High efficiency video coding (HEVC): Replacing or complementing existing compression standards?

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High Efficiency Video Coding (HEVC): replacing or complementing existing compression standards?

Jean-Pierre Henot, Michaël Ropert, Julien Le Tanou, Jean Kypréos and Thomas Guionnet

Abstract — **The HEVC (H.265) video compression standard was finalized in January 2013. It doubles the coding efficiency compared to its predecessor H.264/MPEG-4 AVC, however, with significantly higher complexity. Now that HEVC is available, the question of its industry adoption and implementation within the video broadcasting market segments is addressed in this paper. It is discusses whether HEVC should replace existing compression technology or should be dedicated to emerging markets. It demonstrates that HEVC will coexist with currently deployed video compression standards, and shows how the initial limitation of HEVC to progressive material – eventually penalizing the HEVC standard adoption by the industry – can be overcome. Finally, insight is provided on a software architecture suitable for implementing multi-standard, multi-screen HEVC encoders.**

Index Terms — **HEVC, H.264, AVC, MPEG, IPTV, OTT, BROADCAST.**

I. Introduction

The new HEVC video compression standard was finalized in January 2013. Allowing bitrate reduction of 50% while providing equivalent quality compared to its predecessor H.264/MPEG-4 AVC, it is expected to be rapidly adopted by the video compression industry. However, its coding efficiency comes with a price: significantly higher complexity. Moreover, it has been designed specifically for the encoding of progressive video material, while previous standards, such as H.264/MPEG-4 AVC, provide encoding tools dedicated to interlaced video content as well.

This paper addresses the question of HEVC usefulness and adoption within the video broadcasting market segments. It discusses whether HEVC should replace existing compression technology or should be dedicated to emerging markets. A software architecture suitable for implementing multi-standard, multi-screen HEVC encoders is outlined.

Section II summarizes the development, main features and performance of HEVC. Section III discusses the relevance of HEVC in the video broadcasting market. In section IV, the specific issue of interlaced video handling is addressed. Finally, section V outlines a flexible software-based video encoder architecture.

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II. High Efficiency Video Coding (HEVC)

A. HEVC development

Video coding standards have been developed by two major organizations, namely Video Coding Experts Group (VCEG) from ITU-T and Moving Picture Experts Group (MPEG) from ISO/IEC. The former produced H.261 and H.263 while the latter produced MPEG-1 and MPEG-4 Visual for instance. The two organizations also jointly developed the H.262/MPEG-2 Video and H.264/MPEG-4 Advanced Video Coding (AVC) standards. Those two standards have been of paramount importance for the video industry, enabling large scale broadcast of digital video on various channels. Directly preceding the new HEVC standard, H.264/MPEG-4 AVC was issued in 2003 [1]. It has been a key enabler in many application domains such as high definition (HD) video broadcasting and storage (Blu-ray discs), mobile and Internet TV delivery. Despite its acknowledged compression efficiency, H.264/MPEG-4 AVC is challenged by the increasing popularity of HD video, the emergence of even larger resolutions and the constantly growing video traffic on mobile and Internet networks.

In parallel to the market adoption and development of H.264/MPEG-4 AVC, both the VCEG and MPEG groups conducted exploration activities on coding efficiency improvements from 2004 to 2008. A call for evidence was issued in 2009 [2]. The potential for a significant coding efficiency improvement motivated the creation of a new joint standardization effort. The Joint Collaborative Team on Video Coding (JCT-VC) was established by ITU-T and ISO/IEC in January 2010 and a joint call for proposals was issued [3]. At the first meeting in April 2010, the project name, "HEVC" and a first test model were chosen. During subsequent meetings, coding efficiency, complexity reduction and parallel processing friendly designs were investigated. HEVC evolved until the end of 2012, then reaching a stable state. The new HEVC standard was issued in January 2013 and is known formally as ITU-T H.265 or ISO/IEC 23008-2.

B. HEVC design and features

The high level syntax architecture of HEVC is very similar to H.264/MPEG-4 AVC. The parameter set structures (SPS, PPS) have been complemented by a new video parameter set (VPS). NAL units, slices, SEI and VUI remain almost unchanged [4].

