CASCADING SIMULCAST WAVES TO IMPLEMENT ADVANCED TECHNOLOGIES

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INTRODUCTION

Across the cable industry, 2005 saw the widespread implementation of digital simulcast, allowing analog programming to be replicated in the digital domain, and beginning the realization of all-digital broadcasting. By providing benefits that span enhancing audio and video quality, advancing operations within the cable network such as transport and ad insertion, offering the possibility of lower cost set-top boxes, increasing security by accelerating the transition to digital encryption, and promising improved spectrum utilization through eventual analog reclamation, this first simulcast wave is demonstrating a viable process that offers the possibility of replication for future implementations of advanced technologies.

As cable operators evolve network capabilities to meet changing subscriber preferences and offset competitive pressures, high definition content will become more prevalent. The resulting capacity burden of this and other growing services is accelerating the need to introduce migration to more efficient advanced coding technologies and more flexible content sourcing as well as delivery via IP. The authors assert that, given the success of digital simulcast, future implementations of advanced technologies may include SD and HD simulcast, MPEG-2 and AVC simulcast, as well as IP simulcast.

Pre-planning a scalable, programmable infrastructure that will take into account the removal of outdated equipment, enable spectrum recapture, and chart a path to the ongoing technological enhancements, can provide a clear evolutionary advantage for cable.

Simulcast considerations include:

- triggers for each simulcast wave;
- capability for the HFC network to provide the additional bandwidth needed;
- translation of existing services to the new technology;
- considerations for reducing, or eliminating, the legacy portion being simulcast; and
- impact of preceding simulcast implementation on potential subsequent waves.

This paper examines these issues, discusses the drivers for content format enhancements and reviews how MSO infrastructures can be engineered to best support these cascading simulcast waves.

ACCESS NETWORKS AND CONTENT FORMATS ARE EVOLVING

Changing subscriber preferences combined with aggressive competitive initiatives from both telecom operators and satellite broadcasters have proven the need for network infrastructures that are advanced in functional complexity and effective capacity.

As content delivery mechanisms are diversified via WiFi, WiMax, GPRS and FTTH, cable operators are facing commoditization of their HFC access networks, enabling greater focus to be put on the services and content needed to maintain competitive leverage. Future enhancements to subscriber viewing experiences will likely drive an expansion of HD program offerings, utilization of advanced compression techniques, and adoption of IP technologies.

An increasing demand for HD programming results from subscribers that have invested in high-end digital televisions becoming increasingly frustrated by the resolution of standard definition content on them. With HD a primary competitive lever for the satellite industry, and telecom companies entering the video market with some HD bandwidth challenges, the cable industry will likely transition to expanded HD offerings. Additionally, as more programmers, based on their own competitive drivers, make HD versions of their content available, a simulcast of the increasing programming load with their SD versions can facilitate their introduction on the cable plant.

AVC (advanced video codec) mitigates the bandwidth burden of high definition programming and increasing numbers of programming choices. AVC formats, such as MPEG-4 may grow in popularity among cable operators looking to conserve network bandwidth while offering a broader range of services and content. Additionally, a simulcast of MPEG-2 and AVC formats may be driven by IP set-tops and DOCSIS 3.0 devices coming to market and gaining penetration.

Beyond the convergence of voice, video and data, the expanding role of IP-based networks offer compelling benefits such as dramatic reductions in hardware costs, integration of network management, subscriber portability, adoption of cutting edge technologies such as interactive television and can enable content to come from not only traditional sources but from potentially anyone, anywhere. IP infrastructure offers the potential for enhanced efficiency through the use of established tools such as IP multicast. Near-future developments may include implementation of IP-based HD video and IPTV.

