SCTE Cable-Tec Expo 2007

Attack the HDTV Bandwidth Challenge with a Powerful Technology:

VBR/StatMux for VOD and SDV

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1. Overview

With U.S. HDTV penetration exceeding the 20 percent consumer threshold and quickly accelerating, the next major battleground for premium video subscribers will revolve around HDTV content quantity and video quality. The day of 100 HDTV channels is on the horizon. And with HD-DVD and Blu-ray players promising spectacular HD pictures, consumer video quality expectations are on the rise.

Cable is moving Video on Demand (VOD) to the mass market, and operators have a 1-2 year window of opportunity to capitalize on the potential of HD-VOD before TelcoTV operators either become formidable threats on their own or acquire the DBS companies. But the rich promise of HD-VOD comes with a painful cost; HD-VOD is the king of all bandwidth hogs, underscoring the need for a more bandwidth-efficient video processing technology.

The axiom “never enough bandwidth” is a rare constant in the dynamic field of communications, and this incessant demand for ever more bandwidth must be addressed in a cost-effective and scalable manner. At the same time, service providers must move up the video quality curve while minimizing disruption to the existing infrastructure. System operators simply can’t afford to leave low-hanging bandwidth fruit on the table in the face of such an impending market explosion in HDTV and VOD.

Since the invention of digital television, Variable Bit Rate (VBR) video coding, together with statistical multiplexing (StatMux), has been nearly universally adopted for multiple-service-per-carrier transmission, delivering the best video quality at the lowest bit rate. Today, virtually all multi-channel digital broadcast signals utilize VBR/StatMux.

Furthermore, all DVDs (and now HD-DVD and Blu-ray disks), use VBR for the best video quality at the lowest storage rate. VBR is the natural state of digital video coding, accurately representing the continuously changing peaks and valleys of picture complexity.

It is therefore somewhat puzzling that advanced video service architectures such as VOD and Switched Digital Video (SDV) are being deployed with Constant Bit Rate (CBR) video coding, imposing a severe constraint on both bandwidth efficiency and video quality. It’s true that CBR provides bandwidth predictability per video asset, but as these increasingly lucrative services scale up to ubiquity, CBR’s deficiencies will become magnified. This will occur just when precious spectrum is needed for expanded delivery of linear HDTV content, VOD, HD-VOD, nPVR, and other bandwidth-intensive services.

What is the common link between these advanced video services causing them to be deployed with bandwidth-inefficient CBR? Unlike digital broadcast service, with these advanced “PersonalizedTV” services, the subscriber - rather than the broadcaster or operator - determines the actual content flowing down the last mile pipe, forming a consumer-initiated streaming environment.

But this common thread of a consumer-driven viewing paradigm still doesn’t explain why these advanced services would use CBR in the first place. The underlying answer is that traditional

VBR/StatMux systems were developed for digital broadcast service, and at the time operators launched these advanced services, there were no viable solutions in existence, economically or technically, for this fundamentally different, consumer-initiated streaming environment.

If the viewing paradigm has been flipped on its head toward the consumer side, then it logically follows that an optimal technical solution must represent a dramatic departure from the status quo. In a consumer–generated streaming environment, the "heavy lifting" functions of video processing (coding) only need to occur once, in advance, freeing up the "lighter load" task of multiplexing to scale commensurately, and infinitely, with the consumer demand for streams.

Two important design considerations to address this substantial technical challenge are:

(a) the complete separation of coding and multiplexing; and

(b) utilization of an accurate, objective video quality measurement technique to resolve the apparent paradox of simultaneously enabling greater bandwidth efficiency AND enhanced video quality.

2. HDTV Competitive Environment

When the first digital HDTV broadcast system was unveiled to the FCC in June 1990, the market response quickly moved from stunned disbelief to the more pragmatic question of timing. Yet, only the biggest skeptics would have predicted a 17-year gestation period for HDTV to reach the mass market consumer. That painfully long period was required in order to overcome the stubborn interdependencies of politics, technical standards, content availability and consumer equipment cost. With this market development logjam finally broken wide open, HDTV is the new rage for home television viewing. In 2006, HDTV sets outsold analog NTSC TV sets for the first time in the U.S., with household penetration currently exceeding 20 percent. Kagan Research projects 81 percent penetration by 2010.

After acquiring 30 million subscribers in 13 years, U.S. DBS growth is decelerating primarily due to cable's successful triple-play offering of video, data and voice. But with cable going directly after the voice market, telcos have no choice but to aggressively enter the video market. Regarding HDTV, DirecTV's CES 2007 proclamation of 100 digital HDTV channels has set the stage. The next battleground for attracting and retaining premium video subscribers is HDTV, with content quantity and video quality acting as the heavy artillery.

Table 1 summarizes today's HDTV service provider offerings, along with plans for the future. While HD-DVD, Blu-ray and HD camcorders are media technology platforms rather than service providers, they are nonetheless included for completeness. Importantly, the video quality aspects of these three platforms will become increasingly recognized as superior, due to their ability to offer content in the 1080P format (twice the resolution of 1080i), as well as the much higher bit rates enabled by their expansive storage capacities.

