ELEMENTAL

LIVE 4K ULTRA HD TV

From Demonstration to Service Launch

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INTRODUCTION

HEVC PAVES THE ROAD TO 4K ULTRA HD TV

2013 will be remembered as the year 4K Ultra HD TV turned from concept to reality. CES 2013 saw the introduction of new 4K UHD TV sets, some priced under $1000. A few months later, the ITU-T and ISO/IEC officially published the HEVC (high efficiency video coding) standard, which greatly benefits the processing and delivery of live 4K UHD TV content.

With a new codec enabling 4K content delivery at reasonable bit rates and the availability of affordable television sets, pay TV operators and over-the-top (OTT) service providers will soon launch new 4K TV services as early trials for the marketplace. Given the more flexible time constraints for on-demand video, online streaming services will likely be the first to offer 4K UHD TV content. However, the real value in 4K TV lies in live broadcasting of high profile sporting and tent pole events. This paper specifically focuses on the use of HEVC for broadcasting and streaming live 4K content and the expected trajectory for its adoption by various content providers and deployment to target markets.

4K Ultra HD TV: Stunning Visual Displays

4K UHD TV includes several technical enhancements over current generation high definition TV sets.

- Higher resolution - 4x the pixels, 4K 3840x2160 resolution compared to 1080x720 with HD.
- Bigger color space - 64x the color range with 10-bit color (1.07 billion colors) versus HD 8-bit (16.77 million colors).
- Higher frame rate - 4K includes support for frame rates up to p120 compared with the HD up to p60.
- Wider luminance Range - Initially the brightest and darkest 4K pixels are similar to HD, although the luminance will probably be widened. The ITU-R is exploring the extension of the luminance range.

To clarify, live 4K UHD TV includes content that is created in real-time from live events that are typically intended for display on large and very large viewing devices, including flat screens and video projectors. Smaller devices such as laptops and tablets will also feature 4K displays and include support for 4K UHD cameras, though the value of content playback will be lower than with larger screens.

Figure 1 - Comparison of Video Resolutions

4K UHD TV sets will accept common HD formats including 720p, 1080i and 1080p as inputs. As with SD content on HD screens, UHD TVs will include upscaling technology to match lower resolution content to higher screen resolutions. The visible results will depend on the upscaling process used, but in general will be noticeably inferior to true 4K UHD TV. In addition, there is also a need to distinguish between the 4K UHD TV and 4K digital cinema standards. 4K Ultra HD TV has a resolution of 3840 x 2160 pixels in line with the current 16:9 aspect ratio of HD TVs while the 4K digital cinema standard uses a slightly wider 17:9 aspect ratio with a resolution of 4096 x 2160 pixels.

4K UHD TV content does not require a particular compression algorithm; however, only HEVC is capable of providing the compression efficiency required to deliver 4K UHD TV broadcasts over today's distribution networks. Though there were various live 4K UHD TV demonstrations throughout 2013, virtually all of them used H.264 (AVC) compression for live content or pre-encoded HEVC for on-demand content. This is about to change with the adoption of HEVC for live 4K UHD TV broadcasts and with Elemental as the first vendor prepared to offer a video processing solution capable of supporting live HEVC encoding for 4K Ultra HD TV.

LIVE 4K UHD TV MEANS BUSINESS

Pay TV operators that launch live 4K UHD TV services in 2014 and early 2015 will gain a competitive advantage in terms of technology innovation and premium service revenue. As 4K UHD TV sets continue to fall in price, more and more consumers will be willing to pay for premium 4K services such as access to live sporting events. Rights holders will also want to benefit from the additional revenue generation 4K TV promises and therefore favor deals with providers who already have a 4K UHD TV distribution system in place. Those who wait to launch live 4K services based on 2nd generation technology may lose out on early opportunities and cede market share to OTT competitors who are also planning to introduce 4K UHD TV services early to the market.

