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A Novel Information Hiding Method for H.266/VVC Based on Selections of Luminance Transform and Chrominance Prediction Modes

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Abstract— **This paper proposes a novel information hiding method designed for H.266/Versatile Video Coding (VVC) compressed video streams. In this work, we explore two exclusive tools in H.266/VVC standard, named Multiple Transform Selection (MTS) and Cross-component linear model (CCLM), to hide information. These two tools are utilized to preserve high video reconstruction quality and compression efficiency as well as enhance hidden capacity. In specific, MTS is for hiding information into luminance blocks by modifying the selections of transforms. Comparing with other tools, MTS has less significant impact on compression quality and efficiency. In addition, CCLM is further used to hide information into chrominance blocks to further enlarge the hidden capacity with little impact on the other two metrics. To our best knowledge, it is the first information hiding method exclusively designed for H.266/VVC. Experimental results show that our proposed information hiding method ensures high hidden capacity, remarkable video reconstruction quality and insignificant impact on compression efficiency, which achieves better overall performances comparing to existing methods for compressed video.**

I. INTRODUCTION

Video information hiding is one of the crucial techniques to provide diverse video services, such as video authentication and augmentation [1], [2], [3]. It refers to hiding different types of featured information into video streams for either security authentication, e.g., watermarking, or metadata in video augmentation, e.g., depth-map embedding, motion information embedding, and extended-color information. Thus, the development of advanced video information hiding techniques has high value for various new multimedia applications.

Recently, information hiding techniques for compressed video have received significant attention because videos are typically stored and transmitted in compressed format [4], [5]. Existing compressed video information hiding methods have been well researched in compression standards, including MPEG [6], [7], H.264 [8], [9] and H.265/High Efficiency Video Coding (HEVC) [10], [11]. These methods could be categorized based on their embedding strategies, i.e. transform-domain-based, intra-prediction-based, and inter-prediction-based methods. Transform-domain-based methods modify quantized transform coefficients [12], [13], [14], [15] to embed information. However, this type of method could cause error drifts problems, thus degrading video quality with embedded information. Intra-prediction-based and inter-prediction-based methods are widely proposed to avoid the error drifts problem. Wang et al. [16], [17] and Sheng et al. [18] modify the intra prediction modes in HEVC video format to embed information. Gaj et al. [19] group intra prediction modes based on spatial texture analysis to enhance the re-compression robustness. Shanableh et al. [20] and Yang et al. [21] modify the Coding Block (CB) structure of P frame to embed information. Yang and Li [22] utilize the motion vectors in P-frames of HEVC videos for this purpose. Tew et al. [23] modify the structure of CBs and non-zero transform coefficients to embed information.

Despite the success of the above-mentioned information hiding techniques in previous video compression standards, there is little work to investigate exclusive tools provided in the latest video compression standards H.266/Versatile Video Coding (VVC) [24], [25], [26] to further improve the information hiding methods. H.266/VVC uses a hybrid coding framework, including prediction, transform, quantization, and entropy coding, which is identified as the previous coding standard. But VVC introduces many new compression tools to enhance compression efficiency. For the intra prediction, VVC introduces several new mechanisms [27], such as Matrix weighted Intra Prediction (MIP) [28], Multiple reference line (MRL) [29], and Cross-component linear model (CCLM) [30], which increases the flexibility of mode selection, thus potentially suiting information hiding. Further, H.266/VVC designs a novel adaptive transform selection mechanism, named Multiple Transform Selection (MTS) [31], to switch between horizontal and vertical residual transforms based on the hybrid DCT+DST scheme and make the compression more effective. This provides further flexibility for information hiding.