	March 2007 HD Offering	Future HD Plans
DirecTV	11 national channels; NFL Sunday Ticket games and regional sports network games (plus local into locals)	100 national HDTV channels (with capacity for 150); capacity for 1500 local HDs
EchoStar (DISH)	31 national channels (plus local into locals)	Add HD channels; Move "Voom 15" onto CONUS bird; Expand local HD markets
Verizon FiOS	16 national channels (plus locals)	Add linear HD channels and HD-VOD; Buy DirecTV (?)
AT&T U-Verse	23 national channels (plus locals)	Add linear HD channels; Evolve to VDSL2 or add 2nd DSL line for multi-stream HDTV; Buy EchoStar (?)
Cable	Varies by operator, typically 5-15 national channels (plus locals); Comcast: over 100 hours of HD-VOD	Add linear HD channels; Expand HD-VOD offerings
HD-DVD	Warner Brothers; Universal; Paramount; New Line	Huge content library; 1080P progressive format and 36 Mbps transfer rate for superior video quality
Blu-ray	Sony Pictures; Disney/Buena Vista; 20th Century Fox; Paramount; MGM; Warner Brothers; Lion's Gate	Huge content library; 1080P progressive format and 36 Mbps transfer rate for superior video quality
HD Camcorders	Consumer and "Prosumer" content	Superior video quality; peer-to-peer and "over the top" Internet

Table 1: HDTV Offerings by U.S. Service Providers and Other Platforms

The ability to offer a wide variety of HDTV content at excellent video quality is already becoming crucial for attracting and retaining premium subscribers. DBS operators will offer HD tonnage and attempt to lock up HD sports rights, while dedicating entire spot-beam satellites for local into local signals (so that their subscribers won't need separate terrestrial antennas). Cable operators will increasingly turn to HD-VOD as a competitive differentiator, and can carry local HD signals more cost-effectively than DBS. Being fully switched, TelcoTV/IPTV operators can offer unlimited linear HD content, but will struggle with multi-stream HD unless they have Fiber to the Home (FTTH).

And perhaps most notably, consumers will become spoiled by the unprecedented picture quality from HD-DVD, Blu-ray and HD camcorders, and will start demanding similar quality from their service providers. In particular, the latest hot HD consumer feature is "1080P," and manufacturers and retailers of these platforms are starting to market their ability to give consumers "1080P quality." Since it's impractical for service providers to broadcast 1080P signals (due to complete incompatibility with the installed base), they will need to improve the picture quality through other means, such as increasing the bit rate or employing more advanced video quality enhancement techniques.

These competitive dynamics point to an immutable law of video delivery: there is never enough bandwidth. Stated another way, in the era of 100 HD channels, service providers need to make optimal use of their finite spectrum; CBR for VOD and SDV must give way to VBR/StatMux upon availability of an economically and technically viable solution.

3. VOD and SDV: Cable's Advanced Digital Video Service Architectures

More than a decade has now passed since cable began broadcasting digital TV signals, and digital cable household penetration now exceeds 40 percent nationwide. Prominent extensions to the digital cable revolution include VOD (starting in 2000) and SDV (in 2006).

Successful expansion of these two important service platforms is essential for cable to sustain and enhance its leading subscriber market share position. VOD gives subscribers enormous content libraries, with the consumer convenience of starting the stream at any time, supplemented by pause, fast forward and rewind capabilities. From a competitive standpoint, VOD is cable's best video differentiator against DBS, whose only near-term responses are pre-loading DVRs with files or using broadband Internet pipes and hybrid set-tops.

Cable's unique ability to offer HD-VOD raises the stakes even further. DBS operators could pre-load their subscribers' DVRs with HD-VOD files, but this would consume too high a percentage of the set-top's hard drive, and the Internet is still too "narrow" for HDTV. Cable has a 1-2 year window of opportunity to capitalize on this advantage. Beyond this timeframe, either the telcos will acquire the DBS operators, or the telcos will have built out their FTTH or advanced DSL infrastructures toward a critical mass. Either way, they will eventually be able to offer a competitive HD-VOD service. A combined TelcoTV/DBS offering could merge the downstream payload of a VOD satellite with the upstream DSL path for commands and trick modes.

With HD-VOD being cable’s sharpest and most effective strategic angle against DBS, what is inhibiting cable operators from aggressively marketing HD-VOD to their subscribers? Certainly content availability is an issue, but where there’s a will there’s a way, as proven by Comcast toward the end of 2006 when it exceeded it goal of obtaining 100 hours of HD-VOD content.

The thornier HD-VOD issue is bandwidth, especially in order to deliver excellent video quality. Since a single HD-VOD stream is equivalent to four SD-VOD streams, optimizing the video quality for any given bit rate is essential. In other words, CBR becomes more problematic in the face of a cost-effective VBR/StatMux alternative.

SDV is promising to be a very effective architecture for adding certain types of linear services to cable’s content repertoire. Instead of continuously transmitting all services to all subscribers, SDV services only occupy bandwidth if and when one or more subscribers in a service group request the specific signal. This makes SDV an ideal solution for adding niche and other less popular programming. If the operator is careful about which content is placed on the SDV tier, then significant bandwidth savings can be achieved over digital broadcast.