Satellite TV providers are in a good position to deploy live 4K services rapidly by addressing UHD TV sets that include HEVC decoders or by bundling new HEVC compliant set-top boxes with their service. The same applies to cable operators, while telco operators may launch 4K UHD TV services to add value and further entice consumers to sign up for their fiber to the home (FTTH) offers. However, those telco operators that remain reliant on copper wires are less likely to roll out 4K UHD TV any time before VDSL factoring becomes more prevalent in access networks.

OTT streaming providers may be the first to offer 4K UHD TV services. For example, Netflix announced[1] its plan to be "one of the big suppliers of 4K content" in 2014 through the use of video on-demand (VOD) content. 4K clips are already available on Netflix and YouTube, while 4K UHD video players are available for PCs. The control and ownership of flexible software players differentiates this market's ability to roll out new technologies more quickly. It is possible that OTT will evolve to include live 4K services over time, but initial indications point to most OTT content only being available on demand.

THE MIGRATION FROM LIVE HD TO LIVE 4K UHD TV

GETTING THE MOST OUT OF HD

Premium live TV events are currently broadcast in the High Definition (HD) format using MPEG-2[2] or MPEG-4/H.264[3] compression for distribution. Broadcasts with higher frame rates, which are ideal for sports, are typically deployed with 720p60 with progressive frames compared to 1080i60 with interlaced frames for other standard HD broadcast material in North America and at 720p50 compared to 1080i50 broadcasts in Europe. To clarify, p60 represents a real frame rate of 59.94 fps or double the 29.97 fps rate used for standard SD and HD broadcasts (i60). In Europe p50 accurately represents 50fps or double the standard 25fps used for interlaced broadcasts (i50). Even though most TVs and set-top boxes can

[1] "Netflix Testing 'Ultra HD' 4K Video Streams" http://www.pcmag.com/article2/0,2817,2426728,00.asp
[2] MPEG-2 Part 2 standardized in 1984, see ISO/IEC 13818-2
[3] MPEG-4 Part 10 (AVC) standardized in 2003, see ISO/IEC 14496-10

handle 1080p50 and 1080p60, there are few distribution networks that can support these formats due to the increased bandwidth and lack of deployed tool chains. To justify the cost of switching over millions of subscribers to newer STBs and upgrading their internal networks, providers must either increase the number of services available or greatly improve the customer viewing experience. Support for live 1080p50 or 1080p60 broadcasts may be a good reason for some providers to migrate their infrastructure, but others may decide to make the leap to 4K TV.

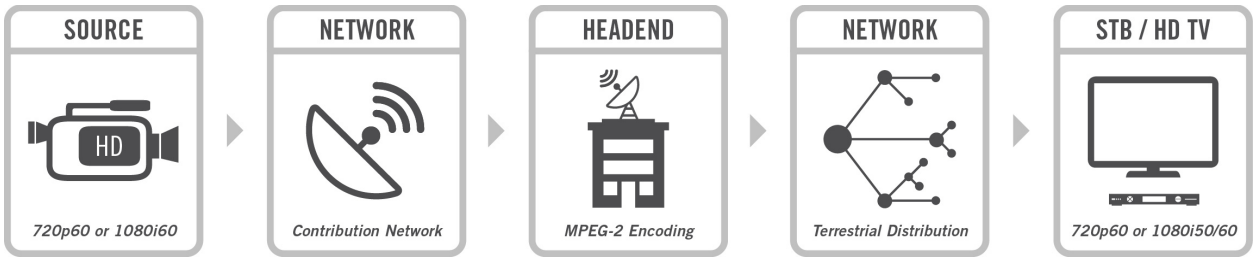

Figure 2 - Typical MPEG-2 HD Workflow

When comparing different types of live distribution networks, it's important to consider the components involved in the workflow, from the initial source to the end viewing device. As shown in figure 2, the contribution network refers to the transport of live video content from a camera to a studio or video headend. This could be as simple as a camera truck beaming uncompressed live video via satellite to the studio. It also may involve light compression using an encoder to reduce satellite bandwidth demand without substantially degrading image quality. The terrestrial distribution network refers to the transport of compressed video from the headend to the pay TV viewer.

