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Improved multiple description wavelet based image coding using Hadamard Transform

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ABSTRACT

A new Multiple Description Transform Coding (MDTC) was proposed by combining the Discrete Wavelet Transform (DWT) and Hadamard Transform (HT). To overcome the inherent drawbacks in the Pairwise Correlating Transform (PCT), which are the computational complexity and hardware implementation, HT was used to introduce an effective redundancy between the descriptions by improving their correlation coefficient. The new approach were analyzed and compared to the conventional scheme in the case of four descriptions by using multiple gray scale test images having different spectral characteristics. The findings show a better performance of the proposed method, especially in the case of two packets lost. In addition, the proposed method ensures a low degradation of the image reconstructed when one packet or two packets are lost. Therefore, the proposed coder provides a good redundancy performance and an easier practical implementation than the classical approach.

1. Introduction

The Multiple Descriptions Coding (MDC) was introduced to overcome different problems of transmission over error-prone networks. It is based on the encoding of an input information source into many correlated descriptions to be transmitted over different channels. At the reception, the original data is reconstructed by using the descriptions received. The quality of the reconstruction improves progressively with increasing the number of received descriptions [1].

Two main practical types of MDC were developed: the first was based on the quantization approach and the second was based on the transform approach. Vaishampayan proposed the first practical scheme using scalar quantizers (MDSQ) [2]. The second approach based on using of Pairwise Correlating Transforms (PCT) had been introduced by Wang et al. [3] and was generalized to the case of more than two descriptions by Goyal et al. [4].

In this study, the MDTC was considered in the case of four descriptions. The MDTC uses DCT and DWT to decorrelate the input source. Then, these uncorrelated transform coefficients were uniformly quantized and fragmented into four descriptions. Subsequently, a certain amount of redundancy was introduced between the uncorrelated descriptions by using PCT. Finally, the correlated descriptions are coded and transmitted through different channels. However, the PCT system has two main drawbacks [5]. The first disadvantage is that the PCT system does not exploit the high correlation between neighboring blocks and the second one is the difficulty of its practical implementation. To overcome these problems, we have proposed an improved scheme of MDTC based on DWT and Hadamard Transform referred as MDTC–DWT–HT. Hadamard Transform was chosen because of its low computational cost (only a small number of additions and subtractions are required to compute it) and its easiness of hardware implementation [6]. It offers several advantages: it is real symmetric and orthogonal, and the sorted Hadamard matrix can be calculated recursively. Moreover, its propriety of orthogonally ensures a simple encoding and decoding process. However, HT has a very poor performance to decorrelate the input data compared to DCT and DFT [7,8]. Therefore, it can be used as correlating transforms like PCT to introduce redundancy between descriptions.

In this paper, MDTC–DWT–PCT and MDTC–DWT–HT image coders are described. Mathematical models of HT, Cascade structure of the PCT and an approach of estimation of lost coefficients are reviewed. Theoretical analysis of two coders is considered. The analysis was based on the evaluation of the correlation coefficient between descriptions as a function of the bit rate. To compare and analyze the performance of both approaches, in the case of four descriptions, seven images having different spectral characteristics have been used as test images. The performances were evaluated

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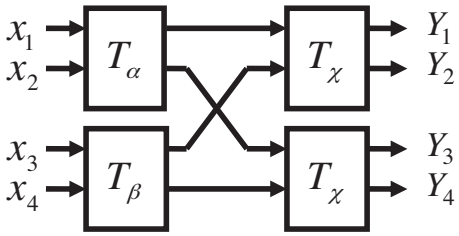

Fig. 1. Cascade structure of the correlating transform in case of 4 descriptions.

by using PSNR in the case of 2 bpp and PSNR according to bit rate for images reconstructions with different qualities. Results show that the proposed method provides correlation coefficient better than the one of conventional at all range of bit rate that leads to the superior performance, especially in the case of two packets lost.

2. Mathematical models of Hadamard Transform

The Hadamard transform was used to introduce redundancy among uncorrelated descriptions as the transform approach i.e. PCT. It is a special case of transforms based on Hadamard matrices. The Hadamard matrix of order 2 is defined by [6]:

$$H_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (1)$$

The Hadamard matrices of higher order can be generated recursively as follows:

$$H_n = H_{n-1} \otimes H_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} H_{n-1} & H_{n-1} \\ H_{n-1} & -H_{n-1} \end{bmatrix}, \quad (2)$$

where $\otimes$ is Kronecker product and n is positive integer.