Transitioning away from legacy formats has occurred more than once in the communications industry. In telephony, the move from analog to digital voice circuits resulted in a range of benefits for both service providers and consumers. A transition to a digital network not only lowered the high operating expenses of analog infrastructures, but new revenue opportunities from features such as three-way calling and call waiting were available at practically no additional cost. When such benefits were realized, the pace of the digital-only transition was implemented quickly, though some analog local loop was maintained to accommodate legacy phone sets. Likewise, the cable industry is rapidly realizing that the benefits of the initial digital-analog simulcast foray exceed the associated costs and complications, and the potential to use the technique for new technologies is enticing.

BENEFITS OF DIGITAL SIMULCAST

By converting analog programming to digital at the headend an MSO can converge its video transport network to a single tier; edge decoding makes both the digital versions and original analog versions available to subscribers. Digital simulcast allows for improved audio and video quality, enables lower CPE costs, and sets the stage for dramatic bandwidth re-capture. Equally significantly, it combats competitive pressures by driving marketing parity with competitors' claims of "all-digital" networks. Consequently, digital simulcast has been embraced by the cable industry and deployments continue apace. A typical digital simulcast network is shown in figure 1.

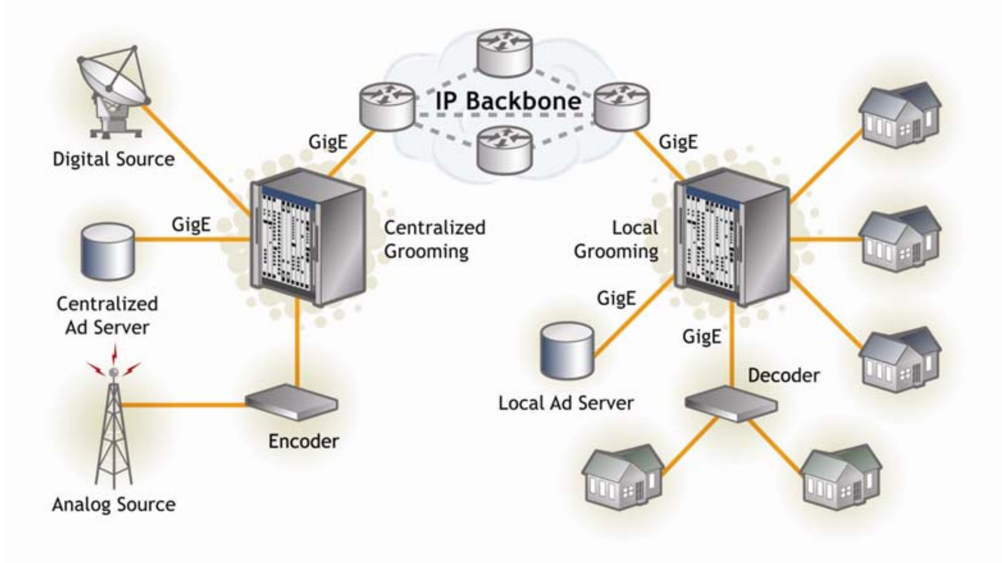

Figure 1: Content from Digital and Analog sources transported across a Digital Simulcast Network

Digital simulcast infrastructures have been designed to accommodate existing and near-term technologies and services by capitalizing on end-to-end digital carriage, processing, centralization and redundancy mechanisms. Key features include:

- closed-loop/open-loop encoded content for controlled, redundant, bandwidth-efficient and easily managed video sources;
- a shift to IP interfaces on statistical multiplexers, decoders, encoders, ad insertion servers, and digital transport, displacing previously dominant and limited DHEI and ASI interfaces;
- centralized digital ad insertion accomplishing improved quality and reduced hardware requirements, with expansion of splicing onto virtually every channel via standards-based cue tones, with ads transcoded at 3.75 Mbps;
- IP multicast of common programs conserving transport bandwidth,
- redundant transport mechanisms including program-level protection switching and layer 1 switching for digital lineups with the same availability as the original life-line analog offerings;
- efficient packing of digital multiplexes for conservation of HFC bandwidth; and
- a transition path to highly functional digital-only set-top boxes removing the need for analog tuning circuitry, associated cost saving, and enabling advanced services to 100% of the subscriber base.

