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Efficient Distributed Video Coding System without Feedback Channel

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ABSTRACT

In distributed video coding (DVC) systems, the complexity of encoders is greatly reduced by removing the motion estimation operations in encoders, since the correlation between frames is utilized in decoders. The transmission of parity bits is requested through the feedback channel, until the related errors are corrected to decode the Wyner-Ziv frames. The requirement to use the feedback channel limits the application of DVC systems. In this paper, we propose an efficient method to remove the feedback channel in DVC systems. First, a simple side information generation method is proposed to calculate the amount of parity bits in the encoder, and it is shown that the proposed method yields good performance with low complexity. Then, by calibrating the theoretical entropy with three parameters, we can calculate the amount of parity bits in the encoder and remove the feedback channel. Moreover, an adaptive method to determine quantization parameters for key frames is proposed. Extensive computer simulations show that the proposed method yields better performance than conventional methods.

Key Words : Distributed video coding system, feedback channel, Wyner-Ziv frame, quantization parameter.

Ⅰ. INTRODUCTION

Video data is usually compressed using video coding standards, such as MPEG or H.264. In these video coding standards, spatial redundancy is removed by transforming the video data into the discrete cosine transform (DCT) domain, and temporal correlation is utilized by adopting motion compensated prediction methods. Since motion compensated prediction requires many operations, conventional video encoders are more complex than decoders. A distributed video coding (DVC) technique, which is based on the Slepian-Wolf and Wyner-Ziv theorems, has been proposed[1,2]. Slepian and Wolf proved that the minimum rate to encode two correlated sources independently is theoretically the same as the minimum rate for joint encoding[1]. Wyner and Ziv extended the Slepian-Wolf theorem to the lossy source coding case, in which quantization is used to compress the data[2]. In DVC systems, the input frames are divided into key frames and Wyner-Ziv frames. While key frames are encoded using intraframe coding techniques, Wyner-Ziv frames are encoded with channel encoders, such as turbo codes or LDPC codes, and only parity bits are transmitted for Wyner-Ziv frames. In the decoder, the side information, which is an estimate of the original Wyner-Ziv frame, is usually obtained by motion compensated interpolation of key frames. Wyner-Ziv frames can be decoded with this side information and transmitted parity bits, since the

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side information can be considered to be a noisy version of the original Wyner-Ziv frame. In this DVC system, the complexity of encoders is greatly reduced by removing motion estimation operations in the encoder, since the correlation between frames is utilized in decoders[3,4].

In the DVC systems, the feedback channel is usually used, since the amount of parity bits is not known at the encoder. The transmission of parity bits is requested through the feedback channel, until related errors are corrected to decode Wyner-Ziv frames. However, in real time applications, feedback channels can't be used due to the time delay they incur. To eliminate the feedback channel, the amount of parity bits should be calculated in the encoder. Brites et al. proposed a simple side information generation technique and encoder rate control method by using the entropy and relative error probabilities[5]. Sheng et al. also proposed an encoder rate control method based on a curve fitting method[6]. However, the coding performance for systems without feedback channels degrades due to the mismatch between the estimated and real bit rates.

In this paper, we propose an efficient DVC system without a feedback channel. To calculate the theoretical entropy in the encoder, we propose a simple side information generation method, which is based on the hexagon-based motion vector search algorithm for core blocks, and show that the proposed method yields good performance with relatively low complexity. The amount of parity bits is calculated by calibrating the theoretical entropy with three parameters, including the relative error probability, to compensate for the mismatch between the theoretical entropy and the actual amount of

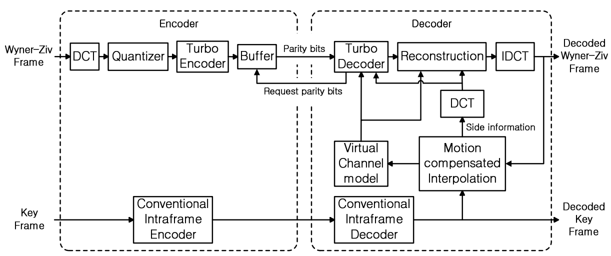

Fig. 1. DVC system

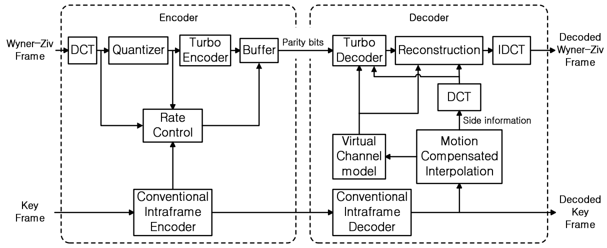

Fig. 2. DVC system without a feedback channel

required parity bits. Moreover, an adaptive estimation method for the quantization parameters to encode key frames is also proposed. The method enables the adaptive quality control of key frames to produce a similar quality for key frames to that of Wyner-Ziv frames. Extensive simulations show that the proposed parity rate estimation method and key frame coding method produce better performance than conventional methods.

