2019 Data Compression Conference (DCC)

Wide Angular Intra Prediction for Versatile Video Coding

Liang Zhao*, Xin Zhao*, Shan Liu*, Xiang Li*, Jani Lainema**, Gagan Rath+, Fabrice Urban+, Fabien Racapé+

*Tencent
Palo Alto, CA 94301, USA
leolzhao@tencent.com

**Nokia
Hantanp. Valtatie 30
Tampere, Finland
jani.lainema@nokia.com

+Technicolor
975 Avenue Des Champs Blancs
35576, Cesson-Sévigné, France
firstname.lastname@technicolor.com

Abstract*: This paper presents a technical overview of Wide Angular Intra Prediction (WAIP) that was adopted into the test model of Versatile Video Coding (VVC) standard. Due to the adoption of flexible block partitioning using binary and ternary splits, a Coding Unit (CU) can have either a square or a rectangular block shape. However, the conventional angular intra prediction directions, ranging from 45 degrees to -135 degrees in clockwise direction, were designed for square CUs. To better optimize the intra prediction for rectangular blocks, WAIP modes were proposed to enable intra prediction directions beyond the range of conventional intra prediction directions. For different aspect ratios of rectangular block shapes, different number of conventional angular intra prediction modes were replaced by WAIP modes. The replaced intra prediction modes are signaled using the original signaling method. Simulation results reportedly show that, with almost no impact on the run-time, on average 0.31% BD-rate reduction is achieved for intra coding using VVC test model (VTM).*

1. Introduction

Intra prediction in HEVC video coding standard employs Planar, DC and 33 directional prediction modes for all block sizes from 4x4 to 32x32 [1][2]. Since the shape of Prediction Unit (PU) for intra prediction in HEVC is always square, these prediction directions are defined to cover a fixed range of angles from 45 degrees to -135 degrees in clockwise direction.

During the development of Versatile Video Coding (VVC), several methods have been proposed to improve the performance of intra prediction. To capture the arbitrary edge directions present in natural videos, the number of directional intra modes was extended from 33, as used in HEVC, to 65 [3]. Multi-line intra prediction [4] was proposed to use more non-adjacent reference lines for intra prediction. The reference line index is signaled before intra prediction modes, and only most probable modes (MPMs) are allowed for non-zero reference lines. Position Dependent Prediction Combination (PDPC) [5][6] was proposed to utilize both left and above reference sample arrays to predict the samples in current block, making the predicted samples more continuous at the block boundaries. Intra mode coding based on 6 most probable modes (MPMs) [7] was proposed to better optimize the mode signaling for the increased directional intra prediction modes. Intra prediction mode and block size dependent 4-tap DCT-IF and Gaussian intra interpolation filter selection [8] was proposed to better accommodate the difference statistics of image samples for different block sizes and intra prediction modes.

2375-0359/19/$31.00 ©2019 IEEE
DOI 10.1109/DCC.2019.00013

Cross component linear model (CCLM) [9][10] was proposed to predict the chroma sample values using the co-located reconstructed luma samples with a local linear regression model, wherein the linear model is computed by the neighboring reconstructed samples adjacent to chroma block and co-located luma block.