Aggressive spectrum re-structuring on the access side allowed the seven EIA (Electronics Industry Association) channels typically needed for digital simulcast to be allocated[1]. Table 1 outlines the bandwidth reclamation strategies used for digital simulcasting along with freeing-up capacity for a variety of near-term advanced services.

[1] 80 analog channels converted into digital with 12:1 multiplexing in a QAM 256.

Bandwidth Reclaim Strategy Steps	Improvement in Bandwidth	Results	Notes
QAM 64 to QAM 256 conversion	*30% per 6 MHz*	*5 EIAs freed per sampled 750 MHz system & 5.8 per sampled 860 MHz system*	
PPV movies moved to VOD	*One 6 MHz slot reclaimed (typ) per PPV package removed (12 services)*	*2 EIAs reclaimed per lineup*	*With higher VOD penetration rates*
Real-time encoding of sports/PPV content	*One 6 MHz slot reclaimed (typ) per PPV package removed (12 services)*	*1.5 EIAs reclaimed per lineup*	
More efficient multiplexing of DTV channels[2]	*≥ 10% per DTV lineup*	*2.3 EIAs freed per sampled 750 MHz system & 2.7 per 860 system*	*Most systems have either underutilized or over-utilized multiplexing per QAM*
Closed-loop encoding	*14% to 25% per QAM*	*14 to 16 services per EIA instead of 12*	
Aggressive use of the spectrum, FM (A-x) channels & roll-off frequencies	*Possible reclaim of FM bandwidth & use of roll-off frequencies*	*Potentially freeing 2 - 10 EIAs*	*These 6 MHz slots have additional requirements for frequency interference offsets*
Reduction of duplicate programming (East vs. West feeds)	*12 duplicate premium programs removed per major site on average*	*≥1 EIA saved per removal of 12 duplicate services in lineup*	
Analog spectrum re-capture	*80 Additional EIAs previously not available*	*Space for nearly 1,000 additional SD programs or more than 200 MPEG-2 HD services*	*FCC date for the broadcast spectrum re-capture currently April 2009, though complete removal of analog programs unlikely for some time*
Switched broadcast	*Oversubscribing each EIA by 2.6 to 4:1 SD services*	*Switched SD MPEG tier can save ~ 6 EIAs[3]*	*HD switched broadcast tier (after the SD/HD wave) also anticipated*

Table 1: Bandwidth Reclamation Strategies for Digital Simulcast

LESSONS LEARNED FROM DIGITAL SIMULCAST

The lessons learned from the first simulcast wave may be applicable to future waves. For example, the migration of many legacy analog services such as CE-GemStar guide data and

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[2] "Optimizing Bandwidth Efficiency Though Intelligent Channel Multiplexing Definitions" by Basil Badawiyeh & Sylvain Riviere, SCTE Cable-Tec Expo 2004.

[3] Based on 4:1 SDB over-subscription in a 230 SD channel pool with 10:1 clamped multiplexing @ 3.75 Mbps in a QAM 256 environment.

Nielsen's Automated Measurement of Lineup, AMOL I & II, along with some closed-captioning formats to digital carriage, required the creation or modification of supporting tools. For instance, SCTE-21 defines a popular and simple mechanism to carry VBI lines. Alternatively, extensions to the ETSI EN 301 775 standard are being formalized today which define digital carriage for a multitude of analog services such as AMOL & CE-GemStar in a manner concurrent with MPEG-2's digital video structure over independent PIDs.

The carriage of messaging and triggering for EAS (emergency alert systems) has changed substantially from the legacy analog mechanisms. In a digital simulcast network, triggering continues to occur via a local ENDEC (encode/decode) in the analog RF domain. However, due to the end-to-end digital architecture, a digital mechanism via SCTE-18 is increasingly being used to trigger EAS edge decoders providing EAS alerts to digital ready QAM tuner television sets.

The flexibility of such recently defined standards provides a basic framework for the digital implementation of the analog services, but truly compliant translation of such services in most cases requires very detailed analysis of feature sets and equipment supported. Future simulcast waves can be more effectively implemented through thorough planning and analysis of the required standards development in advance of execution.

