GROOMING BY DEMAND, INSTEAD OF BY SUPPLY

Seth Kenvin
Vice President, Strategic Marketing
BigBand Networks, Inc.
SCTE Cable-Tec Expo
June 2006
Denver, Colorado

Abstract

Standard definition digital video in the MPEG-2 format has dramatically expanded cable offerings and altered operator business models since the mid-1990s. More recent advances include HDTV launches, and now the industry's beginning embraces of switched broadcast, network-based time shifting, telescoping on-demand content and targeted advertising. Use of advanced video coding formats such as MPEG-4 is anticipated soon. With rises in consumer expectations and competitive pressure from telecom, the Web and elsewhere, the cable industry can be expected to utilize an ever expanding volume and variety of TV programming technologies, formats and delivery models.

Broadcast grooming has become established as an effective means of delivering MPEG-2 standard definition video with great efficiency and operator control. It is based on statistically multiplexing variable bit rate programs within each 6 MHz channel, performing rate shaping to dynamically reduce bit rates of individual programs when necessary to fit capacity, and periodically re-setting channel line-ups for optimal grooming performance. Because this activity is based on relatively static bouquets of content delivered at all times to all areas within a cable system, it can be considered to be supply-driven.

With more switching, targeting, on-demand and utilization of multiple formats, the cable industry is heading towards unique and constantly changing bouquets of content within each node. This is a more demand-driven model. Maintaining grooming practices requires real-time multiplexing across various formats with rate shaping spanning of the heterogeneous programs. To date, such processing, especially at the scale of performing on a node-by-node basis, has not proven economically feasible.

But aided by Moore's Law and algorithmic refinement, media processing capabilities continually advance. Demand-driven statistical multiplexing and rate shaping of switched video programs spanning multiple formats has increasing promise as a means for strengthening the cable industry's competitive position.

Cable Gets Digital

"Digital" has become synonymous with "quality" but not long ago, it was not this way. The rise of digital technologies was more motivated by the associated bandwidth advantages. In fact the quality of the earliest digital programming over cable networks was noticeably inferior to analog offerings with low resolution, flat colors and occasional macro-blocking, especially during faster action sequences. Even the bandwidth efficiency gains paled, compared to what's achievable today, with QAM 64 multiplexing and early MPEG generations resulting in just over half-a-dozen digital programs per 6 MHz channel.

While the earliest digital broadcast efforts over cable were extremely poor relative to what's become achievable over time, they were impressive innovations at the time. And they were absolutely necessary. The early-to-mid '90s saw the rises of the "deathstar" with direct broadcast satellite launching its own digital video models that presented the first real competition in multichannel video, with potential to scale offerings to triple-digit numbers of programs.

Cable responded by fighting digital with digital and even fighting satellite with satellite. Several ventures were launched that aggregated all program feeds at a national super headend, determined the channel line-up, modulated by QAM 64, and uplinked to the

cable industry's own satellites. These satellites distributed the programming to headends nationwide that simply accepted the pre-set line-up and transmitted it down the coaxial cable. Lowest common denominator ruled the day, with every system running according to the video quality and bandwidth efficiencies capable of supporting the least of them.

The game was joined with satellite over program counts, but the cable industry was doing little at that point to leverage its advantage in geographic localization and in having a wired plant. The headend was merely the point at which the nationally uniform digital multiplex met with a handful of locally sourced programs.

Rise Of The Stat Mux

During the late '90s headend-based grooming emerged to begin elevating the role of the local headend in governing its own area's offerings. Instead of simply re-transmitting programming, the headend could re-multiplex content. As a result, local operations could determine their own channel line-ups and modulation schemes with greater autonomy.

One important result of grooming was the start of rising digital quality levels. The super headends have to get their content from somewhere, and this is often a satellite transmission from the programmer. So by the time content reaches a local headend, it was often transmitted by one satellite link, decoded and processed at the super headend according to the specifications of the least capable systems served, and then re-encoded and re-transmitted. Each transmission and each decode / re-encode cycle introduces quality compromises. With grooming, local systems could instead source selected programming directly from programmers, and perform modulation locally per its own parameters and motivations.

