Optimized Multiple Description Image Coding Using Lattice Vector Quantization

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***Abstract*—Multiple description (MD) coding has many applications in transmission of images over unreliable packet or multiple path networks that can not guarantee lossless data delivery. In this paper, an effective multiple description image coding scheme is introduced. This scheme is mainly based on the wavelet transform and multiple description lattice vector quantization (MDLVQ). The characteristics of wavelet coefficients in different frequency subbands are taken into account in the design of the MD image coder with different optimized MDLVQ parameters. The experimental results are presented to demonstrate the effectiveness of the proposed scheme.**

I. INTRODUCTION

Network congestion and delay sensibility pose great challenges for multimedia communication system design. This creates a need for coding approaches combining high compression efficiency and robustness. Multiple description (MD) coding has emerged as an attractive framework for robust transmission over unreliable channels. It can efficiently combat packet loss without any retransmission thus satisfying the demand of real time services and relieving the network congestion [4]. Multiple description coding encodes the source message into several bit streams (description) carrying different information which then can be transmitted over the channels. If only one channel works, the descriptions can be individually decoded to sufficiently guarantee a minimum fidelity in the reconstruction at the receiver. However, when more channels work, the descriptions from the channels can be combined to yield a higher fidelity reconstruction.

The design of MD codes is mainly focused on the MD quantizers [2-3] and transforms [5]. A method of image coding based on multiple description scalar quantization is proposed in [1], which is claimed to achieve a better performance than the coder using the pairwise correlation transforms described in [5]. In this paper, we attempt to use multiple description lattice vector quantization (MDLVQ) combined with wavelet transform in the construction of our robust image coder. In view of the characteristics of wavelet coefficients in different subbands, different MDLVQ parameters are applied in different subbands, which are optimized to maximize image quality under the constraint of bit rate.

The rest of this paper is organized as follows. In Section II, an overview of the proposed MD coding scheme is given. In Section III, the optimization of the MD system parameters is presented in detail. The performance of the proposed scheme is examined against the coder in [1] in Section IV. We conclude the paper in Section V.

II. OVERVIEW OF PROPOSED SCHEME

Our scheme can be depicted in Figure1 and the steps are explained as follows.

Step 1. Wavelet Decomposition

A given input image is decomposed into subbands (Subband 1, Subband 2,…,Subband m, denoted by s_i , $i = 1,2,...,m$).

Step 2. Lattice Vector Quantizer LVQ_i ($i = 1,2,...,m$)

It is well known that different subbands carry unequal weights in terms of overall signal energy. That is, the loss of the small portions in the lowpass bands is likely to render the entire reconstruction worthless, whereas the loss of substantial portions of the high frequency subbands is much less significant. In view of this characteristic, each subband should be processed by a corresponding lattice vector quantizer instead of using a fixed one for all subbands.

In this paper, lattice vector quantization (LVQ) is based on the lattice A_2 . A_2 is equivalent or similar to the hexagonal lattice [6]. The hexagonal lattice may be spanned by the vectors (1,0) and ($-1/2, \sqrt{3}/2$), and so the generator matrix is

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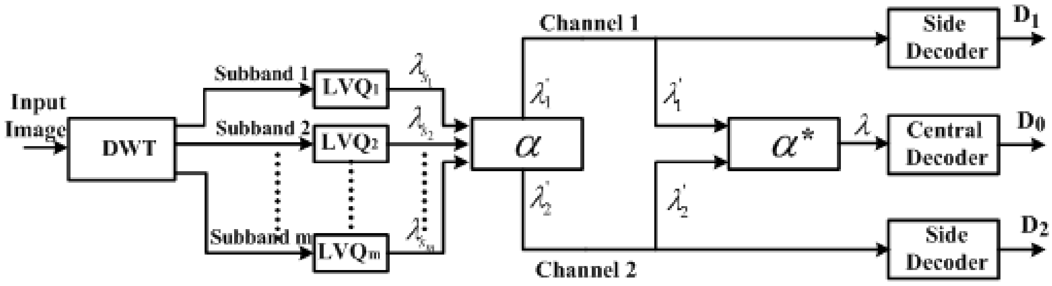

Figure 1. Block diagram of our scheme

$$M = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}. \qquad (1)$$

Every pair of coefficients in each subband s_i can be regarded as a 2-dimensional vector. A corresponding lattice vector quantizer LVQ_i is applied to such 2-dimensional vectors in s_i, thus producing a quantized field λ_{s_i} for each subband. So all the subbands can be quantized to form λ and $\lambda = \{\lambda_{s_i} \mid i = 1, 2, ..., m\} \subset A_2$.

