ENHANCED ADAPTIVE INTRA MODE BIT SKIP FOR H.264/AVC

Lai-Man Po, Liping Wang, Litong Feng, Ka-Ho Ng, Ka-Man Wong
Department of Electronic Engineering,
City University of Hong Kong,
Hong Kong, China
Email: eelmpo@cityu.edu.hk

Kwok-Wai Cheung
Department of Computer Science,
Chu Hai College of Higher Education,
Hong Kong, China

Abstract—**Adaptive intra mode bit skip (AIMBS) can improve the coding efficiency of intra coding in H.264/AVC. However, it has two shortcomings: one is that DC mode is not effectively handled in AIMBS as DC mode is duplicated in both Single-Prediction and Multiple-Prediction processing; the other is that AIMBS does not well match the most probable mode (MPM) estimation scheme of H.264/AVC. To tackle these two shortcomings, an enhanced AIMBS (EAIMBS) scheme with larger bitrate reduction and better QP robustness is presented. In addition, EAIMBS almost maintains as low computational complexity as AIMBS. The proposed technique introduces distance-based weighted prediction (DWP) to replace DC mode in Multiple-Prediction and it calculates the MPM by simplified L-shaped most probable mode estimation (SLMPME) method. Experimental results show that EAIMBS gives in average 3.97% bit-rate reduction and 51% computation reduction at QP=32 compared with H.264/AVC.**

Keywords- Intra coding; H.264; AIMBS; EAIMBS

I. INTRODUCTION

Both intra frame coding and inter frame coding are utilized in H.264/AVC [1][2], which achieves more than 50% coding efficiency improvement compared with previous video coding standards such as H.263 [3] and MPEG-4 [4]. One of the main contributions to this high coding efficiency improvement is the directional spatial prediction for intra coding. Different from previous standards, intra prediction of H.264/AVC is applied in the spatial domain instead of the transform domain. It explores the correlation between adjacent blocks by using one of nine prediction modes to perform spatial prediction for each 4x4 block. This new technique achieves much higher coding efficiency at the cost of large bit consumption for mode representation, which is transmitted to the decoder side. Four bits are required to encode the prediction mode directly. To efficiently encode the bits for mode representation, H.264/AVC supports most probable mode (MPM) scheme in Intra_4x4 coding. The mode bits can be reduced if the mode of the current block can be predicted by MPM.

Recently, an adaptive intra mode bit skip (AIMBS) method was proposed in [6] for further reducing the mode representation overhead. In AIMBS, the smoothness of neighboring reference samples is examined first to determine whether only DC mode or the original 9 modes will be used in intra prediction. For the low-detailed areas, only DC mode will be used and the mode bit can be skipped. The computational complexity is also significantly reduced as the mode selection process is avoided in low-detail areas. However, there are still two shortcomings in AIMBS. One is that the DC mode in the Multiple-Prediction of AIMBS becomes less effective as most of the smooth blocks are classified to the Single-Prediction. The second problem is that the use of MPM estimation scheme in H.264/AVC with AIMBS is not efficient in some cases.

To tackle these problems, an enhanced AIMBS (EAIMBS) is proposed in this paper. In EAIMBS method, the distance-based weighted prediction (DWP) [7] is used to replace the DC mode in Multiple-Prediction and a simplified L-shaped most probable mode estimation (SLMPME) method [8] is used to improve the MPM accuracy. Apart from maintaining complexity reduction in the smooth areas as in AIMBS, the proposed method can also improve the prediction accuracy in the complex areas and improve the robustness with rate-distortion (RD) improvement over a larger QP range.

This paper is organized as follows. In section 2, a brief review of the intra prediction techniques of H.264/AVC and AIMBS is given. In section 3, the proposed EAIMBS is presented based on DWP and SLMPME methods. Experimental results comparing the proposed method with the original H.264/AVC's intra prediction are given in section 4. Finally, conclusions are drawn in Section 5.

II. ADAPTIVE INTRA MODE BIT SKIP

Before introducing the new EAIMBS, we first provide a brief review of the intra prediction in H.264/AVC and AIMBS. H.264/AVC supports three luminance block-based intra predictions. Intra_4x4 has nine spatial prediction modes for enhancing the coding efficiency in complex areas. Intra_16x16 has four modes and they are mainly used in smooth areas. Intra_8x8 is supported only in Fidelity Extension profile [9]. Mode selection is based on the minimization of the Lagrangian cost function [10].

