LAYERED UNEQUAL LOSS PROTECTION WITH PRE-INTERLEAVING FOR PROGRESSIVE IMAGE TRANSMISSION OVER PACKET LOSS CHANNELS

Jianfei Cai *Xiangjun Li*

School of Computer Engineering
Nanyang Technological University
Email: {asjfcai, pg05304684}@ntu.edu.sg

Chang Wen Chen

Dept. of Electrical and Computer Engineering
Florida Institute of Technology
Email: cchen@fit.edu

ABSTRACT

Most existing ULP (unequal loss protection) schemes do not consider the minimum quality requirement and usually have high computation complexity. Previously, we proposed a layered ULP (L-ULP) scheme to solve the mentioned problems at the cost of performance degradation. In this paper, we propose to combine the L-ULP with the pre-interleaving, which is able to delay the occurrence of the first unrecoverable loss in the source data bitstream while still keeping the original priorities among different layers. Experimental results show that the proposed joint L-ULP and pre-interleaving scheme is able to achieve as good performance as that of the ULP while the complexity is much lower.

1. INTRODUCTION

Wavelet-based image codes such as SPIHT and JPEG2000 have shown to be superior to DCT-based image codecs in not only the coding efficiency but also the functionalities such as the progressive property, which allows the bitstream to be truncated in any position and thus provides rate scalability. Although the progressive image coding can provide excellent compression and scalability performance, it makes image bitstreams very sensitive to channel noise such as packet-loss in the Internet and bit errors in wireless links. An error in a bitstream may cause all the following bits become useless. Therefore, error control techniques such as forward error correction (FEC) and automatic repeat request (ARQ) are needed to combat with channel noise to ensure a reliable image transmission.

Recently we have seen extensive studies in FEC-based joint source-channel coding (JSCC) for progressive image and video transmission over packet loss channels [1, 2, 3, 4]. The common idea of these schemes is to use unequal loss protection (ULP), i.e., the more important information is given more protection. Comparing with equal loss protection (ELP), ULP can obtain considerable performance gain and has the property of graceful performance degradation during channel mismatch cases while the complexity of ULP is much higher than ELP since it is not trivial to find the optimal ULP solution. In [1], Mohr et al. developed an unequal loss protection (ULP) framework with fixed-length channel coding blocks, and used a greedy and iterative search algorithm to find the optimal channel coding rates for each channel coding block, which costs comparatively long execution time. Kim et al. [2] proposed to use dynamic programming to find the optimal channel coding rates for each bitplane instead of each channel coding block. Although the experimental results in [2] show that the scheme can be executed much faster than the ULP, its improvement much depends on the number of bitplanes. Besides the high complexity shortcoming, 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 ULP and ELP (HLP) scheme is proposed in [3]. The basic idea of the HLP is to constrain the early portions of a progressive bitstream with equal loss protection whose corresponding PSNRs are less than a threshold while ULP is applied to the rest of the bitstream. Although the HLP can greatly reduce the probability of failure transmission, i.e., below the minimum quality requirement, its complexity is still as high as the ULP.

In our previous work [5], 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 our proposed L-ULP is able to achieve low-complexity and meet the minimum quality requirement, its average PSNR performance is not as good as the HLP or the ULP. In this paper, we propose to combine the L-ULP with the pre-interleaving together to further improve the performance of the L-ULP. The basic idea is to delay the occurrence of the first unrecoverable loss in the source data bitstream since the performance of a progressive image transmission is very much determined

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by the location of the first unrecoverable loss instead of the number of losses.

2. PREVIOUS WORK

The architecture of a general L-ULP scheme can be described as follows. In an $L \times N$ 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 expected distortion in mean square error (MSE) at the receiver end can be formulated as

$$D = d_0 - \sum_{i=1}^{n} \Delta d_i \cdot C_i, \tag{1}$$

where d_0 is the distortion of not using any packet for reconstruction, n is the number of layers, C_i is the probability of correctly decoding the i-th layer, and Δd_i is the corresponding distortion gain. Such a layed ULP is even more complicate than the conventional ULP [1] because we need to find not only the optimal FEC allocation f_i but also the optimal layer division L_i (Assuming n is given.).

