IEICE TRANS. INF. & SYST., VOL.E101–D, NO.1 JANUARY 2018

PAPER Special Section on Enriched Multimedia — Potential and Possibility of Multimedia Contents for the Future —

Scalable Distributed Video Coding for Wireless Video Sensor Networks

Hong YANG[†,††a)], *Nonmember*, Linbo QING[†b)], *Member*, Xiaohai HE[†c)], *and* Shuhua XIONG[†d)], *Nonmembers*

SUMMARY Wireless video sensor networks address problems, such as low power consumption of sensor nodes, low computing capacity of nodes, and unstable channel bandwidth. To transmit video of distributed video coding in wireless video sensor networks, we propose an efficient scalable distributed video coding scheme. In this scheme, the scalable Wyner-Ziv frame is based on transmission of different wavelet information, while the Key frame is based on transmission of different residual information. A successive refinement of side information for the Wyner-Ziv and Key frames are proposed in this scheme. Test results show that both the Wyner-Ziv and Key frames have four layers in quality and bit-rate scalable, but no increase in complexity of the encoder.
key words: *distributed video coding, scalable video coding, wireless video sensor network, wavelet transform, Slepian-Wolf coding*

1. Introduction

Wireless Sensor Networks (WSNs) consist of sensor nodes, base stations and task management nodes [1]. When video sensors are introduced in such systems, new applications/systems will emerge that distributed video sensors/cameras capture video sequences [2]. In response to this demand, research on Wireless Video Sensor Networks (WVSNs) [3] and Wireless Multimedia Sensor Networks (WMSNs) [4] have emerged, which include the network dynamics, low sensor node consumption and limited computing/storage capacity. These features require low complexity video encoders in the nodes. The Distributed Video Coding (DVC) [3], based on the distributed source coding theory, moves the complicated motion estimation and other computation to the decoder side, which is suitable to the application. In recent years, some scholars have conducted considerable research on WVSNs-applied DVC systems. Xiao [5] conducted research on the generation of information under the DVC in the WMSN. Li [6] designed a new efficiency encoder of the DVC in the WVSN. Nikzad [7] tested the performance of the DVC in the WMSN, and analyzed the video quality. Moreover, for the dynamic bandwidth of wireless networks, scalable coding is the best solution [8], which is an adaptation for network and terminal capabilities [9]. Traditional video coding has a scalable coding standard, such as Scalable Video Coding (SVC) [10] and Scalblility extension of High Efficiency Video Coding (SHVC) [11], based on the motion estimation in the layers which increase the complexity of the encoder. SVC has the following basic coding framework: the encoder makes use of the bit stream layers formed by scalable coding, usually including one Base Layer (BL), and one or several Enhancement Layers (ELs); and the decoder provides basic graphic quality with the BL, and provides higher quality with the ELs [9], [11]. Lv [12] proposed a scalable model by combining H.264/ DVC. Van [13] proposed a low encode complexity distributed video coding for HEVC backward compatible scalability. Nakachi et al. [14] designed the layered lossless video coding based on distributed source coding theorem. Although these ideas make use of the advantageous DVC to the traditional SVC, which reduces the complexity, but cannot meet the actual demand of low energy consumption and low complexity for the WVSN. Some researchers study the scalable DVC as a standalone system. Tanaka [15] designed the transform and quantization units for scalable DVC, but did not mention the scalability of Key Frames (KFs) in DVC. Fan [17] proposed scalable DVC by compressed sensing in the wavelet domain, but increased storage of the encoder and the results did not show the scalable feature.

In view of the above analyses, we propose Scalable Distributed Video Coding (SDVC), which is different from the traditional scalable video coding [9]–[11], [18], because the proposed SDVC does not execute the inter-layer prediction, has low encode complexity, and is different from the existing SDVC [15], [17] because the proposed SDVC achieves both the scalability of Wyner-Ziv Frames (WZFs) and the scalability of KFs. The proposed SDVC is more applicable to WVSNs, as shown in the Fig. 1, which consists of encoders, a distribution server with video storage, and end users that receive the video data. Users can watch the video at any time and in any place by accessing the server over the networks. NOTE: we need the low complexity video encoders for WVSNs, the video node need not communicate in the encoder side, and video signals are independent and can be encoded by the DVC system. We focused on the scalable distributed video coding for a single node in this paper, and the Fig. 1 shows multi-view video nodes for the extension example in WVSNs.

