Channel Reliability Dependent Wyner-Ziv Video Coding using Rate Adaptive LDPC code with Degree-1 Syndrome

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***Abstract*— In distributed video coding (DVC), channel coding technique plays a key role to improve the coding performance. However, many iterative channel coding schemes such as LDPC codes and turbo codes suffer from error floor region, which can give some negative impact to the DVC such as degradation in rate-distortion performance. In this paper, to reduce this error floor problem in rate adaptive LDPC code, large cycle length design and source revealing scheme (channel coding scheme with degree-1 syndrome) are applied to the transform domain Wyner-Ziv coding. The proposed scheme is shown to improve the coding performance.**

***Index Terms*— Video coding and Processing, Wyner-Ziv video coding, Source revealing, Degree-1 syndrome**

I. INTRODUCTION

IN this paper, we propose a channel reliability dependent Wyner-Ziv video coding using rate adaptive LDPC code with degree-1 syndrome under the transform domain Wyner-Ziv (TDWZ) setting which is a lossy distributed video coding (DVC) scheme. DVC is developed based on the Slepian-Wolf and the Wyner-Ziv theorems published in 1970's [1], [2] which proved that although DVC encodes two sources separately, it can still achieve the same coding performance of joint encoding if decoding process properly utilizes the correlation existing between the sources [1]–[4]. Much research has been carried out in order to attain the theoretically achievable coding performance by developing pixel or transform-domain coding techniques, quantization, side information generation, and theoretic bound-approaching channel coding schemes [3], [4].

Among them, the channel coding technique has a key role to improve the coding performance [3], [4]. Therefore, usually used in DVC are the near-capacity-approaching channel coding schemes such as LDPC and turbo code [3]–[14]. However, the state of the art iterative channel coding schemes also suffer from the error floor region [15], [16] which can degrade RD performance of DVC.

In this paper, to reduce the error floor region problem of rate adaptive LDPCA channel code [12] in DVC, large cycle LDPCA [17] and source revealing technique (channel coding scheme with degree-1 syndrome) [18], [19] are applied to TDWZ codec. The large cycle LDPCA maximizes the length of cycle of bipartite graph as much as possible because decoding performance of belief propagation depends on the lengths of cycles or degree distribution [17]. The source revealing scheme is a different approach but it can bring additional performance improvement. Source revealing encoder sends both the source and the syndrome information to the decoder. In other words, the decoder can directly use the source information to decode the syndrome. This scheme shows a relatively good performance in low correlation region [18], [19]. Kasai et al. [18] and Shin et al. [19] proposed a source revealing technique for non-binary and binary LDPCA codes, respectively. The binary LDPC is more desirable in DVC because performance and decoding complexity should be considered together [20]. However, its use in DVC has a significant problem - the source bit locations should be shared between encoder and decoder. In other to avoid this problem, the proposed scheme has randomly chosen binary entries group in a picture and the decoder decides whether to use the source revealing using the estimated channel reliability information. The proposed scheme shows better performance up to 0.24 dB (Bjontegaard Δ_{psnr} [21]) compared to the existing DISCOVER's TDWZ scheme [11].

II. TRANSFORM DOMAIN WYNER-ZIV FRAMEWORK

Fig. 1 shows the structure of the proposed transform domain Wyner-Ziv codec. It has been developed based on existing schemes [5]–[14]. The input sequence is divided into KEY and Wyner-Ziv (WZ) pictures, the KEY pictures are H.264/AVC INTRA coded and the WZ pictures are WZ coded.

In WZ encoder, the WZ pictures are divided into 4x4 blocks. The divided blocks are transformed using a 4x4 integer DCT and grouped into 16 sub-bands. Each DCT band is uniformly quantized, but DC and AC bands are handled differently [5], [6]. Rate control is done by using the pre-defined 8 quantization matrices [5], [6]. The grouped and quantized sub-bands are

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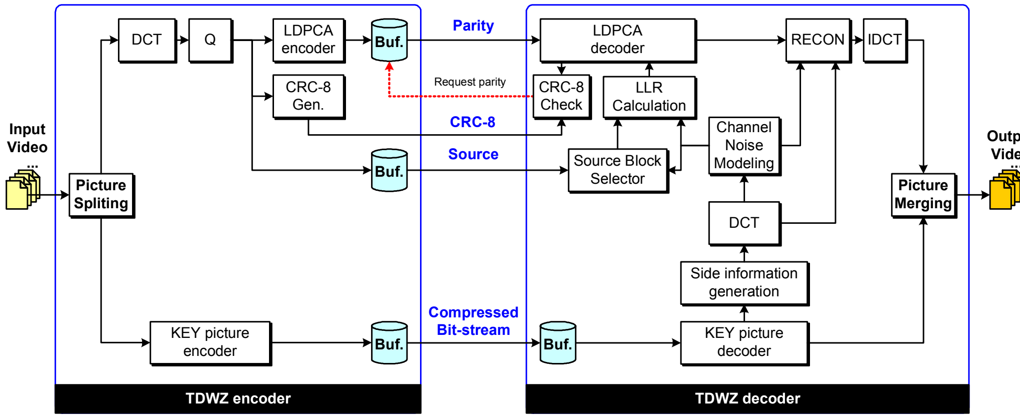