A Hadamard matrix of order N is a $N \times N$ matrix H with entries are either +1 or −1 which satisfies the orthogonal condition [6]. Similarly, H_n is symmetric and orthogonal. Hence,

$$H = H^* = H^t = H^{-1}, \quad (3)$$

3. Pairwise Correlating Transform (PCT)

The Pairwise Correlating Transform (PCT) is one among methods that introduce redundancy between input uncorrelated variables. To generate two correlated descriptions, the correlating transform is defined as [3]:

$$T_\alpha = \begin{bmatrix} \alpha & \frac{1}{2\alpha} \\ -\alpha & \frac{1}{2\alpha} \end{bmatrix} \quad (4)$$

where T_α is a pairing transforms that are applied on 2×2 input vectors independent and identically distributed (i.i.d.), zero-mean Gaussian random vectors with different variances. The 2×2 input

Fig. 2. Lena image reconstruction via MDTC–DWT–PCT image coder with (a) 4 received packets, (b) 3 received packets, (c) 2 received packets, (d) 1 received packet.

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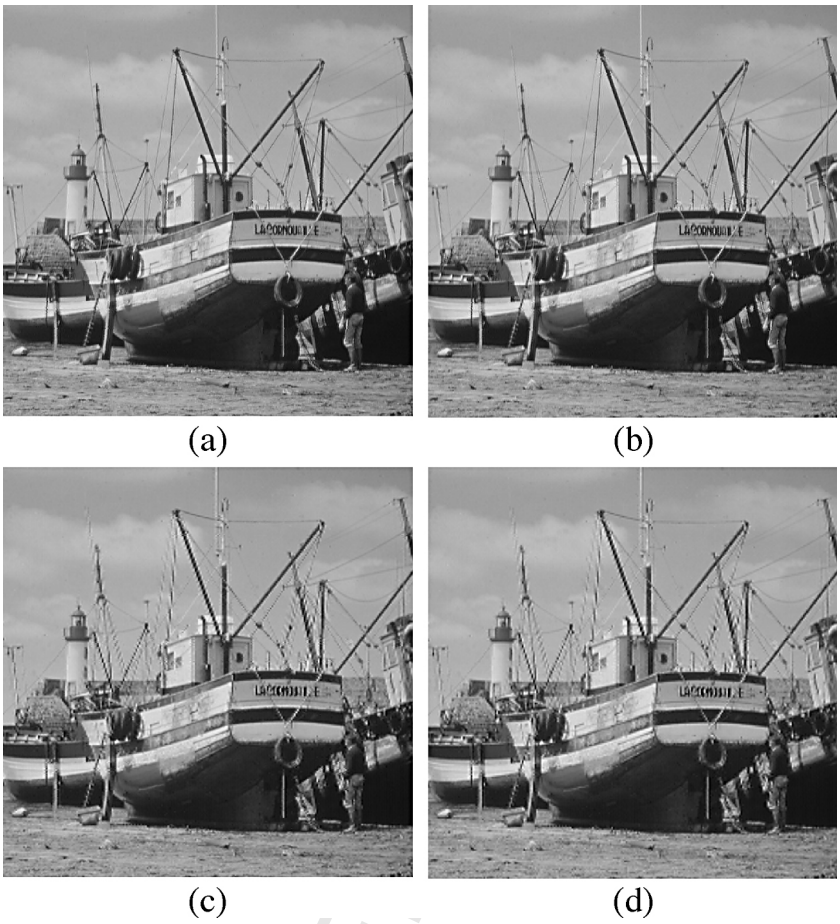

Fig. 3. Boats image reconstruction via MDTC–DWT–PCT image coder with (a) 4 received packets, (b) 3 received packets, (c) 2 received packets, (d) 1 received packet.

vectors were mapped to 2×2 correlated transform coefficients. In the case of four descriptions, the PCT is defined as [3]:

$$T = \begin{bmatrix} T_\chi & 0 \\ 0 & T_\chi \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} T_\alpha & 0 \\ 0 & T_\beta \end{bmatrix} \quad (5)$$

where parameters α, β and χ give a total redundancy and variance of the four correlated descriptions generated by PCT. A cascade structure of PCT used in Multiple Description Transform Coding (MDTC) is illustrated in Fig. 1.

4. Lost descriptions estimation

To estimate the lost descriptions, two scenarios were considered: one when the descriptions are transmitted without truncation and the other is the one where they are transmitted with losses [4].