Support for bulk "community cameras" had necessitated inefficient and analog-only solutions, since a local analog RF inserted video signal takes up an entire 6 MHz channel that could otherwise be used by 12 digital services. This hinders the transition to all-digital networks, requiring an effective solution.

Historical lack of standards, solutions, strict regulation and consumer holdouts are proving difficult for achieving discontinuation of the legacy analog services. The creation and enforcement of standards are key to effective and efficient simulcast implementations, and to successfully transitioning to the new technology as the wave subsides and prior practices are phased out.

CASCADING SIMULCAST WAVES

The success of digital simulcast argues in favor of subsequent waves that could include SD and HD simulcast, MPEG-2 and AVC simulcast, and IP simulcast, though not necessarily in that order. The first wave is likely to be an SD / HD simulcast wave since subscriber demand for HD content is growing. IP simulcast may follow to leverage advancing switching and routing technologies, and increasing availability of compatible subscriber devices. An MPEG-2 over IP implementation may be followed by, or coincide with the rollout of AVC video, also through simulcast practices.

Ideally, one wave subsides before the next begins. For example, the bandwidth burden of digital simulcast begins to diminish through analog reclamation before HD simulcast commences, in order to provide the capacity necessary to accommodate the additional bandwidth needed for HD simulcasting. Due to the pace that cable networks are evolving, however, it is likely that more than one simulcast wave will be running concurrently. The cable industry is characterized by a significant lag between early adopters demanding access to new content and late followers transitioning from legacy technologies.

Anticipated simulcast waves are discussed in the following sections.

SD / HD SIMULCAST

The demand for content in high definition is increasing, and is only natural that consumers with HDTV sets prefer to see native HD content, or at least SD up-converted to its highest possible quality, while those that chose to remain with SD continue to receive content in standard definition. Although the transition of cable networks from analog services to digital is ongoing, the next simulcast wave may already have begun. HD content is already available from some of the major networks and premium cable channels.

However, an HD program consumes four times as much bandwidth as its SD counterpart. Do cable networks have the capacity to simulcast every SD program in HD?

Assuming 230 SD programs are available today, a simulcast of every program in HD would require 60 channels more than are available in a 750 MHz plant:

- from a total availability of 116 channels, 80 channels are required for basic analog programming, leaving only 36 channels available for HD content.
- 230 SD programs, if multiplexed at 12:1 in QAM 256, will consume around 20 channels;
- a simulcast of 230 HD programs multiplexed at 3:1 in QAM 256 will require 77 channels;
- a total of 97 channels for SD and HD are required, but only 36 channels are available, a shortfall of 61 channels.

A selective reduction in the number of analog programs broadcast by cable operators will help free-up capacity for HD content, but there will likely be a remnant of a few dozen analog programs for a very long time. Therefore, a full SD / HD wave would have to be accompanied by an aggressive bandwidth reclaim strategy through techniques such as those detailed in table 1.

Fortunately, MSOs have a tremendous advantage over telecom and satellite providers in how HD content can be delivered since the spectrum has been arranged, and technologies aligned, for maximum efficiency. Switched broadcast, which recently saw its first live deployment, is one option for reclaiming the bandwidth needed to support HD simulcast.

THE ROLE OF SWITCHED BROADCAST

Switched broadcast allows for the reclamation of network capacity and can be used to switch the HD versions of programs in an SD / HD simulcast, with benefits accruing as the number of HD programs increases.

Figure 2 illustrates how switched broadcast can be used to mitigate the channel scarcity described in the previous section. The graph, based on Zipf modelling of data obtained during a switched broadcast trial[4], indicates that the peak utilization of a pool of 500 programs is just over 37%. Since the Zipf statistical modelling assumptions in this case were conservative, the actual benefits obtained in a real world deployment could be significantly higher.