In this work, we propose a novel compressed video information hiding method in H.266/VVC by exploring its unique tools of intra-frame coding for both luminance and chrominance blocks. It achieves a better trade-off among hidden capacity, video quality and compression efficiency. Here, we hide messages into the luminance blocks via modifying the selected transforms of MTS because its impact on

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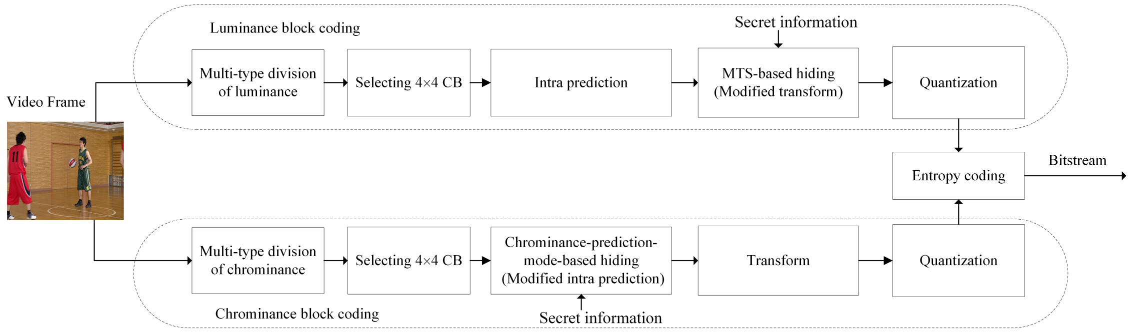

Fig. 1. Information hiding framework of our proposed method.

the video quality and compression efficiency is insignificant. In addition, we further utilize the chrominance prediction modes to increase the hidden capacity as well as offer better video reconstruction quality. The reason is that luminance and chrominance blocks of intra-frame are coded separately in the VVC standard.

Our key contributions are summarized as follows:

- To has superior overall performance compared to other state-of-the-art information hiding methods for compressed video in terms of hidden capacity, video quality and compression efficiency. A novel compressed video information hiding method is proposed by exploring the unique tools of intra-frame coding in VVC. To our best knowledge, it is the first information hiding method exclusively designed for VVC.
- A unique coding tool in VVC, namely MTS, is deployed to hide information into luminance blocks. It has less significant impact on video quality and compression efficiency than other tools in luminance blocks e.g. MIP and MRL. This characteristic could ensure the high video quality, sufficient hidden capacity and insignificant impact on compression efficiency, which cannot be achieved by any information hiding methods designed for previous video coding standards because they cannot use this tool since the transforms for previous video coding standards are fixed.
- Another unique tool in VVC, namely CCLM, is also used to hide information into chrominance blocks. This tool introduces several new chrominance prediction modes. In this manner, the prediction mode selections for information hiding are enlarged, yielding better video quality and lower bitrate increment, which cannot be achieved by any information hiding methods designed for previous video coding standards.

The remainder of the paper is organized as follows. Section II describes the details of the proposed compressed video information hiding method. In Section III, the experimental results are presented to demonstrate the effectiveness of the proposed algorithm. Finally, Section IV draws a conclusion and suggests future work.

II. THE PROPOSED METHOD

In this work, a novel compressed video information hiding method is proposed to achieve an optimal trade-off between hidden capacity and video quality. It consists of an information hiding phase and an extraction phase.

A. Information hiding

A coding unit (CU) is composed of a luminance coding block, two chrominance coding blocks and their syntax elements. In VVC, the division and coding of luminance block and chrominance block in I frame are independent of each other. And I frame is intra frame and convey a wide range of information, is more suitable for information hiding. Therefore, this paper proposes a scheme to hide information in both luminance block and chrominance block of I frame.

As shown in Fig. 1, the secret information is hidden by modifying the selection of transforms in luminance blocks, and intra prediction modes in chrominance blocks. Here, the 4×4 CB of I frames are selected for hiding to ensure the video quality because these small CBs are used to encode texture-rich regions of video frames, which are suitable for information hiding. The detailed steps of MTS-based and chrominance-prediction-mode-based hiding methods are described as follows.