In our previous work [5], we proposed to divide layers according to source coding R-D (rate-distortion) curves $D_s(R_s)$. The basic idea of the proposed layer division is to let each layer have equal distortion gain while the first layer must satisfy the minimum quality requirement. In particular, the layer division can be described as

$$b_i = \begin{cases} D_s^{-1}(d_s^h) & \text{if } i = 1 \\ L(N - \bar{f}) & \text{if } i = n \\ D_s^{-1}(d_s^h - (i-1)\Delta d_s) & \text{if } i = 2, \ldots, n-1 \end{cases} \tag{2}$$

where d_s^h is the highest distortion determined by the minimum quality requirement, $\bar{f}$ is the optimal ELP solution, $\Delta d_s = \frac{d_s^h - d_s^l}{n-1}$ and $d_s^l = D_s(b_n)$. Note that the actual value of b_i may need to change a little during the implementation due to byte alignment and channel block alignment. Since we found the alignment issue only has slight effects on the overall performance, we neglected it and re-formulated the expected distortion after the layer division as

$$D = d_0 - (d_0 - d_s^h) \cdot C_1 - \Delta d_s \sum_{i=2}^{n} C_i. \tag{3}$$

3. L-ULP WITH PRE-INTERLEAVING

3.1. System Description

An interesting channel decoding scheme is reported in [6] which does not aim at achieving low error rate, but rather makes the first error as far out as possible under the actual channel condition. Such a channel decoding scheme can be well combined with progressive image coding since the performance of a progressive image transmission is actually determined by the location of the first unrecoverable error instead of the amount of errors. This important property has not been received enough attention in the area of joint source channel coding for progressive data transmission.

Motivated by the idea presented in [6], in this paper we propose to combine the pre-interleaving with our previous proposed L-ULP scheme for progressive image transmission over packet loss channels. By using the pre-interleaving, we are able to delay the occurrence of the first unrecoverable loss in the source bitstream and thus improve the L-ULP performance. This is the major innovation of our proposed scheme. Fig. 1 gives an example of the L-ULP with three layers to illustrate the basic idea of this innovation. The top one 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 one in Fig. 1 is the proposed L-ULP with pre-interleaving, 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 name it as pre-interleaving. The advantage of applying the pre-interleaving can be explained by the following example. 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 IL-ULP scheme 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.

Note that the pre-interleaving is not suitable for the traditional ULP scheme [1]. This is because in the traditional ULP different rows in the rectangle have different priorities and in order to provide higher priorities for more important information the source bitstream has to be place from left to right and from top to bottom. We would also like to point out the pre-interleaving is not necessary to be applied to the first layer in the L-ULP, which is designed for the minimum quality requirement, since we consider any source decoding with data amount less than b_1 as a transmission failure. In addition, the pre-interleaving will only increase the processing complexity a little bit and it will not increase any transmission delay.

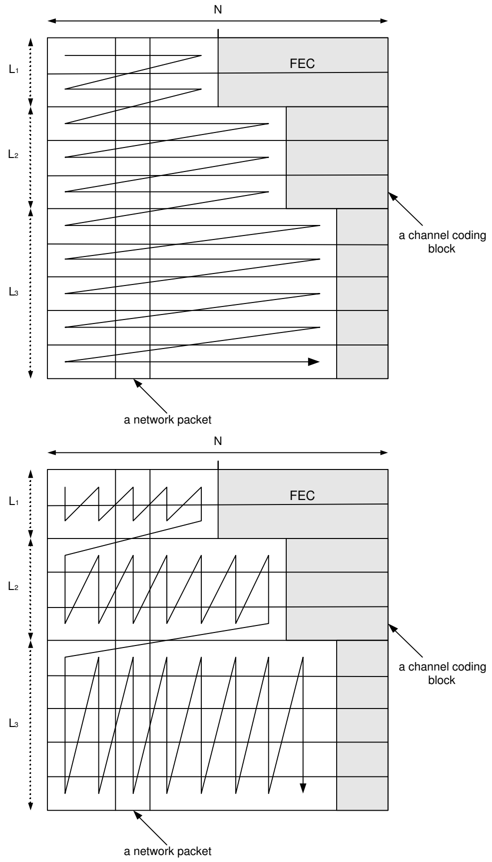

Fig. 1. An example of the L-ULP with three layers. Top: the original L-ULP. Bottom: with the pre-interleaving.

