# Error Concealment using Data Hiding in Wireless Image Transmission

Ali Akbari, Habibollah Danyali, Maria Trocan, and Bertrand Granado

*Abstract* — **The transmission of image/video over unreliable medium like wireless networks generally results in receiving a damaged image/video. In this paper, a novel image error concealment scheme based on the idea of data hiding and Set Partitioning In Hierarchical Trees (SPIHT) coding is investigated. In the encoder side, the coefficients of wavelet decomposed image are partitioned into "perfect trees". The SPIHT coder is applied to encode each per-fect tree independently and generate an efficiently compressed reference code. This code is then embedded into the coefficients of another perfect tree which is located in a different place, using a robust data hiding scheme based on Quantization Index Modulation (QIM). In the decoder side, if a part of the image is lost, the algorithm extracts the embedded code for reference trees related to this part to reconstruct the lost information. Performance results show that for an error prone transmission, the proposed technique is promising to efficiently conceal the lost areas of the transmitted image.**

*Keywords* — **Wireless networks, Error Concealment, Data hiding, SPIHT, Image transmission.**

## I. INTRODUCTION

In recent decades, major advances in image/video communications have been developed based on modern compression algorithms. On the other hand, when an image is transmitted over communication channels, it is generally exposed to packet loss due to channel impairments. Since the packet loss dramatically affects the perceptual quality of the received image/video, designing a robust transmission system is needed to ensure reception of high quality image. Two common techniques to deal with packet losses are forward error correction (FEC) and automatic retransmission query (ARQ) protocols. These methods decrease data transmission rates and increase the network congestion. To overcome these problems, error concealment methods have been introduced.

Many studies have been conducted in the area of error concealment. A group of methods are based on the interpolation in space or transform domain [1]-[3]. In these methods, the lost areas will be recovered using the other successfully received information. In general, these methods have high computational complexity and require a long-time processing. Therefore, they are not suitable for real-time applications such as video-on demand and real-time video multicast system.

The error concealment techniques based on data hiding have recently been introduced. G. Gur et al. [4] investigate an error concealment technique in the transform domain. This method embeds the replica of the original image in the subbands except LL subband. Adsumili et al. [5] propose an error concealment algorithm in the transform domain that involves embedding a binary version of each image into itself using a spread-spectrum scheme. Phadikar et al. [6] propose an error concealment algorithm that is a combination of the interpolation and data hiding methods. This method extracts important features of image such as edges, and embeds into the host using the Quantization Index Modulation (QIM) schemes. The QIM based embedding methods have a remarkable performance in terms of a tradeoff between rate, distortion and robustness. Chen Et al. [7] show that QIM method can provably achieve a better rate-distortion-robustness tradeoff than existing popular spread methods.

One important step in error concealment systems based on data hiding is the generation of a reference image with a high quality and low bit rate for the original host image. The generated reference image is embedded into the host image. Blouck et al. [8] use Discrete Wavelet Transform (DWT) to decompose the original image to several subbands. They consider the coefficients of the lowest low-frequency subband as the reference image. Adsumili et al. [5] generate the reference image using the half-toning operation which is performed on a DWT coefficient, and at the receiver they use an inverse half-toning operation. Lin et al. [9] applied Discrete Cosine Transform (DCT), and then DC components plus some certain AC coefficients are selected as the reference image. The above methods consider low frequency coefficients only, therefore the reference image doesn't have a high quality.

The bitstream of Set Partitioning In Hierarchical Trees (SPIHT) coder [10] has a variety of good characteristics such as good image quality at a very low bit-rate and decoding ability at any point of bitstream (embedded bitstream). These important characteristics lead us to use this coder as a good candidate for generation of the reference image. Specifically, embeddedness property of

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the bitstream enables us to provide better protection for more important bits which are located in the beginning parts of the SPIHT bitstream. The basic idea of the proposed algorithm is to use the SPIHT coder to generate a good reference image of the original image with a high quality and low bit rate. On the other hand, the output bitstream of SPIHT coder is very sensitive to bit errors. In this paper, we use the Error-Resilience SPIHT (ER-SPIHT) coder [11]; a version of the SPIHT coder that is resistant to bit errors. The generated reference image is embedded into the original image in DWT domain using QIM scheme. At the receiver, the reference image is extracted and used to reconstruct the corrupted information of the original image.

