Journal of
Electronic Imaging

JElectronicImaging.org

Efficient temporal and interlayer parameter prediction for weighted prediction in scalable high efficiency video coding

Sik-Ho Tsang
Yui-Lam Chan
Wan-Chi Siu

Sik-Ho Tsang, Yui-Lam Chan, Wan-Chi Siu, "Efficient temporal and interlayer parameter prediction for weighted prediction in scalable high efficiency video coding," *J. Electron. Imaging* **26**(1), 013013 (2017), doi: 10.1117/1.JEI.26.1.013013.

Journal of Electronic Imaging 26(1), 013013 (Jan/Feb 2017)

Efficient temporal and interlayer parameter prediction for weighted prediction in scalable high efficiency video coding

Sik-Ho Tsang, Yui-Lam Chan,* and Wan-Chi Siu
Hong Kong Polytechnic University, Centre for Signal Processing, Department of Electronic and Information Engineering, Kowloon, Hong Kong

Abstract. Weighted prediction (WP) is an efficient video coding tool that was introduced since the establishment of the H.264/AVC video coding standard, for compensating the temporal illumination change in motion estimation and compensation. WP parameters, including a multiplicative weight and an additive offset for each reference frame, are required to be estimated and transmitted to the decoder by slice header. These parameters cause extra bits in the coded video bitstream. High efficiency video coding (HEVC) provides WP parameter prediction to reduce the overhead. Therefore, WP parameter prediction is crucial to research works or applications, which are related to WP. Prior art has been suggested to further improve the WP parameter prediction by implicit prediction of image characteristics and derivation of parameters. By exploiting both temporal and interlayer redundancies, we propose three WP parameter prediction algorithms, enhanced implicit WP parameter, enhanced direct WP parameter derivation, and interlayer WP parameter, to further improve the coding efficiency of HEVC. Results show that our proposed algorithms can achieve up to 5.83% and 5.23% bitrate reduction compared to the conventional scalable HEVC in the base layer for SNR scalability and 2× spatial scalability, respectively. *© 2017 SPIE and IS&T* [DOI: 10.1117/1.JEI.26.1.013013]

Keywords: brightness variation; high efficiency video coding; parameter prediction; scalable high efficiency video coding; video coding; weighted prediction.

Paper 16719 received Aug. 24, 2016; accepted for publication Jan. 17, 2017; published online Feb. 11, 2017.

1 Introduction

Illumination variation along the video sequence reduces the temporal correlation between frames due to the large brightness differences, which induces large prediction error during motion estimation (ME) and motion compensation (MC). Consequently, coding efficiency is decreased. Weighted prediction (WP)[1] tool was first introduced in H.264/AVC[2] and it is still maintained in high efficiency video coding (HEVC)[3,4] due to its efficiency of handling the problem of illumination variation. A set of WP parameters, or equivalently, a multiplicative weight $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ and an additive offset $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, for i'th reference frame in list X (list_x, where x can be 0 or 1, which stands for the forward reference list and the backward reference list, respectively, and COMP can be Y or UV, which stands for luma and chroma components correspondingly) in the S layer (L_S, where L_S can be the base layer, L_B, or the enhancement layer, L_E), are used for sample prediction for ME and MC as below:

$$\mathrm{WP}^{\mathrm{COMP}}_{L_S,\mathrm{curr}} = P^{\mathrm{COMP}}_{L_S,\mathrm{curr}} \times \left(\frac{W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}}{2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}}\right) + O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}, \tag{1}$$

where $P^{\mathrm{COMP}}_{L_S,\mathrm{curr}}$ and $\mathrm{WP}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}$ are, respectively, the current sample to be predicted and the corresponding weighted sample of that particular color component COMP in L_S. And $\mathrm{LWD}^{\mathrm{COMP}}_{L_S}$ is the log weight denominator (LWD) to provide the granularity for the multiplicative weight $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ for luma or chroma. Hence, $\mathrm{LWD}^{\mathrm{COMP}}_{L_S}$ for the current frame, as well as $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, and an associated flag $f^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, which is used for indicating the use of WP for each reference, are the WP parameters for each reference frame estimated and encoded in the slice header.

In H.264/AVC[2] or early development of HEVC,[5,6] all WP parameters are encoded without any prediction, yet large overheads are generated as all the WP parameters are coded independently without any predictions. In addition, many research works or applications related to WP have been done in H.264/AVC,[1,7–17] HEVC,[18,19] scalable HEVC (SHVC)[20,21] and multiview video plus depth coding (MVD).[22–24] Boyce[1] suggested having frame-based explicit and implicit WP parameter estimation for coding the videos with global brightness variation in H.264/AVC. Zhang and Cote[7] and Aoki and Miyamoto[8] proposed a more accurate WP parameter estimation, which uses the AC and DC characteristics. Tsang et al.[9–11] proposed to have multiple WP parameters for one single frame to get higher coding efficiency. In Refs. 12 and 13, block-based WP approaches are suggested. Tsang et al.[12] proposed to use block-based WP parameters for coding videos with flashlight, where WP parameters are coded for each block, whereas Jeong and Park[13] proposed to derive the WP parameters using the neighboring boundary pixels but only in applicable in skip mode. Kwon and Kim[14] and Tsang et al.[15–17] proposed to have region-based WP parameter estimation for coding the videos with local brightness variation (LBV). This region-based WP approach is extended to HEVC in Ref. 18 to

---

*Address all correspondence to: Yui-Lam Chan, E-mail: enylchan@polyu.edu.hk

HEVC for solving the problems of moving area and LBV. Zhang et al.[19] proposed to use a block-based WP approach where WP parameters are estimated by linear regression model. In Refs. 20 and 21, WP is used in SHVC for better interlayer prediction in color gamut scalability so as to support the wide color gamut in ultra high definition videos. In Refs. 22 and 23, pixelwise WP was suggested to have better prediction for blocks located at object boundary in MVD. And Hannuksela et al.[24] proposed to have the depth range-based WP (DRWP) whenever the closest and farthest real world depth values are changed, which makes the luminance of depth map varies temporally.

It is highly motivated to have WP parameter prediction to reduce the overhead. Thus, there was an ad hoc Group 18 (AHG 18) on WP[25] to address this issue. The WP parameter prediction has been first introduced during the development of HEVC and it is currently adopted into the syntax of HEVC.[3,4] To further reduce the overhead, Tanizawa et al.[26] suggested to implicitly predict the image characteristics of the current frame by reference frames. However, as shown in their experimental results, the coding efficiency might be reduced compared with the conventional WP in HEVC due to inaccurate prediction of WP parameters. Tanizawa and Chujoh[27] also proposed to derive the WP parameters for list$_1$ reference frames by those in list$_0$ reference frames with the coding of reference index instead of coding of WP parameters.

In this paper, we first give a description of WP parameter prediction in HEVC[3,4] and the techniques in Refs. 26 and 27 in Sec. 2. In Sec. 3, we propose our WP parameter prediction methods, which can provide lossless and efficient WP parameter prediction while keeping the same video quality as conventional WP in HEVC. Finally, experimental results and comparisons with the existing algorithms are shown in Sec. 4 followed by conclusions in Sec. 5.

2 Prior Art

2.1 *High Efficiency Video Coding Weighted Prediction Parameter Prediction*

In the conventional HEVC,[3,4] the weight and offset for a list$_x$ i'th reference frame in L_S are estimated depending on the AC and DC image characteristics of current frame $(\mathrm{AC}^{\mathrm{COMP}}_{\mathrm{L_S},\mathrm{curr}}, \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}})$ and those of the reference frame $(\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}, \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i})$, which are shown as follows:

$$W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} = \frac{\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}}{\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}} \times 2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$$

$$O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} = \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}} - W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} \times \mathrm{DC}^{\mathrm{COMP}}_{W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}}, \tag{2}$$

with

$$\mathrm{DC}^{\mathrm{COMP}}_{L_S,t} = \frac{1}{N_{L_S}} \sum_{n}^{N_{L_S}} P^{\mathrm{COMP}}_{n,L_S,t}$$

$$\mathrm{AC}^{\mathrm{COMP}}_{L_S,t} = \frac{1}{N_{L_S}} \sum_{n}^{N_{L_S}} |P^{\mathrm{COMP}}_{n,L_S,t} - \mathrm{DC}^{\mathrm{COMP}}_{L_S,t}|, \tag{3}$$

where $P^{\mathrm{COMP}}_{n,L_S,t}$ is the n'th sample in L_S at frame t (t can be curr or list$_x$, i, which means the current frame and list$_x$ i'th reference frame, respectively) and N_{L_S} is the total number of samples in L_S at frame t. The formulae above are derived based on the alpha-blending model of applying the fading effect to the video sequence. The detailed derivations are in Refs. 7 and 8.