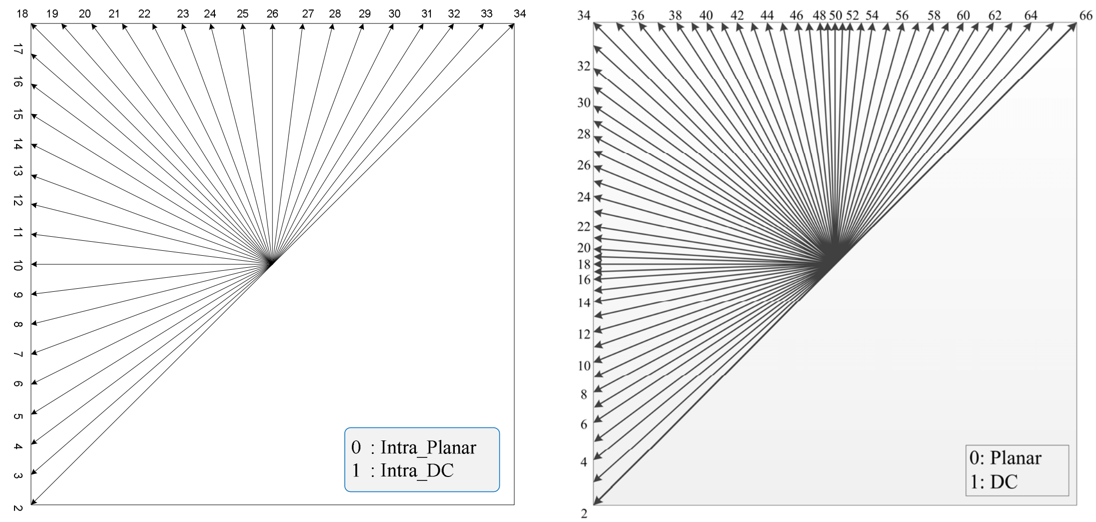
In VVC, due to the adoption of multi-type tree (MTT) using binary and ternary splits, the block shape of a coding unit can be either square or rectangular. Due to the existence of rectangular block shapes, intra prediction directions defined in HEVC and VTM-1.0 are no longer utilized symmetrically. For example, for a horizontal block with width larger than height, it is observed that the -135-degree intra prediction direction is clearly less used than the 45-degree intra prediction direction. However, none of the above mentioned methods addressed the this problem for rectangular blocks. In [11], wide angular intra prediction modes beyond 45 degrees are added to the conventional angular intra prediction modes to further improve the coding efficiency of angular intra prediction for non-square blocks. In [12][13][14], instead of adding prediction modes, a Wide Angular Intra Prediction (WAIP) scheme was proposed to replace several conventional intra prediction modes with wide-angular prediction modes such that the total number of signaled intra prediction modes is kept unchanged. With WAIP, the complexity of encoding the intra mode search remains the same as that of the VVC test model (VTM) and no extra signaling is needed in the bitstream. In [15], it was proposed to further adjust the conventional angular directions and keep all available angular directions from bottom-left diagonal to top-right diagonal for all block shapes.

This paper gives an overview and detailed analysis of the adopted WAIP modes for rectangular blocks. In Section 2, a brief review of 35 intra prediction modes in HEVC and 67 intra prediction modes in VVC is presented. In Section 3, technical details on the proposed methods are described. Experimental results are discussed in Section 4 and Section 5 concludes the paper.

2. Intra Prediction in HEVC and VVC

In HEVC, 35 intra prediction modes are used, as illustrated in Figure 1 (a), where intra prediction modes 0 and 1 refer to the Planar and DC prediction mode, respectively, and modes 2 to 34 refer to directional prediction modes with different directionalities. It is noticed that the prediction directions are assigned to be denser around the horizontal and vertical intra prediction directions because they are most frequently used directions among all the directional prediction angles.

In VVC, an intra prediction scheme based on 65 angular directions was further adopted to capture the edge directions in finer granularity. The intra prediction directions defined in VVC for square blocks are illustrated in Figure 1 (b). Although the number of angular intra prediction directions in VVC has been increased to 65, the range of directions was initially kept the same and started from 45 degrees to -135 degrees in clockwise direction. As shown in Figure 1, modes 34 and 2 indicate 45 degrees and -135 degrees in HEVC while modes 66 and 2 indicate the same directions in VVC.



(a) (b)

Figure 1: (a) 35 intra prediction modes in HEVC and (b) 67 intra prediction modes in VVC.

3. Wide Angular Intra Prediction

3.1. Motivation

In VVC, intra prediction for rectangular block shapes is enabled by using the multi-type tree (MTT) block partitioning structure, which utilizes the binary and ternary splits. In the coding tree structure, a CU can have either a square or rectangular shape. For a W×H block, the available top and left reference sample arrays are equal size including (W + H + 1) samples, as shown in the left part of Figure 2, which is required to cover the afore-mentioned prediction angle range for all pixels to be predicted within current block.

