IJICT International Journal of Information & Communication Technology

ITRC

Volume 1- Number 3- July 2009 (pp.23-34)

A Novel Still Image Error Concealment Using Fragile Watermarking in Wireless Image Transmission and Packet-Switched Networks

Davood Bashiri
Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
davood.bashiri@gmail.com

Ali Aghagolzadeh
Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
aghagol@tabrizu.ac.ir

Javad Musevi niya
Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran.
niya@tabrizu.ac.ir

Mahdi Nooshyar
Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
nooshyar@tabrizu.ac.ir

Received: December 29, 2008- Accepted: July19, 2009

***Abstract*— In this paper, we propose a new error concealment method for covering up the high packet losses of an original image after its transmission through an error-prone channel. Our proposed technique utilizes Discrete Wavelet Transform (DWT) to produce a lower resolution copy of the original image. Then we embed some of discrete cosine transform (DCT) coefficients of this downsized replica of the original image into the original image in the spatial (pixel) domain inside macroblocks (MBs) as a watermark. This technique can be implemented for error-prone channels to combat degradations due to packets loss in a backward-compatible scheme.**

Keywords-Error concealment, Watermarking, Error-prone channels.

چکیده— در این مقاله یک الگوریتم جدید پنهان‌سازی خطا به منظور فائق آمدن بر نرخ بالای حذف بسته های اطلاعاتی در ارسال تصویر از کانالهای مستعد خطا ارائه می‌شود. روش پیشنهادی ما از تبدیل موجک گسسته به منظور تولید یک نسخه با وضوح کم از تصویر اصلی استفاده می‌کند. سپس برخی از ضرایب تبدیل کسینوس گسستهٔ نسخهٔ کوچک شدهٔ تصویر اولیه در تصویر اولیه و در فضای پیکسل و در داخل ماکروبلاکها، به عنوان واترمارک جاسازی می‌شود. این الگوریتم می‌تواند در کانالهای مستعد خطا، به منظور مواجهه با کاهش کیفیت به وجود آمده به واسطه حذف بسته های اطلاعاتی به شیوهٔ سازگاری با وضعیت کانال به کار گرفته شود.

I. INTRODUCTION

Wireless channels may face adverse conditions, especially burst error conditions where errors are likely to occur in clusters. Images transmitted over unreliable channels are highly prone to errors. Among the recent developed image and video coding techniques, the block based techniques have been proved to be the most practical ones and are adopted by the majority of the existing image and video compression standards such as JPEG, MPEG and H.264 [1]. But the block based image coding systems are vulnerable to the transmission impairment [1]. The produced distortion in transmitted images is usually repaired using some post processing techniques and these processes are called error concealment (EC).

EC techniques provide a simple framework to compensate the produced distortions without incurring additional delays and wasting bandwidth resources which are crucial for real-time applications over networks with limited resources. Utilizing data hiding techniques is a suitable approach to overcome these restrictions. In general, to help error detection and concealment at the decoder, a certain amount of redundancy must be added at the waveform-encoder, entropy-encoder or transport-encoder levels. We refer to such added redundancy as concealment redundancy. Fig. 1 illustrates qualitatively the dependency of the reconstructed image and video/image quality on the concealment redundancy and the channel error rate. Fig. 1 shows that as the channel error rate increases, larger percentage of the total bandwidth should be allocated for the concealment redundancy to achieve the better quality [2]. Forward Error Correction (FEC), Automatic Repeat reQuest (ARQ) and hybrid FEC/ARQ schemes may fail especially for the real time applications over channels with high error rates and/or with high propagation delays [3].

The human eye can tolerate only a certain degree of the distortion in image and video; thus EC methods aim to obtain a close approximation of the original signal or attempt to make the output signal at the decoder with the least objectionable to human eyes [2]. In order to alleviate the performance of communication systems, some different error resilient techniques have been proposed [4, 5]. However traditional error resilient techniques are not based on data hiding.

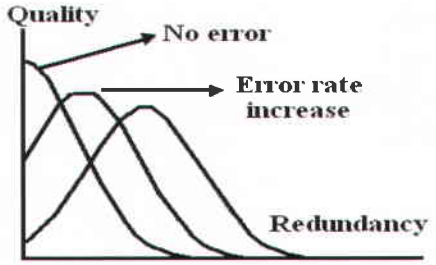

Figure 1: Relationship between the quality of the reconstructed video/image at the decoder and the amount of concealment redundancy employed under different channel error rates [2].

In watermarking based error concealment, some important data from a given image can be chosen and embedded in the image itself. The watermarked image is encoded and sent through the network. At the decoder, embedded data are extracted and the original image is reconstructed using the extracted watermark sets and some specific post processing algorithms. In this way we attempt to conceal channel errors. EC at the decoder requires error detection. A number of the error concealment algorithms presented so far have the capability to detect errors and some others should be used with appropriate error detection algorithms since this kind of algorithms can not detect errors by themselves.

In [6] for a given MB, a domain MB that has the best matching to this reference MB is determined. In [6], Gür determined a domain MB according to Best Neighborhood Matching (BNM) algorithm [1] and then embedded the domain MB addresses as watermark sets in wavelet transform coefficients. At the decoder, we can extract watermark sets as domain MB addresses. By replacing the lost MB by its domain MB we can achieve to the aim of EC. In [6] embedding is done in a way that if we loss a MB, it may be presumed that one or a few watermark sets are destroyed. Wrong extraction of the watermarks leads to incorrect replacing MB instead of the actual domain MB. In this case the reconstructed image becomes splotchy.