Manuscript received April 5, 2017.
Manuscript revised August 17, 2017.
Manuscript publicized October 16, 2017.
[†]The authors are with College of Electronics and Information Engineering, Sichuan University, Chengdu, Sichuan, China.
[††]The author is with Chengdu College of University of Electronic Science and Technology of China, Chengdu, Sichuan, China.
a) E-mail: perky_alan@hotmail.com
b) E-mail: qing_lb@scu.edu.cn (Corresponding author)
c) E-mail: hxh@scu.edu.cn
d) E-mail: xiongsh@scu.edu.cn
DOI: 10.1587/transinf.2017MUP0006

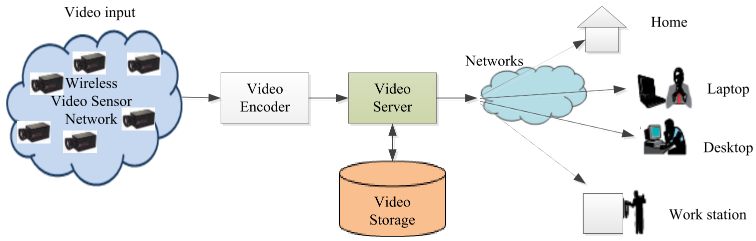


Fig. 1 A typical scalable distributed video coding for wireless video sensor networks

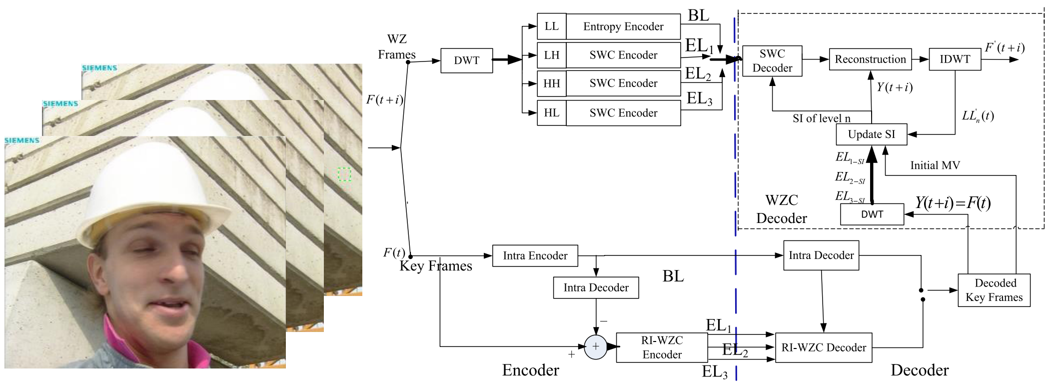


Fig. 2 Proposed scalable distributed video coding framework

The remainder of this paper is organized as follows. Section 2 describes the proposed SDVC scheme in detail; experimental results and the corresponding analyses are given in Sect. 3; and Sect. 4 concludes the paper.

2. The Proposed SDVC Framework

2.1 Architecture of SDVC

The proposed SDVC scheme is shown in Fig. 2. The KFs first obtained the BL by traditional intra-codec (H.264 or HEVC), and obtained the residuals between the current frame and its reconstructed frame, to construct EL_1, EL_2, and EL_3. The WZFs obtained different bit rates due to different sub-band combinations on different layers after wavelet transformation to construct the BL, and three ELs (EL_1, EL_2, EL_3). All the ELs in the SDVC are encoded by the Low Density Parity Check (LDPC) codec, which is proved to be better channel codec in packet lossy network for DVC than LDPC accumulated (LDPCA) code [19].

2.2 The Scalable Idea of WZFs

To make video quality and transmission bit rate scalable, this paper applied discrete wavelet transformation (DWT) of a high compression rate to the DVC system [20]. In this SDVC scheme, WZ video coding, which exploits DWT and Slepian-Wolf Coding (SWC) [3], is the key part. The Fig. 2 illustrates the scalable WZFs. For WZFs, $F(t+i)$, ($i \in [1, \cdots, GOP-1]$), after being processed by DWT, and set the BL is obtained from $LL_3(t+i)$, EL_1 is from $LH_k(t+i)$, EL_2 is from $HH_k(t+i)$, $k \in \{1, 2, 3\}$ and EL_3 is from $HL_k(t+i)$. The $LL_3(t+i)$ is encoded by arithmetic coding and sent to the decoder as the BL of WZFs. While other parameters are encoded by SWC and only the parity bits are transmitted to the decoder, EL_1, EL_2, and EL_3 are obtained.

At the decoder, the quality of side information play an important role in the compreesion and transmission of DVC system. In this work, the decoded KFs $F(t)$ is taken as the side information, $Y(t+i)$. With the help of decompressed $LL_3(t+i)$ and Side Information (SI), $Y(t+i)$, we can obtain the side information of EL_1, EL_2, and EL_3 (expressed as EL_{1_SI}, EL_{2_SI} and EL_{3_SI} in Fig. 2). Then, we can update the side information successively by proposed Successive Refinement of SI, which will be presented in detail in Sect. 2.4. Then, the main information of ELs are decoded with the help of EL_{1_SI}, EL_{2_SI} and EL_{3_SI}, and the received parity bits. Next, EL_1, EL_2 and EL_3, and $Y(t+i)$ are used to recover the reconstruction frame $F(t+i)$.