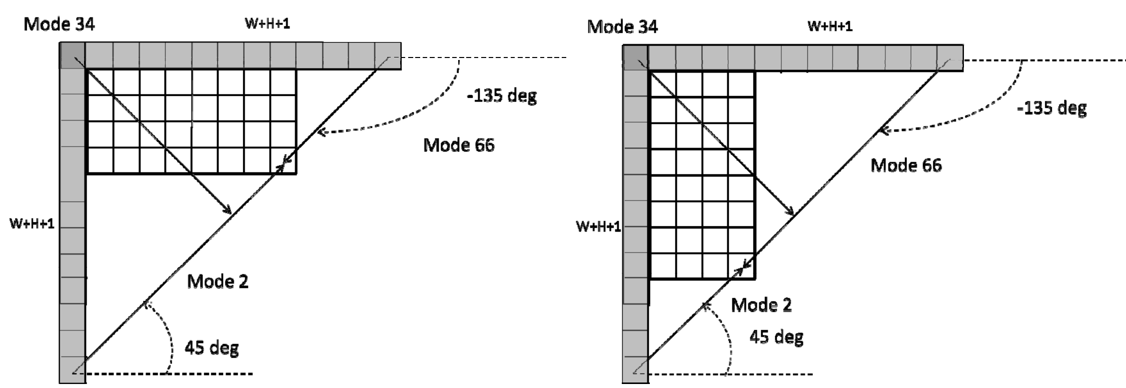


Figure 2: Rectangular blocks (horizontal block on the left, vertical block on the right) with their top and left reference arrays [13].

This definition of the prediction angle set in VTM was designed for the compatibility with HEVC specified directions, without considering the diversified block shapes supported in the MTT block partitioning structure. For instance, as described in [13], when the block is horizontal shape (i.e. W > H), the samples to be predicted are located closer to the top reference array than the left reference array. Similarly, when the block is vertical shape (i.e., H > W), the samples to be predicted are located closer to the left reference array than the top reference array, as shown in Figure 2.

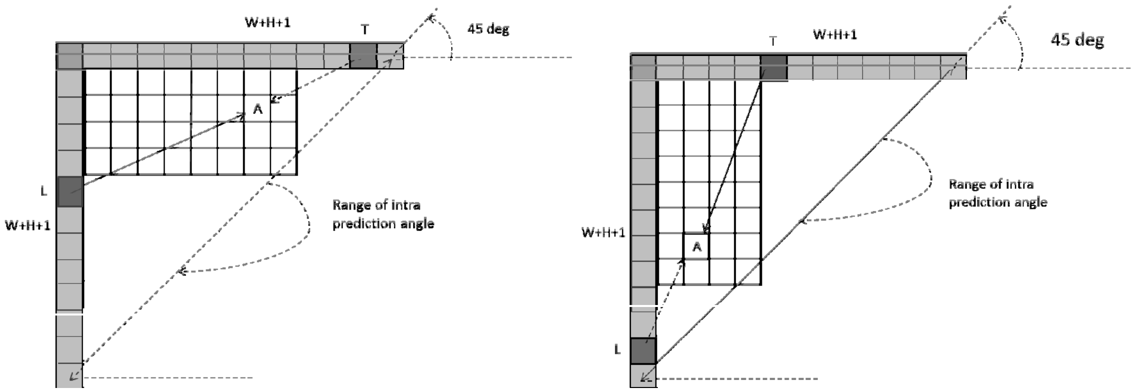


Figure 3: Example of asymmetry for rectangular target blocks [13].

As a result, for some prediction modes, the target pixel is predicted from a farther reference array, whereas the nearer reference array will be excluded because of the defined angles. As shown in Figure 3, on the left, the target pixel A has the predictor sample L on the left reference array with a horizontal prediction direction; Though the sample T on the top reference array is nearer, the vertical prediction direction, so that T could be the predictor sample for A, was not allowed in VTM-1.0. The right figure shows the analogous case for a target pixel in a tall block.