There are three types of parameter prediction in HEVC.[3,4] First, the log weight denominator ($\mathrm{LWD}^{\mathrm{COMP}}_{L_S}$) for chroma (UV), $\mathrm{LWD}^{\mathrm{UV}}_{L_S}$, is predicted by the luma (Y) one, $\mathrm{LWD}^{Y}_{L_S}$:

$$\mathrm{LWD}^{\mathrm{UV}}_{L_S} = \Delta\mathrm{LWD}^{\mathrm{UV}}_{L_S} + \mathrm{LWD}^{Y}_{L_S}, \tag{4}$$

where $\Delta\mathrm{LWD}^{\mathrm{UV}}_{L_S}$ is coded into the slice header. Second, the weights for both luma and chroma ($W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$) are predicted by the default weight $2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$:

$$W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} = \Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} + 2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}, \tag{5}$$

where $\Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ is coded for each reference frame. Third, the offset for chroma ($O^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i}$) is predicted by the estimated weight $W^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i}$:

$$O^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i} = \Delta O^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i} + \left[128 - 128 \times \left(\frac{W^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i}}{2^{\mathrm{LWD}^{\mathrm{UV}}_{L_S}}}\right)\right], \tag{6}$$

with $\Delta O^{\mathrm{UV}}_{L_S,\mathrm{list}_x,i}$ being coded for each reference frame. With the above three parameter predictions, overhead bits for WP parameters can be reduced compared with the one without any predictions.[5,6] To evaluate the overhead percentage of WP parameters in the slice header, we performed simulation on the testing sequences from class A to class F, respectively, Traffic, ParkScene, BasketballDrill, BQSquare, Johnny, and BaskeballDrillText with linear black/white fade-out applied to the first second and linear black/white fade-in applied to the next second. An SHVC Test Model 10 (SHM 10)[28] is used with random access (RA) configuration suggested in the common test conditions (CTC).[29] As shown in Fig. 1, it can be seen that if WP is enabled, WP overheads reside in the slice header from about 72% to 78%, which is a quite large amount of bits and would reduce the coding efficiency as a consequence.

2.2 *Implicit Weighted Prediction Parameter Prediction*

As fading usually happens within a very short period of time along the scene, it can be assumed that the changes in AC and DC image characteristics estimated in Eq. (3) are linear. So, in Refs. 26, AC and DC image characteristics of the current frame $(\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}, \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}})$ are linearly predicted by those of reference frame $(\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}, \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i})$ based on the temporal distances (TD) between frames or equivalently picture order count (POC) differences of the frames. This process is similar to the implicit WP in H.264/AVC.[1] The implicit prediction of AC and DC image characteristics of current frame, $[\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}), \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred})]$, are as follows:

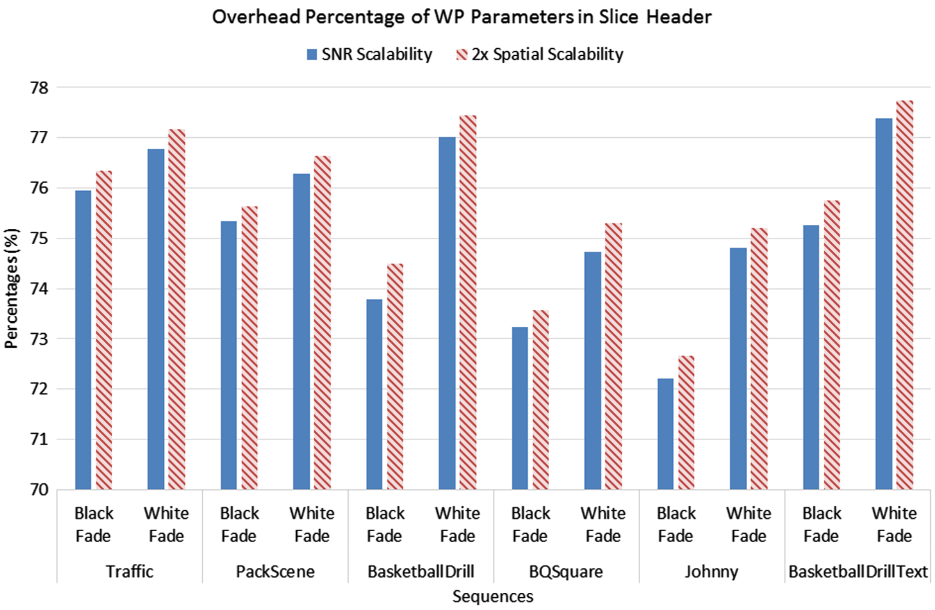

Fig. 1 Overhead percentage of WP parameters in the slice header in SHVC.

$$\begin{aligned}
\mathrm{TD}_B &= \mathrm{POC}_{L_S,\mathrm{curr}} - \mathrm{POC}_{L_S,\mathrm{list}_0,i}\\
\mathrm{TD}_D &= \mathrm{POC}_{L_S,\mathrm{list}_1,j} - \mathrm{POC}_{L_S,\mathrm{list}_0,i}\\
\mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}) &= \frac{\mathrm{TD}_B}{\mathrm{TD}_D} \times \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j} + \left(1 - \frac{\mathrm{TD}_B}{\mathrm{TD}_D}\right)\\
&\quad \times \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_0,i}\\
\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}) &= \frac{\mathrm{TD}_B}{\mathrm{TD}_D} \times \mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j} + \left(1 - \frac{\mathrm{TD}_B}{\mathrm{TD}_D}\right)\\
&\quad \times \mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{list}_0,i},
\end{aligned} \tag{7}$$

where $\mathrm{POC}_{L_S,\mathrm{curr}}$, $\mathrm{POC}_{L_S,\mathrm{list}_0,i}$, and $\mathrm{POC}_{L_S,\mathrm{list}_1,j}$ are the POC of the current frame, list_0 i'th reference frame and list_1 j'th reference frame in L_S, respectively, which are also depicted in Fig. 2. For the sake of simplicity, scaling operation and rounding condition are skipped. The detailed implementation is in Ref. 26. The resultant $[\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}), \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred})]$ would be treated as $(\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}, \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}})$ and would be used to estimate $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ and $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ for each reference frame and each component by Eq. (2). These WP parameters, $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ and $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, are used for ME and MC directly. Hence, they are not required to be coded. Overheads might be largely reduced but with the sacrifice of video quality due to inaccurate WP parameters. It is noted that the two reference frames should be chosen that are closest to the current frame for accurate interpolation of $[\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}), \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred})]$. When interpolation is unavailable, extrapolation can be applied by two list_0 reference frames.

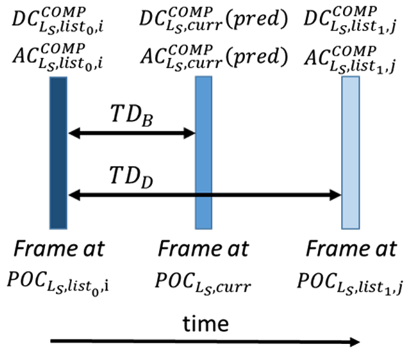

Fig. 2 Illustration for implicit WP parameter prediction (IWPP).

2.3 *Direct Weighted Prediction Parameter Derivation*

In Ref. 27, WP parameter prediction is further enhanced for each reference frame in list_1 by deriving the weight and offset from those reference frames in list_0. For each reference frame in list_1, when the estimated WP parameters, $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j}$ and $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j}$, are exactly the same as those of one reference frame in list_0, then, the WP parameters can be directly reused by signaling that the particular reference index in list_0. Thus, one flag is added to indicate the use of direct derivation. If the flag is 1, the corresponding list_0 reference index for reusing the weight and offset is signaled. Otherwise, the conventional parameter prediction in HEVC is applied. To signal the reference index in list_0, a reference index difference, $\Delta RefIdx_{L_S,\mathrm{list}_1,j}$, between the reference index $RefIdx_{L_S,\mathrm{list}_0,i}$ in list_0 and the reference index $RefIdx_{L_S,\mathrm{list}_1,j}$ in list_1, are coded according to Ref. 30:

$$RefIdx_{L_S,\mathrm{list}_1,j} = \Delta RefIdx_{L_S,\mathrm{list}_1,j} + RefIdx_{L_S,\mathrm{list}_0,i}. \tag{8}$$

This approach can reduce the bitrate while keeping the same video quality of the conventional HEVC. Unlike IWPP, there is still overhead as one signaling flag and one reference index difference are still needed to be coded.

3 Proposed Weighted Prediction Parameter Prediction

To enhance IWPP[26] and enhanced direct WP parameter derivation (DWPD),[27] lossless and more efficient WP parameter prediction in both of the base layer, L_B, and the enhancement layer, L_E, is proposed, which has interlayer WP parameter prediction in L_E as well.

3.1 *Enhanced Implicit Weighted Prediction Parameter Prediction*

Although IWPP can reduce the parameter overhead, it might obtain worse coding efficiency compared with the conventional WP parameter prediction in HEVC, HWPP, due to inaccurate parameter prediction by the implicit prediction of AC and DC image characteristics. This has already been shown in the experimental results of Ref. 26 that the coding efficiency is much worse with the coded sequences with high resolution and large temporal distance using hierarchical B structure. Instead of using $[\mathrm{AC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred}),\ \mathrm{DC}^{\mathrm{COMP}}_{L_S,\mathrm{curr}}(\mathrm{pred})]$ to estimate the WP parameters directly, the weight can be predicted as below:

$$W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} = \Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} + W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred}), \tag{9}$$

where $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ is derived by IWPP rather than using $2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$ in Eq. (5) and $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ is estimated in Eq. (2) directly. Though $\Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ is needed to be coded for each reference frame while there is no signaling bits in IWPP, the predicted weight $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ plus $\Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$, can be guaranteed to be exactly the same as the one used in ME and MC as in Eq. (1). Conversely, $\Delta W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ obtained can be smaller and coded with fewer bits since the predicted $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ is much closer to $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ than the default weight $2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$ as fading happens along the video sequence. In the other words, the difference between $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ and $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$ is smaller than that between $2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$ and $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}$. It can be explained that $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ is estimated in Eq. (7) that the fading effect has taken into account while $2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_S}}$ can only have the values of 2 to the power of LWD. Finally, offset for luma is predicted in a similar manner:

$$O^{Y}_{L_S,\mathrm{list}_x,i} = \Delta O^{Y}_{L_S,\mathrm{list}_x,i} + O^{Y}_{L_S,\mathrm{list}_x,i}(\mathrm{pred}), \tag{10}$$

where $O^{Y}_{L_S,\mathrm{list}_x,i}(\mathrm{pred})$ is derived by IWPP and $O^{Y}_{L_S,\mathrm{list}_x,i}$ is estimated in (2) directly. Since there is no prediction of offset for luma in the conventional HWPP, this prediction can help to reduce the overhead. And the prediction of offset for chroma remains unchanged as formulated in Eq. (6) as it is predicted from the estimated weight $W^{UV}_{L_S,\mathrm{list}_x,i}$, which is already accurate enough.