2.3 The Scalable Idea of KFs

One of the most important factors of a DVC is the transmission of KFs because the decoded adjacent KFs are used to generate SI for the Wyner-Ziv Coding (WZC) decoder. The scalable KFs in the proposed SDVC is shown in Fig. 3, in which the BL makes use of the conventional intra codec, and the ELs can be obtained by the WZC encoder based on Residual Information (RI) of the current frame, $F(t)$, and its reconstructed frame, $F'(t)$. The RI of different layers is obtained as follows:

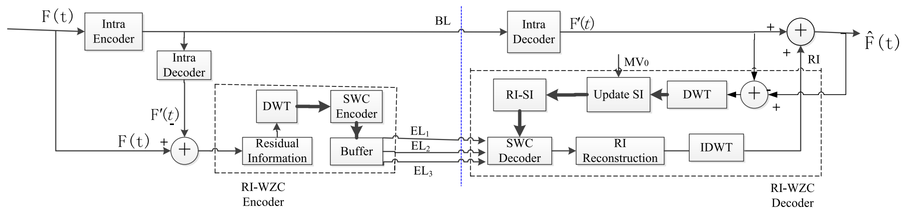


Fig. 3 The proposed scalability of KFs

$$RI(k) = DWT\{F(t)\}\big|_{EL_k} - DWT\{F'(t)\}\big|_{EL_k}, \quad k \in (1, 2, 3) \tag{1}$$

The $RI(k)$ encoded by the SWC, and the parity check bits of different layers are transmitted.

At the decoder, when the KFs are enhanced by the Els (that is the update SI worked in the Fig. 3), there must be enough channel bandwidth. So that the previous frame $F(t-1)$ of the current Key frame $F(t)$ is decoded by its $BL(t-1) + \sum EL_k(t-1), k \in \{1, 2, 3\}$. At this moment, the decoder of Key frame estimate the initial motion vector (MV_0) by motion extrapolation between $LL_3(t)$ and $LL_3(t-1)$, or could be simply set to zero. Thus the decoder knows a low-resolution version $\hat{F}_1(t)$ of the current frame based on decoded $BL(t) + EL_1(t)$, and get a refined estimation of the motion field by using $\hat{F}_1(t)$ and $F(t-1)$. Then the deocder could do the motion compensated prediction (MCP) for the next higher ELs image $\hat{F}_k(t)$ based on multi-resolution motion refinement (MRMR) algorithm [16]. And then reconstructs the RI-SI of different layers, as follows:

$$RI\_SI(k) = DWT\{\hat{F}(t)\}\big|_{EL_k} - DWT\{F'(t)\}\big|_{EL_k} \tag{2}$$

Finally, all bands on all layers of the frames $F'(t)$ are refined to conduct invert DWT and the enhanced decoded current frames $F(t)$ are obtained as follows:

$$\hat{F}(t) = IDWT\left\{RI(k) + DWT\{F'(t)\}\big|_{EL_k}\right\}, \ k \in \{1, 2, 3\} \tag{3}$$

2.4 Successive Refinement of SI

In the decode side, the successive refinement of the SI based on different layers are received in the proposed SDVC, as shown in Fig. 4.

The theory of Slepian-Wolf shows that the precondition to reconstruct the current WZFs is that the bit rate must satisfy the following:

$$R \geq H(BL, EL_1, EL_2, EL_3 \mid Y) \tag{4}$$

Due to the concept of entropy, we derive the following:

$$\begin{aligned} R \geq\ & H(BL \mid Y) + H(EL_1 \mid BL, Y) \\ & + H(EL_2 \mid BL, EL_1, Y) \\ & + H(EL_3 \mid BL, EL_1, EL_2, Y) \end{aligned} \tag{5}$$

and

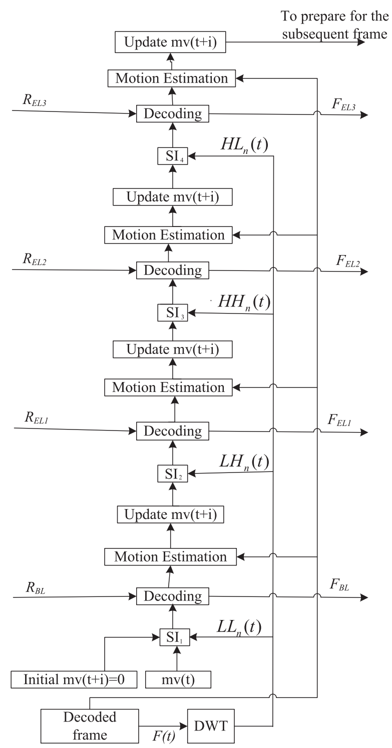


Fig. 4 Successive refinement of SI

$$\begin{cases} R_{BL} \geq H(BL \mid Y) \\ R_{EL_1} \geq H(EL_1 \mid BL, Y) \\ R_{EL_2} \geq H(EL_2 \mid BL, EL_1, Y) \\ R_{EL_3} \geq H(EL_3 \mid BL, EL_1, EL_2, Y) \end{cases} \tag{6}$$

Apparently if all four layers are received, the quality of the reconstruction is the best.

