CTU Level Decoder Energy Consumption Modelling for Decoder Energy-Aware HEVC Encoding

Thanuja Mallikarachchi, Hemantha Kodikara Arachchi, Dumidu S. Talagala and Anil Fernando
Centre for Vision Speech and Signal Processing, University of Surrey, United Kingdom
{d.mallikarachchi, h.kodikaraarachchi, d.talagala}@surrey.ac.uk, w.a.c.fernando@gmail.com

***Abstract*—Accurate modelling of the decoding energy of a CTU is essential to determine the appropriate level of quantization required for decoder energy-aware video encoding. The proposed method predicts the number of nonzero DCT coefficients, and their energy requirements with an average accuracy of 4.8% and 11.19%, respectively.**

I. Introduction

The ubiquitous consumption of video data has made multimedia the most frequently exchanged type of content on modern communication networks. It is estimated that nearly three-fourths of the world's mobile data traffic will be video data by 2019 [1]. The popularity of High Definition (HD) and Ultra-High Definition (UHD) video content and the requirements for the bandwidth efficiency have motivated the introduction of novel video compression standards such as High Efficiency Video Coding (HEVC) [2]. However, the significant increase in the complexity of HEVC [3] has become a non-trivial bottleneck for the video playback in resource constrained handheld consumer electronic (CE) devices such as smartphones, tablets etc. In this context, decoder energy-aware video encoding is becoming crucially important to address the rising video demands and the constraints of the CE devices.

Energy efficient video streaming can be realized by optimizing the wireless receiving energy or by modifying the content to reduce the total energy consumed by the receiver and the decoder [4]. The recent literature reports numerous methods for content adaptation using technologies such as scalable video coding and adaptive streaming to meet the energy constraints of the decoder. The efficiency of these solutions can be further improved with an accurate and detailed model of the decoder's energy requirements. This is especially important since HEVC constitutes a large number of coding modes along with a flexible coding architecture compared to its predecessor, and exhibits diverse decoding energy requirements when encoded under different configurations [5]. However, the state-of-the-art energy models available for HEVC do not capture all the required coding parameters and configurations; thus, requires further investigation of the decoder's energy consumption behavior.

This paper proposes an energy model that parameterizes the relationship between the decoder's energy requirements, the number of nonzero DCT coefficients (NNZ) and the Quantization Parameter (QP). The proposed model determines the NNZ for a given Coding Tree Unit (CTU) and predicts the energy requirements of the decoder, thereby facilitating the encoder to determine the appropriate level of quantization required for a CTU in order to generate an energy efficient bit stream to operate within the decoder's limited energy budget.

The remainder of the paper is organized as follows. Section II describes the proposed energy model and Section III discusses the experimental results and implications of the proposed energy model. Section IV concludes with a summary of the results and a discussion of the future work.

II. Proposed Energy Model

The energy requirements of the HEVC encoding and decoding operations can be presented in terms of the number of CPU cycles consumed by each function [6], which are eventually related to the energy consumed using the relationship between the clock frequency, the effective switched capacitance and the supply voltage [7]. Hence, the proposed energy model utilizes the common instruction level profiling tools [8], to obtain the number of CPU execution cycles to be used as an analogue for the energy consumption.

The decoding process of reconstructing a Coding Unit (CU) constitutes of two main phases; the decoding phase and the decompression phase. The decoding phase involves the entropy decoding of the syntax and residual coefficients, whereas the decompression involves the processes of predicting and reconstructing based on the decoded information. The energy consumption of the decompression phase is dependent on the Transform Unit (TU) size, prediction mode, and the quandtree hierarchy. However, the decoding phase is significantly dominated by the energy consumed to perform the transform coefficient decoding; an operation which is tightly coupled with the content and the QP.

The experimental analysis with respect to 6 training sequences suggests that the transform coefficient decoding

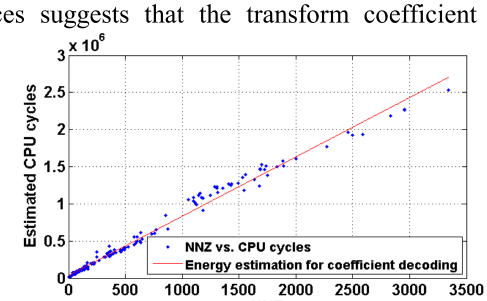

Fig. 1. Modeling of estimated CPU cycles with the number of non-zero coefficients identified within a CTU.

