Analysis of frame partitioning in HEVC ⋆

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Abstract. The paper presents analysis of frame partitioning in the next generation video coding standard HEVC. Complex study on frequency of the particular coding unit, prediction unit and transform unit sizes selection made by the encoder compliant with HEVC technology is included. General conclusions based on extensive experiments for HD video sequences are presented. Such knowledge may be the first step to the development of more efficient mode selection algorithms.

1 Introduction

In the last years the growing importance of multimedia systems transmitting high quality videos is observed. In this context, studies on efficient representation of high resolution images are crucial. Such works have been conducted in last years, and as a result the new High Efficiency Video Coding (HEVC) technology has been developed. The technology has been standardized as ISO/IEC 23008-2 (MPEG-H part 2) and ITU-T H.265 in 2013 [1].

HEVC allows for encoding of high resolution video at half of bitrate of previous technology namely AVC (MPEG-4 Part 10 and H.264)[2]. Higher coding efficiency came at a price of higher encoder complexity.

General idea of the HEVC technology is very similar to the older generation solutions (e.g. MPEG-2, H.263, AVS, VC-1, AVC) [3] and exploits intra- and inter-frame correlation by using prediction coding of image blocks together with block-based transform coding of residual data. But the HEVC allows for greater flexibility in terms of image partitioning and prediction mode selection leading to a stronger compression of high resolution video [4]. Classical macroblock structure has been replaced by more flexible coding tree block structure (CTB). Each CTB allows to quad tree block partitioning from size of 64x64 pixels downto 8x8 pixels. Each block in a partitioning tree is called a coding unit (CU) and can be encoded in intra-frame or inter-frame mode. Within the CU, prediction is performed in prediction units (PU) of various size (both square and rectangular shapes of PU are available). Each CU can also be further recursively divided into transform units (TU) of various sizes from 32x32 downto 4x4 in

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which transform-based coding of residual data is performed. Size of PU and TU can not exceed the size of CU.

CTB partitioning with PU and TU partitioning leads to almost 3000 combinations in case of intra-frames and more than 4500 combinations in case of inter-frames to be analysed by encoder for a single CTB. In other words, great number of combinations is available in the encoder and all of them should be checked in order to choose the optimal one. However, huge computational complexity is the main drawback of such approach. Therefore, not all of combinations are evaluated in practice during encoding. Various methods of speeding up encoder decision have been developed so far, for example [5–8]. Basically all of them are based on observation that some partitioning schemes are very rarely used by the encoder, so they can be omitted resulting in negligible coding efficiency loss.

Nevertheless there are no complex studies of frequency of the particular partitioning selection made by the encoder. Such a knowledge can be further used to develop even more efficient encoder mode selection algorithms. Thorough analysis of image partitioning makes the topic of the paper.

2 Research problem and goal of the work

In this paper we have evaluated frequency of particular CU, PU and TU sizes selection made by the encoder. In particular we are interested in the knowledge of image area covered/encoded with particular CU, PU and TU sizes. The goal is to make detailed analysis for individual frames types used in the HEVC encoder.

3 Methodology of the research

In extensive experiments, seven HD 1920x1080 test video sequences (Fig. 1): *Bluesky*, *Pedestrianarea*, *Riverbed*, *Rushhour*, *Station2*, *Sunflower* and *Tractor*, recommended by ISO/IEC MPEG and ITU-T VCEG working groups have been encoded by the HEVC encoder. In particular HM 10.0 reference software [9] working under Common Test Condition (CTC) [10] was used. CTC defines a set of conditions and encoder configurations designed as a common ground for evaluation of HEVC related technology. In experiments "Random Access" scenario has been used to make the research for high efficiency mode (Fig. 2). Each sequence was encoded multiple times, each time with different quantization parameter (QP) value from a range $10 \div 48$ resulting in a wide range of bitrates. It must be emphasized that, the "Random Access" scenario assumes different values of QP for individual types of frames in the hierarchical coding structure.

4 Experimental results

Coding unit analysis. QP value affects the statistics of CU sizes in frames. Experimental results averaged over all sequences and all frames allow to draw the following general conclusions:

Fig. 1. Test video sequences used in experiments in order from top-left: *Bluesky*, *Pedestrianarea*, *Riverbed*, *Rushhour*, *Station2*, *Sunflower* and *Tractor*.