The rest of this paper is organized as follows: section 2 provides the background, including a review of the SPIHT and ER-SPIHT coders. In section 3, details of the proposed scheme are presented. Simulation results are presented in section 4. Finally, concluding remarks are made in section 5.

## II. Background

### A. Overview of Set Partitioning In Hierarchical Trees (SPIHT) coder

The wavelet-based image/video compression schemes have been increasingly developed, such as JPEG2000 still image compression standard and the SPIHT algorithm for image andH.264, MPEG-x standards for video. Among the wavelet-based image coding methods, the SPIHT algorithm is widely used as a popular tool for embedded wavelet image coding because of its compression efficiency and low complexity.

It is well known that the coefficients of the wavelet transform exhibit self-similarity property across subbands at the same spatial orientation. The SPIHT algorithm defines a 'spatial orientation tree' as a group of wavelet coefficients that root of the tree is in the lowest frequency subband and each node has either no offspring or four offsprings in the same spatial orientation in the higher frequency subband. Fig. 2 shows a spatial orientation tree. The SPIHT algorithm starts by scanning the low-frequency wavelet coefficients and proceeds gradually to higher-frequency coefficients. During the scan, algorithm sorts the wavelet coefficients into a decreasing order of magnitude and transmits the ordered coefficients bitplane.

### B. Error Resilience-SPIHT coder

The SPIHT algorithm has excellent advantages compared with another compression algorithm such as good image quality, fast encoding and decoding, and fully progressive bitstream. However, an error in the output bitstream causes losing the decoder synchronization to the encoder, in other words, error propagates and this dramatically reduces the quality of reconstructed image. In case of image transmission over a wireless channel, worse results are obtained because of occurring burst errors. Therefore it is necessary to protect the SPIHT bitstream for transmission over an error-prone channel.

Literature on the improvement of the SPIHT algorithm performance is quite rich [11]-[13]. In this paper we use the method introduced in [11]. Three spatial orientation trees from each coefficient at a low-frequency subband are considered as a partition. In this paper, we use 'perfect tree' to refer to 'the three spatial orientation trees'. Then, the basic SPIHT algorithm is applied to each perfect tree to produce the separate sub-bitstream for a perfect tree. Therefore the decoder is able to decode each perfect tree independently of the others. The resulting coder is called Error-Resilient SPIHT (ER-SPIHT) coder. Fig. 2 shows the structure of a perfect tree defined by the ER-SPIHT algorithm.

The compressed data of each perfect tree are considered as a packet with a header (PH) and body. The final step is to combine the packets into a single final bit stream. The final bitstream consists of a main header (MH) that includes the common necessary parameters for image decoding (image size and the number of levels of decomposition) and then all packets that are generated by ER-SPIHT coder.

Compression performance of the ER-SPIHT coder is very close to the original SPIHT coder, and it provides a good performance against bit errors and packet losses. If a packet is lost, the degradation is limited to only a small area that is associated with its corresponding tree.

In the next section, we propose a new error concealment method combined with ER-SPIHT coder which enables the decoder to retrieve the tree information that is lost during transmission.

## III. Proposed Method

A block diagram of the proposed method is depicted in Fig. 1. The proposed scheme can be divided into two parts, namely transmission side and receiver side.

### A. Transmission Side

The process carried out at transmission side consists of the following steps:

*Step 1. Image transformation:*

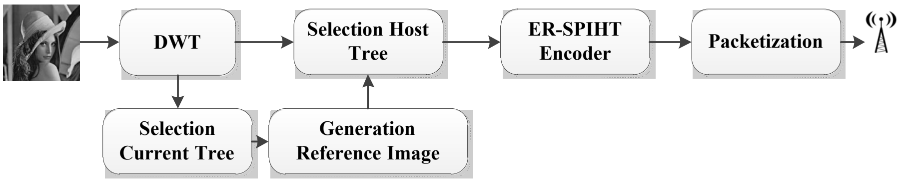
An $n$-level 2D-DWT is applied to the original image to decompose it into $n+1$ subbands. The number of decomposition levels depends on the size of area that is associated with each perfect tree and packet length that allowed for transmission over the channel. With applying an n-level 2D-DWT to an image of a size of 512×512 pixels, each perfect tree is associated with an area of a size $of\ 2^n \times 2^n$.

