ENCODER POWER CONSUMPTION COMPARISON OF DISTRIBUTED VIDEO CODEC AND H.264/AVC IN LOW-COMPLEXITY MODE

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Abstract: **This paper presents a power consumption comparison of a novel approach to video compression based on distributed video coding (DVC) and widely used video compression based on H.264/AVC standard. We have used a low-complexity configuration for H.264/AVC codec. It is well-known that motion estimation (ME) and CABAC entropy coder consume much power so we eliminate ME from the codec and use CAVLC instead of CABAC. Some investigations show that low-complexity DVC outperforms other algorithms in terms of encoder side energy consumption . However, estimations of power consumption for H.264/AVC and DVC stated in this paper show that for current implementations of DVC these statements could be disputed from a power consumption/compression efficiency point of view when comparing to compression algorithms based on differential frame coding (with zero search radius for ME).**

I. INTRODUCTION

During the last years of video codec development more and more attention has been paid to the low-complexity codecs, as they are considered now for use in wireless sensor networks and another systems, where it is necessary to decrease encoding power consumption so that they can achieve longer working time, and the decoder power consumption for these systems is not an important issue. Therefore, power consumption on the encoder side has become one of the most important issues along with compression efficiency.

Distributed Video Coding (DVC) [1], [2] is a new video coding paradigm which fully or partly exploits the video redundancy at the decoder and not anymore at the encoder as in the predictive video coding, thereby shifting computation power from encoder to decoder.

Existing DVC implementations are based on the idea that the encoder uses Intra-coding part from traditional compression algorithms [3] and replaces inter coding with distributed coding. This makes the codec architecture more complex, and hence the encoder power consumption consists of two components: Wyner-Ziv encoder and Intra-encoder.

As an alternative architecture we take the baseline profile of H.264/AVC standard [3] working in differential frame coding mode (no motion coding with zero search radius for motion estimation) and using CAVLC as an entropy coder. One of the ways to show the computational performance of DVC encoder is to measure the working time on test video sequences. In particular, in [4] the working time of JM codec [5] is compared to the DISCOVER codec [6]. However, this comparison methodology should be considered to be preliminary. Firstly, the JM source code is not optimized from the time consuming point of view. Secondly, this comparison for software is not correct for hardware implementation of video compression algorithms.

Therefore, this paper proposes to use as a comparison criteria the power that the encoder consumes to provide the given peak signal-to-noise ratio (PSNR) value. Based on this criteria, we consider efficiency comparison of DVC and H.264/AVC with no motion coding for test video sequences and evaluate PSNR vs. power consumption.

Taking into account the fact that DVC codec and H.264/AVC use the same discrete cosine transform and similar quantization, and deriving simple analytical model we focus on power consumption and complexity gain comparison on the CAVLC and LDPCA encoder parts based on information about their power consumption for specific implementations, namely a 0.18μ TSMC cell library, as presented in [7] and [8], respectively. This approach does not allow to estimate the overall power consumption, but gives us information about relative power consumption for a fixed PSNR value. In addition we provide an equation that explains the dependency of the power consumption gain on implementation efficiency of CAVLC and LDPC and coding efficiency of the compared algorithms.

The hypothesis of this paper is that although DVC is considered to be low-power approach for video encoding [9], common approach based on H.264/AVC with no motion coding can achieve a comparable power consumption for a given PSNR value.

The rest of the paper is organized as follows. Section II describes the H.264/AVC and DVC encoding algorithms. Section III introduces assumptions that lay a basis for deriving a simple model of power consumption of H.264/AVC and DVC and on the basis of this model a formula for power consumption gain is given. In Section IV the results of the comparison are presented.