The bandwidth-saving capability of SDV, however, is being compromised by the use of CBR “clamping.” When the incoming VBR digital broadcast signals are transferred to the SDV environment, one of the first actions is to clamp them to CBR. For a difficult (to compress) signal, if the CBR rate is not sufficiently high, noticeable artifacts will appear due to the chopping off of the video peaks. And for a relatively easy signal, a typical CBR of 3.75 Mbps uses much more bandwidth than necessary (i.e., most of the time, the same quality could have been achieved at a much lower average VBR rate). To address this problem, some operators are planning to move to multi-rate CBR. While multi-rate CBR will allow quality to remain more consistent between the various services on the SDV tier, it still wastes a substantial amount of bandwidth (for the resultant quality) due to the fundamental inefficiencies of CBR.

4. Cable’s Bandwidth Expansion Options

Cable operators have several bandwidth expansion options at their disposal, but some are far more practical than others in any given timeframe. A common economic language is needed in order to compare the alternatives. While such an economic analysis is beyond the scope of this paper, one method is to look at the various options on a $/sub/6 MHz basis. Such a common metric would help bridge the gap between the cost per home passed concept, typical of node splitting, SDV and plant upgrades, and the cost per stream concept of VOD and HD-VOD.

Measured in this manner, a cost-effective VBR/StatMux solution for VOD and SDV is, by far, the most economical way for cable operators to free up bandwidth. Enhancing the VOD and SDV architectures by adding VBR/StatMux could cost operators less than $1/sub/6 MHz channel. Other methods generally cost up to 10-25 times more, if measured on this same basis.

Table 2 shows cable’s bandwidth expansion options.

Technology	Major Drawback(s)
VBR/StatMux for VOD & SDV	**Good option; most cost-effective on "$/sub/6 MHz channel" basis; least disruptive to cable infrastructure**
Switched Digital Video (SDV)	Good option, but CBR clamping causes bandwidth inefficiencies and also constrains quality
Split Node	Significant infrastructure capex; coax plant re-routing/re-wiring
HFC Upgrade to $\geq$ 860 MHz	High infrastructure capex; new set-tops (with wider-band tuners)
Analog Reclamation	Churn risk; digital set-top capex to convert "the other 50%" of subs
Denser QAM (>256)	System performance issues; new set-tops
Spectrum Overlay	Significant cost per home passed
Dense Home Gateway Decoder	High capex (installation at every sub)
MPEG-2 to MPEG-4 AVC (H.264)	High set-top box (and headend) capex

Table 2: Cable's Bandwidth Expansion Options

5. Digital Video Technology: From VBR/StatMux to CBR (and Back Again!)

Since the invention of digital television in the early 1990s, VBR/StatMux has been a key technological element for a very simple reason: it allows the best video quality at the lowest (average) bit rate. But the advanced VOD and SDV architectures, while innovative in their own right, are both being constrained by CBR, primarily due to the lack of a VBR/StatMux solution possessing the necessary cost, density, and other technical requirements.

As shown in Table 3, we are now entering a 3rd Generation phase of statistical multiplexing technologies. The 1st Generation systems involved closed-loop encoders, with the statmux functionality tightly coupled with the video coding functions of the encoder. In the 2nd Generation, the statmux function was decoupled from the source encoder, enabling cable operators to re-package individual services from multiple satellite transponders and to optionally transcode the compressed bitstreams in order to fit more signals in a cable QAM channel.

Both the 1st Generation and 2nd Generation systems apply strictly to digital broadcast signals. The distinguishing feature of a 3rd Generation solution is the ability to apply VBR/StatMux to digital video signals that are directly requested by consumers, such as the case with VOD and SDV. Even though the operator's Session Resource Manager (SRM) controls the actual allocation of streams to the EdgeQAMs, it is the collective subscriber base (per Service Group) that is the ultimate creator of the mux, hence the phrase "Consumer Generated StatMux."

Transcoding and statistical multiplexing are as much art as science, helping to explain the persistent mystique of these esoteric technologies. Nonetheless, the basic principles are fairly straightforward. The transcoder and statmux devices make use of various parameters and information obtainable from a compressed video bitstream in order to re-process the signal and maximize the resultant video quality (or minimize degradation) at the desired bit rate. Within this general framework, there are numerous details and distinctions between competing solutions, relating to such factors as the visual perceptual model, whether processing occurs in the DCT or the pixel domain, how requantization and rate control are accomplished, how motion vectors and motion compensation are handled, and how decoder buffers are utilized.

Table 3 shows the three generations of StatMux, dating from the July 1992 initial deployment of multiple-service-per-carrier digital TV.

	1st Generation VBR/StatMux	2nd Generation VBR/StatMux	3rd Generation VBR/StatMux
Date 1st Used	1992	1999	2007
StatMux Technology	Closed Loop	Open Loop	Consumer Generated StatMux
Mux Generator	Content Provider	System Operator	Subscriber Demand
How mux is created	Television source content is digitized. Then the bit rate of each service is continuously varied, under encoder control, based on number of channels in the encoder/multiplex and the video complexity of each channel.	Fully independent of encoder control. Headend equipment unbundles services from content provider's mux, allows mixing and matching with services from other mux(es), transrates each stream, then statmuxes new package.	Open loop method with following additions: (a) complete separation of coding and multiplexing; (b) video analysis and quality measurement techniques; (c) in response to consumer demand (number of simultaneous streams requested at any time plus video complexity of each stream), headend software statmuxes groups of services.
Primary purpose (apps)	Gives content provider much more efficient bandwidth utilization for digital broadcast services (DBS or satellite distribution to cable headends).	Allows operator to groom, repackage and re-statmux services (for digital broadcast re-distribution over cable/telco plant).	Gives operator much better video quality and bandwidth efficiency for new services such as VOD, HD-VOD, SDV, IPTV, nPVR, targeted ad insertion.