The eight directional prediction modes and DC mode of Intra_4x4 prediction in H.264/AVC are shown in Fig. 1. The predicted pixels P_{ij} are predicted by the upper reconstructed pixels U_j ($0 \leqslant j \leqslant 7$), and left reconstructed pixels L_i ($0 \leqslant i \leqslant 3$), and X. For DC mode, all the pixel values are predicted as the average of eight neighboring pixels given by

$$P_{ij} = \frac{1}{8}\left(\sum_{j=0}^{3} U_j + \sum_{i=0}^{3} L_i\right). \quad (1)$$

MPM is set as the prediction mode of either the upper or the left block whichever has a smaller mode index. If the best mode of the current block is identical to the predefined MPM, only one bit is needed. Otherwise, another 3 bits will be sent to the decoder to indicate the actual best mode. The bitstream format for Intra_4x4 coding of H.264/AVC is shown in Fig. 2, in which the bits for intra prediction modes (16 units) are sent before coded block pattern (CBP) & coefficients. Overall, 16 to 64 bits are required for mode representation, imposing a heavy burden on bitrate consumption. AIMBS tries to reduce this burden by utilizing the fact that if the neighboring reconstructed pixels have similar values, i.e. in very smooth areas, all the 9 prediction modes will give very similar prediction. For instance, when all the neighboring reconstructed pixel values are equal to N, it is unnecessary to perform all the nine prediction modes and the associated rate-distortion optimized (RDO) selection. The DC mode can be used for prediction so that the bits for indicating prediction mode can be saved.

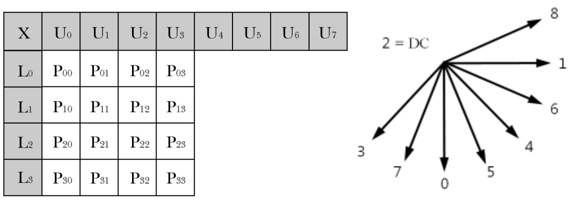

Figure 1. Intra_4x4 prediction.

Intra prediction modes (16 units)	CBP & Coefficients

Figure 2. Intra_4x4 prediction bitstream in H.264/AVC.

CBP & Coefficients	Intra prediction modes (? units)

Figure 3. The bitstream format in AIMBS.

AIMBS uses the variance of the eight reconstructed pixels on the left and above the block under prediction to classify smoothness. Two parameters, σ_p and Th, are defined as

$$\sigma_p = \left\lfloor \left[\sum_{j=0}^{3}(\mu - U_j)^2 + \sum_{i=0}^{3}(\mu - L_i)^2 + 4\right]/8 \right\rfloor, \quad (2)$$

$$\text{Th} = \left\lfloor \frac{{Q_{step}}^2 + 8}{16} \right\rfloor. \quad (3)$$

where μ is the mean value of the neighboring pixels (U_0~U_3 and L_0~L_3) as shown in Fig. 1 and Q_{step} is the quantization parameter. A block is classified as Single-Prediction if $\sigma_p < \text{Th}$. Otherwise, the block is classified as Multiple-Prediction. In Single-Prediction, only DC mode is used and the intra mode bits can be skipped, while nine prediction modes are used in Multiple-Prediction as that of Intra_4x4 in H.264/AVC. However, the DC mode becomes less effective in Multiple-Prediction as it is seldom used in the complex areas. To alleviate this problem, the DC mode is assigned to be the last mode (mode number 8) in AIMBS. On the other hand, the prediction mode bits are only required for the blocks using Multiple-Prediction, then the number of bits for intra prediction modes is variable. In this case, the decoder cannot distinguish the bits for "intra prediction modes" and "CBP & Coefficients". To solve this problem, the bitstream order of these two elements is interchanged as shown in Fig. 3, such that the decoder can use the information of "CBP & Coefficients" to identify the use of Single-Prediction. To tackle the two problems of AIMBS on the ineffectiveness of the DC mode prediction and MPM in Multiple-prediction, two techniques are proposed in the following section to further enhance the performance of the AIMBS.