In [7], we proposed an error concealment algorithm based on the fragile watermarking. At the encoder, for any given MB, the BNM address is determined using BNM algorithm and this information is embedded into the original image. Unlike the previous introduced algorithms, this information is embedded in the spatial domain. Embedding is done by using a shared-key-dependent pseudorandom sequence. This key is produced at the encoder and the watermarks are extracted using this key at the decoder. By embedding watermarks in the spatial domain, if a packet is lost during transmission, the broken watermarks can be found, while the majority of the existing algorithms such as given in [6] do not have this capability. The algorithm proposed in [7] can be implemented for wireless channels and will achieve good subjective and objective performance compared with similar algorithms. But, in some exceptional cases, this algorithm is not fracture-proof against the broken watermarks.

In this paper a novel algorithm is proposed to conceal errors in still image and also to overcome the restriction of our previous work. This is done by applying fragile watermarking. This algorithm can be used for wireless channels that have high error rate. The wrong extracted watermark is detected immediately which is one of the distinguished characteristics of this algorithm. Unlike the former algorithms such as given in [6] which do not have much efficiency in such channels, due to fragility of

watermarking, this algorithm can have higher efficiency which is shown in this paper.

The next section describes the proposed EC algorithm in details. Section 3 presents channel model. The simulation results and the performance analysis and discussion are given in section 4 and 5 respectively. Finally, section 6 concludes this work.

II. THE PROPOSED ALGORITHM

Fig. 2 and Fig. 3 illustrate the block diagrams of the proposed EC method at the encoder and the decoder, respectively.

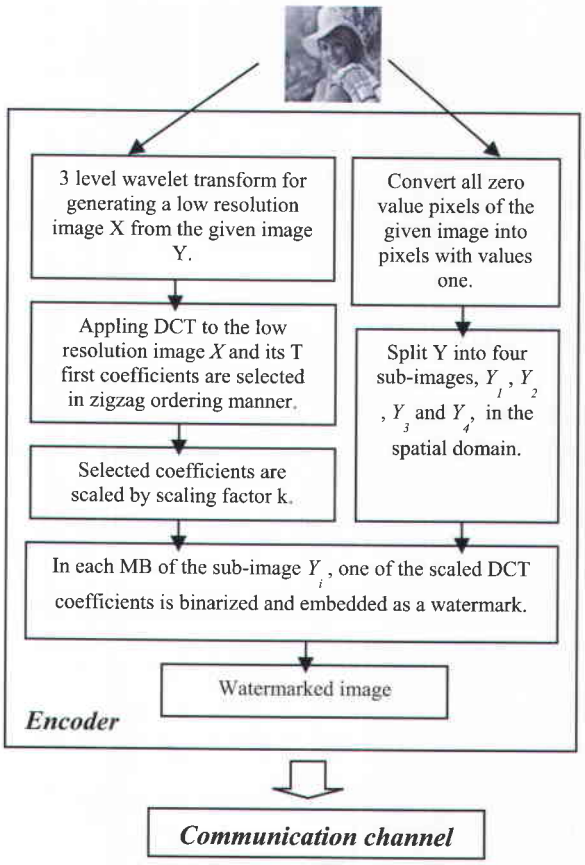

Figure 2: An illustration of the proposed algorithm at the encoder.

In our proposed algorithm, wavelet transformation is applied to the given image in order to produce a lower resolution copy of the image. We can also use a down sampling technique, but wavelet transformation is more appropriate due to filtering effects. We take three level wavelet transform from the original image and, we use LL_3 coefficients as a coarse and low resolution copy of the original image. Fig. 4 illustrates the position of LL_3 coefficients in the process of wavelet transformation. Also we use a scaling factor S to convert linearly the produced low resolution image pixel values into values between 0 and 255.