Table 3: Three Generations of Video StatMux Technology

The fundamental technical objective of digital video, whether for transport or storage application, is to maximize the video quality for any given bit rate. CBR coding, used by default for VOD, SDV and IPTV, fails this basic test, since it requires a very high bit rate to achieve reasonably good video quality, thereby wasting enormous amounts of bandwidth on a cumulative basis. While CBR coding has the advantage of simplicity (the operator knows the occupied bandwidth of each signal in advance), this advantage quickly evaporates as soon as a cost-effective VBR/StatMux solution is available.

Table 4 shows a hypothetical cable system with approximately 300,000 homes passed. The system is currently at 8 percent peak capacity (concurrent streaming capacity) for SD-VOD. For

2008, this system plans to expand its SD-VOD capacity from 8 percent to 12 percent, and also to begin offering HD-VOD at an initial 5 percent concurrent streaming capacity rate.

In 2008, 20 percent of the digital tuners (178,500) are assumed to be HDTV, so there are 35,700 HD tuners (120 per service group). At 12 percent SD-VOD peak capacity and 5 percent HD-VOD peak capacity, this implies a system-wide need for 19,635 SD streams and 1,785 HD streams (equal to 66 SD streams and 6 HD streams per service group, respectively). Note that the HD streams were deducted before calculating the SD stream total ((178,500 x 12%)-1,785) = 19,635.

With 298 service groups in this system, and counting an HD-VOD stream as equivalent to 4 SD-VOD streams, this implies a total streaming capacity of 26,775 (SD equivalent streams) in 2008. Dividing this result by 298 service groups gives 90 streams per service group, requiring 9 QAM channels using the typical SD-VOD 3.75 Mbps CBR rate. Therefore, with CBR, five (5) additional QAM channels (30 MHz incremental spectrum) are required to accommodate this VOD capacity expansion. Assuming 50 percent more streams/QAM with VBR/StatMux, only two (2) additional 6 MHz channels are required to accommodate the same SD-VOD and HD-VOD capacity expansion, representing an 18 MHz spectrum savings over CBR.

	2007	**2008**
Basic Subs (300,000 homes passed)	200,000	210,000
Digital Subs (D-Subs)	80,000 (40%)	105,000 (50%)
D-Tuners/D-Sub	1.5	1.7
D-Tuners	120,000	178,500
D-Tuners/Service Group	500	600
Service Groups	240	298
Peak SD-VOD Capacity	**8%**	**12%**
HD Set-Top Penetration	10%	20%
Peak HD-VOD capacity	**0%**	**5%**
Peak Streaming Capacity	9,600 SD 0 HD	19,635 SD 1,785 HD
# 6 MHz channel slots needed for VOD (using CBR)	4	9
Total required QAM capacity (with CBR)	960	2,682

Table 4: Cable system assumptions for VOD capacity expansion

Table 5 shows the economic benefits of VBR vs. CBR for this sample system. Substantial savings are achieved from lower capital expenditures on EdgeQAM devices. Much more valuable, but more difficult to quantify, are the savings achieved from utilizing less spectrum. The imputed spectrum savings estimate in Table 5 appears conservative in light of the following sanity check: 300,000 homes passed (HP) in this hypothetical system multiplied by $10 per home passed gives a figure of $3 million. Note, in turn, that this $10/HP figure is very low relative to traditional HFC capacity upgrades, which can cost well over $100/HP. Power consumption and rack savings from using fewer EdgeQAM are not shown, but could also be significant.

Of course, there will be a capital cost to the VBR/StatMux solution itself. The "total savings" figure above can therefore be thought of as a proxy for the financial breakeven point of such a solution.

	Staying with CBR	VBR/StatMux @ 50% more streams/QAM	Savings
EdgeQAM CapEx (@$400/QAM)	$688,800	$331,200	$357,600
Additional 6 MHz channel slots required	5	2	$1,260,000 (imputed value based on $2 per sub per 6 MHz channel saved)
Total Savings			$1,617,600 (not including rack space and power consumption savings)

Table 5: VOD Capacity Expansion and CBR vs. VBR Economics

It is also useful to examine the economic benefits of VBR vs. CBR for SDV. Consider the following assumptions and example:

- 200,000 sub system (300,000 homes passed)
- 120 standard definition services in SDV tier
- 50 percent concentration ratio (stream capacity as percent of services in SDV pool)
- With CBR, 10 services per QAM channel
- With VBR, 15 services per QAM channel
- 250 service groups

Table 6 shows the economic benefits of VBR vs. CBR for SDV. For CBR, 6 QAM channels times 250 service groups times $400/QAM = $600,000 capital expenditures for EdgeQAM devices. For VBR, 4 QAM channels times 250 service groups times $400/QAM = $400,000 capital expenditures, a $200,000 savings just for EdgeQAMs.

