Quantitative Performance Evaluation Of the Emerging HEVC/H.265 Video Codec

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ABSTRACT

This paper, deals with the currently under-development video encoding standard H.265/HEVC. The main purpose of this paper is to perform a quantitative performance evaluation of the emerging standard in comparison to its predecessor H.264/AVC. The paper focuses on both the encoding and compression efficiency by measuring the PSNR scores and bit rate values of reference and non-reference signals. For the needs of the paper, the HEVC and AVC reference encoders were used. Scope of the paper is to research if the current working version of the new coding method is approaching or achieves its primary objective, which is to double the compression efficiency of the bit stream without significant degradation of the encoded quality.

Categories and Subject Descriptors

H.5.1 **[Multimedia Information Systems]**: Evaluation/methodology

General Terms

Measurement, Documentation, Performance, Design.

Keywords

HEVC, AVC, H.265, H.264, PSNR.

1. INTRODUCTION

The proliferation of the video services and applications has brought the contemporary world closer to digital videos than ever before, creating new demands for high performance video compression standards [1]–[2] in conjunction with efficient and resilient transmission systems [3]. This has increased the demand for high efficiency video coding methods and for this reason various standardized efforts run in order to derive new and more efficient encoding standards in terms of both performance (i.e. data compression) and video quality (i.e., Quality of Experience).

To meet the ongoing industry requirement for more efficient and standardized video coding techniques, ITU-T/VCEG and ISO-IEC/MPEG have recently formed the joint collaborative team on video coding (JCT-VC). The JCT-VC aims to develop the next generation video coding standard called High Efficiency Video Coding (HEVC) or H.265 as it is widely called, which is being developed as the successor to H.264/AVC.

The HEVC's main objective is to provide significant improvement in the video compression and performance efficiency compared to H.264/AVC, reducing bitrate requirements by half with comparable video quality, probably at the expense of increased computational complexity, which is expected to be three times higher. Thus, the new encoder is expected to satisfy the ever-increasing requirements for cost effective video encoding process in terms of better video quality compression efficiency, video resolution, frame rates and computational complexity.

In this framework, the authors of the paper, by tracking the development of the reference HEVC test model (HM), report on its encoding performance and compression efficiency by measuring the current performance and efficiency of HEVC in respect with its main objectives. More specifically, a set of YUV video signals (reference and non-reference ones) was used as input to both the reference encoders (i.e., HEVC and AVC). The set of test signals covers a variety of spatiotemporal activity, making the benchmarking framework of this paper appropriate for testing the performance efficiency of the new encoder under different signal complexity. For the performance assessment of the two encoders, the PSNR metric was selected.

Upon this introductory section, the rest of the paper is organized as follows: Section 2 introduces the main novel features of H.265/HEVC, providing a brief description. Section 3 describes the performance metric used in this paper. Section 4 describes the encoding process of H.264/AVC and H.265/HEVC and the test signals (reference and non-reference ones) used in the experimental part of this paper. In section 5 the benchmarking between the two codecs under test is performed in terms of compression and performance efficiency. Finally, Section 6 concludes the paper.

2. INTRODUCING HEVC/H.265

2.1 Block-Based Coding

The HEVC continues to implement the block-based hybrid video coding framework [4], with the exception of the increased macro-block size (up to 64x64) compared to AVC. However, three novel block concepts are introduced, namely: the Coding Unit (CU), the Prediction Unit (PU) and the Transform Unit (TU). The general outline of the coding structure is formed by various sizes of CUs, PUs and TUs in a recursive manner, once the size of the Largest Coding Unit (LCU) and the hierarchical depth of CU are defined. Given the size and the hierarchical depth of LCU, CU can be expressed as a recursive 64x64 quad-tree representation as it is depicted in Figure 1, where the leaf nodes of CUs can be further split into PUs or TUs, thus using variable block size (down to 4x4) for various regions of the frame. Since the leaf blocks of the CUs are either PUs or TUs, this means that they are used for prediction methods.

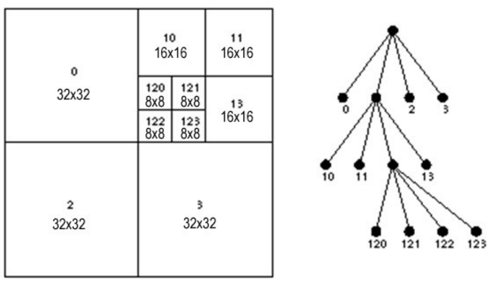

Figure 1. Example of 64x64 quadtree coding

When a prediction method is chosen, then a PU is created and matched to the CU, which contains the information about the type of the prediction method (e.g. intra or inter). The PU in turn may be further split the block to block-leaves and each leaf may apply a different prediction method. On the contrary, the TU is a block area for transform and quantization of data, without being necessary to be limited to coding tree leaf blocks as PU.