Another factor that's become important in local grooming is statistical multiplexing of variable bit rate (VBR) programs with application of rate shaping when necessary. Digital video is VBR in nature. This is because MPEG algorithms largely interpolate changes between frames rather than constantly generate entire frames. When there's deviation from the expected interpolation, which is often the case with particularly rich pictures or intensive action, more bandwidth is required. More static scenes require less bandwidth.

When multiple digital programs are multiplexed within the same channel, it is highly unlikely that a substantial majority of programs will approach peak bandwidth levels at the same instant. Often a peak in one program corresponds with the trough of another. The more programs multiplexed together, the more likely these offsets are advantageously achieved. This is the benefit of statistical multiplexing, and its advantage has been enhanced by migrating towards QAM 256 that has realized close to 40Mbps per six megahertz channel, a more than 30% boost relative to QAM 64.

In those instances when more capacity is required than what is available, rate shaping algorithms have emerged as an important aspect of grooming that is capable of dynamically throttling back the bandwidth allocations (and thus the quality too) of selected programs at moments of peak payload. This can be applied intelligently such that priority is given to the most important, popular or quality-sensitive programs, and rate shaping is applied most aggressively to those programs with complexity profiles that allow for the largest bandwidth efficiency gains without overly effecting quality. This practice is complex, and took a fair amount of algorithmic and architectural refinement to become economically viable, but it is now commonly accepted and practiced economically within local headends for the programming delivered from those sites to all subscribers.

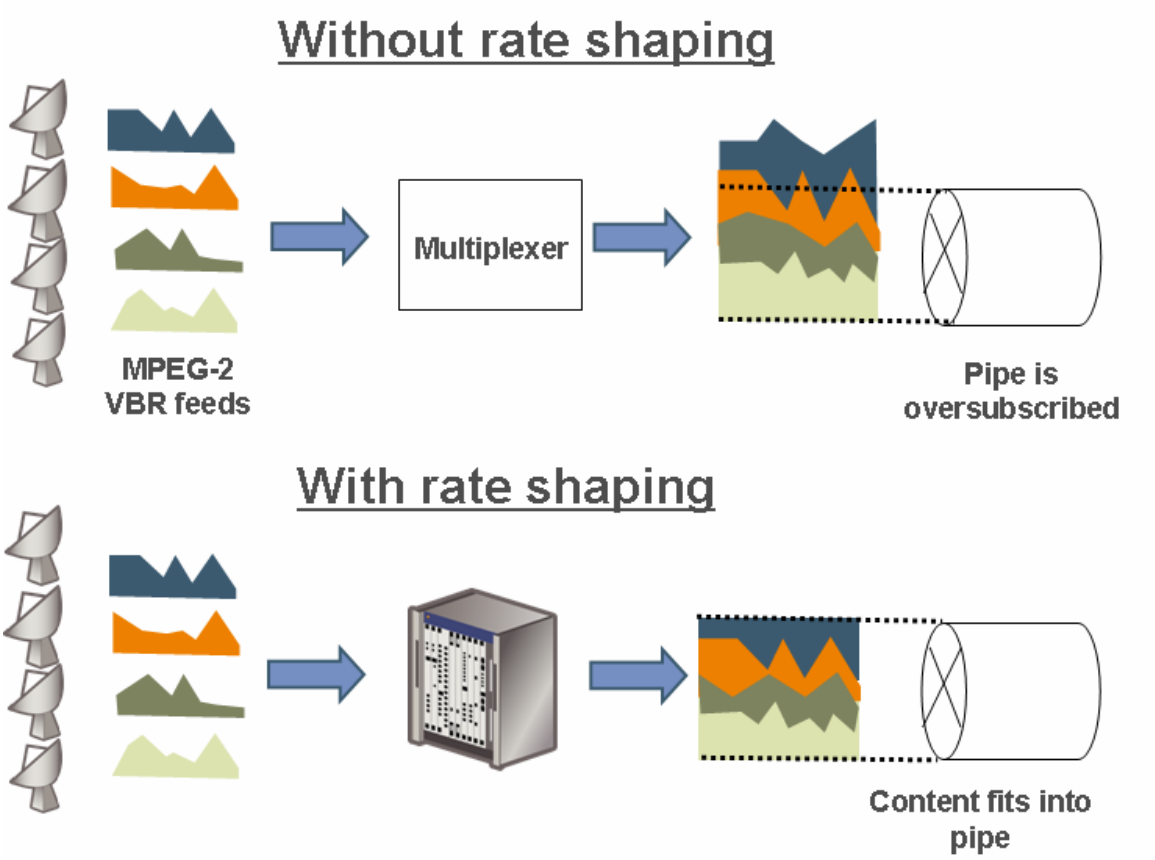

Figure 1. Rate shaping dynamically adjusts bit rate behavior of streams within a multiplex to assure that they meet capacity.