In Section 2, the DVC system is explained. An efficient method of generating side information in the encoder to remove feedback channels is proposed in Section 3. The proposed parity bit rate estimation method and the adaptive quality control of key frames are explained in Section 4 and 5, respectively. Performance is evaluated in Section 6. Finally, Conclusions are given in Section 7.

Ⅱ. DVC SYSTEM

The transform domain DVC system is depicted in Fig. 1[4]. There are two kinds of frames, known as the key frames and Wyner-Ziv frames. Since the key frames are coded using an intraframe coding technique such as the H.264 intraframe coding method. While the Wyner-Ziv frames are coded using a channel encoder, such as the turbo or LDPC encoder, the motion estimation operation is not performed in the encoder. The Wyner-Ziv frames are transformed into the DCT domain to increase the coding efficiency and the channel encoder generates parity bits for each bitplane of the DCT coefficients. In the decoder, the side information is generated using motion compensated interpolation of key frames. Since the side information can be considered as a noisy version of Wyner-Ziv frames, the Wyner-Ziv frames are decoded using parity bits and side information.

If the decoder fails to correct errors in the side information, additional parity bits are required through a feedback channel. Thus, in order to remove the feedback channel, the amount of parity bits for each bitplane should be calculated in the encoder. However, the generation of side information and calculation of noise correlation in the encoder are required to calculate the entropy, which is used to obtain the amount of parity bits. Fig. 2 shows the DVC system structure without a feedback channel. The feedback channel is removed by calculating the amount of parity bits in the encoder.

Ⅲ. EFFICIENT SIDE INFORMATION GENERATION METHOD

The side information should be generated in the encoder to calculate the amount of parity bits. However, it is difficult to use the same complex side information generation method as that used in the decoder, since the low encoder complexity of the DVC system is very important. Thus, we propose a relatively simple side information generation method with good performance.

Brites et al. proposed a simple side information generation method [5], in which only a quarter of all blocks with larger SAD (Sum of Absolute Difference) values is selected after calculating SAD values for two 8×8 blocks in the same location, and the motion vectors of the selected blocks are estimated using the groups depicted in Fig. 3. First, the SAD values of five points including (0,0), which are termed as the first group, are calculated. If the SAD value of the (0,0) point is a minimum, the motion estimation process is terminated. Otherwise, the SAD values of the second group are calculated and compared with those of the first group. If the minimum SAD value is in the first group, the motion estimation process is terminated and the minimum point is selected to calculate the final motion vector. Finally, if the minimum SAD value is in the second group, the SAD values of the third group, which is near the point with the minimum SAD value in the second group, are calculated and compared with those of the second group. For other blocks which have lower SAD, the motion vector is set to be zero. This method is effective for videos with small motions, since the maximum estimation

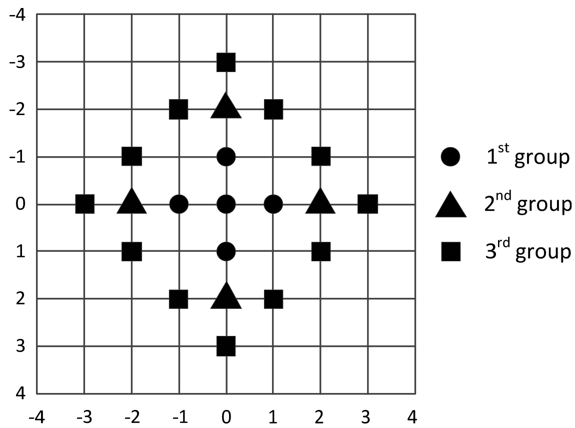

Fig. 3. Three groups for the conventional simple side information generation method (8×8 block)