Fig. 1. Proposed transform domain Wyner-Ziv coding structure

divided into multiple bit-planes [5]–[7]. Each bit-plane is fed to the LDPCA encoder which generates syndrome bits. In conventional DVC encoder, only the generated syndrome bits are stored in a buffer and the systematic bits (=source bits) are discarded. However, in the proposed TDWZ codec, the systematic bits are also stored in a buffer but there is no need to store all systematic bits.

In WZ decoder, motion compensated interpolation based on template matching is performed to generate side information (SI) by using decoded KEY pictures [8]. The Laplacian distribution model parameter between original source and side information is estimated in the process of side information generation [9]. It is called the virtual correlation modeling. Log likelihood ratio (LLR) for each bit-plane per band is calculated for LDPCA decoding using both side information and the Laplacian parameter [7], [9]. The WZ decoder requests a partial syndrome until the decoder has enough information to decode. In order to verify the results of LDPCA decoding, the encoder transmits 8 bit CRC checksum bits to the decoder for each bit-plane [7]. In this paper, the source information can be transmitted to the decoder for source revealing as in Fig. 1. After all bit-planes are decoded in LDPCA decoder, minimum mean square error reconstruction is performed [10]. This reconstruction process includes inverse quantization. After the inverse DCT, the reconstructed WZ picture is generated.

III. Proposed Algorithm

A. Large Cycle LDPCA design

Jang *et al*. proposed a method for constructing rate-adaptive LDPC codes having a large cycle (girth) by syndrome merging with progressive-edge-growth (PEG) because short cycles can cause error floor problem [17]. Fig. 2 shows the performance of a degree-3 regular LDPCA code [12] and a large cycle LDPCA code [15] of length 1584. The performance of the large cycle LDPCA has been improved except only near $H(X\,|\,Y)$=0.8. In this paper, a channel reliability dependent source revealing scheme is proposed to improve additional coding performance for TDWZ.

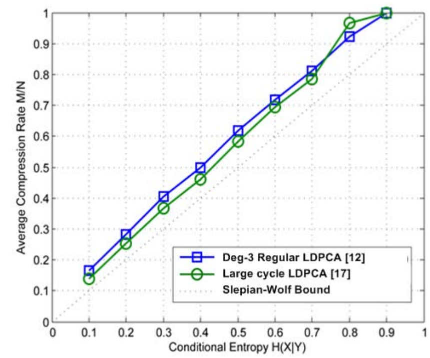


Fig. 2. Performance of degree-3 regular LDPCA code [12] and a large cycle LDPCA code [17] of length 1584

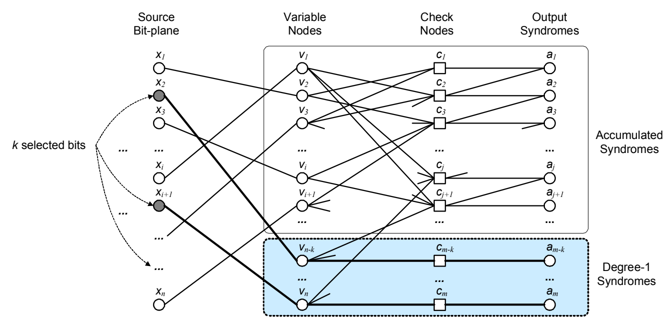


Fig. 3. Example of source revealing for LDPCA [19]

B. Source Revealing in LDPCA

Suppose that the source information $X=\{x_1,x_2,\ldots,x_n\}$ and side information $Y=\{y_1,y_2,\ldots,y_n\}$ are statistically correlated with *i.i.d.* random binary noise $Z=\{z_1,z_2,\ldots,z_n\}$, where X and Y are corresponding to the bit-plane of grouped and quantized transform coefficient for each band in TDWZ codec of Fig. 1. n is a total number of 4x4 blocks. LDPCA encoder generates the accumulated syndrome $A=\{a_1,a_2,\ldots,a_n\}$ from the input X. Conventional LDPCA decoder estimates X by using belief propagation with side information Y and partially transmitted syndrome A', where $A'\subset A$. Here, the LDPCA code consists of sub-codes with L members. Let i denote the index of some member code. Each member code is well designed at its target rate $H(X\,|\,Y)=i/L,\ 1\le i\le L$ [12], [19].