Depending on the existing infrastructure in place, supporting live 1080p60 HD broadcasts might require upgrading headend equipment, replacing legacy encoders, and migrating subscribers to HEVC compliant set-top boxes. Though this investment will pay off through a superior viewing experience and therefore boost potential revenues of some providers, others might decide to skip this step and instead focus on rolling out new 4K UHD TV services.

ROLLING OUT LIVE 4K UHD TV

In order to launch a new service, pay TV operators will need to first go through a trial period. This will involve both reception as well as distribution of 4K content. Operators will need equipment and solutions capable of accepting live 4K UHD TV contribution ingests. They will also need a video processing system powerful enough to encode live 4K UHD video in real time. And finally, they will need to ensure enough bandwidth is available for 4K UHD content. 4K UHD TV with a 30p frame rate using HEVC compression requires twice the bandwidth as current live MPEG-2 HD broadcasts. Increasing the frame rate to 60p, ideal for sports and high-resolution videos, will require three times the bandwidth as HDTV.

The following table summarizes the availability of the main 4K UHD TV workflow components at the end of 2013. There are currently no technical roadblocks for end-to-end trials of live 4K UHD TV at either 30p or 60p frame-rates, though the latter will require upgraded television sets expected in 2014.

2H 2013 Workflow Component	HD 720/1080	4K Ultra HD Trials with HEVC
Camera	Available	Available
Contribution Network	Available, compressed uplink	Available, compressed uplink
Headend Encoder	Available, MPEG-2 or AVC	Elemental HEVC Encoder, 4Kp30 10-bit
Distribution Network	Available, BW = 1x 720/1080	Available, Bandwidth is <=2x 720 (See table 3)
Decoder	Available, HW (STB)	Available, SW HEVC 4Kp30 Decoders
4K Ultra HD TV Set	Available	Available, 4K Ultra HD TVs

Table 1 - 4K UHD Workflow Components

THE FIRST LIVE 4K UHD TV DEMONSTRATIONS

The world's first live 4K UHD TV demonstration broadcast using HEVC took place on October 27, 2013, during the Osaka Marathon. Two cameras provided live 4Kp30 feeds over four 3G SDI connections to an Elemental® Live video processing system. The Elemental Live system compressed the video in real-time in HEVC. The live stream was distributed via a K-Opticom optical fiber network to an 84" Sony 4K screen at the Osaka International Exhibition Center. For the first time in history, the general public could experience the resolution and clarity of a live 4K broadcast utilizing the new compression standard.

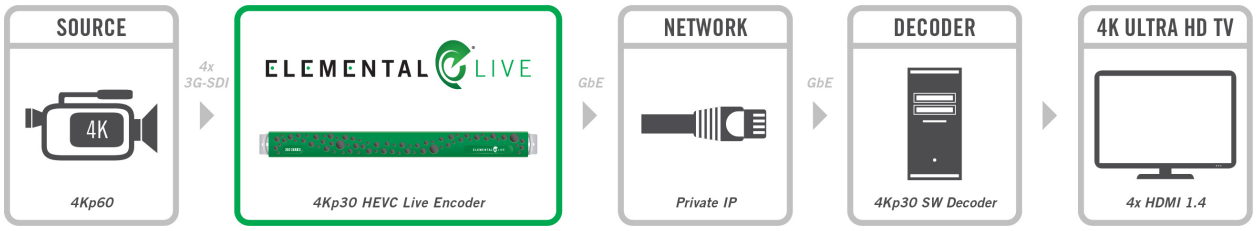

Figure 3 - The First Live 4Kp30 Workflow

According to Takao Fujino, President of K-Opticom, "The stream looked stunning with clear, reliable and very detailed output on Sony 4K televisions. Together, the advanced K-OPT optical fiber network and Elemental's video processing proved real-time 4K HEVC transmission is now a reality."

