HEVC – Enabling Commercial Opportunities Through Next Generation Compression Technology

Lukasz Litwic – Ericsson Television Limited
Introducing High Efficiency Video Coding (HEVC)

• A new video compression standard
• Developed by Joint Collaborative Team on Video Coding JCT-VC (MPEG & VCEG)

• Key Dates
  – Feb 2012 – Committee Draft
High Efficiency Video Coding

• Aim – to deliver equal perceptual picture quality as AVC for half the bitrate of AVC

• HEVC computational complexity over AVC:
  – Could be up to 10x on encoder side
  – Could be 2x-3x on decoder side
Compression Trends

- MPEG-2 VIDEO 1994
- AVC 2003
- HEVC 2013

Bitrate

1995 2005 2015

50% bitrate saving target
Business Trends

Current Business Trends

- Bandwidth and delivery constraints
- Increased reach needed
- Emerging multi-screen to tablet and mobile
- MPEG-2 swap-out

Future Business Trends

- 1080p60/50
- Full HD 3DTV
- Venue viewing @ sports bars
- 4K & higher resolution TV

Bandwidth demand in the multi-screen home
HEVC Encoder Diagram

ENCODER CONTROL

ME/MC

Intra

Mode Dec

Ref. Buffer

ALF

SAO

DF

Recon

T^1

Q^1

T

Q

headers

source

prediction

residuals

bitstream

ENTROPY CODER
HEVC Encoder Diagram
HEVC Encoder Diagram

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ENTROPY CODER
High level tool comparison

**AVC**

- 16x16 block size
- Various symmetric partitions
- 9 intra modes
- 8x8 and 4x4 transform sizes

**HEVC**

- 64x64 block size
- Hierarchical quad-tree partitioning
- 35 intra modes
- 32x32, 16x16, 8x8 and 4x4 transform sizes
HEVC Tools - Coding Tree Unit

- Coding Tree Unit is collection of Coding Units (CU) – CU size 64x64 to 8x8
- CUs can have independent coding modes
- Further partitioning using Prediction Units (Motion Vectors)
- Independent Transform Tree partitioning from 32x32 to 4x4
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Independent Transform Tree partitioning from 32x32 to 4x4
HEVC Tools – Intra Prediction

**AVC**
- DC
- + 8 directional modes

**HEVC**
- DC + Planar
- + 33 directional modes
HEVC Tools – Intra Prediction

**AVC**
- DC
- + 8 directional modes

**HEVC**
- DC + Planar
- + 33 directional modes

![Graph comparing MPEG2, AVC, and HEVC](image)
HEVC Tools – In loop filters

• **Deblocking Filter**
  - similar to AVC deblocking filter but does not filter 4x4 block edges

• **Sample Adaptive Offset (SAO) Filter**
  - calculates edge and band offsets signalled to decoder
  - offsets added to reconstructed pixels
  - SAO is not restricted to block boundaries

Deblocking Filter + SAO Filter
Experiment 1

SVT Multiformat Test Set

Psycho-visual optimizations turned off

AVC High Profile

HEVC Main Profile

HEVC "HE 10"

Bitrate Savings PSNR-Y

PSNR-Y

Bitrate

3840x2160

1920x1080

1280x720

640x360
“HE 10” and Main Profile

• “HE10” includes additional tools not supported in the Main Profile*
  – 10 bit internal storage
  – Non-square transforms
  – Adaptive Loop Filter

Main Profile* - scheduled for release in January 2013
Experiment 1

- Bitrate savings over AVC
- Error bars represent standard deviation
Experiment 2

Psycho-visual optimizations and rate control turned on

AVC High Profile

HEVC Main Profile

3840x2160

640x360

Bitrate Savings
JND

JND

Bitrate

Sports content
Experiment 2 - Mobile

![Image of a soccer field with 640x360 resolution]

![Graph showing JND vs. Bitrate with AVC and HEVC lines, indicating a ~35% decrease in bit rate for HEVC]

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Experiment 2 – 4K

3840x2160

![Graph showing JND and Bitrate/Mbs for AVC and HEVC with ~36% improvement at 16 Mbs.](image-url)
Experiment 2 – 4K