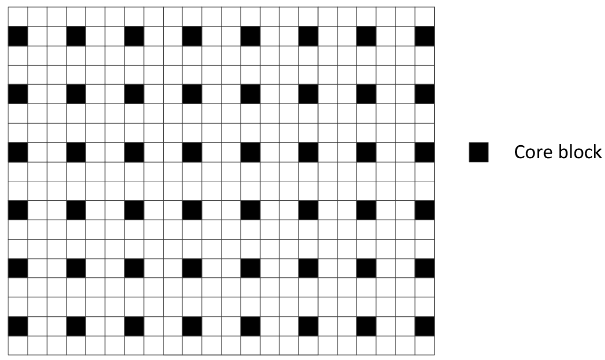

Fig. 4. Locations of core blocks in the proposed simple side information generation method (QCIF video sequence with 8×8 block)

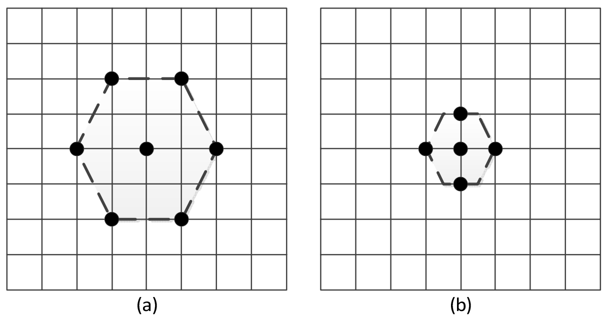

Fig. 5. Hexagon-based search method (a) Seven points, for which the SAD values are calculated (b) Five points, among which the point with the minimum SAD values are selected

range is ±4 and motion estimation is performed only for some of blocks. However, it may not work well for the videos with large motions.

We propose an efficient side information generation method which works well for the video with large motions. To reduce complexity, the motion vectors are calculated only for core blocks and the hexagon-based search algorithm proposed in [7] is used for the motion estimation of core blocks. Fig 4 shows the location of selected core blocks for the motion estimation of QCIF video sequences using 8×8 blocks. The SAD values are calculated for 7 points including the center point in Fig. 5(a). If the center point of the hexagon does not have the minimum value, the calculation is performed again by shifting the center to the point with the minimum value. The process is repeated until the center has the minimum SAD. The point, which has the minimum SAD among the additional 4 points, as shown in Fig. 5(b), is chosen. For the other blocks, the motion vectors of the nearest core blocks are used after calibrating them by Weighted Median Vector Filters (WMVF) [8]. As shown in Section 6, the proposed method requires less computation and works better for video sequences with large motions than conventional methods.

Ⅳ. CALCULATION OF THE AMOUNT OF PARITY BITS IN THE ENCODER

To obtain the amount of parity bits in the encoder, the entropy should be calculated by using [5]

$$H(p_n) = p_n \times \log_2(\frac{1}{p_n}) + (1-p_n) \times \log_2(\frac{1}{1-p_n}), \quad (1)$$

where p_n denotes the conditional probability for the jth bitplane of the nth DCT coefficient and can be calculated by using

$$p_n = \frac{p(B^j(X_n^{DCT}) = 1 | B^{j-1}(X_n^{DCT}), Y^{DCT})}{p(B^{j-1}(X_n^{DCT}) | Y^{DCT})}. \quad (2)$$

B^j denotes the jth bitplane, and X represents the original Wyner-Ziv frame, while Y denotes the generated side information. That is, X_n^{DCT} is the nth DCT coefficient of the Wyner-Ziv frame and Y^{DCT} is the side information in the DCT domain. The conditional entropy in (1) is the minimum transmission rate for each bitplane and the theoretical average bit rate can be calculated by using

$$R_{theory} = H_{X/Y}^{B_j} \approx \frac{1}{N}\sum_{n=1}^{N} H(p_n). \quad (3)$$

The bit rate in (3) is theoretically calculated and we should compensate for it to get the actual bit rate. Sheng et al. proposed the following equation

$$R_{real} = a \times R_{theory} + b, \quad (4)$$

where R_{real} means the actual parity bit rate and R_{theory} is the theoretical minimum parity rate calculated in (3). Also, the values of a and b are calculated as 1.1 and 0.01, respectively [6]. Brites et al. calculated the actual parity bit rates using the following equation [5]

$$R_{real} = \frac{1}{2} \times R_{theory} \times e^{R_{theory}} + \sqrt{0.5} \times \sqrt{P}, \quad (5)$$

where P is the relative error probability, which represents the probability of the bits which are classified as error bits in the current bitplane and no error bit in the previous bitplane. This correction factor is used, since more parity bits are needed to compensate for the mismatch generated in the calculation of the integral value of probability. We propose the following parity rate estimation equation

$$R_{real} = a \times (R_{theory} + P) + b, \quad (6)$$

in which the parity rate is estimated more accurately by compensating for the theoretical entropy with the relative error probability and calibrating it with two parameters, a and b. Fig. 6 and 7, in which the actual and estimated parity rates are compared, show the accuracy of the proposed method, if the parameters, a and b, are set to be 1.5 and 0.02, respectively.