*Step 2. Generation of the reference image:*

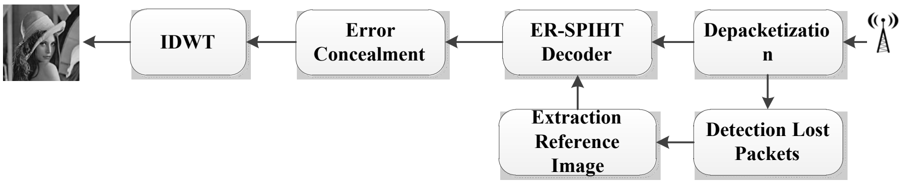
The ER-SPIHT coder is applied to encode the decomposed coefficients. We use ER-SPIHT coder instead of SPIHT coder because of its error resilience feature. Then, the output bitstream of ER-SPIHT is used as the reference code to be embedded to the host image at transform domain. In other words, for each perfect tree a very low bit-rate sub-bitstream is provided. Bit budget that is assigned to each perfect tree depends on the capacity of the data hiding algorithm.

*Step 3. Watermark embedding:*

*(a) Embedding function:* We use the Quantization Index modulation (QIM) [6]-[7] to embed data into the host



**(a) Transmission Side**



**(b) Reciever Side**

Fig. 1. Block diagram of the proposed method. (a) Transmitter Side (b) Receiver Side.

media. QIM is an extension to basic quantization that is traded off between capacity, robustness and imperceptibility. Dither modulation is a convenient method and a low-complexity structure for QIM embedding. It has the characteristic that quantization cells and reconstruction points of any quantizer are shifted versions of the quantization cells and reconstruction points of any other quantizer [7]. In this method each bit of the reference code($w \in \{0,1\}$)is modulated with a different length-$l$dither vector $d(w)$. In this paper, the length of dither sequence is 1. Then one coefficients of host tree of subband $b$are quantized with the following function is called embedding function ($S$):

$$S(X_b, w) = Q(X_b + d_b(w), \Delta_b) - d_b(w) \tag{1}$$

where$X_b$ is DWT coefficient of subband $b$, $Q$ is a uniform quantizer with step size $\Delta_b$,$\Delta_b$is a constant for all coefficients at subband $b$. $\Delta_b$ for subband $b$ is calculated so as to establish a balance between robustness and transparency. It is calculated using the following formula [15]:

$$\Delta_b = 2^{R_b - \epsilon_b}\left(1 + \frac{\mu_b}{2^{11}}\right) \tag{2}$$

where $R_b$ is the nominal dynamic range of subband $b$.$\varepsilon_b$and$\mu_b$are parameters that are adjusted $\Delta_b$. The $d_b(w)$for $w \in \{0,1\}$ is the dither for embedding bit 0 and 1. The $d_b(0)$ is a uniform random variable over $[-\Delta_b/2, \Delta_b/2]$.The $d_b(1)$is constructed as follows:

$$d_b(1) = f(d_b(0)) = d_b(0) - sgn(d_b(0)) \times \frac{\Delta_b}{2} \tag{3}$$

where $sgn(.)$is the sign function.

*(b)Selection of perfect tree and subband coefficients for embedding:* In step 2, a very low bit-rate code is generated for each perfect tree. Each sub-bitstream of a certain perfect tree (current tree) is embedded into the coefficients of other perfect tree. The host perfect tree is selected far from the current perfect tree to reduce the probability of simultaneous loss of both the current tree and the host tree. Fig. 2 shows a 4-level 2D-DWT of an image and the current/host perfect trees for embedding.