3.2 *Enhanced Direct Weighted Prediction Parameter Derivation*

Instead of signaling a flag and a reference index in list_0 for reusing the WP parameters for the reference frame in list_1 from one reference frame in list_0 indicated by the reference index in list_0, we propose not to signal any bits. As aforementioned in Ref. 27, the reference frame with the same weight and offset of the reference frame in list_0 needs the additional signaling bits to indicate which reference frame in list_0 would be employed for reusing of WP parameters. As an alternative, we would retrieve the WP parameters by checking the POC of each reference frame in list_0 so that additional signaling bits are not required. If the POC of list_1 reference frame is equal to the POC of one of the list_0 reference frames, the corresponding WP parameters, $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_0,i}$ and $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_0,i}$, for that particular list_0 reference frame can be directly reused for the list_1 reference frame:

$$\begin{matrix} W^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j} = W^{\mathrm{COMP}}_{L_S,\mathrm{list}_x,i} \\ O^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j} = O^{\mathrm{COMP}}_{L_S,\mathrm{list}_0,i} \end{matrix} \quad \text{if } \mathrm{POC}_{L_S,\mathrm{list}_1,j} = \mathrm{POC}_{L_S,\mathrm{list}_0,i}. \tag{11}$$

This is because POC is used for declaring the frame number of a frame within a sequence, if the POC of a reference frame in list_0 is the same as the POC of a reference frame in list_1, they point to the same frame within the sequence. This implies that if $\mathrm{POC}_{L_S,\mathrm{list}_1,j}$ is equal to $\mathrm{POC}_{L_S,\mathrm{list}_0,i}$, they actually refer to the same video frame and the AC and DC image characteristics estimated must be the same according to Eq. (3). The coding of $W^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j}$ and $O^{\mathrm{COMP}}_{L_S,\mathrm{list}_1,j}$ can be skipped. Compared with DWPD,[27] the additional signaling bit and the reference index difference in Eq. (8) can also be saved, which can improve the coding efficiency.

3.3 *Interlayer Weighted Prediction Parameter Prediction in Enhancement Layer*

In the conventional SHVC, the same parameter prediction approach, HWPP, is used in L_E. There is no interlayer exploitation even though the correlation between L_B and L_E is high. The log weight denominator for luma in L_B, $\mathrm{LWD}^{Y}_{L_B}$, to provide the granularity for weight, should be highly correlated to the log weight denominator for luma in L_E, $\mathrm{LWD}^{Y}_{L_E}$ as they are talking about the same video content. Thus, $\mathrm{LWD}^{Y}_{L_E}$ would be predicted from $\mathrm{LWD}^{Y}_{L_B}$:

$$\mathrm{LWD}^{Y}_{L_E} = \Delta\mathrm{LWD}^{Y}_{L_E} + \mathrm{LWD}^{Y}_{L_B}, \tag{12}$$

where $\Delta\mathrm{LWD}^{Y}_{L_E}$ is coded with fewer bits compared with $\mathrm{LWD}^{Y}_{L_E}$. For SNR scalability, frames in L_E are encoded with smaller quantization parameters (QP) for higher video quality, whereas for spatial scalability, frames in L_E are encoded with higher resolution. Nevertheless, the AC and DC image characteristics of reconstructed frames between L_B and L_E are close to each other. In Fig. 3, the DC and AC values for each frame in base layer and enhancement layer for the BasketballDrillText with black fade for 2× spatial scalability are shown. We can observe that $\{\mathrm{AC}^{Y}_{L_S,t}, \mathrm{DC}^{Y}_{L_S,t}\}$ and $\{\mathrm{AC}^{Y}_{L_E,t}, \mathrm{DC}^{Y}_{L_E,t}\}$ are very close such that the weight and offset estimated in Eq. (2) would be very close. For this reason, we propose to predict the weight and offset for each list_x reference frame in L_E by those in L_B:

$$\begin{aligned} W^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} &= \Delta W^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} + W^{\mathrm{COMP}}_{L_B,\mathrm{list}_x,i} \\ O^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} &= \Delta O^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} + O^{\mathrm{COMP}}_{L_B,\mathrm{list}_x,i}. \end{aligned} \tag{13}$$

Thus, only $\Delta W^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i}$ and $\Delta O^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i}$ are coded. If $\mathrm{LWD}^{Y}_{L_B}$ and $\mathrm{LWD}^{Y}_{L_E}$ are not the same, $W^{\mathrm{COMP}}_{L_B,\mathrm{list}_x,i}$ should be normalized before predicting the weight in L_E:

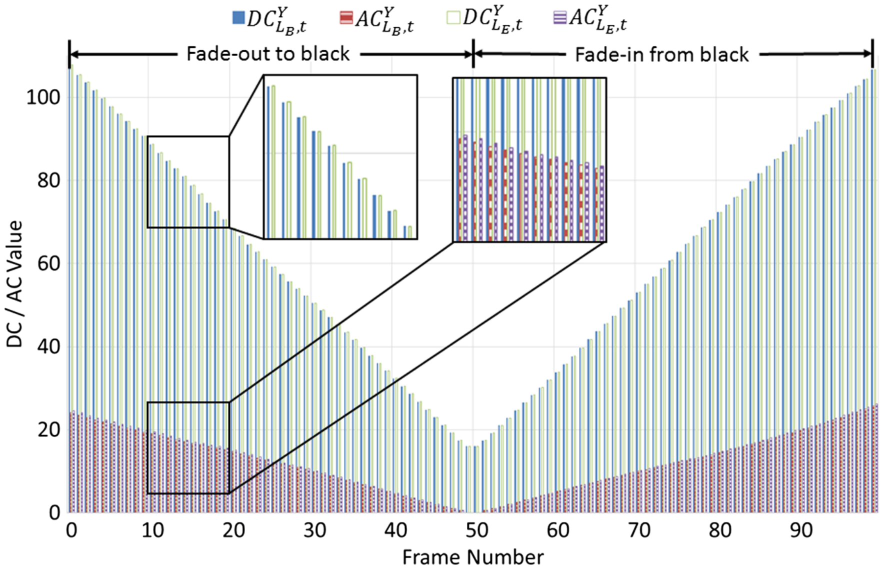

Fig. 3 DC and AC values in base layer and enhancement layer for the BasketballDrillText with black fade for 2× spatial scalability.

$$W^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} = \Delta W^{\mathrm{COMP}}_{L_E,\mathrm{list}_x,i} + W^{\mathrm{COMP}}_{L_B,\mathrm{list}_x,i} \times \left(\frac{2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_E}}}{2^{\mathrm{LWD}^{\mathrm{COMP}}_{L_B}}}\right). \tag{14}$$

It is noted that our proposed WP parameter prediction would include enhanced implicit weighted prediction parameter (EIWPP) in L_B, enhanced direct WP parameter derivation (EDWPD) in both L_B and L_E as well as ILWPP in L_E. If the proposed approaches cannot be applied, the conventional HWPP would be performed. In detail, in L_B, if the reference frame is in list_1, EDWPD first attempts to predict the WP parameter from each reference frame in list_0 based on (11). Otherwise, if there is no match or if the reference frame is in list_0, we would check whether there are two reference frames with different POC so as to avoid TD_D becoming zero in Eq. (7). If so, EIWPP would be used for predicting the WP parameter, otherwise HWPP would be applied. In L_E, if the reference frame is in list_1, EDWPD is used to predict the WP parameter first. Otherwise, if there is no match or if the reference frame is in list_0, ILWPP would be used for predicting the WP parameters.

4 Experimental Results

To evaluate the performances of the proposed algorithms, we perform experiments on the testing sequences from class A to class F, as tabulated in Table 1: "Traffic, PeopleOnStreet, ParkScene, BQTerrace, RaceHorses, BasketballDrill, BQSquare, BasketballPass, FourPeople, Johnny, BasketballDrillText and ChinaSpeed" with linear fade-out applied to the first second and linear fade-in applied to the next second as follows:

$$\begin{aligned} P^{\mathrm{COMP}}_{n,L_S,t} &= \tfrac{t}{T} \times P^{\mathrm{COMP}}_{n,L_S,t}(Orig) + \left(1 - \tfrac{t}{T}\right) \times C \quad \text{if fade-in} \\ P^{\mathrm{COMP}}_{n,L_S,t} &= \left(1 - \tfrac{t}{T}\right) \times P^{\mathrm{COMP}}_{n,L_S,t}(Orig) + \tfrac{t}{T} \times C \quad \text{if fade-out}, \end{aligned} \tag{15}$$

where $P^{\mathrm{COMP}}_{n,L_S,t}(Orig)$ is the n'th original sample value of that particular color component COMP in L_S at frame t. T is the duration of fading effect and C is the target color value. For instance, to have black fade for 24-fps (frame per second) sequence ParkScene, linear fade-out to black effect is applied to the first 24 frames and linear fade-in from black effect is applied to the following 24 frames. SHVC Test Model 10 (SHM 10)[28] was used with the CTC[29] using RA, low delay (LD), and low delay P (LDP) configurations. Tables 1–3 show the Bjontegaard delta bitrate (BDBR)[31] and the slice header overhead bitrate difference (ΔOH) of various algorithms against the conventional HWPP using RA, LD, LDP configurations, respectively, for SNR scalability. ΔOH is estimated as follows:

$$\Delta\mathrm{OH} = \frac{\mathrm{OH}_{\mathrm{Proposed}} - \mathrm{OH}_{\mathrm{HWPP}}}{\mathrm{OH}_{\mathrm{HWPP}}} \times 100\%, \tag{16}$$

where $\mathrm{OH}_{\mathrm{HWPP}}$ and $\mathrm{OH}_{\mathrm{Proposed}}$ are the slice header overhead bits using the conventional HWPP algorithm and the proposed algorithm, respectively. It is noted that the PSNR measured are exactly the same for all algorithms except IWPP and IWPP + DWPD. This is because only IWPP will sacrifice the coding efficiency to save the overhead of WP parameters in the slice header while other algorithms will not.