HEVC relies on the classical hybrid video coding scheme, comprising closed loop motion compensation and transform coding. It retains multiple references and the flexible GOP structure of H.264/MPEG-4 AVC. However, it departs from the previous encoder architectures at almost every elementary step.

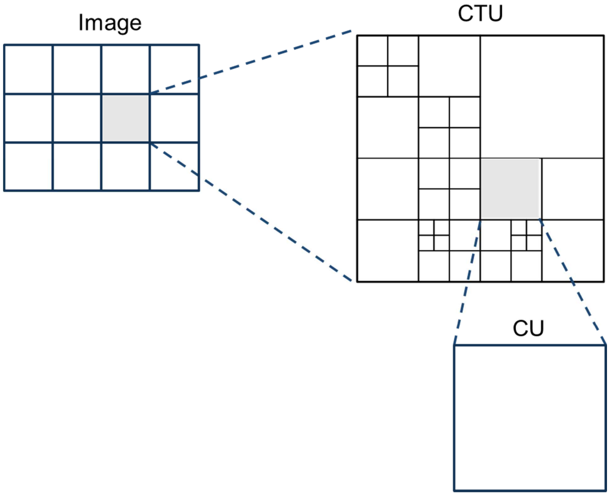

Figure 1: Example of HEVC image partitioning into CTUs and CUs.

First, the previous fixed macroblock size picture subdivision is replaced by a more flexible recursive quadtree structure. The picture is divided into coding tree units (CTU). The size of a CTU is specified at the encoder and can be 64x64, 32x32 or 16x16. The CTU is composed of a luma coding tree block (CTB) and the two corresponding chroma CTBs. The CTBs can be subdivided into smaller blocks following a quadtree structure. Luma and chroma CTBs are subdivided jointly. The leaves of the CTBs are coding blocks (CB). A luma CB and two associated chroma CBs form a coding unit (CU). Image splitting into CTUs and CUs is depicted on Figure 1~~Figure 1~~.

A CU can be encoded using either intra or inter prediction. The CU is the root of the prediction unit (PU) partitioning structure and the PU is composed of prediction blocks (PB). A predefined set of partitions is available. Let a CB be of size 2Nx2N. In intra mode, a PB can have the same size as the CB (2Nx2N), or be divided into four square partitions (NxN). In inter mode, the PB can similarly be of size 2Nx2N or subdivided in NxN parts. Moreover, 6 rectangular partitions (Figure 2~~Figure 2~~), including 4 asymmetric, are available.

The prediction residual is handled at the CU level. The CU is divided into square transform units (TU) following the residual quad-tree (RQT) structure (Figure 3). The transform size may be equal or smaller than the CU size.

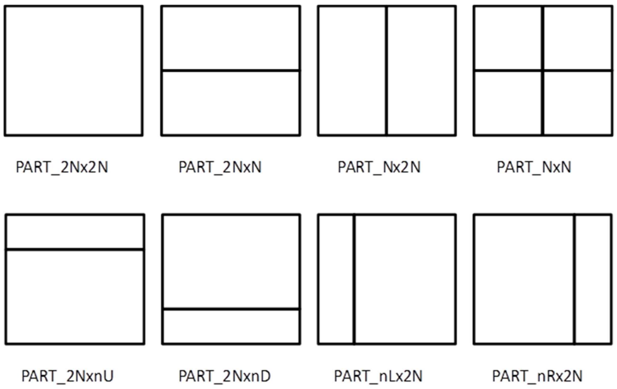

Figure 2: HEVC modes for CU partitioning into PUs.

Intra prediction is enhanced compared to H.264/MPEG-4 AVC. The decoded boundary samples of adjacent PBs are filtered before being used for intra prediction. Thirty three directional modes, one planar and one DC mode are available. A most probable mode (MPM) strategy avoids excessive mode signaling overhead.

Inter prediction is performed through quarter-sample precision motion compensation. Fractional-sample positions are interpolated using 7-tap or 8-tap filters. A PB can be predicted uni-directionally or bi-directionally. Weighted prediction is also allowed, as in H.264/MPEG-4 AVC. Advanced motion vector prediction (AMVP) enhances motion vector prediction. Several motion vector (MV) candidates are normatively derived and indexed, thus reducing motion vector differences by selecting the most relevant candidate. Similarly, the merge mode takes advantage of spatial and temporal correlation between MVs. In that mode, only an index has to be transmitted along with PB residual instead of full MV information. The same index strategy is used to enhance the skip mode.

