

MULTI LAYER BASED RATE CONTROL ALGORITHM FOR HEVC

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Abstract—The specialized QP determination and reference picture set (RPS) mechanism in High Efficiency Video Coding (HEVC) significantly improves the coding efficiency. In this paper, we propose a frame layer rate control algorithm for HEVC based on this specialized mechanism. Firstly, we design a RPS based hierarchical partition structure. Then an efficient hierarchical bit allocation scheme is proposed. Moreover, a novel header bits ratio prediction method is also provided to further improve the accuracy of bit allocation. Finally, an improved mean of absolute difference (MAD) prediction scheme is provided for quadratic R-Q model to calculate an accurate quantization parameter. Experimental results demonstrate the proposed algorithm has much better R-D performance. Compared with the state-of-the-art rate control scheme for HEVC, the BD-Rate gain can be up to 30% and BD-PSNR gain can be 0.6dB on average in Low_Delay configuration. Moreover, our proposed algorithm also provides smaller mismatch between the target bit rate and the actual bit rate.

I. INTRODUCTION

HEVC (High Efficiency Video Coding) is the latest video coding standard developed by JCT-VC (Joint Collaborative Team on Video Coding), [1]. Compared with the previous video coding standards, such as H.264/AVC [2], the coding efficiency has been improved significantly.

Rate control plays a crucial role in any video coding standard, which operates with the available bit rate and buffer constraints. Generally speaking, it can be categorized into Group of Picture (GOP) level, frame level and basic unit level in terms of processing unit. Rate control can be decomposed into two procedures [3], which firstly allocates limited bits quote to each processing unit, including GOP, frame and macroblock (MB) and secondly calculates the quantization parameter (QP) to ensure that the output bit rate match the target bit rate well.

In the previous video coding standard H.264/AVC, many rate control algorithms and rate quantization (R-Q) models have been investigated for rate control. In [4], a quadratic R-Q model is proposed under the assumption that the predicted residues follow the Laplacian Distribution, which employs the mean of absolute difference (MAD) to estimate the

complexity of basic coding units. Based on the Quadratic R-Q model, JVT-G012 [5] proposed a rate control algorithm for H.264/AVC and meanwhile provided a novel linear model to predict the MAD of the next coding unit to solve the “chicken-egg” dilemma. Jiang *etc.* [6] proposed a PSNR-based frame complexity estimation algorithm to improve the exiting MAD measure. So the possible big fluctuation of video quality can be avoided. Due to the big difference of header bits among adjacent frames, [7] proposed an enhanced R-Q model based on a much accurate header bits prediction model using the number of nonzero motion vector. At present, rate control for HEVC has not been thoroughly studied yet. Based on the traditional quadratic R-Q model, [8] proposed a unified R-Q model called quadratic pixel-based unified rate-quantization (URQ) model for rate control of HEVC. The algorithm considered the new features that the size of prediction unit (PU) varies so the bit allocation must be accordance with the number of pixels.

Owning to the specialized coding structure of HEVC, many new features related to rate control, such as bit allocation, R-Q model, and overhead information prediction are all different from the previous methods before. If these problems can be properly solved, rate control for HEVC can be widely applied. In this paper, we propose a frame layer rate control algorithm for HEVC. Firstly, we design a hierarchical structure based on the specialized reference frame set (RFS) of HEVC. Then an efficient hierarchical bit allocation method is proposed to keep the frames in RFS be of high video quality. Moreover, a novel header bits ratio prediction method is also provided to further improve the accuracy of bit allocation. Finally, an improved MAD prediction scheme for quadratic R-Q model is provided to calculate an accurate quantization parameter (QP).

The rest of the paper is organized as follows. Section II introduces the specialized QP determination and reference picture set (RPS) mechanism and the proposed multi layer partition based on the special mechanism. Proposed rate control algorithm for HEVC is described in section III. Section IV presents the experimental results. Finally, we conclude the paper in section V.