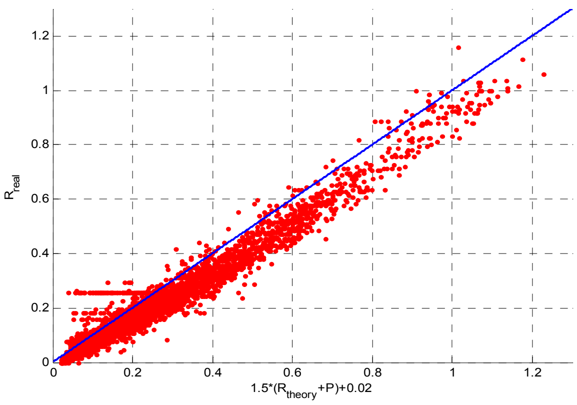

Fig. 6. Comparing the parity bit rates calculated in the proposed method with the actual bit rates (Foreman, 7th quantization table is used to encode Wyner-Ziv frames)

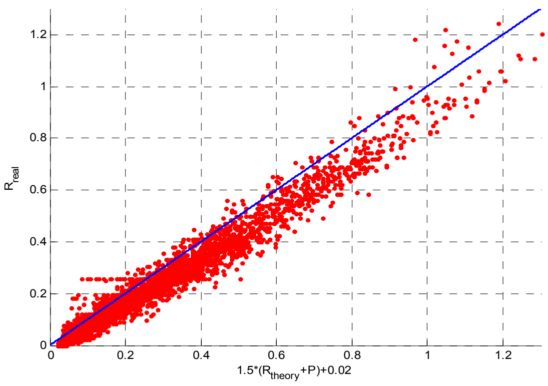

Fig. 7. Comparing the parity bit rates calculated in the proposed method with the actual bit rates (Coastguard, 7th quantization table is used to encode Wyner-Ziv frames)

V. PROPOSED KEY FRAME CODING METHOD

In the conventional DVC systems, the quantization parameters of key frames, which are encoded using H.264 intraframe coding method, are fixed, once they are determined as a function of quantization parameters of Wyner-Ziv frames for each video sequence, as is shown in Table 1 and Fig. 8[9]. However, the quality of reconstructed key frames is different from that of Wyner-Ziv frames, if we use this kind of fixed quantization parameters for key frames.

We propose an adaptive method to determine the quantization parameters for key frames to produce a similar quality for key frames to that of Wyner-Ziv frames. We already proposed the concept of an adaptive method in [10] and we improve the method by using the Laplacian distribution in the encoder. The adaptation method is depicted in Fig. 9, where the quantization parameter is updated by using the MSE estimator of Wyner-Ziv frames and an intra quantization parameter estimator. It was shown that the step size of the H.264 quantizer becomes double when the quantization parameter increases by 6 [11]. The relation between the quantization parameter and quantization step size is as follows

$$Q_{step} = 2^{(QP-4)/6}, \tag{7}$$

where QP is the quantization parameter and Q_{step} is the quantization step size. The relation between the MSE and the quantization step size can be simplified by the following relation [12]

$$MSE = \rho Q_{step}. \tag{8}$$

Using (7) and (8), we can get the following relationship between the MSE and the quantization parameter

$$MSE = \rho \cdot 2^{(QP-4)/6}. \tag{9}$$

By using (9), we can estimate the quantization parameters of key frames. Since the quality of the

Table 1. Conventional quantization parameters for key frames

Wyner-Ziv frame quantization table / Video sequence (QCIF)	0	1	2	3	4	5	6	7
Coastguard	38	37	37	34	33	31	30	26
Foreman	40	39	38	34	34	32	29	25
Hall monitor	37	36	36	33	33	31	29	24
Stefan	44	43	41	36	36	34	31	25

