A Novel Image Transmission System Based on Joint Source-Channel Coding

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Abstract. A novel joint source/channel image coding algorithm for image transmission system was proposed. The proposed algorithm is based on the best wavelet packet in a rate-distortion sense. Because of the noise in transmission channel, the channel and the channel code information had been introduced to the source image coding. The image coding is based on wavelet packet, and a bit plane coding algorithm have been used for the wavelet packet sub-band coding, so the coded bit streams can be match to UEP transmission by WICP-LDPC code. The simulation results in BSC channel show that, the proposed algorithm is better than the EEP and several other image transmission algorithms.

Keywords: joint source channel coding, best wavelet packet, UEP, image transmission.

1 Introduction

As the development of wireless communications technology, multimedia communications becomes more and more attention. As the most important and most basic technology, image transmission technology has become a hot research topic in recent years. The traditional image transmission system is based on the Shannon separation theorem [1], however, its codec complexity and storage capacity are both demanding, because of these defects, the traditional system is hard to meet in practical applications, especially in wireless communications. However, this issue has inspired the exploration and research of joint source channel coding (JSCC) algorithm. At present, many of the specific image communication system based on JSCC have been proposed [2-6]. There is an important class of JSCC system in those systems is unequal error protection (UEP) system, which divide the source into different parts in accordance with the significance level, when the channel coding implement different error protection. As the channel transmission processing, the sensitivity of the bit error rate the in different types of data is completely different, therefore, the equal error protection (EEP), which take all the information for the same level of error control coding, is a bandwidth waste on the protection of non-essential information, and the protection of critical information has become deficient. Fortunately, the use of UEP is a good way to solve this contradiction.

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Wavelet image coding is a very successful source coding, it can achieve very good compression ratio. In recent years, many efficient algorithms have been proposed, such as embedded coding algorithm interception (EBCOT) algorithm, which is the core of JEPG2000 algorithm [7,8], and the optimal wavelet packet based image compression algorithm [9-10]. However, these wavelet coding algorithms is designed for the separation system, they can not be effectively bound into the UEP channel coding. Based on the above considerations, a novel image source coding algorithm based on optimal wavelet packet have been proposed, which can be good match for WICP-LDPC channel coding [11]. In Section 2, we present our optimal wavelet packet algorithm. Section 3 formulates our UEP channel coding problem which used WICP-LDPC, and present the system model. Section 4 provides simulation details use the system in Section III. Finally, we conclude the paper in Section 5.

2 WP Image Coding

2.1 Prune Algorithm of the WP

The basic idea of wavelet packets is using the decomposition of non-octave band, to make the given signals select their best base adaptively. There is a general approach for the choice of optimal basis, which is to define a cost function, then look for the full tree to find a sub-tree, which make the global cost function minimum. That means, during the tree-pruning procedure, the cost of a parent sub-band $J(P)$ is compared with the sum of its four children's costs $\Sigma J(C_i)$, as the Fig.1 shows. If the parent's cost is costly, the four sub-branches are retained, and the parent's cost is updated to the sum of its children's costs, otherwise the four sub-branches are pruned. When this tree-pruning procedure reaches the root node, the best sub-tree that minimizes the global cost function is found.

Ramchandran and Vetterli propose a rate-distortion based cost function [9], which is given by

$$J(\lambda) = D + \lambda \cdot R \tag{1}$$

where λ is the quality factor, which controls the tradeoff between the distortion D and the budget bit rate R. The rate-distortion cost function can solve the problem of the best basis selection in a rate-distortion sense. For any given wavelet packet, the decomposition of the leaf node will correspond to the packet sub-band. Assuming that the sub-band can be represented by the {B1, B_2, ..., B_m}, and because of the additivity between rate and distortion, the global cost function can be represented by

$$J(\lambda) = \sum_{i=1}^{m} (D_i(R_i) + \lambda R_i) \tag{2}$$

where R_i is the sum rate of sub-band B_i, and D_i is the sum distortion of sub-band B_i.

