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Distortion Propagation Based Quantization Parameter Cascading Method for Screen Content Video Coding

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ABSTRACT Screen content video (SCV) is generated by computers, including animation, texts and graphics. SCV contains continuous static frames and many scene changes, making SCV different from conventional camera captured video (CCV) in terms of temporal characteristic. Therefore, conventional quantization parameter (QP) cascading method may not be efficient for SCV. In this paper, a distortion propagation based QP cascading method is proposed for SCV. The special temporal characteristic of SCV is considered and the distortion propagation of every coding tree unit (CTU) is measured. Based on the CTU level distortion propagation, the improved QP cascading method is designed. Experimental results show that compared with other methods, the proposed could achieve better rate distortion (RD) performance and less encoding time.

INDEX TERMS Rate control, video coding, mobile, screen content, HEVC.

I. INTRODUCTION

High Efficient Video Coding (HEVC) is the latest state-of-the-art video coding standard, developed by JCT-VC (Joint Collaborative Team of Video Coding), and it can save about 50% bitrate at similar quality compared with H.264 [2]. After finalization of the HEVC base specification, JCT-VC continued to work on extensions. The screen content coding (SCC) extensions [3] improve compression capability for video containing a significant portion of rendered (moving or static) graphics, text, or animation rather than camera captured video scenes. In the past few years, screen content video is more and more popular in applications, such as remote desktop, video conferencing, screen sharing, and cloud computing. Moreover, with the development of Internet of Things [4], [6] and 5G techniques [7], [8] improving the compression performance of screen content videos could combine the screen content application with communication better [5], [9].

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To improve the coding efficiency of SCV, many new techniques have been proposed. including two powerful coding techniques (intra block copy [11] and palette mode [12]). Intra block copy utilizes the repeated patterns in screen contents, and the palette mode exploits the characteristic of limited colours in screen contents. Based on these two techniques, many improved methods have been proposed to provide better block matching and coding performance [13]–[15], [27].

In addition to designing new tools in video coding standard, setting encoding parameters could also help to improve coding performance in the limited bandwidth. QP cascading (QPC) method is one of encoding parameter setting methods. The starting point of QPC method is the hierarchical inter-frame prediction structure in video coding. Concretely, in a Group-of-Picture (GOP), pictures in higher layers could be predicted from pictures in lower layers. In other words, pictures in lower layers could effect more pictures because they are referenced by more pictures. Thus simply pictures in lower layers should be encoded with higher quality to improve RD performance, which is the basic thought of QP cascading method.

In the past years, plenty of QP cascading methods have been proposed, which can be simply classified into two categories: static QPC method and adaptive QPC method. The static QPC method is an empirical method, every frame is assigned an QP offset (ΔQP), which is a fixed empirical value and the final QP value of every frame is $QP_{base}+\Delta QP$, where QP_{base} is the base QP. Many classical static QPC methods have been proposed for H.264 [16], H.264 scalable video coding [17] and HEVC [18]. The adaptive QPC method is content-adaptive method, the QP offset is dynamically changing according to the video contents. Aimed at H.264 baseline profile, Wan *et al.* [19] proposed a content-aware QPC method for the hierarchical P structure. The QP at the highest layer was determined based on the desired target bit rate. Then, the QPs for all other layers was specified based on the above QP and the offset spassed indirectly by summarizing the prediction modes of all layers. Aimed at scalable video coding, Li et al. [20] developed an adaptive QPC scheme. The error propagation due to quantization in every layer was measured and the RD curve was emulated. QPs of each layer was obtained according to the emulation results. Based on the work in [20], Li *et al.* [21] proposed an improved QPC method, where the RD optimization problem of QPC was formulated by minimizing the overall distortion of a GOP, subject to an average bit rate of all pictures within a GOP. Aimed at HEVC low delay profile, Zhao et al. proposed a scheme to adaptively optimize the QP set of all hierarchical layers. The QPC problem was formulated as a non-liner programming problem and was solved by using the inherent inter layer RD dependencies and adaptively updating the RD models for each GOP.

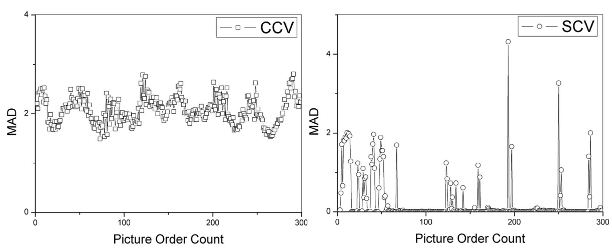


FIGURE 1. Frame MAD(mean absolute difference) distribution comparison between CCV and SCV. CCV used here: *BasketballDrill*, SCV used here: *Slide Editing*.