II. H.264/AVC AND DVC ENCODERS DESCRIPTION

II-A. H.264/AVC encoder

This paper considers only low-complexity low-power consumption implementation of H.264/AVC. The aim of this work is to show that even this simple version of H.264/AVC can achieve good results that can compete with the results of DVC solutions. Therefore, we eliminate ME (that consumes much power [10], [11]) and apply CAVLC instead of CABAC and use H.264/AVC with no motion coding. The encoding process for each frame for H.264/AVC [3] for our differential frame coding mode includes the following operations:

1) A fixed Group of Pictures (GOP) is divided into 2 kinds of the frames, i.e. Intra-predicted (I) and Bidirectionally-predicted (B). Each frame is further divided into non-overlapping blocks of size 16×16 (macroblocks).
2) For each macroblock in I-frame Intra-prediction is performed. Then 4×4 DCT and quantization are perfomed on the residual data that is further entropy encoded with Context-Adaptive Variable Length Coder (CAVLC).
3) For each macroblock in B-frame Inter-prediction is performed. In order to avoid complex motion estimation in H.264/AVC Inter mode, differential frame coding is used. As for Intra-mode, according to the coding procedure of H.264/AVC, the produced residue is transformed, quantized and entropy coded.

II-B. DVC encoder

This paper considers feedback channel based transform domain Wyner-Ziv video coding [12]. The encoding procedure includes the following main operations:

1) A fixed Group of Pictures (GOP=*N*) is adopted to split video sequences into two kinds of frames, i.e. Key frames and Wyner-Ziv frames. Periodically one frame out of *N* in the video sequence is named as key frame and intermediate frames are Wyner-Ziv frames. The key frames are Intra coded by using a conventional video coding solution such as H.264/AVC Intra (see Sect. II-A) while the Wyner-Ziv frames are coded using a Wyner-Ziv video coding approach.
2) Each Wyner-Ziv frame X_i is partitioned into non-overlapped 4×4 blocks and a DCT [3] is applied to each of them.
3) The transform coefficients within a given band $b_k, k \in \{0...15\}$, are grouped together and then quantized. DC coefficients are uniformly scalar quantized and AC coefficients are dead zone quantized, respectively.
4) After quantization, the coefficients are binarized. The binary bits with the same significance are formed to a bitplane, which is given to a rate compatible Low Density Parity Check Accumulate (LDPCA) encoder [13]. Starting from the most significant bitplane, each bitplane is independently encoded by the LDPCA encoder, the corresponding accumulated syndrome is stored in a buffer together with an 8-bit Cyclic Redundancy Check (CRC).

III. H.264/AVC AND DVC POWER CONSUMPTION

Taking into account, that the considered H.264/AVC scheme is not using motion estimation and preprocessing, assume that power consumption of H.264/AVC encoder depends on DCT/quantization part and entropy encoder part only. Consider that power consumption of the part that performs transform and quantization f_{tran}^{h264} depends on the number of pixels, processed per time unit, and CAVLC power consumption f_{CAVLC} is a function of the output bitrate. Therefore analytically power consumption of H.264/AVC encoder can be written as

$$P_{h264} = f_{tran}^{h264}(F_I + F_B, W, H) + f_{\mathrm{CAVLC}}(R_I + R_B), \quad (1)$$

where F_{I} and F_{B} are frame rate for I and B frames respectively, W and H are frame width and height, R_{I} and R_{B} are bit rate of compressed video stream correspondent to I and B frames.

For the sake of simplicity, assume that CAVLC power consumption is a linear function of the output bitrate [14]:

$$f_{\mathrm{CAVLC}}(R_I + R_B) = (R_{\mathrm{I}} + R_{\mathrm{B}}) \cdot C_{\mathrm{CAVLC}} + P_{\mathrm{CAVLC}}^0, \quad (2)$$

where C_{CAVLC} is the CAVLC complexity, which depends on the concrete hardware implementation of H.264/AVC encoder, P_{CAVLC}^0 is constant component of power consumtion.

In turn, DVC encoder power consumption consists of two parts: Intra-encoder and Wyner-Ziv encoder. Therefore, in the same way, power consumption of DVC encoder can be written as

$$\begin{array}{l} P_{\mathrm{DVC}} = f_{tran}^{h264}(F_I, W, H) + f_{\mathrm{CAVLC}}(R_I) \\ +f_{tran}^{dvc}(F_W, W, H) + f_{\mathrm{LDPC}}(R_W), \end{array} \quad (3)$$

where F_{W} and R_{W} are frame rate and bitrate of the compressed video stream for Wyner-Ziv frames, respectively.

In the same way, power consumption of LDPC part can be written as

$$f_{\mathrm{LDPC}}(R_W) = R_W \cdot C_{\mathrm{LDPC}} + P_{\mathrm{LDPC}}^0, \quad (4)$$

where C_{LDPC} is the LDPC complexity, which depends on the concrete hardware implementation of the LDPC encoder.