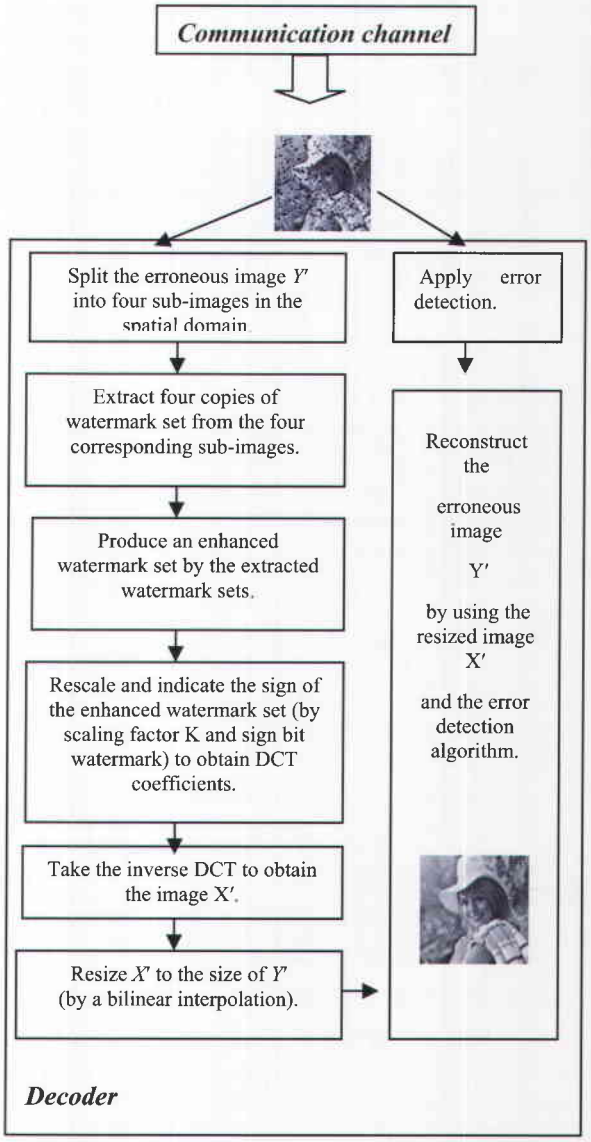

Figure 3: An illustration of the proposed algorithm at the decoder.

We called the low resolution gray level image obtained by the above mentioned 3-level DWT X. This image is used to produce the intended and necessary data which are embedded in the host image as a watermark. We take discrete cosine transform (DCT) of X. The DCT has two useful properties for image and video compression: energy compaction, concentrating the image energy into a small number of coefficients, and decorrelation, minimizing the interdependencies between coefficients. Then the first T coefficients of the transformation result are chosen in zigzag ordering manner. We embed these coefficients as intended data in the host image after quantizing and binarizing. Those coefficients which are not embedded will be considered zero at the decoder side. Since some of the DCT coefficients, such as DC or some other AC coefficients, have high values and a large number of bits is necessary to represent and embed them, a scaling factor K (K>1) is used to reduce the coefficients' values. Selected

coefficients are embedded in the spatial domain in the original host image to be transmitted. For this purpose, we use a pseudorandom key that is generated at the encoder. Embedding is done by splitting the host image Y into four sub-images Y_1, Y_2, Y_3 and Y_4 (Fig 5). Selected DCT coefficients are embedded correspondingly in all four sub-images, so by losing a watermark in one of them, the corresponding watermark can be extracted from the other sub-images and in this way we remedy the fragility aspect of algorithm.

In order to localize the effects of channel error due to loosing or breaking watermarks, besides embedding watermarks in the spatial domain, we embed them in each sub-image only in a single MB. In this manner if a packet is lost during transmission, the corresponding watermarks are extracted (based on the proposed approach) as zero. Therefore, we extract the corresponding watermarks from the other sub-images.

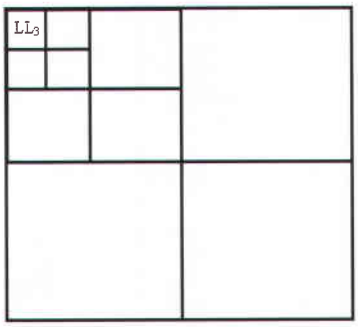

Figure 4: Position of LL_3 coefficient in wavelet transformation.

Since the scaled DCT coefficients have a great range, allocating the same number of bits for all of them and embedding many zeros for small coefficient values may result in increasing the watermarking distortion of the host image. Furthermore, if we extract these watermark bits as one, instead of zero, the main advantage of the desired can be overshadowed. Therefore we should use different number of bits for each DCT coefficient in order to control the watermarking distortion and also the extraction errors. In this way, we assign large number of bits for high value coefficients and small number of bits for low value coefficients. Using this approach may result in producing pseudorandom key which is appropriate with matrices' dimensions. The pseudorandom key determines the pixels of the given MB which the intended data should be embedded. Since the DCT coefficients may be positive or negative, we can consider a sign bit in watermark data. If we are aware of the watermarking algorithm at the encoder, extracting the embedded watermark requires the knowledge of the pseudorandom keys, the matrix dimensions, the scaling factor S (in the spatial domain), the scaling factor K (for DCT coefficients) and the definition of the sign bit. So by hiding and encryption of this information, we can achieve a high level of security in bits streaming through the employed network.

In order to apply the error detection algorithm, before embedding the watermark, we should change the value of all zero value pixels to one. The resultant distortion of this process will not be recognized by naked eyes.

If a MB is received at the decoder with all zero value pixels, certainly this MB has been lost. So its watermarks (that according to the proposed approach have been extracted as zeros) prove to be unimportant and the corresponding watermark can be extracted by three other sub-images.

Figure 5: Splitting the host image into four sub-images.

A. Encoder

The following processes are done in the encoder side:

Stage 1: Read the original image Y, with size of $[N_1 \times N_2]$.

Stage 2: Generate the low resolution image X from the given image Y using DWT as described before.

Stage 3: DCT transformation is applied to the gray level image X and then the first T transformed coefficients are selected by a zigzag ordering manner. The number T is chosen so that the number of the selected coefficients is a quarter of total number of MBs within the given image Y. In this way, we can embed the selected and scaled coefficients in all four sub-images of the image Y.

Stage 4: In this stage, we convert all zero value pixels of image into pixels with values one.

Stage 5: We split the given image Y into four sub-images Y_1, Y_2, Y_3 and Y_4 in the spatial domain.