Above mentioned QPC methods were designed for conventional camera captured video (CCV), as screen content video (SCV) has significantly different characteristics from camera captured video, as shown in Fig. 1, the existing QPC methods aimed at CCV may be not suitable for SCV. Therefore in the past few years, some QPC methods aimed at SCV have been developed [22]–[24]. Fan *et al.* [22] firstly proposed a frame level quantization parameter optimization method for SCV. The inter-frame correlation was measured and the QP offset of every frame was adaptively adjusted according to the correlation measurement. Li *et al.* [23] developed a CTU level QP setting method for SCV. Regions was classified into static region and moving region, the static region was set smaller QP to reduce quality refinement. And in our previous work [24], the RD characteristic of SCV was simplified and formulated to a RD optimization problem, based on the solution, a robust frame level QPC method was proposed.

However, existing QPC methods for SCV haven't made quantitative description for distortion propagation of SCV. As we know, the distortion propagation characteristic is the key factor for QPC. Therefore in this paper, a CTU level distortion propagation measurement is proposed and based on the measurement, the QP offset of every CTU is adjusted. Concretely, the main contributions of this paper are as follows:

- Two classical method to investigate distortion propagation are reviewed.
- An algorithm to measure CTU level distortion propagation is designed using the hash-based search.
- A CTU level QP cascading scheme is proposed based on the distortion propagation measurement.

The rest of this paper is organized as follows. Section 2 introduces the proposed QPC method in detail. Section 3 presents the experimental results. And conclusions are drawn in Section 4.

II. PROPOSED QPC METHOD

In this section, firstly related work of the proposed method is analyzed, next our distortion propagation measurement of SCV is present, then the distortion propagation based QPC scheme is proposed, finally the whole proposed QPC method is summarized as a flowchart.

A. RELATED WORK

As the proposed method is designed for low-delay (LD) configuration in HEVC, we make a brief introduction for HEVC default QPC method and corresponding methods to measure distortion propagation. Hierarchical prediction structure is used in HEVC, as shown in Fig. 2, where. Pictures in lower

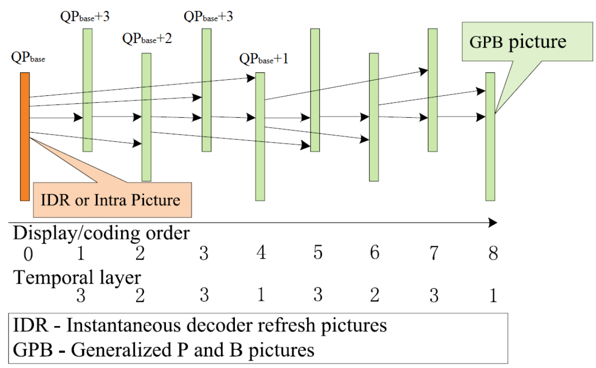


FIGURE 2. Hierarchical prediction structure and default QPC of LD configuration in HEVC.

layer are referenced by pictures in higher layers, thus pictures in lower layer are assigned smaller QP. For example, the intra pictures (or IDR pictures) are in the lowest layer, thus they are assigned the base QP (QP_{base}), pictures in *3-th* layer only reference other pictures, thus they are assigned the largest QP ($QP_{base} + 3$).

Obviously, the above static QPC method is unable to fully explore the potentials of QPC and is unable to achieve optimal RD performance [21]. Therefore, researchers usually explore the potentials of QPC by studying the distortion propagation factor. Distortion propagation reflects the influence of the coding unit, the bigger distortion propagation factor is, the higher quality coding unit should be, so that the high quality could be propagated to more coding units. There are two well-known two ways to investigate distortion propagation, the one is through experiment (called Way-A here) [25], the other one is by theoretical derivation (called Way-B here) [26].

Concretely, in Way-A, the referenced picture in the *i-th* layer is encoded with different parameters (i.e. different QPs), the distortion of the referenced picture and its predicted picture are extracted as D_i and D^p respectively. Then the relationship between D_i and D^p is investigated and usually described as linear relationship as

$$\Delta D^p = \alpha \cdot \Delta D_i \tag{1}$$

where, α is the model parameter. Based on the analysis of inter-layer dependency, the influence of D_i on the distortion of the total sequence (D_{total}) could be obtained as

$$\Delta D_{total} = \begin{cases} \dfrac{(1+2\alpha)^N}{1-\alpha}\Delta D_i, & i = 0 \\ (1+2\alpha)^{N-i}\Delta D_i, & 1 \le i \le N. \end{cases} \tag{2}$$

where, N is the total layer depth (i.e. $N = 4$ in LD configuration). In brief, the distortion propagation factor of the picture in *i-th* layer is $\Delta D_{total}/\Delta D_i$.

