ELEMENTAL

UNIFIED LINEAR TV DELIVERY

Software-Defined Video in Cable and Satellite Operations

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

INTRODUCTION

UNIFYING TRADITIONAL AND MULTISCREEN WORKFLOWS

Software-based video solutions are driving growth and innovation in the television and video industries. Elemental Technologies plays an instrumental role in enabling the market success of multiscreen, live-to-VOD TV services and emerging 4K/HEVC adoption. Elemental's software-based video encoding and just-in-time (JIT) video packaging enable exciting new OTT and VOD services for the likes of the BBC, Comcast, ESPN, HBO, MLB.com, Sky, and Turner Broadcasting System. Each of these traditional media companies now allows consumers to watch content from any device, anywhere and at any time.

As these services gain popularity, video providers are able to quickly scale up and introduce new features thanks to the inherent agility of software. Software-defined paradigms are now being applied to traditional linear TV delivery and the next generation of linear TV networks. New implementations of traditional functions like statistical multiplexing and digital ad insertion are now available in forward-looking software architectures capable of offering continuous improvements in cost-performance ratios for ground and cloud-based processing, networking and storage.

Software-based platforms open new possibilities for cable, satellite, and terrestrial TV allowing for immediate adaption and expansion across standard data-center resources. Support for new codecs, color gamuts and third party integrations can be implemented through simple updates thanks to the flexible nature and shorter development cycles of software. The challenge is to ensure that all functions and technologies are completely software-enabled.

The software abstraction of video processing functions from underlying hardware infrastructure allows encoders, transcoders, origin servers and multiplexers to be logically configured as virtual modules without the need for manual cabling. Entire systems can be managed and controlled for network optimization and reliability through a unified operator interface. New multiscreen, live-to-VOD and targeted advertising services can be deployed alongside traditional and new linear workflows to further drive resource management efficiencies.

This paper provides examples as to how software-defined video encoding, multiplexing, and system management can enable operators to extract additional capacity from their networks, increase the QoS, and reliability of linear TV delivery networks through full system redundancy, simplified workflows and advanced configuration options. Finally, the benefits of software-based video processing are highlighted through the mapping of migration plans to HEVC and 4K Ultra HD TV.

TRADITIONAL LINEAR TV WORKFLOWS

THE PROBLEM WITH STATIC INFRASTRUCTURE

Most linear television operations today include legacy video processing equipment dedicated to specific tasks such as encoding, splicing and multiplexing. Although these workflows may perform well, their functions remain tied to specific hardware components, many times all the way to the chip level. While some hardware systems have upgradable firmware, potential enhancements remain limited to on-board processing power. Adopting a newer and more efficient codec or significant updates to existing codec specifications often requires a complete hardware replacement.

Today's digital TV systems typically rely predominantly on two video compression formats: MPEG-2 and H.264. The emergence of HEVC promises greater encoding efficiencies and supports higher picture quality and differentiated new services in the form of 4K Ultra HD TV. HEVC efficiencies can also extend to benefit video providers with limited bandwidth, such as IPTV operators. Though the North American cable TV market continues to use MPEG-2 for most linear delivery networks, H.264 encoding is required for satellite and IPTV as well as multiscreen OTT and VOD streaming. HEVC is being considered for green-field cable and satellite deployments as well as for those launching 4K services. Simultaneous support for all three of these compression formats within workflows and delivery networks is often the goal as it allows for more seamless migration of technology through an operator's network.

THE STATE OF THE MUX

Today, support for content distribution across most traditional pay TV networks requires advanced compression and statistical multiplexing methodologies. What was once a single 6Mhz wide (8Mhz in Europe) analog SD channel now typically supports several multiplexed HD sub-channels. Since QAM bandwidth for delivering these channels is fixed, one approach to allocating bandwidth is to simply divide the total available bandwidth by the number of sub-channels and then evenly allocate constant bitrate (CBR) encoding levels. However, this static allocation method is extremely inefficient as bandwidth is equally spread across simple and more complex video scenes.