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II. MULTI LAYER PARTITION STRUCTURE FOR HEVC

The specialized QP determination and RPS mechanism under Low_Delay configuration significantly improves the encoding efficiency. In HEVC, four successive frames except I frame are considered as a coding group which is called as RateGop in our paper, in which the QP of each frame has fixed difference with QP of I frame, QP_I , as illustrated in (1).

$$QP = \begin{cases} QP_I + 1 & \text{if } (POC \% 4 == 0) \\ QP_I + 2 & \text{if } (POC \% 4 == 2) \\ QP_I + 3 & \text{else} \end{cases} \quad (1)$$

Different with RPS of H.264/AVC, RPS of HEVC is composed of one frame with the nearest temporal distance and three frames with lowest QP in Decoded Picture Buffer (DPB). For each frame's RPS, the *GopId* is firstly calculated as follows.

$$GopId = (POC - 1) \% 4 \quad (2)$$

Then RPS for the current frame is determined by the corresponding Delta POC depending on *GopId*. Delta POC is difference between POC of the current frame and POC of previous coded frame. Table I presents the Delta POC of the reference frame for different *GopId*. Such specialized RPS takes more consideration of inter dependency into account and deduces improved encoding efficiency.

TABLE I. REFERENCE PICTURE SET (RPS) IN HEVC

GopId	Delta_POC			
0	-1	-5	-9	-13
1	-1	-2	-6	-10
2	-1	-3	-7	-11
3	-1	-4	-8	-12

From the Table 1, we can conclude different frame in a RateGop has different influence on the following frames. Generally, the frame with QP as $QP_I + 1$ which is of relatively high reconstructed video quality will be referred more than once which plays a crucial role. Other frame in the same RateGop is only referred once, so they are less important than the frame with $QP_I + 1$ in terms of the reference by the following frames. The frame with QP as $QP_I + 1$ is considered as a key frame in our paper.

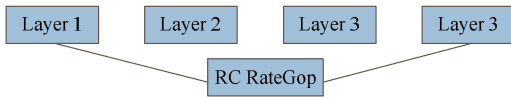


Figure 1. Hierarchical Structure of Rate Control RateGop

Based on the special RPS and different influence on the following frames, we define a Rate Control RateGop (RCRG) which is composed of four frames including one key frame and its following three frames and then divide the frames into three layers. Since the first frame plays a crucial role which will be referred by the following frame more times and has great influence on the final coding performance, so the first layer includes the first frame in a RCRG. The second layer

includes the second frame of the RateGop, whose video quality mainly depends on the first layer because its nearest reference frame usually has high video quality and the other reference frames is much further. The remaining two frames whose two nearest reference frames locate in the same RCRG belongs to the third layer. Fig. 2 shows our proposed hierarchical structure of RCRG.

III. PROPOSED MULTI LAYER BASED RATE CONTROL ALGORITHM

In this section, we will give our proposed rate control algorithm from the following parts: bit allocation, header bits prediction and improved MAD prediction scheme for quadratic R-Q model. The ultimate task is to obtain accurate QP to get high R-D performance and low bit rate mismatch.

A. Hierarchical RateGop Based Bit Allocation

Target bit allocation is a most crucial part during the rate control which will be utilized in the calculation of QP. In this paper, we propose a hierarchical bit allocation method based on the multi layer partition illustrated in section II.

Firstly, the bits for a RCRG are allocated as following.

$$T_{RateGop} = N_{RateGop} \times R_{remaining} / F_{num} \quad (3)$$

where $T_{RateGop}$ denotes the target bits for a RateGop, $R_{remaining}$ is the remaining bits after encoding the previous frames, $N_{RateGop}$ indicates the number of the frame in a RCRG and F_{num} denotes the remaining frames to be coded. Due to the temporal correlation between the adjacent RCRGs and in order to get a smooth bit rate, the allocated bits for a RCRG is further modified as,

$$T'_{RateGop} = \alpha \times T_{RateGop} + (1 - \alpha) \times T_{RateGop_pre} \quad (4)$$

where $T_{RateGop_pre}$ denotes the actual bits of the previous RCRG and α is set as 0.5 empirically.

