ROBUST TRANSMISSION OF JPEG2000 ENCODED IMAGES OVER PACKET LOSS CHANNELS

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ABSTRACT

JPEG2000, the latest international image compression standard, owns many unique characteristics that are different from other well-known image compression schemes such as JPEG and SPIHT. As a result, how to robustly transmit JPEG2000 bitstreams is an important research topic. In this paper, we apply our previous IL-ULP (improved layered unequal loss protection) scheme to transmit JPEG2000 coded images. We propose an accurate end-to-end distortion model to analyze the influence of different channel packets on the distortion of received images, where we consider the distortion contribution from each coding pass in each code-block. Our end-to-end analysis provides a feasible way to optimally allocate unequal FEC to a JPEG2000 bitstream according to given channel conditions. Experimental results demonstrate that our proposed IL-ULP can achieve good performance for transmission of JPEG2000 bitstreams.

1. INTRODUCTION

JPEG2000, which is fundamentally based on the discrete wavelet transform (DWT) and embedded block coding with optimal truncation (EBCOT) [1], is the latest image compression standard. It offers a host of features beyond the capabilities of conventional JPEG, including superior low bit rate coding performance, region of interest (ROI) coding, good error resilience, and more. The fundamental building blocks of a typical JPEG2000 encoder includes preprocessing, discrete wavelet transform (DWT), quantization and entropy coding [2]. In pre-processing, the input image is first partitioned into tiles, followed by level offset and component transformation. After the pre-processing, DWT is applied to generate spatial frequency sub-bands. Each sub-band is further divided into code-blocks. Then, all wavelet coefficients are subjected to uniform scalar quantization with dead-zone. The resulting quantization indices of each code-block in each sub-band are entropy coded independently, where each bit-plane is coded by the context-dependent arithmetic coding, from the most significant bit-plane to the least significant bit-plane. The compressed data are organized into *J2K packets*. A J2K packet is the basic component of the JPEG2000 codestream. Note that J2K packet is different from network packets.

In literature, we have seen extensive studies in FEC-based joint source-channel coding (JSCC) for progressive image transmission over packet loss channels [3, 4]. Their common idea is to use unequal loss protection (ULP). Compared with equal loss protection (ELP), ULP can obtain considerable performance gain and has the property of graceful performance degradation. However, the complexity of ULP is high since it is not trivial to find the optimal ULP solution. Besides, most existing ULP schemes do not consider the minimum image quality requirement, which results in applying unnecessary ULP process to the early portions of a bitstream whose corresponding reconstructed images are of low quality and thus useless for practical applications. By observing this problem, a hybrid protection (HLP) scheme is proposed in [4]. Its basic idea is to constrain the early parts of a progressive bitstream with ELP while ULP is applied to the rest. Although HLP can greatly reduce the probability of failure transmission, i.e., below the minimum quality requirement, its complexity is still as high as ULP.

ULP has also been applied to JPEG2000 to combat channel noise including Internet packet loss and bit errors in wireless links [5, 6]. In [5], the authors demonstrated that earlier quality layers should be assigned more protection, while they did not clarify how to optimize the FEC selection. In [6], V. Sanchez et al. proposed a method named adaptive unequal channel protection (AUCP) for optimal FEC selection. However, the AUCP scheme has two shortcomings. First, it simply neglects the contribution of code-blocks that are not included in a J2K packet for the first time, and no FEC will be provided for network packets that do not contain any new code-block data. This results in noticeable inaccuracy in the computation of the channel impairment effect. Second, in AUCP, the distortion analysis is performed at the J2K packet level instead of the desired network packet level.

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In our previous work [7], we proposed a layered ULP (L-ULP) scheme to tackle both the minimum quality requirement and the high computation complexity issue by smartly choosing the layers. Although the L-ULP scheme is able to achieve low-complexity and meet the minimum quality requirement, its average PSNR performance is not as good as that of the HLP. Therefore, we further proposed an improved L-ULP (IL-ULP) scheme in [7], which is a combination of the L-ULP and the pre-interleaving. The rationale behind this combination comes from the basic assumption, i.e. the performance of a progressive image transmission is very much determined by the location of the first unrecoverable error instead of the amount of errors. We have demonstrated the effectiveness of the IL-ULP scheme on SPIHT coded image bitstreams.