Figure 4 - Live 4K UHD Coverage of the 2013 Osaka Marathon

On December 10, 2013, Elemental hosted the world's first live demonstration of 4Kp50/60 (full frame rate) HEVC encoding. The demonstration took place in London and was open to members of the press and a select group of video pay TV operators. Elemental captured professional sports content with a 4Kp60 camera to provide the ultimate sharpness, color, and brightness possible for the 4K UHD TV demo. An Elemental Live video processing system was used to encode and deliver this content as a 4Kp60 HEVC output to a PC-based decoder with final rendering on an 84-inch Planar 4K television, capable of 10-bit color display.

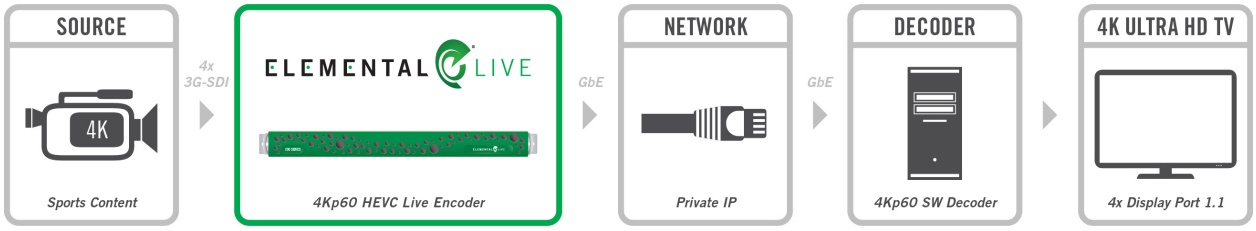

Figure 5 - The First Live 4Kp60 Workflow

Figure 6 - Elemental Captures 4Kp60 Professional Sports Content

Depending on the complexity of the scene, the bandwidth output of the Elemental Live system varies between 14 - 25 Mbps, which represents 99.8% or better encoding efficiency of the original uncompressed content. Elemental Live remains completely compatible with existing delivery capacity of most cable, satellite and IP distribution networks worldwide.

Compression	MPEG-2		MPEG-4 (AVC)		Elemental HEVC	
8-bit color, Bitrates (Mbps)	9.5 - 14	10 - 15	6 - 9	18 - 25		
10-bit color, Bitrates(Mbps)					10 - 18	< 25
Format	720p60	1080i60	1080i60	4Kp30	4Kp30	4Kp60
Horizontal x Vertical Pixels	1280x720	1920x1080	1920x1080	3840x2160	3840x2160	3840x2160
Mpix/Frame	1	1	1	8.3	8.3	8.3
Uncompressed Bitrate	1.125 Gbps	1.5 Gbps	1.5 Gbps	6 Gbps	6 Gbps	12 Gbps

Table 2 - Real-time Broadcast 16:9 Formats and Bandwidth

2014 – 4K UHD TV GOES LIVE

2014 promises a rapid increase in live 4K UHD TV trials as broadcasters and pay TV operators prepare for new service launches. Some of the trials will be used purely for technical testing, others will provide an opportunity to communicate an upcoming 4K UHD TV offer to prospective customers.

In order to ensure success, pay TV operators must first determine how content will be acquired. Will they be managing their own satellite uplinks or will they receive live contribution feeds from a partner broadcaster? Once received, how will they transfer the live feeds to their video processing platform? What type of video processing platform will they use for HEVC encoding? How much bandwidth will they require? And finally, what type of playback devices will they be delivering streams to?

CONTENT DELIVERY FROM THE CAMERA OR SOURCE TO THE ENCODERS

The current generation of 4K 10-bit cameras output a huge amount of uncompressed data requiring up to 12 Gbps of bandwidth. There are several ways to transfer content from a camera to a main location for encoding. One of the ways is to lightly compress the live camera output locally using AVC/H.264 compression. This means reducing transport bandwidth to between 100 and 200 Mbps so that content can be sent via a satellite link to a studio while preserving as much detail as possible. The content can then be decompressed for processing by an HEVC 4K encoder.

Figure 7 - Typical Live 4K Workflow in 2014

Another method is to use an embedded IP fiber optic network to transport uncompressed video content over a 40 Gbps IP connection. This makes sense for staged events, but is not possible for spontaneous coverage such as breaking news events.