In this work, we focused on the scalability of distributed video coding, and assumed the channel conditions is known in the WVSN. If the channel bandwidth is enough, we can do continuous optimization of rate distortion on the level of acceptable distortions ($D_{BL} \geq D_{EL_1} \geq D_{EL_2} \geq D_{EL_3}$); and have the following:

$$\begin{cases} R_{BL} = R_F(D_{BL}) \\ R_{BL} + R_{EL_1} = R_F(D_{EL_1}) \\ R_{BL} + R_{EL_1} + R_{EL_2} = R_F(D_{EL_2}) \\ R_{BL} + R_{EL_1} + R_{EL_2} + R_{EL_3} = R_F(D_{EL_3}) \end{cases} \tag{7}$$

which means that the more layers the decoder receives, the better the quality.

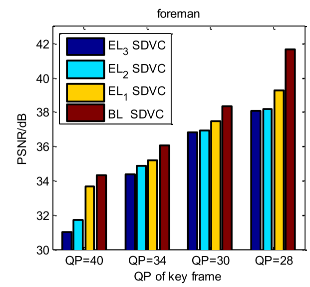
The specific successive refinement of SI and the decoding procedures are as follows:

Step 1: The channel bandwidth only suit the transmission of the BL. Set the initial motion vector $mv(t+i)$ as 0 for the current decoded frame, $F(t+i)$ first, and due to the correlation of the neighbor frames, the motion vector of the previous frame, $mv(t)$, is taken as a reference. The decoded previous frame, $F(t)$, helps estimate the side information, SI_1, of the current frame. Then, we use SI_1 and the received bits of the BL to conduct channel decoding, and reconstruct the frame, F_{BL}, corresponding to BL. When the channel bandwidth is low, the SDVC system will take the current, F_{BL}, as the decoding frame, which has poor quality compared with the original WZFs, but subjectively acceptable.
Step 2: If the channel bandwidth is higher, the decoder can receive the first EL (EL_1), and the decoder makes use of the previous decoded BL frame as a lower-resolution data, F_{BL}, to refine the motion field by performing multi-resolution motion refinement (MRMR). The details are: After the BL $LL_3(t)$ is decoded, the motion vector $mv(t)$ is refined by motion estimation between $LL_3(t+i)$ and $LL_3(t)$. Then, Predict $LH'_k(t+i)$, $k \in \{1,2,3\}$ by copying the corresponding motion compensated coefficients in $LH_k(t)$, $k \in \{1,2,3\}$. And the refined $mv'(t)$ is used to generate the SI for the high-frequency subbands $LH_k(t+i)$, $k \in \{1,2,3\}$ with higher quality. That is the decoder be able to learn from the already-decoded lower-resolution data to refine the motion estimation (ME), which in turn greatly improves the SI quality as well as the coding efficiency for the higher resolution data, and obtain an updated motion vector, $mv(t+i) = mv'(t)$ [16]. We have the updated side information, SI_2, for the current frame, and obtain a reconstructed better quality frame, F_{EL_1}.
Step 3: If the channel bandwidth is enough, and EL_2 or EL_3 is received, the similar decoding process as step 2 will be employed to obtain a reconstructed frame, F_{EL_2} or F_{EL_3}, with higher quality.

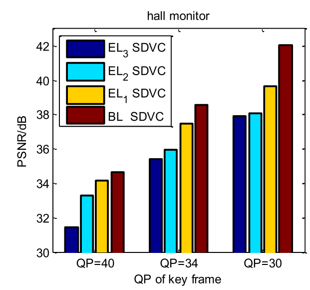
3. Experiment and Analysis of the Proposed SDVC

3.1 Experimental Conditions Setting

In order to validate the effectiveness of the proposed SDVC scheme, the HEVC testing model HM16.5, was adopted for the simulation bench. There are 5 quantization matrices (QPs) for WZFs in the SDVC encoder {5, 10, 15, 20, 25}, which make use of the QPs introduced in [16]; and {28, 30, 34, 40} for KFs. The GOP is set as 8. To verify the feasibility and validity of the SDVC system proposed in this paper, two standard test video sequences ('foreman' and 'hall monitor') of different motion characters were employed. We tested the first 100 frames of the video sequence, which is in cif (352*288) format. During those tests, the frame rates were 30 Hz. The quality of the SI, which is generated by the adjacent KFs, affects the performance of the whole DVC system, so we tested the scalable performance of the KFs and compared with SHVC [11] first. Second, we tested the scalability of WZFs, which was compared with [17], and conducted experimental analysis of the quality scalability when the decoder received the BL or other ELs. Finally, we tested the subjective visual performance of the KFs and the WZFs as the number of layers received increases.