Instead, a more efficient method is to pool together the available bandwidth for several sub-channels and apply active variable bitrate (VBR) encoding per sub-channel in order to increase overall picture quality and free up bandwidth for the channels that need it most at any point in time. A statistical multiplexer is used to analyze the frame-by-frame complexity of incoming video across multiple sub-channels while a bitrate controller sets the target bitrate levels of each encoder so that their total matches the full bandwidth available.

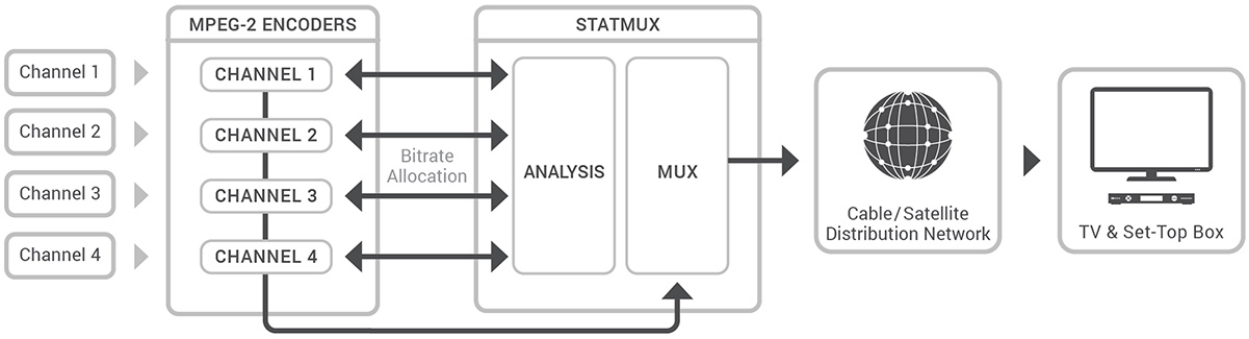

Figure 1 – Traditional Linear TV System Within a 4:1 Statmux Configuration

Increasing channel counts and improved picture quality requirements are driving additional planning and provisioning challenges for limited network bandwidth. Adding more QAMs (or other RF) is costly or often not possible. Improving encoder design and efficiency allows providers to increase the amount of content included in existing mux pools. Dedicated statmux hardware requires switching out older equipment to support newer and more efficient encoders.

THE FLEXIBILITY OF A SOFTWARE APPROACH

To alleviate the cost and complexity of keeping up with continual industry transformation, many TV operators are now looking to software-based solutions that can be easily updated to accommodate technology changes and product enhancements. These solutions initially gained a foothold in the multiscreen video processing market and are now being pulled into traditional TV delivery applications. The improving price-performance ratios of off-the-shelf hardware directly benefit software platforms, allowing for much greater levels of scalability and infrastructure flexibility.

Software-defined video solutions are in part differentiated by the ability to migrate changes and improvements amongst different codecs such as MPEG-2 and H.264. This is not possible with hardware-based solutions for video compression. For example, many of the video compression and computation optimization techniques developed for H.264 and HEVC encoding can be implemented back into the MPEG-2 codec. The MPEG-2 codec can benefit from the pre-filtering and enhanced search algorithms designed for H.264 and HEVC to further improve picture quality and encoding efficiency. This ability to take modern codec design techniques and apply them to mature formats is a key benefit of software-defined video solutions.

For more aggressive unified headend strategies, encoders can ingest 4K UHD or HD content and transcode it into parallel HEVC UHD and MPEG-2 or H.264 HD and SD streams, allowing a single system to create multi-resolution channel outputs from a single source. Whatever the codec combination, an optimal linear video delivery solution is designed to adapt and grow with rapidly evolving cable, satellite and terrestrial network requirements.