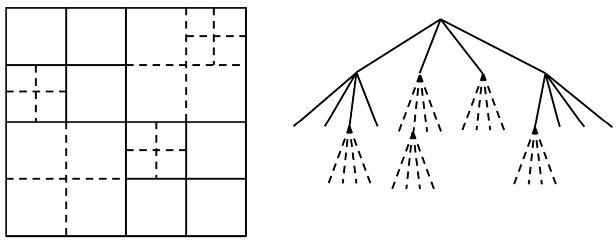

Figure 3: CTU splitting into CUs (plain lines) and TUs (dashed lines) with associated quad-tree.

Quantization and transformation are similar to H.264/MPEG-4 AVC, with transform sizes going from 4x4 to 32x32, squares only. A new in-loop de-blocking filter has been included in HEVC. Moreover, sample adaptive offset (SAO) has been introduced. It is implemented in the prediction loop, after the loop filter. Its non-linear mapping allows better reconstruction of the original signal. It requires some parameters to be determined by the encoder.

CABAC has been retained as the only entropy encoder. Compared to H.264/MPEG-4 AVC, the arithmetic encoding engine remains unchanged. However, in order to reduce the overall complexity, the binarization part has been revisited and the number of contexts has been reduced.

Finally, in order to handle the augmented complexity of HEVC compared to previous standards and also to take advantage of modern multi-core architectures, several high level parallelization strategies are available, namely slices, wavefront parallel processing (WPP) and tiles.

C. *HEVC performance and complexity*

Regarding coding efficiency, HEVC provides a significant improvement compared to H.264/MPEG-4 AVC. In a configuration that could be used for video broadcasting, objective bitrate gains at constant quality of 34% are reported [5]~~[10]~~. It is also claimed that the subjective quality is much better, thus allowing reduction of the bitrate by a factor of 2 compared H.264/MPEG-4 AVC [11]. One has to note though, that these results are obtained using the HEVC reference model (HM). This software is designed to demonstrate the optimal coding efficiency achievable and is not suited to applications.

Several complexity analyses of HEVC have already been conducted [6][7][8]. It is reported that although HEVC is more complex than previous standards, the decoder complexity remains reasonable. The encoder, on the other hand, has many more parameters to choose. It is reported that an HEVC encoder can be more than 4 times slower than an H.264/MPEG-4 AVC encoder [6].

III. HEVC, EXTENDING HD VIDEO DELIVERY

New generations of access or broadcast networks have been launched successfully with a major increase in bandwidth available to deliver new services. DVB-S2 for satellite and DVB-T2 for terrestrial distribution have increased the capacity of the distribution network by more than 30% to 60%.

DVB-T2 offers a bandwidth around 40Mbps, when the previous generation offered 24Mbps.

In the telecom (telco) access network, the figures announced are even more impressive with bandwidth increased from 3 Mbps to 100 Mbps when switching from 3G to 4G networks (these are practical rates, theoretical ones being even more aggressive).

With this increased capacity, why should we care about bandwidth and looking for more efficient compression?

Many homes are still connected through legacy ADSL networks. This implies that the broadband download speed is still below 10Mbps in most cases (9.6Mbps was the mean download speed in UK in 2012 [9]), shared across services in the home, such as web browsing, file download, gaming, and video. This will still be one of the bottlenecks in the extension of HDTV distribution to the home as foreseen by telecom operators.

New generation of mobile terminals (tablets and smartphones) now come with display resolutions supporting HDTV, or even higher, driving the video consumption on those devices, and the demand for higher video quality at higher bitrates.

The expected yearly growth rate for mobile video in the coming years is around 75% [10]. This already creates high pressure on the access bandwidth of the 4G networks. Telcos are pushing to offload the mobile traffic to the home network through Wi-Fi, when ADSL capacity is already scarce.

Television displays supporting 4K/UHD are being announced and will be broadly available starting summer 2013, and will drive demand for higher quality pictures at higher bitrates.