In Way-B, For a coding unit i (U_i) in frame (f_i of a sequence with K frames, the temporal propagation chain is constructed by identifying the affected unit U_{i+1} in f_{i+1}, U_{i+2} in f_{i+2} through its effect on U_{i+1}, and so on until the end of the sequence. The detailed derivation process is omitted here and the final distortion propagation factor κ could be calculated as

$$\kappa_i = \sum_{s=i+1}^{K} \prod_{t=i+1}^{s} \delta \cdot D_t / D_t^{MCP} \tag{3}$$

where, δ is constant, D_t is the distortion of the *t-th* coding unit and D_t^{MCP} means the motion compensation predicted (MCP) error of the affected unit U_t.

B. DISTORTION PROPAGATION MEASUREMENT

Aforementioned Way-A and Way-B are based on the assumption that the video contents are continuous so that pictures in the same layer but in different GOP could be treated equally. Thus Way-A and Way-B are not suitable for screen content video, because frame contents of SCV are discontinuous, thus different GOPs in one SCV have different characteristics. Therefore, in this paper, the distortion propagation of SCV is measured in the real encoding process, which is described as follows.

The proposed distortion propagation measurement is as shown in Algorithm 1, and corresponding notations are defined in Tab. 1. Briefly, every CTU needs to search its matching block in the current picture and subsequent pictures, the total number of found matching block is set as the distortion propagation factor. It should be noted that in this paper, the searching process of matching block utilizes the hash-based search. Because the classical motion estimation method in multiple pictures is too complex and unsuitable for LD encoding. Moreover, the accurate measurement is to searching all the rest pictures, but it is not allowed in low delay encoding process. In order to avoid bringing too much delay, jointly consider the temporal characteristic of screen content video, the searching frames number SN is set to 3 in our experiment, which could distinguish the distortion propagation from three level: little ($DPF = 0$), moderate ($DPF = 1, 2$) and sufficient ($DPF = 3, 4$).

TABLE 1. Notations used in proposed QPC algorithm.

f_i	the *i-th* frame
CTU_k	the *k-th* CTU in the current frame
H_k	the hash value of CTU_k
N_{CTU}	the total number of the CTU in one frame
DPF_k	distortion propagation factor of the *k-th* CTU
SN	searching frames number of distortion propagation measurement

Fig. 3 shows the average DPF of every frame (defined as in Eq. (4)) for sequence *Slide Editing*. We can see that the DPF_{avg} of most frames are bigger than 2, which means most CTUs have sufficient distortion propagation, this is consistent with the fact that in *Slide Editing*, contents of most CTUs will persist for a long time.

$$DPF_{avg} = \frac{1}{N_{CTU}} \sum_{i=1}^{N_{CTU}} DPF_i \tag{4}$$

C. QPC SCHEME

Based on the DPF value, we jointly consider the hierarchical prediction structure in LD configuration and propose the CTU level QPC scheme as

$$QP(i) = QP_{base} + f(TL_i, DPF_i) \tag{5}$$

where, $QP(i)$ is the assigned QP of the *i-th* frame, TL_i is the temporal layer (as depicted in Fig. 2) of the *i-th* frame, DPF_i is

Algorithm 1 Distortion Propagation Measurement for Screen Content Video

Input: f_i, CTU_k
Output: DPF_k

$j = i$;
$DPF_k = 1$;
Calculate the hash value H_k of CTU_k **while** $j \leq i + SN$ **do**
  if $j == i$ **then**
    Get the block set B_0 with the same hash value of H_k amoung the rest CTUs in f_i;
    if $B_0 \neq \varnothing$ **then**
      $DPF_k = DPF_k + 1$;
    end
    ;
  else
    Get the block set B_{H_k} with the same hash value of H_k in f_j;
    if $B_{H_k} \neq \varnothing$ **then**
      $DPF_k = DPF_k + 1$;
    end
    ;
  end
  $j = j + 1$;
end

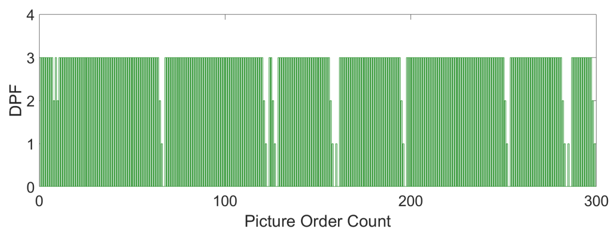


FIGURE 3. Illustration of the average ***DPF*** of every frame for ***Slide Editing***.

TABLE 2. QP offset calculation.