Stage 6: In each MB of the sub-image Y_i , one of the binarized DCT coefficients is embedded as a watermark.

The embedding process is done as follows:

```
If (W(j) == 1)
        P(i) = max (p(i), p(i+1), p(i+2), p(i+3),
        p(i+4)) +TH ;
Else if (W(j) == 0)
        P(i) = min (p(i), p(i+1), p(i+2), p(i+3),
        p(i+4)) -TH ;
End
```

where p(i) is the ith pixel of zigzag ordering in MB, and i is jth element of A(j) which the later is the shared key dependent pseudorandom permutation of the pixels ; W(j) is the jth element of binarized DCT coefficient vector constituting the watermark and TH is a threshold value as described later.

It should be noted that W(end) (the last bit) is a sign bit and, by definition of the encoder and the decoder, it can be used for network security purposes.

Embedding in each MB is done in the spatial domain by arranging pixels of MB in zigzag ordering manner. This is done to avoid creation of several adjacent pixels with the same values. But it is still possible that five successive pixels have the same values and cause problem in watermark extraction. Since the maximum or the minimum value of five equal values is equal to one of them, therefore we can not determine the correct watermark in the extraction process. Therefore, we increase and decrease, respectively, the maximum and the minimum values by a threshold value, TH. Choosing high values for TH ensures the correct extraction of watermark but the watermarking distortion increases. Therefore in our simulations, we use TH equal to 1. We are aware that the original image is a gray level still image with pixels' values from 0 to 255. So, after pixels' values manipulation, this restriction must be applied.

B. Decoder

The following processes are done in the decoder side:

Stage 1: Read the erroneous received image Y'.

Stage 2: Split Y' into four sub-images in the spatial domain.

Stage 3: By generating the same shared-key dependent pseudorandom sequence which was used in the encoder, the watermark extraction algorithm is performed separately on each of four sub-images.

The extracting process is done as follows:

If { PR(j) > (median (PR(i), PR(i+1), PR(i+2), PR(i+3), PR(i+4)) }

WR(j) = 1

Else

WR(j) = 0

End

where PR(i) is ith pixel of zigzag ordering in MB, i is jth element of A(j), WR(j) is the jth element of the extracted binarized DCT coefficients constituting watermark.

According to the above extraction algorithm, if one MB is lost, its watermark is immediately extracted as zero which is one of the distinguishing characteristics of this algorithm.

Stage 4: From four sub-images Y_1, Y_2, Y_3 and Y_4, four collections of watermarks are extracted. By converting the binarized extracted watermarks into decimal values and applying the sign bits to them, we obtain four matrices W_1, W_2, W_3 and W_4 (the extracted watermarks from four subimages) of DCT coefficients. We form matrix W in which any zero value element of matrix W_i is replaced by corresponding non-zero value element(s) of the other three matrices (if it is available). In this way, we replace a zero value extracted watermark with its correct value.

[i, j] = size W_1;

For K=1: i

For L=1: j

W(K,L) = non_zero_value{ W_1(K,L), W_2(K,L), W_3(K,L), W_4(K,L) };

End

End

In this way, we replace zero extracted watermarks with their correct values (provided that they will be available on the other three subimages).

Stage 5: Rescale the element of matrix W by the scaling factor K.

Stage 6: Take inverse DCT transform from DCT coefficients matrix W. In this way we reconstructed the low resolution image X'.

Stage 7: By applying a bilinear interpolation (the output pixel value is calculated as a weighted average of pixels in the nearest 2-by-2 neighborhood) the dimensions of the image X' are adjusted to have the same dimensions of image Y'.

Stage 8: We would look for the lost MB in image Y' (if a MB has zero value pixels, it has been lost).

Stage 9: Replace the lost MB(s) by its (their) corresponding MB(s) in the resized image X'.

III. CHANNEL MODEL

When data is transferred over a channel with burst errors, in analyzing the communication performance, the packet error statistics are more important than the bit error statistics [8]. Error modeling for such channels can be done using the simple Gilbert-Elliot model [9].

Error-prone channel in this paper is modeled as a two-state discrete-time Markov process with Gilbert model as illustrated in Fig. 6. Packets belonging to an image are fully corrupted in the bad channel state (Ploss,b≈1) while the probability of the packet losses in the good channel state is negligibly small (Ploss,g≈0). We assume that the packet losses are in consecutive order based on the given transition probabilities. Even though this simplified model does not capture all details of a fading channel, it does

provide a robust model for wireless channels with burst-error characteristics, such as satellite links. In our simulations, the state transition probabilities are adjusted in a way that the desired level of packet loss is achieved. Due to the fading dynamics of an error-prone channel and/or the bottle neck at the transmitter, this scenario may be highly expected in various applications.

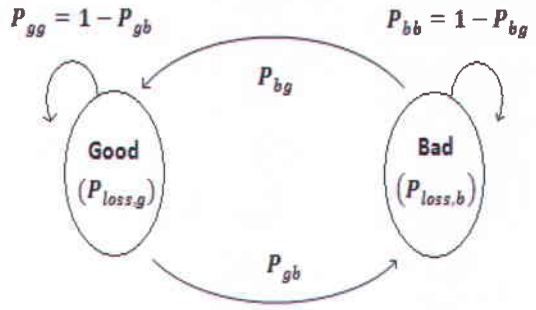

Figure 6: Gilbert channel model. Subscript b is for the bad state, whereas g stands for the good state and p_{ij} is the transition probability from state i to state j where i, j ⊂ {b, g} [9].