The introduction of this flexible sub-partitioning mechanism is one of the most important elements for higher compression performance in the encoded video signals, due to the adaptive accuracy of the encoding process on specific parts of the signal content. Thus, the more complex the video content is at specific areas, the better encoding performance is succeeded, due to the recursively break down coding of the parent CU block to four children blocks of smaller sizes (i.e., each one of them being the ¼ of the original CU block)..Therefore, this quad-tree approach provides smaller blocks which in turn build higher overhead, but it provides more efficient predictions.

2.2 Intra-Prediction in HEVC/H.265

The current intra prediction technique in HEVC unifies two simplified directional intra-prediction methods: the Arbitrary Direction Intra and the Angular Intra Prediction. The unified intra prediction technique enables a lower-complexity method in which parallel processing can be achieved. More specifically, samples of already decoded adjacent PUs are used in order to define the type of the intra prediction method (i.e., horizontal, vertical or depending on the block size up to 34 angular directions).

2.3 Inter-Prediction in HEVC/H.265

The inter prediction in HEVC uses the frames stored in a reference frame buffer, which allows multiple bi-direction frame reference. A reference picture index and a motion vector displacement are needed in order to select reference area. The merging of adjacent PUs is possible, by the motion vector, not necessarily of rectangular shape as their parent CUs. In order to achieve encoding efficiency, skip and direct modes similar to the AVC ones are defined, and motion vector derivation or a new scheme named motion vector competition is performed on adjacent PUs. Motion compensation is performed with a quarter-sample motion vector precision. At TU level (which commonly is not larger than the PU), an integer spatial transform (with range from 4x4 to 64x64) is used, similar in concept to the DCT transform. In addition a rotational transform can be used for block sizes larger than 8x8, and apply only to lower frequency components. In AVC scaling, quantization and scanning of transform are performed in a similar way.

At CU level, an Adaptive Loop Filter (ALF) can be applied prior to copying the frame into the reference picture buffer in order to minimize distortion relative to the original picture. Additionally a de-blocking filter is operated within the prediction loop (similar to the AVC de-blocking filter design). After applying these two filters the display output is written to the picture buffer.

2.4 Entropy Coding in HEVC/H.265

The HEVC defines two context-adaptive entropy coding patterns, one for the higher-complexity mode and one for the lower-complexity mode. The lower-complexity mode is based on a variable length code (VLC) table selection for all the syntax elements, while using a particular code table, which is picked in a context-based scheme depending on previous decoded values. This design is very similar to the CALVC pattern from AVC, but enables even simpler implementation according to its more systematic structure. A re-sorting of code table elements can be used as a supplementary compression improvement.

The higher-complexity design uses a binarization and context adaptation pattern similar to the AVC entropy coder, CABAC, but with the difference of using a set of variable-length-to-variable-length codes (indexing a variable number of bins into a variable number of encoded bits) instead of using an arithmetic coding engine. This is performed by applying a bank of parallel VLC coders – each of which is responsible for a certain range of odds of binary events (which area referred to as bins). The coding performance can be better parallelized and has higher throughput per processing cycle than CABAC, although being very similar to it. It must be noted that the compression performance of this design can be significantly higher than the lower-complexity VLC.

2.5 Encoding Profiles

The HEVC reference software has three main profile categories, namely: i) Intra Profile, which uses only I frames to code, aiming to studio usage, ii) Random Access Profile, which uses I frames with hierarchical bidirectional B frames, providing efficient compression but high computational power, and iii) the Low Delay profile, which uses only one I frame at the beginning and the rest frames are P or unidirectional B (i.e., restricted to previous frames), aiming to real time applications that require low delay in the coding process (like video telephony).

Each of the aforementioned profiles may be applied to a Low Complexity variant, where some of the encoding tools are disabled or switched to simpler modes that require less computational power, thus there are faster. Thus, six total profiles are available, with the low delay profile being further split to B or P frame mode.

3. PERFORMANCE METRIC

For the purposes of this paper the PSNR performance metric was used, providing a more profound and clear statement regarding the encoding efficiency of the HEVC encoder compared to AVC one.

$$PSNR = 10 \times \log_{10} \frac{MaxErr^2 \times w \times h}{\sum_{i=0,j=0}^{w,h} (x_{i,j} - y_{i,j})^2}$$

The PSNR metric is mostly used as a measure to calculate the error and noise introduced during the encoding process, to an encoded video signal compared to the original one. It is also used as an approximation to human perception of reconstruction quality, thus becoming a very useful tool for the purposes of these tests. It is defined via the mean squared error for two w (video width) x h (video height) monochrome images $x_{i,j}$ and $y_{i,j}$ where one of the images is considered a noisy approximation of the other, with *MaxErr* being the maximum possible absolute value of color components difference.