- Visual assessment showed gains of about 50%
- JND metric not trained on HEVC distortions
- Psycho-visual optimizations algorithm more mature for AVC

![Graph showing JND vs. Bitrate for AVC and HEVC]

JND

Bitrate / Mbs

8  12  16  20

~36%
Conclusion

• HEVC delivers up to 50% bitrate savings over AVC

• HEVC is approaching completion in January 2013

• Ericsson is actively involved in development
Conclusion

• HEVC offers major commercial benefits
  – Reduce overall bandwidth requirements and costs
  – Increased reach for DSL applications
  – Further penetration of multi-screen for home and mobile

• HEVC unlocks future business not possible with today’s state-of-the-art AVC
  – 1080p60/50 better than today’s 1080i data rates
  – Future 4K TV at commercially viable data rates
  – Full resolution HD 3DTV comparable to today’s HDTV (2D) data rates
Thank you.
HEVC – Enabling Commercial Opportunities Through Next Generation Compression Technology

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2012 SMPTE Annual Technical Conference

Abstract. High Efficiency Video Coding (HEVC) is near completion by the ITU-T | ISO/IEC Joint Collaborative Team on Video Coding (JCT-VC). The aim of HEVC is to revolutionize the compression world with a potential 50% bitrate saving over Advanced Video Coding (AVC, or H.264 / MPEG-4 AVC) and even more dramatic bandwidth savings compared to MPEG-2 Video.

HEVC is already attracting much interest in all established TV markets, from content acquisition to distribution and delivery to the home over all networks. More interestingly, forecasts predict that 90% of all IP traffic will be video by 2015. This makes HEVC an attractive enabler for new types of video consumption, from mobile devices served over unmanaged networks to high end 4K TV to the home.

This paper compares simulation results from the JCT-VC HEVC test model against an industry-leading AVC encoder. Compression efficiency is measured by objective metrics (PNSR and JND) for several sequences over a range of operating points and resolutions. In addition, the paper examines the behavior of selected HEVC tool enhancements that facilitate the compression gains over AVC. Finally, the paper explores the significance of these compression efficiency gains for a variety of applications.

Keywords. High Efficiency Video Coding, HEVC, video compression.
Introduction

In 2003 ITU-T rec. H.264 | ISO/IEC 14496-10 MPEG-4 Advanced Video Coding (AVC) standard was introduced [1]. AVC delivered 50% bitrate saving over existing MPEG-2 Video standard while maintaining the same picture quality. This changed economics of HD content deployment with direct-to-home broadcasting being one of the AVC’s key success stories. Over the past years, AVC’s commercial benefits helped to establish this technology across many applications, from mobile and adaptive multi-bitrate streaming over the Internet, to contribution quality for mastering and archiving.

10 years after introduction of AVC, a new video compression standard is in development with plans for distribution in 2013. High Efficiency Video Coding (HEVC) aims to reduce bitrates by further 50% over AVC. Can history repeat itself? Certainly some previous trends have sharply accelerated and totally new trends have appeared since AVC was first standardized:

- HD content is increasing. That content needs storing, moving and delivering in a multi-screen environment. Multi-screen households now have multiple HD capable TVs (73% of all TVs shipped worldwide are HD TVs), computers, tablets and mobile phones. Consumers also expect the best picture quality possible on all their media devices.
- Telcos are now deeply involved in video content delivery and want to increase service reach in IPTV over DSL.
- Cable operators in turn are increasingly offering telephony and want to increase the number of video services in the available bandwidth.
- Terrestrial broadcasters, who have long been dealing with severe bandwidth constraints, want to offer more services including mobile TV.
- Interest in 1080p60/50 and even higher resolution workflow is growing and a cost effective business model is needed.
- The 3DTV business model continues to be debated and there are calls for full HD 3DTV delivery economics to be improved.
- In 2003 mobile phones were still primarily traditional phone, for voice conversations. Now they are enormously more powerful video capable and evolving fast.
- 4K TV to the home is becoming a hot topic, with almost all TV manufacturers showing 4K TV models at the International Consumer Electronics Show this year.

Figure 1. Business and compression bitrate trends.
HEVC Overview

High Efficiency Video Coding (HEVC) is a new video coding standardization initiative by the joint forces of ITU-T and ISO/IEC [2]. The development is lead by Joint Collaborative Team on Video Coding (JCT-VC) which comprises of video experts from ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG). The goal is to improve video coding efficiency providing further 50% bitrate saving over AVC.

