Energy Reduction Opportunities in an HEVC Real-Time Encoder

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***Abstract*—High Efficiency Video Coding (HEVC) is one of the latest released video standards and offers up to 40% bitrate savings when compared to the widespread H.264/AVC standard, at the cost of a substantial complexity growth. Constraining the complexity of HEVC encoding is a challenging task for embedded applications based on a software encoder. In the last few years, the Internet of Thingss (IoTs) has become a reality. Forecoming applications are likely to boost mobile video demand to an unprecedented level. In this context, designing energy-efficient HEVC real-time encoders is becoming a major challenge for software and hardware designers.**

In this paper, an analysis is conducted of the energy reduction opportunities offered by an HEVC encoder. The energy reduction search space is demonstrated, and the impact on energy consumption of encoding tools at various levels of granularity is measured.

***Index Terms*—Energy consumption, HEVC, real-time encoder, embedded platforms.**

I. Introduction

Nowadays, numerous embedded application embed video coding. The *High Efficiency Video Coding* (HEVC) [1]–[3] standard represents the state-of-the-art in video coding. When compared with the previous MPEG AVC, HEVC Main profile reduces the bit rate by 40% on average for a similar objective image quality [4], [5]. Such a gain reduces the energy needed for transmitting video. On the other hand, the computational complexity of the encoders is significantly increased. This additional complexity brought by HEVC is mostly due to the new Coding Tree Unit (CTU) quad-tree block partitioning structure, which exponentially increases the exhaustive Rate-Distortion (RD) search process. In the All Intra (AI) coding configuration, HEVC uses a total of 35 intra-predictions modes including planar, DC, and 33 angular modes [3]. Moreover, in Random Access (RA) and Low Delay (LD) configurations modes, inter prediction supports symmetric and asymmetric partitioning in Prediction Unit (PU) that generate 8 splitting modes [2]. The Rate-Distortion Optimization (RDO) adds even more complexity with an exhaustive search over all Intra prediction modes and Inter splitting modes in the quad-tree.

The main limitation of the evolution of embedded systems, particularly in terms of computational performance, comes from the bounded energy density of batteries. This limitation is a major constraint of image and video applications, video encoding and decoding being some of the most energy-consuming algorithms on smart phones. A large share of systems are likely to integrate an HEVC codec in the long run and will require to be energy aware. *Power consumption* constraints represent a serious challenge for embedded HEVC real-time encoder design. For embedded applications, hardware solutions [6] exist that consume low energy. As for software, there exist several open-source HEVC encoders [7]–[10] including the HEVC reference software model (HEVC test Model (HM)). This latter is open source and widely used, as it achieves the best coding efficiency (in terms of RD) at the cost of a high computational complexity. The *x265*, *f265* and *Kvaazar* HEVC software encoders provide real-time encoding, leveraging parallel processing and low-level Single Instruction Multiple Data (SIMD) optimizations. Hardware and software based encoders can benefits from the complexity reduction techniques detailed in Section II. The major part of the HEVC complexity analysis available in literature are based on HM [4], [11]–[13] but their results can not be directly extended to real-time video encoders. Only a few studies are specifically focused on energy consumption [12], [13]. In this paper we propose to analyse energy reduction opportunities by considering different levels of granularity from global video parameters to prediction unit determination. The term search space is used in this paper as the set of all possible configurations offering different trade-offs between application performance and energy. The search space is defined in terms of energy reduction for complexity reduction methods at different levels of granularity. In the context of software video encoding on embedded systems, where computational resources are scarce; experimental studies are carried out with the real time HEVC encoder *Kvazaar* [14]–[16]. The aim of this work is to study energy consumption and RD degradation in a real-time HEVC encoder when constraining the encoding at different levels of granularity. We introduce the notion of Minimal Energy Points (MEPs) which represent the boundaries of energy consumption for a given configuration.

The rest of this paper is organized as follows. Section II presents an overview of State-of-the-Art methods to reduce the encoder computational complexity. Section III details the experimental setup and a coarse-grain energy consumption analysis. Section IV defines the MEP and the energy reduction search space for complexity reduction techniques.

