ERROR RESILIENT MULTIPLE DESCRIPTION CODING BASED ON WAVELET TREE CODING AND EREC FOR WIRELESS NETWORKS

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ABSTRACT

In this paper, we propose an integrated error resilient MDC scheme for wireless networks with both packet loss and random bit errors. Two descriptions are first generated independently by using index assignment MDSQ. For each description, multiple bitstreams are then generated based on wavelet trees along the spatial orientations. The spatial-orientation trees in the wavelet domain are individually encoded using SPIHT. Error propagation is thus limited within each bitstreams. However, synchronization words are usually needed to avoid error propagation across multiple independent bitstreams. In order to maintain high compression efficiency robust synchronization, we adopt EREC to re-organize these variable-length bitstreams into fixed-length data slots before multiplexing and transmission. Therefore, the synchronization of the start of each bitstream can be automatically obtained at the receiver. Finally, to alleviate the devastating image degradation resulted from errors in the beginning of the bitstreams, we propose an error concealment technique to both constrain the EREC/MDC decoding and post-process the decoded wavelet coefficients.

1. INTRODUCTION

Multimedia data transmission for mobile wireless applications needs to combat the mobile channel impairments which are reflected as both packet loss and random bit errors. Automatic repeat request (ARQ) retransmission is one technology to handle the hostile channels but generally introduces a large delay. This is not appropriate for applications such as multimedia data transmission in which limited bandwidth and/or real-time processing are the norm.

Multiple description coding (MDC) is an effective way to combat possible channel impairments over packet loss networks. In MDC, two descriptions are usually separately generated and transmitted over different channels. At the destination, if both descriptions are received, a maximum quality signal reconstruction is possible. Otherwise, the receiver can still reconstruct image and video with a lower quality, but may still be acceptable to the user.

The first practical results on multiple descriptions were presented by Vaishampayn [1] with a simple procedure to design MD scalar quantizers. Wang et al. [2] and Goyal et al. [3] proposed MD transform coding that necessitates another correlation transform in addition to the conventional decoding transform. Servetto et al. [4] proposed an MD wavelet based coding and Jiang and Ortega [5] developed an MD extension to the SPIHT coder of Said and Pearlman [6] by separating Zerotrees into polyphase components. However, these MDC schemes share one common shortcoming: individual description lacks of adequate error resilience capability for the random channel bit errors.

We believe that one key issue to improve the error resilience in each description is to limit the error propagation due to the nature of embedded coding. Therefore, in this research, for each description, we individually encode the spatial-orientation trees in the wavelet domain using SPIHT so that error propagation is limited within a single bitstream. To guarantee this limitation of error propagation, synchronization code words, with added redundancy, are often used to avoid the corruption of the boundary between bitstreams. In order to enhance the error resilience capability to bit error while maintaining high compression, we apply the error resilient entropy coding (EREC) proposed by Redmill et al. [7] by re-grouping the variable-length bitstream blocks into fixed-length slots. In this case, the synchronization of individual bitstreams can then be obtained naturally at the receiver.

In the following sections, we will describe the proposed error resilient MDC scheme in detail. This scheme integrates MDSQ, wavelet tree image coding, EREC, and error concealment to improve robustness of image transmission over error prone channels with both packet loss and random bit error.

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2. SYSTEM DESCRIPTION

The proposed image transmission system is shown in Fig. 1. A given image is decomposed into subbands by discrete wavelet transform (DWT), and then each of subband coefficients is quantized with MDSQ and two descriptions are created by index assignments. For each description, the spatial-orientation trees in the wavelet domain are individually encoded using SPIHT to generate independent multiple bitstreams. Before transmission over noisy channel, EREC is then employed to re-organize these encoded variable-length bitstreams into fixed-length slots so that the beginning of each block can be automatically determined at the receiver. To enable an error concealment process at the receiver, a small number of parity bits are added after the EREC encoding.

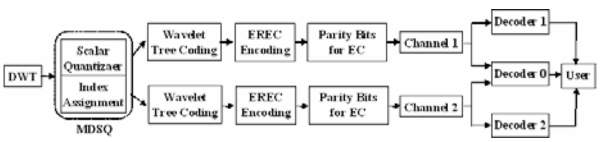

Figure 1: Diagram of the proposed system

2.1 MDSQ

The MDSQ was introduced by Vaishampayan [1] and it is first practical multiple description coding scheme. This MD quantizer consists of two parts: a scalar quantizer and an index assignment. The scalar quantizer maps continuous-valued random variables to points in a countable set and the index assignment splits the information about each sample into two complementary and possibly redundant descriptions of the same sample. One example of two index assignments is shown in Figure 2. To apply the MDSQ to image coding, a given image is decomposed into subbands, and then a uniform scalar quantizer is applied to each of the subband coefficients, thus producing a quantized field. The bins of a quantized field are placed in a matrix and two descriptions are created by mapping each quantized coefficients to a pair (row/column) of numbers, using the index assignment component of a MD quantizer. Row and column indexes are sent over each channel. If both descriptions are received, the original quantization bin can be recovered; if not, the original quantization bin is known to be one of those in the received row/column indexes. Unlike a single channel scalar quantizer, the performance of a multiple description is dependent on the index assignment.