III. ENHANCED ADAPTIVE INTRA MODE BIT SKIP

A. AIMBS-DWP Method

The ineffectiveness of the DC mode in Multiple-Prediction of AIMBS is mainly due to the fact that most of the smooth 4x4 blocks are classified into Single-Prediction. In addition, the DC mode is not effective in predicting complex block without directional preference in Multiple-Prediction. To further improve the coding efficiency, the distance-based weighted prediction (DWP) proposed in [7] is used to replace DC mode in Multiple-Prediction. DWP mainly focuses on improving the prediction accuracy of DC mode in complex areas of a video frame. In Intra_4x4 prediction, 8 directional modes are used to predict the regions with unified directions and DC mode is used to predict the areas where the textures have no unified directions. However, DC mode cannot adapt any kind of variations. DWP is proposed to replace DC mode to predict some non-unified varying areas, which occurs commonly in ordinary videos. This mode is designed based on the empirical model that the correlation between two pixels is inversely proportional to the distance between them. Consequently, the prediction value of Pij can be calculated by (4) as shown below:

$$P_{\text{ij}} = \frac{L_i \times (i+1) + U_j \times (j+1) + \Delta}{i + \text{j} + 2}. \quad (4)$$

where Δ is the adjusting coefficient.

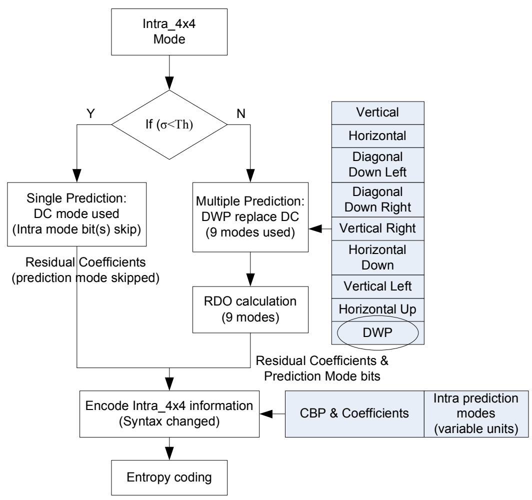

Figure 4. Flowchart of the proposed AIMBS-DWP method.

The first proposed improvement to AIMBS method is called AIMBS-DWP. This method enables the Multiple-

Prediction of AIMBS to handle the complex block without directional preference by DWP mode. On the other hand, in order to limit the increase in complexity, DWP is used only in Multiple-Prediction. Thus, the selection of Single-Prediction or Multiple-Prediction can also be viewed as the judgment of using the simple DC mode or the complicated DWP mode. In this way, AIMBS-DWP method can maintain lower bitrate and shorter encoding time in low detailed areas and also improve the prediction accuracy in high detailed areas. Overall, it performs well in both the smooth and complex areas. The flowchart of the proposed AIMBS-DWP for Intra_4x4 prediction is shown in Fig. 4. The selection of Single-Prediction or Multiple-Prediction is determined by the smoothness parameter σ_p defined in (2). Single-Prediction uses only DC mode without RDO mode selection. The bits for indicating modes can be skipped. Multiple-Prediction has eight directional modes and a DWP mode for RDO mode selection.

B. SLMPME Method

The second problem of AIMBS is its MPM estimation is not effective by using H.264/AVC's MPM scheme. In this case, the MPM of current block is chosen as the mode with smaller index between the left and the upper block in H.264/AVC. However, this selection method is not always appropriate. As mentioned before, the mode with smaller index, which only indicates its higher probability of occurrence, is not necessarily better than the other modes in some cases. It is possible to further enhance the coding efficiency by using advanced MPM scheme in Multiple-Prediction of AIMBS. The biggest problem of the MPM scheme in H.264/AVC is that the neighboring texture information cannot be fully considered. In this scheme, only one mode is selected as MPM from the left and upper modes. The directional information of other neighboring block is neglected. To tackle this problem, an L-shaped template most probable mode estimation (LMPME) method is proposed in [8]. In LMPME method, the L-shaped template is shown in Fig. 5, which covers upper, left, and upper-left areas. Considering the spatial correlation between the current block and the template region, as well as the coding complexity, the template size M is chosen to be 2 pixels.

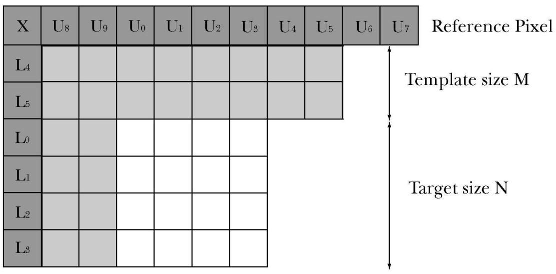

Figure 5. The L-shaped template.