4.1. Without truncation

Given an input signal, whose N components are assumed to be independent and identically distributed with zero-mean and Gaussian, is transformed and transmitted:

$$x = (x_1 x_2 \ldots x_N)^t \quad (6)$$

The input vector x is transformed to another vector z using an $N \times N$ orthogonal correlating transform T as:

$$z = Tx \quad (7)$$

where $z = (z_1 z_2 \ldots z_N)^t$ represents all transmitted components.

The original data x can be recovered from the received components z as:

$$x = T^{-1} z = T^t z, \quad (8)$$

4.2. With truncation

In this case, the vector $z = (z_1 z_2 \ldots z_N)^t$ is then truncated. Let's assume that the first k transformed components are transmitted and received and the other $(N-k)$ transformed components are erased, such as:

Received transformed components: $z_r = (z_1 z_2 \ldots z_k)^t$
Erased transformed components: $z_e = (z_{k+1} z_{k+2} \ldots z_N)^t$

So, the transformed components that must be received are:

$$z = Tx = (z_r z_e)^t \quad (9)$$

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Fig. 4. Lena image reconstruction via MDTC–DWT–HT image coder with (a) 4 received packets, (b) 3 received packets, (c) 2 received packets, (d) 1 received packet.

In reception, a replica of original x is reconstructed by using minimum Mean Square Error (MSE) as:

$$\hat{x} = E\left\{\frac{x}{z_r}\right\} = E\left\{\frac{T^{-1}Tx}{z_r}\right\} = T^{-1}E\left\{\frac{z}{z_r}\right\}$$

$$\hat{x} = T^{-1}E\left\{\frac{\begin{bmatrix} z_r \\ z_e \end{bmatrix}}{z_r}\right\} = T^{-1}\begin{Bmatrix} z_r \\ E\{z_e/z_r\} \end{Bmatrix} \quad (10)$$

where $E\{.\}$ is the expectation operator.

If the correlation matrix of z is partitioned in a way compatible with the partition of z as [9]:

$$R_z = TR_xT^t = \begin{bmatrix} R_1 & M \\ M^t & R_2 \end{bmatrix} \quad (11)$$

where R_x and R_y are the correlation matrix of vectors x and z respectively.

So,

$$E\left\{\frac{z_e}{z_r}\right\} = M^tR_1^{-1}z_r \quad (12)$$

From (10) and (12), the input vector $\hat{x}$ is estimated from the received components z_r as:

$$\hat{x} = T^{-1}\begin{Bmatrix} z_r \\ M^tR_1^{-1}z_r \end{Bmatrix} \quad (13)$$

5. MDTC–PCT–DWT image coder

The implementation of the MDTC–DWT based on PCT coder proceeds according to the following steps [10]:

- Subtract 128 from input image to distribute the pixel values in the range of [−128, 127].
- Transform the resulting image from spatial domain to frequency domain by using 2D-DWT.
- Quantize the DWT output coefficients (four subbands: LL1, HL1, LH1, and HH1).
- Vectorize the resultant four quantized subbands into four packets, each packet correspond one subband (Packet N° 1, 2, 3 and 4).
- Apply the correlating transform on the four uncorrelated packets using PCT to generate four correlated descriptions.
- Apply the entropy coded on the four obtained descriptions and transmitted over different channels.

At a receiver, the image was reconstructed by the inverse process. If the transmission was achieved without truncation, the estimation of transmitted components was obtained by using the first scenario mentioned in Section 4.1. In other hand, if the