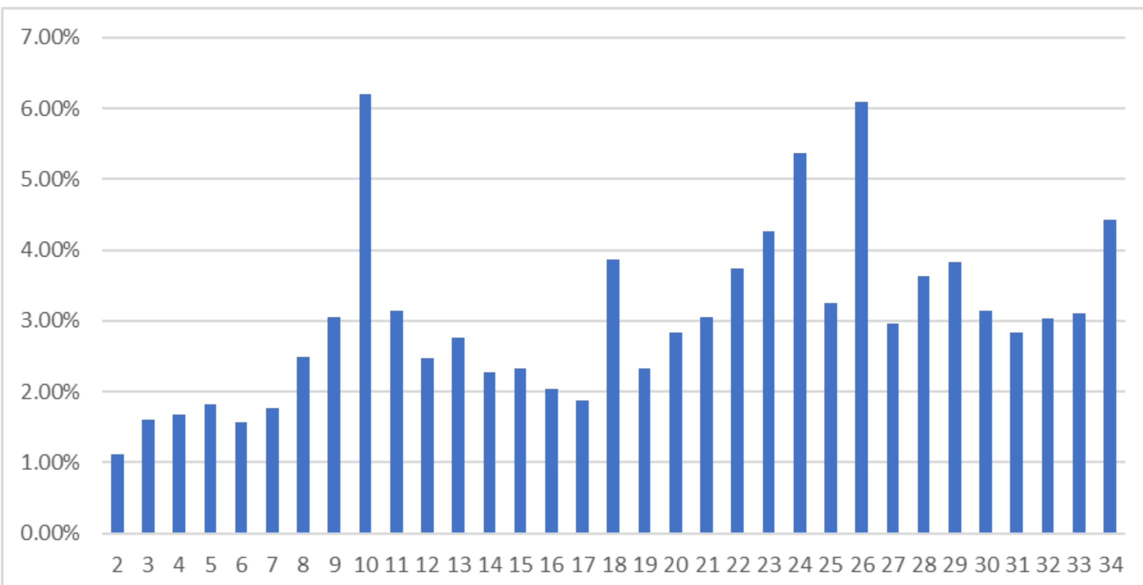


Figure 4: Intra prediction mode distribution for 16x8 blocks

To further illustrate the problem of the intra prediction for rectangular blocks, the statistics of mode distribution of intra prediction modes is collected and shown. As shown in Figure 4, the number of occurrences of each intra prediction mode for the BasketballDrill sequence in Class C at QP equal to 22 is calculated, wherein the value in y-axis indicates the number of occurrences of a given intra prediction mode and x-axis indicates the associated intra prediction mode number. The occurrences for intra prediction modes 2 to 7 are significantly smaller than other modes in case of 35 intra prediction modes.

3.2. Proposed Wide Angular Intra Prediction

To address the problem of intra prediction for rectangular blocks, wide angle modes beyond the range of prediction directions covered by conventional intra prediction are proposed for rectangular blocks. There new modes are referred to as wide angular intra prediction modes and only applied for non-square blocks as follows:

- Angles going beyond 45 degrees in top-right direction if block width is larger than block height
- Angles going beyond 45 degrees in bottom-left direction if block height is larger than block width

Each wide-angular intra prediction direction is associated with one conventional intra prediction direction, which captures the same prediction direction, but using opposite side of reference samples (left column or top row). For example, in Figure 5, in case of 35 intra prediction modes in HEVC, wide-angular modes 35 and 36 are associated with conventional intra prediction mode 3 and 4, respectively.