IV. SIMULATION RESULTS

Our experiments were conducted on some benchmark gray-scale images such as "Lena", "Elaine" and "Barbara" of size 512×512 for providing quantitative results of EC method proposed in this paper. Peak-signal-to-noise-ratio (PSNR) is employed as the performance metric analysis witch is defined for the reconstructed image as follows:

$$PSNR = 10\log_{10}\frac{(255)^2}{\frac{1}{N_1 \times N_2}\sum_{i=1}^{N_1}\sum_{j=1}^{N_2}(X(i,j)-Y(i,j))^2}$$

Where N_1 and N_2 is the number of pixels in each row and column of the image, respectively, and X(i,j) and Y(i,j) are pixel values in the original and the reconstructed images, respectively. The maximum value for the pixel values is assumed to be 255.

Each MB has a size of 8×8 pixels. Thus, there were 4096 MBs in image. So, we chose T as 1024 in our experiment. The wavelet used for DWT is reverse biorthogonal wavelet. The parameters for Gilbert channel model are set so that we obtain the desired percentage of MBs lost during transmission. The original Lena image is shown in Fig. 7. Fig. 8 shows the result of three levels wavelet transformation of the original image to produce a low resolution replica of the original image at the encoder side. Fig. 9 shows the watermarked image which is the output of the encoder and to be sent through the channel. Fig. 10 shows the erroneous image which is received through the channel and is the input to the decoder. Four produced sub-images of the extracted watermarks, W_1, W_2, W_3 and W_4 on the decoder side after rescaling and inverse DCT are shown in Fig. 11. The combination of four extracted watermarks as described in Section II.B followed by rescaling and inverse DCT leads to the reconstructed version of the low resolution image, X', is shown in Fig. 12. The reconstructed low resolution image X' is resized which we call it X" is shown in Fig. 13. The reconstructed image by the proposed algorithm in this paper is shown in Fig. 14. Figures 15 through 22 are related to the Elaine image corresponding to figures 7 through 14, as described above. The reconstructed image by simulation of the method given in [6] for Elaine image with 10% of block loss is shown in Fig. 23. The PSNR of the received erroneous image for Elaine shown in Fig. 18 is 15.0063. PSNR value of our reconstructed image from Fig. 18 shown in Fig.22 is 32.0339. The PSNR value of the reconstructed image by method given in [6] shown in Fig. 23 is 26.4437. We have conducted similar experiments for Barbara image. The corresponding images are not shown due to lack of space but the quantitative results are discussed in the next sections.

V. PERFORMANCE ANALYSIS AND DISCUSSION

The quantitative results for our proposed algorithm for "Elaine", "Lena" and "Barbara" for block loss rate ranging from 2.5% to 30% are given in Table 1. For each case, the damaged image is the image received at the output of the erroneous channel. The watermarked image is the image at the output of encoder and the input image to the erroneous channel. The error concealed image is the final reconstructed image. All PSNR values are calculated with respect to the original image. The PSNR performances are plotted in Fig. 24, Fig. 25 and Fig. 26. Some of the reconstructed images are shown in Fig. 14, Fig. 22 and Fig.23.

For comparison, the reconstruction results of the dc concealment, direct BNM and 1-order BNM results proposed in [10] for "Barbara" is given in Table 2. It should be noted that the algorithm proposed in [10] is not based on data hiding; therefore in this kind of error resilient techniques there is no watermarking distortion, i.e. the input image the erroneous channel is the original image.

Comparing the results shown in Table 1 and Table 2 reveals that the algorithm given in [10] performs substantially better. The algorithm given in [10] is based on five consequent steps including fetching, searching, matching, competing and recovering. Naturally, these five stages induce a high burden of computational complexity. On the other hand, two main computations in our algorithm are DWT and DCT which can be implemented by fast algorithm. Therefore the computational complexity of our algorithm is relatively low. Moreover, in our algorithm, the major computational complexity is shifted to the encoder side. This capability can be useful for broadcasting applications which can be the extension of our works for video signals. For

improving our proposed algorithm performance, we can use watermarking algorithms with less distortion and visible effects on the watermarked image. Watermarking based error concealment algorithms are very fast compared to the traditional error concealment algorithms which are not based on data hiding. For example in [1], to recover the lost MBs, a searching procedure is applied within a large range in the image in the decoder side. The purpose of such full searching procedure is to find a good N×N block (no pixel is missing) in the image that can best approximate the matching part of the range block through an appropriate blockwise luminance transformation. The mean square error (MSE) between the transformed domain block and the range block in the matching part is used as a criterion to evaluate the matching result. Each of the candidate domain blocks in the image will result in its corresponding MSE.

In watermarking based algorithms, more computational complexity is shifted to the encoder side but they have a little inferior performance. Furthermore, in watermarking based algorithms we use the original image for watermark production whereas traditional error concealment algorithms such as [1] used the damaged image at the decoder side to find the appropriate corresponding block.