In the source revealing scheme [19], decoder can also use partially transmitted source information X', where $X' \subset X$. If some variable nodes are known (revealed) in decoder, the variable nodes are removed from the bipartite graph of LDPC [18],[19],[22]. Fig. 3 shows the concept of the source revealing. If the encoder transmits k selected source bits (see the gray filled circles in Fig. 3) in quantized bit-planes $X = \{x_1, x_2, ..., x_n\}$ to the decoder, then k source bits are connected to degree-1 variable nodes $V' = \{v_{n-k}, v_{n-k+1}, ..., v_n\}$. If a decoder receives degree-1 syndromes, then the decoder can restore the original source perfectly for the corresponding syndromes because the received degree-1 syndromes $A' = \{a_{m-k}, a_{m-k+1}, ..., a_m\}$ and the original sources are one to one connecting through the check nodes $C' = \{c_{m-k}, c_{m-k+1}, ..., c_m\}$, where m is the number of check nodes. This scheme can show a good performance in low correlation region [18], [19]. The method [19] is more suitable for the proposed TDWZ codec because of binary LDPCA case. Note that in order to use [19] in DVC, encoder and decoder should commonly know locations of selected source bits but it is not suitable for the practical coding environment. To avoid this problem, we employ an adaptive source revealing scheme with binary LDPCA codes for each bit-plane.

C. Adaptive Source Revealing Scheme

The minimum rate estimation algorithm is proposed to reduce the number of feedbacks in DVC [7]. In our proposed scheme, the estimated minimum required bit-rate $R_{\min}$ is used as channel reliability measure. $R_{\min}$ is given by the conditional entropy $H(X \mid Y)$ between source X and side information Y as (1). This conditional entropy can be calculated by crossover probability $p = \Pr(X \neq Y)$ for each bit-plane. The crossover probability p is calculated by using DCT coefficient of side information and previous decoded bit-planes [7].

$$H(X \mid Y) = -p \log_2(p) - (1-p)\log_2(p) \tag{1}$$

To decide whether to use source revealing in decoding process for each bit-plane or not, we use estimated minimum required bit-rate $R_{\min}$. It can be assumed that high $R_{\min}$ means low channel reliability. Therefore, $R_{\min}$ is greater than a threshold value R_{Thd}, then decoder requests both partial syndrome and source bits instead of only partial syndrome bits to the encoder. Here, let L_{cutoff} be the cut-off value of member index of syndrome. In decoding process, if the current feedback index is less than L_{cutoff}, syndrome is transmitted. In other case, source bits members are transmitted. For example, suppose that $L = 66$, $L_{cutoff} = 46$, and the real number of feedbacks is 56, then, transmitted syndrome and source members are 46 and 10 (=56-46), respectively. In this paper, we use $L_{cutoff} = 46$ according to the experiment results [17]. The minimum rate threshold value R_{Thd} = 0.85 is selected experimentally. The source member's entries are randomly selected in a picture in order for statistical stationary. The transmission order of the partial source information is also random but the random permutation and selection information are pre-shared between encoder and decoder. Therefore, there is no need to transfer the location information for the source revealing between encoder and decoder.

IV. Simulation Results

Simulations are performed with the proposed TDWZ codec in Fig. 1. The key pictures are compressed using MPEG-4 AVC/H.264 intra coding (JM17.2) with main profile, and the Wyner-Ziv pictures are coded using the proposed Wyner-Ziv coding method. Foreman with Siemens logo and Soccer sequences are used for test (149 pictures) with group of pictures size of 2. Spatial and temporal resolutions are QCIF and 15Hz, respectively. For comparison, our TDWZ and DISCOVER codec were used with binary regular degree-3 LDPCA code [12]. The maximum number of iterations for belief propagation is 100 with hard decision aided early termination scheme [12].