Setting the statistical multiplexes of each 6 MHz channel has become another process in its own right. The best balance of efficiency and quality is achieved when consideration is given to each program's typical payload, complexity profile, and subjective priority. If each multiplex has a variety of these characteristics, it tends to be best for the operator. This way, at the moments when the multiplex's cumulative bandwidth is too high, rate shaping emphasis can be placed on the programs with big payloads, attractive complexity profiles (ie bigger bandwidth gains achievable with lower quality impact) and lower priorities set by the operator, and those with opposite characteristics can be spared. For this reason, it is desirable for an operator to reassess and adjust channel line-ups occasionally in order to achieve these sorts of multiplexes.

With time, local grooming with statistical multiplexing including rate shaping and occasional line-up adjustment has become the predominant method for digital broadcasting over cable. Both quality and quantity of programming have increased. Further innovations have also improved economic performance. One of these is the increasing usage of Gigabit Ethernet technologies to aggregate what used to be multiple disparate headends. Rather than each facility operating downlinking of many feeds, this is performed only in one or very few sites. This yields some of the local control that was first realized with the onset of grooming, but makes up for it with better economics by setting the line-up, rate shaping and modulating fewer times.

Another more recent development has been the onset of local digital advertising. Insertion of local advertising into national program feeds has become an important

aspect of operator negotiations with programmers, and has provided them with a major revenues source. The SCTE-30 and SCTE-35 standards for digital cue tones and splicing allow this practice to extend to digital content. These practices include zoning in which multiple ads are simultaneously spliced into multiple versions of the same program, each transported towards its relevant audiences. This begins moving the pendulum back towards directing content at more precise groups of subscribers from the movement towards digital aggregation facilitated by Gigabit Ethernet transport.

The cable industry has been in perpetual motion ever since introducing digital content and more innovations have come on as well. These include the growth of HDTV as a programming format, for which grooming concentrations are reduced to 3-4 programs per multiplex from levels of approximately 12-16 with standard definition. Also digital simulcasting enables all-digital consumption by providing both digital and analog versions of basic and enhanced basic programming. But combined with other bandwidth-intensive developments such as the growth of VOD and faster broadband Internet speeds, the static statistical multiplex is increasingly dubious as to whether it provides the cable industry with its most efficient means of seizing leadership in the competition to provide digital services.

Video Gets Switched

A period has dawned in which every network operator is pressured to provide the full volume and variety of media and services instead of merely continuing with the offering for which its network was architected. While this movement enables cable to enter the voice market, it also brings new competitors into the industry's legacy video space. Telecom operators are particularly intent on entering video through a combination of optical and copper access network technologies. This provides further motivation for continuing cable innovation.

The beneficiary from all of this innovation is the subscriber to broadband and rich media services. Individuals are themselves becoming more sophisticated in their usage of services, increasingly demanding that they be provided the precise content they want at any time, delivered to whichever device they choose. They are further expecting increasing degrees of personalization and interactivity within the content that they consume. Static multiplexing practices by cable are increasingly problematic as demand is decreasingly supportive of being aggregated into specific geographies or synchronized to particular timing.

The cable industry is reacting with switching technologies. Live television and on-demand practices are being blended in pioneering deployments of network-based time shifting, allowing subscribers to begin programs in progress when they note they're on, or to pre-determine certain programs to save in a personal repository for later controlled delivery over the network. As programmer arrangements are reconciled, this is likely to extend towards providing all recent programming in an on-demand model.