VI. CONCLUSION

The experimental results indicate that the proposed scheme in this paper is a promising image restoration technique which may enable image transmission systems to cope with burst error channel conditions of wireless and packet-switched networks. A fragile watermarking algorithm based on DCT and DWT was introduced which has structural compatibility with the current and the upcoming image/video compression standards. For security aspect of the proposed scheme, a pseudorandom sequence generated by a key was used to effectively encrypt the watermark. The simulation results indicate that this algorithm provides significant improvement over the existing watermarking based algorithms in terms of both subjective and objective evaluations.

Figure 7: The original "Lena" of size 512 by 512.

Figure 8: Three levels of wavelet transformation for the original image to produce a low resolution replica of the original image.

Figure 9: The watermarked image to be sent through the channel.

Figure 10: The received erroneous image with 10% of MBs lost and PSNR = 15.52.

Figure 11: Four produced sub-images of the extracted watermarks, w_1, w_2, w_3 and w_4 after rescaling and inverse DCT.

Figure 12: The low resolution image X', produced by rescaling and inverse DCT of w.

Figure 13: The resized image X''.

Figure 14: Our reconstructed image after error concealment of Fig. 10; PSNR=30.5964.

Figure 15: The original "Elaien" of size 512 by 512.

Figure 16: Three levels of wavelet transformation for the original image to produce a downsized replica of the original image.

Figure 17: The watermarked image to be sent through the channel.

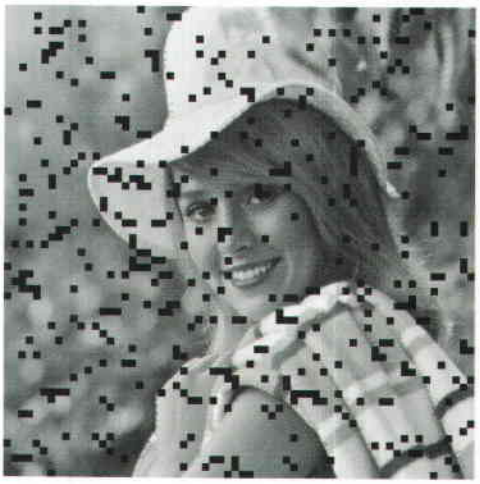

Figure 18: The received erroneous image with 10% of MBs lost and PSNR = 15.0063.

Figure 19: Four produced sub-images of the extracted watermarks, w_1, w_2, w_3 and w_4 after rescaling and inverse DCT.

Figure 20: The low resolution image X', produced by rescaling and inverse DCT of w.

Figure: 21 The resized image X''.

Figure 22: Our reconstructed image after error concealment of Fig. 18; PSNR=32.0339.

Figure 23: The reconstructed image after error concealment of Fig. 18, by the method given in [6]; PSNR= 26.4437.

Table 1: PSNR performance for our EC algorithm with block loss rate ranging from 2.5% to 30%.

Images		Block Loss Rate								
		2.50%	5.00%	7.50%	10.00%	12.50%	15.00%	17.50%	20.00%	30.00%
"Lena"	Watermarked Image	31.32	31.32	31.32	31.32	31.32	31.32	31.32	31.32	31.32
	Damaged Image	20.85	18.62	16.58	15.52	14.58	13.72	13.43	12.54	10.76
	Error Concealed Image	31.15	30.90	30.72	30.59	29.73	29.15	29.32	28.20	25.29
"Elaine"	Watermarked Image	33.53	33.53	33.53	33.53	33.53	33.53	33.53	33.53	33.53
	Damaged Image	20.27	17.83	16.00	15.00	13.69	13.12	12.88	12.00	10.35
	Error Concealed Image	33.01	32.73	32.30	32.03	31.57	31.24	30.52	30.06	27.91
"Barbara"	Watermarked Image	28.45	28.45	28.45	28.45	28.45	28.45	28.45	28.45	28.45
	Damaged Image	20.98	18.10	16.43	15.86	14.37	13.82	13.36	12.67	11.10
	Error Concealed Image	28.13	27.95	27.65	27.36	26.81	26.80	26.46	26.26	24.10

Table 2: PSNR performance for different EC methods with block loss rate ranging from 2.5% to 15% [10].

Error Concealment Algorithm	Block Loss Rate					
	2.5 %	5.0 %	7.5 %	10.0 %	12.5 %	15.0 %
without concealment	22.8 dB	19.4 dB	17.7 dB	16.4 dB	15.3 dB	14.6 dB
dc concealment	36.6 dB	32.9 dB	31.4 dB	30.0 dB	29.2 dB	28.0 dB
direct BNM	41.1 dB	39.0 dB	36.3 dB	35.7 dB	33.6 dB	32.3 dB
1-order BNM	41.8 dB	39.6 dB	37.6 dB	37.1 dB	35.0 dB	33.2 dB