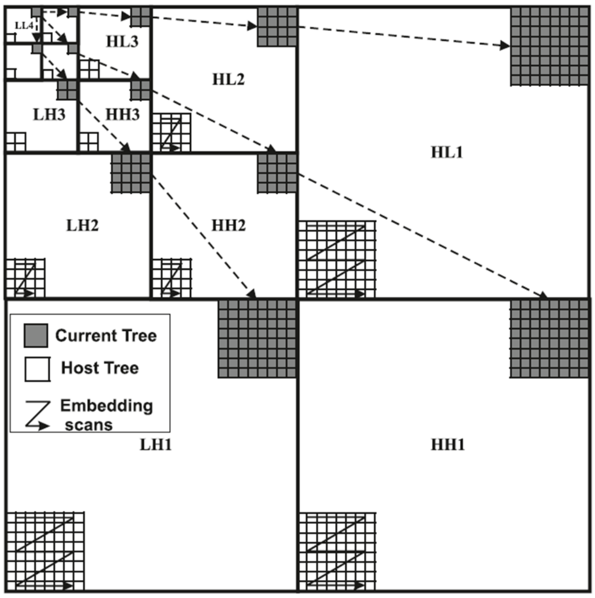


Fig. 2. Spatial orientation trees and perfect trees (current/host) across wavelet subband in SPIHT and ER-PIHT coder, respectively.

The SPIHT code of each complete tree is embedded into the coefficients of one other complete tree which are located in the level-1 and level-2 subbands (i.e. $HL_i, LH_i, HH_i, i = 1,2$). The reason is that it is well known that the Human visual system is less sensitive to changes at these coefficients. For an n-level 2D-DWT, the numbers of the perfect tree coefficients of level-1 and level-2 subbands are $3 \times (2^{n-1} \times 2^{n-1})$and $3 \times (2^{n-2} \times 2^{n-2})$, respectively. Therefore, embedding capacity for each perfect tree is $C = 3 \times (2^{n-1} \times 2^{n-1} + 2^{n-2} \times 2^{n-2})$ bits. It means the bit budget for the step of reference image generation is at least $C$ bits. The algorithm starts by scanning these coefficients at the level-2 subbands and proceeds gradually to coefficients at level-1 subbands. Essentially, the algorithm employs a dynamically-determined scanning pattern to embed the reference code. Fig. 2 shows the scanning pattern at one typical perfect tree.

*Step 5. Image encoding and network packetization:*

After all the reference code has been embedded to the decomposition coefficients, embedded coefficients are fed to ER-SPIHT coder for compression. Each ER-SPIHT packet is packetized into RTP protocol payloads [14]. If any RTP packet is lost, the impact of data lost is limited to a small area of original image. The size of ER-SPIHT packets usually is within the range of packet sizes observed by standard protocols which is between 40 byte to 1500 byte. However, if the ER-SPIHT packet size exceeds the MTU (Maximum Transfer Unit) size, the perfect tree is divided into three spatial orientation trees and each tree is independently coded.

### B. Receiver Side

*Step 1. Network depacketization and image decoding:*

At the receiver, received network packets are depacketized to retrieve ER-SPIHT packets. The loss of packets is detected by the gap between network packets [14]. The index of the lost packet is stored for the error concealment step. Then ER-SPIHT decoder is applied to retrieve ER-SPIHT packets and regenerate the decomposition coefficients of image.

*Step 2. Error concealment:*

In this step, the coefficients of perfect trees that are associated with lost packets are recovered. After the detection of lost packet index, the sub-bitstream that is associated with a lost packet is extracted from the host perfect tree.

*(a) Extraction function:* The minimum distance decoding is used to extract the replica of the perfect tree. The algorithm starts by scanning these coefficients at the level-2 subbands and proceeds gradually to coefficients at the level-2 subbands. The scanning pattern is similar to decoder one. At any coefficient, a corresponding watermark bit$(w')$is extracted using the following rule:

$$w' = \underset{m}{\operatorname{argmin}} |Y_b - S_b(Y, m)|, \quad m \in 0,1 \qquad (4)$$

where $Y_b$ is the received coefficient at subband $b$ and $w'$ is an extracted watermark bit.