Network-based time shifting adds yet another bandwidth-hungry service to the cable plant. A related feature of increasing consideration is telescoping. In this practice, a subscriber who notes a topic of personal interest such as an advertisement or a particular element of a program being watched, may have the option of perusing longer form content on this particular topic. In the mean time, the main program being watched would be paused for later resumption. This process transitions that subscriber's consumption from broadcast to an individual stream in a VOD model, even when the original program is rejoined, since its timing is now offset from the original broadcast.

To facilitate all of these emerging models and their bandwidth demands, there is increasing adoption of switching, not only applied to stored video, but to live content as well. Instead of constantly delivering all programming to all subscribers, switched broadcast systems dynamically direct content only to those areas in which it's being watched in real time. This technology is compatible with existing program feeds, distribution plants (as long as they're 2-way) and digital set-top boxes. Deployments demonstrate potential to conserve more than half of the bandwidth that's allocated to the digital programs being switched.

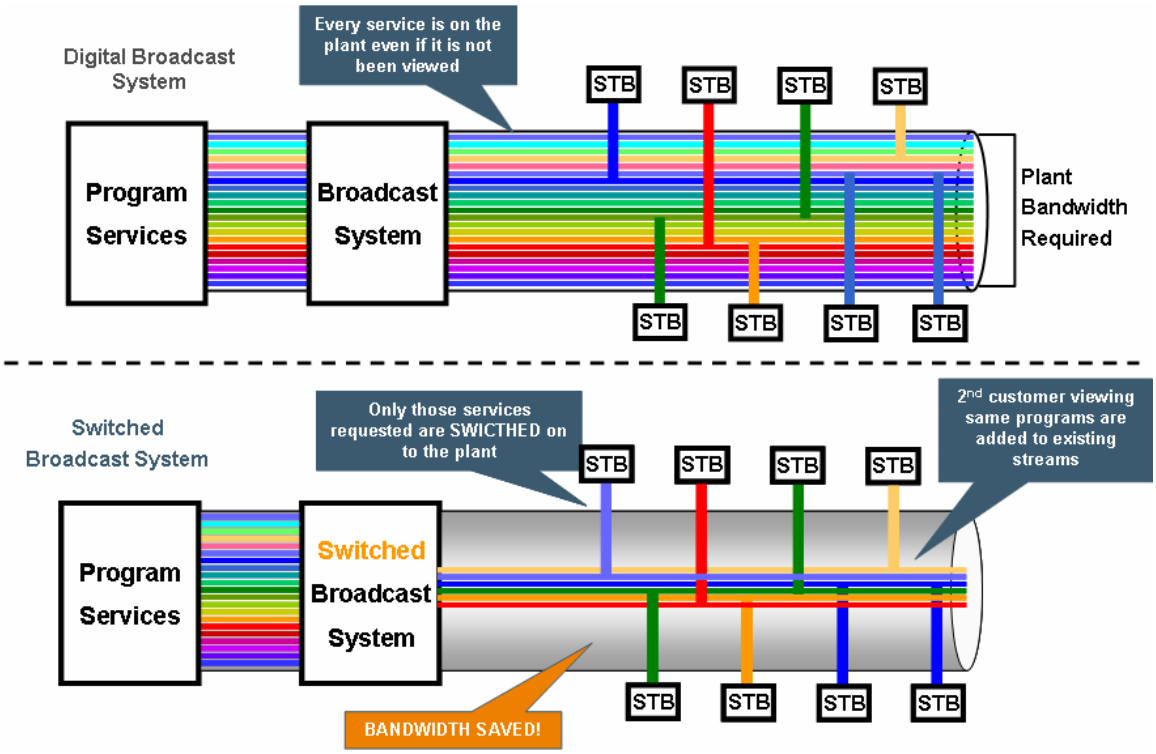

Figure 2. Switched broadcast delivers only the programs being watched within each node or service group, saving substantial bandwidth as opposed to delivering every program to each subscriber at all times.

Because a single digital program is delivered to just one or very few subscribers in switched broadcast, it is most economical and feasible to deliver the streams in constant bit rate (CBR), even though this reduces the bandwidth efficiency of each stream by 50% or more. CBR can support about 10 standard definition programs per multiplex within 6 MHz by QAM 256, versus 16 or sometimes even more by VBR. Current rate shaping technologies require too much processing to be worth the bandwidth gain by application to streams delivered to such small audiences, plus the efficiency gain by switching is sufficient to alleviate the need for rate shaping these programs for the time being.