Secondly is to allocate suitable target bits for each frame in a RCRG. The frame in upper layer should be allocated more bits due to its crucial role and fewer bits are allocated for the frames in lower layers. So based on the proposed hierarchical partition, the target bits allocated for the frames in different layers is implemented as follow,

$$T_{i,j} = \alpha_{i,j} \times T'_{RateGop} \quad j = 1, 2, 3 \quad (5)$$

where $T_{i,j}$ and $\alpha_{i,j}$ denotes the target allocated bits and bits ratio of the frame in j -th layer of i -th RCRG respectively. The initial value of the parameters in (5) is set as 0.5, 0.3 and 0.2. Then the parameters will be updated adaptively as

$$\alpha_{i,j} = \frac{1}{3} (\alpha_{i-3,j} + \alpha_{i-2,j} + \alpha_{i-1,j}) \quad j = 1, 2, 3 \quad (6)$$

The proposed bit allocation scheme ensures that the frames in layer 1 can be allocated more bits, so frames in the current RFS can be of high video quality and improved coding performance can be expected.

B. Header Bits Prediction

In the traditional rate control algorithm of H.264/AVC, the header bits are the same as the previous coded frame. While in HEVC, the special RPS mechanism makes the above method unsuitable. E.g. for the frame of layer 1 in a RCRG, the

number of header bits may be bigger than the target bits of the next frame incurring the inapposite QP.

In [7], the header bits for inter coding macro-block are modeled with the number of nonzero motion vector elements and motion vectors. Inspired by [7], in our experiments it was found that the header bits has strong linear relationship with the number of PU and MVD, as shown in Fig. 2. From the curve, it can be seen that the header bits R_h can be modeled as:

$$T_h = \alpha \times (\text{Num}_{pu} + \beta \times \text{MVD}) + \gamma \quad (7)$$

where T_h indicates the header bits, Num_{pu} is the number of PU in one frame. The parameter γ is usually small which can be set as zero and other parameters can be calculated by linear regression method.

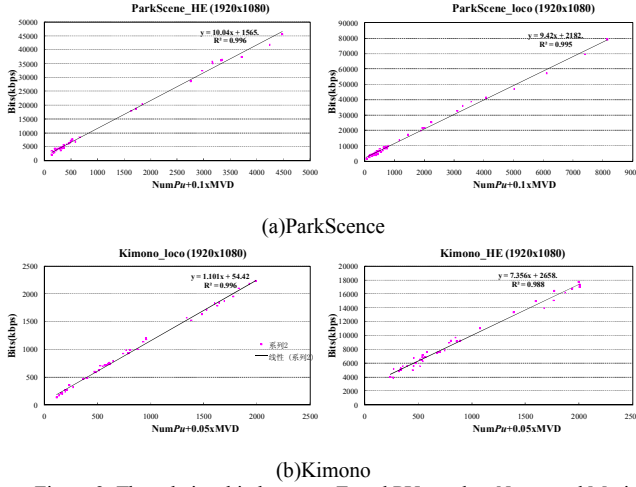


Figure 2. The relationship between T_h and PU number Num_{pu} and Motion Vector Difference MVD (a) Parkscene (b) Kimono

C. Rate Control RateGop based MAD prediction

Once the target bits and the evaluation of header bits for a frame are determined, the next step is to compute a suitable QP which heavily depends on the R-Q model to meet target bits of the frame. In the previous work [4], the source rate is modeled as a function of the quantization step and MAD as follows,

$$T_{texture} = a \times \frac{MAD}{QP} + b \times \frac{MAD}{QP^2} \quad (8)$$

where a, b are model parameters and QP is quantization step, $T_{texture}$ denotes the target bits for the texture information and can be obtained from the difference of total bits $T_{i,j}$ and header bits T_h , MAD reflects the complexity of the residual information which can be calculated by (9),

$$MAD = a_1 \times MAD_{pre} + a_2 \quad (9)$$

where MAD_{pre} denotes the MAD of the previous coded frame.