As with VOD, the spectrum savings achieved due to using VBR/StatMux instead of CBR are far more valuable than the QAM device savings. The imputed spectrum savings estimate in Table 5 appears conservative in light of the following sanity check: 300,000 homes passed in this hypothetical system multiplied by $10 per home passed (HP) gives a figure of $3 million. Note, in turn, that this $10/HP figure is very low relative to traditional HFC capacity upgrades, which can cost well over $100/HP. Power consumption and rack savings from using fewer EdgeQAM are not shown, but could also be significant.

Of course, there will be a capital cost to the VBR/StatMux solution itself. The "total savings" figure above can therefore be thought of as a proxy for the financial breakeven point of such a solution.

	CBR	VBR	Savings
EdgeQAM CapEx ($400/QAM)	$600,000	$400,000	$200,000
Spectrum required (# of 6 MHz channel slots)	6	4	$800,000 (imputed value based on $2 per sub per 6 MHz channel saved)
Total Savings			$1,000,000 (not including rack space and power consumption savings)

Table 6: SDV CBR vs. VBR economics

To illustrate the magnitude of CBR's inefficiencies on a macro industry scale, consider the following VOD data:

Cumulative SD-VOD streams delivered by U.S. cable operators	7 billion
Constant Bit Rate (CBR) per stream (SD-VOD)	3.75 Mbps
Average viewing time per stream	0.5 hours
CBR bandwidth inefficiency[1]	33%

The above numbers imply that U.S. cable operators, in the aggregate, have sent two (2) Billion Gigabytes of excess data through their HFC pipes due to CBR. This number is so high it can also be expressed as two (2) Exabytes.[2]

[1] A VBR/StatMux solution enabling 50% more streams/QAM (e.g., 15 VBR streams vs. 10 CBR streams), implies a 33% bandwidth waste factor due to CBR.

[2] 1000 Megabytes is a Gigabyte; 1000 Gigabytes is a Terabyte; 1000 Terabytes is a Petabyte; 1000 Petabytes is an Exabyte.

Figures 1 and 2 below show the capacity differential per QAM channel between today's CBR method and VBR/StatMux.

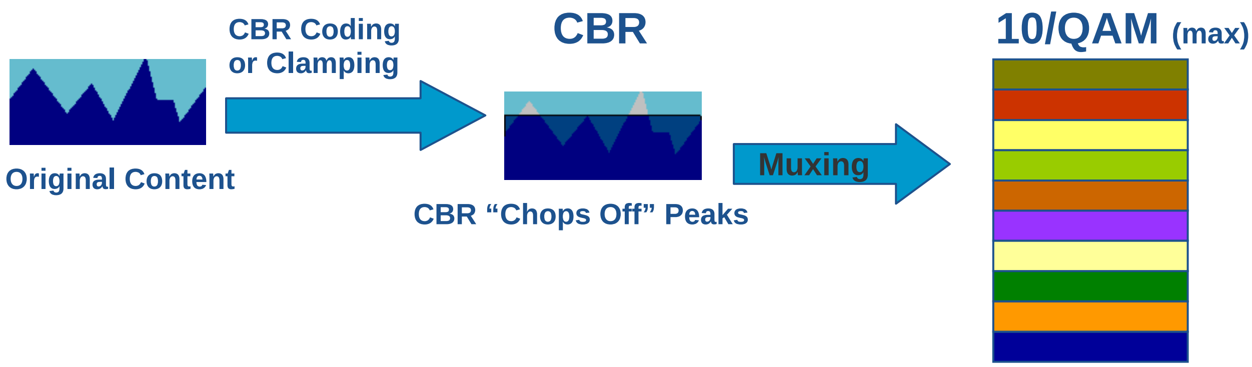

Figure 1: Maximum of 10 SD-VOD CBR streams per QAM Channel

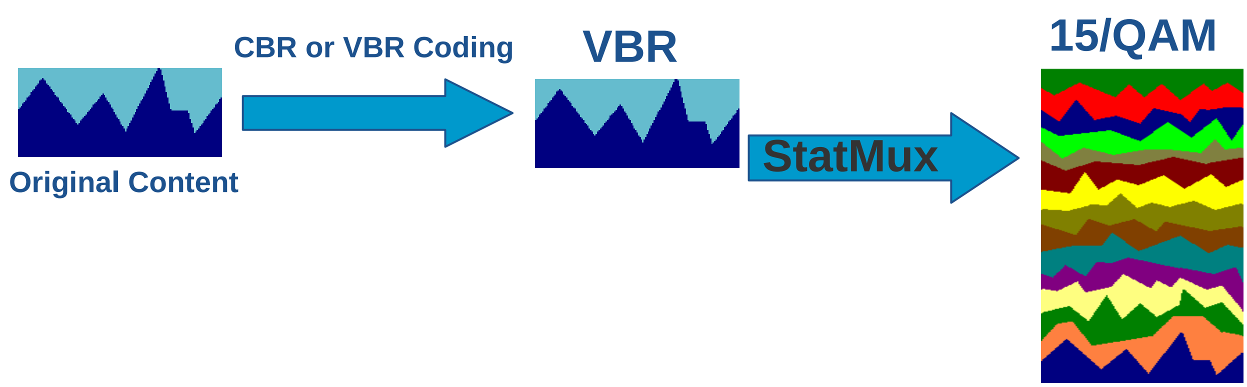

Figure 2: Fifteen (15) SD-VOD streams Per QAM with VBR/StatMux

If VBR/StatMux is such an obvious choice for digital video, then why is CBR used for both VOD and SDV? The fundamental answer is that no viable VBR/StatMux solution was in existence when these services launched. The word "viable" in this context implies both economic and technical issues. If used for VOD or SDV, the traditional statistical multiplexing methods used extensively for digital broadcast signals would run up against insurmountable hurdles in the following areas:

1) Economics (over $100/stream)
2) Rack space inefficiency (under 1000 streams per Rack Unit (RU))
3) Incremental consumer response delay (1-4 seconds)
4) Incompatibility with SDV centralized bulk encryption and VOD pre-encryption

6. Scaling Up PersonalizedTV Services Requires a New Technological Approach

In order to overcome these four hurdles, and thereby deliver the video quality and bandwidth efficiency benefits of VBR/StatMux to VOD, SDV, and other PersonalizedTV services, a radically different technological and architectural approach to video processing and statistical multiplexing is required. It must be based upon "Consumer Generated StatMux" dynamics rather than the traditional method in which the content provider or system operator determines in advance which digital signals make up the RF mux.

The broadcast-oriented technique of performing both the video processing and multiplexing functions in tight sequence, every time a mux is created, is inapplicable to the PersonalizedTV environment in which consumers determine the streams flowing down the last mile pipes.

A viable approach to solving this vexing problem requires a fundamental technology shift with at least two major differences relative to traditional statistical multiplexing methods. The first major difference involves a complete separation of video processing (coding) and multiplexing. With this division of labor, alternative compressed elements can be prepared in advance and indexed by quality measurement criteria. These alternative elements are called Interchangeable Compressed Elements (ICE). Then, the optimal elements can be selected on-the-fly for channel multiplexing in response to instantaneous consumer demand.

This separation of coding and multiplexing has major beneficial cost implications. With approximately 98 percent of the workload being performed only once per VOD file (or once per signal for SDV), the relatively easy 2 percent recurring workload can be delegated to the statistical multiplexing device. In this manner, the solution has the attribute of being able to scale commensurately with the number of streams being demanded by subscribers, a perfect fit for the dynamics of consumer-initiated video content such as VOD and SDV.

The notion of moving the StatMux function to the network edge, facilitated by the separation of coding and multiplexing, has important implications for cable's ongoing architectural and service evolution. An Edge StatMux is ideally positioned not only for end-to-end VBR but also for delivering increasingly personalized services, such as targeted ad insertion and SDV Unicast. Furthermore, by working in conjunction with EdgeQAM devices, QAM sharing of VOD, SDV, and potentially other signals is facilitated and further optimized.

Separation of the coding and multiplexing functions also allows unprecedented stream count density to occur (thousands of streams per RU), since the StatMux device is doing much less work on a recurring basis. Finally, negligible incremental consumer delay is incurred (trick modes for VOD or channel change for SDV), since the time-consuming and processing-intensive video coding portions have been accomplished in advance.

The second major difference from traditional statistical multiplexing techniques is incorporation of an objective video quality measurement subsystem. Such a subsystem involves a set of algorithms, built into the video pre-processing software, and serving the role of accurately emulating the human visual system. By analyzing frames of compressed video, as well as macroblocks within these frames, the subsystem can effectively determine which sections of video can be coded at lower bit rates without impacting the video quality. In other words, the algorithms determine precisely where the waste exists in the CBR VOD file, and then exploit these inefficiencies with VBR/StatMux. And the same process can be applied to live VBR digital broadcast signals in the case of SDV or nPVR.

The video quality measurement technology can also be used to achieve true video Quality of Service (QoS) in a consumer-generated streaming environment. Unlike digital broadcast, in which the cable operator or content provider pre-determines the digital service line-up for each multiplex, with VOD and SDV the composition of the digital line-up per multiplex is not known in advance. The video quality measurement algorithms are therefore used to analyze the available streams in advance, employing a deterministic manner for VOD and utilizing empirical data for SDV. The effective bit rate (similar to VBR average) can then be provided to the Global Session Resource Manager (G-SRM) or Edge Resource Manager (ERM) to facilitate video QoS and more intelligent load balancing.

Importantly, this intrinsic video QoS capability enables customers to calibrate the system, including the ability to decide the optimal tradeoff between bandwidth efficiency and video quality. It has already been shown that state-of-the-art algorithms are sufficiently powerful to enable, even for difficult content, 15 SD-VOD VBR streams or 3 HD-VOD VBR streams in a 256 QAM channel, at the same quality as today's capacity of 10 SD-VOD CBR streams or 2 HD-VOD CBR streams. Even better performance is expected for SDV, since the VBR digital broadcast sources are generally higher quality than CBR VOD source files.

In Figure 3, three (3) difficult HD-VOD CBR files (each encoded at 15 Mbps) were input into a video pre-processing subsystem with intrinsic video quality measurement capability. The pre-processor analyzes each stream, and then employs the video QoS algorithms to create Interchangeable Compressed Elements (ICE), effectively constructing a VBR signal with the same quality as the source video. Using metadata from the pre-processor, the downstream StatMux device then optimally packs the 38.8 Mbps 256 QAM channel.