Compared to H.264/MPEG-4 AVC, HEVC will help resolve those issues by dividing the required transmission capacity by a factor of two – or even higher – with the same video quality [11][12] HDTV services will be achievable at bitrates below 3Mbps in 720p50 format and between 3 to 4Mbps in 1080i50.

This should enable the extension of HDTV services to close to 100% of users on ADSL networks, as currently promoted by European telcos [13], and enable the broadcast of more HDTV services on the terrestrial networks, allowing the complete conversion from SD to HD without the need to extend the spectrum. By coupling DVB-T2 and HEVC, potentially up to 8 full-HD services could be launched where only 3 were available with H.264/MPEG-4 AVC and DVB-T.

Furthermore, it will benefit the launch of 4K/UHD services in the near future.

By the same token, delivering HD services to the next generation of mobile appliances will now be achievable with 720p pictures transmitted at around 1Mbps for small screens.

While the video standard has been finalized in early 2013, there is still on-going activity on the transport layers for HEVC delivery. The draft definition of the encapsulation of HEVC streams in the MPEG Transport Stream layer is a minor amendment to the existing standard and should be achieved smoothly. Then, other standardization bodies will consolidate the use of HEVC in their specific field of application. The work is in progress for terrestrial and satellite broadcast by DVB, as well as by 3GPP for the transport of HEVC over 4G networks, where the encapsulation of video for HTTP streaming is considered using the MPEG-DASH protocol layer [14].

IV. INTERLACING IN HEVC

Despite the continuous growth of progressive scan format usage, data flow from video production to delivery through heterogeneous networks (cable, satellite, telcos, broadcast, etc.) is still massively using interlaced video content. , Most content is natively sampled in 1080i resolution, and traditional delivery of HDTV services to the home often relies upon interlaced formats [15]. For example, the native production format used for the 2012 London Olympics was 1080i50; and, content archives around the world store nearly 15 years of HDTV content in 1080i. Based on this observation, it seems obvious - widely for economical purposes - that new video coding standards, such as HEVC, should handle interlaced content as well as progressive content.

Efficient encoding of interlaced content with H.264/MPEG-4 AVC is ensured thanks to specific interlace coding tools working either at picture level (Picture Adaptive Frame Field, PAFF) or at block level (Macroblock Adaptive Frame Field, MBAFF) [16].

Paradoxically, compared to the widespread video production and delivery practices, 100% of new multi-screens display only progressive format. In order to simplify ecosystems, HEVC has been specifically designed for progressive content, and consequently frame coding. A question is raised: what are the ready-to-use technical solutions to handle interlaced content within HEVC?

HEVC Text specification draft 10 [16], through VUI and SEI, provides specific syntax to signal if the input video sequence should be coded as frame or field. Signaling is constrained at the coded video sequence (CVS) level, meaning that eventual adaptive frame/field switching could happen only on IDR.

In that context, campaign tests have been done to assess HEVC performance for interlaced video content. In [17], HEVC Frame coding only and HEVC Field coding only are respectively compared to H.264/MPEG-4 AVC with interlaced tools (PAFF and MBAFF) turned on. Results emphasize that performance of HEVC over H.264/MPEG-4 AVC in field or frame mode can vary significantly depending on sequence motion characteristics. Field only mode is more efficient for sequences with large motion, while frame only mode is more adapted to sequences with low motion. Observations made by the Authors tend to conclude that performance of HEVC could improve significantly if adaptive frame/field coding at least at picture level were allowed. However, this conclusion is contradicted in [18]. The Authors demonstrate that HEVC performance on interlaced content is significantly improved while using field only mode and a well-adapted GOP structure allowing cross-reference between top/bottom fields. According to objective and subjective test results conducted, it was observed that the performance improvement of HEVC compared to H.264/MPEG-4 AVC on interlaced video content is close to progressive video content.