As stated above, DVC encoder and H.264/AVC use the same DCT and similar quantization part. Therefore, if $F_B = F_W$ then

$$f_{tran}^{h264}(F_I+F_B, W, H) \approx f_{tran}^{h264}(F_I, W, H)+f_{tran}^{dvc}(F_W, W, H), \quad (5)$$

From (1), (3) and (5) it follows that the power consumption gain of DVC encoder can be estimated by measurements of CAVLC and LPDC (here we assume that the power consumption estimation of LDPC is similar to LDPCA used in DVC).

Let us assume that H.264/AVC and DVC encoders use the same numbers of I frames in GOP. Then power consumption gain of DVC scheme can be written as

$$\begin{aligned}\Delta P = P_{h264} - P_{dvc} \approx f_{\text{CAVLC}}(R_B) - f_{\text{LDPC}}(R_W) = \\ = R_{\text{B}} \cdot C_{\text{CAVLC}} - R_{\text{W}} \cdot C_{\text{LDPC}} + \Delta P^0.\end{aligned} \quad (6)$$

As was already stated above, this paper proposes to use as comparison criteria the power consumption that the encoder needs to provide a given frame distortion value. For analytical description of this criteria lwe use the following operational rate-distortion function model [15]:

$$D(R) = \frac{\theta}{R - R^0} + D^0, \quad (7)$$

where θ, R^0 and D^0 are model parameters [15], D and R are distortion and bit rate for given video sequence.

From (6) and (7) it follows that the power consumption gain of DVC encoder for given distortion value $D(R_B^*) = D(R_W^*) = D$ can be written as:

$$\begin{aligned}\Delta P = \Big(\frac{\theta_B}{D - D_B^0} + R_B^0\Big) \cdot C_{\text{CAVLC}} - \\ -\Big(\frac{\theta_W}{D - D_W^0} + R_W^0\Big) \cdot C_{\text{LDPC}} + \Delta P^0.\end{aligned} \quad (8)$$

Let us assume that $D_W^0 \approx D_B^0$, then (8) can be simplified as:

$$\Delta P \approx \frac{\alpha_1}{D + \alpha_2} + \alpha_3, \quad (9)$$

where α_1–α_3 are constants.

IV. PERFORMANCE COMPARISON

For practical experiments the JM codec v.16.2 [5] which is the H.264/AVC reference software and DISCOVER codec [6] which is a reference software for distributed video coding were used. Practical results were obtained for four test video sequences ”foreman” and ”hall monitor” at QCIF (176x144) resolution, 15 Hz, 150 frames and ”foreman” and ”hall monitor” at CIF (352x288) resolution, 30 Hz, 300 frames.

For power consumption estimation of CAVLC and LDPC we have used the results published in [7] and [8], respectively, and the linear models (2) and (4) were used to extract the power consumption values. All power consumption measurements were achieved for 0.18μ TSMC cell library. Although this library could not be considered very new, both CAVLC and LDPC results were obtained for the same experimantal conditions and, therefore, if one solution consumes less power on 0.18μ TSMC cell library than another, most likely it will also consume less power on the advanced technologies.

The rate-distortion performance (Fig. 1–4) and the power consumption estimated as described in Section III. The results were combined to evaluate PSNR/Power consumption. Figures 5–8 show the relative power consumption for different GOP sizes. Thereafter, we chose the points on the curves with minimum power consumption for DVC and H.264/AVC and calculate the difference. This difference is shown on Fig. 9–12 denoted as ”estimated results”. These graphs also show the results for the proposed model (9), that approximates the DVC power consumption gain relative to H.264/AVC in low-complexity mode very accurately.

Results show that for most relevant visual quality range (30-40 dB) DVC with LDPC allows to decrease power consumption of entropy coding about 15-60% compared to CAVLC for H.264/AVC in differential frame coding mode. Taking DCT and Quantization blocks into account this gain is not dramatic and may not warrant the use of feedback in the DVC scheme considered.

V. CONCLUSION

In this paper two low-complexity codecs were discussed and compared. We have proposed a simple analytical model that allows to estimate power consumption gain of DVC from H.264/AVC. This model shows the dependency between encoding algorithms efficiency and implementation efficiency of CAVLC and LDPC and power consumption gain.