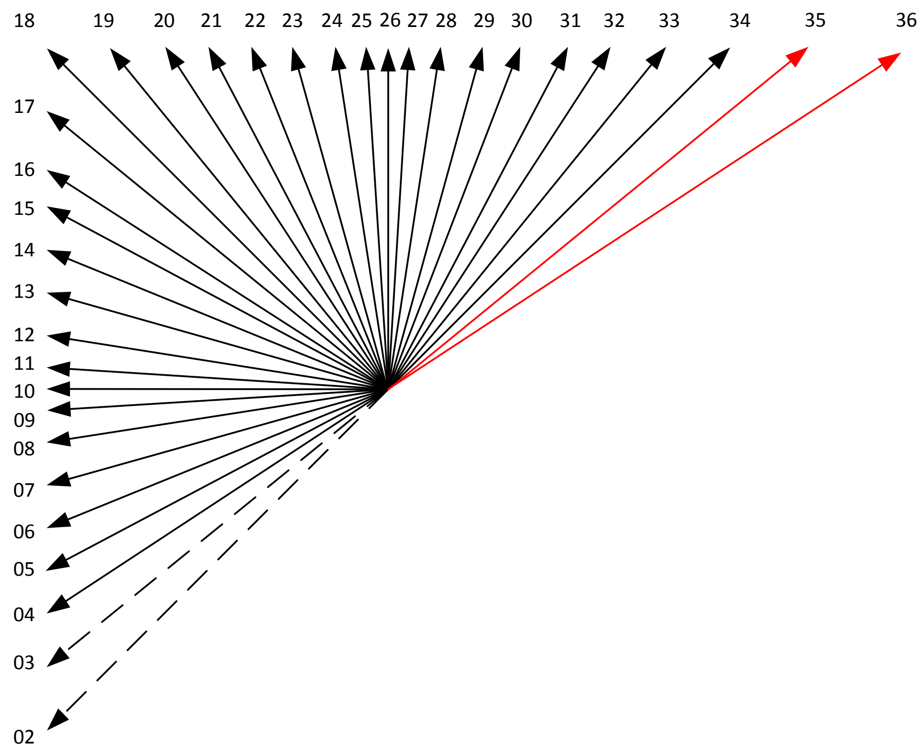


Figure 5: Examples of replacing conventional intra prediction modes by wide angular intra prediction modes

For the intra mode coding of WAIP directions, since the reference samples used for wide angular directions is closer to current block compared to reference samples used for several conventional angular directions, it is proposed to replace several conventional angular intra prediction modes with wide angular modes. The replaced modes are signaled using the original method and remapped to the indexes of wide angular modes after parsing. The total number of intra prediction modes is kept unchanged and the intra mode coding is also kept unchanged. Figure 5 shows an example of how angular intra modes are replaced with wide angular modes for a horizontal rectangular block. In this example, mode 2 and mode 3 are replaced with wide angle mode 35 and mode 36.

The number of replaced angular directions are dependent on the aspect ratio of rectangular blocks, which is illustrated in Table 1.

Table 1: Number of replaced modes for different block aspect ratio

Aspect ratio	Number of replaced intra prediction modes
W / H = 2 or 1/2	6
W / H = 4 or 1/4	10
W / H = 8 or 1/8	12
H / W = 16 or 1/16	14

This new definition of intra modes requires to adapt the Most Probable Modes (MPM)-based prediction mode coding. Since the neighbor blocks of a target block can have different shapes from the target block, their prediction modes need to be mapped to the prediction modes of the target block. A simple solution is to use the original mode indexing with respective directions. In this case, the mode indices corresponding to the removed directions for a target block are mapped to the closest opposite direction which are newly included. If the direction of prediction associated with a mode is still valid for a target block, there is no mapping required.

3.3. Adjustment for conventional angles

In VTM-2.0.1, diagonal directions (mode 2, 34, and 66) for square blocks are all included. However, the diagonal directions for non-square block shapes are not always covered. Hence, it is proposed to slightly adjust the intra prediction angles so that the diagonal directions of all block shapes are included in the angular directions. In VTM-2.0.1, the aspect ratio of an intra coding unit follows M:1 or 1:M, where M can be 1, 2, 4, 8, or 16. Hence, the angular directions α, with $\tan(\alpha)$ equals to {2/32, 4/32, 8/32, 16/32, 32/32}, are included into the list of available angular directions. To achieve this goal, the conventional angles are modified as shown in Table 2. With this modification, more integer-position samples are used as predictor so that interpolation error is further reduced.