4.1 *Proposed Enhanced Implicit Weighted Prediction Parameter Prediction Versus Enhanced Implicit Weighted Prediction Parameter in Base Layer*

As tabulated from Tables 1–3, the state-of-the-art IWPP[26] can achieve average overhead reduction of 61.57%, 31.77%, and 72.60% for RA, LD, and LDP, respectively, compared with HWPP, which are higher than those in EIWPP of 31.87%, 9.12%, and 39.81% for RA, LD, and LDP, respectively. Nevertheless, IWPP obtains only 17.47%, 29.40%, and 2.96% average bitrate increase for RA, LD, and LDP, respectively, which means that IWPP is even worse than HWPP. On the other hand, EIWPP can obtain 0.70%, 0.34%, and 0.84% average bitrate reduction and 31.87%, 9.12%, and 39.81% average overhead reduction for RA, LD, and LDP, respectively, since EIWPP can perform lossless WP parameter prediction according to Eqs. (9)

Table 1 BDBR (%) and ΔOH (%) of various approaches against HWPP using RA configuration for SNR scalability.

Class	Sequences	Fade Type	IWPP (BL)		DWPD (BL)		IWPP + DWPD (BL)		EIWPP (BL)		EDWPD (BL)		EIWPP + EDWPD (BL)		EIWPP + EDWPD (BL + EL)		EIWPP + EDWPD + ILWPP (BL + EL)	
			BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH
A	Traffic	Black	20.52	−62.54	−0.06	−16.41	20.50	−66.16	−0.11	−31.36	−0.06	−18.69	−0.16	−45.16	−0.17	−42.71	−0.20	−52.60
		White	17.02	−60.85	−0.06	−16.24	17.00	−65.86	−0.14	−39.81	−0.06	−18.44	−0.18	−51.58	−0.19	−48.79	−0.22	−56.57
	People OnStreet	Black	6.52	−62.03	−0.02	−16.12	6.51	−65.90	−0.04	−29.37	−0.02	−18.40	−0.06	−43.26	−0.06	−40.94	−0.08	−51.72
		White	5.19	−59.58	−0.02	−15.62	5.18	−64.88	−0.05	−37.30	−0.02	−17.88	−0.06	−48.86	−0.07	−46.21	−0.09	−55.25
B	ParkScene	Black	20.80	−61.75	−0.11	−17.25	20.78	−65.42	−0.16	−26.48	−0.12	−19.59	−0.25	−41.82	−0.25	−39.52	−0.32	−50.04
		White	25.95	−59.07	−0.10	−16.55	25.91	−64.66	−0.20	−31.98	−0.12	−18.81	−0.28	−45.33	−0.28	−42.91	−0.35	−53.17
	BQTerrace	Black	28.28	−59.16	−0.10	−13.83	28.25	−62.16	−0.19	−26.60	−0.12	−16.44	−0.28	−39.54	−0.26	−37.16	−0.32	−46.96
		White	26.78	−62.48	−0.11	−14.41	26.75	−65.17	−0.26	−33.82	−0.13	−16.81	−0.35	−45.81	−0.32	−43.17	−0.38	−51.86
C	RaceHorses	Black	4.29	−61.61	−0.14	−14.96	4.26	−64.41	−0.31	−33.13	−0.16	−17.44	−0.43	−45.68	−0.41	−42.79	−0.50	−51.64
		White	3.73	−61.51	−0.17	−15.65	3.67	−66.36	−0.44	−40.73	−0.20	−17.83	−0.56	−51.62	−0.55	−48.86	−0.64	−57.00
	Basketball Drill	Black	11.13	−62.29	−0.35	−15.59	11.03	−65.86	−0.55	−24.66	−0.40	−17.87	−0.86	−38.75	−0.88	−36.69	−1.18	−49.15
		White	10.57	−64.18	−0.38	−15.58	10.46	−68.06	−0.69	−28.79	−0.42	−17.68	−1.02	−42.28	−1.04	−40.17	−1.36	−52.49
D	BQSquare	Black	22.12	−60.73	−0.70	−13.80	21.94	−63.42	−1.40	−28.47	−0.80	−16.34	−2.02	−41.00	−1.99	−38.58	−2.47	−48.11
		White	20.54	−62.29	−0.76	−14.57	20.34	−65.18	−1.81	−35.13	−0.88	−16.96	−2.44	−47.00	−2.41	−44.34	−2.83	−52.28
	Basketball Pass	Black	5.58	−62.53	−0.92	−15.02	5.33	−65.85	−1.66	−27.47	−1.05	−17.32	−2.48	−40.86	−2.48	−38.64	−3.21	−50.05
		White	5.44	−63.50	−0.95	−14.53	5.16	−67.11	−2.06	−32.34	−1.07	−16.72	−2.85	−44.66	−2.84	−42.32	−3.56	−52.97
E	FourPeople	Black	29.27	−59.38	−0.35	−14.00	29.19	−62.05	−0.69	−27.94	−0.41	−16.65	−1.00	−40.45	−1.10	−38.02	−1.36	−47.13
		White	31.18	−62.01	−0.41	−14.85	31.07	−65.13	−0.97	−35.59	−0.47	−17.23	−1.29	−47.31	−1.41	−44.61	−1.66	−52.62
	Johnny	Black	38.67	−59.68	−0.66	−14.01	38.48	−62.99	−1.45	−31.19	−0.76	−16.54	−2.01	−43.31	−2.02	−40.74	−2.42	−49.20
		White	38.58	−61.72	−0.73	−14.65	38.35	−65.55	−1.97	−39.63	−0.84	−16.94	−2.52	−50.52	−2.58	−47.69	−2.95	−54.78
F	Basketball DrillText	Black	12.67	−62.36	−0.31	−15.09	12.59	−65.53	−0.54	−26.51	−0.36	−17.43	−0.82	−40.29	−0.85	−38.13	−1.09	−49.31
		White	12.53	−64.15	−0.35	−15.36	12.43	−67.89	−0.70	−31.05	−0.39	−17.48	−1.00	−44.11	−1.02	−41.86	−1.30	−53.17
	China Speed	Black	11.86	−61.72	−0.12	−16.05	11.83	−65.50	−0.21	−29.59	−0.13	−18.38	−0.31	−43.37	−0.35	−40.99	−0.43	−51.46
		White	9.96	−60.55	−0.12	−16.42	9.91	−66.06	−0.27	−36.01	−0.14	−18.57	−0.36	−48.42	−0.40	−45.88	−0.48	−55.26
Average		Black	17.64	−61.32	−0.32	−15.18	17.56	−64.60	−0.61	−28.57	−0.37	−17.59	−0.89	−41.96	−0.90	−39.58	−1.13	−49.78
		White	17.29	−61.82	−0.35	−15.37	17.19	−65.99	−0.80	−35.18	−0.39	−17.61	−1.08	−47.29	−1.09	−44.73	−1.32	−53.95
		All	17.47	−61.57	−0.33	−15.27	17.37	−65.30	−0.70	−31.87	−0.38	−17.60	−0.98	−44.62	−1.00	−42.15	−1.22	−51.87

Table 2 BDBR (%) and ΔOH (%) of various approaches against HWPP using LD configuration for SNR scalability.