1) MTS-based Hiding: In the framework of video encoding, transform coding plays a vital role in achieving good compression efficiency. VVC uses the MTS scheme for coding luminance blocks and introduces two new transform matrices: DST-VII and DCT-VIII [32]. Different transform matrices can be applied in both the horizontal and vertical directions of the CBs. Thus, there are six transforms in VVC including Transform Skip, namely TS, as shown in Table I.

There is little impact on video encoding performance when we hide information by changing transforms of the MTS. The reason is that the transform selection of the MTS in VVC practice, e.g., VTM [33](VVC reference software), is sub-optimal as it runs a fast selection algorithm to reduce the computational complexity. Consequently, the transform selection of the MTS is the most suitable element for us to hide information.

The MTS transforms are divided into two groups for their selection since the hidden information has binary codes, i.e. '0' and '1'. To do this, we design a grouping strategy based

TABLE I

TRANSFORMS FOR CODING LUMINANCE BLOCKS IN VVC

MTSIdx	Transform matrices	
	Horizontal	Vertical
0	DCT2	
1	Transform skip(TS)	
2	DST7	DST7
3	DCT8	DST7
4	DST7	DCT8
5	DCT8	DCT8

on analyzing statistical probability to minimize the negative impact on video reconstruction quality when switching the optimal transform to another transform for information hiding. To mitigate the negative impact of hiding, the sub-optimal transform, which is defined as the transform with the highest frequency chosen by the VVC encoder when excluding the optimal transform, is better to be divided into the opposite group of the optimal transform. Fig. 2 illustrates the frequency distributions to select the sub-optimal transform when the optimal transform is excluded. For example, Fig. 2 (a) shows that the frequency of choosing the sub-optimal transform 2 is much higher than other transforms when the optimal transform is 0. Thus transform 0 and transform 2 are better to be in different groups. By using this strategy, the transforms $\{2, 3, 5\}$ are in the first group and transforms $\{0, 1, 4\}$ are in the second group. In our proposed method, if the information bit is '1', the optimal transform in each 4×4 luminance CB is selected from $\{0, 1, 4\}$ listed in Table I. Otherwise, the optimal transform is selected from the transforms $\{2, 3, 5\}$.

$$mtsIdx_h = \begin{cases} \underset{mtsIdx \in \{0,1,4\}}{\arg\min} \quad (D(mtsIdx) + \lambda \cdot R(mtsIdx), \\ \qquad\qquad\qquad\qquad \text{if } bit = 1 \\ \underset{mtsIdx \in \{2,3,5\}}{\arg\min} \quad (D(mtsIdx) + \lambda \cdot R(mtsIdx), \\ \qquad\qquad\qquad\qquad \text{if } bit = 0 \end{cases} \tag{1}$$

where $mtsIdx$ and $mtsIdx_h$ represent the index of different transform and the selected transform for information hiding, $D(\cdot)$ and $R(\cdot)$ represent the compressed distortion and the number of bits required by using the transform with index of $mtsIdx$, and λ is the Lagrangian parameter.

2) Chrominance-prediction-mode-based Hiding: VVC adopts eight chroma intra prediction modes, including five traditional prediction modes which are PLANAR, VER, HOR, DC, DM_CHROMA, and three innovative cross-component linear models (CCLM), which are LM_CHROMA, MDLM_L, MDLM_T, to reduce the redundancy between color components.

Similarly to the grouping division of MTS transforms, we divide chrominance prediction modes into two different groups for information hiding. The frequency distributions of the sub-optimal chrominance prediction modes are shown in Fig 3. As a result, if the secret information is '1', the optimal prediction mode in the 4×4 chrominance CB is selected