To estimate the MPM, all the nine modes are performed on the L-shaped template. The calculation procedures of prediction modes are similar to the Intra_4x4 prediction in H.264/AVC, except for the region shape. To choose the best prediction mode for the template, sum of absolute differences (SAD) is used as the cost function. However, performing all the nine modes and comparing their SAD costs to estimate the MPM involve heavy computational load. To take the advantage of LMPME method and to overcome its drawback, a simplified LMPME (SLMPME) method is proposed to estimate MPM in the Multiple-Prediction of AIMBS. First, only the left and upper modes are considered. As the modes of neighboring blocks include the directional texture information of neighboring areas, it is probable that the textures of the current block and its neighboring blocks are continuous. The actual prediction mode of the current block is more likely to be the left or upper mode than other modes. Secondly, we make use of the L-shaped template in LMPME method. The template provides more comprehensive information of neighboring areas, so that the SLMPME method can make a more suitable choice of MPM than the conventional scheme in H.264/AVC. In this way, it can also avoid the inaccuracy caused by the improper arrangement of mode index. SLMPME method jointly uses the information of the decoded modes and decoded pixels of the neighboring areas to improve the efficiency of MPM estimation. The flowchart of the SLMPME method is shown in Fig. 6. In the diagram, "blockA" and "blockB" refers to the left and the upper neighbor blocks of the current block, while "modeA" and "modeB" refers to the prediction modes of block A and block B, respectively.

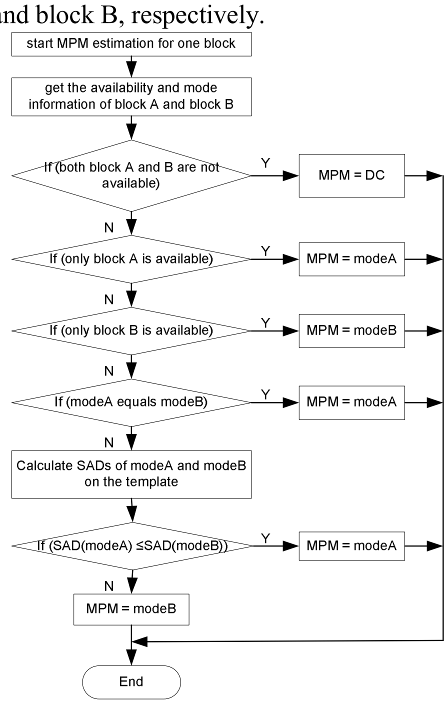

Figure 6. Flowchart of SLMPME method.

C. EAIMBS Method

To tackle these two problems of AIMBS, the proposed enhanced AIMBS (EAIMBS) uses AIMBS-DWP and SLMPME methods to enhance the coding efficiency. The flowchart of the EAIMBS method is shown in Fig. 7. First, the encoder decides whether Single-Prediction or Multiple-Prediction to be used by checking the smoothness of neighboring reference samples as AIMBS method in Intra_4x4 prediction. Two improvements are made in Multiple-Prediction: one is that the MPM is calculated by SLMPME method; the other is that DC mode is replaced by DWP in Intra_4x4 prediction.

The prediction mode bits can be divided into three cases:

(1) Skip mode bit case: If the neighboring reference samples are very similar, only DC mode is performed. In this case, no bits are needed to transmit, for that the decoder can check the smoothness of the decoded reference samples itself, which can decide whether Single-Prediction is used or not. It is the best case in terms of mode bits compression.

(2) MPM case: It refers to the case that the best mode of the current block is identical to the pre-defined MPM in Multiple-Prediction. The pre-defined MPM is calculated by SLMPME method. In this case, only 1 bit flag is required to transmit because the decoder can repeat the MPM estimation process to get the same pre-defined MPM. It is another case that can save the mode bits.

(3) Non-MPM case: It is the case that the best mode of current block is not the pre-defined MPM. In this case, the best mode cannot be retrieved explicitly by any decoded information. The encoder transmits 1 bit to indicate "non-MPM" and 3 more bits to indicate the chosen mode.