However, this basic assumption does not strictly hold for JPEG2000. Since in JPEG2000 each code-block in a subband is independently coded, with the help of the error-resilient tools the decoder is able to re-start decoding from the next code-block if the current one is corrupted. Therefore, in this paper, we study the performance of applying the IL-ULP scheme to JPEG2000 encoded images. In particular, we take the characteristics of JPEG2000 into consideration and develop a model for end-to-end distortion analysis. Unlike the AUCP scheme, our end-to-end distortion analysis is performed in the network packet level and we consider the contributions of all the code-blocks. Experimental results show that the IL-ULP scheme performs very well for the transmission of JPEG2000 encoded images.

The rest of this paper is organized as follows. Section 2 gives a brief description of our previously proposed IL-ULP scheme. Section 3 analyzes the end-to-end distortion. Experimental results are presented in Section 4, and finally conclusions are drawn in Section 5.

2. PREVIOUS WORK

The main idea of the IL-ULP scheme is to delay the occurrence of the first unrecoverable loss in the source bitstream by using the pre-interleaving, and thus improve the performance. Fig. 1 gives an example of the L-ULP with three layers to illustrate this idea. In the $L \times N$ rectangle where L is the packet length and N is the number of packets, each row is a channel coding block and each column is a packet. Let L_i and f_i denote the number of rows and the allocated FEC length for the i-th layer. Reed-Solomon (RS) codes with 8 bits/symbol are used as channel codes. An $(N, N - f_i)$ RS code encodes each segment of $N - f_i$ source symbols into a channel block of N symbols, and it can correct up to f_i symbol loss. A layer is defined as a group of consecutive rows with the same loss protection choices independent of other rows. The top diagram in Fig. 1 is the original L-ULP, where the source bitstream is placed in the rectangle from left to right and from top to bottom. The bottom diagram in Fig. 1 is the IL-ULP, where in the rectangle the source bitstream is still placed from top to bottom but in each layer it is placed in a vertical direction instead of the horizontal direction. Since such an interleaving is performed before channel encoding, we named it as pre-interleaving. The advantage of applying the pre-interleaving can be explained by the following example. Let b_i denote the number of source bits in the i-th layer. Suppose there exist unrecoverable packet losses and the first unrecoverable loss occurs in the j-th packet in the third layer. For this case, the original L-ULP can use maximal $[b_1 + b_2 + (j - 1)]$ symbols for source decoding while the scheme of combining L-ULP with pre-interleaving can take maximal $[b_1 + b_2 + (j - 1) \cdot L_3]$ for source decoding, which will result in a better performance. The performance gain will be even more significant in the cases of small values of n and large values of L such as Internet packet sizes.

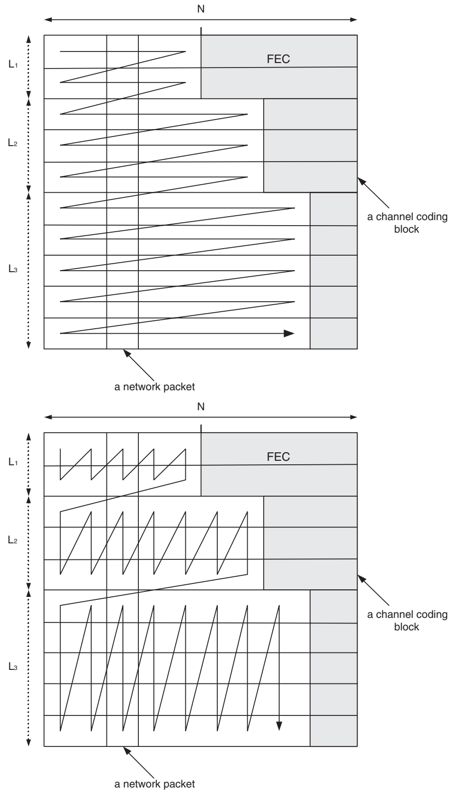

Fig. 1. An example of the L-ULP with three layers. Top: the original L-ULP. Bottom: with the pre-interleaving.