Step 3. Labeling Function α [2]

Information about the lattice vector quantized field λ is sent across the two channels, subjected to bit rate constraints imposed by each individual channel. This is done by a labeling function α followed by entropy coding.

The labeling function α maps $\lambda \subset \Lambda$ to a pair $(\lambda_1', \lambda_2') \in \Lambda' \times \Lambda'$, where Λ' is a sublattice of Λ with the index N, $N = |\Lambda / \Lambda'|$ [2]. The index N is used to control the amount of redundancy in a lattice vector quantizer. In this paper, Λ is chosen as A_2 lattice. Figure2 is the example of a sublattice with index N =13.

In the case of N =13, according to the labeling function α, we can obtain the labeling function as in Table I. In the table we can assign each λ a label (or a pair) (λ_1', λ_2'). λ_1' is transmitted in the channel 1 and λ_2' in the channel 2 in order to guarantee the balance of reconstructed quality by any single description in the two channels. Then we can extend the assignment to the entire lattice due to the shift property of hexagon [2].

Step 4. Central Decoder and Side Decoder

At the receiver, if either of the descriptions is lost, the available description is dequantized by using the side decoder including entropy decoding and the side distortion denoted by D_1 and D_2 respectively will be yielded in the reconstruction. However, if both descriptions are received, the two descriptions must be processed by the central decoder after entropy decoding and the function α^* will map a pair (λ_1', λ_2') to λ correctly. The central distortion denoted by D_0 is produced in the reconstruction using central decoder.

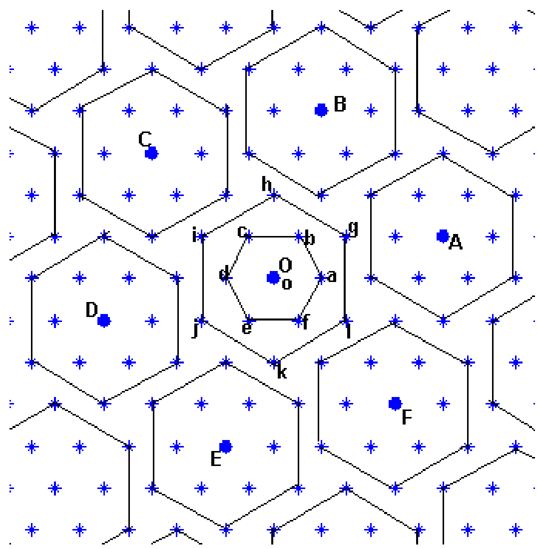

Figure 2. An example of sublattice with index 13. Lattice points are labeled by *a,b,c,…,l,* and sublattice points is A,B,C,…,F.

TABLE I. LABELING FUNCTION WITH N =13

Lattice Point λ	Label	Lattice Point λ	Label
o	(O,O)		
a	(O,A)	d	(D,O)
b	(O,B)	e	(E,O)
c	(O,C)	f	(F,O)
g	(B,F)	j	(C,E)
h	(C,A)	k	(D,F)
i	(B,D)	l	(A,E)

III. OPTIMIZATION OF SYSTEM PARAMETERS

In our scheme, there are two important factors which will affect the reconstruction image quality and the bit rate when coding a particular image. The first one is the area of hexagonal lattice in Step 2, while the other is the choice of index in Step 3.

Since the lattice A_2 is the space which can be spanned by two vectors (1,0) and ($-1/2, \sqrt{3}/2$), the area of the hexagonal lattice is determined by the two vectors. However, we can keep the shape of the hexagonal lattice and at the same time change its area by multiplying the generator matrix M by a factor $\delta, (\delta \in R, \delta > 0)$. The factor δ in the LVQ is similar to the step size in scalar quantization, where the value of δ can determine whether the lattice vector quantization is a fine or coarse one. Considering the distribution characteristics of wavelet coefficients, coarse lattice vector quantizers are chosen for the high frequency subbands and fine ones for low frequency subbands.