Table 2 Modified conventional angular direction table

Original angles	0	1	2	3	5	7	9	11	13	15	17	19	21	23	26	29	32
Modified angles	0	1	2	3	4	6	8	10	12	14	16	18	20	23	26	29	32

Another benefit of this adjustment is that all available angular directions are kept within the range between bottom-left diagonal direction and top-right diagonal direction for all block sizes, as shown in Figure 6. As a result, the number of reference samples in the top reference row and left reference column can be restricted to 2 * W + 1 and 2 * H + 1 for all block shapes.

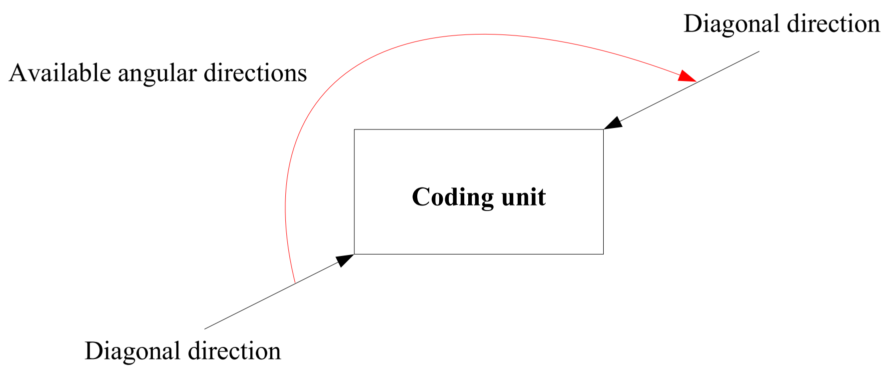


Figure 6: Available angular directions for different block shapes

4. Experimental Results

In this section, the experimental results when enabling WAIP for rectangular blocks are provided, where the experiment is conducted using the VVC Test Model VTM-2.0.1.

All the conducted experiments follow the JVET common test conditions (CTC) [16] defined in the scope of the VVC standard development. There are 26 test sequences distributed in different categories, including 4K (3840×2160), 1080P (1920×2160), 720P (1920×1080), WVGA (832×480), WQVGA (416×240) and screen content videos. All Intra (AI) configuration is used in the experiment. The BD-rates (%) are computed using quantization parameters 22, 27, 32 and 37 to evaluate objective coding efficiency. Reported average BD-rates are calculated by averaging the experimental results of Class A1, A2, B, C and E. Table 3 shows the experimental results of WAIP in AI configuration when Position Dependent Prediction Combination (PDPC) and Multiple Transform Selection (MTS) are disabled in VTM-2.0.1. Experimental results indicate that WAIP has consistent coding gain for almost all the test sequences, wherein the average luma coding gain is 0.31%, the maximum luma coding gain is 0.92% for the BasketballDrill sequence in Class C, and the only test case with a minor loss is the SlideEditing sequence in Class F. In addition, since WAIP does not increase the number of rate-distortion calculations at the encoder, the encoding time keeps almost the same as the anchor.

Table 3: Coding performance of WAIP in AI configuration

Class	Sequence	BD Y	BD U	BD V	Enc time	Dec time
A1	Tango2	-0.22%	-0.47%	-0.41%	101%	100%
	FoodMarket4	-0.03%	0.03%	0.00%	100%	100%
	Campfire	-0.17%	-0.21%	-0.11%	100%	99%
A2	CatRobot1	-0.35%	-0.42%	-0.46%	99%	100%
	DaylightRoad2	-0.29%	-0.44%	-0.43%	100%	100%
	ParkRunning3	-0.11%	-0.14%	-0.10%	100%	100%