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[4] *"The Statistics of Switched Broadcast", the 2005 Conference on Emerging Technologies, by Nishith Sinha, Cox Communications and Ran Oz & S. V. Vasudevan, BigBand Networks.*

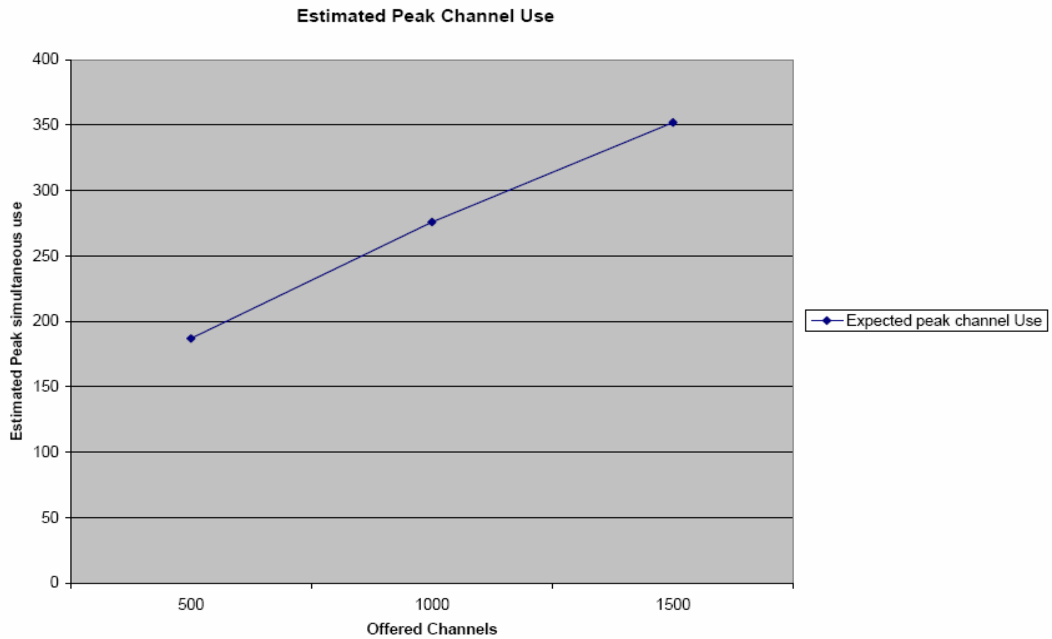

Figure 2: Expected Utilization of Switched Broadcast tiers based on Zipf modelling

Assuming that SD and HD subscribers have similar viewing preferences, a peak utilization of 37% of a 500 program pool (250 SD & 250 HD) implies that the total number of simultaneous programs watched will be around 186 (93 SD + 93 HD). Adoption of switched broadcast will reduce the channel requirement as follows:

- 93 SD programs, at 12:1 multiplexing in QAM 256 system, requires 8 channels;
- 93 HD programs, at 3:1 multiplexing in a QAM 256 system, requires 31 channels;
- the channel requirement is, therefore, reduced by 58 channels.

Under these assumptions, the total channel requirements have been reduced significantly, making a full 1:1 SD / HD simulcast a viable possibility. However, the nature of statistics is such that the real gain, when broadcasting pools are disaggregated into provision to separate populations of SD and HD subscribers, is less than that due to the reverse of statistical multiplexing, so again, other techniques should be considered in parallel with switched broadcast.

At present switched broadcast uses constant bit rate program streams, requiring separate pools of SD and HD programs. However, future enhancements to switched broadcast technology will achieve additional bandwidth benefits by enabling rate shaping of statistical multiplexes that have been formed from combinations of constant bit rate SD and HD programs. In this scenario, rate shaping will dynamically select HD streams that have been clamped at low, medium and high bit rates, based on the capacity available within a statistical multiplex at a given instant, or if efficient and low-cost VBR rate shaping can be applied.