(a) The 'foreman' sequence



(b) The 'hall monitor' sequence

Fig. 5 The SI quality of the KFs

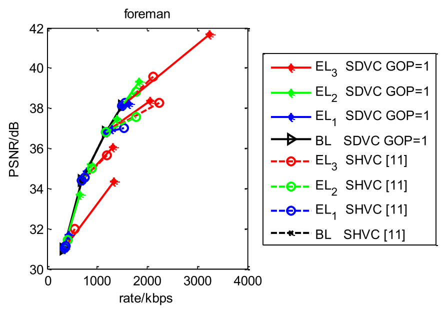
3.2 Scalability Performance of SI in KFs

3.2.1 Successive Refinement of SI in KFs

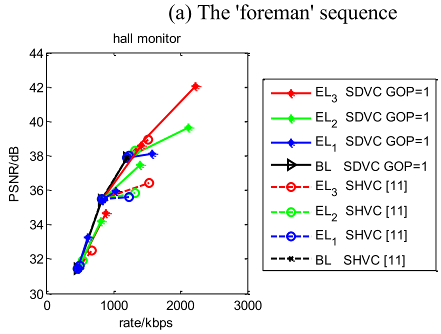
When the RI-WZC decoder receives more and more layers, the proposed SI successive refinement scheme has better correlation between videos, and the quality of RI-SI is better. The reconstructed quality of the KFs (PSNR) improved as more layers were received, as shown in Fig. 5, in which the QP of RI in the RI-WZC set at 5 and 10, and the QP of the KFs set at 28, 30, 34, and 40. The PSNR of EL_1 compared with BL improved about 2dB in the 'hall monitor' when the QP was 40 and 0.3dB when the QP was 30. The quality of BL is sufficient when the QP is 30, and the promotion of EL_1 is not apparent.

3.2.2 Scalability of the KFs

As the quality of SI in the KFs are successively refined, the RD of the KFs in the SDVC is shown in Fig. 6, and compared with the SHVC [11]. The encodings of SHVC were operated according to the Scalable HEVC (SHVC) Test Model 6 (SHM 6.0) standard. When set the same QP, the RDs of the BL in the SDVC and SHVC are the same. The PSNR improved more as the more ELs were received, both in the SDVC and the SHVC. The scalable performance of the SDVC was superior to the SHVC in some sequences, such as the 'hall monitor', and in some QP values of other test sequences, such as in the 'foreman' when 1000 kbps



(a) The 'foreman' sequence



(b) The 'hall monitor' sequence

Fig. 6 KFs scalability

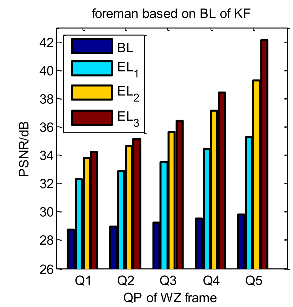
and in the ‘hall monitor’ when 780 kbps. For some QP, the SHVC scheme outperforms the SDVC scheme at bit rates because it conducts the prediction between different layers. When the channel bandwidth is favorable, the SDVC system can obtain a favorable decoding effect of KFs. The result in Fig. 6 shows the KFs of SDVC with RI achieves some improvement compared to SHVC. This improvement benefits from the fact that the RI exploits the similarity between the BL and ELs.

3.2.3 Successive Refinement of SI in the WZFs

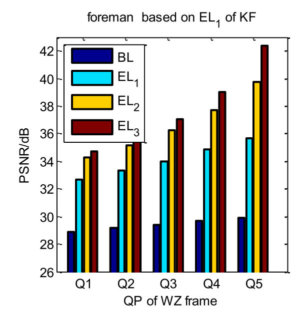
Due to the SI successive refinement scheme, the WZC decoder receives one or more layers, and the quality of the SI increases, to obtain a higher quality decoded video. The results of layered SI are shown in Fig. 7, in which the different QP set as follows: Q1 = 25, Q2 = 20, Q3 = 15, Q4 = 10, and Q5 = 5 in the WZC encoder. The Fig. 7 (a) shows the PSNR of four layers in ‘foreman’ WZFs when the KFs only receives the BL, and Fig. 7 (c) for ‘hall monitor’; Fig. 7 (b) shows when the EL_1 is received, and Fig. 7 (d) for ‘hall monitor’. Comparing Fig. 7 (a) with (b), the WZFs quality increased as the KFs quality improved, such as 0.5dB increase in the EL_1 at Q1, and the same results when compare Fig. 7 (c) with (d), which illustrates the impact of SI quality in the SDVC scheme. The PSNR of EL_1 compared with BL improved about 2.5-4dB in the ‘foreman’ and ‘hall monitor’. The experiment shows that the proposed scalability of WZFs based on different DWT layers in this paper are valid.