II. Related Works

Different levels of parameters can be adjusted to reduce the complexity of an encoding process. The parameters with the highest level of granularity are the video parameters such as its resolution and its frame rate. On the second level, there is the

Profile level which corresponds to the temporal configuration: AI frames, RA or LD inter frames. Then come the encoder parameters, such as the Quantization Parameter (QP) parameter, that also has a significant impact on complexity. Finally, most methods reducing the encoder computational complexity focus on the definition of a new frame partitioning, especially the coding trees and PU determinations as summarized in Table I.

TABLE I
COMPUTATIONAL COMPLEXITY REDUCTION TECHNIQUES FOR HEVC

Category	Brief Desciption	Ref	CR (%)	BD-rate
Coding Tree Structure Determination	Fast splitting and pruning method	[17]	50%	+0.6%
	Coding tree pruning	[18]	40%	+0.52%
	Top Skip and Early Termination	[19]	45%	+1.9%
	Early Termination	[20]	48%	+1.7%
	Early Termination	[21]	35%	+0.25%
	Early Termination	[22]	38%	+1.68%
PU Determination	Pixel gradient statistics	[23]	28%	0.53%
	PU map prediction	[24]	44%	+1.27%
	Intra mode prediction	[25]	28%	+0.49%
	Correlation	[26]	52%	0.88%
	Gradient information	[27]	20%	0.74%
	Skip motion estimation	[28]	48%	2.9%
	Mode sorting	[29]	29.3%	0.78%

A. Coding Tree Unit Level Complexity Reduction Methods

To reduce the computational complexity of HEVC encoders, algorithmic solutions have been proposed to speedup coding tree partitioning by testing less partition configurations. A fast splitting and pruning method for intra-encoding is proposed in [17]. This method is composed of two complementary techniques using Bayes decision rules: the early Coding Unit (CU) splitting decision and the early CU pruning decision. The experimental results show that this method is able to reduce computational complexity by 50% with a Bjøntegaard Delta Bit Rate (BD-BR) increase of 0.6%. In [18], a fast CU decision method is proposed by an early determination of the CU sizes based on coding tree pruning which yields a complexity reduction of 40% with a 0.52% increase of BD-BR.

Authors in [19] introduce two novel techniques for fast RDO process: *Top Skip* and *Early Termination*. The *Top Skip* selects a starting Coding Tree Block (CTB) depth corresponding to a given level of CU splitting. The *Early Termination* method is used to stop the CU splitting process if the best RD-cost is already lower than a given threshold. The techniques are developed on inter predictions and obtain an average of saving time around 45% for a BD-BR increase of 1.9%. The methods proposed in [20]–[22] use intermediate information of encoding steps to determine whether the current CU needs to be partitioned or can be completely encoded.

B. Prediction Level Complexity Reduction Methods

Different methods have been proposed to reduce the computational complexity of the prediction part of the encoder.

In [23], a fast Intra mode decision algorithm based on pixel gradient statistics and mode refinement is proposed. This method achieves about 28% of complexity reduction with a 0.53% BD-BR increase. Authors in [24] propose a method using texture variance to predict efficiently the PU maps and to avoid evaluating recursive PU sizes. This method reduces the complexity by 44% for a BD-BR increase of 1.27%.

[25] reduces the candidates in RDO process using direction information of the neighbouring blocks. Experimental results show that this method provides 28% of complexity reduction for a 0.49% BD-BR increase.

Work in [26] shows a strong correlations of the prediction mode, motion vector and RD-cost between different tree depth levels. This correlation is used to early select *SKIP* mode. This method reduces the complexity by 52% for a 0.88% BD-BR increase. In [27] a gradient based Intra mode decision algorithm is proposed. This method reduces the number of candidate modes in the RDO process and reduces the complexity by 20% for a 0.74% BD-BR increase. In [28], authors explore the relationship between the impossible modes and the distribution of the distortions to help choosing the units to skip. The method reduces computational complexity by about 48% with a 2.9% BD-BR increase. Authors in [29] propose a fast HEVC mode decision algorithm which uses information of training frames to sort and restrict the tested prediction modes. Experimental results show that this method reduces the complexity by 29.3% for an average of 0.78% BD-BR loss.

