with "5 Nines" availability, entailing No-Single-Point-of-Failure (No SPOF), redundant hot-swap fans, redundant load-sharing and hot-swap power-supply units, redundant hot-swap platform management card, and hot-swap N+1 processing/multiplexing cards.

6. **Interoperability**. The Edge StatMux must plug seamlessly into the existing infrastructure. It has to be able to re-use the current installed base of broadcast, VOD and SDV QAM devices, as well as off-load advanced functionality from the QAM devices. It should also support the installed base of VOD servers and possibly off-load dynamic ad insertion and slow-motion trick mode functionalities.

7. **Very Low Latency**. The delay is not to exceed an additional 100msec in VOD trick-mode transitions or SDV channel change. The Edge StatMux should also support instantaneous channel change to further reduce the delay by another 250msec on average.

8. **Encryption**. It is usually preferable in SDV deployments to use the more cost-effective upstream bulk-encryption technology rather than session-based encryption. Some amount of VOD content is also being pre-encrypted at content origination. Therefore, an Edge StatMux must support the variety of encryption schemes: SDV bulk-encryption, VOD pre-encryption as well as session-based encryption.

9. **Management**. Must support standard NGOD and ISA element management and session control protocols, managing by proxy the QAM device and the 1:1 StatMux to QAM connection, as well as aggregate alarms and events.

10. **Splicing**. Last but not least, an Edge StatMux should support the insertion of unique ads per stream with no capacity or quality degradation.

Content

Standard Definition SDV Unicast, combined with Edge StatMux capability, can provide 100+ HD Broadcast channels, 8-10% HD VOD service and unlimited SD content for Broadcast, VOD and Time Shifted TV, without adding a single QAM device (!). It also enables controlled content migration of SD Broadcast to SD Unicast and service migration, SG to SG and Hub to Hub.

Let's look at some usage assumptions and results:

	2007	2008	2009	2010
Total Tuners / SG	500	550	600	650
SD Tuners	400	350	250	125
HD Tuners	100	200	350	525
HD Penetration	20%	36%	58%	81%
Maximum Tuners on	75%	75%	75%	75%
SD Peak Usage	40%	40%	40%	40%
Total SD streams	150	105	75	38
HD VOD Peak Usage	8%	10%	12%	15%
Total HD Streams	8	20	42	79
Total QAM w/o statmux	18	19	24	35
Total QAM w/ statmux	12	12	16	24

Assuming:

- Typical Service Groups (SG) of 500-1000 home passed and 500 digital tuners out of which 400 are SD tuners and 100 are HD tuners (20% HD penetration in 2007).

- Aggressive digital penetration of 10% more digital STB per year.

- HD penetration growth projected to climb to 81% in 2010 according to Kagan Research.

Regarding the next two numbers to be assumed, it is important note that network design should be based on peak usage. The peak video consumption occurs Thursday evening Prime Time, 8-11PM. The number of tuners that are on in the Sun-Wed window is typically around 20%, however, on Thursday evening it might peak to 60-70%. Therefore:

- Maximum number tuners on is 75% per SG, SD or HD.

- Maximum tuners watching digital SD at peak usage is 40%. On Thursday night, it is estimates that 60-80% of subscribers are tuned to 20-30 channels in the analog/simulcast tier (e.g., ABC, CBS, NBC, Fox, CW, USA, FX, Fox News, ESPN, CNN, MTV, Disney, HBO, Discovery, PBS, etc.). Dynamically leaving 60 SD streams at the Broadcast tier or letting tuners tune to analog under peak usage will readily ensure the 40% peak usage assumption of SD Unicast.

- Although it has been observed that HD tuners predominantly "want" to tune to HD content, since the HD content offering is still insufficient in 2007, it is assumed this year that users will still tune to substantial SD content over prime time and, and this is accounted for in the SD Unicast capacity calculation. At the point where 100+ HD Broadcast channels and 10% HD VOD service are deployed, HD tuners are excluded from the SD Unicast calculation.

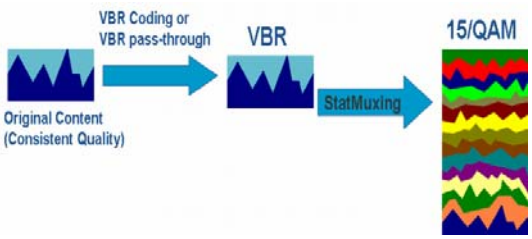
- SD VOD, Time Shifted TV, nPVR services are in high demand. In SD Unicast, these services are unlimited. Over time, similar services will be required for HD and therefore it is assumed that HD-VOD peak usage is to grow at a rate even faster than the SD-VOD growth curve.