16	8	0	0
8	0	0	0
0	0	0	0
0	0	0	0

0

32	8	0	0
8	0	0	0
0	0	0	0
0	0	0	0

1

32	8	4	0
8	4	0	0
4	0	0	0
0	0	0	0

2

32	16	8	4
16	8	4	0
8	4	0	0
4	0	0	0

3

32	16	8	4
16	8	4	4
8	4	4	0
4	4	0	0

4

64	16	8	8
16	8	8	4
8	8	4	4
8	4	4	0

5

64	32	16	8
32	16	8	4
16	8	4	4
8	4	4	0

6

128	64	32	16
64	32	16	8
32	16	8	4
16	8	4	0

7

Fig. 8. Quantization tables for Wyner-Ziv frames

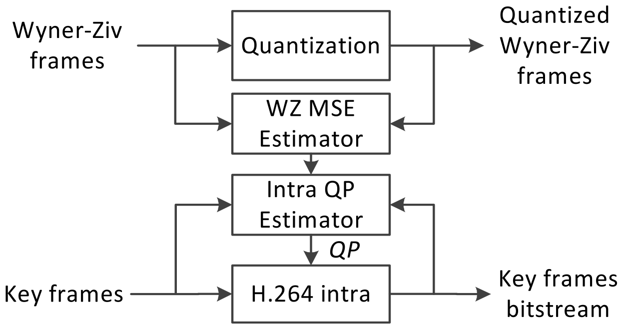

Fig. 9. Proposed estimation method of key frame quantization parameters in the encoder

key frame greatly affects the generation of side information which is used for the reconstruction of Wyner-Ziv frames, we get the integer quantization parameters of key frames by truncating the real number *QP* calculated in (9), which produces a similar MSE to the value calculated in the WZ MSE estimator. Since ρ in (9) depends on each input video sequence, it should be calculated for each video sequence to find out the quantization parameters of the key frame adaptively. We calculate the estimated value for the current frame using previous frames by the following equation

$$\rho_{est} = \frac{1}{N} \sum_{i=1}^{N} \frac{MSE_i}{2^{(QP_i - 4)/6}}, \tag{10}$$

where ρ_{est} is the estimated value for the current key frame. MSE_i and QP_i are actual MSE for the previous ith key frame and quantization parameter, respectively. That is, ρ_{est} is the estimated value for the current key frame using N previous key frames. By using ρest calculated in (10) for the value of ρ in (9) and the MSE calculated in the WZ MSE estimator, the value of *QP* in (9) can be calculated and the quality of the reconstructed key frame becomes similar to that of Wyner-Ziv frame. In the method proposed previously by the authors, the performance degrades and the quality of reconstructed key frames in the decoder is different from that of decoded Wyner-Ziv frames, since the Laplacian probability distribution is not used for noise modeling in the encoder [10]. However, in this paper we solved this problem by using the Laplacian probability distribution, which can be calculated using the estimated side information in the encoder.

Table 2. The average number of SAD function calls per frame to generate side information in the encoder (using the proposed key frame coding method)

Wyner-Ziv frame Quantization table / Video sequence (QCIF)		0	1	2	3	4	5	6	7
Coastguard	Conventional [5]	995.89	953.47	950.37	944.62	944.14	938.61	935.70	929.17
	Proposed	633.74	592.11	582.10	563.89	562.36	539.36	524.43	501.30
	Gain (%)	36.364	37.899	38.75	40.305	40.437	42.536	43.953	46.049
Foreman	Conventional [5]	1308.72	1278.67	1276.92	1278.20	1275.70	1272.08	1270.75	1268.89
	Proposed	640.46	608.14	600.57	585.26	585.31	577.40	565.17	553.38
	Gain (%)	51.062	52.44	52.967	54.212	54.119	54.61	55.525	56.389
Hall monitor	Conventional [5]	1080.77	963.93	965.56	954.23	952.94	935.87	932.63	935.10
	Proposed	551.87	487.03	489.81	483.66	483.52	459.18	456.34	444.69
	Gain (%)	48.937	49.475	49.272	49.314	49.26	50.935	51.07	52.445
Stefan	Conventional [5]	1143.49	1145.90	1146.27	1141.31	1142.96	1145.80	1146.94	1145.84
	Proposed	609.98	599.08	594.73	578.53	579.84	575.45	576.45	572.14
	Gain (%)	46.656	47.72	48.116	49.31	49.269	49.777	49.74	50.068

Table 3. Average PSNR calculated between the original Wyner-Ziv frame and side information generated in the encoder (using the proposed key frame coding method)