TL	DPF	$f(TL, DPF)$
{0,1,2,3}	0	3
{0,1,2,3}	{3, 4}	1
otherwise		$TL + (2 - DPF)$

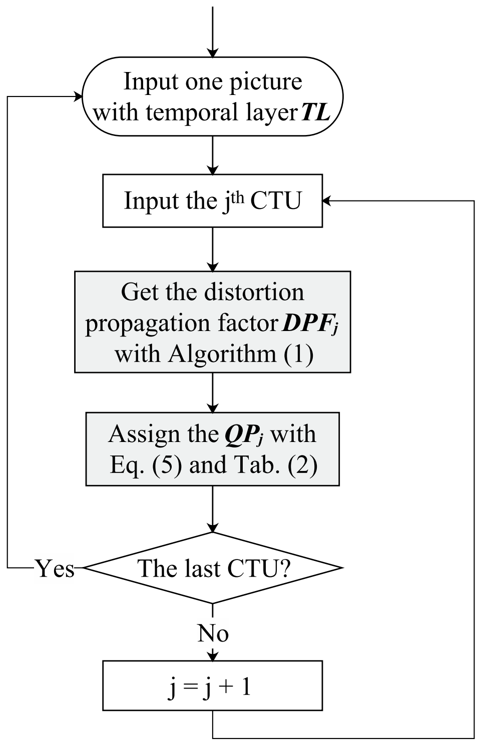


FIGURE 4. Flowchart of the proposed QP cascading method.

the DPF of the i-th frame and $f(\cdot)$ is the function to calculate QP offset.

The function $f(\cdot)$ is expressed with a look-up table as shown in Tab. 2. We can see that firstly when DPF equals to 0, no matter what TL is, $f(TL, DPF)$ will be 3. Because $DPF = 0$ means that the current block has little influence on subsequent blocks, high encoding quality of the current block has little influence on the whole video quality, but increases the bit cost, degrading the RD performance. Therefore, block whose DPF equals to 0 will be assigned the largest QP ($QP_{base} + 3$). Then, when $DPF \geq 3$, no matter what TL is, $f(TL, DPF)$ will be 3. Because $DPF \geq 3$ means that the current block will be referenced by many subsequent blocks, high encoding quality of the current block will be sufficient propagated to the whole video, increasing the RD performance. Therefore, block with $DPF \geq 3$ will be assigned the smallest QP QP_{min} ($QP_{base}+1$). Finally, in other cases, QP offset is adjusted based on the default QP offset. Concretely, if DPF equals to 2, it means the current block has influence on the current GOP, thus the QP offset will be assigned only based on the temporal layer TL. If DPF equals to 1, it means the current block has limited influence on the current GOP, thus the QP offset will be added an additional increment, as $TL + 1$.

D. SUMMARY

The proposed QP cascading method could be summarized in Fig. 4. In summary, the proposed QPC method is at the CTU level. For every CTU, firstly its distortion propagation factor (DPF) is measured based on the hash-search method as shown in Algorithm 1. Then, based on the DPF and the temporal layer TL of the current picture, the finally CTU level QP is assigned according to Eq. (5) and Tab. 2.

TABLE 3. Testing video sequences.

Resolution	Format	Sequence name	Abbreviation	Frame number
1280 × 720	YCbCr 4:2:0	SlideEditing_1280x720_30.yuv	*SE*	300
1280 × 720	YCbCr 4:4:4	sc_web_browsing_1280x720_30_8bit_300_444_r1.yuv	*WB*	300
1280 × 720	YCbCr 4:4:4	sc_video_conferencing_doc_sharing_1280x720_30_300_8bit_444.yuv	*VCDS*	300
1280 × 720	YCbCr 4:4:4	sc_wordEditing_1280x720_60_8bit_444.yuv	*WE*	600
1280 × 720	YCbCr 4:2:0	sc_map_1280x720_60_8bit_444.yuv	*MAP*	600
1920 × 1080	YCbCr 4:4:4	sc_ppt_doc_xls_1920x1080_20_8bit_200_444_r1.yuv	*PPT*	200
1920 × 1080	YCbCr 4:4:4	sc_pcb_layout_1920x1080_20_200_8bit_444.yuv	*PCB*	200
1920 × 1080	YCbCr 4:2:0	ChineseDocumentEditing_1920x1080_30_8bit_420.yuv	*CDE*	300
1920 × 1080	YCbCr 4:2:0	CircuitLayoutPresentation_1920x1080_30_8bit_420.yuv	*CLP*	300
1920 × 1080	YCbCr 4:2:0	EnglishDocumentEditing_1920x1080_30_8bit_420.yuv	*EDE*	300
1920 × 1080	YCbCr 4:2:0	ClearTypeSpreadsheet_1920x1080_30_8bit_420.yuv	*CTS*	300

III. EXPERIMENTAL RESULT

In this section, firstly the experimental design is introduced, then the coding efficiency compared, finally the complexity comparison is present.