In Figure 4, a similar result is shown for sixteen (16) SD-VOD VBR signals, each originally encoded at 3.75 Mbps CBR.

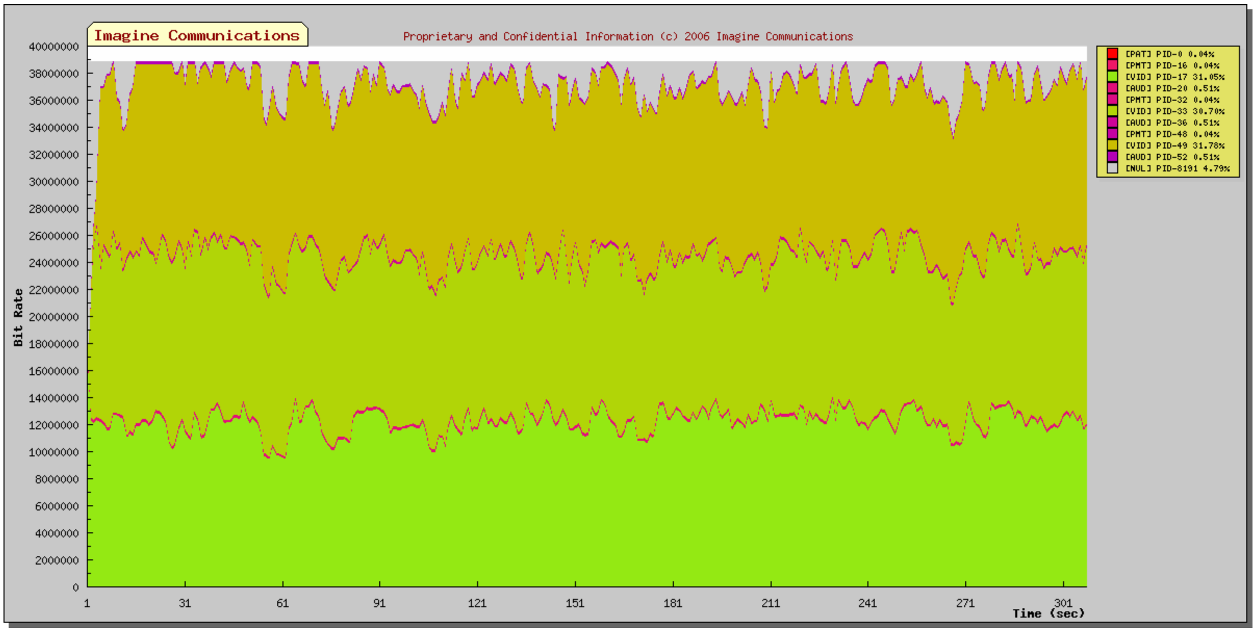

Figure 3: Three (3) HD-VOD VBR Streams in 256 QAM Channel

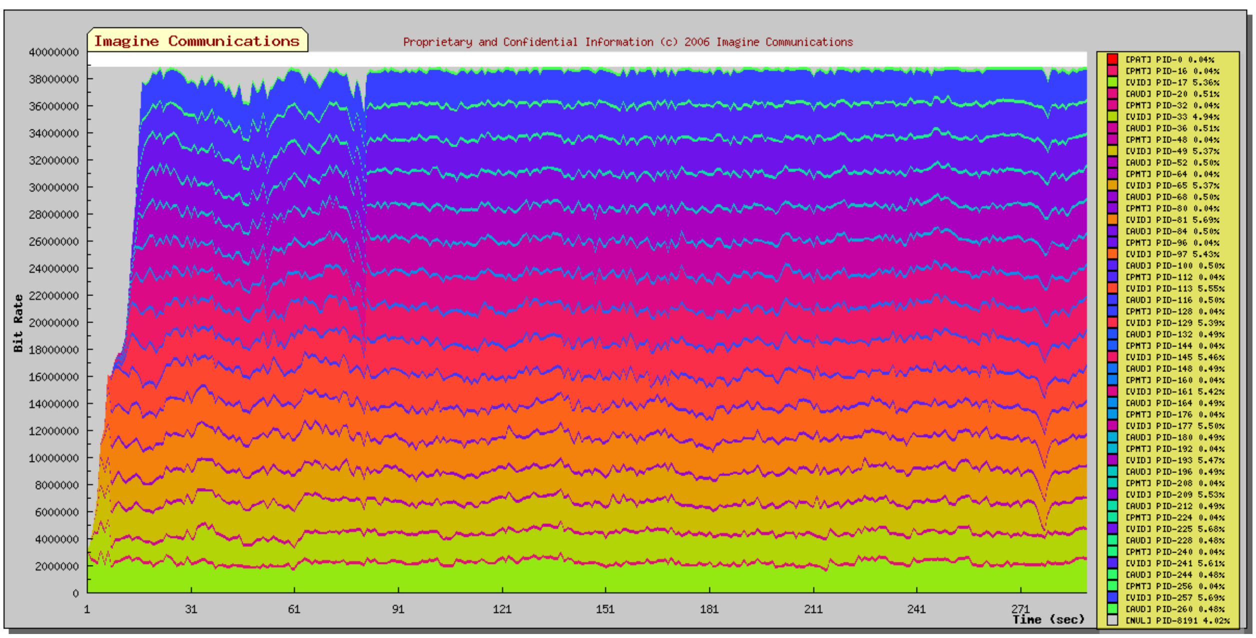

Figure 4: Sixteen (16) SD-VOD VBR Streams in 256 QAM Channel

Figure 5 depicts a high level network diagram, with the pre-processing functions (VOD Processor and SDV Staging Processor) and the statistical multiplexing function plugging seamlessly into the existing cable infrastructure.