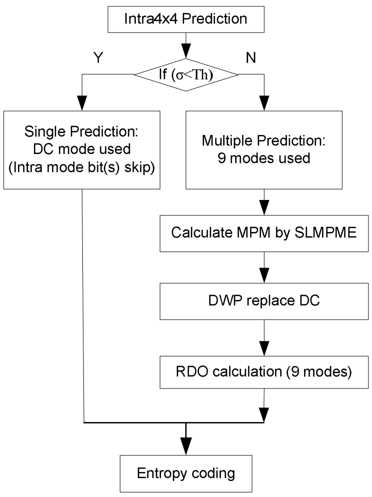

Figure 7. Flowchart of the combined method.

IV. EXPERIMENTAL RESULTS

As two improvements have been made to AIMBS, the simulation results are analyzed in two parts: AIMBS-DWP and EAIMBS. To evaluate the performance improvements of the proposed methods compared with AIMBS, we choose the same experimental sequences and conditions referenced in [6]. The proposed AIMBS-DWP and EAIMBS methods are implemented on H.264/AVC reference software JM 11.0 [11]. Three CIF sequences (Mobile, Paris, and Foreman), four 720P sequences (City, Night, Crew and Shuttlestart) and one 1080P sequence (Rolling Tomato) were used in the experiments. All the sequences are compressed with intra prediction only, including Intra_4x4 and Intra_16x16. The average PSNR gains and bitrate reductions, which are obtained by comparing with anchor intra prediction scheme in H.264/AVC, are calculated based on the BD-PSNR [12].

A. Experimental Results of AIMBS-DWP

Table I shows the simulation results of DWP, AIMBS and AIMBS-DWP methods coded by CAVLC and QPs are set to 22, 27, 32, and 37. The bitrate reduction of the AIMBS-DWP method is 3.83%, which is a little greater than the addition of bitrate reduction of DWP (0.72%) and AIMBS (3.08%). The average PSNR gain of AIMBS-DWP is 0.19 dB for all sequences. In addition, the AIMBS-DWP can also maintain the time saving rate of AIMBS method, as shown in Table III. The improvement in HD sequences is more significant than that in CIF sequences. It is because higher resolution sequences usually have relatively lower spatial complexity in a 4x4 block, in which the neighboring reference samples usually have similar values. In this case, the AIMBS can reduce the mode bits significantly.

Compared with AIMBS, the AIMBS-DWP method achieves more significant improvements in the complicated sequences, such as City and Night sequences. The significant improvement comes from the high prediction accuracy of DWP method, which is added to the Multiple-Prediction of AIMBS. The DWP mode is good at predicting the detailed areas, which usually exist in complicated sequences. Generally, the AIMBS method performs better for the low complexity sequences, while DWP performs better for the high complexity sequences. In AIMBS-DWP, AIMBS reduces the mode bits for low complexity areas and DWP increases the prediction accuracy for high complexity areas. We can say that AIMBS-DWP improves the robustness of AIMBS.

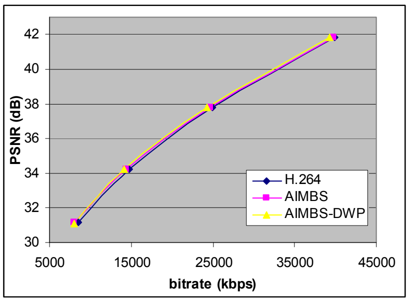

Figure 8. Comparison of RD curves of H.264, AIMBS, and AIMBS-DWP coding with CAVLC in medium QPs for City sequence.

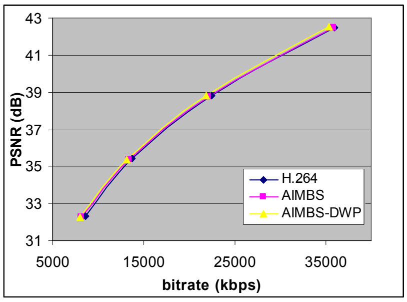

Figure 9. Comparison of RD curves of H.264, AIMBS, and AIMBS-DWP coding with CAVLC in medium QPs for Night sequence.