Dynamic Grooming

While initially spurred by the need for greater bandwidth efficiency, switched broadcast technologies are now also being leveraged to advance functionality to subscribers. Whenever content is being switched, it opens possibilities for greater personalization and richer functionality.

Key to greater functionality on switched broadcast programming is transitioning the delivery from multicasting to unicasting. This means that adjacent subscribers viewing the same program each receives an individual stream. This stream can support faster surfing among programs because a subscriber's set-top box does not have to re-tune, and the stream can be delivered with an i-frame first for instant resolution. Switched unicast can also deliver targeted advertising, with each subscriber seeing content relevant to personal demographics and interests, regardless of what's being watched.

Like many advances in functionality, switched unicast puts more burden on bandwidth. Because unwatched programs don't consume bandwidth, overall switched unicast tends to be more efficient than traditional broadcasting. But because subscribers watching the same program do not share streams, the efficiencies of multicast methods of switched broadcast are not fully realized. However, unicast can partially alleviate this by introducing an interim solution for rate shaping of switched broadcast streams.

First of all, this practice entails switching VBR programs. But instead of performing rate shaping on each stream in real time when capacity of a multiplex is exceeded, the bandwidth reduction exercise can be performed more centrally, before switching and transporting programs to the edge locations where they're being watched. This consolidates the required media processing to only be performed once per program rather than potentially multiple times at the edge locations, and also reduces the overall media processing hardware and functionality required. The fiber portion of the transport network can be considered relatively bandwidth unconstrained, and therefore the different profile versions can all be transported. Then, when the multiplex is constructed at the edge, the best quality profile that fits each program's bandwidth allocation at the moment can be selected.

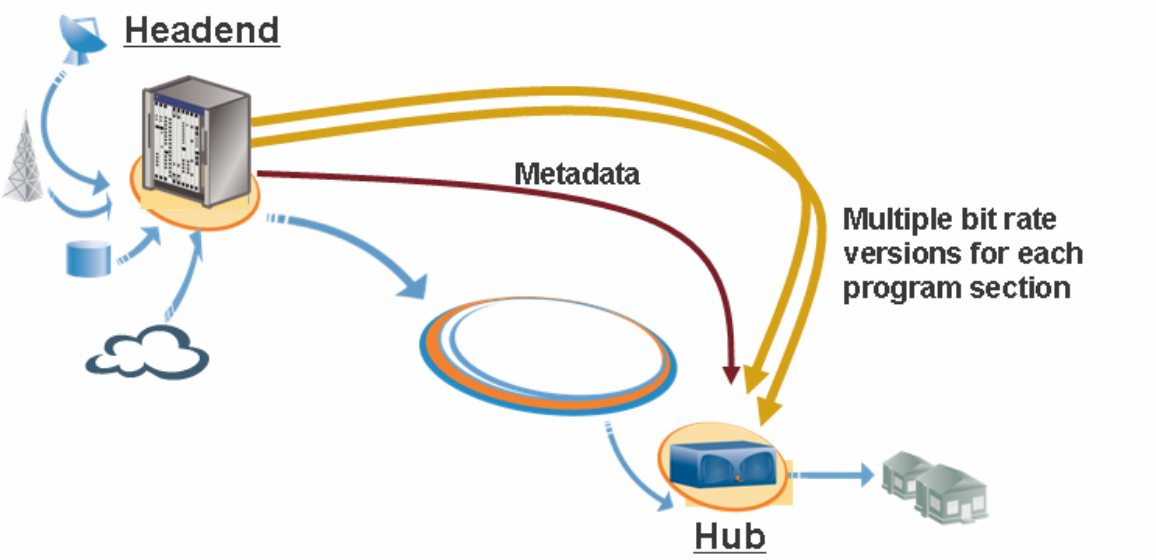

Figure 3. Headend-based rate shaping with hub-based selection can be applied to switched broadcast of VBR feeds as an interim solution until edge-based rate shaping becomes economically viable.

With ongoing progress of Moore's law and algorithmic refinement, it will eventually be economically feasible to perform true edge-based rate shaping of switched broadcast streams. In the mean time, headend rate shaping with edge-based stream selection can support an effective transition period.