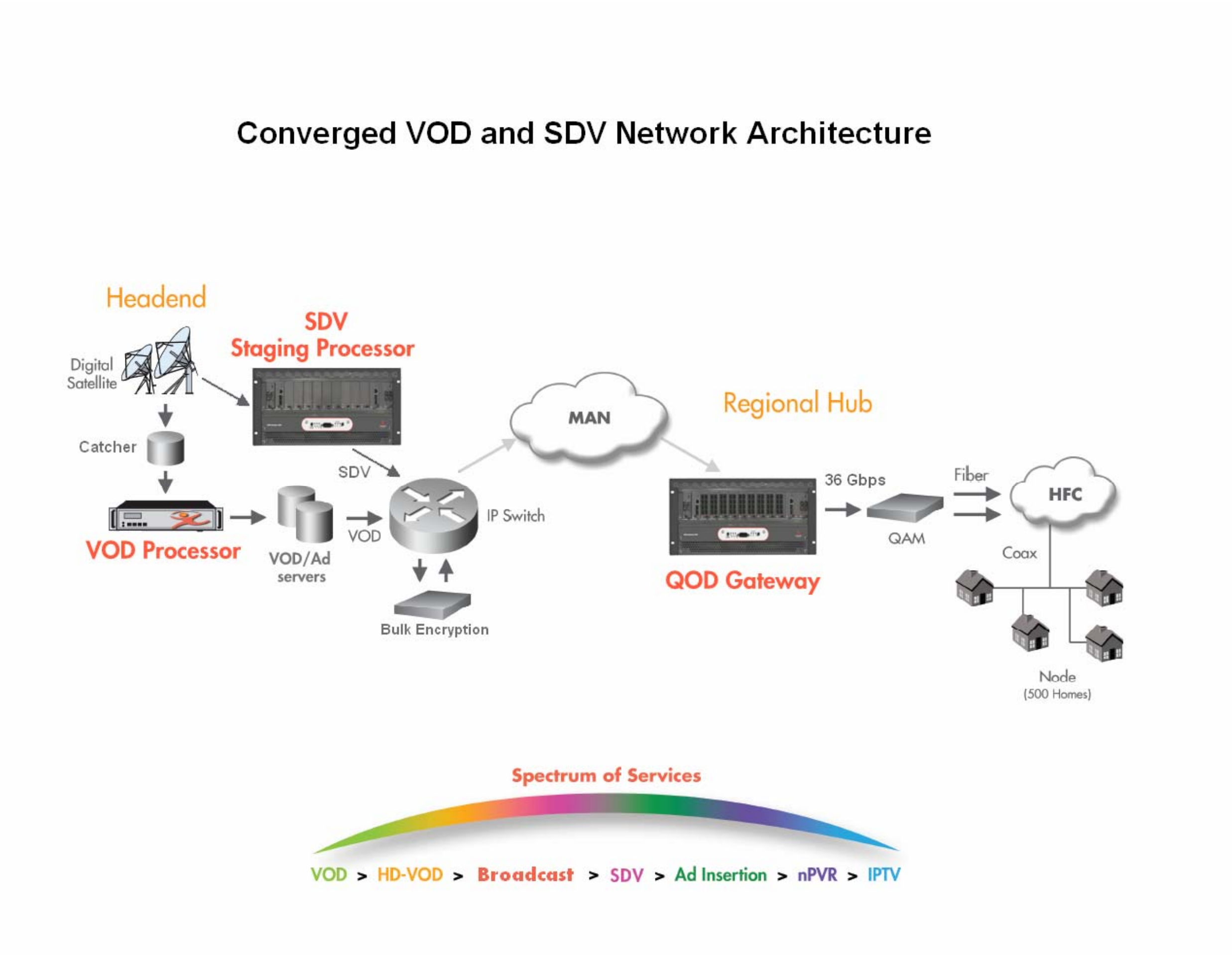

Figure 5: VBR/StatMux Solution in VOD/SDV Cable Infrastructure

7. Conclusion

HDTV is finally on the fast track to ubiquity. Premium subscribers will gravitate toward operators offering the most HDTV content and the best video quality, along with convenient services such as HD-VOD. For operators, attaining this pot of gold requires resolving the huge bandwidth challenges imposed by HDTV and VOD.

Cable operators have multiple options for creating new bandwidth. While each of these options may have a time and a place, the conversion from CBR to VBR/StatMux, effectively increasing VOD and SDV streams per QAM by up to 50 percent without degrading video quality, is by far the most economical choice on a "$/sub/6 MHz" basis. It is also the least disruptive to existing infrastructure, and saves rack space, power, and capital expenditures due to a 33-50 percent reduction in required EdgeQAM devices.

By leveraging a VBR/StatMux solution for VOD and SDV, operators will be able to massively scale their deployments, while providing better video quality to match or surpass competing platforms and preserving valuable spectrum for the upcoming HDTV bandwidth explosion.