The results of this analysis are quite promising. With just 12 QAM channels per SG it would be possible to deliver unlimited SD content and 8-10% HD- VOD service, while freeing up the spectral resource for about 100 HD Broadcast channels. In the 2009-2010 timeframe, if HD penetration increases as projected, a SG split of 2:1 will be further required to maintain 12 QAM channels per SG, in order to keep up with the increased HD-VOD services.

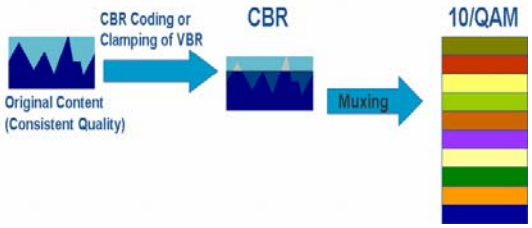
In the future, assuming SG/node splits will eventually reduce the number of HD tuners per SG to 250-300 HD tuners, this will enable, in conjunction with the Edge StatMux architecture further expansion to unlimited HDTV SDV Unicast, completely removing the bandwidth constraint. At this point, the age-old adage "never enough bandwidth: may finally be inapplicable to cable's robust architecture.

Video Quality Management

Video compression standards such as MPEG-2 and H.264 take advantage of temporal redundancies. MPEG-2 encoding of an SDTV signal, which is temporarily rich in motion and scene changes takes 4-4.5Mbps, providing the same quality as a "talking-heads" scene at 2Mbps. This is why a consistent quality coding technique must use the Variable Bit Rate (VBR) format, which provides the optimal video compression scheme. This is also why DVDs use VBR to optimize video quality and storage efficiency. Moreover, virtually all digital broadcast multi-channels content in North America uses VBR and Statistical Multiplexing.



Significantly, CBR encoding or the "clamping" process of conversion from VBR to CBR, limit the video quality by chopping off the peaks. Moreover CBR multiplexing reduces the QAM and bandwidth efficiency by another 33% down to 10 streams per QAM channel.



Current advanced SDV systems plan to overcome the CBR quality degradation problem by using a method called "Multi-rate CBR", assigning higher bit rates for selected high-complexity services such as sports channels, therefore reducing the QAM efficiency even more. With VBR coding, a good quality sports channel peaks at about 5Mbps but may averages approximately 2.5Mbps. Applying multi-rate CBR coding, it is only possible to carry 8 such “difficult” services over a 38.8Mbps 256QAM channel. In contrast, with VBR/StatMux at the same quality, it would be possible to carry 15 channels, i.e. almost twice as much.

In fact the process of allocating bit rate by the ERM/GSRM in a VBR/StatMux is akin to allocating bit rates in a multi-rate CBR system: every stream is assigned a different effective bit rate which resembles its VBR average, e.g. a sports channel may have a higher average bit rate than a news channel. The Staging Processor continuously monitors the VBR average and publishes it to the ERM/GSRM. The average bit rate is measured statistically per channel and may attain multiple values according to the time of day/week. A video quality monitoring system analyzes the VOD assets in advance in a similar manner, providing a deterministic VBR average to the ERM/GSRM over ADI interface bit rate field.

Until now it has not been economical to extend VBR usage to the video distribution network edge for advanced service architectures such as VOD and SDV. However, the Edge-StatMux architecture changes the equation. The new VBR StatMux solution optimizes video quality over each QAM channel. Advanced Edge StatMux technology can multiplex 15 SDTV streams at broadcast quality, without sacrificing the economics. In VOD and switched video environments, since the QAM channels are not fully utilized 99% of the time, it is possible to further raise the quality bar without sacrificing the capacity gains attainable with the Edge StatMux architecture.

Conclusions

In this paper we addressed the various options to mitigate the bandwidth demand induced by the accelerated HDTV and VOD penetration trends. It is concluded that a promising avenue to meet this challenging spectral demand is a Switched Digital Video variant involving Standard Definition SDV Unicast and Edge Statistical Multiplexing (Edge StatMux). The benefits of the architecture in terms of bandwidth efficiency, deployment migration, video-quality, and overall user experience (including personalized ad insertion) are coupled with an upward leap in video quality enabled by porting the VBR video format to the network edge, with increased video quality and bandwidth efficiency. Our deployment projection model accounting for content and usage patterns indicates that the new architecture provides an important new tool in the arsenal of the cable television operators, to economically and competitively manage the HDTV and VOD penetration trends, while meeting enhanced quality of service requirements.

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