B	MarketPlace	-0.06%	-0.16%	-0.18%	100%	100%
	RitualDance	-0.26%	-0.20%	-0.26%	100%	101%
	Cactus	-0.31%	-0.45%	-0.39%	101%	100%
	BasketballDrive	-0.37%	-0.50%	-0.69%	100%	99%
	BQTerrace	-0.60%	-1.20%	-1.04%	99%	100%
C	BasketballDrill	**-0.92%**	**-1.16%**	**-1.69%**	100%	99%
	BQMall	-0.17%	-0.14%	0.00%	99%	99%
	PartyScene	-0.09%	0.06%	-0.16%	99%	100%
	RaceHorses	-0.21%	-0.34%	-0.44%	100%	99%
E	FourPeople	-0.49%	-0.21%	-0.26%	99%	100%
	Johnny	-0.44%	0.12%	-0.47%	99%	99%
	KristenAndSara	-0.46%	-0.35%	-0.62%	100%	100%
D	BasketballPass	-0.27%	-0.38%	0.07%	99%	100%
	BQSquare	-0.28%	-0.29%	-0.68%	99%	100%
	BlowingBubbles	-0.14%	-0.34%	-0.39%	100%	100%
	RaceHorses	-0.32%	-0.53%	-0.38%	99%	101%
F	BasketballDrillText	-0.67%	-0.90%	-1.18%	99%	100%
	ArenaOfValor	-0.50%	-0.50%	-0.54%	100%	99%
	SlideEditing	0.03%	-0.02%	-0.01%	101%	100%
	SlideShow	-0.21%	-0.35%	-0.28%	101%	99%
Average		**-0.31%**	**-0.34%**	**-0.43%**	**100%**	**100%**

Figure 7 shows the intra prediction mode distribution for 16x8 blocks in BasketballDrill sequence at QP equal to 22 with the proposed WAIP method in case of 35 intra prediction modes. As shown, the number of occurrences for intra prediction modes 2 to 7 is clearly better balanced compared to the case illustrated in Figure 4.

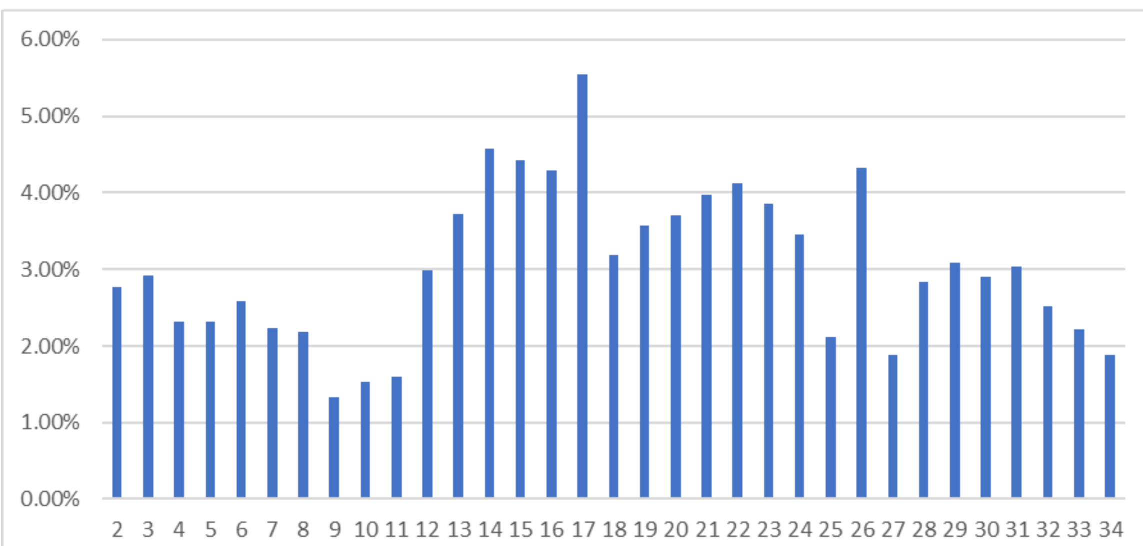


Figure 7: Intra prediction mode distribution for 16x8 blocks

5. Conclusion

Wide Angular Intra Prediction (WAIP) has been adopted into both the test model and the working draft for VVC standard. In this paper, the design of the WAIP tool is described in detail. It is composed of three components: (1) the definition of WAIP modes; (2) intra mode coding for WAIP and (3) adjustment of the conventional angular intra prediction modes. Experimental results show that WAIP provides consistent coding gain for both natural contents and artificial screen contents with almost no encoding and decoding time increase.