In this paper we have compared only the kernel of the video codecs, and the difference is rather small. If we consider other costs, the difference may be insignificant. Therefore, taking into account the complexity increase due to DVC introducing a different coding unit, than the one already used for intra/keyframes and the small gain in comparison to H.264/AVC may be preferable to use H.264/AVC in differential coding mode for the systems that require low encoding complexity.

The authors would like to note that this paper uses simple models and assumptions and focused on LDPC as replacement of CAVLC. This does not take into consideration some other components of the power consumption like memory access, residual data calculation for Inter-mode in H.264/AVC and bit-plane coding along with CRC calculation in DVC. The model is planned to be made more precise in the future work.

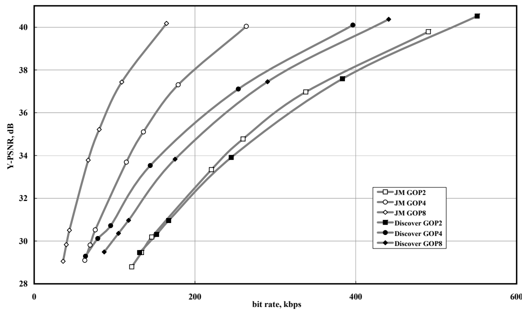

Fig. 1. Rate-distortion performance comparison for “hall monitor qcif“

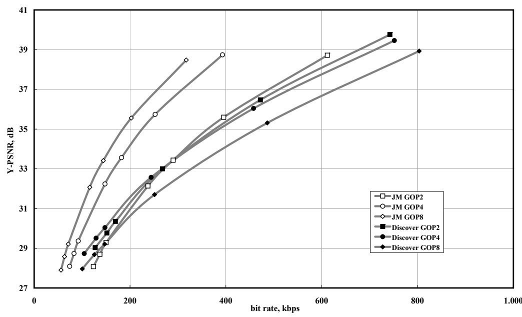

Fig. 2. Rate-distortion performance comparison for “foreman monitor qcif“