Switched broadcast performs an important role in enabling simulcast by providing bandwidth savings during the simulcast phase and once the transition has been completed. After the transition has ended, switched broadcast continues to enable operators to provide a broad range of programming in the new format with virtually no bandwidth burden. By offering subscribers service packages that offer a broad range of HD programming counts, cable operators can position themselves to compete effectively against satellite and telecom providers.

MPEG-2 / AVC SIMULCAST

As illustrated, even with application of powerful tools like switched broadcast and analog reclamation, expanding to a complete HD tier poses strong bandwidth challenges. A transition to an advanced codec such as MPEG-4 allows huge amounts of spatial and temporal advantages that, by eliminating more granular levels of picture redundancy and providing better prediction of frames, can be additional efficient mechanisms for delivering improved picture quality at minimal bandwidth requirements. Decoupling the access network from the available content is a catalyst for many to adopt alternative delivery mechanisms. Today, many prominent programmers have dual video feeds, some formulated for standard MPEG-2 delivery and others utilizing advanced compression techniques, for delivery over broadband access networks.

This may be sufficient motivation for MSOs to undertake an AVC simulcast wave. Although guidelines for compression / bandwidth efficiency versus noise immunity for the HFC network have been determined for MPEG-2 transmission, similar guidelines for an AVC implementation will take time to develop.

Some of the triggers to an AVC simulcast wave include the following:

- lack of spectrum bandwidth;
- availability of sources and content in AVC format;
- availability of AVC set-top boxes or other CPE;
- availability of AVC encoding, statistical multiplexers, ad insertion and headend processing equipment; and
- maturity of previous simulcast waves.

Initially, AVC content might easily find its way onto networks in support of differentiated tier services such as AVC / HD / VOD or AVC / HD / SB over hybrid digital set-top implementations. As content and the network continue to evolve, additional delivery scenarios would be devised via proven mechanisms such as broadcast video and switched broadcast.

Unlike an HD simulcast wave, which would be triggered by subscriber demands for this programming in this format, initial AVC implementations would be necessitated by the need to conserve bandwidth consumption on the HFC network. The tiered availability of AVC programming could initially be delivered as digital turn-around content as seen prior to the development of MPEG-2 statistical multiplexers. As bandwidth limitations on the HFC network increase, further consideration can be given to headend processing, bit-rate definitions, equipment buffer calculations, channel acquisition times, GOP structure and other MPEG-2 services and their AVC equivalents. Additionally, the advent of an AVC statistical multiplexer would herald a multi-codec environment that extended to IP video, VOD, PVR and DPI environments.

IP SIMULCAST

AVC practices are closely integrated with IP trends, at the highest layer of the networking stack. The expanding IP role in delivering triple-play traffic to an ever increasing array of devices extends to lower layers as well. Access to multiple subscriber devices is enhanced, enabling programming to be delivered to a variety of devices in the home, business and elsewhere. For instance, ESPN makes programming available via MPEG-2 over IP for delivery to subscriber PCs. Also, several large cable operators are experimenting with streaming of live broadcast video to their subscribers' DOCSIS cable modems.

IP simulcast promises such expansion of content to PCs as well as set-top boxes which would gain more IP orientation through initiatives such as DOCSIS set-top gateway. As IP penetrates the end-to-end network, consolidation benefits, similar to those achieved through the convergence of video, voice and data services over GigE transport, can be realized.

Additionally, the Internet enables content to be stored in one location and downloaded in another, driving a highly personalized, on-demand model. The opportunity already exists for a subscriber to watch a local high school football game from Denver or a Serie A soccer game from Italy, all within the comfort of a home in Seattle.

Arguably a form of the IP simulcast wave is already underway today since a wide range of movies and other video content available from cable operators is also available from websites such as flix-online, Movielink.com, CinemaNow and so on. However, this is not simulcast in the true sense because the movies are carried over the DOCSIS portion of the cable network at different times.

