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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 embed information. These two tools are utilized to preserve high video reconstruction quality and compression efficiency as well as enhance embedding capacity. In specific, MTS is for embedding information into luminance blocks by modifying the selections of coding transforms. Comparing with other tools, MTS has less significant impact on compression quality and efficiency. In addition, CCLM is further used to embed information into chrominance blocks to further enlarge the embedding 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 embedding capacity, remarkable video reconstruction quality and insignificant impact on compression efficiency, which achieves a 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 embedding 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, 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 attentions because videos are typically stored and transmitted in compressed format. Existing compressed video information hiding methods have been well researched in compression standards, including MPEG [4], [5], H.264 [6], [7] and H.265/High Efficiency Video Coding (HEVC) [8], [9]. 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 [10], [11], [12], [13] to embed information. However, this type of methods could cause error drifts problem, 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. [14], [15] and Sheng et al. [16] modify the intra prediction modes in HEVC video format to embed information. Gaj et al. [17] group intra prediction modes based on spatial texture analysis to enhance the re-compression robustness. Shanableh et al. [18] and Yang et al. [19] modify the Coding Block (CB) structure of P frame to embed information. Yang and Li [20] utilize the motion vectors in P-frames of HEVC videos for the purpose. Tew et al. [21] 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) [22], [23], [24] to further improve the information hiding methods. H.266/VVC introduces many new compression tools to enhance the compression efficiency. For the intra prediction, H.266/VVC introduces several new mechanisms [25], such as Matrix weighted Intra Prediction (MIP) [26], Multiple reference line (MRL) [27], and Cross-component linear model (CCLM) [28], 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) [29], 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 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 because luminance and chrominance blocks of intra-frame are coded

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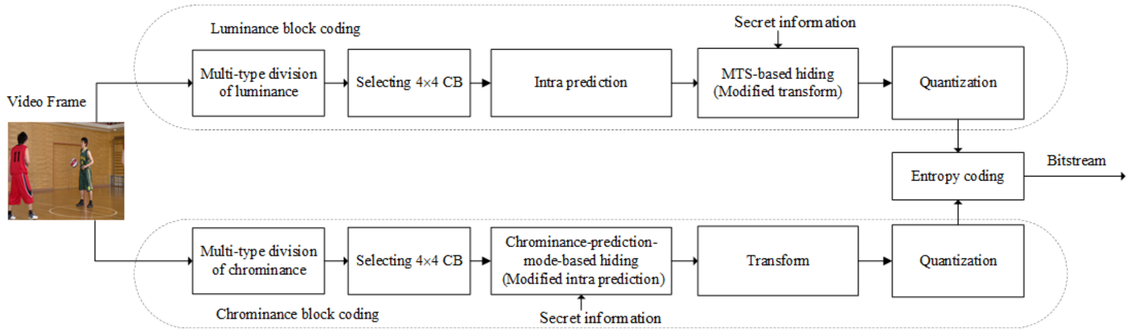

Fig. 1. Information hiding framework.

separately in the VVC standard.

Our key contributions are summarized as follows:

- 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.
- A comprehensive set of experiments is performed to demonstrate our proposed algorithm 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.

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 the 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 and corresponding 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. Therefore, this paper proposes a scheme to hide information in luminance block and chrominance block of I frame.

As shown in Figure 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 code 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 coding, 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 [30]. 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, 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 because the transform selection of the MTS in VVC practice, e.g., VTM [31](VVC reference software), is suboptimal 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.

To ensure the video quality after hiding information, we establish a mapping rule between the secret information and the transform groups to realize information hiding. Because choosing different transforms have different effects on video quality, the sub-optimal transform of an optimal transform is selected as the transform after hiding information. In this case, the impact on the video quality is minimal.

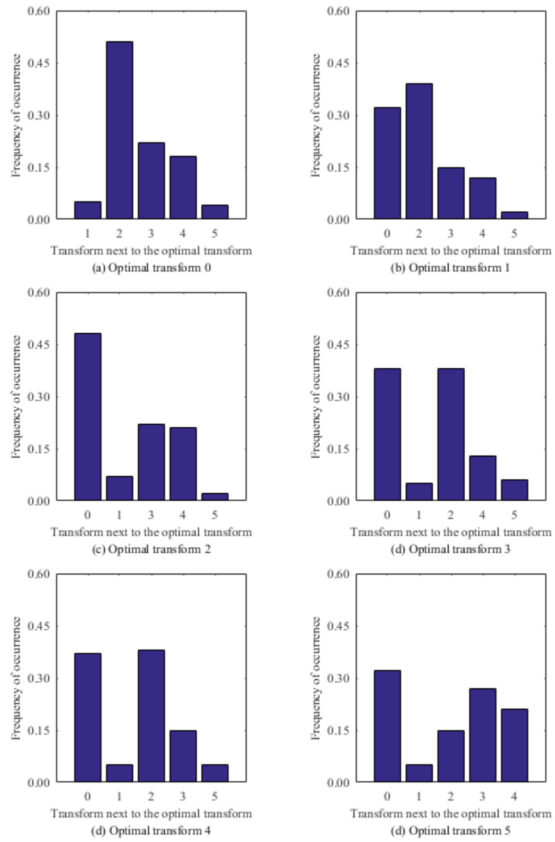

Fig. 2. When the optimal transform is determined, the distribution of the transform next to the optimal transform