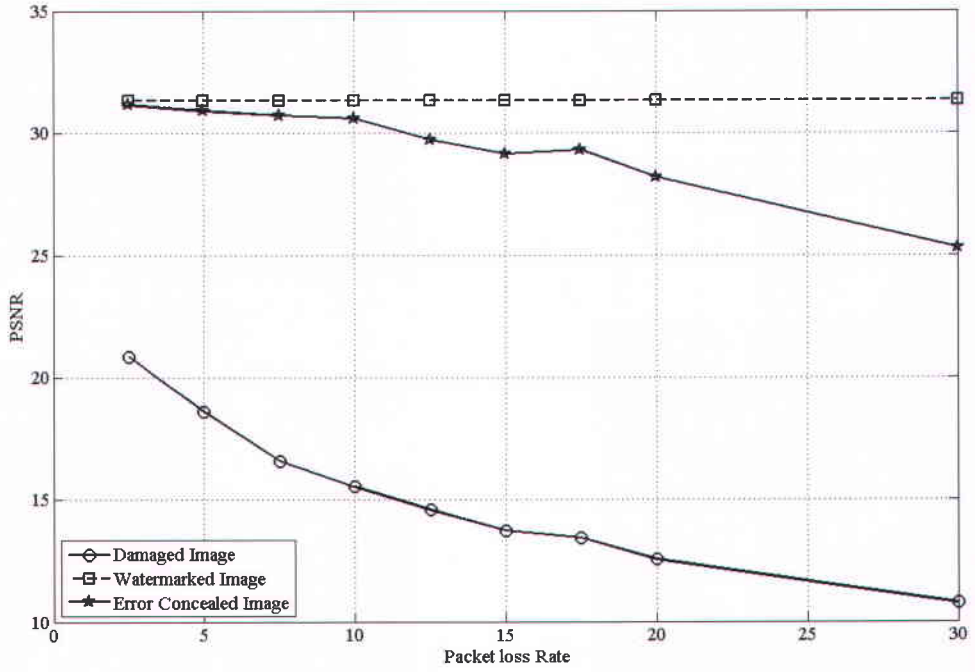

Figure 24: PSNR performance for our algorithm for "Lena".

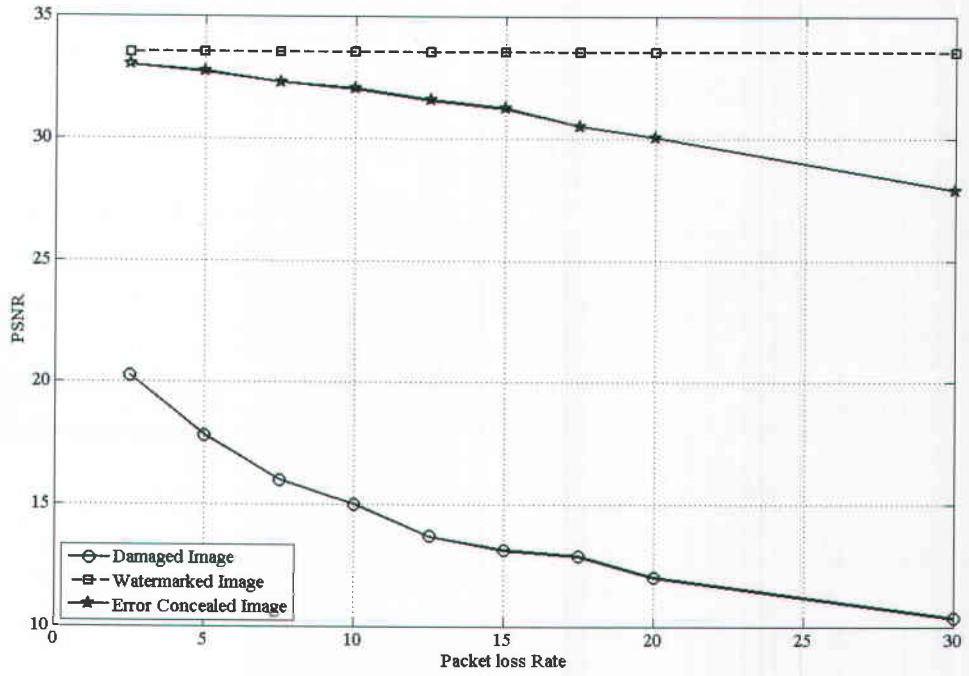

Figure 25: PSNR performance for our algorithm for "Elaine".