*(b) Error concealment:* The ER-SPIHT decoder can independently decode each extracted sub-bitstream (at any bit-rate) which is associated with one perfect tree. After decoding, the coefficients of damaged perfect tree are replaced with coefficients of the decoded perfect tree. Then a 4-level 2D inverse DWT is applied to get the error concealed image.

## IV. EXPERIMENTAL RESULTS

In this section, we evaluate the performance of the proposed scheme. Simulations are done over four popular grayscale images; Lena, Goldhill, Peppers, Bridge. Two common objective measures Peak Signal to Noise Ratio (PSNR) and Mean Structure Similarity Index Measure (MSSIM) [15] are used to measure the distortion of the watermarked image with respect to the original image.

The original images are transformed using four levels 2D DWT. The Daubechies (9.7) filter is used because of its high energy compaction. This property makes that the ER-SPIHT coder generates one very low bit-rate bitstream of the original image that included important information.

For image transmission, the ER-SPIHT is applied to the embedded coefficients and compressed nearly lossless. In the nearly lossless compression, perceptual distortion between the reconstructed and original image is negligible. Compression rates for Lena, Goldhill, Zelda, and Bridge are 4.55 bpp, 5 bpp, 5.27 bpp, 5.95 bpp, respectively.

Using a 4-level wavelet decomposition will produce 1024 independent variable-size data packets. To simplify the simulation, the tests are conducted under the following conditions:

- Each ER-SPIHT packet is packetized into one RTP payload. Then, a single network packet loss will result in one ER-SPIHT packet loss that is associated with the area of a size of 16×16,
- The ER packet size is assumed to be less than the MTU, Bit errors over successfully received packets are trivial,
- Position of the lost packets (lost perfect tree) and the associated host perfect tree were known to the decoder, and
- No retransmissions occur. If a packet containing coded information for another lost packet is lost, the proposed method is failed. When this situation occurs, the system checks the received coefficients at the neighborhood of the lost coefficient in the lowest subband. Then, the lost coefficient is simply replaced with the average value of the correctly received coefficient. We note that in a moderate packet loss rate, the possibility that two relevant packets are simultaneously lost can be considered reasonably low.

We consider the number of the lost packets to be 1.5-5%, 10%, 15%, 20%, 25%, 30% of all packets. Table 1 summarizes the results of the error concealment in a channel with 15% packet loss for images coded losslessly in terms of PSNR (dB) and MSSIM, respectively. For each image, PSNR and MSSIM of the loss-free image ($\mathrm{PSNR}_{\mathrm{lossfree}}/\mathrm{MSSIM}_{\mathrm{lossfree}}$), PSNR and MSSIM of the received image($\mathrm{PSNR}_{\mathrm{rec}}/\mathrm{MSSIM}_{\mathrm{rec}}$), PSNR and MSSIM of the concealed image($\mathrm{PSNR}_{\mathrm{con}}/\mathrm{MSSIM}_{\mathrm{con}}$)are noted. We can see that the quality of retrieved image with our proposed method approaches to the quality of loss-free compressed image.

Figs. 3 and 4 show the improvement value in quality with a variation in the number of packet loss in terms of PSNR (dB) and MSSIM, respectively. The results are averaged over 25 iterations due to randomness in loss for wireless networks. We can see that the improvement in the PSNR and MSSIM values increased with increasing the number of lost packets. As can be seen in Fig. 3, the improvement value for the Bridge is smaller. This image has a high texture; therefore, more bits are needed to hide a more high-quality reference. Anyway, our proposed method has a fixed capacity for hiding the reference image. For this reason, the concealed image quality for this image is smaller than for others. Fig. 4 shows that the improvement values for all test images are nearly the same. Although our proposed method has a poor performance for high texture images in terms of PSNR, it has a high ability to provide the same conceptual quality for all types of images.