A. EXPERIMENTAL DESIGN

To verify the effectiveness of the proposed QP setting method, we implemented it into the HEVC reference software (HM-16.10+SCM-8.0) [29]. The test platform is a PC with an eight-core Intel Core i7 @2.00GHz CPU, 8GB RAM, and x64 Windows7. Our testing materials are the recommended screen content sequences of JCT-VC proposals [30]–[32], as shown in Tab. 3. Considering the low delay requirement in screen content applications, all the testing sequences are encoded with IBBB structure, configured with encoder_lowdelay_main_scc.cfg [29].

Our proposed QPC method is compared with the default QPC method in HEVC (abbreviated as HM-QP) and AH-QP [23]. Since the source code of AH-QP has not been disclosed, we re-implemented AH-QP into HM-16.10+SCM-8.0. As HM-16.10+SCM-8.0 is the updated version of the testing reference software used in [23], the testing results of AH-QP may be different.

B. CODING EFFICIENCY COMPARISON

The coding efficiency is measured in terms of BDBR (Bjøntegaard delta bit rate) and BD-PSNR (Bj øntegaard delta peak signal-to-noise rate) [34], which represent the average bit rate reduction and PSNR increase respectively. The proposed method is compared with HM-QP and AH-QP respectively, as listed in Tab. 4. Compared with the default QPC method, the proposed method can averagely achieve 6.5% bitrate reduction and 0.85dB PSNR increase; compared with AH-QP, the proposed method can averagely achieve 1.8% bitrate reduction and 0.21dB PSNR increase. As for *CLP*, *MAP* and *WE*, AH-QP and the proposed method obtain relatively bigger BDBR compared with HM-QP, mainly due to obvious bitrate decrease for CTUs whose *DPF* are 0. As for *SE*, *CTS* and *EDE*, the proposed method achieves more than 0.1dB BD-PSNR increase compared with AH-QP, mainly due to the smallest QP assignment for CTUs with $DPF \geq 3$. As for *CDE*, *VCDS*, *PPT* and *WB*, the proposed method gets less than 0.3% BDBR reduction against AH-QP. To further analyze the coding efficiency, we take *CLP*, *SE* and *WB* as example.

TABLE 4. Coding efficiency comparison.

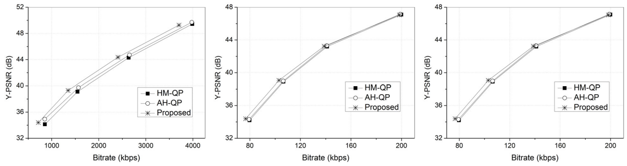
Sequence	Proposed vs HM-QP		Proposed vs AH-QP	
	BDBR	BD-PSNR	BDBR	BD-PSNR
CDE	-4.2	0.70	-0.3	0.04
CLP	-12.2	1.23	-7.5	0.73
VCDS	-6.1	0.57	-0.3	0.04
CTS	-1.5	0.07	-0.6	0.11
EDE	-4.4	0.74	-0.6	0.09
MAP	-9.1	0.92	-3.5	0.45
PPT	-1.5	0.47	-0.1	0.04
SE	-3.2	0.43	-2.3	0.30
WB	-6.2	1.16	-0.3	0.06
WE	-16.5	2.15	-2.5	0.26
Average	**-6.5**	**0.85**	**-1.8**	**0.21**

BDBR: %, BD-PSNR: dB.

For *CLP*, compared with HM-QP and AH-QP, the proposed method gets 12.2% and 7.5% BDBR decrease respectively, and the RD curve is depicted in Fig. 5(a). Obvious coding gain of the proposed method is achieved in *CLP* for two reasons, firstly there are many CTUs with sufficient distortion propagation (these CTUs remain static for successive frames), which is assigned QP_{min} in the proposed method and the coding efficiency could be improved obviously. Secondly, there are many CTUs with little distortion propagation (these CTUs only exist in one frame and disappear in the next

TABLE 5. Encoding complexity comparison.

Method \ Sequence		*CDE*	*CLP*	*VCDS*	*CTS*	*EDE*	*MAP*	*PPT*	*SE*	*WB*	*WE*	**Average**
$\Delta T(\%)$	AH-QP	-12.0	-1.7	-10.9	-3.2	-4.8	-7.7	-0.5	-11.4	-7.2	-15.3	**-7.5**
	proposed	-12.1	-4.7	-10.3	-1.6	-3.4	-9.7	+1.2	-17.2	-5.4	-14.2	**-7.7**



(a) *CLP* (b) *SE* (c) *WB*

FIGURE 5. RD curve comparison.