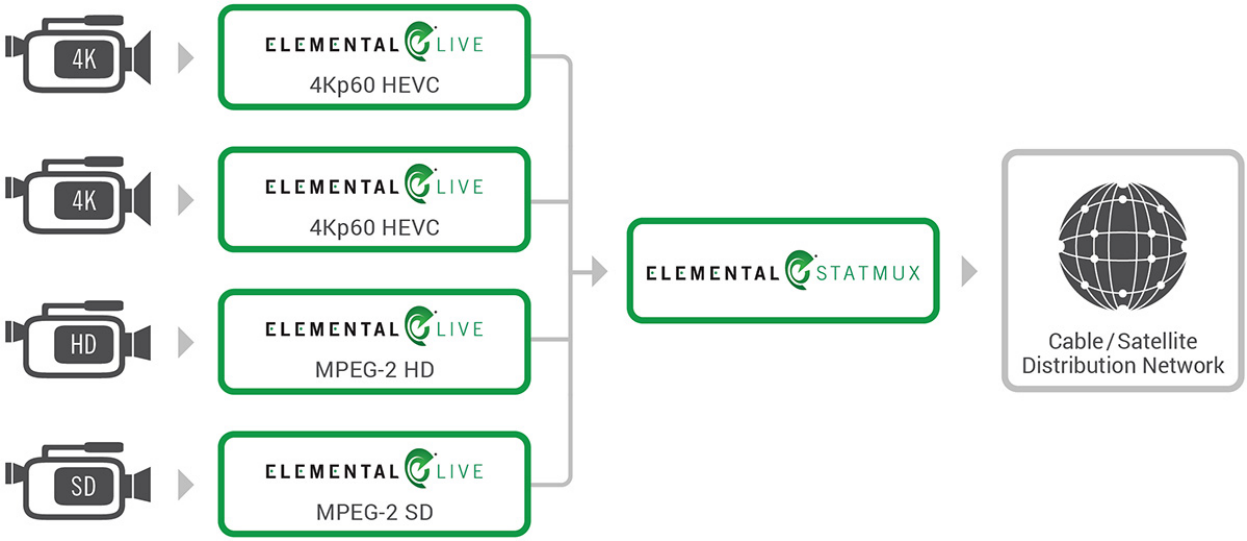

Figure 2 – Elemental Statmux Allows Simultaneous Muxing for Ultra HD, HD and SD

ELEMENTAL SOFTWARE BRINGS THE FUTURE BACK TO THE PAST

EXPERIENCE IN CONSUMER-DRIVEN VIDEO DELIVERY

At a high level, multiscreen video delivery requires encoding, content protection and monetization in terms very similar to traditional pay TV requirements. Encoding functions differ in the ways metadata is handled and in the types and number of outputs required, but input, redundancy and reliability requirements are similar.

Down in the details, however, many parts of the two delivery workflow are significantly different, with alternate technologies for encryption, alternate delivery protocols and many different types of metadata. Adding to these differences is the frantic pace of change driven by a heavy dependence on consumer devices that are typically updated yearly and delivery standards updating roughly every six months. Support for multiscreen video delivery requires software-based solutions that are nimble enough to accommodate rapid change while simultaneously maintaining the reliability required for 24/7 services. The evolution of streaming protocols and monetization strategies for over–the-top services generally makes required an advanced origin server, such as Elemental® Delta, to perform just-in-time packaging, streaming and DRM. Through an advanced origin solution, content can be encoded once, stored in a deliverable mezzanine format, and repackaged and encrypted uniquely for new devices and evolving customer expectations.

For a 24/7 service, regardless of the deployment model or workflow, the possibility of failure at any point in the signal path needs to be well understood, with counter measures in place to provide the shortest interruption possible. All of this experience can also be applied to traditional video operations where the pace of change needs to match that of disruptive multiscreen services.

MULTI-CODEC, MULTI-RESOLUTION STATISTICAL MULTIPLEXING

Elemental® Statmux is a statistical multiplexer designed to accommodate current linear TV workflows with a close eye on the future.