The notion of appointment-based television is fading as PVRs and increasing popularity of on-demand programming removes requirements for particular programming to be viewed at particular times. Content owners are increasingly seeking ways to liberate how their content is made available and MSOs will respond with increasing utilization of the Internet to meet this demand. Additionally, recent industry announcements demonstrate a migration to an Internet-based on-demand model. This trend heralds an IP simulcast wave in which a program is broadcast to legacy subscribers at the same time that it is being transported to a storage location for live or delayed viewing later by a subscriber on an IP-enabled device in the home or elsewhere.

To enable such portability, digital rights management and copyright protection technologies have to be implemented. Significant strides have been made in watermarking technology, allowing content to be tracked from source through every consumption portal or interface, thereby providing its owners with a valuable lifetime history.

The demand for time-shifting and place shifting is such that an IP simulcast wave will may coincide with an AVC simulcast wave, or even begin, earlier depending on which technology has earlier availability of associated subscriber devices.

VERSATILE NETWORKING FUNCTIONALITY

Deployment of programmable platforms will allow network functionality to evolve requirements as the industry moves through successive simulcast waves, eliminating forklift upgrades and reducing truck rolls. Innovative platform architectures can accommodate new programming formats by being field upgradeable, allowing ports initially handling legacy formats to support new formats. This can occur without impact on the subscriber viewing experience, and at minimal cost to operations. Remote provisioning of functionality from a central location is possible using SNMP-enabled networking platforms.

With multiple overlapping simulcast waves, the complexity of managing all facilities and traffic is more complex, potentially introducing new vulnerabilities at least as the waves are initiated. IP-based management protocols can also ensure timely alerts in the event of network degradations, allowing maintenance teams to implement pro-active repairs before the subscriber viewing experience is affected. Survivability measures, such as redundancy of platforms and dual sources can improve network availability to carrier-class standards, especially when automatic protection switching is implemented. Additionally, program-level protection switching achieves the highest service reliability levels by affecting a failover if the quality of a single program degrades below preset thresholds.

Innovations in the transport network provide the bandwidth to support both the legacy and new formats in a simulcast deployment. Optical transmission is the perfect vehicle for simulcast waves since fiber optics are format agnostic, and with the use of wavelength division multiplexing practically unlimited bandwidth is available for both legacy and new simulcast formats.

Switched broadcast offers compelling bandwidth reclamation benefits in the access network. By allowing cable operators to deliver only those programs requested in real-time by subscribers, the bandwidth burden on the HFC network is significantly mitigated. This important benefit is particularly relevant to this paper, as it can change the simulcast bandwidth equation. Enhancements to current switched broadcast functionality may enable rate shaping of variable bit rate statistical multiplexes created from combinations of SD and HD content.

Ultimately, optimal bandwidth management depends on best management of network edge resources, including the dynamic allocation of bandwidth across all digital services including multiple formats and protocols. The versatility to change capacity allocations is an important consideration during simulcast planning.

CONCLUSION

The success of digital simulcast has provided benefits to both operators and subscribers. Driven by a number of factors, including changing customer viewing preferences and competitive pressures, the cable industry is expanding service offerings, and this may necessitate future replications of the digital simulcast model. Possibilities include SD and HD simulcast, MPEG-2 and AVC simulcast, and IP simulcast.

Valuable lessons have been learned from the current digital simulcast wave, and these can be applied to future simulcast waves to enable cable operators to implement technology transitions with minimal impact on operations and time-to-revenue. This paper has reviewed the lessons of digital simulcast in detail.

Switched broadcast helps mitigate the bandwidth taxation associated with simulcast. The switched broadcast solution can, for example, significantly reduce the number of EIA channels required to accommodate a 1:1 simulcast of SD and HD content, allowing 250 programs in both formats to almost fit into the current 116 channels currently available on 750 MHz networks.

The transitory nature of simulcast, which mandates a shift from one legacy technology to a new format, demands versatile network functionality. Field-programmable platforms that can be reconfigured without service interruption, and with minimal impact on operations, are needed. Additionally, sufficient capacity in both the transport and access segment of the network is necessary and can be attained using optical transmission, and flexible management of edge resources.