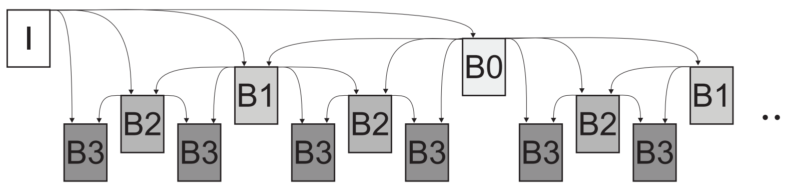

Fig. 2. Hierarchical structure of frame prediction used in experiments (according to CTC). Only part of inter-prediction sources is marked.

– In the case of small QPs, the large CU (i.e. 64x64) is rarely used (below 5%). In such a case the most commonly used sizes of CU are 32x32 and 16x16 (about 75%).
– With the increase of QP the amount of big CUs also increases (up to 90%). In particular, for really high QPs 16x16 CUs and smaller ones are rarely used by encoder (below 10%).

Going into details there is a large convergence of the results obtained for $B0$, $B1$, $B2$, and $B3$ frames, but these results are significantly different from those obtained for I frames. In particular, significantly higher percentage contribution of 8x8 CUs is observed in I frames in the case of small QPs. Why is this happening? In the HEVC encoder the size of CU determines the size of PUs in which image prediction is realized. Selected size of CU is the upper limit for the size of PUs and TUs. In the case of complex image textures, CU is divided into smaller blocks in order to increase encoding efficiency. Thus, the increased use of smaller CUs for small QP values, where details of textures are preserved (for intra- and inter-frames). In addition, the prediction of complex image parts is more demanding in the case of intra-frames, hence more frequent (than in inter-frames) selection of small CUs. Detailed data for these experiments are shown in Fig. 3 for a wide range of QP values. The most likely explanation for this is the following. By strong data quantization (high QP values) the vast majority of transform coefficients take zero value. Therefore, it is more reasonable to carry out encoding in smaller CUs in order to preserve from sending large amount of control data. In this case, large CUs are more often applied.

Prediction unit analysis. There are two categories of PUs: square and rectangular. Overall square PUs are chosen more frequently than rectangular ones (see Fig. 4). With increasing QP, frequency of choosing small and rectangular PUs decreases. Interesting observation is that rectangular PUs of size 64xN and Nx64 are chosen more frequently for average values of QP than for extreme ones. On average PUs of size 4x4 are hardly ever selected for QP greater than 24.

The distribution of PUs for I frames and B frames is quite different. Mainly due to lack of rectangular PUs in I frames (which results from HEVC standard). Moreover small PUs are chosen 5 times more frequently in I frames than in B frames. For I frames it is harder to accurately predict content in larger PUs so encoder chooses smaller units. 4x4 PUs are not used for QPs greater than 18 in B frames and for QP greater than 36 in I frames which is a huge difference. Distribution of frequency of various sizes PUs in $B0$, $B1$, $B2$, and $B3$ frames is quite similar. The only difference is a frequency of choosing 4x4 PUs. Results in $B0$ frames and comparable to frequency in I frames. But having in mind the number of $B0$ frames, it has no significant impact on overall statistics for all B frames.

Transform unit analysis. For each CU, encoder decides how to divide it into TU blocks (i.e. TU block size equal to the CU size or CU divided into smaller TUs). Therefore there is a strong relationship between statistics of the TU and CU size. This is confirmed by the results of experiments (see Fig. 5):

– With the increase of the QP the share of large TUs (i.e 32x32 and 16x16) also increases. In particular, due to strong quantization (high QP values) most of transform coefficients are equal to zero. Therefore, it is better to carry out encoding in larger blocks (less control data which means higher coding efficiency).
– In the case of small values of QP, the smaller sized TUs are more frequently used. It is related to CU statistics discussed earlier.

In the HEVC encoder a large area of the frame is covered by the TU blocks for which prediction error signal is not sent to decoder (all quantized transform coefficients are equal to zero). This is particularly evident for B frames for which higher efficiency of predicting coding may be observed. Although detailed results differ between the $B0$, $B1$, $B2$, and $B3$ frames, in each of these frames increase of QP value increases the number of such blocks (up to 50% of the frame). In contrary, for I frames share of such TUs is very low (below 5% due to smaller efficiency of intra prediction).