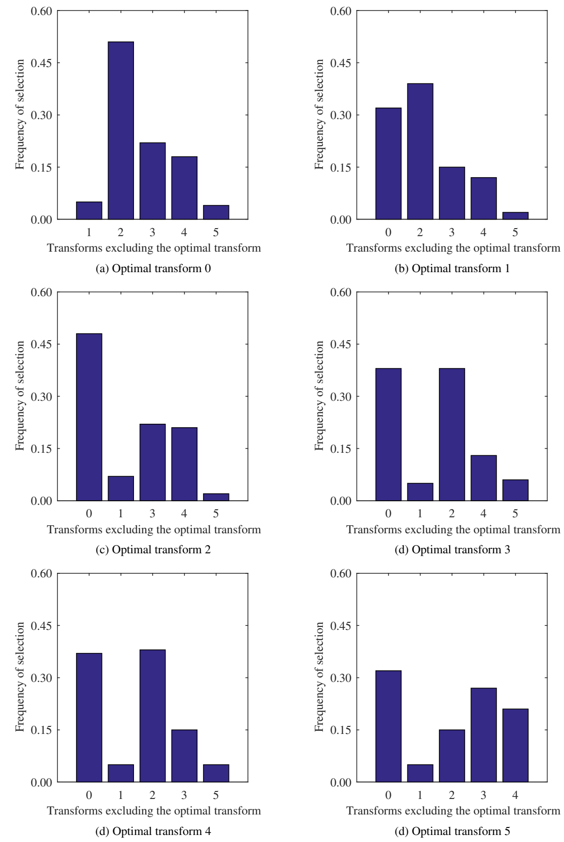

Fig. 2. When the optimal transform is determined, the distribution of the transforms excluding the optimal transform

from $\{1, 18, 50, 67\}$. Otherwise, the optimal prediction mode is selected from $\{0, 68, 69, 70\}$.

$$mode_h = \begin{cases} \underset{mode \in \{1,18,50,67\}}{\arg\min} \quad (D(mode) + \lambda \cdot R(mode), \\ \qquad\qquad\qquad\qquad \text{if } bit = 1 \\ \underset{mode \in \{0,68,69,70\}}{\arg\min} \quad (D(mode) + \lambda \cdot R(mode), \\ \qquad\qquad\qquad\qquad \text{if } bit = 0 \end{cases} \tag{2}$$

where $mode$ and $mode_h$ represent different prediction mode and the selected prediction mode for information hiding, $D(\cdot)$ and $R(\cdot)$ represent the compressed distortion and the number of bits required by using the prediction mode, and λ is the Lagrangian parameter.

B. Information extraction

The extraction of secret information is very simple and fast, and the information can be extracted only by partially decoding the I frame, the extraction framework is shown in Fig. 4. We use 4×4 luminance and chrominance CBs for information extraction. For a 4×4 luminance CB, its partially decoded to obtain its index of utilized transform. If this index is belong to $\{0, 1, 4\}$, the extracted information bit is '1'. Otherwise, the extracted information bit is '0'. For a 4×4 chrominance CB, the extracted information bit