Therefore, we count the distribution of the transform next to the optimal transform when the optimal transform is determined, as shown in Figure 2. Take Figure 2 (a) as an example, when the optimal transform is 0, the transform next to the optimal transform are determined according to the rate-distortion cost and its appearance frequency are counted. It can be seen that the occurrence frequency of 2 is the highest, so the sub-optimal transform of 0 is 2. According to the statistical probability distribution of the sub-optimal transform of different optimal transform, we divide the optimal transform and the sub-optimal transform into different groups to map the information to ensure the video quality after the information is hidden.

As a result, if the information bit is '1', the optimal transform in each luminance CB is selected from $\{0, 1, 4\}$ listed in Table I. Otherwise, the optimal transform is selected from the rest options.

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

TABLE I

TRANSFORMS FOR CODING LUMINANCE BLOCKS IN VVC

MTSIdx	Intra	
	Horizontal	Vertical
0	DCT2	
1	TS	
2	DST7	DST7
3	DCT8	DST7
4	DST7	DCT8
5	DCT8	DCT8

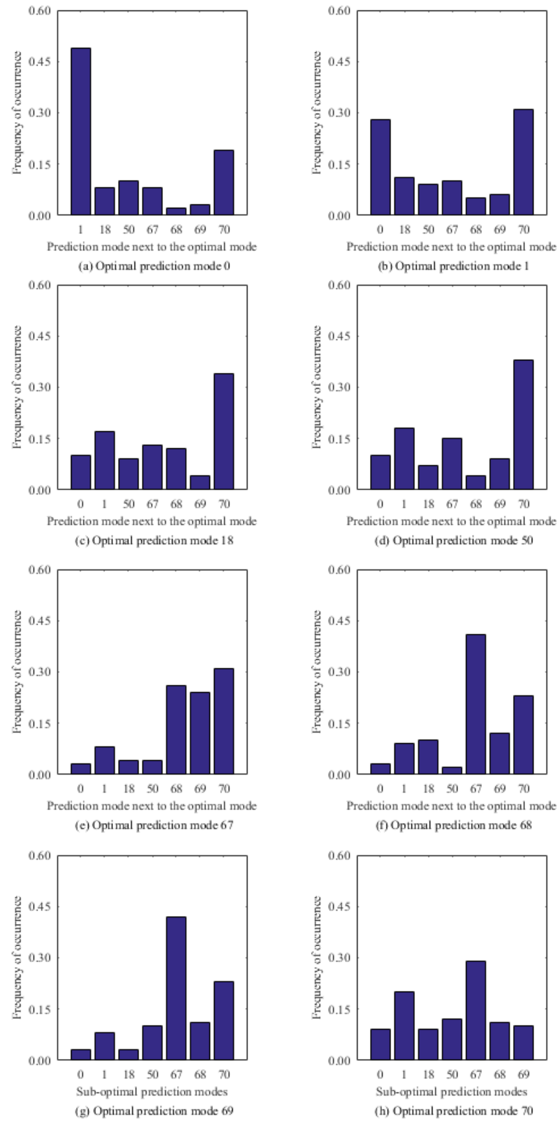

Fig. 3. When the optimal prediction mode is determined, the distribution of the prediction mode next to the optimal prediction mode

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 chrom inance prediction modes, including five traditional prediction modes which are PLA-

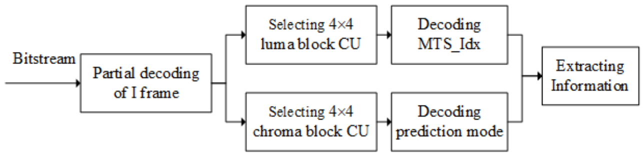

Fig. 4. Extraction framework of hidden information.

NAR, 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.

We establish a mapping between the chrominance prediction modes and the secret information to hide the information. The mapping groups are divided following the same method of that in MTS-based Hiding to enhance video quality, as shown in Figure 3. As a result, if the embedded information is '1', the suboptimal prediction mode in the chrominance CB is selected from {1, 18, 50, 67}. Otherwise, the suboptimal prediction mode is selected from {0, 68, 69, 70}.