Video sequence (QCIF) \ Wyner-Ziv frame Quantization table		0	1	2	3	4	5	6	7
Coastguard	Conventional [5]	26.685	28.447	28.8	29.351	29.384	30.209	30.501	31.023
	Proposed	27.039	29.439	30.031	30.833	30.895	32.28	32.877	33.682
Foreman	Conventional [5]	26.123	27.709	27.984	28.551	28.586	29.156	29.418	29.973
	Proposed	26.628	28.895	29.329	30.391	30.416	31.549	32.168	33.347
Hall monitor	Conventional [5]	27.098	32.722	32.707	33.511	33.55	36.081	36.615	38.054
	Proposed	26.989	32.709	32.704	33.483	33.524	36.42	36.996	38.607
Stefan	Conventional [5]	21.599	21.994	22.066	22.45	22.557	22.787	22.914	23.13
	Proposed	23.517	24.344	24.524	25.641	25.852	26.383	26.814	27.397

Table 4. Average key frame quantization parameters estimated in the proposed method

Video sequence (QCIF) \ Wyner-Ziv frame Quantization table	0	1	2	3	4	5	6	7
Coastguard	40.90	36.32	35.39	33.61	33.53	30.33	28.68	24.51
Foreman	42.36	38.05	37.10	34.36	34.19	31.48	29.11	24.38
Hall monitor	43.32	35.35	35.40	34.07	34.02	39.62	28.47	24.17
Stefan	42.12	40.54	39.98	37.00	36.6	34.74	32.68	28.42

Ⅵ. PERFORMANCE EVALUATION

The performance of the proposed DVC system was evaluated using the test video sequences of Coastguard 300 frames, Foreman 400 frames, Hall monitor 300 frames and Stefan 100 frames in the QCIF format. The frame rates are 25 Hz for the Coastguard and Stefan video sequences, and 30 Hz for the Foreman and Hall monitor video sequences. Side information is generated in the decoder by using the following motion compensated interpolation method. First, the forward motion estimation method is used to obtain the initial motion vector and the motion vector is calculated precisely by using the bilateral motion compensated interpolation method. Then, the motion vector is corrected by weighted median vector filters. The block size is set to 16×16 for the forward motion estimation method and the search range is 48×48. The block size for bilateral motion estimation and weighted median vector filters is 8×8. Also, the motion vector for the motion compensated interpolation is obtained after filtering the key frames with a low-pass filter to reduce the influence of noise. A uniform quantizer and a quantizer with a dead-zone are used to quantize the DC and AC values of the DCT coefficients, respectively. In the decoder, the side information is used as the initial value of the reconstructed Wyner-Ziv frames. That is, if no parity bit is transmitted, the initial reconstructed Wyner-Ziv frame is set to be the side information. As the parity bits are transmitted, the reconstructed Wyner-Ziv frames are refined using the dequantization process.

As is proposed in Section 3, the side information in the encoder is estimated to calculate the amount of parity bits and the range of motion estimation for core blocks in the hexagon-based search algorithm is 40×40. The motion vectors of the other blocks are set to be equal to those of the nearest core blocks and are calibrated using weighted median vector filters. In the encoder, the correlated noise is approximately modeled by the Laplacian distribution using the estimated side information in the encoder.

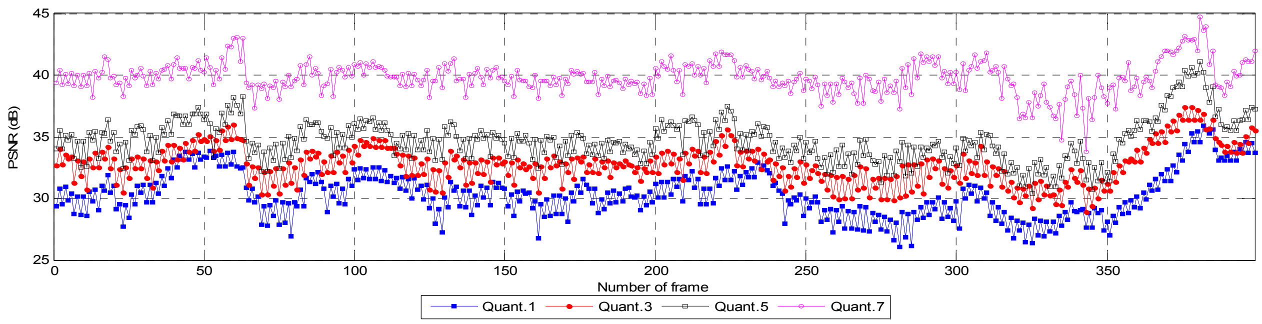

Fig. 10. PSNR for each frame (Foreman, using the proposed key frame coding method)