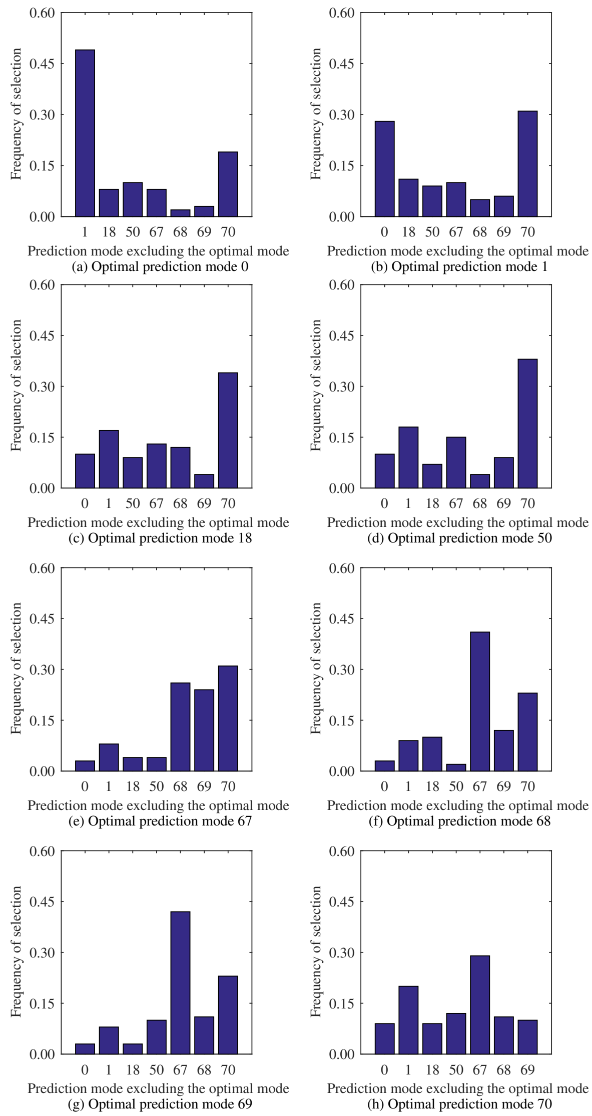

Fig. 3. When the optimal prediction mode is determined, the distribution of the prediction modes excluding the optimal prediction mode

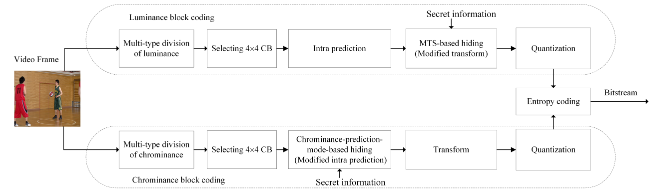

Fig. 4. Extraction framework of hidden information.

is '1' if its prediction mode is belong to {1, 18, 50, 67}. Otherwise, the extracted information bit is '0'. Repeat the above operations for all the 4×4 CBs until the secret information is extracted.

III. Experimental results and discussions

In this section, we use four standard video sequences with different resolutions and different texture complexity. These sequences include BlowingBubbles (resolution: 416×240), PartyScene_832×480, vidyo1_1280×720, and BQTerrace_1920×1080, as the testing set [34]. We evaluate the information hiding method performances by conducting an ablation study of different tools in VVC and then compare our proposed method with three existing information hiding benchmarks designed for HEVC. Note that all our proposed and the benchmark methods are implemented on the same coding environment, which is the VVC reference software VTM6.0, to avoid the bias caused by different coding standards. The detailed parameters are as follows: (1) the GOP size is 4, (2) the GOP structure is "I-P-P-P", (3) the quantization parameter (QP) is set to 27, (4) the IntraPeriod is 4, (5) the number of encoded frames is 40, and (6) the rest parameters are set to the VTM default configurations. We test the video bitrates and the values of peak signal to noise ratio (PSNR) of videos under different hidden capacities to evaluate the impacts of information hiding on compression efficiency and the video quality of the testing methods.

A. Ablation study

In this section, we evaluate different hiding strategies based on three unique tools in Intra-frame coding of VVC, which are MRL, MIP, and MTS, and compare them with our proposed combined method. The MRL-based hiding modifies the selected reference lines while the MIP-based hiding modifies the selected prediction modes. The MTS-based hiding is a part of our proposed method (II-A.1). The testing results are listed in Table II. In this table, Proposed I only uses MTS-based hiding while the Proposed II combines the MTS-based hiding and chrominance-prediction-mode-based hiding. NA values of bitrate and PSNR under a certain hidden capacity mean that this hidden capacity is not achievable. In addition, the bolded number in the table represents the best performance. Note that the hidden capacities of different video sequences vary based on the resolutions and texture complexity. For example, the BlowingBubbles with lower resolutions and the vidyo1 with lower texture complexity are expected to have smaller hidden capacities comparing to the others.