Given the amount of complexity reduction methods and the limited knowledge of their impact on energy consumption and bitrate, this paper intends to evaluate the energy sparing opportunities offered by different complexity reduction methods.

III. VIDEO AND ENCODER PARAMETER EFFECT

This Section presents an experimental characterization and evaluation of the energy consumption in a real-time HEVC encoder. A hierarchical approach is applied in this work to highlight parameters of different levels of granularity, from the levels with the most impact on energy consumption, i.e. the global parameters of the encoder, to the levels with lower impact, such as the prediction techniques of Intra modes.

A. Experimental Setup

To conduct the experiments, 22 video sequences [30] that differ broadly from one another in terms of frame rate, bit depth, motion, texture and spatial resolution were used.

All tests were performed on one core of the embedded *EmETXe-i87M0* platform from *Arbor Technologies* based on an Intel Core i5-4402E processor at 1.6 GHz. The studied HEVC software encoder is Kvazaar and AI configuration is used as a basis for all test configurations.

To measure the energy of the platform, a National Instrument (NI) PXI-6280 external data acquisition board is used. The power is evaluated by measuring the current drawn by the board through a shunt 0.1Ω resistor added for this purpose and by knowing the power voltage of the platform. Intel Running Average Power Limit (RAPL) interfaces are also used to get the energy of the CPU package, which includes cores, IOs, DRAM and integrated graphic chipset.

As shown in [31], RAPL power measurements are coherent with external measure and [32] proves the reliability of this internal measure across various applications. In this work, only

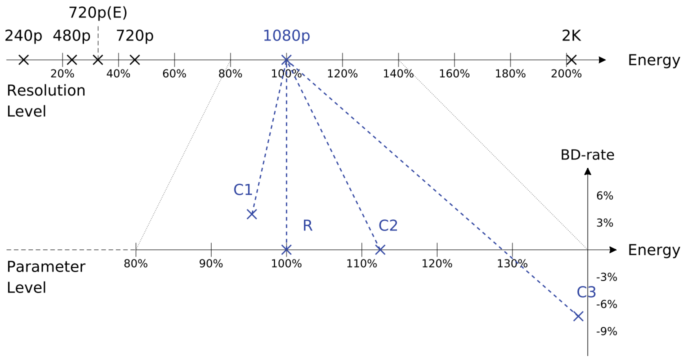

Fig. 1. Normalized energy according to resolutions and configurations

the power gap between IDLE state and video encoding is measured. The CPU is considered to be in IDLE state when it spends more than 90% of its time in the C7 C-states mode.

The power of the board is measured to 16.7W when the CPU is in idle mode and goes up to 31W during video encoding in average. RAPL shows that 72% of this gap is due to the CPU package, the rest of the power going to the external memory, the voltage regulators and other elements of the board.

The proposed study does not take into account the *Profile level*. There is a significant energy consumption gap between the different profiles of frame encoding. Indeed, RA or LD profiles consume 2 to 8 times more energy than the AI profile. This paper being focused on low energy real-time encoding, the analysis is conducted on the lowest energy AI profile.

B. Coarse-grain energy consumption analysis

Video encoders and especially HEVC encoders, include a large number of configurations and tools, each one having different impacts on energy consumption. This section studies the impact of the input video stream properties and the coarse-grain features of the encoder.

a) Resolution and frame rate level: First of all, the resolution of a video is what holds the most impact on the energy consumption of its encoding. The upper part of Figure 1 shows the normalized energy consumption average versus video resolution (2K, 1080p, 720p, 480p, 240p) for 100 frames. Encoding the 1080p video sequence consumes in average 2592 Joules, which is used to normalized the results. The energy consumption of HEVC encodings increases linearly with the number of pixels by frame. Since the stability of the energy-per-pixel is stable, the frame rate becomes a significant parameter to reduce the energy consumption. For example, for two videos, with one having two times the resolution of the other and half the frame rate, the energy consumption will be approximately the same. Videos of class E (720p(E)) are a special case and do not follow the linear consumption since their content have specific properties such as a fix background.

b) Encoder parameter level: The first HEVC-specific parameter level being used to reduce the energy consumption is based on three independent processes of the Intra prediction: the *Filters (sample adaptive offset + deblocking filter)*, the *Transform skipping* test and the *Rate-Distortion Optimisation Quantization (RDOQ)*. Four configurations are derived from