Table 5. Average PSNR for Wyner-Ziv and key frames (using the proposed key frame coding method)

Wyner-Ziv frame Quantization table / Video sequence (QCIF)		0	1	2	3	4	5	6	7
Coastguard	KEY	27.05	29.80	30.41	31.59	31.65	33.93	35.19	38.64
	WZ	28.01	30.61	31.16	32.40	32.47	34.46	35.71	38.85
Foreman	KEY	27.11	29.81	30.41	32.20	32.31	34.23	35.91	39.55
	WZ	28.51	30.87	31.41	33.30	33.46	35.16	36.75	40.08
Hall monitor	KEY	26.61	32.57	32.55	33.55	33.59	37.00	37.87	40.92
	WZ	27.92	33.38	33.41	34.57	34.63	37.57	38.55	41.39
Stefan	KEY	24.29	25.52	25.95	28.30	28.63	30.27	32.08	35.99
	WZ	24.96	26.02	26.47	28.95	29.29	30.88	32.66	36.46

Turbo code is used as channel codes to correct the difference between the side information and the original Wyner-Ziv frame. It shows performance close to Shannon limit and has flexible parity bit control scheme[14]. The correlated noise model used in the turbo decoder is modeled by the Laplacian distribution using the side information generated in the decoder.

To analyze the complexity and the performance of the proposed side information estimation method in the encoder, we calculated the average number of SAD function calls to generate the side information and the average PSNR performance between the estimated side information and the original Wyner-Ziv frame. As can be seen in Table 2, the average number of SAD calculations for the proposed method is about half of that for the conventional method[5]. In Table 3, it is shown that the proposed method shows the superior PSNR performance compared to the conventional methods for almost all video sequences. For the Hall monitor sequence without fast motions, the proposed method shows similar performance to that for the conventional method.

In the proposed DVC system, the quantization parameter of key frames is adaptively controlled using (9) and (10), where N is set to be 2, and the first and second key frames are quantized using the parameter in Table 1. Table 4 shows the average key frame parameters and Fig. 10 shows PSNR results for each quantization table of Wyner-Ziv frames of Foreman sequence, where the odd and even frames are the key frames and Wyner-Ziv frames, respectively. The PSNR results for key frames adaptively follows those for Wyner-Ziv frames even for frames with large changes, such as 60th and 300th frames. In Table 5, the average PSNR results of Wyner-Ziv frames and key frames are shown. As can be seen in Fig. 10 and Table 5, the PSNRs for Wyner-Ziv frames are slightly different from those for key frames, since the side information generated using the simple method in the encoder is different from that in the decoder and the correlated noise modeling, which is based on the side information generation method, may not be correct. However, the quantization parameter of key frames is adaptively found in the proposed method, while it is fixed and should be calculated separately in the conventional method.

To analyze performance of the DVC system, in which the feedback channel is removed using the proposed parity bit estimation method, the rate distortion performance for the proposed method is depicted in Figs. 11-14 with the results for two conventional methods[5,6]. The results for the system with feedback channel and H.264 intraframe coding results for both key and Wyner-Ziv frames are given for comparison. In all three parity rate estimation cases, the average bit rates and PSNRs for both key and Wyner-Ziv frames are calculated by using the same proposed side information generation method in the encoder and adaptive quantization parameter determination method for key frames.

Thus, the results only compare the performance for three parity rate estimation methods. The conventional rate estimation methods by Sheng et al. and Brites et al. are denoted as conventional 1 and 2[5-6], respectively. As can be seen in the results, the proposed parity rate estimation method shows PSNR improvement of 0.6~0.8dB at high bit rates for the Coastguard sequence and 0.2~1dB for the Foreman sequence than the conventional methods. The proposed method shows about 0.8dB PSNR improvement for the Hall monitor sequence compared to the conventional method 1, and 0.5dB PSNR improvement for the Stefan sequence compared to the conventional method 2.