For the lattice A_2, the choice of index N will not change the central distortion D_0. However, the side distortion D_1 and D_2 will be sensitive to the value of N. When the index N is changed from 7 to 13, D_0 has no change but D_1 and D_2 will increase obviously. On the other hand, the bit rate will decrease with the increase of N.

Similar to the optimization scheme in [3], we formulate the MD design problem as yielding optimal performance in the presence of the constraints of the side distortion and the bit rate. To facilitate the following description, some notations are defined as follows.

- Let I denote an image, and $S = \{s_1, s_2, ..., s_m\}$ its m wavelet subbands after the decomposition.
- $\delta_S = \{\delta_{s_i} \mid i = 1,2,...,m\}$ denotes the set of the magnified degrees of the lattice areas for different subbands.
- $N_S = \{N_{s_i} \mid i = 1,2,...,m\}$ denotes the set of the indexes N used in the labeling function α for different subbands.
- $D_0(S, \delta_S, N_S)$, $D_1(S, \delta_S, N_S)$ and $D_2(S, \delta_S, N_S)$ denote the mean squared errors (MSE) from the central decoder and the side decoders for the input image I, respectively, given the lattice vector quatizers with parameter δ_S and the index set N_S for the labeling function.
- $R_1(S, \delta_S, N_S)$ and $R_2(S, \delta_S, N_S)$ denote the bit rates for encoding each description of I, respectively, using the given lattice vector quatizers with parameter δ_S and the index set N_S for the labeling function.

Our goal is to find the optimal parameters δ_S and N_S in solving the following optimization problem:

$$\min_{\delta_S, N_S} D_0(S, \delta_S, N_S) \qquad (2)$$

subject to

Condition 1: $R_1(S, \delta_S, N_S) = R_2(S, \delta_S, N_S) \le R_{budget}$ (3)

Condition 2: $D_1(S, \delta_S, N_S) = D_2(S, \delta_S, N_S) \le D_{budget}$ (4)

where R_{budget} denotes the available bit rate to encode each description and D_{budget} is the maximum distortion acceptable for single-channel reconstruction.

The basic algorithm shown in Figure3 is to make use of the monotonicity of both R and D as the function of δ_S. Firstly, after initialization a smallest δ_S is searched to minimize D_0 subject to Condition 1. Secondly, according to Condition 2, we can update N_S sequentially from high frequency subbands to low ones. In Figure4 the sequence is LH1, HL1, HH1, LH2, HL2, HH2, … , LH4, HL4, HH4, LL4. Then the updated N_S affects $R_1(S, \delta_S, N_S)$ and $R_2(S, \delta_S, N_S)$ in Condition 1 and consequently δ_S will be updated to minimize D_0 further. So the two steps will be iterated to update δ_S and N_S until D_0 has little change.