5 Conclusions and final remarks

The results documented in the paper give useful information about the statistics of selection of CUs, PUs and TUs of different sizes by the HEVC encoder. In order to draw detailed conclusions an independent analysis was done for individual frame types (I, $B0$, $B1$, $B2$, and $B3$). Additionally all the results were averaged and presented in the paper to highlight the general remarks. Huge collection of experimental results enables analysis of frame partitioning for a wide range of bitrates (QP values from 10 to 48). Achieved results allow to formulate two general conclusions:

1) The higher QP the major area of the frame is covered by larger CUs, PUs and TUs (up to 80%, 83% and 87% respectively).

2) There is a significant difference between results obtained for I and B frames. For the same QP value for I frames smaller sizes of CUs, PUs and TUs than for B frames are used.

The results are the basis for further study leading to the development of fast mode decisions in the HEVC encoder. The knowledge on statistics of frame partitioning acquired in the paper gives direct information which combinations of CU, PU and TU can be omitted in order to speed up the encoder mode selection process. Appropriate remarks have been presented in experimental section.

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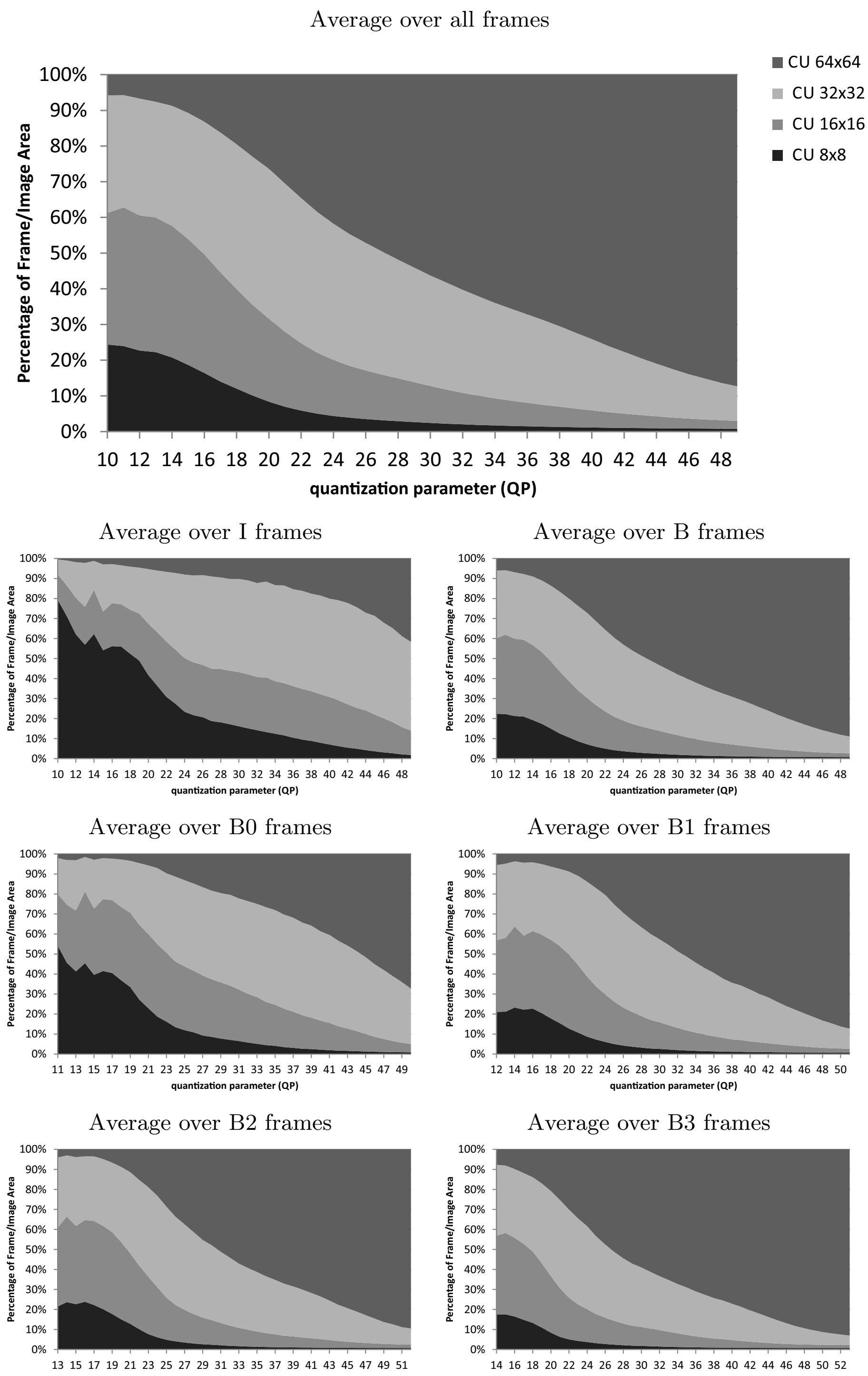

Fig. 3. Percentage of frame/image area covered by different sizes of CU. The QP values for individual types of frames in the hierarchical coding structure are adjusted according to "Random Access" scenario.