As shown in Table II, all the testing hiding strategies have insignificant increase of video bitrate or decrease of PSNR under different hidden capacities, confirming the insignificant impact on compression efficiency and the remarkable video quality. Moreover, the proposed MTS-based hiding has much higher hidden capacity with lower bitrate increment and higher PSNR compared with MRL-based hiding and MIP-based hiding due to its insignificant impact on the compression efficiency. It demonstrates that the MTS is the most suitable tool for information hiding in Intra-frame coding of VVC. Moreover, the proposed combined method further enhances the hidden capacity and achieves similar video quality and compression efficiency comparing to the method using MTS-based hiding only, proving the superiority of the combined method.

B. Comparison with other compressed video methods

To further demonstrate the superiority of our proposed method, we compare its information hiding performance

TABLE II

COMPARISON OF THE MRL-BASED AND MIP-BASED EMBEDDING STRATEGIES WITH OUR PROPOSED METHOD

Video sequences	Capacity	MRL-based		MIP-based		Proposed I (MTS only)		Proposed II (Combined)	
		Bitrate	PSNR	Bitrate	PSNR	Bitrate	Psnr	Bitrate	PSNR
BlowingBubbles 416×240 (Bitrate:1712.020 PSNR:36.655)	0.4k	1714.490	36.647	1713.980	36.657	**1711.750**	36.655	1712.970	**36.660**
	0.8k	1715.840	36.641	**1713.100**	36.652	1713.140	36.655	1713.360	**36.658**
	1.9k	NA	NA	1712.900	36.643	1713.220	36.649	**1712.040**	**36.653**
	2.6k	NA	NA	NA	NA	**1711.460**	36.647	1712.340	**36.648**
	3.6k	NA	NA	NA	NA	NA	NA	**1713.720**	**36.645**
PartyScene 832×480 (Bitrate:9750.130 PSNR: 35.879)	3.4k	9759.910	35.872	9752.320	35.876	**9751.280**	**35.877**	9752.660	35.875
	6.9k	9769.080	35.865	9753.380	35.870	**9749.340**	35.871	9752.820	**35.872**
	13k	NA	NA	9766.050	**35.869**	**9752.730**	35.866	9756.350	35.867
	16k	NA	NA	NA	NA	**9751.620**	35.862	9754.540	**35.863**
	20k	NA	NA	NA	NA	NA	NA	**9755.970**	**35.857**
vidyo1 1280×720 (Bitrate:3162.156 PSNR: 43.285)	0.3k	3165.144	**43.284**	3160.320	43.281	**3159.672**	43.281	3160.620	43.283
	0.6k	3166.116	43.279	**3160.776**	43.278	3161.280	43.284	3163.836	**43.285**
	0.9k	NA	NA	NA	NA	**3162.252**	**43.285**	3163.932	43.284
	1.2k	NA	NA	NA	NA	**3163.812**	43.285	3165.720	**43.286**
	2.0k	NA	NA	NA	NA	NA	NA	**3166.332**	**43.285**
BQTerrace 1920×1080 (Bitrate:27357.888 PSNR: 36.854)	5.8k	27379.020	36.853	27374.820	36.852	27367.176	**36.854**	**27360.744**	36.853
	11.7k	27396.960	36.851	27410.244	36.851	27371.220	**36.853**	**27360.564**	36.852
	17.0k	NA	NA	NA	NA	27376.920	**36.854**	**27364.176**	36.850
	22.0k	NA	NA	NA	NA	27378.228	**36.852**	**27370.164**	36.849
	24.9k	NA	NA	NA	NA	NA	NA	**27376.116**	**36.850**