3. IL-ULP FOR JPEG2000

Assuming all the N packets share the same packet loss probability, we can approximate the expected distortion at the receiver end as

$$D = D_0 + \sum_{i=1}^{n} \sum_{k=f_i+1}^{f_{i-1}} (P(N,k) \frac{k}{N} \Delta D_i) \qquad (1)$$

where D_0 is the minimum distortion, n is the number of layers, $P(N,k)$ is the probability of losing k packets out of the total N packets, ΔD_i is the distortion loss for i-th layer, and $\frac{k}{N}\Delta D_i$ means the average proportional loss due to losing k packets in the i-th layer. ΔD_i is further derived as

$$\Delta D_i = \sum_{j=1}^{N-f_i} \Delta D_{i,j} \qquad (2)$$

where $\Delta D_{i,j}$ is the distortion loss contributed by the part of data $p_{i,j}$, which locates in the i-th layer and belongs to the j-th network packet p_j.

If any part of the main header of the JPEG2000 bitstream is corrupted, the decoding will fail. Thus, when any $p_{i,j}$ in the i-th layer contains information from the main header, the corresponding distortion loss should take the maximum value, i.e.

$$\Delta D_i = \sum_{s=1}^{S} \sum_{b=1}^{B_s} \sum_{cp=1}^{CP_b} G_{cp} \qquad (3)$$

where S is the total number of subbands, B_s is the total number of code-blocks in the s-th subband, CP_b is the total number of the included coding passes for the code-block b, and G_{cp} is the distortion loss corresponding to coding pass cp. For all other cases, $\Delta D_{i,j}$ depends on the number of new code-blocks included in $p_{i,j}$, i.e.

$$\Delta D_{i,j} = \sum_{b=1}^{B_{i,j}} \sum_{cp=CP_{b,i,j}}^{CP_b} G_{cp} \cdot \psi(i,j,b) \qquad (4)$$

where $B_{i,j}$ and $CP_{b,i,j}$ are the total number of code-blocks and the first coding pass of code-block b in $p_{i,j}$, respectively, and

$$\psi(i,j,b) = \begin{cases} 1 & \text{if the code block } b \text{ is first-time included} \\ & \text{in the } i\text{-th layer} \\ 0 & \text{otherwise} \end{cases}$$

Note that Eq. 4 is the key difference between our proposed end-to-end distortion model and the model in the AUCP algorithm. Specifically, the AUCP only considers the distortion contribution from the brand new code-blocks in a packet, while the definition of new code-blocks in our model is with respect to a particular layer. For example, we consider the distortion contribution from the b-th code block in $p_{i,j}$ as long as it is first-time included in the i-th layer, no matter whether it has been included in the previous layers or not. This is reasonable because ΔD_i is defined for the case that the first uncorrected loss occurs in the i-th layer. Thus, even if a code-block has been included in the previous layers, all the corresponding pre-included coding passes should be correct with respect to ΔD_i, and we only need to consider the distortion caused by losing the first pass of the code-block included in the i-th layer. Through the above discussion, we can see that our end-to-end distortion model is more accurate than that in the AUCP algorithm.

Both G_{cp} and the related coding pass length, L_{cp}, can be obtained readily from JPEG2000 implementation software such as Kakadu [8]. All other parameters including D_0, CP_b, $B_{i,j}$, and $CP_{b,i,j}$ can also be computed during the encoding process. Due to the complexity of the JPEG2000 and the proposed end-to-end distortion analysis, a fast error control algorithm is desired. Thus, in this paper, we direct match the JPEG2000 quality layers into the IL-ULP layers, and we adopt the fast local search algorithm in [9] to find the optimal FEC allocation.