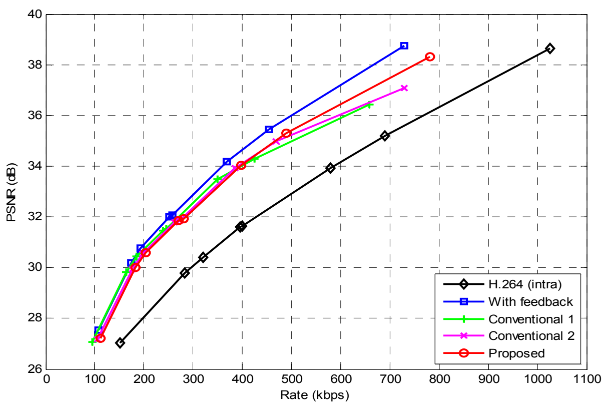

Fig. 11. Performance comparison for each parity rate estimation method (Coastguard, Only parity rate estimation methods are compared by using the same proposed side information generation and key frame encoding method in all three encoder rate control methods)

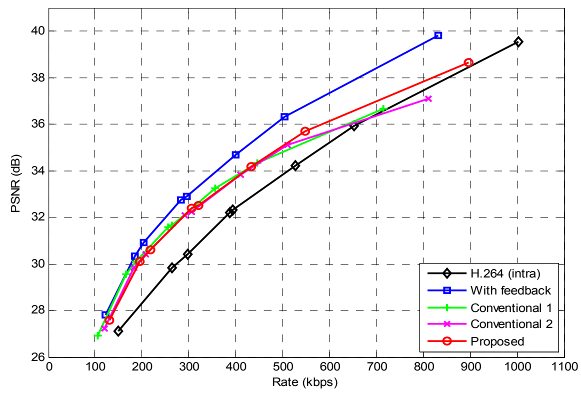

Fig. 12. Performance comparison for each parity rate estimation method (Foreman, Only parity rate estimation methods are compared by using the same proposed side information generation and key frame encoding method in all three encoder rate control methods)

Ⅶ. CONCLUSIONS

In this paper, an efficient method to remove the feedback channel in the DVC system was proposed. First, the side information generation method using hexagon-based motion vector search for core blocks was proposed and it was shown that the proposed method yields good performance with relatively low complexity. Then, the amount of parity bits was estimated in the encoder by using three parameters which compensate for the theoretical entropy to obtain the amount of parity bits required to correct side information. Extensive computer simulations showed that the proposed parity rate estimation method works better than the conventional methods. The adaptive calculation method of quantization parameters for key frames was also proposed. It was shown that the proposed method provides the adaptive quality control of key frames. Thus, we think that the proposed DVC system without feedback channel can be effectively used for the real time application.

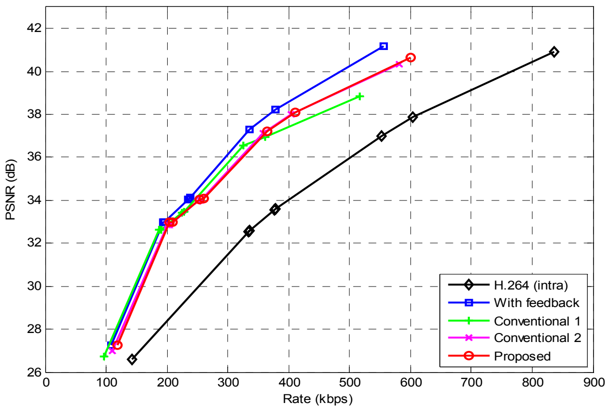

Fig. 13. Performance comparison for each parity rate estimation method (Hall monitor, Only parity rate estimation methods are compared by using the same proposed side information generation and key frame encoding method in all three encoder rate control methods)

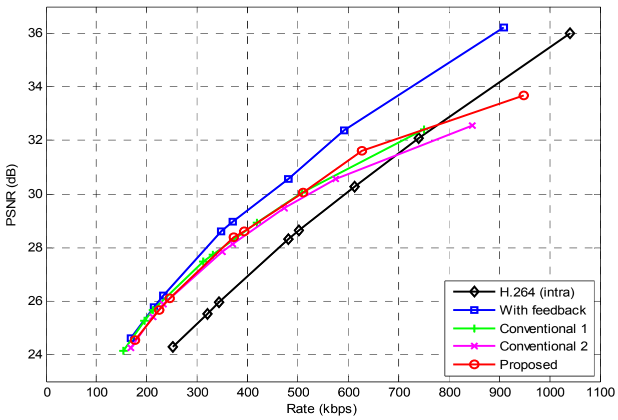

Fig. 14. Performance comparison for each parity rate estimation method (Stefan, Only parity rate estimation methods are compared by using the same proposed side information generation and key frame encoding method in all three encoder rate control methods)

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