AVAILABILITY OF PLAYBACK DEVICES

Operators looking to broadcast live 4K UHD TV must first ensure that viewers have an appropriate decoder for their 4K television sets. Decoders may be embedded either into a television set or come as an HEVC set-top box unit. A range of HEVC compliant STBs and 4K UHD television sets will be announced at the January 2014 Consumer Electronics Show (CES) in Las Vegas. System-on-a-chip (SoC) vendors including Broadcom, STMicroelectronics, and Qualcomm plan to provide required chip components by mid-2014. STB vendors such as Technicolor, Pace, Arris and others are projecting commercial shipments of HEVC 4K STBs starting in the second half of 2014.

Satellite and cable operators should therefore have plenty of STB options to support premium live 4K UHD TV rollout plans before the end of 2014.

HOW OPERATORS CAN DELIVER ON THE 4K UHD TV PROMISE

Rollout plans for live 4K UHD TV services will differ depending on the type of television distribution technology used and the amount of bandwidth available. Operators need to take into account the specifics of their delivery infrastructure. In some cases this could mean investing in additional infrastructure to provide the extra bandwidth needed. In other cases, it may require optimizing bitrate allocation between multiple channels in order to provide the best use of available bandwidth at any single point in time. In most cases, an operator will need to do both.

For satellite operators, the roll out of live 4K Ultra HD pay TV services may require the addition of a new transponder. In North America, for example, a new transponder could carry around nine 4Kp30 programs. For 4Kp60 content, such as for major sporting events, a transponder could carry around six programs simultaneously. It is also possible to mix 4Kp30 and 4Kp60 programs or even mix 4K and HD programs using the same transponder.

Adding 4K programs to existing transponders is another possible solution. The statistical multiplexer and encoders must be compatible and able to automatically communicate with each other in order to maximize the efficiency of the link. Adding a 4K program to an existing transponder likely means that an existing program may be moved or dropped to make room for a new 4K channel. When possible, it is always preferable to add a new transponder for new services rather than to risk disrupting existing services.

For a cable operator, the simplest path to live 4K UHD TV is through the addition of a new QAM (quadrature amplitude modulator). A QAM can carry around four 4Kp30 programs or around three 4Kp60 programs. It is also possible to place multiple 4kp30 and 4kp60 programs into a single QAM.

Cable operators with DOCSIS 3.1 distribution infrastructure have another option. DOCSIS 3.1 offers the ability to bond two or more QAM into a single pipe. A statistical multiplexer operating with 2x or 3x more available bandwidth can carry more programs than the same number of individual QAMs, owing to efficiency gains from having more programs in the one statistical multiplex pool.

In some parts of the world, the terrestrial distribution network can be over microwave or other wireless technologies. Pay TV content may be transmitted over either DVB-T or DVB-T2 physical layer pipes. DVB-T, the first generation standard, usually varies between 18-24 Mbps. DVB-T has a relatively narrow capacity that may support just one or two 4K UHD TV programs while DVB-T2 has similar capacity to a cable 256 QAM, allowing additional statistical multiplex options.

Issues which may affect the rate of live 4K UHD TV service rollout include:

- Conversion of live TV cameras from HD to 4K UHD format.
- Production tool and equipment upgrades supporting the full display capability of 4K UHD TV sets (4Kp60 10-bit format).
- Commercial availability and price of 4K STBs or televisions with embedded 4K decoders.
- Sales of 4K UHD TVs - the rate at which consumers buy 4K UHD TV sets will help determine how quickly live 4K services will be launched. As prices continue to fall and 4K UHD TV sets become a “normal” purchase, it will drive pay TV services to replace HD with 4K UHD TV content more broadly.

CONCLUSION

As television manufacturers introduce bigger, better, and cheaper models, more consumers will be tempted to upgrade their sets. Though 4K content may initially be restricted to on-demand video, pay TV operators will be

able to generate real value through 4K broadcasts of live premium content. Launching a live 4K UHD TV service not only means additional subscription and advertising revenues, but also a way to differentiate their overall service from the competition.