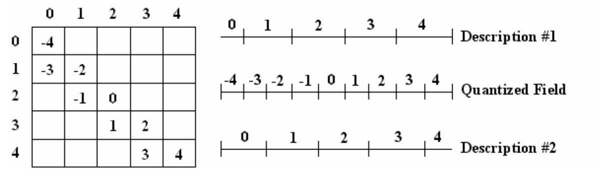

Figure 2: Illustration of index assignment

2.2 Multiple Wavelet Tree Coding

After the hierarchical wavelet decomposition, there is a direct relationship between wavelet coefficients and what they represent in the image content. The left of Figure 3 is the spatial orientation tree structure proposed by Said et al [6]. This wavelet tree is rooted at the lowest frequency subband. Each node in the tree has either no descendants or four offspring grouped in 2×2 adjacent coefficients. If all coefficients in the tree are grouped together, they constitute a square block of data as shown in the right of Fig. 3. These data are the frequency components for a specific image area with the same block size at the corresponding position. As a result, one tree corresponds solely to one image block. For each wavelet tree, the SPIHT is employed to encode it independently. Accordingly this scheme can also be regarded as a block-based coding scheme.

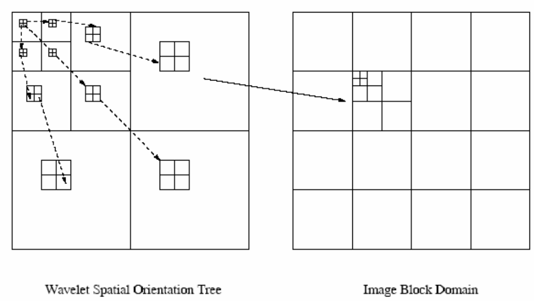

Figure 3: Wavelet tree and its image content

2.3 EREC

EREC is originally proposed by Redmill et al [7] to handle the sequential transmission of variable length coded DCT data blocks over noisy channels. For the DCT based block image coding schemes such as JPEG, H.263 etc., the length of the coded binary bits in one block is generally different from those of other blocks. If these variable length blocks are multiplexed sequentially for transmission, channel errors may corrupt the boundary information between blocks and hence cause a catastrophic decoding of the image. The key idea of the EREC is to re-organize the variable length data blocks into fixed length slots with negligibly increased data size [7]. As shown in Figure 4, the data in the blocks is allocated to the corresponding slots, starting from the beginning of each block. Blocks that are larger than slot size are chopped and the remained data are put into other slots that still have available space according to a pre-defined offset sequence. Therefore, at the receiving end, the start of each block can be automatically determined as the start of each fixed length slot. Without channel errors, the decoder can follow the same algorithm to recover all variable length blocks using the same offset sequence.

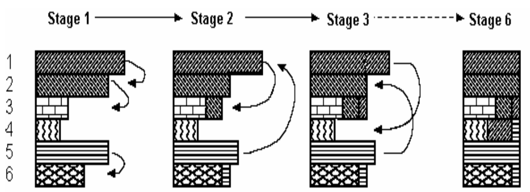

Figure 4: EREC example

When channel error occurs, the error propagation in EREC decoding more likely impacts the data close to the end of each block than the data close to the beginning of each block. This characteristic fits well with the wavelet tree embedded coding we adopted. In our scheme, coefficients are encoded from the highest bit-layer to the lowest bit-layer. Therefore, the importance of coded data generally decreases along the bitstream from the beginning. In the case of noisy channels, the error propagation will more likely to impact the lower bit-layers, which generally contribute less to the distortion energy.

2.4 Error Concealment

The SPIHT algorithm generates progressive data. As a result, an error in the beginning of each bitstream may cause a catastrophic decoding because of its high distortion for its pixel amplitude and its potential to deviate the subsequent decoding path according to the set partitioning rules. Thus, SPIHT decoding of each bitstream in an error prone environment may stop much earlier or later than it should be. This also causes corruption of EREC decoding because EREC decoding requires the SPIHT decoding to stop at a pre-defined position. In order to alleviate the significant impact of errors in the first few bytes in each bitstream, we add one parity bit for the first several L bytes (L = 4 is used in the simulation) in each data slot after EREC encoding. That is, the first 8L bits will have one more bit for the detection of the odd number of errors. EREC decoding actually depends on the SPIHT decoding to find out the stop position of each bitstream. For example, if SPIHT decoding of one slot of data has not met the stop point, this slot is deemed to be a part of the bitstream. Otherwise, the slot consists of a complete bitstream and the data from some other bitstreams.