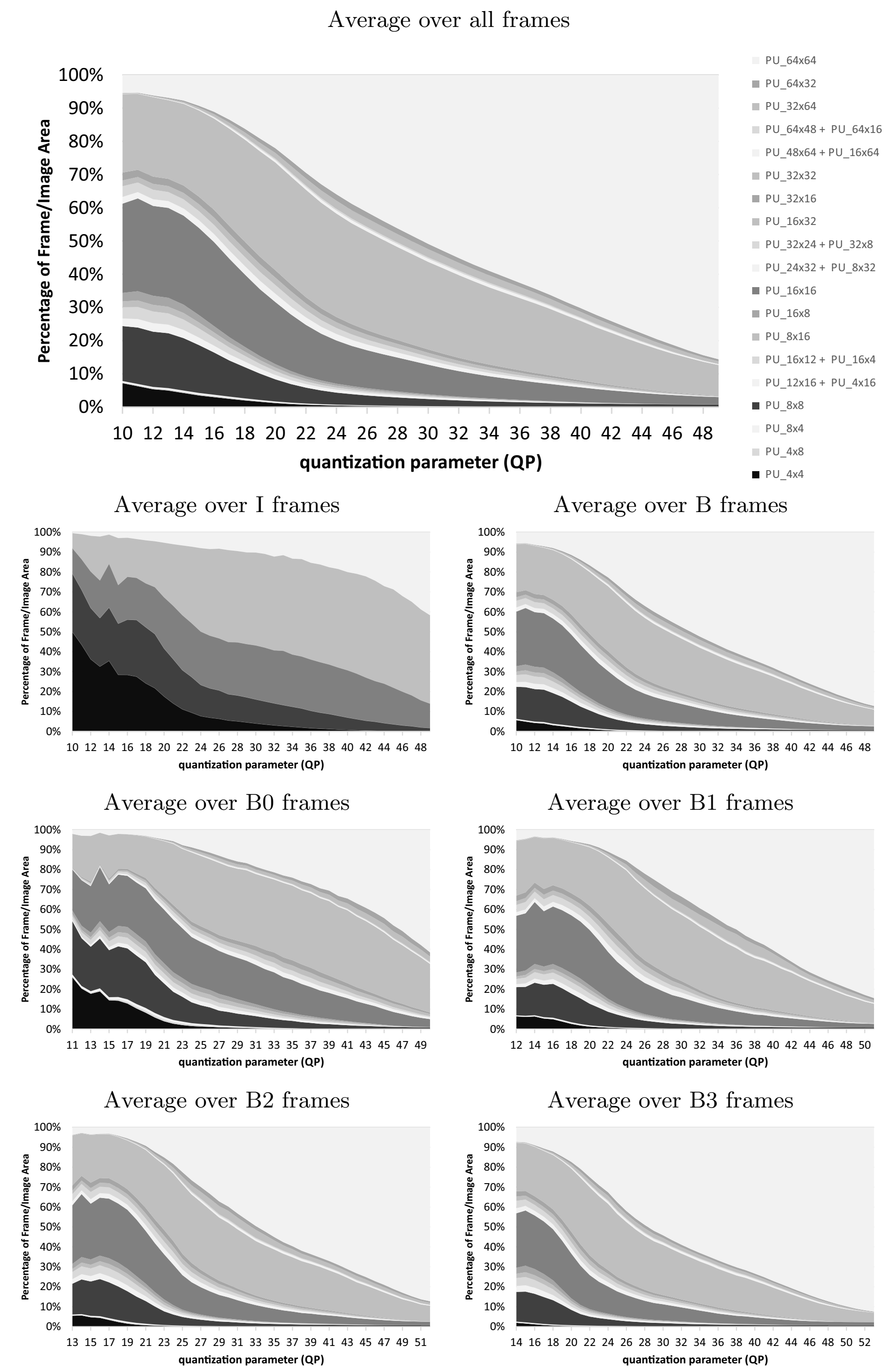

Fig. 4. Percentage of frame/image area covered by different sizes of PU. The QP values for individual types of frames in the hierarchical coding structure are adjusted according to "Random Access" scenario.