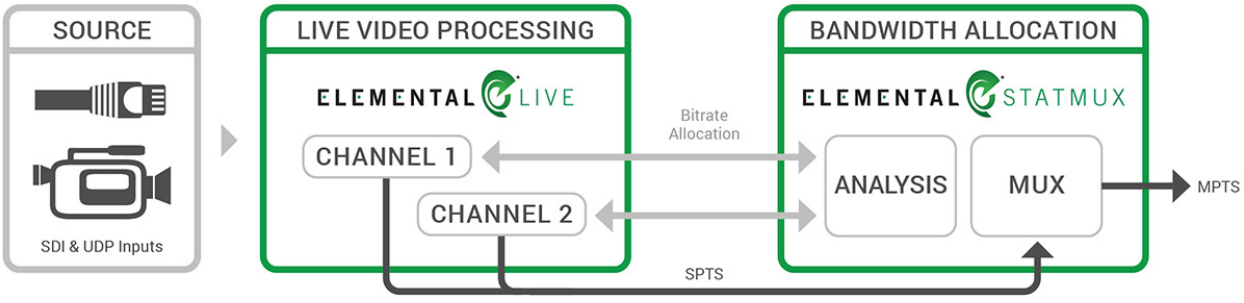

Figure 3 – Elemental Statmux Architecture

With Elemental Statmux and encoding from Elemental® Live, new choices and opportunities arise for determining an ideal mux pool. Support for mux pools that contain mixed codecs such as MPEG-2 and HEVC or H.264 and HEVC allow QAM optimization for both existing services as well as new services. The addition of multi-resolution support advances the idea of statistical multiplexing by enabling new services, including the creation of mux pools containing UHD 4K channels along with HD and SD channels, allowing network operators to thoroughly optimize bandwidth usage. With deployments of the

more recent DOCSIS QAM bonding specifications beginning to take place, the flexibility of including both 4K UHD TV with HEVC and H.264 HD streams within an up to 250Mb mux extends the options and flexibility available for channel configurations even further.

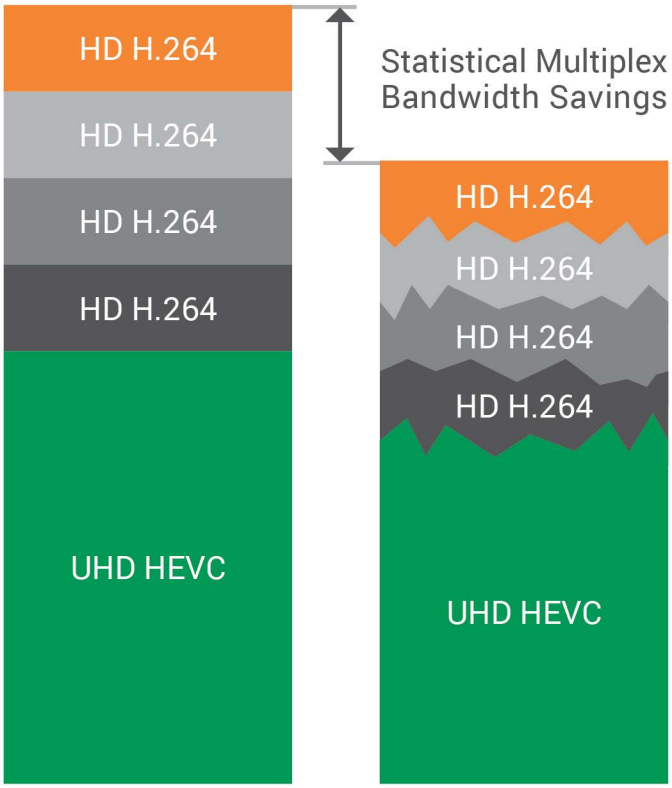

Figure 4 – Bandwidth Savings in a Multi-resolution, Multi-codec Mux Pool

The tables provided in the Appendix of this document include example statmux options for carrying 4K UHD programs over existing pay TV infrastructure simultaneously with existing HD and SD programs. The actual configurations will vary depending on a pay TV operator's preferences based on complexity of typical program content.

In contrast to most hardware-based equipment, Elemental Statmux can potentially operate as part of a linear TV solution embedded within the encoder or as a standalone system. The advantage of having an embedded statmux is that it not only requires minimal rack space, but can also be easily duplicated to a standby system for full redundancy. With support for MPEG-2, H.264 and HEVC, Elemental video solutions can integrate both linear and OTT video delivery within a single unified workflow.

Alternatively, some operators may deploy separate standalone encoders and statmux units. With this approach, each encoder is capable of providing UHD, HD and SD outputs with the standalone Elemental Statmux product acting as a central controller for a large number of encoders and statmux pools. The Elemental Statmux solution is designed for managed networks in comparison with the unmanaged networks found in over-the-top solutions.