References

[1] G. J. Sullivan, J.-R. Ohm, W.-J. Han, and T. Wiegand, “Overview of the High Efficiency Video Coding (HEVC) Standard,” IEEE Transactions on Circuits and System for Video Technology, vol. 22, no. 12, pp. 1649–1668, Dec. 2012.

[2] J. Lainema, F. Bossen, W.-J. Han, J. Min, and K. Ugur, “Intra coding of the HEVC standard,” IEEE Transactions on Circuits and System for Video Technology, vol. 22, no. 12, pp. 1792–1801, Dec. 2012.

[3] N. Choi, Y. Piao, K. Choi, and C. Kim “CE3.3 related: Intra 67 modes coding with 3MPM,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K0529, Ljubljana, SL, Jul. 2018.

[4] B. Bross, P. Keydel, H. Schwarz, D. Marpe, T. Wiegand, L. Zhao, X. Zhao, X. Li, S. Liu, Y.-J. Chang, H.-Y. Jiang, P.-H. Lin, C.-C. Kuo, C.-C. Lin, and C.-L. Lin, “CE3: Multiple reference line intra prediction,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0283, Macao, CN, Oct. 2018

[5] X. Zhao, V. Seregin, A. Said, K. Zhang, H. E. Egilmez, and M. Karczewicz, “Low-Complexity Intra Prediction Refinements for Video Coding,” in IEEE Picture Coding Symposium (PCS), pp. 139–143, San Fransisco, USA, Jun. 2018.

[6] A. Said, X. Zhao, M. Karczewicz, J. Chen, and F. Zou, “Position Dependent Prediction Combination for Intra-frame Coding,” in IEEE International Conference on Image Processing, pp. 534–538, Phoenix, USA, Sep. 2016.

[7] L. Li, J. Heo, J. Choi, J. Choi, S. Yoo, S. Kim, and J. Lim, “CE3-6.2.1: Extended MPM list,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0165, Macao, CN, Oct. 2018.

[8] A. Filippov, V. Rufitskiy, J. Chen, G. Van der Auwera, A. K. Ramasubramonian, V. Seregin, T. Hsieh and M. Karczewicz, “CE3: A combination of tests 3.1.2 and 3.1.4 for intra reference sample interpolation filter,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0628, Macao, CN, Oct. 2018.

[9] X. Ma, H. Yang, and J. Chen, “CE3: Tests of cross-component linear model in BMS,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K0190, Ljubljana, SL, Jul. 2018.

[10] G. Laroche, J. Taquet, C. Gisquet, and P. Onno, “CE3-5.1: On cross-component linear model simplification,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0191, Macau, CN, Oct. 2018.

[11] J. Lainema, “CE3: Wide-angle intra prediction,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K0046, Ljubljana, SL, Jul. 2018.

[12] F. Racapé, G. Rath, F. Urban, L. Zhao, S. Liu, X. Zhao, X. Li, A. Filippov, V. Rufitskiy, and J. Chen, “CE3-related: Wide-angle intra prediction for non-square blocks”, Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K0500, Ljubljana, SL, Jul. 2018.

[13] G. Rath, F. Urban and F. Racapé, "CE3-related: Block Shape Adaptive Intra Prediction Directions", Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K0169, Ljubljana, SL, Jul. 2018.

[14] L. Zhao, S. Liu, X. Zhao, and X. Li, “CE3-related: Wide angular intra prediction for non-square blocks,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0279, Macau, CN, Oct. 2018.

[15] L. Zhao, X. Zhao, S. Liu, and X. Li, “CE3-related: Unification of angular intra prediction for square and non-square blocks,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-L0279, Macau, CN, Oct. 2018.

[16] F. Bossen, J. Boyce, X. Li, V. Seregin and K. Sühring, “JVET common test conditions and software reference configurations for SDR video,” Joint Video Exploration Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-K1010, Sep. 2018.