Moreover, thanks to available SEI syntax, sequence adaptive field frame encoding (SAFF) is possible in HEVC; preliminary results using SAFF in Random-Access Main Profile test condition are depicted in [19]. An Intra Period of one second is used, then for each GOP best frame or field mode is selected a posteriori based on R-D gains. HEVC SAFF exhibits significant bitrate savings over HEVC Field Only, of -3% and -20% for luma and chroma, respectively. At this time, an MPEG-AHG is further evaluating SAFF with improved GOP structures and additional features [20][21]. Also, it is important to point out that decoders conforming to the first version of the HEVC specification are allowed to ignore the SEI syntax dedicated to frame/field information. If SEI is ignored while using SAFF-based encoding, it may result in poorly decoded picture quality despite efficient encoding. Hence, an amendment to the current version of the HEVC text specification, specifying that specific frame/field mode SEI is mandatory for decoding conformance, would be very helpful for interoperability with future HEVC decoders.

As an alternative to frame or field coding, de-interlacing prior to frame encoding has been evaluated in [22] and [23]. Gains over HEVC Field coding and H.264/MPEG-4 AVC with both PAFF and MBAFF enabled, are significant and subjective viewing gives full satisfaction. Nevertheless, performance of de-interlacing prior to encoding is obviously closely dependent on de-interlacer capability.

Finally, HEVC performance for interlaced content is close to HEVC performance for progressive content. Syntax and technical solutions exist to handle properly interlaced video sources. HEVC field-only encoding, with the appropriate GOP structure, can efficiently answer most interlaced video source compression needs; especially for content with high motion characteristics, such as sport content. Furthermore, adaptive frame/field solutions are possible, with SAFF coding, and enable to improvement of HEVC field-mode performance. Alternative solution, such as de-interlacing prior to frame encoding can also be envisaged, depending on targeted screens and market segments.

V. HEVC ENCODING ARCHITECTURE

As discussed in section III, the introduction of the HEVC standard will not be the end of pre-existing MPEG-2 and H.264/MPEG-4 AVC services, but rather, will correspond to the launch of additional services to new devices, over new networks. From an operator and broadcaster standpoint, this does not require them to drop existing services, but rather, capitalize on previous investments in video compression solutions by extending new services.

From a single (live or offline) video source, a single operator will need to address: MPEG-2 services to legacy set-top boxes (STBs), H.264/MPEG-4 AVC statmux for direct to home (DTH) broadcast, H.264/MPEG-4 AVC constant (or capped) bitrate for IPTV distribution, H.264/MPEG-4 AVC adaptive bitrate (ABR) for over the top (OTT) distribution to connected TV or smartphones and tablets, and now HEVC services to a new generation of appliances, either in statmux, constant bitrate, or adaptive bitrate modes.

At the same time, content will have to be de-interlaced (or inverse telecined) for some display and market segments like OTT for example, while kept interlaced for others like IPTV, DTH or digital terrestrial television (DTT) where displays like HDTV screens are well designed to perform the de-interlacing algorithm just before rendering the content.

While hardware solutions are well adapted for a single legacy format, software solutions offer the flexibility to deliver video originated from a single source to all devices from a single encoding appliance generating all resolutions and formats.

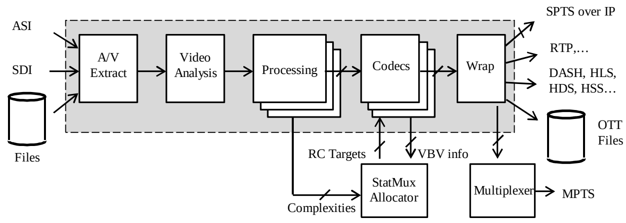

Figure 4: Converged multi-screen encoder architecture.

From an architecture standpoint, a converged multi-screen encoder will provide functional blocks as depicted in Figure 4~~Figure 4~~.