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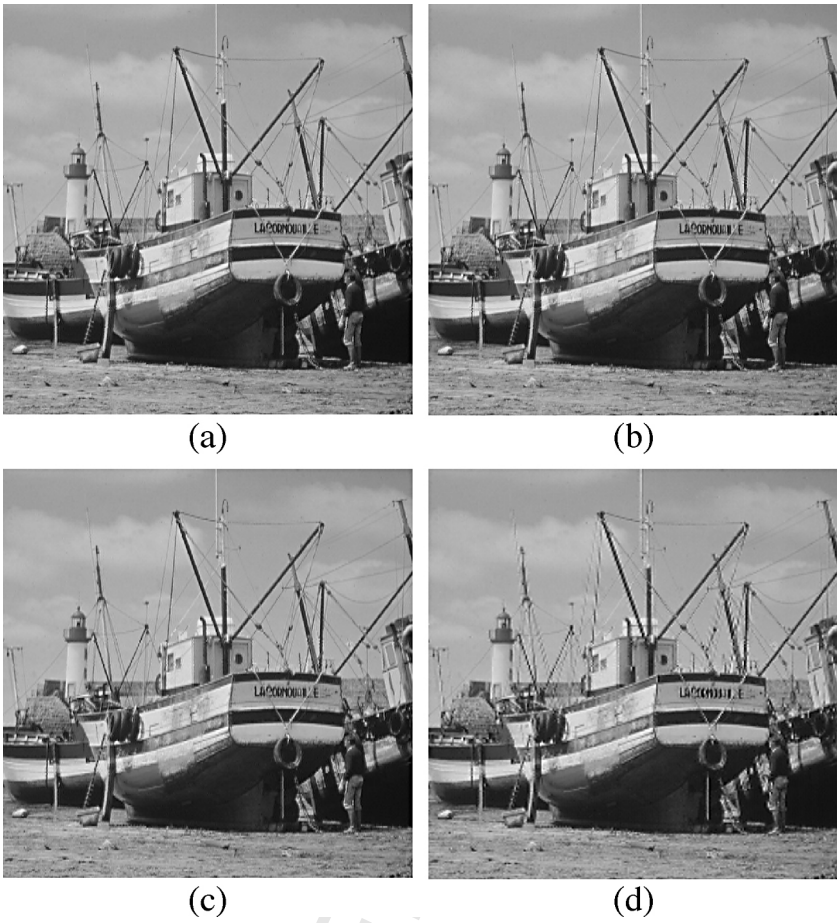

Fig. 5. Boats image reconstruction via MDTC–DWT–HT image coder with (a) 4 received packets, (b) 3 received packets, (c) 2 received packets, (d) 1 received packet.

transmission was achieved with truncation caused by transmission over packet erasure networks, the estimation of transmitted components was obtained by using the second scenario mentioned in Section 4.2.

6. MDTC–DWT–HT image coder

The MDTC based on the Discrete Wavelet Transform (DWT) and the Hadamard Transform (HT) is implemented according to the following steps:

- Subtract 128 from each block to distribute the pixel values in the range of [−128, 127]
- Transform the resulting image from spatial domain to frequency domain by using 2D-DWT.
- Quantize the DWT output coefficients (four subbands: LL1, HL1, LH1, and HH1).
- Vectorize of the resultant four quantized subbands into four packets, each packet correspond one subband (Packet N° 1, 2, 3 and 4).
- Apply the Hadamard Transform on four packets to generate four correlated descriptions.
- Apply the entropy coding on the four descriptions and transmit them over channels.

At a receiver, the above process was reversed to obtain an estimation of transmitted image according to one of the two hypotheses described in Section 4. A Block diagram of MDTC image coders based on PCT or HT is shown in Fig. 6.

7. Theoretical analysis of two coders

The MDTC is based on the encoding of an input data into many correlated descriptions. To analyze a performance of MDTC coder based on PCT or HT, we have calculated the correlation coefficient between descriptions as a function of the bit rate for seven 512×512 gray-scales test images having different spectral characteristics as shown in Fig. 7. This figure shows that the MDTC–DWT–HT is more efficient than MDTC–DWT–PCT in term of correlation coefficient at all range of bit rates. For example, at lower bit rate (0.4 bpp), the HT provides a correlation coefficient of 98.92% better than that obtained by using the PCT (97.75%). Similarly, at higher bit rate (2 bpp), the HT provides a correlation coefficient of 98.76% better than that obtained by using the PCT (97.74%).

The high correlation between the descriptions provides a low quality degradation of the reconstructed images in the case of packets loss. Therefore, the use of HT to introduce the redundancy between the descriptions has improved their correlation coefficient and the received descriptions become more robust in erasure channels.

8. Simulation results and discussions

To analyze the performance of the proposed coder, we conducted simulation experiments on seven 512×512 gray-scales

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Table 1
PSNR (dB) values for the descriptions obtained by using MDTC–DWT–PCT image coder.