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

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 Figure 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 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 [32]. 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, the 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. 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 with those of three existing compressed video methods in HEVC [16], [19], [21] 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. As shown in Table III, our proposed

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	0.4k	1714.490	36.647	1713.980	36.657	**1711.750**	36.655	1712.970	**36.660**
416×240	0.8k	1715.840	36.641	**1713.100**	36.652	1713.140	36.655	1713.360	**36.658**
(Bitrate:1712.020	1.9k	NA	NA	1712.900	36.643	1713.220	36.649	**1712.040**	**36.653**
PSNR:36.655)	2.6k	NA	NA	NA	NA	**1711.460**	36.647	1712.340	**36.648**
	3.6k	NA	NA	NA	NA	NA	NA	**1713.720**	**36.6450**
PartyScene	3.4k	9759.910	35.872	9752.320	35.876	**9751.280**	**35.877**	9752.660	35.875
832×480	6.9k	9769.080	35.865	9753.380	35.870	**9749.340**	35.871	9752.820	**35.872**
(Bitrate:9750.130	13k	NA	NA	9766.050	**35.869**	**9752.730**	35.866	9756.350	35.867
PSNR: 35.879)	16k	NA	NA	NA	NA	**9751.620**	35.862	9754.540	**35.863**
	20k	NA	NA	NA	NA	NA	NA	**9754.300**	**35.857**
vidyo1	0.3k	3165.144	**43.284**	3160.320	43.281	**3159.672**	43.281	3160.620	43.283
1280×720	0.6k	3166.116	43.279	**3160.776**	43.278	3161.280	43.284	3163.836	**43.285**
(Bitrate:3162.156	0.9k	NA	NA	NA	NA	**3162.252**	**43.285**	3163.932	43.284
PSNR: 43.285)	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	5.8k	27379.020	36.853	27374.820	36.852	27367.176	**36.854**	**27360.744**	36.853
1920×1080	11.7k	27396.960	36.851	27410.244	36.851	27371.220	**36.853**	**27360.564**	36.852
(Bitrate:27357.888	17.0k	NA	NA	NA	NA	27376.920	**36.854**	**27364.176**	36.850
PSNR: 36.854)	22.0k	NA	NA	NA	NA	27378.228	**36.852**	**27370.164**	36.850
	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.* [16]		Yang *et al.* [19]		Tew *et al.* [21]		Proposed (Combined)	
		Bitrate	PSNR	Bitrate	PSNR	Bitrate	PSNR	Bitrate	PSNR
BlowingBubbles	1.5k	1711.410	36.650	1720.800	36.617	1754.760	36.636	**1711.010**	**36.658**
416×240	1.9k	NA	NA	1721.730	36.606	1755.640	36.635	**1712.040**	**36.653**
(Bitrate:1712.020	2.2k	NA	NA	1723.880	36.606	1756.160	36.633	**1712.820**	**36.653**
PSNR:36.655)	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	3.9k	9752.980	35.871	9777.530	35.854	9919.660	35.862	**9752.660**	**35.875**
832×480	7.9k	**9753.170**	35.872	9798.090	35.840	9927.300	35.859	9754.300	**35.872**
(Bitrate:9750.130	11k	NA	NA	9815.860	35.831	9936.040	35.860	**9753.750**	**35.868**
PSNR: 35.879)	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	0.3k	3163.140	**43.285**	3163.788	43.282	3524.772	43.045	**3160.620**	43.283
1280×720	0.6k	3164.088	43.282	3165.696	43.282	3527.820	43.047	**3163.836**	**43.285**
(Bitrate:3162.156	0.9k	3165.276	43.283	3167.688	43.281	3527.928	43.045	**3163.932**	**43.284**
PSNR: 43.285)	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	5.4k	**27344.280**	36.851	27378.768	36.847	28686.900	36.814	27362.016	**36.853**
1920×1080	10.8k	**27335.952**	**36.853**	27399.636	36.844	28707.024	36.814	27358.704	36.852
(Bitrate:27357.888	12.6k	NA	NA	27404.620	36.843	28709.832	36.814	**27365.928**	**36.852**
PSNR: 36.854)	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**

method achieves a better overall performance in terms of capacity, bitrate and PSNR compared with existing methods. Compared with [16], 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 [16] for the testing videos. Comparing to the methods [19], [21], 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 [19], [21] on the testing videos under different hidden capacities, which are 35.385 and 488.643, respectively.

C. Analysis of robustness

The information hiding algorithm based on compressed video proposed in this paper is fundamentally robust to a majority of adversarial attacks, e.g., salt and pepper noise addition, Gaussian noise addition, and Gaussian filtering, because of its insensitivity to any attacks which manipulate the frames of the videos. Although the methods based on the modifications of transform coefficients may be better than the proposed method when against re-encoding and transcoding attacks, none of these methods can achieve such high hidden capacity and video quality as the proposed one due to their error drifting problems.

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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