Since the fundamental framework of HEVC still belongs to hybrid coding framework, then the original quadratic model is still effective but the new features of HEVC influencing the bit rate should be considered. HEVC has considered more inter dependency among coding frames, so it is unsuitable to predict the MAD of the current coding frame only according to

one previous coded frame. For any frame, its RFS has been shown in section II. The influence of the reference frame should be further taken into account to predict a more accurate MAD.

In our paper, we propose an improved MAD prediction scheme as follows. Firstly, the MAD of current coding frame is predicted according to (9). Then based on the proposed multi layer partition, the predicted MAD is modified as follows.

$$MAD' = QP_{step_ratio} \times MAD \quad (10)$$

$$QP_{step_ratio} = \frac{Q_{step}}{Q_{step_upper}} \quad (11)$$

where $QP_{stepratio}$ indicates the influence weight of the reference frame on the MAD, Q_{step} is the quantization step and the Q_{step_upper} denotes the quantization step of the frame in the first layer. Actually, it is a chicken-egg problem to get $QP_{stepratio}$ since the Q_{step} cannot be obtained before getting the corresponding QP. Consequently, the $QP_{stepratio}$ of the previous RCRG is utilized to replace the current $QP_{stepratio}$ in order to predict the MAD.

IV. EXPERIMENTAL RESULTS

In order to verify the efficiency of our proposed algorithm, we first integrated the proposed algorithm scheme into the HM and compared with the HM anchor and URQ algorithm which is the recommended rate control algorithm in HM at present. The rate estimation accuracy is measured by the frame layer mismatch ratio by

$$M\% = \frac{|R_{target} - R_{actual}|}{R_{target}} \times 100\%$$

where R_{actual} denotes the actual bits of the encoded frame. Standard test sequences provided by HEVC are adopted to test the proposed algorithm.

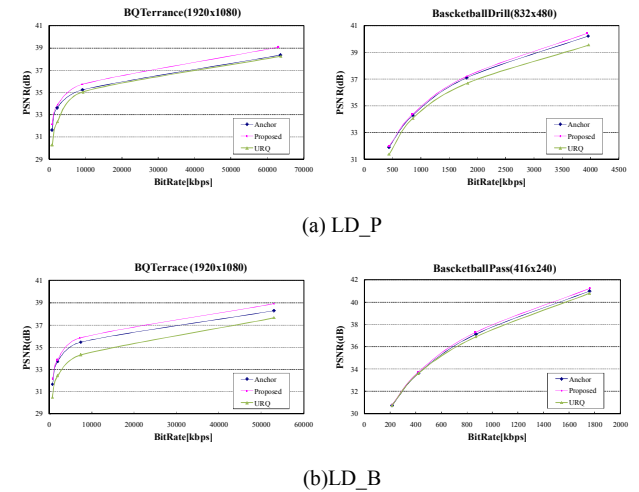


Figure 3. RD curves of the performance comparison for the proposed algorithm under different testing configurations

Table II and Table III present the performance comparisons for the proposed algorithm with HM anchor and URQ algorithm. From the tables, we can conclude the proposed algorithm presents much better encoding

performance. Compared with URQ algorithm, the BD_Rate and BD_PSNR gain can be over 20% and 0.6db on average. Table IV shows the bit rate mismatch ratio comparisons. It is evident that the proposed algorithm generates smaller mismatch between target bit rate and actual bit rate. Fig. 3 shows the RD curves of the performance comparisons on three standard test sequences, *BQTerrace*, *BasketballDrill* and *BasketballPass*. From the curves, it can be observed that the proposed algorithm works well for both high resolution and low resolution sequences.