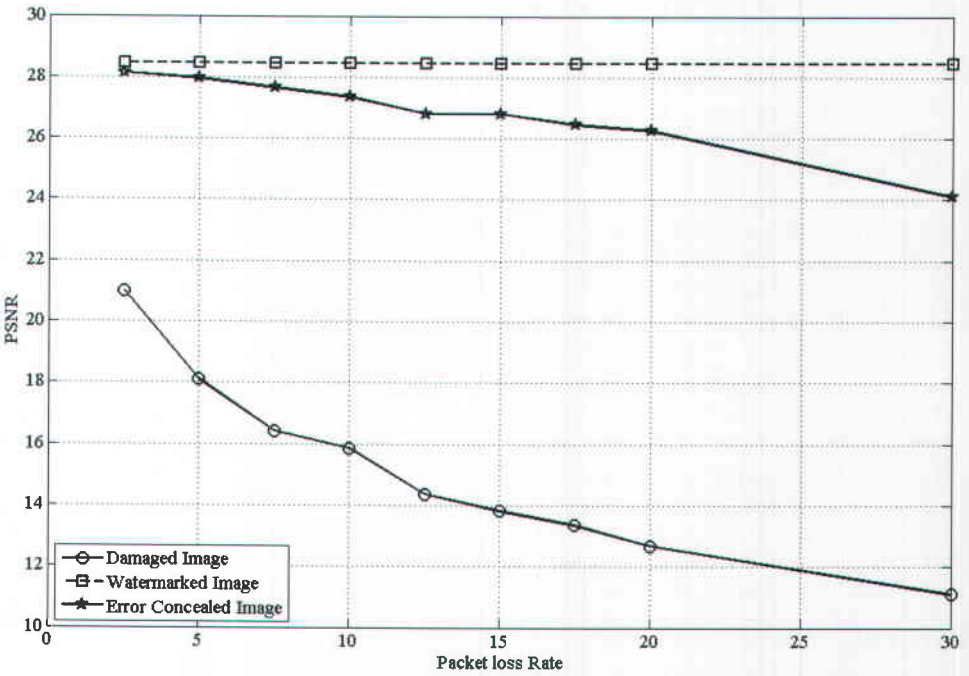

Figure 26: PSNR performance for our algorithm for "Barbara".

ACKNOWLEDGEMENT

The authors would like to thank the anonymous reviewers for their valuable comments and recommendations to enhance the content of the paper. The authors would also like to thank Iran Telecommunication Research Center, Tehran, Iran, for partially supporting this research.

REFERENCES

[1] Z. Wang, Y. Yu and D. Zhang, "Best Neighborhood Matching: An Information Loss Restoration Technique for Block-Based Image Coding Systems," IEEE Transactions on Image Processing, Vol. 7, No.7, pp.1056-1061, July 1998.

[2] Y. Wang and Q. F. Zhu, "Error Control and Concealment for Video Communication: A Review," Proceeding of IEEE, Vol. 86, No. 5, pp. 974-997, May 1998.

[3] J. Zhu and S. Roy, "Performance of land mobile satellite communication (LMSC) channel with hybrid FEC/ARQ," in *Proc. GLOBECOM'02*, pp. 2851–2854, 2002.

[4] I. Moccagaua, S. Soudagar, J. Liang and H. Chen, "Error-Resilient Coding in JPEG-2000 and MPEG4," IEEE Journal in Selected Area in Communications, Vol. 18, No.6, pp. 899-914, 2000.

[5] Y. Wang, S. Wenger, J. Wen and A. G. Katsaggelos, "Error resilient video coding techniques," IEEE Signal Processing Magazine, Vol. 17, No. 4, pp. 61-82, July 2000.

[6] G. Gür, F. Alagöz and M. Abdel-Hafez, "A novel error concealment method for images using watermarking in error-prone channels," in Proc 16th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC'05), 2005.

[7] D. Bashiri, A. Aghagolzadeh, J. Museviniya, and M. Nooshyar, " Still Image Error Concealment Using Fragile Watermarking Based on BNM Algorithm for Wireless Channels," 5th Iranian Conference on Machine Vision and Image Processing, MVIP2008, University of Tabriz, Tabriz, Iran, November 4-6, 2008 (in Persian).

[8] C. Jiao, L. Schwiebert and B. Xu, "On Modeling the Packet Error Statistics in Bursty Channels," in Proc. 27th Annual IEEE Conference on Local Computer Networks (LCN02), pp. 534-541, Florida, USA, November 2002.

[9] E. N. Gilbert, "Capacity of a Burst-noise Channel," Bell System Technical Journal, Vol. 39, pp. 1253-1265, September 1960.

[10] D. Zhang, Y. Yu and Z. Wang, "Image Information Restoration Based on Long-Range Correlation", IEEE Transactions on Circuit and Systems for Video Technology, Vol. 12, No.5, pp.331-341, May 200

Davood Bashiri received his B.S. degree from Islamic Azad University of Qazvin, Qazvin, Iran, in 2005 and M.Sc. degree from University of Tabriz, Tabriz, Iran, in 2008, both in Electrical Engineering. His research interests are Image Processing, watermarking and wireless communication systems.

Ali Aghagolzadeh received B.S. degree from University of Tabriz, Tabriz, Iran, in 1985 and M.Sc. degree from Illinois Institute of Technology, Chicago, IL, USA, in 1988 and Ph.D. degree from Purdue University, West Lafayette, IN, USA, in 1991 all in Electrical Engineering. He is currently a professor of Electrical Engineering at University of Tabriz. His research interests are Digital Signal and Image Processing, Image Coding and Communication, Computer Vision, Image Analysis, and Human - Computer Interaction.

Javad Musevi Niya was born in Ahar, Iran. He received his B.S. degree from the University of Tehran and his M.Sc. and Ph.D. Degrees both in communications from Sharif University of Technology (SUT) and the University of Tabriz, respectively. Since September 2006, he has been with the Faculty of Electrical and Computer Engineering of the University of Tabriz. His current research interests include wireless communication systems, multimedia networks and signal processing for communication systems.

Mahdi Nooshyar received his B.S. degree in Electrical Engineering in 1996 from University of Tabriz, Tabriz, Iran, and the M.Sc. degree in Electrical Engineering in 1998 from Tarbiat Modarres University, Tehran, Iran. He is currently pursuing the Ph.D. degree in Electrical Engineering in University of Tabriz. His current research interests include information and coding theories, distributed and multiterminal source coding, image coding and communication, and wireless communications.