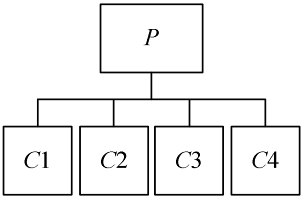

Fig. 1. A branch of the full tree

Then, the optimal wavelet packet pruning algorithm can be presented as follows. In every branch of the tree, if (3) is satisfied, the parent sub-band will be retained; otherwise it is broken down into four child sub-bands. When the tree pruning algorithm reach the root node, as the given λ, it can get the best wavelet packet decomposition and optimal quantization for each sub-band encoding.

$$D_0 + \lambda R_0 \leq \sum\nolimits_{i=1}^{4} D_i + \lambda R_i \tag{3}$$

In the image transmission system, due to the presence of channel noise, the stream of source compression coding need another channel coding, which increases the total coding rate, and the channel noise increases the total distortion. Assumptions the ratio between increased total code rate and the original rate is σ, then, the global cost function can be represented by

$$J(\lambda) = \sum_{i=1}^{m} (D_i(R_i) + \lambda R_i + D(\sigma)) \tag{4}$$

where, $D(\sigma)$ is the distortion caused by channel noise. Let e be the error of the original code words $\boldsymbol{x}$ from the decoding code words $\boldsymbol{y}$, that means $e=|\boldsymbol{x}-\boldsymbol{y}|$, then we can get

$$\mathrm{E}(e) = (2^{\sigma R_i} - 1)P \tag{5}$$

and

$$\mathrm{E}(D(\sigma)) = \frac{\sum \left[(2^{\sigma R_i} - 1)P \right]^2}{n} = \left[(2^{\sigma R_i} - 1)P \right]^2 \tag{6}$$

where, σR_i is the total rate of the sub-band B_i; P is the BER of the noise channel, it is related in noise channel and channel coding. In this paper, we use BSC channel for the simulated channel, and calculate (7) by its channel BER p. For other given noise channel, P can be determined by the specific coding and decoding methods and the noise channel. So in a given error control coding algorithm, we can calculate the P in deferent SNR, and store it in a table, In the actual transmission coding, the encoder will look for the storage table to find the channel coding rate, based on the current channel condition and transmission requirements.

$$D_0 + \lambda R_0 + \left[(2^{\sigma R_0} - 1)P \right]^2 \leq \sum\nolimits_{i=1}^{4} D_i + \lambda R_i + \left[(2^{\sigma R_i} - 1)P \right]^2 \tag{7}$$

In summary, the choice of optimal wavelet basis is summarized as follows:

- Decompose the input image to a given depth N to form the full decomposition tree.
- For a given *, look for the storage table, find the* σ, P, then populate each node of the full tree with the *equation (7)* over all the rate-distortion pairs of that node.
- Prune the full tree recursively, starting from the leaf nodes to the root node, by making spilt/merge binary decisions. From this step the best basis and the corresponding quantizers are known for the given λ.
- Iterate over λ using bisection search method to meet the target bit rate R.

2.2 Block-partitioning Coding Algorithm

After WP decomposition, each WP sub-band needs a block-partitioning coding to quantize the WP sub-band. Consider a WP sub-band $\boldsymbol{\Omega}$, whose coefficient p located at position (i, j) is denoted by $c_{i,j}$. A sub-block B of $\boldsymbol{\Omega}$ is said to be significant with respect to a threshold n, if

$$\max_{(i,j)\in B}\{|c_{i,j}|\} \geq 2^n \tag{8}$$

otherwise, it is insignificant.

The block-partitioning coding algorithm adopts a bit-plane coding fashion. The main idea is to locate significant coefficients in each bit-plane and encode groups of insignificant coefficients efficiently with a few symbols. To achieve this objective, the coding algorithm tests the significance of a coefficient block first. If the block is significant in current bit-plane n, it is partitioned to find significant coefficient in it, as shown in Fig. 2; otherwise, it is retained for the next bit-plane revisit.

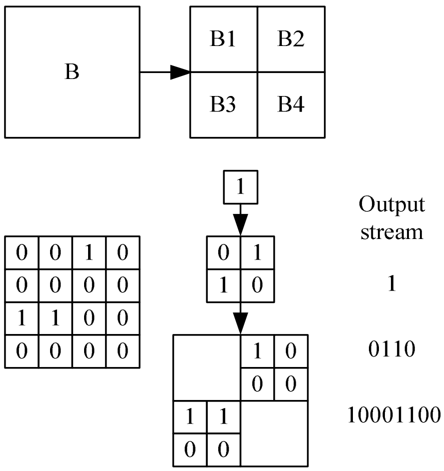

Fig. 2. Partition of a significant coefficient block

3 Transmission System by UEP

3.1 The WIPC-LDPC Coding

Ma and Yuan [11] propose a irregular low-density parity-check (LDPC) code based on weight-increasing parity-check matrix (WIPC), which have an excellent unequal error protection (UEP) performance. With systematic encoding, the important information bits in information sequence could successfully be mapped to the elite bits of an irregular LDPC code. Accordingly, the bit plane coding in section II can be mapped into WIPC-LDPC based on their importance.