When errors in one bitstream cause the SPIHT decoding to stop in a wrong position, EREC decoding from fixed-length slots to variable-length blocks will be impaired by losing the correct mapping between the slots and blocks. Consequently, data from several different bitstreams might be mis-regarded as data of one bitstream. Therefore, in our error concealment, when one slot is detected to have bit errors in the beginning, this slot will not be used again after the first step of EREC decoding. Moreover, all its corresponding blocks determined by the offset sequence will not accept data from other slots after the first step of EREC decoding.

For MD decoding, one slot that has bit errors in the beginning is also treated as lost slot and is not used for inverse index assignment. Three scenarios are considered in the MD decoding. (1) If the same order slots of two descriptions arrive at the receiver, these two slots are recombined by inverse index assignment. (2) If either one of the same order slot of two descriptions arrives, the available slot is dequantized using the single channel inverse quantizer. (3) When two same order slots are lost, each coefficient of this lost block will be compensated by the average of its neighbor coefficients in the lowest frequency subband.

3. EXPERIMENTAL RESULTS

We have conducted experiments on the 512 × 512 gray-scale Lena image. Three-scale wavelet transform is applied, and then each of the subband coefficients is quantized with the MDSQ scheme. Two descriptions are generated by two index assignments and, for each description, 1024 wavelet trees are constructed. A random offset sequence is adopted for the EREC operation. In the decoding of EREC, it is required that the EREC can find the end of each blocks in the absence of channel errors. In our experiment, we obtain self-termination by specifying 0 as the value of stop-layer for the source encoding and decoding of each wavelet tree. A total of 1024 parity bits for each description are added for the error concealment purpose, which results in 0.008 bpp extra overhead. The total coding rate including parity bits is 1.0 bpp. We are packing 32 slots as one packet (each packet is 512 bytes). Therefore, a total of 64 packets are generated from a given image. When there is no packet loss during image transmission, the results of two-channel decoder and one-channel decoder are 37.4 dB and 33.4 dB, respectively.

Figure 5 shows the error resilient performance of the proposed scheme over the binary symmetric channel (BSC). 20 trials were carried out for each channel condition. Comparing with single description scheme [6] and the existing MDC scheme [5], PSNR drops from 40.46 and 38.92 dB to 37.40 dB for error free cases. However, at the error rate of 1e-4, the proposed scheme outperforms the single description and the reference MDC for more than 11 dB. Second, the improvement of the proposed error concealment is significant. The performance with error concealment outperforms the scheme without error concealment in all BER conditions, with the highest improvement of 3.4 dB.

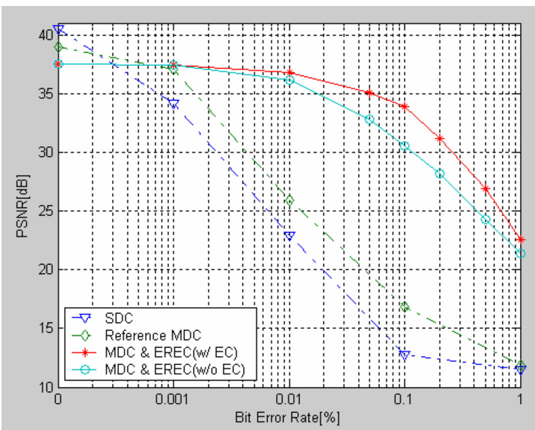

Figure 5: PSNR vs. BER, with and without EC

The performance of our proposed scheme over both packet loss and BER is showed in Figure 6. From Figure 6, we note that our proposed scheme is able to achieve not only error resilience but also graceful degradation over error prone channels with both packet loss and bit error.

4. CONCLUSION

In this paper, we have proposed an integrated error resilient multiple description coding scheme combining MDSQ, multiple wavelet tree coding, EREC, and error concealment. We have demonstrated through analysis that each of these components has contributed to the overall robustness of the proposed transmission of compressed images over wireless networks. Significant improvement over single description and the existing MDC schemes have also been demonstrated by various simulations of the proposed integrated scheme.

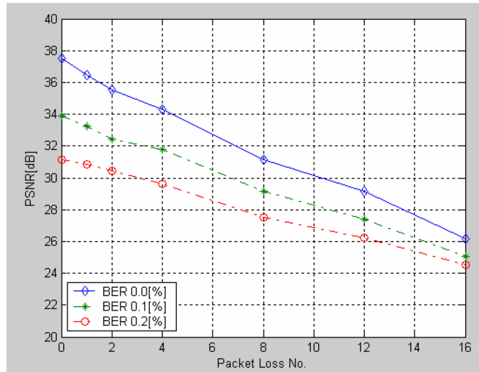

Figure 6: PSNR vs. packet loss and BER

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