Class	Sequences	Fade Type	IWPP (BL)		DWPD (BL)		IWPP + DWPD (BL)		EIWPP (BL)		EDWPD (BL)		EIWPP + EDWPD (BL)		EIWPP + EDWPD (BL + EL)		EIWPP + EDWPD + ILWPP (BL + EL)	
			BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH
A	Traffic	Black	42.00	−34.08	−0.23	−40.75	41.86	−57.98	−0.06	−10.69	−0.25	−43.28	−0.28	−48.63	−0.28	−47.26	−0.36	−62.08
		White	54.44	−31.86	−0.24	−40.87	54.29	−57.00	−0.04	−7.44	−0.25	−43.38	−0.27	−47.10	−0.27	−45.76	−0.36	−61.78
	People OnStreet	Black	18.20	−32.13	−0.08	−40.82	18.15	−57.07	−0.02	−11.53	−0.08	−43.34	−0.09	−49.11	−0.10	−47.70	−0.14	−62.47
		White	21.19	−31.28	−0.08	−40.69	21.14	−56.55	−0.01	−7.46	−0.08	−43.25	−0.09	−46.98	−0.10	−45.62	−0.13	−61.80
B	ParkScene	Black	28.33	−37.86	−0.37	−40.65	28.13	−59.80	−0.10	−10.47	−0.39	−43.23	−0.44	−48.46	−0.39	−47.07	−0.51	−61.78
		White	49.89	−30.62	−0.37	−40.74	49.65	−56.21	−0.06	−6.71	−0.40	−43.30	−0.43	−46.65	−0.38	−45.34	−0.51	−61.32
	BQTerrace	Black	41.89	−35.11	−0.56	−40.69	41.56	−58.44	−0.13	−9.45	−0.60	−43.26	−0.66	−47.98	−0.55	−46.71	−0.72	−61.43
		White	36.33	−33.17	−0.60	−41.10	35.95	−57.86	−0.12	−8.37	−0.64	−43.56	−0.70	−47.74	−0.57	−46.53	−0.76	−62.11
C	RaceHorses	Black	10.33	−26.53	−0.54	−39.63	9.97	−53.11	−0.15	−11.45	−0.58	−42.49	−0.66	−48.21	−0.61	−46.66	−0.80	−61.26
		White	17.31	−29.66	−0.64	−40.85	16.89	−55.90	−0.11	−6.79	−0.68	−43.36	−0.74	−46.75	−0.69	−45.45	−0.94	−61.80
	Basketball Drill	Black	17.01	−30.60	−1.63	−41.53	15.96	−57.00	−0.40	−10.20	−1.73	−43.85	−1.92	−48.95	−1.93	−47.75	−2.55	−63.08
		White	18.46	−31.96	−1.74	−42.08	17.36	−58.22	−0.37	−8.91	−1.83	−44.25	−2.02	−48.71	−2.01	−47.52	−2.70	−63.80
D	BQSquare	Black	24.11	−34.34	−3.34	−40.79	22.06	−58.14	−0.80	−9.77	−3.55	−43.33	−3.95	−48.21	−3.56	−46.94	−4.67	−61.66
		White	18.94	−31.46	−3.44	−41.09	16.69	−57.01	−0.76	−8.98	−3.65	−43.55	−4.04	−48.04	−3.63	−46.77	−4.84	−62.24
	Basketball Pass	Black	10.13	−31.18	−3.86	−41.30	7.67	−57.06	−0.96	−10.25	−4.09	−43.69	−4.57	−48.82	−4.39	−47.56	−5.78	−62.64
		White	10.86	−30.38	−3.92	−41.45	8.30	−56.82	−0.75	−7.87	−4.15	−43.81	−4.52	−47.74	−4.32	−46.53	−5.83	−62.66
E	FourPeople	Black	36.41	−32.78	−1.92	−40.71	35.21	−57.25	−0.49	−10.32	−2.04	−43.27	−2.29	−48.43	−2.37	−47.15	−3.10	−61.70
		White	43.02	−30.35	−2.10	−41.39	41.65	−56.69	−0.44	−8.67	−2.22	−43.76	−2.44	−48.10	−2.50	−46.89	−3.34	−62.59
	Johnny	Black	59.59	−30.34	−3.43	−41.24	57.33	−56.52	−0.84	−9.98	−3.63	−43.65	−4.05	−48.64	−3.81	−47.38	−5.03	−62.40
		White	63.40	−30.19	−3.56	−41.60	61.03	−56.82	−0.71	−8.29	−3.76	−43.91	−4.12	−48.06	−3.88	−46.86	−5.22	−62.84
F	Basketball DrillText	Black	17.24	−29.69	−1.50	−41.41	16.26	−56.42	−0.34	−9.43	−1.58	−43.77	−1.75	−48.48	−1.79	−47.27	−2.38	−62.65
		White	20.98	−30.80	−1.59	−41.89	19.94	−57.43	−0.31	−8.10	−1.68	−44.12	−1.83	−48.16	−1.85	−47.00	−2.50	−63.38
	ChinaSpeed	Black	18.18	−35.36	−0.47	−40.96	17.90	−58.87	−0.12	−10.41	−0.50	−43.43	−0.56	−48.63	−0.63	−47.31	−0.82	−62.33
		White	27.28	−30.73	−0.48	−41.35	26.96	−56.89	−0.08	−7.26	−0.51	−43.71	−0.55	−47.34	−0.62	−46.07	−0.84	−62.27
Average		Black	26.95	−32.50	−1.49	−40.87	26.00	−57.30	−0.37	−10.33	−1.58	−43.38	−1.77	−48.55	−1.70	−47.23	−2.24	−62.12
		White	31.84	−31.04	−1.56	−41.26	30.82	−56.95	−0.31	−7.90	−1.65	−43.66	−1.81	−47.61	−1.73	−46.36	−2.33	−62.38
		All	29.40	−31.77	−1.53	−41.07	28.41	−57.13	−0.34	−9.12	−1.62	−43.52	−1.79	−48.08	−1.72	−46.80	−2.28	−62.25

Table 3 BDBR (%) and ΔOH (%) of various approaches against HWPP using LDP configuration for SNR scalability.

			IWPP (BL)		DWPD (BL)		IWPP + DWPD (BL)		EIWPP (BL)		EDWPD (BL)		EIWPP + EDWPD (BL)		EIWPP + EDWPD (BL + EL)		EIWPP + EDWPD + ILWPP (BL + EL)	
Class	Sequences	Fade Type	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH
A	Traffic	Black	3.71	−71.65	0.00	0.00	3.71	−71.65	−0.13	−40.44	0.00	0.00	−0.13	−40.44	−0.13	−39.01	−0.16	−50.01
		White	3.34	−72.01	0.00	0.00	3.34	−72.01	−0.14	−44.97	0.00	0.00	−0.14	−44.97	−0.14	−43.33	−0.17	−53.05
	People OnStreet	Black	2.37	−71.86	0.00	0.00	2.37	−71.86	−0.04	−38.43	0.00	0.00	−0.04	−38.43	−0.05	−37.01	−0.06	−49.27
		White	2.25	−71.60	0.00	0.00	2.25	−71.60	−0.04	−42.60	0.00	0.00	−0.04	−42.60	−0.05	−40.95	−0.06	−51.95
B	ParkScene	Black	3.57	−71.32	0.00	0.00	3.57	−71.32	−0.18	−35.74	0.00	0.00	−0.18	−35.74	−0.16	−34.31	−0.22	−47.31
		White	4.23	−71.61	0.00	0.00	4.23	−71.61	−0.20	−37.69	0.00	0.00	−0.20	−37.69	−0.17	−36.16	−0.23	−48.94
	BQTerrace	Black	5.62	−71.61	0.00	0.00	5.62	−71.61	−0.28	−38.65	0.00	0.00	−0.28	−38.65	−0.22	−37.27	−0.28	−48.46
		White	3.45	−72.76	0.00	0.00	3.45	−72.76	−0.34	−44.36	0.00	0.00	−0.34	−44.36	−0.26	−42.82	−0.32	−52.46
C	RaceHorses	Black	0.78	−68.76	0.00	0.00	0.78	−68.76	−0.35	−44.32	0.00	0.00	−0.35	−44.32	−0.32	−42.49	−0.39	−51.10
		White	0.55	−71.91	0.00	0.00	0.55	−71.91	−0.42	−46.67	0.00	0.00	−0.42	−46.67	−0.39	−44.95	−0.47	−54.03
	BasketballDrill	Black	4.41	−73.87	0.00	0.00	4.41	−73.87	−0.65	−29.62	0.00	0.00	−0.65	−29.62	−0.64	−28.68	−1.03	−45.70
		White	4.37	−75.37	0.00	0.00	4.37	−75.37	−0.73	−31.73	0.00	0.00	−0.73	−31.73	−0.72	−30.71	−1.13	−48.13
D	BQSquare	Black	−0.46	−71.93	0.00	0.00	−0.46	−71.93	−1.91	−40.17	0.00	0.00	−1.91	−40.17	−1.60	−38.74	−2.04	−49.33
		White	−0.78	−72.67	0.00	0.00	−0.78	−72.67	−2.18	−45.36	0.00	0.00	−2.18	−45.36	−1.84	−43.83	−2.22	−52.85
	Basketball Pass	Black	−0.35	−73.27	0.00	0.00	−0.35	−73.27	−1.84	−33.54	0.00	0.00	−1.84	−33.54	−1.75	−32.44	−2.54	−47.08
		White	−0.71	−73.65	0.00	0.00	−0.71	−73.65	−1.99	−35.82	0.00	0.00	−1.99	−35.82	−1.87	−34.57	−2.67	−49.15
E	FourPeople	Black	5.17	−71.77	0.00	0.00	5.17	−71.77	−1.07	−39.54	0.00	0.00	−1.07	−39.54	−1.07	−38.13	−1.39	−49.03
		White	4.72	−73.55	0.00	0.00	4.72	−73.55	−1.29	−45.15	0.00	0.00	−1.29	−45.15	−1.30	−43.60	−1.59	−53.22
	Johnny	Black	6.62	−73.08	0.00	0.00	6.62	−73.08	−1.99	−42.20	0.00	0.00	−1.99	−42.20	−1.82	−40.73	−2.29	−51.14
		White	5.15	−74.10	0.00	0.00	5.15	−74.10	−2.45	−49.83	0.00	0.00	−2.45	−49.83	−2.25	−48.18	−2.62	−55.91
F	Basketball DrillText	Black	2.18	−73.55	0.00	0.00	2.18	−73.55	−0.67	−33.17	0.00	0.00	−0.67	−33.17	−0.68	−32.13	−1.00	−47.11
		White	2.42	−74.87	0.00	0.00	2.42	−74.87	−0.73	−34.45	0.00	0.00	−0.73	−34.45	−0.73	−33.42	−1.07	−49.18
	ChinaSpeed	Black	5.42	−72.24	0.00	0.00	5.42	−72.24	−0.25	−39.46	0.00	0.00	−0.25	−39.46	−0.28	−38.10	−0.37	−49.78
		White	2.95	−73.45	0.00	0.00	2.95	−73.45	−0.27	−41.52	0.00	0.00	−0.27	−41.52	−0.30	−40.06	−0.39	−51.74
Average		Black	3.25	−72.08	0.00	0.00	3.25	−72.08	−0.78	−37.94	0.00	0.00	−0.78	−37.94	−0.73	−36.58	−0.98	−48.78
		White	2.66	−73.13	0.00	0.00	2.66	−73.13	−0.90	−41.68	0.00	0.00	−0.90	−41.68	−0.83	−40.21	−1.08	−51.72
		All	2.96	−72.60	0.00	0.00	2.96	−72.60	−0.84	−39.81	0.00	0.00	−0.84	−39.81	−0.78	−38.40	−1.03	−50.25

