An Introduction to Ultra HDTV and HEVC

By Gregory Cox, Senior Application Engineer, ATEME – July 2013

We are yet again at a precipice in technology with the introduction of HEVC and 4K. This is the new standard of video quality that will boast resolutions far beyond HD and catapult television into what we will all come to visualize as Ultra High Definition (UHD) TV.

Will this be another iteration of 3D? Or will this parallel the impact HD had on SD in Markets ranging from broadcast, to cable, to mobile devices and cellular phones. Broadcasters and content/service providers are in a heated race to answer this question. The major challenge/hurdle that everyone is tripping over is the bandwidth that will be required to deliver such media. To make any kind of hypothesis as to how this will pan out, we’ll need to dig deeper into what HEVC and 4K actually are. Let’s begin by first understanding the differences between HEVC and 4K. While some may use them interchangeably, they are different and should not be confused.

4K and UHDTV

The ITU (International Telecom Union) Ultra High Definition standard includes two formats, a “4K” format named UHDTV1 and an “8K” format, UHDTV2. UHDTV1 is a resolution which is 4 times the resolution of HD (1920x1080) for television while True 4K is effectively a standard for digital cinema with 4096x2160 resolution. UHDTV resolutions will be delivered to the home as UHDTV at an astounding 3840x2160 lines (8.3 megapixels). The final iteration of the UHDTV standard (resolution) is UHDTV2. UHDTV2 is 7680 pixels × 4320 lines (33.2 megapixels) and is considered for future deliveries.

UDHDTV is assumed to have a picture aspect ratio of 16:9 and framerates will range from 23.976 to 120Hz as a progressive scan and will support 4:2:0, 4:2:2, and 4:4:4 chroma sampling. Bit depths will soar to 10-bit, 12-bit and potentially higher levels of color precision with an extended gamut.
HEVC

High Efficiency Video Coding (HEVC) is the newest video coding standard of the ITU-T Video Coding Experts Group and the ISO/IEC Moving Picture Experts Group. The main goal of the HEVC standardization effort is to enable significantly improved compression performance relative to existing standards—in the range of 50% bit-rate reduction for equal perceptual video quality. The HEVC standard is designed to achieve multiple goals, including coding efficiency, ease of transport system integration and data loss resilience, as well as ease of implementation using parallel processing architectures. HEVC is also known as H.265 or MPEG-H part 2 and will be the delivery path for UHDTV.

H.264/AVC  HEVC

Here is an example of the progression to the new resolution that UHDTV is expected to bring:

**Increased detail perception**
Industry Challenges

Aside from delivery concerns to the end users, another questionable item that all broadcasters and service providers are struggling with is timing. This timing is specific to when a significant number of consumers will actually have a 4K UHDTV viewing monitor or television in the home. While there will be an initial movement by wealthy consumers who can afford the outrageous prices in the first push to market, deliveries are expected to reach all customers if this race is expected to maintain pace with any velocity. Currently there are many offerings as it relates to monitors however the price point begins right around the “4K” mark! Many consumers will wait for prices to drop from the stratosphere before committing to this new HD format and television manufacturers are already looking into strategic ways to bring this cost down.

The difficulty of 4K UHDTV spills over into the home as well, to consumers. Broadcasters will too have to consider other devices that sit in the majority of television viewers’ homes - set top boxes. Set top boxes currently have chipsets that are not capable of processing the new format and the boxes are unable to decode 4K UHDTV material. There’s also the question of the HDD and the ability to store massive amounts of data for DVR purposes. This will be an integral part in how 4K UHDTV is delivered to the home. Along with determining how broadcasters, cable and satellite providers will get 4K UDHTV to the set top box – if there is a set-top-box – interconnectivity within the home is currently an issue. HDMI is the choice cable, in many homes, for delivering a High Quality HD Digital signal to the television. Currently HDMI is limited to 30Hz under the latest HDMI standard of 1.6. While the 4K standard provides for a range of rates, it is believed that HDMI will be required to deliver 60hz to the television. It is expected that this will be supported with HDMI 2.0 slated for delivery in 2013.

So we’ve identified what 4K UHDTV and HEVC are, and we know that broadcasters have work to do to get the media to end-users. But we’ve forgotten one major point in all of this; how can you send 4 to 8 times the amount of data to the end-user without spending billions in infrastructure make-overs? Many of the older broadcasting plants are SDI, which makes for difficult transportation of high resolution content across the manufacturing plant. Will the promise of new customers and new revenue streams validate potentially moving existing infrastructure to an all fiber plant? Will plants that are currently fiber have any obvious advantage in positioning themselves for this new technology? These are questions that still remain to be determined and only time will tell.

HEVC can be powerful if leveraged properly. One of the most important points to look at is coding structure. ATEME has developed the most advanced HEVC encoder product in the industry and has been building codecs since 1991 and does not “third party” algorithms. It is a partner of the 4EVER (for Enhanced Video ExpeRience) Project, a French research consortium that started as a three-year collaboration and multi-million euro research plan. The objectives of the consortium were to research, develop and promote an enhanced quality television experience. As an active contributor to the HEVC standardization process we’ve involved our own experts. For more information about the 4EVER Project visit: http://www.4ever-project.com/
HEVC Coding

Let’s dig into the detailed complexity of HEVC and its coding structure. The HEVC coded is optimized with the Quadtree Coding Structure. A quadtree is a tree data structure in which each internal node has exactly four children. Quadtrees are most often used to partition a two-dimensional space by recursively subdividing it into four quadrants or regions. The regions may be square or rectangular, or may have arbitrary shapes.