3.2.4 Scalability of the WZFs

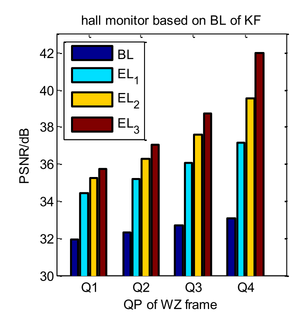
The Fig. 8 shows the RD of the scalability of WZFs based



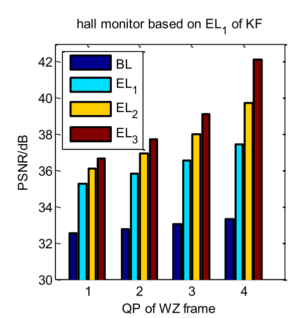
(a)BL-KFs based 'foreman' sequence



(b)EL_1-KFs based 'foreman' sequence



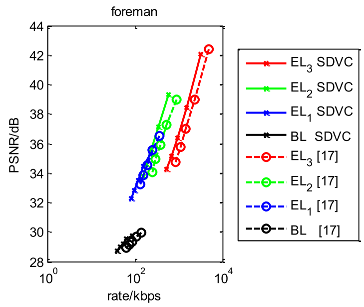
(c)BL-KFs based 'hall monitor' sequence



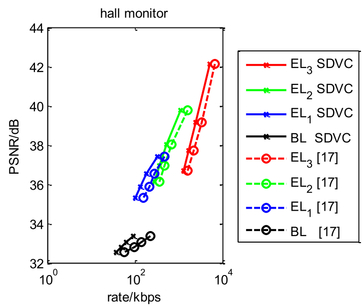
(d)EL_1-KFs based 'hall monitor' sequence

Fig. 7 SI quality of scalable WZFs

on the BL of KFs, in which the rate in the proposed SDVC scheme is slightly lower than the scheme of the level-based [17]. The logarithmic abscissa in Fig. 8 shows the gap between the test results more clearly. Taking the ‘foreman’ sequence as an example, the delta rate of EL_3 is up to 1000 kbps when the QP is 5 and 200 kbps when QP is 25. The delta rate of the ‘hall monitor’ is higher than the ‘foreman’. The proposed SDVC scheme is an equal division



(a) The 'foreman' sequence



(b)The 'hall monitor' sequence

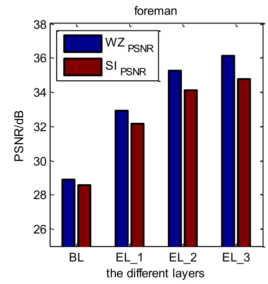
Fig. 8 Comparing the two scalability schemes of WZFs in SDVC

model for the Els, in which the size of different Els are the same, such as the EL_1 is composed by $LH_k(t+i)$, EL_2 is composed by $HH_k(t+i)$ and EL_3 is composed by $HL_k(t+i)$, $k \in \{1, 2, 3\}$ [20]. Thus, the more SI is upgraded in the EL_1 of the proposed scheme, less bit rate is used in the next ELs. The level-based scheme [17] is not an equal division, such as the EL_3 is $LH_1(t+i)$, $HH_1(t+i)$, and $HL_1(t+i)$, which are the maximum size in DWT. Thus, it uses more rates in the level-based scheme. The PSNR of the proposed SDVC scheme is enhanced higher than the scheme of the level-based [17], such as the delta of PSNR is 2dB when the rate is 3500 kbps in the 'foreman' sequence.

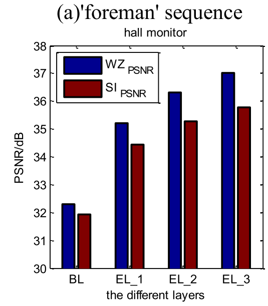
3.3 Subjective Quality of the Proposed SDVC System

In order to show that the subjective quality of SDVC increases with the more layers received, Fig. 10 demonstrates the decoding quality of the 23rd frame of the 'foreman' sequence when different layers are received. Fig. 10 (a) represents the subjective quality when the BL is received only, in which the image of eyes, eyebrows and other parts are very vague; Fig. 10 (b) represents the quality when EL_1 is received, in which the image quality better than Fig. 10 (a) when received the BL only; Fig. 10 (c) represents quality when EL_2 is received; and Fig. 10 (d) represents the effect when all layers are received, in which the highlight in the eye and the texture of the eyebrows are more obvious. The decoded quality of the WZFs and the KFs based on different layers are acceptable and the subjective quality is incremental with the PSNR value.

Figure 11 demonstrates the reconstructed quality of the 70th frame of the 'hall monitor' sequence. Compare Fig. 11 (a) with Fig. 11 (b), the texture of the right leg is dif-

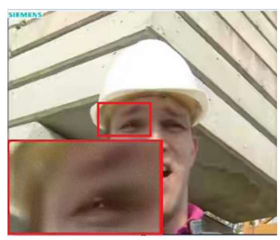


(a)'foreman' sequence

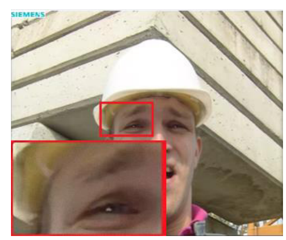


(b)'hall monitor' sequence

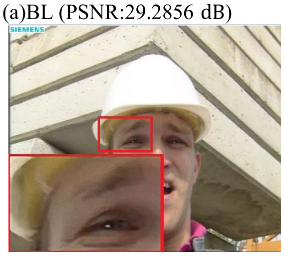
Fig. 9 Comparison quality of SI and WZFs