With all of the capture, encoding, and video delivery components available, the rate of 4K UHD TV service roll-out is expected to rapidly increase in 2014 and beyond. Elemental has already demonstrated the viability of an end-to-end live 4K Ultra HD TV workflow using Elemental Live HEVC video processing, the world's first real-time encoder for 4K HEVC. All the other required components for delivering live 4K UHD TV, including cameras, set-top boxes and television sets will be available by mid-2014. Some unknown variables, especially the cost of 4K STBs and TV sets, could delay the full uptake of 4K UHD TV technology, but this will be a matter of quarters, not years or decades.

The table below shows the expected status of the main 4K Ultra HD workflow components in the second half of 2014. As is evident, the deployment of the first live 4K Ultra HD services are expected in 2014.

2H 2014 Workflow Component	Live 4Kp30 Service	Live 4Kp60 Service
Camera	Available	Available
Production tools	Available	Available
Contribution Network	Available	Available
Real time HEVC 10-bit Encoder and Statmux	Available (Elemental)	Available (Elemental)
Distribution Network	Available	Available
HEVC Set Top Box (STB)	Available	Available
4K Ultra HD TV Set	Available	Available

Table 3 - 2014 Launch Readiness for 4Kp30 and 4Kp60

APPENDIX – ESSENTIAL EQUIPMENT AND TECHNOLOGY

4K CAMERAS

Image resolution: 3840 x 2160
Live 4K UHD TV frames per second: 24/30, 50/60
Color space: 10-bit
Recording options: 4:2:0 or 4:2:2
Output: H.264/AVC compressed, MPEG-2 Transport Stream
Output cables 4Kp24/30/50/60: 4 x 3G SDI, 2 x 6G SDI
Output cables 4Kp24: 4 x HD-SDI
Representative vendors: Canon, JVC, Sony
Innovation: Qualcomm Snapdragon chip, Acer Liquid S2 Smartphone with 4K video camera

ELEMENTAL 4K HEVC ENCODER REQUIREMENTS

Input cables: 4 x 3G SDI 4K @ 30/40/60p
Input cables: 4 x HD-SDI 4K @ 24p
Input cables: 1 x 10 Gigabit Ethernet, 1 x 1 Gigabit Ethernet
Color bit depth: 10-bit (recommended) or 8-bit
Output: MPEG-2 Transport Stream or MPEG-DASH
Output: Gigabit Ethernet

SOFTWARE DECODER REQUIREMENTS

Inputs: 4K (3840 x 2160) content encapsulated in MPEG-2 Transport Stream, over Gigabit Ethernet
Decoder: HEVC compressed 4Kp24/30/50/60 10-bit
Outputs up to 4Kp60: 1 x HDMI 2.0, DisplayPort 1.2
Output 4Kp24/30: 4 x HDMI 1.4

HARDWARE DECODER REQUIREMENTS

Inputs: 4K (3840 x 2160) content encapsulated in MPEG-2 Transport Stream, over Gigabit Ethernet
Decoder: HEVC compressed 4Kp24/30/50/60 10-bit
Outputs up to 4Kp60: 1 x HDMI 2.0, 4 x 3G SDI
Outputs 4Kp24/30: 4 x HDMI 1.4
Output 4Kp24: 4 x HD-SDI
Representative STB vendors: Technicolor, Pace, and more
Over-the-Top (OTT) decoder vendors: Apple, Sony PlayStation, Wii U, and Microsoft Windows 8
Representative STB SoC vendors: Broadcom, STMicroelectronics, Qualcomm

4K ULTRA HD TV REQUIREMENTS

Inputs for 4Kp24/30/50/60: 4 x 1.4 HDMI, 1 x 2.0 HDMI, 1 x Display Port, 4 x 3G SDI
Early 4K UHDTV vendors: CHINMEI, Hisense, LG, Panasonic, Philips, Samsung, Sharp, Sony, TCL, Toshiba
Early 4K Monitor vendors: ASUS, Panasonic, Sony, ViewSonic