FULL SYSTEM REDUNDANCY FOR MAXIMUM UP-TIME

In traditional linear TV deployments, failures were historically limited to a single channel because a single hardware encoder was used for each individual channel. More recent and powerful encoders support multiple channels in a single system. Channels from a multi-channel encoder system with an input or power failure must be switched over to redundant systems, manually or automatically, with minimal or no signal loss depending on the system design. Due to the timing and complexity of failover situations, it's extremely important to eliminate dependence on the content characteristics of the channels. However, redundancy usually comes at the cost of configuration complexity, rack space requirements, and operating expenses.

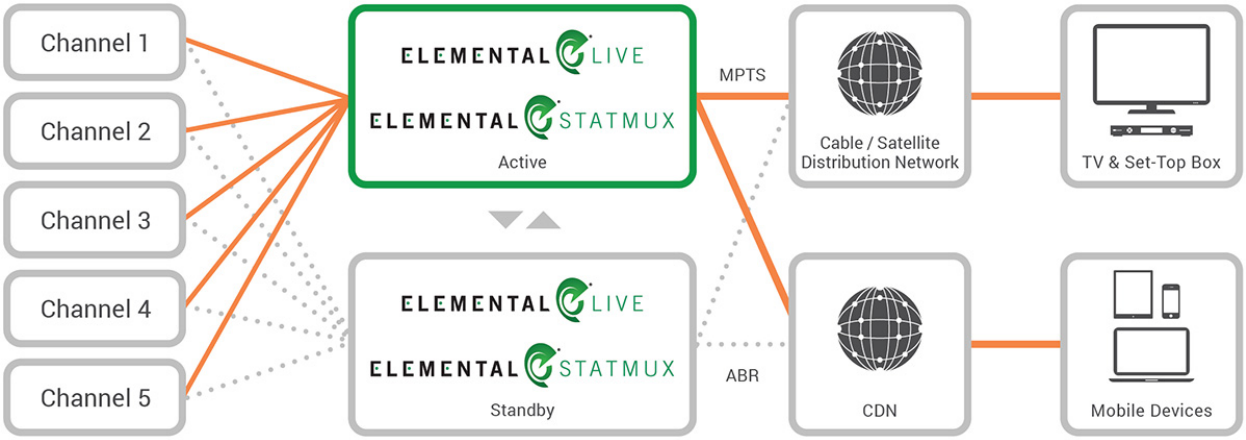

Figure 5 – Input, Node and Output Redundancy for Each Component in the System

With software-defined video processing, linear TV processing, network and storage resources can be dynamically provisioned for video encoding, muxing, and other linear TV delivery functions. Service upgrades, channel line-up changes and system maintenance tasks can be performed without any downtime by switching live functions over to redundant hardware or virtual machines. Elemental software runs on Linux and has been deployed by more than 600 Elemental customers. The Linux operating system eliminates the need for the occasional restarts required by Windows solutions while simultaneously reducing the deployment time for spinning up additional software-based nodes.

For example, Elemental Live encoders support seamless input switching that allows for changing sources with zero dropped frames, node redundancy configured through Elemental® Conductor management software, delivery of statistical multiplexing complexity data to multiple Elemental Statmux units and output listening for 1+1 redundancy scenarios. Since Elemental Statmux can operate in a 1+1 scenario, a failover event will not impact the encoders; similar input and output redundancy strategies to those used by the encoder are also available.