and (10), which means that the WP parameters used in both EIWPP and HWPP are exactly the same, which can obtain the same PSNR. And EIWPP can obtain at most 2.06%, 0.96%, and 2.45% bitrate reduction for RA, LD, and LDP, respectively. To illustrate this fact, the weight and offset of the nearest reference in list_0 predicted by IWPP for each frame by the sequence "BasketballDrillText" using RA configuration are depicted in Figs. 4 and 5, respectively. The actual one is the one that is used for ME and MC in HEVC. From the figures, we can see that the weights and offsets predicted by IWPP are relatively closer to the actual one compared with those predicted by HWPP. However, there is still difference between the actual one and the predicted one, which consequently obtain worse rate distortion (RD) performance than HWPP as IWPP uses the predicted weights and offsets directly for ME and MC. But our proposed EIWPP would rather encode the difference between the actual one and predicted one and would use the actual one for ME and MC. And the difference obtained is smaller than the difference obtained by HWPP. This is because the weights predicted by HWPP, $2^{\mathrm{LWD}_{L_S}^{\mathrm{COMP}}}$, can only have the value of 2 to the power of LWD while the weights predicted by EIWPP, $W_{L_S,\mathrm{list}_x,i}^{\mathrm{COMP}}(\mathrm{pred})$, is predicted that the fading effect has taken into account. It is noted that the missing points in Figs. 4 and 5 are the time instants that having the intraframes.

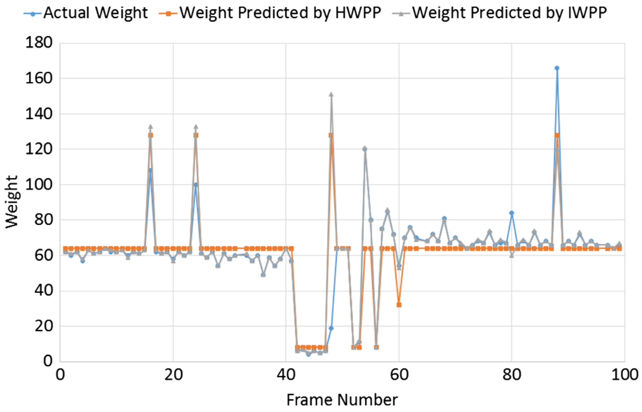

Fig. 4 The actual weights and the weights predicted by HWPP and IWPP.

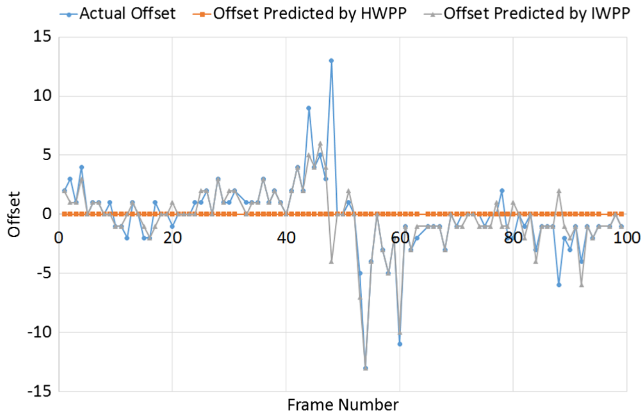

Fig. 5 The actual offsets and the offsets predicted by HWPP and IWPP.

4.2 *Proposed Enhanced Direct Weighted Prediction Parameter Derivation Versus Enhanced Direct WP Parameter Derivation in Base Layer*

For DWPD,[27] it can achieve 0.33% and 1.53% average bitrate reduction for RA and LD, respectively, compared with HWPP and with corresponding 15.27% and 41.07% overhead reduction. It is noted that there is no bitrate reduction or overhead reduction for DWPD since there is no list_1 reference for the LDP configuration. Alternatively, our proposed EDWPD can achieve better average bitrate reduction of 0.38% and 1.62% and larger overhead reduction of 17.60% and 43.52% for RA and LD, respectively. This is because DWPD still needs to code an additional flag and a reference index difference for each reference frame in list_1 while EDWPD only needs to search the same POC in list_0 without any signaling bits.

4.3 *Performance of Proposed EIWPP + EDWPD in Base Layer*

As previously mentioned, IWPP sacrifices the coding performance for reducing the overhead bits in the slice header. Due to this reason, any methods cooperated with IWPP would also reduce the coding performance. As from Tables 1–3, among all the approaches, IWPP + DWPD can achieve the largest average overhead reduction of 65.30%, 57.13%, and 72.60% for RA, LD, and LDP, respectively. However, there are average bitrate increases of 17.37%, 28.41%, and 2.96% for RA, LD, and LDP, respectively, which are worse than those of the conventional HWPP. Conversely, our proposed EIWPP and EDWPD can be cooperated together to become EIWPP + EDWPD in which it can achieve 0.98%, 1.79%, and 0.84% average bitrate reduction and at most 2.85%, 4.57%, and 2.45% bitrate reduction for RA, LD and LDP, respectively. It is noted that EIWPP + EDWPD + ILWPP obtains the same RD performance as EIWPP + EDWPD. This is due to the fact that ILWPP can only be applied in the enhancement layer.

4.4 *Performance of Proposed EIWPP + EDWPD + ILWPP in Enhancement Layer Using SNR Scalability*

In this part, we focus on the performances of EIWPP + EDWPD and EIWPP + EDWPD + ILWPP against HWPP. As from Tables 1–3, for EIWPP + EDWPD, both EIWPP and EDWPD are used in both L_B and L_E. EIWPP + EDWPD obtains 1.00%, 1.72%, and 0.78% average bitrate reduction and 42.15%, 46.80%, and 38.40% overhead reduction only in L_E for RA, LD and LDP, respectively. And it can obtain at most 2.84%, 4.39%, and 2.25% bitrate reduction. EIWPP + EDWPD + ILWPP obtains even better average bitrate reduction of 1.22%, 2.28%, and 1.03% and larger overhead reduction of 51.87%, 62.25%, and 50.25% in L_E for RA, LD, and LDP, respectively. And it can obtain at most 3.56%, 5.83%, and 2.67% bitrate reduction for RA, LD, and LDP, respectively. That means the estimated WP parameters are strongly correlated between L_B and L_E. It can be concluded that with the use of ILWPP, our proposed algorithm can get a more accurate parameter prediction.

4.5 *Performance of Proposed EIWPP + EDWPD + ILWPP in Enhancement Layer Using* 2× *Spatial Scalability*

To have more comprehensive analysis, experiments were also performed with 2× spatial scalability. Table 4 shows the BDBR and ΔOH of various algorithms against the conventional HWPP using RA, LD, LDP configurations, respectively, for 2× spatial scalability. Similar to the results from Tables 1–3, our EIWPP + EDWPD + ILWPP obtains 1.02%, 2.09%, and 0.88% average bitrate reduction and 49.00%, 59.86%, and 46.39% overhead reduction in L_E for RA, LD, and LDP, respectively. It is noted that IWPP obtains at most 5.04% and 5.34% bitrate reduction for the sequence "BQSquare" with black and white fades, respectively, for the LDP configuration. This is because IWPP can accurately predict the weights and offsets for this sequence. However, IWPP obtains 1.60% and 0.86% average bitrate increase for the LDP configuration compared with HWPP.

4.6 *Discussion of Parameter Prediction with Video Resolution and Bitrate*

Slice header overhead almost will not grow with the video resolution but only the bits occupied by the encoded video contents would be increased. Slice header overhead can be treated as constant. Therefore, the percentage of bitrate reduction by parameter prediction gets minor while the video resolution increases. This phenomenon can be observed from Tables 1–4. Therefore, parameter prediction is especially useful for video with lower video resolution. We can observe that for the sequence "BasketballPass" with black fades, by using our proposed EIWPP + EDWPD, in L_B, 2.48%, 4.57%, and 1.84% bitrate reduction is achieved compared with HWPP for RA, LD, and LDP, respectively, for SNR scalability. For 2× spatial scalability, 3.91%, 6.94%, and 2.84% bitrate reduction can be achieved compared with HWPP for RA, LD, and LDP respectively. By using our

Table 4 BDBR (%) and ΔOH (%) of various approaches against HWPP using RA, LD, and LDP configuration for 2× spatial scalability.