HEVC development started with the first JCT-VC meeting in April 2010 and subsequent meetings have attracted contributions from numerous organizations from different fields including broadcast, research, video conferencing and medical imaging. Currently, throughout 2012, HEVC development is being stabilized. Draft International Standard has been released in July 2012 and Final Draft International Standard is aimed to be released in January 2013.

HEVC is a hybrid codec using block based predictions and transform coding approach (see Figure 2). In this sense it has followed prior codecs and top-level architecture resembles very much the one of AVC. In the encoder, block based predictions of a video frame are formed using intra (from the same video frame) or motion compensated inter (from past or future video frames) prediction mechanisms. Source video frame and predictions are used to form a residual signal which is transformed and quantised, and subsequently entropy coded. In decoding loop of the encoder (and in the decoder) inverse quantisation and inverse transform are used to recreate the residual signal which is combined with replicated block based predictions to generate a reconstructed video frame (recon). A cascade of in-loop filters is available to the encoder before a decoded frame is stored in a reference picture buffer.

Figure 2. HEVC encoder block diagram.

HEVC Tools and Profiles

Although there are top-level similarities between HEVC and AVC, several key differences exist between the two codecs. HEVC has extended several ideas from AVC, which were not feasible for hardware implementation a decade ago, and added new tools for better coding efficiency:

- flexible Coding Unit quadtree structure with size ranging from 64x64 to 8x8.
- independent Prediction Unit (64x64 to 4x4) and Transform Unit (32x32 to 4x4).
- 35 Intra Prediction modes.
- Advanced Motion Vector Prediction with multiple candidates available for competition and merging.
- 8-tap luma and 4-tap chroma interpolation filters.
In addition to better compression performance HEVC has simplified some tools and concepts with a special emphasis on ability to perform encoding/decoding operations in parallel in order to support efficient implementations on multi-core platforms.

- In-loop de-blocking filter - has been redesigned to remove spatial dependencies across the picture which allows parallel implementation.
- Wavefront Parallel Processing (WPP) / Tiles / Entropy Slices / Dependent Slices – tools to support parallel encoding/decoding.
- Single Entropy Coder – CABAC (Context Adaptive Binary Arithmetic Coder) is the only entropy coder supported in HEVC.
- Single reference picture management scheme – HEVC replaced two AVC reference management schemes with Reference Picture Set scheme which explicitly signals reference picture buffer description for each picture.

During the 8th HEVC meeting (Feb. 2012) Main Profile was created targeting initial applications for HEVC. Table 1 presents toolset comparison between AVC High Profile, HEVC Main Profile and HEVC “High Efficiency 10” config.

<table>
<thead>
<tr>
<th>AVC High Profile</th>
<th>HEVC “High Efficiency 10” Config</th>
<th>HEVC Main Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>16x16 Macroblock</td>
<td>Coding Tree Unit partitioned into Coding Units in a quad-tree fashion (64x64 down to 8x8)</td>
<td></td>
</tr>
<tr>
<td>Partitions (16x16 to 4x4)</td>
<td>Prediction Units (64x64 to 4x4)</td>
<td>Transform Units (32x32 to 4x4)</td>
</tr>
<tr>
<td>Intra prediction - square</td>
<td>Intra prediction – square</td>
<td>4x4 Transform skip</td>
</tr>
<tr>
<td>Inter prediction – square + non-square</td>
<td>Intra prediction – square + non-square + asymmetric</td>
<td>4x4 Transform skip</td>
</tr>
<tr>
<td>8x8 and 4x4 transforms</td>
<td>Transform Units (32x32 to 4x4) + 4x4 Transform skip + non-square transforms</td>
<td></td>
</tr>
<tr>
<td>Intra prediction (8 directions + DC)</td>
<td>Intra Prediction (33 directions + DC + planar)</td>
<td></td>
</tr>
<tr>
<td>Inter prediction luma 6-tap + 2-tap to 1/4 pel</td>
<td>Inter prediction luma 8-tap to 1/4 pel</td>
<td></td>
</tr>
<tr>
<td>Inter prediction chroma bi-linear interpolation to 1/8 pel</td>
<td>Inter prediction chroma 4-tap to 1/8 pel</td>
<td></td>
</tr>
<tr>
<td>Motion vector prediction</td>
<td>Advanced motion vector prediction (spatial + temporal)</td>
<td></td>
</tr>
<tr>
<td>8b/sample storage &amp; output</td>
<td>10b/sample storage &amp; output</td>
<td>8b/sample storage &amp; output</td>
</tr>
<tr>
<td>In-loop deblocking filter</td>
<td>In-loop deblocking filter + Sample Adaptive Offset (SAO) filter</td>
<td>In-loop deblocking filter + Sample Adaptive Offset (SAO) filter</td>
</tr>
<tr>
<td>CABAC or CAVLC (CAVLC = Context Adaptive Variable Length Coding)</td>
<td>CABAC using parallel operations (CAVLC = Context Adaptive Binary Arithmetic Coding)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Top level comparison of tools between AVC, Main Profile HEVC and “High Efficiency 10” HEVC config (status after 10th HEVC meeting July 2012). Additional restrictions apply for different Levels.
Analysis of Selected HEVC Tools