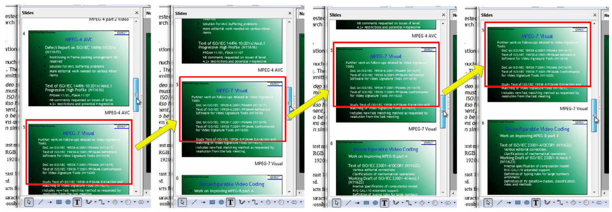

(a) f_9 (b) f_{10} (c) f_{11} (d) f_{12}

FIGURE 6. The part regions (558 × 400) of pictures f_9 to f_{12} in *SE*.

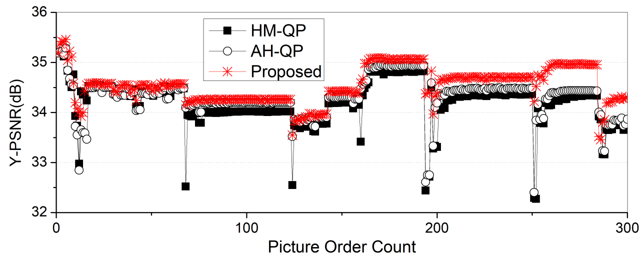


FIGURE 7. Frame PSNR distribution comparison of *SE*. The base QP is 37.

frame), which is assigned the biggest QP in the proposed method and the coding efficiency could be improved further.

For *SE*, compared with AH-QP, the proposed method can achieve 2.3% BDBR decrease, and Fig. 5(b) displays the RD curve of *SE*. *SE* has plenty of translational regions as illustrated in Fig. 6, which will be found in Algorithm 1 and assigned QP_{min} in the proposed method. While these translational regions are assigned the default hierarchical QP in AH-QP.

For *WB*, compared with AH-QP, the proposed method can only achieve 0.3% BDBR decrease, and Fig. 5(c) displays the RD curve of *WB*. Little coding gain of the proposed method against AH-QP is achieved because in *WB*, all the CTUs with sufficient distortion propagation are static regions, thus these CTUs will be assigned QP_{min} in both AH-QP and the proposed method. Simultaneously, there are few CTUs whose *DPF* equals to 0, thus in most cases, the CTU-level QP assignment in AH-QP is same with that in the proposed method, causing the similar RD performance.

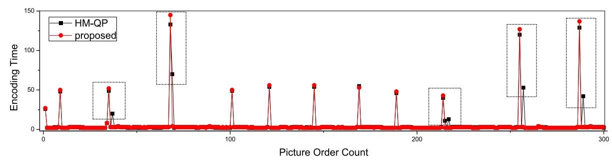
Finally, take sequence*SE* as example, the frame level quality comparison is shown in Fig. 7. We can see that Compared with other two methods, the proposed method gets the best quality almost for every frame, which verifies the effectiveness of the proposed QPC method.

C. CODING COMPLEXITY COMPARISON

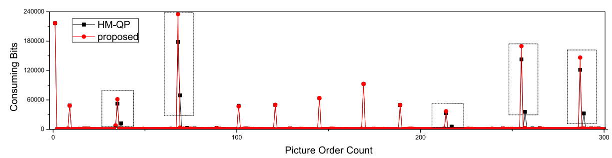
The coding complexity of two improved QPC methods is compared by using HM-QP as the anchor. And compared with HM-QP method, the encoding time increase ΔT is defined as

$$\Delta T = (T^{IQPC} - T^{HM-QP})/T^{HM-QP} \times 100\% \tag{6}$$

where, T^{IQPC} is the total encoding time of the improved QPC method to be compared, T^{HM-QP} is the total encoding time of HM-QP method.



(a) Encoding time



(b) Bit cost

FIGURE 8. Encoding time and bit cost distribution of *WB*. The base QP is 27.

The coding complexity of AH-QP and the proposed method compared with HM-QP is listed in Tab. 5. Compared with HM-QP, the encoding time of AH-QP and the proposed method averagely decreases by 7.5% and 7.7% respectively. The main reason is that the encoder with HM-QP will consume more time on quality refinement, which is circled with dashed rectangle in Fig. 8. As for the proposed method, it effectively reduce quality refinement to assign QP_{min} for regions with sufficient distortion propagation, and the proposed method could reduce quality refinement better than AH-QP because AH-QP only assign QP_{min} for static regions. Simultaneously, the proposed method assign QP_{max}

for regions with little ditortion propagation, which is not considered in AH-QP, thus the proposed method could save more coding time than AH-QP. However, as the proposed method is based on hash-search, therefore the total coding complexity of the proposed method is similar to AH-QP.