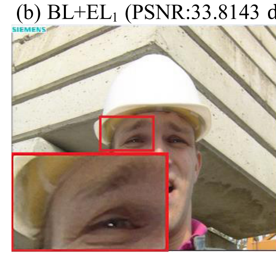
(a)BL (PSNR:29.2856 dB)



(b) BL+EL_1 (PSNR:33.8143 dB)



(c) BL+EL_1+EL_2 (PSNR:36.8086 dB)



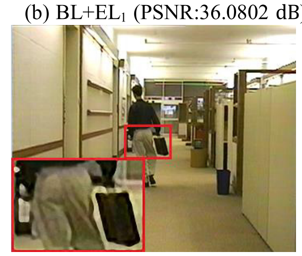
(d) all layers (PSNR:38.2218 dB)

Fig. 10 Reconstructed the 23rd frame of 'foreman' sequence

(a)BL (PSNR:32.6820 dB)

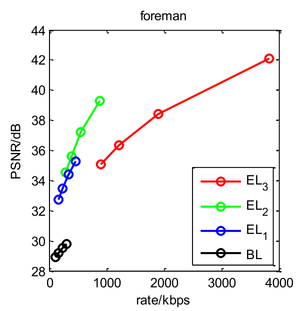
(b) BL+EL_1 (PSNR:36.0802 dB)

(c) BL+EL_1+EL_2 (PSNR:37.6081 dB)

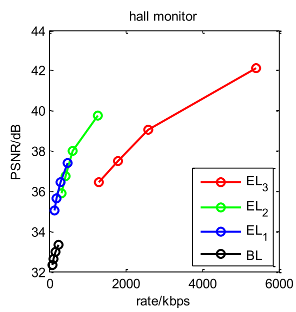


(d) all layers (PSNR:38.7313 dB)

Fig. 11 Reconstructed the 70th frame of 'hall monitor' sequence



(a) The 'foreman' sequence



(b) The 'hall monitor' sequence

Fig. 12 The scalability of overall SDVC

ference; the texture of the left leg is more and more obvious from Fig. 11 (b) to Fig. 11 (d). The vertical line on the left baffle is also becoming more and more apparent.

3.4 The Overall Scalability of the Proposed SDVC

In order to show the overall performance of SDVC, we tested the mean PSNR and rate between the WZFs and the KFs. The overall RD of the standard test video is shown in Fig. 12, which illustrates the scalability of the proposed SDVC and indicates the same theoretical analysis. The more layers the decoder receives (the more bit rates), the better quality will be (the higher PSNR).

4. Conclusion

This paper presented a framework of scalable video communications based on DVC in WVSNs scenarios. The peculiarities of the proposed scalable distributed video coding paradigm have been introduced to smooth transmission, such as the type of compressed data over the bandwidth instability channel. A scalable KFs scheme and a scalable WZFs scheme are proposed for different channel bandwidths. The results shown that all these new proposals significantly contribute to the performance of SDVC in a practical scenario.

The proposed techniques are an effective first step in the direction of a practical system for a high performance error resilient DVC transmission over an instability network and a significant step in developing low complexity and high error-resilient video transmission for the WVSN. Future studies concerning the rate estimation based on region of interest which influence the compression and performance, and concerning rate control for the feedback-free coding scenario will result in less transmission latency. Furthermore, the transmission of multi-view DVC over the WVSN could be further studied.

Acknowledgments

This project was supported by the Fundamental Research Funds for the Central Universities (No.2015SCU04A11), the National Natural Science Foundation of China Grant (No.61471248) and the Education research project of Sichuan (No. 2014-Edu-034).