The following section presents more detailed description of three selected key tools and explains how they facilitate efficient video coding.

**Coding Tree Unit**

Fixed size 16x16 pixels macroblock unit used in MPEG-2 and AVC, in HEVC has been replaced by a flexible size structure called Coding Tree Unit (CTU). CTU size can be up to 64x64 pixels and it can be split into Coding Units (CU) in a quadtree fashion. This means that CTU can be split into four CU and each of the four CUs can be further split into four CU. The depth of this iterative process is signalled in the bitstream and the smallest allowed CU size is 8x8. Each CU is independent entity which means that CTU may contain a mixture of intra and inter predicted CU.

Each CU has its own Prediction Unit (PU) and Transform Units (TU) definitions. Prediction unit defines how CU is split into partitions. Transform Unit is independent from Prediction Unit which means that smaller or larger size transforms than PU size. In the latter case this means spanning more than one prediction unit within one transform unit. Moreover Transform Units can be partitioned in a quadtree fashion within a CU.

This powerful arrangement of coding blocks brings obvious benefits from coding performance point of view. Large block sizes are going to be extremely efficient in coding homogenous textures e.g. sky or static parts of a video frame. At the same time, quadtree splitting and asymmetric partitions are going to benefit coding of detailed areas and edge conditions. Example of Coding Units arrangement is shown in Figure 3.

![Figure 3. Screen shot from an HEVC bitstream analyser showing overlay of Coding Units (white thick line) and Prediction Units (yellow thin line).](image)

**Intra Prediction**

Intra frames play significant role in video coding. Their quality and size have important implications for coding efficiency. Intra frames provide refresh to the decoder and allow switching between streams. Furthermore, Intra frames serve as key reference frames therefore their quality is essential. On the other hand Intra frames cost far more bits than Inter predicted
frame due to less efficient prediction. Like AVC, HEVC does not suffer from encoder-decoder drift and long I-frame intervals (GOPs) provide the best coding efficiency. However, most broadcast applications restrict GOP lengths for fast channel change times. Therefore quality-size balance needs to be carefully managed.

HEVC improved efficiency of Intra frames coding by increasing directional resolution almost 4 times (33 directions) over AVC intra prediction modes (8 directions). In addition, HEVC provides planar and DC intra prediction modes (AVC 1 DC mode). Figure 4 shows an example of bitrate savings for an intra picture over AVC and MPEG-2. For the same quality picture AVC requires almost 30% more bits than HEVC while MPEG-2 requires almost 90% more bits.

**In Loop Filters**

HEVC has significantly extended the choice of in-loop filters available to encoder. In addition to Deblocking Filter (DF) available in AVC, two more filters were added: Sample Adaptive Offset (SAO) filter and Adaptive Loop Filter (ALF). The filters are arranged in a cascade (see Fig. 2) starting with DF, followed by SAO and ALF. The main difference between SAO and ALF and DF is that the latter one is used on block edges whereas SAO and ALF can be applied to any pixel in a video frame. The other difference is that parameters of the filters such as offsets in case of SAO and filter coefficients in case of ALF are determined by encoder and signalled in a bitstream. Brief summary of the filters is given below.