IV. CONCLUSION

In this paper, the problem of QP cascading in screen content coding is addressed. Since screen content videos have discontinuous contents, thus the distortion propagation factor of screen content video is different from the conventional camera captured video and the traditional hierarchical QPC method may degrade the coding efficiency of screen content coding. In this context, a distortion propagation based QP cascading method is proposed for screen content coding. Firstly, based on the hash-search method, the distortion propagation factor of screen content video is measured for every coding tree unit. Then, based on the distortion propagation factor and temporal layer of every coding unit, the improved QP setting method is proposed at block level. Finally, Experimental results show that the proposed QPC method outperforms other QP setting methods in terms of coding efficiency and coding complexity.

REFERENCES

[1] G. J. Sullivan, J.-R. Ohm, W.-J. Han, and T. Wiegand, "Overview of the high efficiency video coding (HEVC) standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 22, no. 12, pp. 1649–1668, Dec. 2012.

[2] T. Wiegand, G. J. Sullivan, G. Bjøntegaard, and A. Luthra, "Overview of the H.264/AVC video coding standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 13, no. 7, pp. 560–576, Jul. 2003.

[3] W.-H. Peng, F. G. Walls, R. A. Cohen, J. Xu, J. Ostermann, A. MacInnis, and T. Lin, "Overview of screen content video coding: Technologies, standards, and beyond," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 6, no. 4, pp. 393–408, Dec. 2016.

[4] D. Wu, H. Shi, H. Wang, R. Wang, and H. Fang, "A feature-based learning system for Internet of Things applications," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1928–1937, Apr. 2019.

[5] Z. Li, Y. Jiang, Y. Gao, D. Yang, and L. Sang, "On buffer-constrained throughput of a wireless-powered communication system," *IEEE J. Sel. Areas Commun.*, vol. 37, no. 2, pp. 283–297, Feb. 2019.

[6] P. Zhang, X. Kang, D. Wu, and R. Wang, "High-accuracy entity state prediction method based on deep belief network toward IoT search," *IEEE Wireless Commun. Lett.*, vol. 8, no. 2, pp. 492–495, Apr. 2019.

[7] D. Wu, Z. Zhang, S. Wu, J. Yang, and R. Wang, "Biologically inspired resource allocation for network slices in 5G-enabled Internet of Things," *IEEE Internet Things J.*, to be published, doi: 10.1109/JIOT.2018.2888543.

[8] Z. Zhang and L. Wang, "Social tie-driven content priority scheme for D2D communications," *Inf. Sci.*, vol. 480, pp. 160–173, Apr. 2019.

[9] D. Wu, B. Liu, Q. Yang, and R. Wang, "Social-aware cooperative caching mechanism in mobile social networks," *J. Netw. Comput. Appl.*, to be published, doi: 10.1016/j.jnca.2019.102457.

[10] B. Li, J. Xu, and F. Wu, "A unified framework of hash-based matching for screen content coding," in *Proc. IEEE Vis. Commun. Image Process. Conf. (VCIP)*, Dec. 2014, pp. 530–533.

[11] X. Xu, S. Liu, T.-D. Chuang, Y.-W. Huang, S.-M. Lei, K. Rapaka, C. Pang, V. Seregin, Y.-K. Wangm, and M. Karczewicz, "Intra block copy in HEVC screen content coding extensions," *IEEE J. Emerg. Sel. Topic Circuits Syst.*, vol. 6, no. 4, pp. 409–419, Dec. 2016.

[12] P. Onno, X. Xiu, Y.-W. Huang, and R. Joshi, *Suggested Combined Software and Text for Run-Based Palette Mode*, Standard JCTVC-R0348, ISO/IEC, ITU-T, Sapporo, Japan, 2014.

[13] W. Zhu, W. Ding, J. Xu, Y. Shi, and B. Yin, "Hash-based block matching for screen content coding," *IEEE Trans. Multimed.*, vol. 17, no. 7, pp. 935–944, Jul. 2015.

[14] C.-C. Chen and W.-H. Peng, "Intra line copy for HEVC screen content intra-picture prediction," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 27, no. 7, pp. 1568–1579, Jul. 2017.

[15] L. Zhao, K. Zhou, J. Guo, S. Wang, and T. Lin, "A universal string matching approach to screen content coding," *IEEE Trans. Multimedia*, vol. 20, no. 4, pp. 796–809, Apr. 2018.

[16] H. Schwarz, D. Marpe, and T. Wiegand, "Analysis of hierarchical B pictures and MCTF," in *Proc. IEEE Int. Conf. Multimedia Expo (ICME)*, Jul. 2006, pp. 1929–1932.

[17] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the scalable video coding extension of the H.264/AVC standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 17, no. 9, pp. 1103–1120, Sep. 2007.