Configurations		Fade Type	IWPP (BL)		DWPD (BL)		IWPP + DWPD (BL)		EIWPP (BL)		EDWPD (BL)		EIWPP + EDWPD (BL)		EIWPP + EDWPD (BL + EL)		EIWPP + EDWPD + ILWPP (BL + EL)	
			BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH	BDBR	ΔOH
RA	Average	Black	14.85	−61.98	−0.52	−15.33	14.69	−65.35	−1.00	−29.09	−0.60	−17.76	−1.45	−42.60	−0.81	−39.86	−0.93	−46.77
		White	14.60	−62.51	−0.57	−15.57	14.42	−66.75	−1.30	−35.66	−0.64	−17.82	−1.75	−47.92	−0.98	−45.00	−1.10	−51.24
		All	14.72	−62.25	−0.54	−15.45	14.56	−66.05	−1.15	−32.38	−0.62	−17.79	−1.60	−45.26	−0.89	−42.43	−1.02	−49.00
	Best	Black	2.84	−63.50	−1.47	−17.22	2.40	−66.89	−2.87	−34.33	−1.66	−19.61	−4.12	−46.84	−2.18	−43.34	−2.39	−51.28
		White	3.02	−64.76	−1.62	−16.74	2.54	−68.65	−3.85	−41.31	−1.84	−19.02	−5.12	−52.32	−2.49	−49.18	−2.83	−56.23
		All	2.84	−64.76	−1.62	−17.22	2.40	−68.65	−3.85	−41.31	−1.84	−19.61	−5.12	−52.32	−2.49	−49.18	−2.83	−56.23
LD	Average	Black	22.70	−33.16	−2.33	−41.08	21.24	−57.85	−0.57	−10.26	−2.47	−43.59	−2.75	−48.72	−1.63	−47.31	−2.04	−59.65
		White	26.87	−31.65	−2.42	−41.43	25.30	−57.43	−0.48	−7.85	−2.56	−43.84	−2.80	−47.77	−1.67	−46.42	−2.14	−60.07
		All	24.78	−32.41	−2.38	−41.26	23.27	−57.64	−0.52	−9.05	−2.51	−43.72	−2.78	−48.24	−1.65	−46.86	−2.09	−59.86
	Best	Black	8.65	−38.03	−6.35	−41.73	4.95	−60.06	−1.56	−11.48	−6.74	−44.05	−7.53	−49.12	−4.08	−47.84	−5.00	−61.38
		White	9.96	−33.94	−6.47	−42.27	6.13	−58.75	−1.44	−9.16	−6.86	−44.44	−7.58	−48.86	−3.98	−47.60	−5.23	−62.22
		All	8.65	−38.03	−6.47	−42.27	4.95	−60.06	−1.56	−11.48	−6.86	−44.44	−7.58	−49.12	−4.08	−47.84	−5.23	−62.22
LDP	Average	Black	1.60	−72.72	0.00	0.00	1.60	−72.72	−1.24	−38.36	0.00	0.00	−1.24	−38.36	−0.70	−36.78	−0.82	−45.10
		White	0.86	−73.68	0.00	0.00	0.86	−73.68	−1.41	−42.09	0.00	0.00	−1.41	−42.09	−0.81	−40.37	−0.95	−47.68
		All	1.23	−73.20	0.00	0.00	1.23	−73.20	−1.32	−40.22	0.00	0.00	−1.32	−40.22	−0.76	−38.57	−0.88	−46.39
	Best	Black	−5.04	−74.43	0.00	0.00	−5.04	−74.43	−3.66	−45.19	0.00	0.00	−3.66	−45.19	−1.85	−42.95	−2.22	−50.60
		White	−5.34	−75.96	0.00	0.00	−5.34	−75.96	−4.14	−49.87	0.00	0.00	−4.14	−49.87	−2.27	−48.19	−2.57	−54.46
		All	−5.34	−75.96	0.00	0.00	−5.34	−75.96	−4.14	−49.87	0.00	0.00	−4.14	−49.87	−2.27	−48.19	−2.57	−54.46

proposed EIWPP + EDWPD + ILWPP, in L_E, 3.21%, 5.78%, and 2.54% bitrate reduction can be achieved compared with HWPP for RA, LD, and LDP, respectively, for SNR scalability, whereas 2.39%, 5.00%, and 1.96% bitrate reduction can be provided compared with HWPP for RA, LD, and LDP, respectively, for 2× spatial scalability. Another phenomenon is that the percentage of bitrate reduction by parameter prediction becomes minor while the video bitrate increases in Tables 5 and 6. In these tables, they tabulate the file size reduction in bytes of each bitstream (ΔBytes) by EIWPP + EDWPD + ILWPP compared with HWPP. As the file size (bitrate) increases due to the decrease in QP, ΔBytes gets smaller. This fact can be revealed in Tables 5 and 6. For instance, in Table 5, by using our proposed EIWPP + EDWPD + ILWPP for the sequence "BasketballPass" using RA configuration, 4.82% file size reduction is obtained at low bitrate

Table 5 ΔBytes (%) of proposed EIWPP + EDWPD + ILWPP against HWPP for SNR scalability.

Class	Sequences with black fade	RA			LD			LDP		
		HWPP	EIWPP + EDWPD + ILWPP		HWPP	EIWPP + EDWPD + ILWPP		HWPP	EIWPP + EDWPD + ILWPP	
		Bytes	Bytes	ΔBytes (%)	Bytes	Bytes	ΔBytes (%)	Bytes	Bytes	ΔBytes (%)
A	Traffic	2110527	2109018	−0.07	2400763	2397874	−0.12	2583562	2582239	−0.05
		1097126	1095606	−0.14	1204966	1202089	−0.24	1256750	1255426	−0.11
		641966	640460	−0.23	678116	675223	−0.43	693371	692047	−0.19
		379563	378063	−0.40	389152	386263	−0.74	393814	392483	−0.34
B	ParkScene	1169849	1168727	−0.10	1421658	1419479	−0.15	1475319	1474690	−0.04
		577615	576460	−0.20	706929	704756	−0.31	718397	717767	−0.09
		304586	303437	−0.38	371348	369165	−0.59	374437	373801	−0.17
		161152	160009	−0.71	195520	193345	−1.11	195671	195040	−0.32
C	RaceHorses	811874	810555	−0.16	933038	930672	−0.25	967872	967176	−0.07
		416475	415133	−0.32	480160	477776	−0.50	486724	486021	−0.14
		231185	229814	−0.59	262340	259926	−0.92	263083	262377	−0.27
		127040	125632	−1.11	140151	137693	−1.75	138067	137345	−0.52
D	Basketball Pass	195106	192740	−1.21	231223	225963	−2.27	233082	230847	−0.96
		114870	112490	−2.07	137289	132057	−3.81	135745	133526	−1.63
		72083	69729	−3.27	86517	81290	−6.04	83790	81571	−2.65
		48104	45787	−4.82	57414	52190	−9.10	54158	51943	−4.09
E	FourPeople	453838	451487	−0.52	517561	511987	−1.08	554364	552772	−0.29
		264120	261719	−0.91	288388	282801	−1.94	297796	296199	−0.54
		168961	166594	−1.40	179775	174213	−3.09	180341	178720	−0.90
		110932	108601	−2.10	116639	111035	−4.80	113835	112198	−1.44
F	Basketball DrillText	549865	547556	−0.42	599690	594554	−0.86	635812	634334	−0.23
		309789	307476	−0.75	334474	329346	−1.53	344078	342593	−0.43
		186855	184567	−1.22	198162	193049	−2.58	199834	198339	−0.75
		115494	113242	−1.95	120847	115745	−4.22	120305	118811	−1.24

Table 6 ΔBytes (%) of proposed EIWPP + EDWPD + ILWPP against HWPP for 2× spatial scalability.

Class	Sequences with black fade	RA			LD			LDP		
		HWPP	EIWPP + EDWPD + ILWPP		HWPP	EIWPP + EDWPD + ILWPP		HWPP	EIWPP + EDWPD + ILWPP	
		Bytes	Bytes	ΔBytes (%)	Bytes	Bytes	ΔBytes (%)	Bytes	Bytes	ΔBytes (%)
A	Traffic	2470299	2468860	−0.06	2624014	2621201	−0.11	2811962	2810720	−0.04
		1340294	1338839	−0.11	1336377	1333561	−0.21	1379348	1378096	−0.09
		785655	784208	−0.18	751075	748260	−0.37	760728	759486	−0.16
		462850	461398	−0.31	427688	424887	−0.65	428089	426830	−0.29
B	ParkScene	1169451	1168627	−0.07	1426038	1423992	−0.14	1478903	1478406	−0.03
		582073	581262	−0.14	709979	707929	−0.29	719171	718669	−0.07
		304707	303871	−0.27	368794	366747	−0.56	369318	368815	−0.14
		160473	159652	−0.51	192498	190451	−1.06	192640	192137	−0.26
C	RaceHorses	904604	903646	−0.11	1029148	1026792	−0.23	1057072	1056391	−0.06
		474532	473564	−0.20	527323	524945	−0.45	532553	531867	−0.13
		262573	261567	−0.38	285833	283416	−0.85	285657	284977	−0.24
		144990	143966	−0.71	155996	153559	−1.56	154913	154219	−0.45
D	Basketball Pass	219376	217369	−0.91	251801	246868	−1.96	253414	251536	−0.74
		130176	128168	−1.54	149258	144343	−3.29	147248	145378	−1.27
		81039	79046	−2.46	92903	88006	−5.27	90161	88296	−2.07
		52941	50952	−3.76	60897	56004	−8.03	57774	55913	−3.22
E	FourPeople	539144	537437	−0.32	555962	550513	−0.98	581532	580053	−0.25
		319236	317499	−0.54	312434	306990	−1.74	317508	316020	−0.47
		201726	199995	−0.86	193261	187777	−2.84	191024	189556	−0.77
		129910	128197	−1.32	123370	117900	−4.43	119204	117712	−1.25
F	Basketball DrillText	624981	623232	−0.28	666544	661516	−0.75	700583	699202	−0.20
		356524	354777	−0.49	371565	366549	−1.35	381502	380116	−0.36
		213187	211454	−0.81	218570	213562	−2.29	220832	219454	−0.62
		131214	129500	−1.31	132445	127462	−3.76	131822	130453	−1.04

but only 1.21% file size reduction is achieved at high bitrate. This can be explained that when bitrate becomes higher, the residual data becomes a larger portion within the bitstream, and the slice header overhead becomes less significant. In view of that, our proposed approaches become less effective since our proposed approaches are focusing on reducing the overhead. Thereby, it can be concluded that our proposed approach is much more effective for low bitrate applications, such as low-cost surveillance or in-car cameras. Notwithstanding, we can observe that for the sequence "BasketballPass" with black fades, our proposed approach can obtain up to 9.10% and 8.03% file size reduction for SNR and 2× spatial scalabilities, respectively.