Test images	Without loss PSNR (dB)	One packet lost (N° 2) PSNR (dB)	Two packets lost (N° 1 and 3) PSNR (dB)	Three packets lost (N° 2, 3 and 4) PSNR (dB)
Lena	42.9365	42.0068	31.8587	31.4648
Zelda	42.5279	42.2807	32.7240	32.4240
Crowd	40.9688	38.5140	30.5362	29.8199
Peppers	39.0196	36.8293	32.2958	30.9444
Girlface	39.7859	38.3715	31.0015	30.4502
Goldhill	39.0685	36.1040	29.7696	28.7772
Boats	40.3045	38.2607	29.3393	28.7330

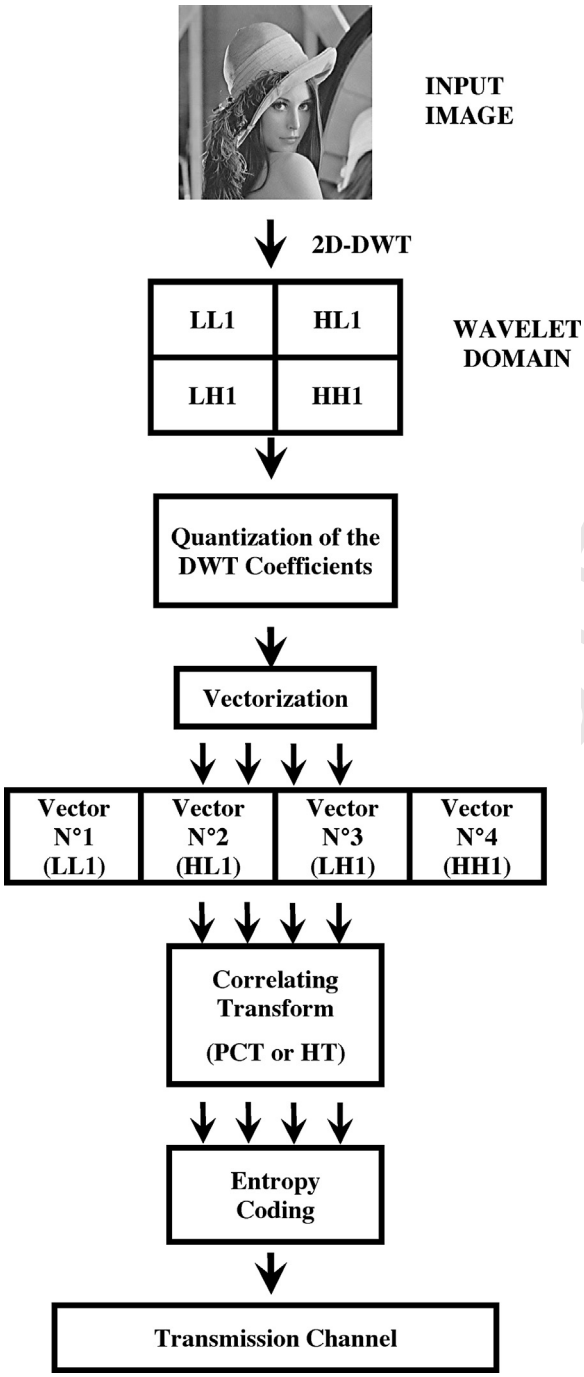

Fig. 6. Block diagram of MDTC image coders based on PCT or HT.

images having different spectral characteristics and compared the results with those of the conventional based on PCT in the case of four descriptions. The quantitative distortion of estimated descriptions was measured by peak-to-peak signal to noise ratio (PSNR) defined as:

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{255^2}{\mathrm{MSE}}\right) \quad (14)$$

where MSE is a mean square defined as:

$$\mathrm{MSE} = \frac{1}{M \times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}(I(i,j) - K(i,j))^2 \quad (15)$$

where M and N are the height and the width of the image respectively and I and K are the image source and its approximate, respectively.

We have measured the PSNR of the restored images in the cases of 0, 1, 2 and 3 descriptions dropped, each one has a bit rate of 2 bpp. The corresponding results are presented in Table 1 and Table 2 for MDTC–DWT–PCT and MDTC–DWT–HT coders respectively. In the case of lossless, these results show that the performance is very similar for both MDC coders. However, the performance of the proposed MDC coder is better than the conventional one in the case of loss (1, 2 or 3 packets). In addition, the results in Table 2 show that the best performance is obtained with Zelda image in the case of one packet lost (2 and 3 packets lost) and the worst one is obtained with the Boats image as it is confirmed by the visual quality of the reconstructed images (Figs. 2–5). In order to confirm the good performance of MDTC–DWT–HT, we have evaluated PSNR as a function of the bit rate for different qualities of reconstitutions. Results depicted in Fig. 8 shows that the MDTC–DWT–HT coder provides a slightly improvement on the MDTC–DWT–PCT coder in the case of one lost packet. In the case of two packets lost, the proposed coder shows a great improvement of 6–8 dB in relatively to

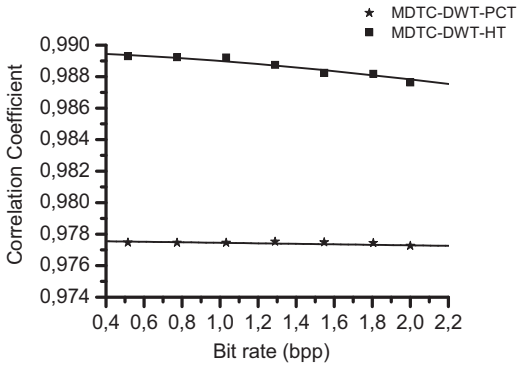

Fig. 7. Relationship between the correlation coefficient and the bit rate for MDTC based on PCT or HT.