Assuming the maximum threshold of the bit plane coding is N, obviously, the plane with threshold N has the highest important level, and with the decrease of the threshold, the importance of the plane will decrease. Thereby, we can select N degrees in the information nodes of WIPC-LDPC, assuming that the numbers of information nodes in each degree are S_1, S_2, $\cdots$, S_N, where, S_N have the highest important level, and S_1 have the lowest level. Then the channel coding processing can be represented as follows:

- Rearrange the bit plane coding streams to construct a new information vector $\boldsymbol{V}$. Get S_N bits from the plane N, $S_{N\text{-}1}$ bits from plane N-1, …, S_1 bits from plane 1, then arrange them as Fig. 3 shows.
- Encode the information vector $\boldsymbol{V}$ with WIPC-LDPC code.

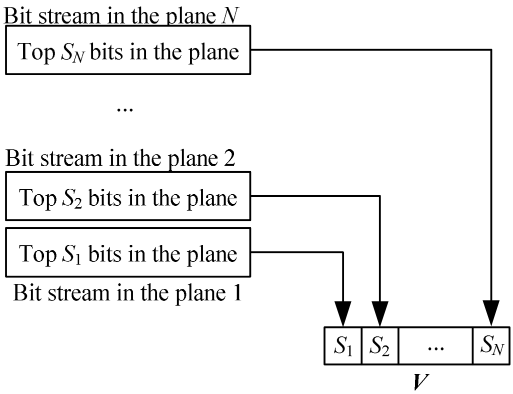

Fig. 3. The structure of information vector

3.2 System Model

As Fig. 4 shows, the work processing of joint coding system is as follows:

- For a given channel and rate requirement, get P and σ by looking for the storage table.

- Prune the WP tree of the source image according to (7) and bit-plane coding.
- Channel encode with WIPC-LDPC.

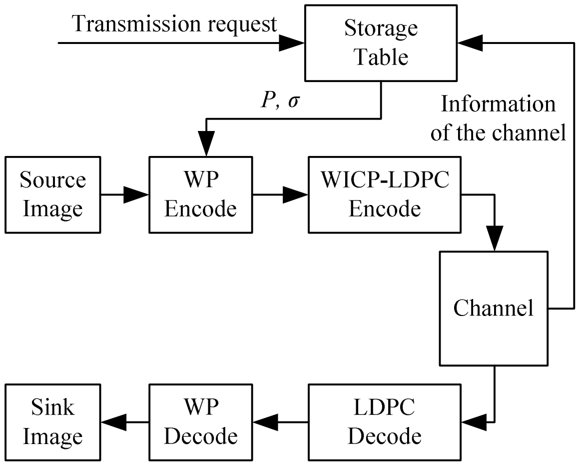

Fig. 4. The joint coding transmission system

4 Simulation

Computer simulations are carried out on BSC channel to assess the performance of the proposed transmission system, using several popular images, *lena*, *barbara* and *goldhill*. The parameters of the selected LDPC code are as follows: the code length is 8192 bits, rate is 0.5 and the column polynomial of the irregular LDPC is

$$\lambda(x) = 0.1322x + 0.124x^2 + 0.3306x^{19} + 0.4132x^{49} \tag{9}$$

The row polynomial is

$$\rho(x) = 0.8678x^{14} + 0.1322x^{15} \tag{10}$$

The elementary transformation of the matrix derived by $\lambda(x)$ can be transformed to a WIPC matrix, and this WIPC-LDPC code has the following properties, the first 4096 bits are parity bits, the followed 2560 bits have the degree of 3, the next 1024 bits have the degree of 20, the final 512 bits have the degree of 50. And the σ of this WIPC-LDPC code is 2, when it is used in error control code on BSC channel. BP decoding algorithm has been used in channel decoding, the number of iterations set to 50.