4. SIGNALS AND ENCODING PROCESS

For the evaluation process two reference video clips (Bubbles, Horse Race) [5] and two non-reference unique videos (Apocalypto Trailer and Batman Dark Night Trailer) were used, which represent various levels of spatial and temporal activity. A representative snapshot of each signal is depicted on Figure 2.

The test signals have spatial resolution 416x240 and 352x288 (reference and non-reference respectively), and for the experimental needs of this paper were encoded from their original uncompressed YUV format to ISO AVC Main Profile (MP) and to the following profiles of HEVC, namely: i. Random Access Profile (RAP), ii. Random Access Low Complexity Profile (RALCP), iii. Low Delay Profile (LDP), and iv. Low Delay P Profile (LDPP). Across all the encoding process, the reference software was used for both the AVC and HEVC coding. Especially for HEVC the HEVC Test Model (HM) Reference Software 5.1 was used [6].

Figure 2.The test signals

In order to maintain and achieve an ideal comparison between the various profiles, it is necessary all the profile configurations to have identical or very similar parameter values. For this reason, the GOP structure for all the encoding profiles and between the two encoding methods consisted of either I, P or B except in cases of LDP and LDPP where I and B only, and I and P only, patterns were used respectively, ensuring by this method the benchmarking of both Intra- and Inter-coding efficiency between AVC and HEVC standard profiles.

The Quantization Parameter (QP), for I and P frames, has a great impact on visual quality and compression rate, as it regulates how much spatial detail is maintained. For this reason, a group of QP values {12, 22, 32, 42, 51} was used, enabling the creation of an extensive evaluation results database and creating a more complete and rich set of measurements.

5. BENCHMARKING OF HEVC AND AVC

5.1 Performance Comparison

In this section, the video quality of the HEVC algorithm is examined, in comparison to the AVC for the video signals under test, when the same encoding parameters have been selected (i.e. the QP for both I and P or B frames were set to the value of {12, 22, 32, 42, 51} in both AVC and HEVC profiles).

The first comparison between HEVC and AVC is related to the average PSNR value vs. QP. Table 1 shows the average PSNR values and the corresponding QPs from all the test video signals, for the Main Profile (MP) of AVC and the four HEVC profiles (LDP, LDPP, RAP, RALCP).

Table 1. Average PSNR of H.264/AVC(MP) vs. HEVC(LDP,LDPP,RAP,RALCP)

QP	MP	LDP	LDPP	RAP	RALCP
12	52.08022	50.07781	50.14053	48.60677	48.04049
22	43.82217	42.21041	42.13275	41.87272	41.37249
32	36.71928	34.82381	34.79465	35.04391	34.73854
42	29.62316	29.04746	29.03886	29.51388	29.30517
51	11.73947	24.85184	24.86316	25.35809	25.20807

The graphical representation of the PSNR values from Table1, is shown in Figure 2

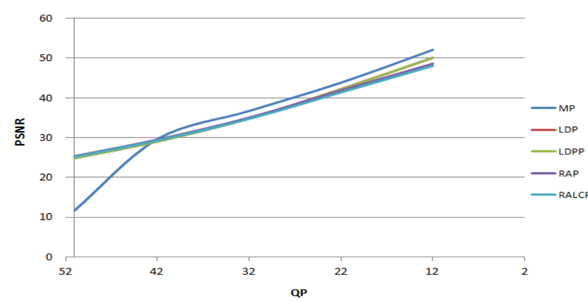

Figure 2 Average PSNR vs QP of HEVC and AVC signals

It can be observed that, the HEVC profiles have slightly degraded video quality, as compared to the Main Profile of AVC for QP values between 12 and 42. This degradation is between 1-2dB. Furthermore the AVC achieves slightly better video quality on low QPs, but on the other hand as the QP value gradually increases the AVC's encoding efficiency is reduced, reaching to an abrupt downfall on quality when the QP equals to 51. On the other hand HEVC performs much better than AVC as it scores PSNR at acceptable values, for QP higher than 42, while retaining its linearity. Additionally, the AVC's MP decoded video for QP equal to 51, proves not viewable (Figure 3), while HEVC RAP achieves acceptable video quality.

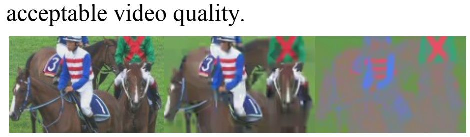

Figure 3. Original frame (on left) and decoded ones (HEVC in the middle, AVC on the right with QP=51)

5.2 Compression Efficiency Comparison

This section presents the experimental results of the comparison between HEVC and AVC encoded signals' bit rate. During the evaluation tests a set of QP values {12, 22, 32, 42, 51} was used in order to examine a variety of bit rate cases, and evaluate the compression efficiency of HEVC, when compared to AVC. The average values of the test results are shown in Table 2, which enlists the combined average bit rate for each profile of the four test video signals.