4. EXPERIMENTAL RESULTS

In this section, we compare the performance between the L-ULP scheme and the IL-ULP scheme to see whether the IL-ULP can achieve better performance or not for JPEG2000 bitstreams. The three gray scale 512×512 images, "Lena", "Boat", "Goldhill", are used as test images. We choose the packet size of 100 bytes. We adopt the simplified Gilbert-Elliott channel (GEC), a two-state Markov model, as the packet loss model. The GEC model has two states: Good state and Bad State. In Good state there is no packet loss while in Bad state packets are always lost. The testing average packet loss rate (p_l) is from 5% to 20% and the average burst length is fixed to 5 packets. RS codes with 8 bits/symbol are used for channel coding. We select 25 dB as a PSNR threshold for the minimum quality requirement. We fix the total bandwidth to 0.25 bpp, which corresponds to a total number of packets of 82. We fix the number of JPEG2000 quality layers, which is the same as the IL-ULP layers, as 5. All experimental results are obtained over 1000 independent simulations.

Fig. 2 shows the distortion performance of transmitting different images under different packet loss rates. It can be seen that IL-ULP always outperforms the L-ULP. This is not surprising. By carefully checking the FEC allocation, we found the main reason lies in the main header protection for a JPEG2000 bitstream. For the L-ULP scheme, the main header typically spans over the entire $N - f_1$ packets in the first layer. Thus, any packet loss in the first layer will cause the decoding failure. On the other hand, for the IL-ULP case, only the earliest several packets in the first layer contain the main header information. As a result, the L-ULP scheme tends to allocate more protection to the first quality layer than the IL-ULP does. When their quality layers have the same source bit rates, the L-ULP scheme will leave smaller space for the remaining several layers than the IL-ULP. Therefore, compared with the IL-ULP, the L-ULP is allocated fewer source bytes.

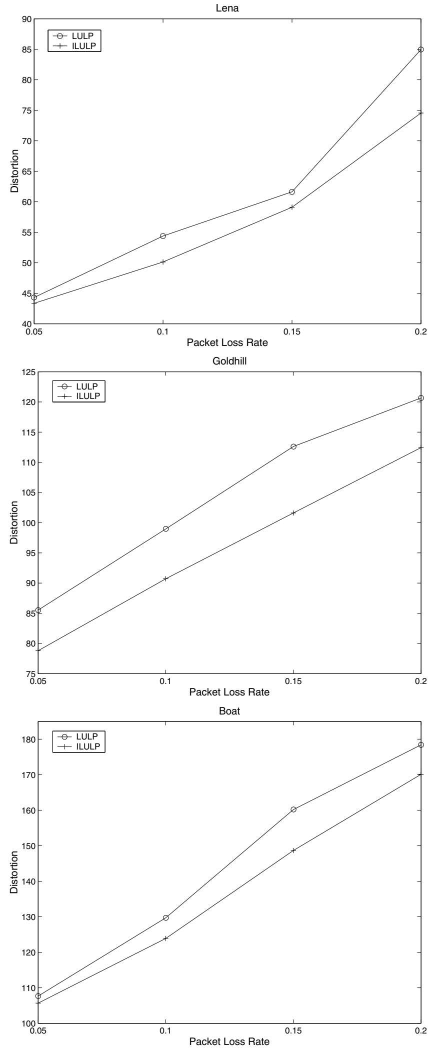

Fig. 2. The performance comparison between the IL-ULP and L-ULP for transmitting Lena, Goldhill, and Boat under different packet loss rates.

5. CONCLUSION

Since JPEG2000 has unique error-resilient feature, i.e. able to further decode its progressive bitstream after encountering some errors or losses, in this paper, our purpose is to investigate the performance of our previously proposed IL-ULP, which is originally designed for traditional progressive bitstreams, for JPEG2000 bitstreams. The experimental results have demonstrated that, for JPEG2000 encoded images, pre-interleaving can still function and the IL-ULP can provide superior performance. Moreover, our developed end-to-end distortion model, which considers the contributions of all the code-blocks, is much more accurate than the existing model in the AUCP algorithm. We believe the end-to-end distortion model for JPEG2000 and the concept of pre-interleaving can be applied to other ULP schemes.

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