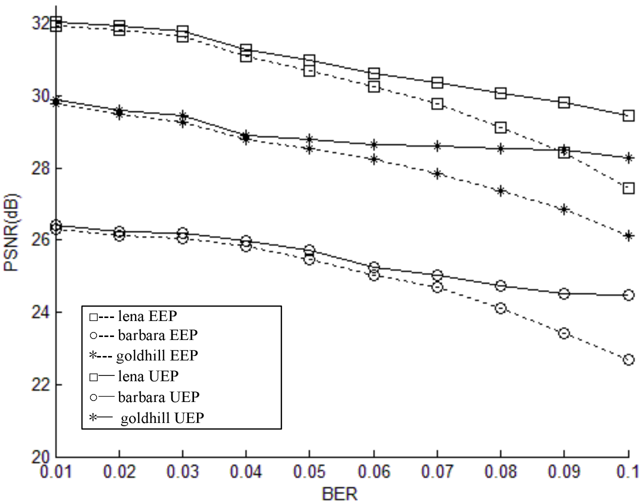

Fig. 5. PSNR when the rate is 0.25bpp

As a comparison test, EEP transmission using general irregular LDPC as channel coding, and its generator polynomial is $\lambda(x)$. Fig. 5 shows the results when the transmission rate is 0.25bpp, and Fig. 6 is 0.5bpp.

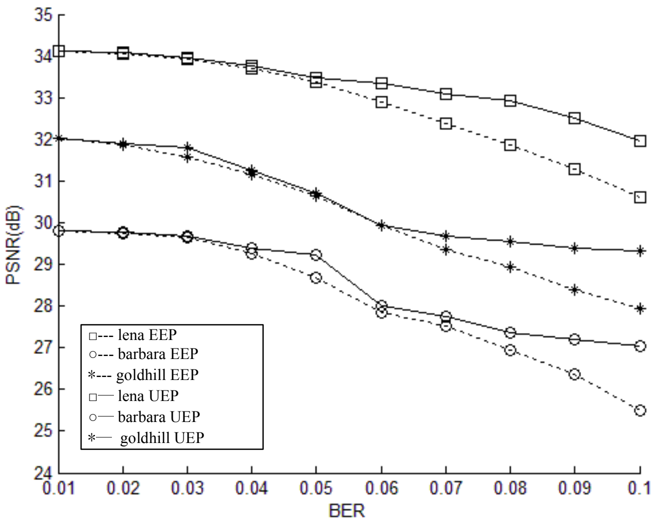

Fig. 6. PSNR when the rate is 0.5bpp

Fig. 5 and Fig. 6 show WIPC-LDPC codes with UEP scheme is significantly better than the general irregular LDPC codes. And with the increase of channel bit error, UEP can gain greater image quality improved. At the same time, compare Fig. 5 and Fig. 6, can be derived that, the advantage of UEP is more obvious when the transmission rate is low. Thus, in poor transmission conditions, low rate and high channel error, the use of UEP transmission can improve the quality of the reconstructed image more obviously.

Table 1 compares the proposed algorithm and the algorithms proposed by Sherwood, Banister and Lan, when the transmission rate is 0.25bpp, while Table 2 is the rate of 0.5bpp. TABLE I and TABLE II show that the proposed joint coding algorithm is generally better than other algorithms.

Table 1. PSNR of the restructure image while rate=0.25bpp

BER		Lena	Barbara	Goldhill
0.1	algorithm in [2]	29.40	24.71	27.69
	algorithm in [3]	30.21	24.25	27.92
	algorithm in [4]	30.68	24.33	28.49
	proposed algorithm	29.44	24.49	28.27
0.03	algorithm in [2]	31.90	26.32	29.16
	algorithm in [3]	32.32	25.99	29.21
	algorithm in [4]	32.74	26.18	29.37
	proposed algorithm	31.77	26.25	29.41

Table 2. PSNR of the restructure image while rate=0.5bpp

BER		Lena	Barbara	Goldhill
0.1	algorithm in [2]	31.10	26.99	28.60
	algorithm in [3]	31.76	26.77	29.89
	algorithm in [4]	32.21	27.31	28.92
	proposed algorithm	31.97	27.03	30.31
0.03	algorithm in [2]	34.15	29.12	31.38
	algorithm in [3]	34.50	29.41	31.50
	algorithm in [4]	34.82	29.30	31.66
	proposed algorithm	34.77	31.10	31.99

5 Conclusion

In this paper, a novel joint source/channel image coding algorithm was proposed based on the best wavelet packet in a rate-distortion sense. Different from other wavelet packet image coding, the channel and the channel code information were introduced to the source coding, so the proposed algorithm could be applied to image transmission. The coding of wavelet packet sub-band used bit plane coding, thereby made the bit streams match to UEP transmission by WICP-LDPC code. The simulation results show that, in poor transmission conditions, low rate and high channel error, the use of UEP transmission can improve the quality of the reconstructed image more obviously. And the proposed joint coding algorithm has better performance than the algorithm proposed by Sherwood, Banister, and Lan.

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