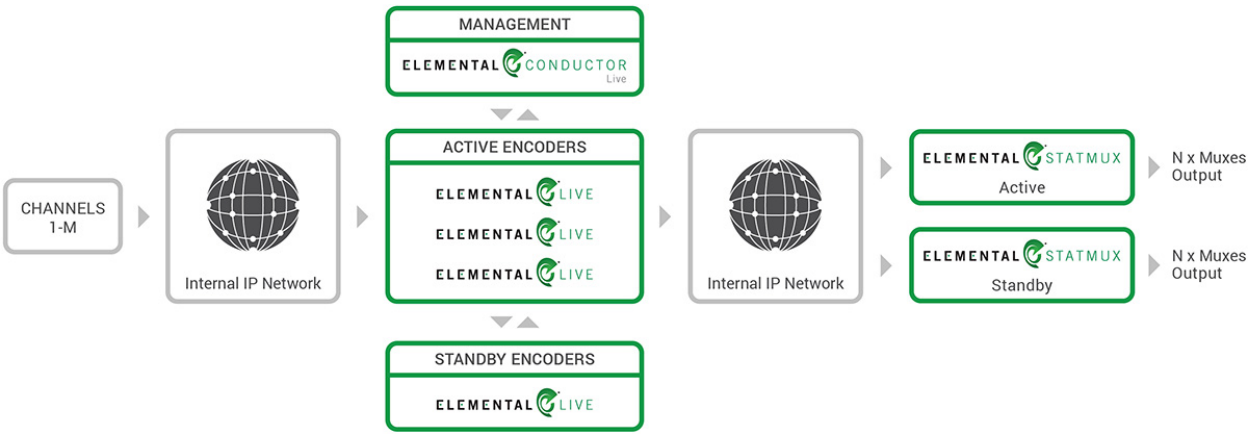

Figure 6 – Fully Redundant Linear TV Delivery System Using Stand-Alone Elemental Solutions

The flexibility and scalability of Elemental software provides many other types of redundancy configurations including 1+1, N+1, and M+N, which are required for more advanced services and complex use cases. Redundancy solutions are designed to cover all services from traditional managed network delivery to multiscreen delivery and for all resolutions from SD to UHD. The result is maximum reliability and minimized costs for on-going maintenance.

ADVANCED CONFIGURATION AND NODE MANAGEMENT

Elemental Conductor management software offers the features and functionality required by pay TV operators for live workflows. New capabilities such as bulk actions that allow multiple channels to be stopped, started and edited simultaneously simplifies management of hundreds of channels while ensuring configurations are synchronized. The combined capabilities of template-based channel configuration and secure authentication capabilities provide confidence that all channels are configured with the desired settings by authorized users. Likewise, audit logs provide insight into the changes made by authorized users. Manual or automatic failover switching with customer-defined conditions add a layer of redundancy control required for maximum reliability and is one of the layers of redundancy control implemented within the Elemental solution ecosystem.

CONCLUSION

There are many reasons linear TV providers may need to upgrade their infrastructure, including natural cyclical equipment updates or the introduction of new services such as 4K Ultra HD TV broadcasts or advanced live-to-VOD. Relying on dedicated hardware is becoming an increasingly complicated and unattractive strategy for most providers compared with using software platforms that are more flexible and scale with increased demand for expanded services. Software solutions from Elemental support MPEG-2, H.264 and HEVC and include statistical multiplexing with the ability to mix resolutions and codecs on the same mux channel. This opens many different possibilities for pay TV operators and enables a smooth migration path from legacy standards.