The macroblocks used in H.264/AVC are replaced by Coding Tree Units in HEVC. The above image shows how an image block is split into the quad tree structure. The Coding Tree Unit (CTU) consists of a Luma Coding Tree Block (CTB) and the corresponding chroma CTBs and syntax elements. The CTU specifies the positions and the sizes of the Luma Coding Block (CB) and chroma CB. One Luma CB and generally two chroma CBs together with syntax, form a Coding Unit (CU). A CTB can have one CU or be split into several CUs. The decision to code an area of image as intra or inter is taken at the CU level. A CU is the root for both Prediction Unit (PU) and Transform Unit (TU). A Prediction Block (PB) can be the size of a CB or be split further into smaller luma and chroma PBs. The supported sizes are 64x64, 32x32, 16x16, 8x8 and 4x4. Details are seen in the image below.
For inter prediction modes, non-square modes are allowed as shown below. An inter frame PB cannot have a size of 4x4.

For intra prediction, HEVC specifies 35 different prediction modes for luma samples. For each PB, any one of the 35 prediction modes can be used to generate a prediction. Both the encoder and decoder always use the row of pixels to the top, and the column of pixels to the left of the current prediction block, to generate the prediction. The prediction mode specifies how the top row or the left column should be used to generate a prediction. In HEVC, there are 33 angular modes, a DC mode and an interpolation mode. The figure below shows the angular modes and the corresponding mode numbers in HEVC.

H.264/AVC

HEVC

9 prediction directions

33 prediction directions

HEVC = Luma: 35 prediction directions (33 + Planar + DC)

Depending on the position of the intra prediction block, any number of neighboring samples may not be available. For example, they could be external to the picture, in another slice, or belong to a CU that will be decoded in the future (causality violation). Any samples that are not available are filled in using a well-defined process after which the neighboring arrays are completely full of valid samples. Depending on the block size and intra mode, the neighboring arrays are filtered.

Rate Distortion Optimized coding decision
To generate a prediction for the current block, the decoder has the pixels to the top and the left pixels. The encoder must also determine the size of the prediction block (PB) to be used. For a coding block, the HEVC encoder must check for all possible prediction modes at all allowed PB sizes and select the best combinations of PB sizes and modes to encode a certain coding unit (CU). This decision is made based on rate distortion optimization (RDO). With no time constraint when encoding content offline, it is possible to try all the possible encoding modes, measure distortion for every mode, and apply the mode decision based on these results. But the real-time encoding of live content requires shortcuts and original prediction algorithm to guess those results and make a smart mode decision without running a full encoding process of each possible mode. These original prediction algorithms are the main reason why two “standard” encoders, despite their compliance to the same standard, can produce very different results.

The process of intra prediction mode decision in HEVC involves the encoder measuring the values of distortion and rate for each of the 35 available modes and then selecting the mode that provides the lowest rate-distortion cost.

In the HEVC encoder, the PB size is also determined using rate-distortion optimization. While larger PBs are more efficient, smaller PBs are required in regions of high detail and texture. The encoder should measure the values of distortion and rate for each of the 35 modes at every level of the PU subtree.
HEVC toolset versus MGEG-2 and H.264/AVC

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ATEME has provided for several technical contributions to the standardization of HEVC such as parallelization tools (wavefront and tiles), intra coding tools, and high-level syntax. We have also offered professional considerations relating to 10/12bit, 4:2:2, and 4:4:4 specifications along with profile considerations. The largest contributions to the HEVC saga offered by ATEME are interlaced support and coding tools. There are two patents pending on this topic.

**Proposed Solution for Interlaced Content**

HEVC is generally not perceived as an efficient coding standard for interlaced content, which recent research has proven to be untrue. Indeed the new codec, pending a proper use of its toolset, can be applied very effectively to interlaced content by applying SAFF (Sequence Adaptive Frame Field) together with efficient field coding techniques and elaborate coding decision for each sequence. SAFF is designed to provide the best of both worlds as it relates to progressive and interlaced content. This is due to coding modes being switched based on the content. This switching occurs at GOP (Group of Pictures) boundaries to ensure HEVC compliancy. This approach to interlaced content encoding allows coding efficiency results in HEVC to reach practically the same levels as what has been observed to date on progressive content in terms of PSNR (Peak Signal to Noise Ratio). When encoding a mixture of progressive and interlaced content, PSNR results are always better with SAFF when compared to Field only or Frame only coding.

While HEVC was originally designed for progressive video only, encoding interlaced content is possible. Broadcasters are hugely concerned regarding this fact as many house large libraries of legacy interlaced content that will need to be transcoded into the HEVC format.

**Conclusion**

Ultimately the HEVC codec will provide up to 50% bandwidth savings for today and tomorrow’s television broadcasting. After contributing significantly to the standardization effort, ATEME will offer one of the most advanced implementations of the standard that broadcasters can deploy in the field to benefit from these bandwidth savings. ATEME will offer its first deliveries of HEVC on the TITAN product line to support OTT platforms for PCs, connected TVs, mobile devices and cellular phones. ATEME will also offer HEVC for UHDTV as broadcasters prepare to embrace the new format. UHDTV Proof of Concepts and trials are at an all-time high while distributors, aggregators and service providers scramble to deliver the first immersed viewing experience to the home.

**About the Author**

Gregory Cox has over 10 years of engineering experience derived from companies like Ascent Media, Avail-TVN, and Telestream, where he developed his expertise in media workflows, video over IP, networking, post production and video compression. After joining ATEME in 2012, he was able to feed his obsession with new technologies by diving head first into the evolving world of HEVC and 4K/UHDTV. Recently, he was a speaker on 4K/UHDTV and HEVC at this year’s WBU-ISOG hosted by Fox and will be speaking at the upcoming SMPTE Symposium 4K/UHD Business Track.

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