TABLE II
ENCODER PARAMETER CONFIGURATIONS

Tool	Configuration C1	R	C2	C3
Filters (SAO+DF)	D	E	E	E
Transform skipping	D	D	E	D
RDOQ	D	D	D	E

D: Disable, E: Enable

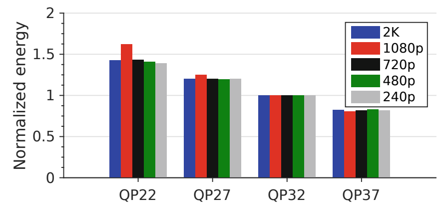

Fig. 2. QP impacts according to resolutions

these parameters due to their significant impact on the energy consumption, as show in Table II. The baseline configuration is defined as *R* and the three others by *C1*, *C2* and *C3*. The lower part of Figure 1 shows the average normalized energy consumption of all configurations for the 1080p resolution. On the vertical axis, the average BD-BRs are computed for four values of QP (22, 27, 32, 37). The BD-BR and the energy consumption, which is the result of the sum of the energies for the four QP, are normalized by the *R* configuration. In HEVC encoders, the tools increasing the energy consumption improve significantly the RD performance and thus the BD-BR. Figure 1 shows that the *Transform Skip* tool (C2) is not relevant in a real-time application due to its bad BD-BR/energy consumption trade off (the complexity increases without significant quality improvement).

c) QP level: Figure 2 plots the average energy consumption (normalized by QP32) as a function of QP when the *R* configuration is used for encoding. Figure 2 shows that the energy consumption decreases as QP increases. This is because an encoding with higher QP quantizes data more aggressively, leading to a larger share of null coefficients after quantization and the RDO process is stopped sooner. This leads to faster encoding, and in turns less energy spent.

As a first conclusion, the coarse-grain analysis performed in a hierarchical approach shows that the energy consumption of a video encoding is linearly impacted by the resolution of the input video and differently impacted by high level HEVC features. In the next section, we analyse the energetic impact of lower granularity parameters. These parameters are driven by the RDO process and can significantly reduce complexity, as shown in Section II. We also define the MEP which bounds the energy reduction search space.

IV. ENERGETIC IMPACT OF THE RDO

Complexity reduction techniques aim to improve the selection of the best configurations in the HEVC encoder in order to lower the energy consumption while trying to limit the deterioration of the rate distortion performance.

A. Determination of the Minimal Energy Point (MEP)

The RDO selects CTU partitioning and prediction mode which lead to the minimal RD-cost. Depending on the entropy of the encoded block, different sizes of CTUs are suitable. The RDO block carries out an exhaustive search in the partition set S by testing all possible CTU split partitioning and coding modes. As described in Section II, complexity reduction techniques reduce the number of tested solutions (set S) and thus can reduce significantly the energy consumption.

We define the theoretical lower bound of the energy consumption for the two levels of the RDO: *CTU level* and *Intra prediction (IP) level*. These lower bounds are called respectively the Minimal Energy Point of *CTU level* (MEP-CTU) and the Minimal Energy Point of *IP level* (MEP-IP). The MEP is the energy obtained when the encoder is able to predict perfectly the best solution and thus only this solution is carried-out to encode the CTU.Therefore, the energy consumption of the search process is reduced to the energy consumption of the solution and so the MEP is the minimal energy consumption point that can be achieved.

B. Energy Reduction Search Space

Section II defines two levels of reduction techniques corresponding to an iterative RDO processes: *CTU level* and *Prediction Level*. In the Kvazaar HEVC encoder, two features have been developed to reduce the number of iterative searches for the two levels: *early_split_termination* and *full_intra_search*. The first feature stops the RDO splitting process when all transform coefficients are inferred to be equal to zero. When *full_intra_search* is disabled, the number of angular modes searched is reduced. These two features lead to distinct configurations linked to corresponding levels: *CTU level* and *IP level*. To each configuration and level is matched a MEP that defines the 9 configurations described in Table III and their respective energy consumptions are plotted in Figure 3.