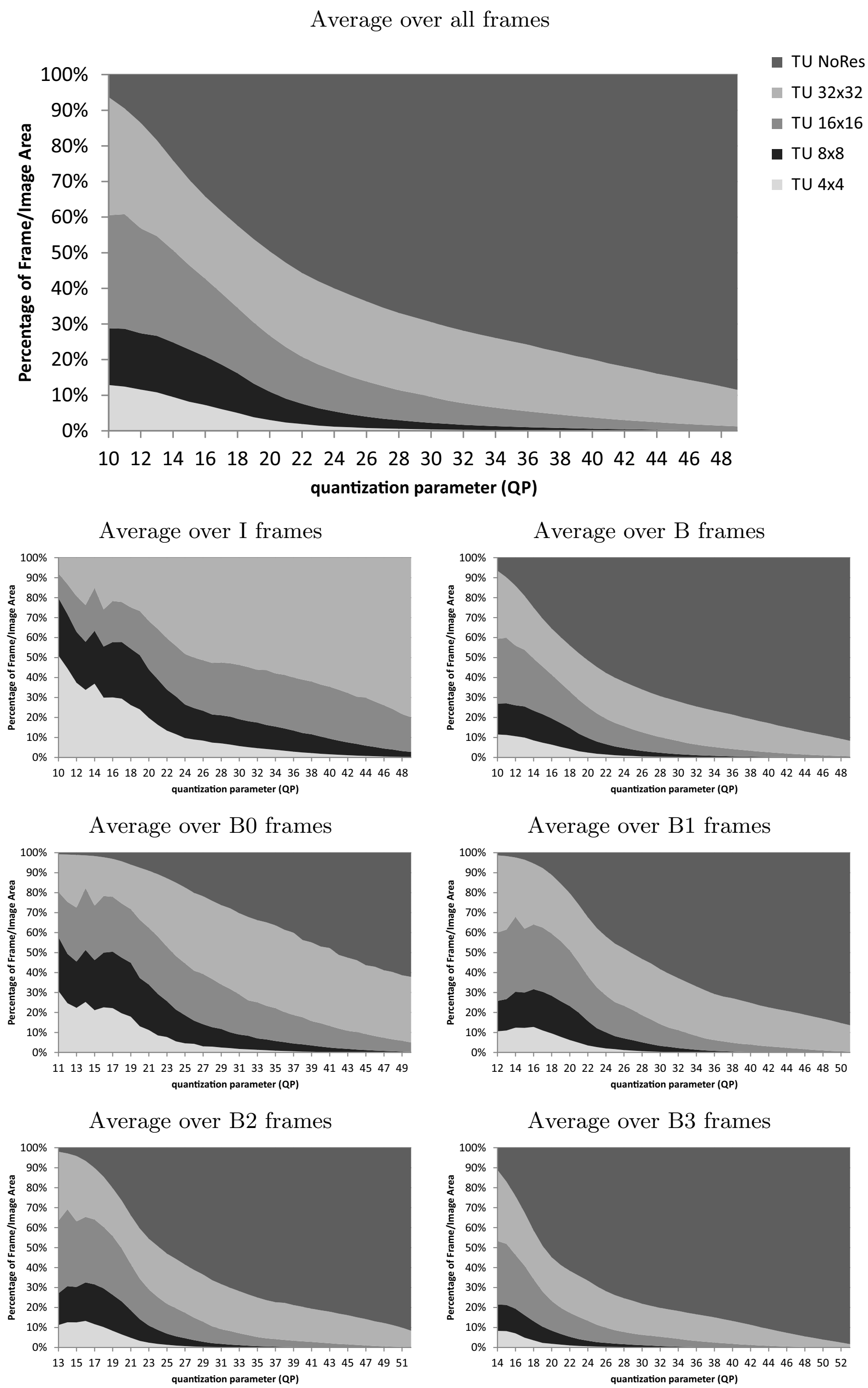

Fig. 5. Percentage of frame/image area covered by different sizes of TU. The QP values for individual types of frames in the hierarchical coding structure are adjusted according to "Random Access" scenario.