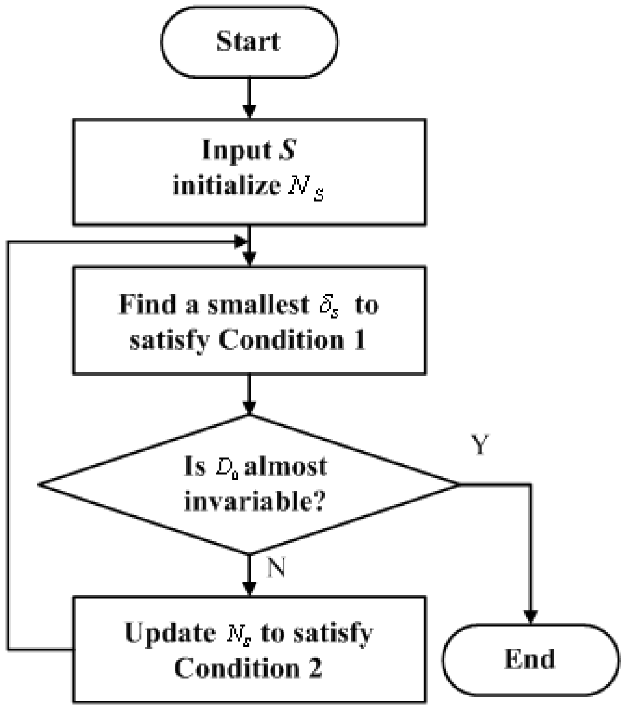

Figure 3. The flow chart of optimization algorithm

IV. EXPERIMENTAL RESULTS

The standard image Lena (512×512) is chosen to test our scheme. In addition, 10/18 Daubechies wavelet is used for wavelet decomposition and target bit rate per channel is in the range 0.3-1.4 bpp. In Figure4, we give an example result of optimized parameters obtained for each subband. From the example, we can see the parameters of δ_S are larger for high frequency subbands and smaller for low one. The parameters of N_S is also set in the same way. So the choice of parameters in optimization algorithm accords with the distribution characteristics of wavelet coefficients.

As a reference, we compare the performance attained by our MD image coder with the MD image coder in [1]. Figure5 shows the PSNR values obtained by our proposed scheme and the referenced one when reconstructed images are from two descriptions. Figure6 depicts the PSNR values achieved when reconstructed images are produced by only one description. Compared with the MD image coder in [1], our method can achieve 2~4 dB better reconstruction from a single description and 3~6 dB better reconstruction from both descriptions.

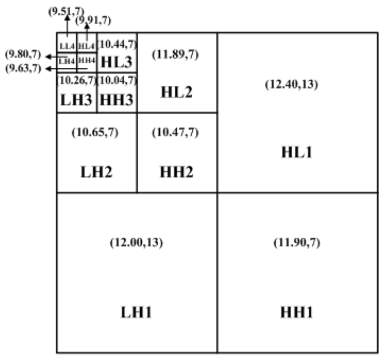

Figure 4. An example result of optimized parameters (δ_S, N): LH1(12.00,13), HL1(12.40,13), HH1(11.90,7), LH2(10.65,7), HL2(11.89,7), HH2(10.47,7), LH3(10.26,7), HL3(10.44,7), HH3(10.04,7), LH4(9.80,7), HL4(9.91,7), HH4(9.63,7), LL4(9.51,7) (central PSNR:38.28dB, side PSNR: 33.21dB, 0.46bpp)

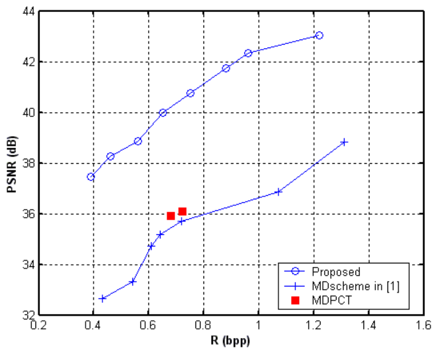

Figure 5. PSNR values achieved from both descriptions in the proposed scheme, MDscheme in [1] and MDPCT [5]

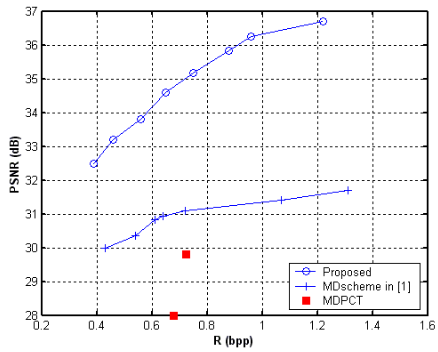

Figure 6. PSNR values achieved from only one description in the proposed scheme, MDscheme in [1] and MDPCT [5]

V. CONCLUSION

In the paper, we have presented an MD image coding scheme using MD lattice vector quantizers, where the parameters in the MDLVQ are optimized in favor of the characteristics of image wavelet coefficients. Our method can achieve better performance than the MD image coder in [1]. In our view, the gain achieved by our method against the referenced one is mainly attributed to the use of MDLVQ together with some degrees of adaptations in choosing the area of lattice and the index of labeling function for different subbands, with the help of an optimization algorithm.

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