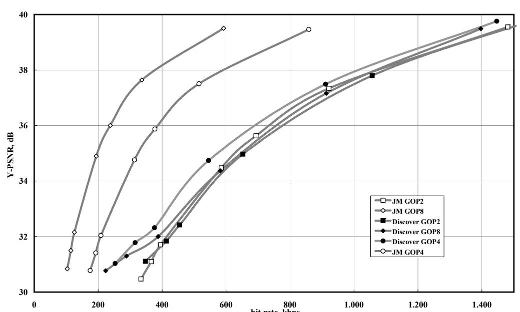

Fig. 3. Rate-distortion performance comparison for “hall cif“

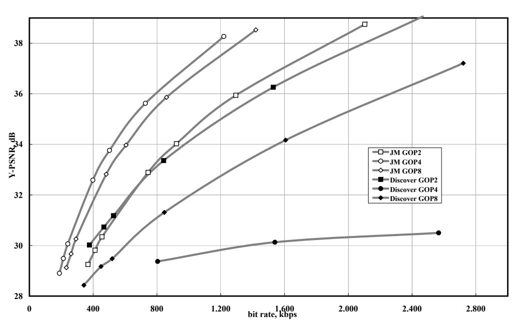

Fig. 4. Rate-distortion performance comparison for “foreman cif“

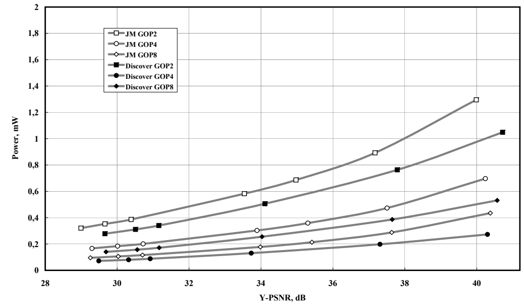

Fig. 5. Relative power consumption comparison for “hall qcif“

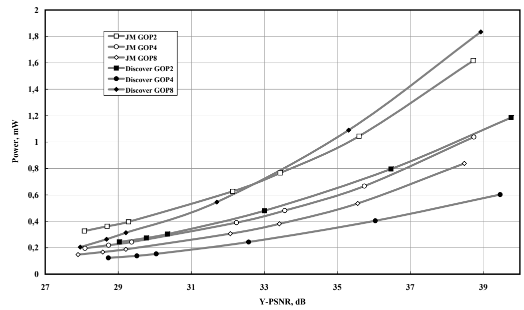

Fig. 6. Relative power consumption comparison for “foreman qcif“

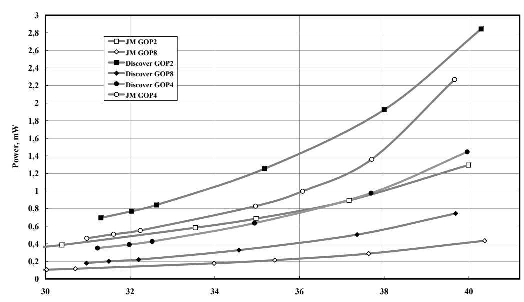

Fig. 7. Relative power consumption comparison for “hall cif“

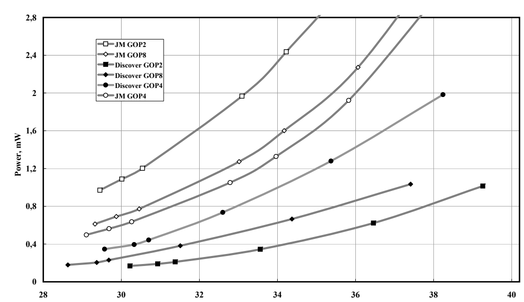

Fig. 8. Relative power consumption comparison for “foreman cif“

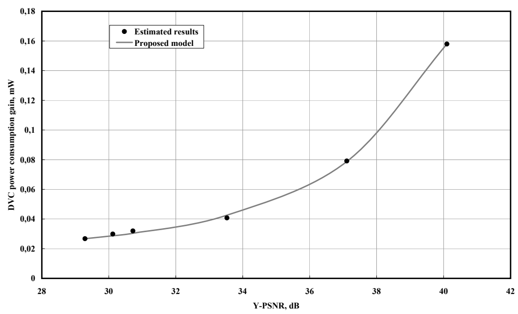

Fig. 9. DVC power consumption gain for “hall qcif“

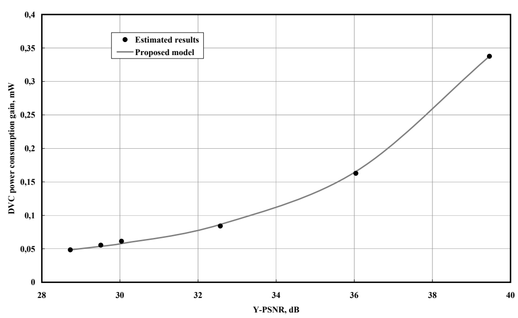

Fig. 10. DVC power consumption gain for “foreman qcif“

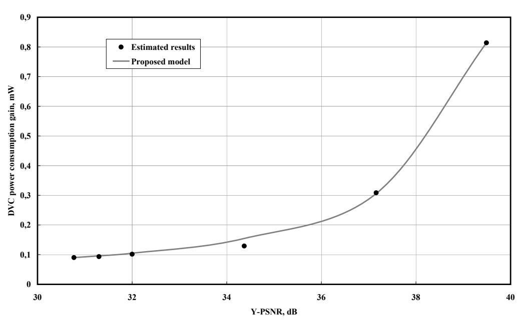

Fig. 11. DVC power consumption gain for “hall cif“

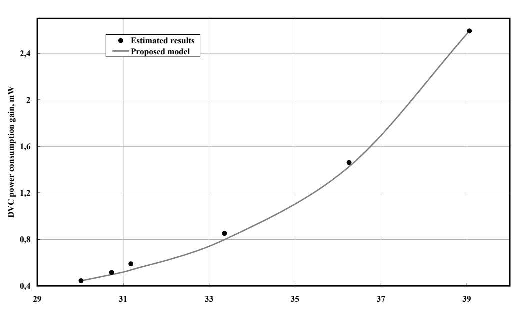

Fig. 12. DVC power consumption gain for “foreman cif“

VI. REFERENCES

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