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energy for a CTU with a given configuration can be modeled as a linear function of NNZ. The data analyzed for CTUs with TU sizes fixed at 32 were fitted to a linear model (Fig. 1) formulated as,

$$E_{coeff\_dec} = 799.2 \times x + (32730), \quad (1)$$

where x is the number of non-zero coefficients. The Goodness of Fit of the fitted model for the set of sequences analyzed is 0.9952, which suggests that the estimated CPU cycles adhere to the fitted curve.

The generation of decoder energy-aware bit streams requires the encoder to estimate NNZ for a CTU, thereby determining the QP to be utilized while encoding to achieve the desired energy budget of the decoder. For this purpose, the behavior of NNZ for a CTU which is encoded under a given configuration is analyzed with QP values ranging from 1-51. The experimental studies reveal that the NNZ, after the quantization process for a given block, reduces with the increasing QP (Fig. 2), and can be characterized using

$$NNZ = a * \exp\left(-\left(\frac{q-b}{c}\right)^2\right), \quad (2)$$

where NNZ is the number of non-zero coefficients, q is the QP and a, b, and c are content dependent parameters which are determined through a training phase for a given block.

III. Experimental Results and Discussion

The proposed energy model and the nonzero coefficient prediction is evaluated for various content types using a HM reference software implementation running on a system with a 3.4 GHz processor and 8GB RAM. The 1st frame of the test sequences is encoded with QPs 22, 27, 32, and 37 and the NNZ for each CTU is predicted (NNZ_{pred}). Then the estimated CPU cycles with NNZ_{pred} are calculated using (1) and compared with the actual CPU cycles consumed to decode the actual coefficients [8]. The accuracy of the nonzero coefficient prediction for each CTU is measured as,

$$NNZ_{error} = 100 * \frac{\left|NNZ_{pred} - NNZ_{act}\right|}{NNZ_{act}}, \quad (3)$$

where NNZ_{act} is the actual nonzero coefficients for the CTU. The accuracy of the CPU cycle estimation is measured as,

$$E_{error} = 100 * \frac{\left|E_{pred} - E_{act}\right|}{E_{act}} \quad (4)$$

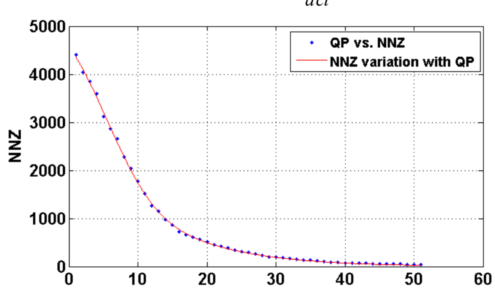

Fig. 2. Modeling of NNZ with QP for a CTU that exhibits a standard deviation of 17.93 in its DCT coefficient distribution.

TABLE I
Performance of the Proposed NNZ and Energy Prediction Model

Sequence	QP 22		QP 37	
	NNZ_{error} (%)	E_{error} (%)	NNZ_{error} (%)	E_{error} (%)
Beergarden 1080p	1.20	5.94	6.38	9.80
Kimono 1080p	3.08	7.18	8.84	10.09
Musicians 1080p	2.66	8.08	8.97	19.73
Park Scene 1080p	2.04	5.81	9.77	17.22
flower CIF	1.77	8.39	8.63	17.17
Stefan CIF	0.73	4.73	5.06	11.70
Coastguard CIF	1.03	3.79	8.53	20.30
Container CIF	1.00	10.10	7.60	19.07
Average	**1.68**	**6.75**	**7.97**	**15.63**

where E_{pred} and E_{act} are the estimated and actual CPU cycles for the coefficient decoding phase, respectively.

The average NNZ_{error} and E_{error} are presented in the Table I for 2 QP levels. It can be observed that the average error of predicting NNZ and their energy requirements are 4.8% and 11.19%, respectively. The experimental results further reveal that the accuracy of the prediction is high with lower QPs than higher QP levels. It is evident that the proposed model can be utilized at the encoders to determine a suitable QP for a CTU to satisfy the energy requirements of the video playback devices.

IV. Conclusion

This paper proposes a CTU level decoder energy model to facilitate the encoders to determine decoder energy-aware coding parameters during the encoding process. The model parameterizes the relationship between NNZ, QP and consumed CPU cycles for coefficient decoding. Therefore, the utilization of the proposed model facilitates the encoders to determine QP for a CTU, such that the energy requirements of the decoders are satisfied. The future work will focus on defining a decoder energy-aware coding parameter selection framework at the encoder that utilizes the proposed energy model in order to generate energy efficient video bit streams.

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