5 Conclusions

There is no parameter prediction of WP in H.264/AVC and in the early development of HEVC. Hence, the conventional HWPP is included in HEVC. Prior art has also been proposed to have parameter prediction using implicit prediction and direct derivation. But there is still room for improvement. In this paper, we further proposed two parameter prediction algorithms by explicit coding after implicit prediction (EIWPP) and implicit derivation based on frame time instant (EDWPD), which can be used in the conventional HEVC or base layer in SHVC. Moreover, we extend the development in the enhancement layer by interlayer prediction (ILWPP) for SHVC. Experimental results show that our proposed algorithms can efficiently reduce the overhead bitrate and subsequently improve the coding performance without any loss of video quality. We believe that there are still many redundant data in HEVC that has not yet been exploited besides the parameter prediction for WP. Thus, in future, we would also like to examine other redundant data prediction or removal approaches for other places in HEVC, such as the slice header and the coding unit.

Acknowledgments

This work was supported by the Centre for Signal Processing, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University (PolyU), and a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Grant No. PolyU 152016/14E).

References

1. J. Boyce, "Weighted prediction in the H.264/MPEG AVC video coding standard," in *Proc. of the 2004 Int. Symp. on Circuits and Systems (ISCAS '04)*, Vancouver, Canada, Vol. 3, pp. 789–792 (2004).
2. ITU-T and ISO/IEC JTC 1, "Advanced video coding for generic audio-visual services," ITU-T Rec. H.264 and ISO/IEC 14496–10 (AVC), vers. 16 (2012).
3. G. J. Sullvian et al., "Overview of the high efficiency video coding (HEVC) standard," *IEEE Trans. Circuits Syst. Video Technol.* **22**(12), 1649–1668 (2012).
4. B. Bross et al., "High efficiency video coding (HEVC) text specification draft 10 (for FDIS & Last Call)," JCT-VC, JCTVC-L1003, vers 34 (2013).
5. S. Takamura et al., "Weighted prediction with parameter estimation," JCT-VC, JCTVC-F397, Torino, Italy (2011).
6. A. Tanizawa, T. Chujoh, and T. Yamakage, "AHG18: explicit weighted prediction with simple WP parameter estimation," JCT-VC, JCTVC-F326, Torino, Italy (2011).
7. R. Zhang and G. Cote, "Accurate parameter estimation and efficient fade detection for weighted prediction in H.264 video compression," in *15th IEEE Int. Conf. on Image Processing (ICIP '08)*, San Diego, California, pp. 2836–2839 (2008).
8. H. Aoki and Y. Miyamoto, "An H.264 weighted prediction parameter estimation method for fade effects in video scenes," in *15th IEEE Int. Conf. on Image Processing (ICIP '08)*, San Diego, California, pp. 2112–2115 (2008).
9. S. H. Tsang, Y. L. Chan, and W. C. Siu, "New weighted prediction architecture for coding scenes with various fading effects image and video processing," in *Proc. of the 2010 Int. Conf. on Signal Processing and Multimedia Applications (SIGMAP '10)*, Athens, Greece, pp. 118–123 (2010).
10. S. H. Tsang and Y. L. Chan, "H.264 video coding with multiple weighted prediction models," in *17th IEEE Int. Conf. on Image Processing (ICIP '10)*, Hong Kong, pp. 2069–2072 (2010).
11. S. H. Tsang, Y. L. Chan, and W. C. Siu, "Multiple weighted prediction models for video coding with brightness variations," *IET Image Process.* **6**(4), 434–443 (2012).
12. S. H. Tsang, Y. L. Chan, and W. C. Siu, "Flash scene video coding using weighted prediction," *J. Visual Commun. Image Represent.* **23**(2), 264–270 (2012).
13. S. Jeong and H. Park, "Offset compensation method for skip mode in hybrid video coding," *IEEE Trans. Circuits Syst. Video Technol.* **24**(10), 1825–1831 (2014).
14. D. K. Kwon and H. J. Kim, "Region-based weighted prediction for real-time H.264 encoder," in *Proc. of IEEE Int. Conf. on Consumer Electronics (ICCE '22)*, Las Vegas, Nevada, pp. 47–48 (2011).
15. S. H. Tsang et al., "H.264 region-based weighted prediction for scenes with local brightness variations," in *Constantinides Int. Workshop on Signal Processing (CIWSP '13)*, London, United Kingdom, pp. 1–4 (2013).
16. S. H. Tsang, Y. L. Chan, and W. C. Siu, "Region-based weighted prediction for coding video with local brightness variations," *IEEE Trans. Circuits Syst. Video Technol.* **23**(3), 549–561 (2013).
17. S. H. Tsang et al., "Region-based weighted prediction algorithm for H.264/AVC video coding," in *IEEE Int. Symp. on Circuits and Systems (ISCAS '13)*, Beijing, China, pp. 269–272 (2013).
18. S. W. Lim and J. H. Moon, "Adaptive weighted prediction based on moving area extraction and local brightness variation detection," in *Proc. of Int. Conf. on Consumer Electronics—Berlin (ICCE-Berlin '15)*, Berlin, Germany, pp. 467–470 (2015).
19. N. Zhang et al., "Enhanced inter prediction with localized weighted prediction in HEVC," in *Visual Communications and Image Processing (VCIP '15)*, Singapore, pp. 1–4 (2015).
20. A. Aminlou et al., "Weighted-prediction-based color gamut scalability extension for the H.265/HEVC video codec," in *Proc. of Int. Conf. on Acoustics, Speech, and Signal Processing (ICASSP '14)*, Florence, Italy, pp. 7427–7431 (2014).
21. D. B. Sansli et al., "Improved weighted prediction based color gamut scalability in SHVC," in *IEEE Visual Communications and Image Processing Conf.*, Valletta, Malta, pp. 201–204 (2014).
22. S. Shimizu et al., "Depth-based weighted bi-prediction for video plus depth map coding," in *19th IEEE Int. Conf. on Image Processing (ICIP '12)*, pp. 1313–1316, Orlando, Florida (2012).
23. C. Zhu et al., "Texture-aware depth prediction in 3D video coding," *IEEE Trans. Broadcast.* **62**(2), 482–486 (2016).
24. M. M. Hannuksela et al., "Multiview-video-plus-depth coding based on the advanced video coding standard," *IEEE Trans. Image Process.* **22**(9), 3449–3458 (2013).
25. P. Bordes and T. K. Tan, "JCT-VC AHG report: weighted prediction (AHG18)," JCT-VC, JCTVC-F018, Torino, Italy (2011).
26. A. Tanizawa, T. Chujoh, and T. Yamakage, "Multi-directional implicit weighted prediction based on image characteristics of reference pictures for inter coding," in *19th IEEE Int. Conf. on Image Processing (ICIP '12)*, Orlando, Florida, pp. 1545–1548 (2012).
27. A. Tanizawa and T. Chujoh, "Efficient weighted prediction parameter signaling using parameter prediction and direct derivation," in *20th IEEE Int. Conf. on Image Processing (ICIP '13)*, Melbourne, Australia, pp. 1900–1903 (2013).
28. "Scalable HEVC (SHVC) test model 10 (SHM 10)," https://hevc.hhi.fraunhofer.de/svn/svn_SHVCSoftware/tags/SHM-10.0/.
29. V. Seregin and Y. Ye, "Common SHM test conditions and software reference configurations," JCT-VC, JCTVC-Q1009, Valencia, Spain (2014).
30. A. Tanizawa, T. Chujoh, and T. Yamakage, "Improved weighted prediction parameter signaling," JCT-VC, JCTVC-J0222, Stockholm, Sweden (2012).
31. G. Bjontegaard, "Calculation of average PSNR differences between RD-curves," Video Coding Experts Group (VCEG), VCEG-M33, Austin, Texas (2001).

Sik-Ho Tsang received his PhD degrees from Hong Kong Polytechnic University, Hong Kong, in 2013. He is currently a research fellow in the Department of Electronic and Information Engineering. His current research interests involve multimedia technology, video compression such as HEVC, depth coding, and screen content coding. He is a reviewer of international journals, including the *IEEE Transactions on Image Processing* and *Transactions on Circuits and Systems for Video Technology*.

Yui-Lam Chan received his PhD from Hong Kong Polytechnic University in 1997. He is now an associate professor at the Department of Electronic and Information Engineering. He has published over 100 research papers in various international journals and conferences. He serves as an associate editor of *IEEE Transaction on Image Processing*. His research and technical interests include video compression, video transcoding, digital TV/HDTV, 3DTV, multiview-video coding, future video coding standards, etc.

Wan-Chi Siu received his PhD from the Imperial College of Science, Technology and Medicine in 1984. He has been the chair professor with the Department of EIE since 1992. He is currently the director of the Centre for Signal Processing. His works on motion estimation, transcoding, and DCT algorithms are well received by academic peers with high citations. He has authored over 400 research papers. He is a fellow of IEEE, IET, and HKIE.