Figure 3 shows the average energy consumption and BD-BR of the different configurations organized in the two levels: *CTU level* and *IP level* for 1080p sequences. The energy reference point (*R*) is based on the *R* configuration of the Table II. As shown by the *T* point on Figure 3, the *early_split_termination* tool reduces the energy consumption without degrading the BD-BR (+0.16%). The *full_intra_search* does not affect the BD-BR as the RDO process can compensate by adjusting the CTU splitting shown by *T1* and *R1*. This compensation does not apply to *M1* because its CTU splitting is fixed and thus an important increase of 2.03% of BD-BR is observed. Each *CTU level* energy point serves as a MEP reference point for several *IP levels*. The MEPs show the maximum achievable energy reduction.

The *energy reduction search space* is defined by the percentage of energy reduction between a reference point and its associated MEP. All complexity reduction techniques summarized

TABLE III
CTU AND IP CONFIGURATIONS

Tool	Configuration								
	M2	M1	M	T2	T1	T	R2	R1	R
early_split_termination	-	-	-	E	E	E	D	D	D
full_intra_search	-	D	E	-	D	E	-	D	E
MEP-CTU	E	E	E	D	D	D	D	D	D
MEP-IP	E	D	D	E	D	D	E	D	D

D: Disable, E: Enable, -: no impact

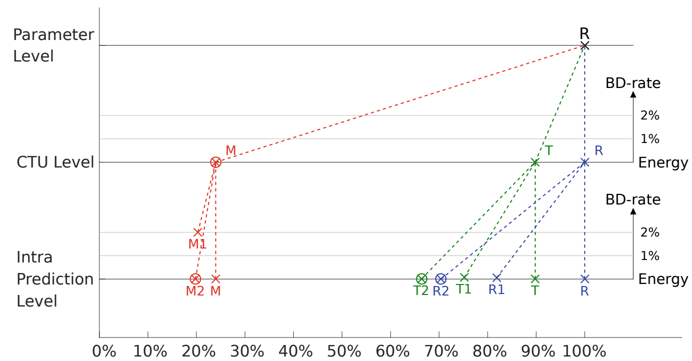

Fig. 3. Normalized energy according to CTU and IP configurations , with ⊗ for MEP

TABLE IV
NORMALIZED ENERGY CONSUMPTION ACCORDING TO RESOLUTION (%)

Res.	Configuration								
	M2	M1	M	T2	T1	T	R2	R1	R
2k	18.3	19.7	23.4	61.5	73.9	90.9	65.0	80.1	100
1080p	19.0	20.8	23.9	63.4	73.5	89.3	67.6	80.8	100
720p	16.3	18.5	21.9	49.2	60.7	75.5	58.7	77.1	100
720p(E)	18.4	20.0	23.9	66.3	74.8	87.8	71.0	83.2	100
480p	20.4	21.6	25.6	69.1	78.3	93.4	71.7	82.9	100
240p	22.8	23.8	27.9	74.6	80.5	95.5	76.3	83.4	100

in Section II are constrained within this space of achievable energy reduction. Table IV summarizes the normalized energy reduction for the different video resolutions. The results show that the search space is consistent across all resolutions and that the largest energy reduction search space occurs at the *CTU level* with up to 78.1% of potential energy reduction whereas working on the *IP level* offers 30% at best.

From this analysis we can conclude that in real-time software HEVC encoder, the energy problematic can be more efficiently addressed by reducing complexity at the *CTU level* rather than at the *IP level*.

V. CONCLUSION

Complementary to State-of-the-Art complexity reduction techniques, this paper proposes an analysis of energy reduction opportunities by considering different levels of granularity, from global video parameter to prediction unit determination. We measure the search space in terms of energy reduction according to parameters of different granularity levels. This study demonstrates several elements: at the coarsest granularity, the energy of HEVC real-time Intra encoding is proportional to video resolution. At middle granularity, the transform skipping method is not effective in reducing encoding energy. At a lower granularity, the *CTU level* has a potential of energy reduction up to 78.1% whereas the *IP level* offers at best 30% of energy reduction.

The results of this study will be used in future work into a smart encoding energy controller based on real-time energy consumption information.

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