The graphical representation of Table 2 data is presented in Figure 3 and in Figure 4 zoomed in low bit rate cases. From Table 2, it is clear that the compression efficiency of HEVC is significantly better than AVC. For QP values from 12 up to 42, HEVC undoubtedly surpasses AVC, as it requires 32% to 62% less bitrate for all the video signals.

Table 2. Average Bit Rate vs. QP for H.264/AVC (MP) and HEVC (LDP, LDPP, RAP, RALCP)

QP	MP	LDP	LDPP	RAP	RALCP
12	10716.83	5080.182	5402.373	4176.731	4011.801
22	2054.2	1249.342	1316.253	1105.972	1083.826
32	582.2025	284.7245	286.4473	274.3813	277.2903
42	114.2425	78.63425	77.82075	78.31875	77.6965
51	6.8	34.1	33.64975	34.5805	33.2445

The huge margin between the performances of the 2 encoders can be clearly seen in Figures 3 and 4.

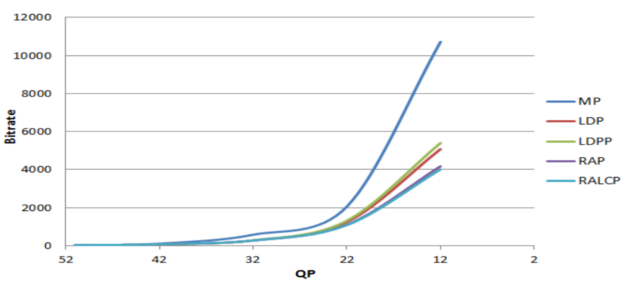

Figure 3. Average Bit Rate vs. QP for H.264/AVC (MP) and HEVC (LDP, LDPP, RAP, RALCP)

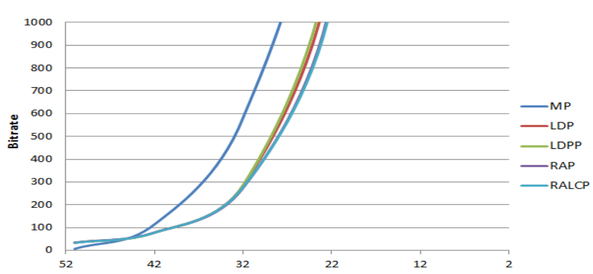

Figure 4. Average Bit Rate vs. QP for up to 1000 kbps.

However, for QP values between 42 and 51, AVC surpasses HEVC in compression rate, achieving significantly lower bitrate values. But as, it is thoroughly depicted in the previous section the video quality of AVC, in QP value equal to 51, is extremely low, making the decoded content not perceptually accepted.

In Figure 3, the apparent gap can be noticed separating the AVC average bit rate line from the HEVC ones, in a distant view including values up to 12kbps. Additionally in Figure 4 a more detailed and zoomed view of the same evaluation tests can be observed, portraying even better the compression efficiency of the two encoders in low bit rate cases.

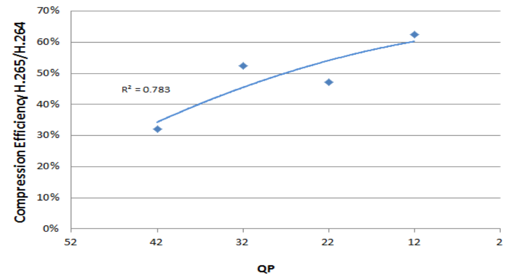

Figure 5. Average Compression Efficiency (%) vs. QP for HEVC RALCP and AVC MP.

A more comprehensive representation of the compression efficiency (%) of HEVC in comparison to AVC is depicted in Figure 5. The curve of this figure shows that for QP values from 12 to 42, the compression efficiency improvement of HEVC ranges from 32% to 62%. For values of QP between 42 and 51 the curve is intentionally not considered, as the quality of the decoded AVC video content is degraded to significantly low levels.

6. CONCLUSIONS

This paper performs a quantitative comparison between the HEVC and AVC encoders, in terms of video quality and compression efficiency. It is shown that the novel currently developing encoder achieves a 32% to 62% compression enhancement, while it attains 1 to 2dB reduced video quality, compared to its predecessor. Furthermore, HEVC in relatively low bitrates shows a linear performance in video quality, while AVC abruptly degrades to unsatisfactory video quality levels.

7. ACKNOWLEDGEMENT

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