TABLE III

COMPARISON OF OUR PROPOSED METHOD WITH OTHER BENCHMARK COMPRESSED VIDEO INFORMATION HIDNG

Video sequences	Capacity	Sheng *et al.* [18]		Yang *et al.* [21]		Tew *et al.* [23]		Proposed (Combined)	
		Bitrate	PSNR	Bitrate	PSNR	Bitrate	PSNR	Bitrate	PSNR
BlowingBubbles 416×240 (Bitrate:1712.020 PSNR:36.655)	1.5k	1711.410	36.650	1720.800	36.617	1754.760	36.636	**1711.010**	**36.658**
	1.9k	NA	NA	1721.730	36.606	1755.640	36.635	**1712.040**	**36.653**
	2.2k	NA	NA	1723.880	36.606	1756.160	36.633	**1712.820**	**36.653**
	2.9k	NA	NA	1726.080	36.594	1758.800	36.635	**1713.210**	**36.648**
	3.6k	NA	NA	1729.090	36.582	1759.470	36.635	**1713.720**	**36.645**
PartyScene 832×480 (Bitrate:9750.130 PSNR: 35.879)	3.9k	9752.980	35.871	9777.530	35.854	9919.660	35.862	**9752.660**	**35.875**
	7.9k	**9753.170**	35.872	9798.090	35.840	9927.300	35.859	9754.300	**35.872**
	11k	NA	NA	9815.860	35.831	9936.040	35.860	**9753.750**	**35.868**
	15k	NA	NA	9836.300	35.820	9941.120	35.859	**9753.940**	**35.864**
	20k	NA	NA	9860.110	35.805	9951.860	**35.858**	**9755.970**	35.857
vidyo1 1280×720 (Bitrate:3162.156 PSNR: 43.285)	0.3k	3163.140	**43.285**	3163.788	43.282	3524.772	43.045	**3160.620**	43.283
	0.6k	3164.088	43.282	3165.696	43.282	3527.820	43.047	**3163.836**	**43.285**
	0.9k	3165.276	43.283	3167.688	43.281	3527.928	43.045	**3163.932**	**43.284**
	1.4k	NA	NA	3170.268	43.280	3530.940	43.047	**3164.916**	**43.286**
	2k	NA	NA	3176.664	43.273	3530.976	43.046	**3166.332**	**43.285**
BQTerrace 1920×1080 (Bitrate:27357.888 PSNR: 36.854)	5.4k	**27344.280**	36.851	27378.768	36.847	28686.900	36.814	27362.016	**36.853**
	10.8k	**27335.952**	**36.853**	27399.636	36.844	28707.024	36.814	27358.704	36.852
	12.6k	NA	NA	27404.620	36.843	28709.832	36.814	**27365.928**	**36.852**
	18.8k	NA	NA	27428.520	36.840	28730.220	36.813	**27362.760**	**36.849**
	24.9k	NA	NA	27451.320	36.837	28748.016	36.813	**27376.116**	**36.850**

with those of three existing compressed video methods in HEVC [18], [21], [23] in terms of bitrate and PSNR under different hidden capacities. The results are shown in Table III. Here, NA values of bitrate and PSNR under a certain hidden capacity mean that the method cannot achieve this hidden capacity. In addition, the bolded number in the table represents the best performance. As shown in Table III, our proposed method achieves a better overall performance in terms of capacity, bitrate and PSNR compared with existing methods. Compared with [18], the hidden capacity of our proposed method is much higher although the reconstruction quality and bitrate increment of these two methods is comparable. In specific, the hidden capacities of our hiding method are about 2.5 times of those of [18] for the testing videos. Comparing to the methods [21], [23], our proposed method achieves much lower bitrate increment with higher PSNR under different hidden capacities. Specifically, the average increment between the bitrates of the compressed videos after information hiding and the original compressed videos by using our proposed method is as small as 3.096. This value is only 8.7% and 0.6% of those by using [21], [23] on the testing videos under different hidden capacities, which are 35.385 and 488.643, respectively.

IV. Conclusion

In this paper, we have proposed a novel compressed video information hiding method for VVC by selecting the luminance transform and chrominance prediction modes. This is the first information hiding method exclusively designed for VVC to achieve better information hiding performance comparing to the methods designed for previous compression standards. Experimental results have demonstrated that our proposed method outperforms existing methods in terms of the overall performances of hidden capacity, video quality and compression efficiency. Our future work aims to commercialize our proposed method to address copyright breach issues and video forgery problems.

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