- "A/V Extract" is an ingest element (live or offline), able to unwrap the previous transport layer (live), or extract video from a file container. It also decodes if needed, for example in MPEG-2 over IP feeds. This part includes dedicated I/O components like ASI extensions or SDI inputs, or standards RJ45 connectors.
- "Analysis" is a common video analysis block, also known as "look-ahead", which stores several frames. In particular, it computes video complexity of images, detects sequence transitions (cuts, fade, dissolves, etc.), and performs a coarse motion estimation to provide vector fields that will be beneficial for various encoding formats including MPEG-2, H.264/MPEG-4 AVC and HEVC. The delay generated by the look-ahead block is programmable.
- "Processing" is based on the information provided earlier; this block performs, filtering like de-blocking, de-interlacing, frequency up-sampling toward 50fps, and resizing for OTT, as needed. Resizing the motion information is scaled according to the scale change ratio.
- "Codecs" are compression cores scalable to the number of profiles, resolutions and encoding formats. External motion vectors are used as seeds, and the bitrate target is a dynamic parameter that allows the codec blocks to be connected to an external statistical multiplexer. In addition to the compressed output, instantaneous VBV levels are exhibited to provide feedback information when a statistical multiplexer is used.
- "Wrap" is the very last block. It is dedicated to the output adaptation. Depending on the use case, it can produce various formats.
  - OTT live multi-bitrate formats (MPEG-DASH, HLS, HSS, HDS, MPEG-2 TS) to feed an origin server
  - OTT storage format (MPEG-4, HLS, HSS) or for Catch-up TV purposes
  - TS over IP stream for IPTV
  - 3GPP RTP/RTSP, ISMA, DASH

Thanks to a converged software architecture, a smooth transition to the new HEVC standard will be proposed to cover both short-term and long-term initiatives of operators and broadcasters, preserving the need to accommodate the delivery to existing legacy appliances and enabling service expansion for new media delivery. Regarding the software modifications, the only two modified blocks are "codec", with the addition of HEVC, and "wrap" because some signaling must be added to well convey HEVC over the different storage or streaming layers.

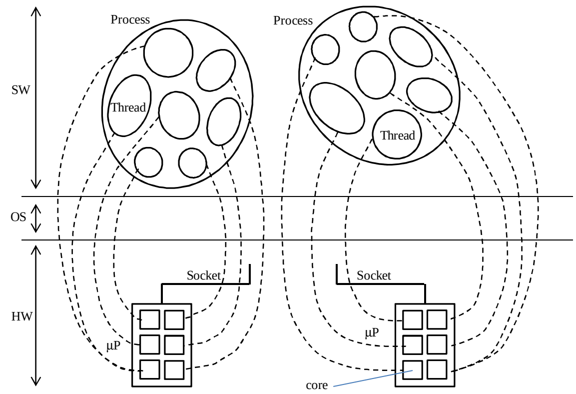

Figure 5: Parallel processing mapping on a multi-core architecture.

A purely software-based design is another aspect of the multi-screen encoder architecture that optimally address multi-channels, multi-standards, and a high density level on a single platform. The latest general purpose platforms are multi-processor, each processor is multi-core. The software has to map automatically to the platform architecture in order to perform several operations in parallel, as depicted in Figure 5~~Figure 5~~.

- Several synchronized threads are used internally in each codec block [24], mixing slices and stripes.
- Some "opportunistic" threads which do not require hard synchronization are left in charge of the OS to take advantage of CPU drops. It avoids penalizing synchronized threads CPU needs.
- Several standard threads (with simple rendezvous) are used in the video analysis, processing and the final wrap blocks.
- Threads are left nomads (no threads affinity) to take advantage of CPU drops. Well combined with Processes, they do not (often) migrate between sockets.
- Processes are reserved for the duplication of channels (from input to output). It can be understood as one process = one channel. Gathering of pertinent operations in a single process is important: it indicates the OS that normally, no resources (memory, busses, caches, etc.) have to be shared between processes.

To be complete, the multi-screen encoder is also designed using software pipelining as a CPU optimization technique. It is not described in this document.

VI. Conclusion

The HEVC video compression standard reduces bitrates by 50% at equivalent quality compared to its predecessor H.264/MPEG-4 AVC. It is therefore expected to be rapidly adopted and implemented by the broadcast industry. Indeed, it is shown in this paper that although HEVC has to coexist with current deployed video compression standards, many emerging market segments – such as mobile-HD and 4K UHD

– can benefit immediately from its performance. It is also shown in this paper that with relevant settings, HEVC is very efficient on interlaced video material, though it has been designed for progressive video content in the first place.

Transport infrastructures are unchanged, transport layers are standardized, players are available and thanks to software architectures such as the one presented in this paper, encoders will be rapidly available. As HEVC is a very recent and complex technology, the first encoders will not deliver the full coding efficiency achievable. There will be some room for improvements. Software implementation provides the relevant flexibility for new feature additions, HEVC complexity handling and further adaptation as the market transitions from older compression standards toward HEVC.

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