[18] K. McCann, B. Bross, W. J. Han, I. K. Kim, K. Sugimoto, and G. J. Sullivan, *High Efficiency Video Coding (HEVC) Test Model 16 (HM 16) Encoder Description*, Standard ISO/IEC, JCTVC-R1002, ITU-T, Sapporo, Japan, 2014.

[19] W. Wan, Y. Chen, Y.-K. Wang, M. M. Hannuksela, H. Li, and M. Gabbouj, "Efficient hierarchical inter picture coding for H.264/AVC baseline profile," in *Proc. Picture Coding Symp. (PCS)*, May 2009, pp. 1–4.

[20] X. Li, P. Amon, A. Hutter, and A. Kaup, "Model based analysis for quantization parameter cascading in hierarchical video coding," in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Nov. 2009, pp. 3765–3768.

[21] X. Li, P. Amon, A. Hutter, and A. Kaup, "Adaptive quantization parameter cascading for hierarchical video coding," in *Proc. IEEE Int. Symp. Circuits Syst. (ISCAS)*, May/Jun. 2010, pp. 4197–4200.

[22] J. Fan, S. Wang, S. Wang, R. Xiong, and S. Ma, "Inter-frame correlation based quantization parameter offset optimization for screen content video coding," in *Proc. IEEE Int. Conf. Multimedia Big Data (ICMBD)*, Apr. 2015, pp. 420–423.

[23] J. Li, B. Li, J. Xu, and R. Xiong, "An adaptive hierarchical QP setting for screen content coding," in *Proc. IEEE Vis. Commun. Image Process. (VCIP)*, Dec. 2015, pp. 1–4.

[24] T. Tang, L. Li, and D. Wang, "A robust hierarchical QP setting for screen content coding," in *Proc. IEEE Int. Conf. Acoust., Speech Signal Process. (ICASSP)*, Apr. 2018, pp. 1777–1781.

[25] T. Zhao, Z. Wang, and C. W. Chen, "Adaptive quantization parameter cascading in HEVC hierarchical coding," *IEEE Trans. Image Process.*, vol. 25, no. 7, pp. 2997–3009, Jul. 2016.

[26] T. Yang, C. Zhu, X. Fan, and Q. Peng, "Source distortion temporal propagation model for motion compensated video coding optimization," in *Proc. IEEE Int. Conf. Multimedia Expo (ICME)*, Jul. 2012, pp. 85–90.

[27] D. Wu, Q. Liu, H. Wang, Q. Yang, and R. Wang, "Cache less for more: Exploiting cooperative video caching and delivery in D2D communications," *IEEE Trans. Multimedia*, vol. 21, no. 7, pp. 1788–1798, Jul. 2019.

[28] Z. Zhang, T. Zeng, X. Yu, and S. Sun, "Social-aware D2D pairing for cooperative video transmission using matching theory," *Mobile Netw. Appl.*, vol. 23, no. 3, pp. 639–649, Feb. 2018.

[29] *HEVC Reference Software Tags (Revision 4998)*. Accessed: Jul. 18, 2016. [Online]. Available: https://hevc.hhi.fraunhofer.de/trac/hevc/browser#tags

[30] C. Rosewarne, K. Sharman, and D. Flynn, *Common Test Conditions and Software Reference Configurations for HEVC Range Extensions*, Standard JCTVC-P1006, ISO/IEC, ITU-T, San Jose, CA, USA, 2014.

[31] H. Yu, R. Cohen, K. Rapaka, and J. Xu, *Common Test Conditions for Screen Content Coding*, Standard JCTVC-X1015, ISO/IEC, ITU-T, Geneva, Switzerland, 2016.

[32] V. Baroncini, H. Yu, and R. Joshi, *Draft of Final Report on SCC Verification Test*, Standard JCTVC-AA0040, ISO/IEC, ITU-T, Hobart, TAS, Australia, 2017.

[33] Y. Gong, S. Wan, K. Yang, H. R. Wu, and Y. Liu, "Temporal-layer-motivated lambda domain picture level rate control for random-access configuration in H.265/HEVC," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 29, no. 1, pp. 156–170, Jan. 2019.

[34] G. Bjøntegaard, *Calculation of Average PSNR Differences Between RD-Curves*, document VCEG-M33, ITU-T SG-16, Video Coding Experts Group (VCEG), 2001.

[35] T. Tang, L. Li, and J. Li, "Improved hierarchical quantisation parameter setting method for screen content coding in high efficiency video coding," *IET Image Process.*, vol. 13, no. 8, pp. 1382–1390, Jun. 2019.

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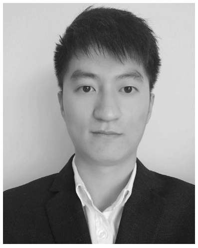

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