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Table 2
PSNR (dB) values for the descriptions obtained by using MDTC–DWT–HT image coder.

Test images	Without loss PSNR (dB)	One packet lost (N° 2) PSNR (dB)	Two packets lost (N° 1 and 3) PSNR (dB)	Three packets lost (N° 2, 3 and 4) PSNR (dB)
Lena	42.9365	42.4925	40.1461	35.1318
Zelda	42.5279	42.2072	41.5112	35.4250
Crowd	40.9688	38.9940	33.0805	31.2146
Peppers	39.0196	36.3159	34.5128	31.2332
Girlface	39.7859	38.5462	36.2168	33.4791
Goldhill	39.0685	36.2738	32.3380	29.1021
Boats	40.3045	38.4830	35.1659	29.1305

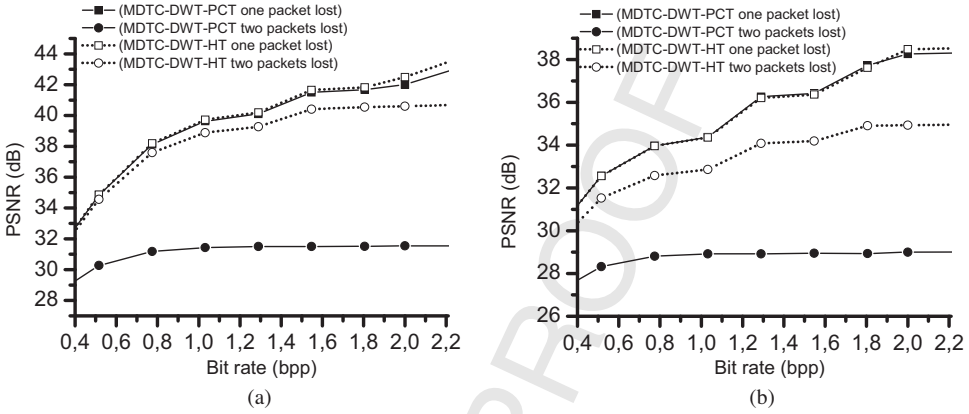

Fig. 8. PSNR as a function of the bit rate for (a) Lena image, (b) Boats image.

MDTC–DWT–PCT image coder. Likewise, the proposed coder offers a small degradation quality of reconstruction images between one packet lost and two packets lost to compare to results obtained by the conventional coder where the degradation was important. For example, at 2 bpp, the proposed coder makes a degradation of about 2.35 dB between one packet lost and two packets lost concerning Lena image. However, for the same image and bit rate, the conventional coder makes an important degradation of 10.15 dB. The small degradation quality of reconstruction obtained by the proposed method is due to HT has improved the correlation coefficient of PCT and descriptions become more robust in front of troubles of transmission channel (packets lost). Therefore, the proposed coder based HT outperforms totally the conventional coder based PCT.

9. Conclusion

In this paper, we considered a new scheme of MDTC based on Hadamard Transform for coding still images for the case of four descriptions. We carried out a comparative study of MDTC–DWT–PCT and MDTC–DWT–HT coders on seven images having different spectral characteristics. We showed that our proposed MDC scheme provides a high correlation between descriptions and achieves significant improvement over the classical MDC coder especially in the case of two packets lost. Therefore, the use of HT to introduce the redundancy between the descriptions has improved their correlation coefficient and the received descriptions become more robust in erasure channels. Likewise, in the proposed coder, the quality of the reconstructed images with two packets lost is slightly degraded compared to the quality of the reconstructed images with only one packet lost (2.35 dB). However, this degradation is higher in the conventional MDTC based PCT (10.15 dB). In addition, the proposed approach provides an easier practical implementation and lower computational complexity than the conventional approach. Therefore, the MDTC–DWT–HT coder completely outperforms the classical MDTC–DWT–PCT coder.

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