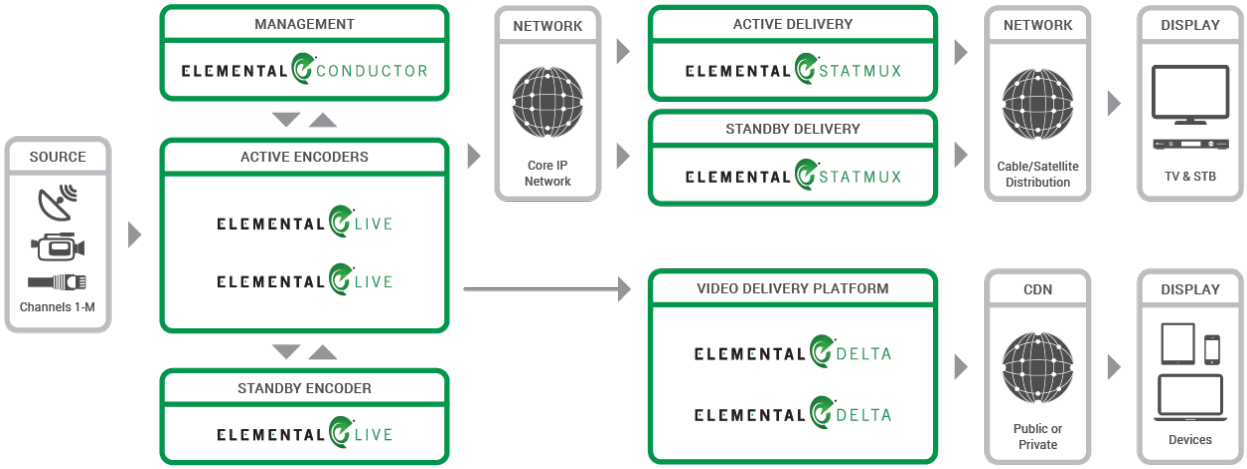

Figure 7 – Elemental Statmux within the Elemental SDV Ecosystem

Leading cable and satellite operators are using software-defined video processing to enable multiscreen TV as well and traditional linear delivery. Unifying these workflows to take advantage of the synergies in operations and processing is a logical next step. As the price-to-performance ratios of off-the-shelf hardware continue to improve and private cloud IT capabilities mature, the business case for shifting traditional video encoding and multiplexing to software-defined video infrastructure has continued to expand and the number of operators doing so has grown.

The key benefits of a linear video solution from Elemental include:

- Multiscreen OTT services can be integrated within a linear workflow for a converged headend
- Scalability and flexibility
- Standalone or integrated statmux options
- Highly efficient MPEG-2, H.264 and HEVC compression for maximum bandwidth optimization
- Mux pools including a mixture of MPEG-2, H.264 and HEVC codecs
- Mux pools including a mixture of SD, HD and 4K UHD resolutions
- Reduced space, cabling, and energy requirements
- Full system redundancy at reduced cost and logical sub-channel failover
- Elemental Conductor for system management and integration with pay TV “manager of manager” systems

By using a software-based approach from Elemental, cable and satellite operators can reduce dependency on underlying hardware infrastructures. This opens up new system configuration, expansion and enhancement possibilities and allows for the introduction of innovative services.

APPENDIX

Table 1 details statmux options for the common 38.8 Mbps mux. Typically video content that is MPEG-2 compressed has two audio channels. To that end, 0.8 Mbps is reserved per program to support the audio payload.

38.8 Mbps Transport	Avg HD Video Bitrate	Avg SD Video Bitrate	Total Video	Audio Budget per Program	Total Audio	Total Budget
4:1 HD	8.8 Mbps		35.2 Mbps	0.8 Mbps	3.2 Mpbs	38.8 Mbps
5:1 HD	6.9 Mbps		34.5 Mbps	0.8 Mbps	4.0 Mbps	38.5 Mbps
Mix: 3 HD + 3 SD	8.8 Mbps	2.0 Mbps	32.4 Mbps	0.8 Mbps	4.8 Mbps	37.2 Mbps
Mix: 4 HD + 2 SD	6.9 Mbps	2.0 Mbps	31.6 Mbps	0.8 Mbps	4.8 Mbps	36.4 Mbps
15:1 SD		1.7 Mbps	25.5 Mbps	0.8 Mbps	12.0 Mbps	37.5 Mbps
16:1 SD		1.55 Mbps	24.8 Mbps	0.8 Mbps	12.8 Mbps	37.6 Mbps

Table 1 – N : 1 MPEG-2 Statistical Mux Deployments – Cable

Table 2 lists options for carrying 4K UHD programs over existing pay TV infrastructure. Some cable operators may use DOCSIS to bond QAMs together, increasing the payload capacity of the mux. Elemental encoders can create simultaneous outputs of an HD version of the same program; therefore, the “mix” options include both 4K and MPEG-2 HD outputs.