The RD curves of City and Night sequences are shown in Fig. 8 and Fig. 9. The proposed AIMBS-DWP persistently gives better performances than AIMBS throughout the whole bitrate range. It achieves greater improvements in the high bitrate (small QPs) range. Small QPs imply the picture has many detailed areas, in which AIMBS is inefficient. However, the advantage of DWP is shown in this case. Thus, the improvement of AIMBS-DWP compared with AIMBS is more significant in small QPs. Fig. 10 shows the probability distributions of nine prediction modes in Multiple-Prediction of AIMBS and AIMBS-DWP for Foreman sequence, respectively. The percentages of mode distributions only consider the Multiple-Prediction case. In Multiple-Prediction of AIMBS, the usage of DC mode is less than 10%, which shows it is seldom used indeed. In AIMBS-DWP, however, the usage of DWP mode is about 15%. The increase of the usage percentage of DWP indicates its higher prediction accuracy and adaptability than original DC mode in Multiple-Prediction. The increase of the prediction accuracy of DWP will reduce the bitrate for residual coefficients.

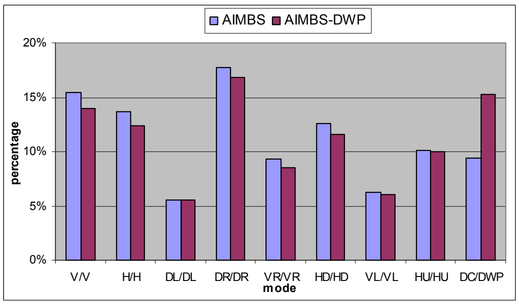

Figure 10. Comparison of probability distributions of nine prediction modes in Multiple-Prediction of AIMBS and AIMBS-DWP (Foreman sequence, QP=22).

TABLE I. COMPARISON OF RD PERFORMANCES OF DWP, AIMBS, AND AIMBS-DWP CODING WITH CAVLC.

Methods / Sequences	DWP		AIMBS		AIMBS-DWP	
	Δbitrate (%)	**ΔPSNR (dB)**	**Δbitrate (%)**	**ΔPSNR (dB)**	**Δbitrate (%)**	**ΔPSNR (dB)**
Paris	-0.81	0.08	-1.01	0.09	-1.91	0.17
Mobile	-0.52	0.06	-0.49	0.05	-1.03	0.11
Average coding efficiency for CIF	**-0.59**	**0.06**	**-1.48**	**0.11**	**-2.16**	**0.17**
City	-1.40	0.10	-1.68	0.11	-3.09	0.21
Crew	-0.29	0.01	-4.41	0.18	-4.65	0.19
Night	-1.48	0.11	-1.91	0.13	-3.30	0.23
Shuttlestart	-0.73	0.03	-5.58	0.22	-6.38	0.25
Rolling Tomato	-0.12	0.00	-6.62	0.11	-6.71	0.11
Average coding efficiency for HD	**-0.80**	**0.05**	**-4.04**	**0.15**	**-4.83**	**0.20**
Total average	**-0.72**	**0.05**	**-3.08**	**0.13**	**-3.83**	**0.19**

TABLE II. COMPARISON OF RD PERFORMANCES OF AIMBS, AIMBS-DWP, AND EAIMBS.

Methods / Sequences	AIMBS		AIMBS-DWP		EAIMBS	
	Δbitrate (%)	**ΔPSNR (dB)**	**Δbitrate (%)**	**ΔPSNR (dB)**	**Δbitrate (%)**	**ΔPSNR (dB)**
Paris	-1.01	0.09	-1.91	0.17	-2.04	0.19
Foreman	-2.95	0.18	-3.55	0.22	-4.11	0.25
Mobile	-0.49	0.05	-1.03	0.11	-1.12	0.12
Average coding efficiency for CIF	**-1.48**	**0.11**	**-2.16**	**0.17**	**-2.42**	**0.19**
City	-1.68	0.11	-3.09	0.21	-3.28	0.22
Crew	-4.41	0.18	-4.65	0.19	-4.79	0.19
Night	-1.91	0.13	-3.30	0.23	-3.40	0.24
Shuttlestart	-5.58	0.22	-6.38	0.25	-6.34	0.25
Rolling Tomato	-6.62	0.11	-6.71	0.11	-6.67	0.11
Average coding efficiency for HD	**-4.04**	**0.15**	**-4.83**	**0.20**	**-4.90**	**0.20**
Total average	**-3.08**	**0.13**	**-3.83**	**0.19**	**-3.97**	**0.20**

TABLE III. COMPARISON OF ENCODING TIME SAVING OF AIMBS, AIMBS-DWP, AND EAIMBS WITH QP={27, 32}.