References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: a survey,” Computer Networks, vol.38, no.4, pp.393–422, 2002.
[2] C.-C. Chiu, S.-Y. Chien, C.-H. Lee, V.S. Somayazulu, and Y.-K. Chen, “Distributed video coding: A promising solution for distributed wireless video sensors or not?,” Visual Communications and Image Processing (VCIP) IEEE, pp.1–4. 2011.
[3] R. Puri, A. Majumdar, P. Ishwar, and K. Ramchandran, “Distributed video coding in wireless sensor networks,” IEEE Signal Process. Mag., vol.23, no.4, pp.94–106, 2006.
[4] M. Jacobs, N. Deligiannis, F. Verbist, J. Slowack, J. Barbarien, and d. W.R. Van, “Demo: Distributed video coding applications in wireless multimedia sensor networks,” ACM/IEEE International Conference on Distributed Smart Cameras 2011, vol.47, pp.1–2, 2011.
[5] F. Xiao, J. Liu, L. Sun, and R. Wang, “A new side information estimate based distributed video coding algorithm for wireless multimedia sensor networks,” International Journal of Advancements in Computing Technology, vol.4, no.1, pp.320–326, 2012.
[6] L. Li, K.R. Vijayanagar, K. Choi, J. Kim, and T.H. Han, “Energy efficient encoder design of distributed video coding for wireless video sensor network,” Information Japan, vol.16, no.7, pp.5059–5071. 2013.
[7] M. Nikzad, A. Bohlooli, and K. Jamshidi, “Video quality analysis of distributed video coding in wireless multimedia sensor networks,” International Journal of Information Technology & Computer Science, vol.7, no.1, pp.12–20, 2014.
[8] 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, 2007.
[9] J.-R. Ohm, “Advances in Scalable Video Coding,” Proc. IEEE, vol.93, no.1, pp.42–56, 2005.
[10] S. Hwang, H.R. Guo, W. Hsieh, et al., “Performance Analysis of SVC,” IEEE Trans. Circuits Syst. Video Technol., vol.17, no.9, pp.1194–1203, 2007.
[11] J.M. Boyce, Y. Ye, J. Chen, et al., “Overview of SHVC: Scalable Extensions of the High Efficiency Video Coding (HEVC) Standard,” IEEE Trans. Circuits Syst. Video Technol., vol.26, no.1, pp.20–34, 2016.
[12] R. Lv, L. Qing, Y. Yu, X. He, and Q. Zeng, “Scalable combined h.264/distributed video coding,” Compel International Journal of Computations & Mathematics in Electrical, vol.29, no.2, pp.388–404, 2010.
[13] X.H. Van, J. Ascenso, and F. Pereira, “Hevc backward compatible scalability: a low encoding complexity distributed video coding based approach,” Signal Processing Image Communication, vol.33, pp.51–70, 2015.
[14] T. Nakachi and T. Fujii, “Layered Lossless Video Coding based on Distributed Source Coding Theorem,” IEICE Tech. Rep., vol.115,

no.75, SIS2015-13, pp.69–74, June 2015.

[15] N. Tanaka, M. Okada, K. Sakomizu, and T. Onoye, "Vlsi design of transform and quantization units in scalable distributed video coding," IEICE Tech. Rep., vol.113, no.78, SIS2013-8, pp.39–44, June 2013.

[16] W. Liu, L. Dong, and W. Zeng, "Motion refinement based progressive side-information estimation for wyner-ziv video coding," IEEE Trans. Circuits Syst. Video Technol., vol.20, no.12, pp.1863–1875. 2010.

[17] N. Fan, X. Zhu, Y. Liu, et al., "Scalable Distributed Video Coding Using Compressed Sensing in Wavelet Domain," IEEE Vehicular Technology Conference, pp.1–5, 2013.

[18] H. Sun, A. Vetro, and J. Xin, "An overview of scalable video streaming[J]," Wireless Communications & Mobile Computing, vol.7, no.2, pp.159–172, 2007.

[19] L. Qing, E. Masala, and X. He, "Practical distributed video coding in packet lossy channels," Optical Engineering, vol.52, no.7, p.071506, 2013.

[20] G. Minami, Z. Xiong, A. Wang, and S. Mehrotra, "3-D wavelet coding of video with arbitrary regions of support," IEEE Trans. Circuits Syst. Video Technol., vol.11, no.9, pp.1063–1068, 2001.

Hong Yang received the B.S. degree in Southwest University of Science and Technology and M.S. degree in University of Electronic Science and Technology of China, Sichuan, China, in 2005 and 2008, respectively. She is currently a Ph.D. candidate in the Electronics Information Science and Technology from Sichuan University. Her main research interests include image and video coding technologies and video transmitted from wireless networks.

Linbo Qing received the Ph.D degree in communication and information system in 2008 from the Sichuan University, Chengdu, China. From Feb. to Aug. 2011, he was a visiting researcher at the Agder Mobility Laboratory, University of Agder, Norway where he worked on data aggregation and security in mobile communications. From Sep. 2011 to Feb. 2012, he was a visiting researcher at the Internet Media Group, Politecnico di Torino, Turin, Italy, where he worked on distributed video coding and transmission. Dr. Qing is currently an associate professor in the College of Electronics and Information Engineering at the Sichuan University. Dr. Qing co-authored over 30 scientific publications in image processing related topics. Dr. Qing is a IEEE member. His main research interests include image processing, video coding & transmission, and information theory.

Xiaohai He received his Ph.D. degree in Biomedical Engineering in 2002 from the Sichuan University, Chengdu, China. He is a professor in College of Electronics and Information Engineering at the Sichuan University. Dr. He is an Editor of both the Journal of Information and Electronic Engineering and the Journal of Data Acquisition & Processing. Dr. He is a IEEE member and a senior member of the Chinese Institute of Electronics. His research interests include image processing, pattern recognition, and image communication. He is the corresponding author and can be contacted at: xhx@scu.edu.cn.

Shuhua Xiong received her Ph.D. degree in 2007 from Sichuan University, China. She is an associate professor in college of Electronics and Information Engineering at Sichuan University. Her research interests include multimedia communication, signal and image processing.