38.8 Mbps Transport	HEVC Avg 4Kp60 Video Rate	MPEG-2 HD	Total Video, Mbps	Audio Budget / Program	Total Audio, Mbps	Total Budget, Mbps
2:1 4Kp60	18.0 Mbps		36.0	0.8 Mbps	1.6	37.6
Mix: 1 4K + 2 HD	18.0 Mbps	9.0 Mbps	36.0	0.8 Mbps	2.4	38.4
DOCSIS-3.1 Bonded QAM						
77.6 Mbps Transport (2xQAM)	HEVC Avg 4Kp60 Video Rate	MPEG-2 HD	Total Video, Mbps	Audio Budget / Program	Total Audio, Mbps	Total Budget, Mbps
4:1 4K	18.0 Mbps		72.0	0.8 Mbps	3.2	75.2
Mix: 3 4K + 2 HD	18.0 Mbps	9.0 Mbps	72.0	0.8 Mbps	4.0	76.0
116.4 Mbps Transport (3xQAM)	HEVC Avg 4Kp60 Video Rate	MPEG-2 HD	Total Video, Mbps	Audio Budget / Program	Total Audio, Mbps	Total Budget, Mbps
6:1 4K	18.0 Mbps		108.0	0.8 Mbps	4.8	112.8
Mix: 4 4K + 4 HD	18.0 Mbps	9.0 Mbps	108.0	0.8 Mbps	6.4	114.4

Table 2 – N : 1 MPEG-2 / 4K UHD TV Statistical Mux Deployments

Table 3 shows mux options for two different DVB-T2 transports. Typically video content that is AVC (MPEG-4) compressed has four audio channels to cover linguistic diversity in the service area. To that end, 1.6 Mbps is reserved per program to support the audio payload.

40 Mbps DVB-T2	AVC Avg HD Video bitrate	AVC Avg SD Video bitrate	Total Video	Audio Budget / Program	Total Audio	Total Budget
6:1 HD	5.0 Mbps		30.0 Mbps	1.6 Mbps	9.6 Mbps	39.6 Mbps
7:1 HD	4.0 Mbps		28.0 Mbps	1.6 Mbps	11.2 Mbps	39.2 Mbps
8:1 HD	3.3 Mbps		26.4 Mbps	1.6 Mbps	12.8 Mbps	39.2 Mbps
Mix 4 HD+3 SD	5.0 Mbps	2.0 Mbps	26.0 Mbps	1.6 Mbps	11.2 Mbps	37.2 Mbps
Mix 5 HD+3 SD	4.0 Mbps	1.7 Mbps	25.1 Mbps	1.6 Mbps	12.8 Mbps	37.9 Mbps
Mix 6 HD+3 SD	3.3 Mbps	1.4 Mbps	24.0 Mbps	1.6 Mbps	14.4 Mbps	38.4 Mbps
11:1 SD		2.0 Mbps	22.0 Mbps	1.6 Mbps	17.6 Mbps	39.6 Mbps
12:1 SD		1.7 Mbps	20.4 Mbps	1.6 Mbps	19.2 Mbps	39.6 Mbps
13:1 SD		1.4 Mbps	18.2 Mbps	1.6 Mbps	20.8 Mbps	39.0 Mbps
51.2 Mbps DVB-T2	AVC Avg HD Video bitrate	AVC Avg SD Video bitrate	Total Video	Audio Budget / Program	Total Audio	Total Budget
7:1 HD	5.0 Mbps		35.0 Mbps	1.6 Mbps	11.2 Mbps	46.2 Mbps
9:1 HD	4.0 Mbps		36.0 Mbps	1.6 Mbps	14.4 Mbps	50.4 Mbps
10:1 HD	3.3 Mbps		33.0 Mbps	1.6 Mbps	16.0 Mbps	49.0 Mbps
Mix 5 HD+5 SD	5.0 Mbps	2.0 Mbps	35.0 Mbps	1.6 Mbps	16.0 Mbps	51.0 Mbps
Mix 6 HD+5 SD	4.0 Mbps	1.7 Mbps	32.5 Mbps	1.6 Mbps	17.6 Mbps	50.1 Mbps
Mix 6 HD+7 SD	3.3 Mbps	1.4 Mbps	29.6 Mbps	1.6 Mbps	20.8 Mbps	50.4 Mbps
14:1 SD		2.0 Mbps	28.0 Mbps	1.6 Mbps	22.4 Mbps	50.4 Mbps
15:1 SD		1.7 Mbps	25.5 Mbps	1.6 Mbps	24.0 Mbps	49.5 Mbps
16:1 SD		1.4 Mbps	22.4 Mbps	1.6 Mbps	25.6 Mbps	48.0 Mbps

Table 3 – N : 1 AVC Statistical Statmux Deployments – Cable DVB-T2