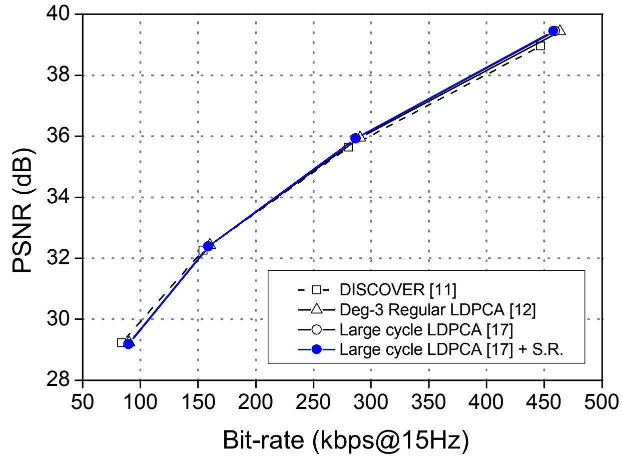
From an implementation point of view, if the decoder receives some source bits, LLR values should be updated as (2), where $\hat{x}_i$ is an estimated bit of quantized DCT band in i th 4x4 block. X^{b-1} is a $b-1$ th already decoded bit-plane and $x_i^{b-1} \in X^{b-1}$. The simulator cannot handle infinite value. Therefore, the absolute value of the LLR is limited to 200.

$$LLR_i = \log_2 \frac{\Pr(\hat{x}_i = 1 \mid y, x_i^{b-1}, ..., x_i^1)}{\Pr(\hat{x}_i = 0 \mid y, x_i^{b-1}, ..., x_i^1)} = \begin{cases} \infty & , x_i = 1 \\ -\infty & , x_i = 0 \end{cases},$$
$$X^{b-1} = \{x_1^{b-1}, x_2^{b-1}, ..., x_n^{b-1}\} \tag{2}$$

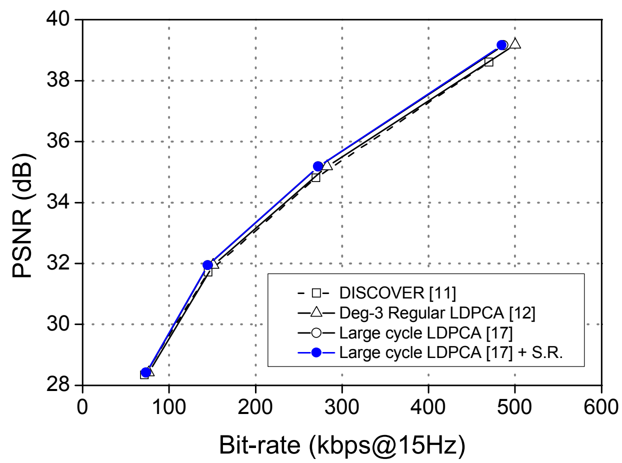
Table I shows the Bjontegaard Δ_{rate} and Δ_{psnr} among the tests. Fig. 4 shows the rate-distortion performance. The large cycle LDPCA with source revealing scheme shows the best performance. For example, the Soccer sequence has $\Delta_{psnr} = 0.24$ dB gain and $\Delta_{rate} = 4.40$ % bit-rate saving compared to the DISCOVER [11]. In Table I, bit-rate saving of source revealing is 0.23% and 0.26% for each test sequence, respectively. Table II shows the average saved bits through source revealing. Although, the bit-rate saving mainly occurs in large cycle LDPCA, the source revealing can be useful in weakly correlated region such as a bit-plane of least significant bit (LSB). For example, the average saved bits per picture increases in high bit-rate region (Q_m=8) as in Table II.

V. Conclusion

In this paper, large cycle length design and source revealing scheme are applied to our transform domain Wyner-Ziv codec. The proposed scheme reduced the error floor effect of LDPCA code and selectively transmits the source and syndrome information depending on each bit-plane. The propose scheme shows better performance up to 0.24dB compared to the existing DISCOVER's TDWZ scheme.



(a) Foreman QCIF@15Hz, 149 pictures



(b) Soccer QCIF@15Hz, 149 pictures

Fig. 4 Rate-distortion performance with large cycle LDPCA and source revealing

TABLE I
PERFORMANCE COMPARISON

Tests	Large cycle LDPCA [17] + Source Revealing			
	Foreman		Soccer	
	Δ_{rate} (%)	Δ_{psnr} (dB)	Δ_{rate} (%)	Δ_{psnr} (dB)
DISCOVER [11]	-0.27	0.03	-4.40	0.24
Deg-3 LDPCA [12]	-0.65	0.04	-3.90	0.22
Large cycle LDPCA [17]	-0.23	0.01	-0.26	0.02

TABLE II
AVERAGE BIT SAVING PER PICTURE BY SOURCE REVEALING

Q_m	Foreman		Soccer	
	Avg. saved bits per pic.	Avg. saved # of request member codes per pic.	Avg. saved bits per pic.	Avg. saved # of request member codes per pic.
2	45.00	1.88	61.30	2.55
4	41.41	1.73	29.23	1.22
7	69.64	2.90	70.39	2.93
8	206.01	8.58	239.57	9.98

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