Figure 4. Intra Picture Coding Efficiency for “Cactus” sequence.

![Image of bitrate savings comparison between AVC, HEVC, and MPEG-2 for an intra picture.](image)

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![Image of SAO and ALF filters off (left) and on (right).](image)
• Deblocking Filter – reduces block edges. HEVC DF has a similar behaviour to AVC’s DF but has been redesigned to reduce complexity. Another difference as compared to AVC is that 4x4 edges are not filtered. DF is included in Main Profile.

• Sample Adaptive Offset – reduces difference between recon and source frames by applying offsets to pixels which can be classified to Band Offsets (plain areas pixels) or Edge Offsets (near edge pixels). Filter can also be switched off for selected parts of a video frame. SAO is included in Main Profile.

• Adaptive Loop Filter – reduces difference between reconstructed and source frames by applying spatial filter of predefined shapes. Coefficients are determined by encoder and signalled in a bitstream. Quadtree split within CU is allowed to signal ‘On’ / ‘Off’ flags. ALF is the most complex of the three filters and it is not currently included in Main Profile.

Experiments

We conducted preliminary tests of HEVC compression gains over AVC for internal evaluation. In the first experiment the SVT multi format test set [3] was used to investigate bitrate savings across a range of resolutions. The SVT test set includes five sequences with a mix of coding difficulty. The HEVC test model HM-5 [4] was compared against an industry leading real-time AVC encoder. The latter one had subjective optimisations and rate control switched off since HM-5 model does not support those non-normative parts of the encoder. Bitrate savings were calculated using Bjontegaard Delta (B-D) bitrate from PSNR results [5]. Figure 6 shows average bitrate saving results using B-D bitrate for HEVC Main Profile and “High Efficiency 10” config (HE) over AVC. Error bars represent standard deviation.

The results show that on average HEVC offers over 30% bitrate saving over AVC for all tested resolutions. There is a significant variation in bitrate saving results between individual sequences and the largest bitrate savings over AVC were found to be reaching up to 50% for 720p/1080p and over 70% for 4K (2160p) resolution.

Figure 6. Bitrate saving results for HEVC Main Profile and “High Efficiency 10” config using HM-5 HEVC model over AVC.

A second test was run where our HEVC model in Main Profile (including full rate control and subjective optimisations) was compared with a commercially available realtime AVC encoder. The content used in this experiment (moderate to high criticality sports sequences) suggests that HEVC could deliver bitrates of 800kbit/s for 360p and of 10Mbit/s for 4K, while providing
acceptable picture quality (equivalent AVC bitrates are 1300kbit/s and 16Mbit/s respectively) (Figure 7).

**Conclusion**

HEVC is a new video coding standard which is currently in development. HEVC aims to increase coding efficiency by 50% over the existing AVC video coding standard. Several new coding tools including large size coding units, new prediction modes and new in-loop filters, have been added to HEVC to facilitate the coding gains. Ericsson preliminary experiments show that between 30% to 50% bitrate savings over AVC across a wide range of resolutions could be achieved with the current HEVC toolset.

HEVC offers commercial benefits to existing applications and future usage scenarios by reducing overall bandwidth requirements and costs. Some example applications include increasing reach of IPTV over DSL, further penetration of multi screen in the home and for mobile devices, improved picture quality for mobile devices and the replacement of MPEG-2 Video legacy set-top boxes and receivers. HEVC also enables future business not possible with today’s state-of-the art video compression standards. Examples include 1080p60/50 at significantly lower bitrates, full resolution HD 3DTV at bitrates comparable to today’s HD data rates, and 4K resolution TV at commercially viable data rates.

HEVC is planned for distribution in 2013 with Final Draft International Standard being ready for ratification in January 2013. Ericsson is actively involved in the HEVC development effort.

Figure 7. JND results for 360p (left) and 4K (2160p) (right) test sequences coded at 25Hz. AVC encoder was run in High Profile. Ericsson HEVC test model was run in Main Profile.
Acknowledgements

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1. ITU-T Recommendation H.264 and ISO/IEC 144496-10 (MPEG-4) AVC: "Advanced Video Coding for Generic Audiovisual Services".