V. CONCLUSIONS

Based on the specialized QP determination and reference picture set (RPS) mechanism in HEVC, a frame layer rate control algorithm is studied in our paper. Firstly, we design a hierarchical partition structure based on the specialized mechanism. Then an efficient hierarchical bit allocation method is proposed to ensure the high quality of the key frames. Moreover, a simple but effective header bite prediction scheme is proposed to achieve more accurate bit allocation based on the new coding features of HEVC. Finally, an improved MAD prediction scheme is provided for quadratic R-Q model to calculate an accurate quantization parameter (QP). The experimental results show that the proposed rate control scheme does much better than the recommended rate control algorithm of HEVC. The maximum average coding gain can be up to 0.77dB for LB-HE coding. Moreover, our proposed algorithm also provides smaller mismatch between the target bit rate and the actual bit rate.

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TABLE II. PERFORMANCE COMPARISON FOR THE PROPOSED ALGORITHM WITH HM ANCHOR AND URQ

Sequences	LB-HE			
	Gain over HM		Gain over URQ	
	BD-Rate	BD-PSNR	BD-Rate	BD-PSNR
ClassB	-4.26%	0.08	-36.70%	1.05
ClassC	-2.31%	0.09	-15.80%	0.66
ClassD	-1.58%	0.08	-16.26%	0.68
ClassE	-2.90%	0.09	-18.87%	0.68
Avg	-2.76%	0.085	-21.91%	0.77
Sequences	LP-HE			
	Gain over HM		Gain over URQ	
	BD-Rate	BD-PSNR	BD-Rate	BD-PSNR
ClassB	-1.92%	0.06	-16.19%	0.43
ClassC	-2.25%	0.09	-9.80%	0.40
ClassD	-1.64%	0.08	-11.25%	0.48
ClassE	-3.13%	0.09	-10.87%	0.34
Avg	-2.24%	0.08	-12.03%	0.41

TABLE III. PERFORMANCE COMPARISON FOR THE PROPOSED ALGORITHM WITH HM ANCHOR AND H213[8] FOR LB-LC AND LP-LC CODING CONFIGURATION TESTING

Sequences	LB-LC			
	Gain over HM		Gain over URQ	
	BD-Rate	BD-PSNR	BD-Rate	BD-PSNR
ClassB	-0.90%	0.02	-31.28%	0.95
ClassC	-0.42%	0.02	-15.12%	0.63
ClassD	-1.21%	0.06	-15.27%	0.63
ClassE	-0.88%	0.04	-16.08%	0.62
Avg	-0.85%	0.04	-19.44%	0.71
Sequences	LP-LC			
	Gain over HM		Gain over URQ	
	BD-Rate	BD-PSNR	BD-Rate	BD-PSNR
ClassB	-0.02%	0.01	-18.93%	0.52
ClassC	-0.42%	0.01	-5.76%	0.22
ClassD	-1.01%	0.05	-11.94%	0.47
ClassE	-1.14%	0.04	-8.67%	0.28
Avg	-0.65%	0.03	-11.33%	0.37

TABLE IV. MISMATCH COMPARISON FOR THE PROPOSED ALGORITHM WITH HM5.0 AND H213[8] FOR LB-HE AND LP-HE CONFIGURATION TESTING

Sequences	LB-HE		LB-LC	
	URQ	Proposed	URQ	Proposed
ClassB	-1.59%	-0.48%	-1.06%	-0.64%
ClassC	-0.57%	-0.29%	-0.79%	-0.35%
ClassD	0.42%	0.75%	-0.32%	0.10%
ClassE	0.49%	-0.11%	0.49%	0.10%
Avg	-0.31%	-0.03%	-0.42%	-0.20%
Sequences	LP-HE		LP-LC	
	URQ	Proposed	URQ	Proposed
ClassB	-1.56%	-0.65%	-1.50%	-0.23%
ClassC	-0.69%	-0.17%	-0.81%	-0.16%
ClassD	-0.45%	0.02%	-0.71%	-0.11%
ClassE	-0.20%	-0.08%	-0.30%	0.01%
Avg	-0.73%	-0.22%	-0.83%	-0.12%