Sequences	Encoding time saving (%)					
	AIMBS		**AIMBS-DWP**		**EAIMBS**	
	QP=27	**QP=32**	**QP=27**	**QP=32**	**QP=27**	**QP=32**
Paris	-15.59	-25.35	-13.93	-23.27	-12.75	-22.93
Foreman	-27.82	-49.75	-26.32	-48.58	-25.32	-48.32
Mobile	-11.83	-18.63	-9.63	-16.57	-8.65	-15.78
City	-26.29	-59.78	-24.80	-58.87	-23.72	-58.55
Crew	-54.38	-69.49	-53.60	-69.04	-53.25	-68.87
Night	-22.51	-39.37	-21.02	-38.07	-19.94	-37.59
Shuttlestart	-65.11	-78.76	-64.94	-78.68	-64.49	-78.59
Rolling Tomato	-63.43	-76.38	-62.94	-76.08	-62.81	-76.14
Total average	**-35.87**	**-52.19**	**-34.65**	**-51.15**	**-33.87**	**-50.85**

B. Experimental Results of EAIMBS

Furthermore, the SLMPME method is also implemented in Multiple-Prediction of AIMBS-DWP to estimate the MPM. The combined method of AIMBS-DWP-SLMPME is called EAIMBS. Table II shows that the average bitrate reduction of EAIMBS is 3.97%, with its maximum of 6.67% achieved in 1080p sequence of Rolling Tomato. The improvement is obtained by the high accuracy of MPM estimation of SLMPME. The RD performance of H.264/AVC can be improved more significantly by the overall combined method of EAIMBS.

In order to measure the complexity increase of AIMBS-DWP and EAIMBS, the total encoding time saving of AIMBS, AIMBS-DWP, and EAIMBS methods will be compared when QP=27 and QP=32. The comparison results are listed in Table III. The encoding time saving listed in the table is defined as follows:

$$Total\ encoding\ time\ saving(\%) = \frac{T_{method} - T_{JM}}{T_{JM}} \times 100. \quad (5)$$

where T_{JM} denotes the total encoding time processed by JM 11.0 and T_{method} denotes the total encoding time processed by AIMBS, AIMBS-DWP, and EAIMBS respectively. It can be seen that the AIMBS-DWP method saves the encoding time on the average of 34.65% and 51.15% at QP=27 and QP=32 respectively, which are close to the time saving of AIMBS. Furthermore, EAIMBS achieves the average time saving of 33.87% and 50.85% at QP=27 and QP=32 respectively. Compared with AIMBS, the time increase of EAIMBS is only about 2%. Although both the SLMPME and DWP methods will increase the computation complexity in Multiple-Prediction process, the overall encoding time of EAIMBS is still much lower than the original H.264/AVC scheme. This is because the time saving in Single-Prediction is more than the time increment in Multiple-Prediction.

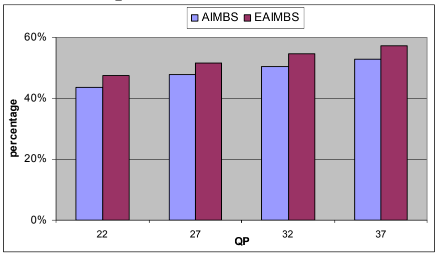

Figure 11. Comparison of MPM hit rate in Multiple-Prediction in AIMBS and EAIMBS.

Fig. 11 shows the hit rate of MPM in Multiple-Prediction in AIMBS and EAIMBS, respectively. The hit rate is increased by about 4%, which is achieved by the high estimation accuracy of SLMPME in EAIMBS. The increment of MPM hit rate will brings the further bitrate reduction of mode

V. CONCLUSIONS

In this paper, an enhanced AIMBS (EAIMBS) method is proposed to improve the coding efficiency of Intra_4x4 prediction of H.264/AVC. To overcome the shortcomings of AIMBS method, the DWP mode is proposed to replace the DC mode in Multiple-Prediction of AIMBS. Moreover, the SLMPME method is adopted to estimate the MPM in Multiple-Prediction of AIMBS. Experimental results show that EAIMBS achieves 3.97% bitrate reduction or 0.2dB PSNR improvement compared with H.264/AVC. EAIMBS can also improve the robustness of AIMBS as it can work well in larger range of QPs.

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