More Formats, Devices, Delivery Models

While telecom video models emerge and cable increasingly switches its offerings, yet another new class of entrant is arising to provide digital media services. With faster broadband access, subscribers can go straight to the Web to get high quality video alongside other content. Programmers are providing some of this content directly, as are a combination of start-up and established Web companies. These offerings are often described as “over the top” because they leverage the infrastructure of network operators in order to provide services that are competitive with the network operator’s business.

These over-the-top services are in several ways more expansive (and in several more limited) that most current TV programming offerings. There is little restriction on getting the real estate to offer content unlike the scarce programming schedule of linear program networks that are themselves contending for limited broadcast spectrum space. As a result, many more titles can be made available from the Web, and occasionally highly unexpected content from a seemingly random source can become extremely popular. Over-the-top also contributes to establishing a pattern of content of different media forms being available to multiple types of devices, as is the case now with video to PCs.

Interest in consuming video on new devices goes beyond PCs. There are increasing numbers of services and products which support video to handheld devices. The cable industry has strong potential to participate in this trend through its emerging wireless services partnerships. The expanding range of devices for video consumption expand the number of encoding techniques to be supported and also call for a range of bit-rate profiles to accommodate varying access bandwidths as well as to make sensible determinations of the appropriate quality levels for various displays used, from small handheld screens that don’t even require the floor of standard definition bit rates, to HDTV screens approaching 100 inches diagonal that call for 1080P and even better transmissions. Cumulative trends have ushered in simultaneous consideration of not only time-shifting, but also place-shifting and device shifting, adding several dimensions of variables in how video is delivered.

Cable does have a couple of current instances of providing the same content in different formats. This includes simulcasting both digital and analog versions of programs in order to facilitate all-digital reception on certain devices. Also, many HDTV offerings follow the exact same program schedule as a standard definition counterpart. But as the number of versions of programs proliferate to both higher and lower quality levels, and additional encoding techniques, switching becomes an imperative because there is not sufficient bandwidth to constantly carry every version of every program, even if one assumes substantial analog reclamation. This is further substantiated by the increasing amount of programming that there is pressure to offer, and the increasing time-shifting control that subscribers expect.

Just like pressure from over-the-top offerings is one of several contributors to increasingly varied demand, it’s also a factor in the spread of supply. Instead of just receiving satellite and terrestrial feeds from a few consolidated suppliers, cable operators may find themselves accessing extremely varied content. This is already increasingly including widespread international feeds that could spread to include practically any live program from anywhere in the world. With less expensive digital video equipment and more accessible software editing tools, there is also an expansion in the number of entities that can produce video programming, down to the level of

individual hobbyists. With demand for fare further down the “long tail” increasing via the Internet, cable operators should consider tapping into that content for its video offerings.

Another area of expanding supply possibilities is in advertising. Regional targeting is established, and personal targeting is anticipated. Models that have proven successful on the Internet are under increasing consideration for television advertising. This includes real-time transactions for content for delivery to certain profiles of subscribers and / or certain contexts of programming being viewed. Should this develop, it’s possible that an operator will conduct an auction to deliver to a very specific demographic of viewer that only makes economical sense to serve on a national basis with sufficient scale. An advertiser interested in this demographic could purchase an avail for that profile and provide the content to the operator in real time for splicing into programming. This further spreads and complicates how programs are sourced.

Evolving Local Cable Systems

Performing dynamic resource allocation to all formats of digital content can be implemented by the cable industry in stages to optimize economics and management capabilities. In fact this is already happening in the cases of video on-demand, multicasting of switched broadcast and broadband Internet access. Eventually sessions across these different services and media formats will be combined in real-time multiplexes that leverage their offsetting characteristics, but today there is dynamic allocation of spectrum and associated resources within each of these services. And just like this interim state has been accomplished by leveraging the industry’s hybrid fiber/coaxial network investment with limited incremental architectural work, so too can coming changes be achieved with careful planning by discrete incorporation of the right technologies at the right points of the network, scaled up openly over time.