TABLE 1. QUALITY OF CONCEALMENT (PSNR & MSSIM)
THE PROPOSED ALGORITHM IN 15% RANDOM PACKET LOSS, IMAGES WERE CODED LOSSLESSLY.

| **Test Image** | **Loss-Free Image** | | **Received Image** | | **Concealed Image** | | **Improvement value** | |
|---|---|---|---|---|---|---|---|---|
| | PSNR (dB) | MSSIM | PSNR (dB) | MSSIM | PSNR (dB) | MSSIM | PSNR (dB) | MSSIM |
| Lena | 40.64 | 0.98 | 13.64 | 0.61 | 37.68 | 0.97 | 24.04 | 0.36 |
| Goldhill | 42.59 | 0.99 | 14.57 | 0.64 | 37.42 | 0.98 | 22.58 | 0.34 |
| Zelda | 43.19 | 0.99 | 14.49 | 0.62 | 41.34 | 0.99 | 26.85 | 0.37 |
| Bridge | 38.62 | 0.99 | 14.48 | 0.69 | 32.65 | 0.97 | 18.17 | 0.28 |

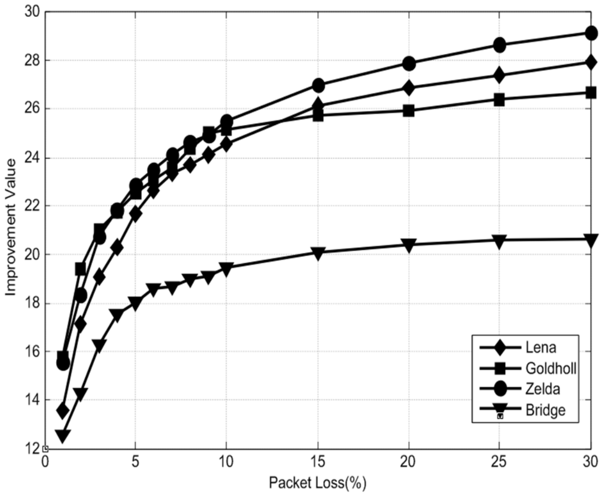


Fig. 3. Improvement in quality after error concealment in terms of PSNR (dB) in various packet loss rates.

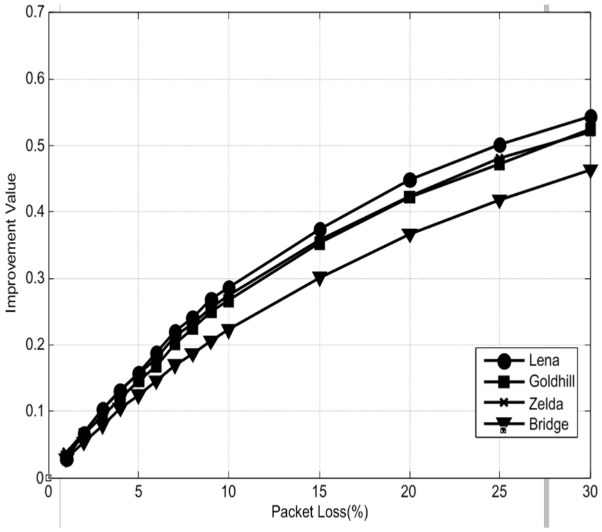


Fig. 4. Improvement in quality after error concealment in terms of MSSIM in various packet loss rates.

Fig. 5 shows a sample of image transmission for the Lena image with 15% packet loss. The results show that the proposed method has improved the image quality, both subjectively and objectively.

Received image
PSNR = 13.41dB
MSSIM = 0.608

Concealed image
PSNR = 39.54dB
MSSIM = 0.982

Fig. 5. Results for the Lena image with 15% packet loss.

## V. CONCLUSION

A novel error concealment based on data hiding is presented to repair the lost areas of the original image due to channel impairments. The method is combined with the ER-SPIHT to compensate the lost areas. The obtained results indicate that this method provides a significant improvement of the quality of the received image such that it approaches to the quality of loss-free compressed image, especially for bursty channel error conditions. Therefore, the proposed method is useful for the compensation of the lost areas of the original image, at the expense of increased coder complexity. Except in a special case, the proposed technique does not impose any overhead to the communication channel due to the required feedback or any retransmission of the lost packets.

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