The current adoption of multicasting switched broadcast reveals just how efficiently new applications can be layered onto the cable plant, with leveraging of its existing technologies. Programmable digital set-top boxes and networks based on switching-friendly Gigabit Ethernet facilitate extension of functionality towards dynamic delivery of live content only to those areas with real-time demand. The new elements to be added include management servers that monitor and respond to establishment and discontinuation of viewing sessions, and expanded edge modulation capacity in order to achieve node-by-node bouquets of programming, instead of having to modulate only once per the entire cable system, or for geographic zones that aggregate multiple nodes within it.

As demand-driven multiplexing spanning all services and media arrives as a practice, there will be requirement for more edge processing besides modulation. This is likely to include transcoding between different formats such as MPEG-2 and MPEG-4, splicing targeted content within streams, and rate shaping across different formats within a multiplex. For simplicity and economics, it is desirable that the range of edge processing be limited to a few functions, with more complex and varied processing consolidated to the headend, as advocated above for interim rate shaping of streams in unicasting switched broadcast. In anticipation of expanding edge processing, cable operators should prioritize deployment of edge infrastructure today that is modular and programmable, although it is also important to prioritize for cost, size profile and power consumption since the number of streams being processed in dynamic multiplexes will increase substantially.

One other area for scaling up local systems is in on-demand infrastructure. As time shifting of programming expands and becomes more network-based, there is need to ingest and store more content from more sources. Storage can also be utilized to insert targeted advertising and other personalized content within media streams. Another consideration is that storage can be distributed across locations including edge-based for frequently utilized content in order to save on transport requirements, and more consolidated, even at a facility of the content provider, for more sporadically accessed content in order to save on storage requirements. This would also require intelligent management servers able to identify and source from the right locations for required content. Like innovations in edge processing, expanding on-demand resources and associated management can be intelligently implemented in an evolutionary manner.

Evaluating the requirements for grooming and processing that is more responsive to demand reveals that much of the work is already completed in terms of content standards, network infrastructure, and deployed devices. In fact, many current cable initiatives such as increasing Internet access speeds and digital simulcasting reveal just how efficiently change can be implemented with the right infrastructure in place. While competitive forces and increasing consumer sophistication drive shortening implementation cycles, well planned initiatives can enable controlled and gradual transformation, with the right functionalities coming into play at the right times.

Conclusion: Demand-Based Grooming

The overall spread of sources of content and ways in which content is being consumed is expanding rapidly. The prospects for this to continue are clear, and increasing competitiveness between cable and alternative methods of content delivery indicate that these trends extend for a long time.

In aggregate, trends are towards a cable plant sourcing supply from an expansive base of worldwide feeds using satellite, fiber, terrestrial and other connectivity. This content is to be delivered to subscribers through a combination of pull-model choice and push-model personal targeting. It will be at varying quality levels ranging from less than today's standard definition to greater than today's high definition. It will also be in various digitally encoded formats, as well as analog video that will sustain for a while longer. And rich functionality must be supported including on-demand trick play modes, interactivity and place shifting.

Operators can no longer create static multiplexes across all of the content they provide as there is too much content delivered by too many methods. Instead of this established approach of supply-based grooming, the multiplexing must be responsive to real time demand. Performing this optimally requires real time determination of what's being delivered to whom, with comprehension of the profile of the content, the subscriber and the device being used. Just like similar factors have been manually incorporated into occasional adjustments to statistical multiplexing line-ups, such calculations can be done automatically in real time. To further optimize things, multiplexing should enable combinations of different media and encoding techniques within the same channels, and rate shaping available to each individual stream. While this is complex, it is technically achievable, especially as practically all digital offerings over cable can share modulation by QAM 256 as a common characteristic.

Dynamic multiplexing with media processing across a variety of formats is surely an ambitious agenda. It will be years before this is economically and logistically practical. But Moore's Law continues to lead towards denser, more economical and more powerful

processing platforms, and enhancement of algorithms for practices like encoding and rate shaping continues apace as well. The destination of complete demand-based grooming incorporating all offerings remains years away. In the interim, cable will gradually erode its historic silo mentality. For example, plans are already underway to combine switched broadcast and VOD fare within the same channels. As these trends continue, cable is extremely strongly positioned with it's high-speed, two-way, addressable plant, adaptable to various formats and protocols, to flourish in the competition to satisfy consumers' increasing demand to maximize the choice, control and convenience of their digital media experiences.

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