3.2. Analysis of End-to-End Distortion

The expected distortion for the proposed L-ULP scheme with the pre-interleaving can be written as

$$D(\overrightarrow{f}) = d_0 - \sum_{i=1}^{n} \sum_{j=1}^{N-f_i} \Delta d_i^j \cdot C_i^j, \tag{4}$$

where $\overrightarrow{f} = \{f_1, f_2, \dots, f_n\}, f_1 \geq f_2 \geq \cdots \geq f_n$, C_i^j is the probability of correctly decoding the j-th packet in the i-th layer and Δd_i^j is the corresponding distortion gain. Given f_i, Δd_i^j can be obtained according to source coding R-D curves $D_s(R_s)$. C_i^j can be calculated according to the given packet loss model. In this research, we adopt the simplified Gilbert-Elliott channel (GEC) [7], 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.

3.3. Optimal FEC Selection

Based on the layer division method described in Eqn. (2), the optimal FEC selection problem can be summarized as: given the total bandwidth $N \cdot L$ and the number of layers n, how to find the optimal f_i so that the expected distortion shown in Eqn. (4) can be minimized. Similar to the ULP scheme, we can use iterative search to find the optimal f_i, which is very complicated. The complexity could be as high as the ULP. This contradicts our initial objective, i.e., to propose a low complexity L-ULP scheme for fast image transmission over packet loss channels. Hence, in this research we choose Eqn. (3) as our cost function for optimal FEC selection. We only consider the pre-interleaving effect in computing the optimal ELP solution $\bar{f}$ while we do not consider the pre-interleaving effects in the stage of optimal FEC selection.

It is clear that in Eqn. (3) d_0, d_s^h and Δd_s are either constant or fixed after the layer division. The function can be separated into n independent units. A unit i is associated with the term C_i, which only depends on f_i and is independent of the FEC selection for other layers. Therefore, such optimal FEC selection problem is the same as the optimal bit allocation among n independent units, which can be solved by using the gradient search method described in [8].

4. EXPERIMENTAL RESULTS

The standard 512x512 Lena image with 8 bits per pixel is used as the test image. We choose the packet size of 200 bytes and use the GEC model. The testing average packet loss rate (p_l) is from 5% to 30% and the average burst length is fixed to 16 packets. SPIHT is adopted as the codec for source coding and RS codes with 8 bits/symbol are used for channel coding. We choose 25 dB as a PSNR threshold for the minimum quality requirement. Any image transmission with a PSNR value less than the threshold is deemed as a failure transmission. The size of the rectangle is chosen to have 80 packets, corresponding to a total bandwidth of 0.488 bpp. We compare our proposed joint L-ULP and pre-interleaving scheme, termed as the improved L-ULP (IL-ULP), with the original L-ULP scheme, the optimal ELP scheme and the HLP scheme [3]. The HLP considers each row in the rectangle as a layer and uses iterative search to find the optimal FEC allocation f_i while it limits the foremost several rows with equal loss protection in order to satisfy the minimum quality requirement. In the IL-ULP and the L-ULP schemes, the number of layers is fixed to 5.

Fig. 2 shows the comparison of the average effective PSNR of transmitting the Lena image under different packet loss rates over 1000 simulations. The average effective PSNR is defined as the average PSNR without counting the contributions from failure image transmissions. It can be observed that the IL-ULP outperforms the ELP with up to 2.51 dB gain, and outperforms the original L-ULP with up to 1.91 dB gain. It is surprising to see that the performance of the IL-ULP is as good as the HLP and at many cases it is even better than the HLP. For instance, the IL-ULP has 0.57 dB gain over the HLP for the Lena image at $p_l = 0.05$. This demonstrates the effectiveness of combining the pre-interleaving with the L-ULP. We also compare the complexity and the probability of failure image transmission P_f between the IL-ULP and the HLP as shown in Table 1. The complexity is measured in terms of the number of loops executed in the corresponding optimal FEC selection algorithms since the optimal FEC selection is the most time-consuming portion in all the ULP schemes. For the HLP, the number of loops is obtained by counting the number of times calculating the distortion in Eqn. (1). For the IL-ULP, the number of loops is obtained by counting the number of times calculating a R-D slope. Note that the IL-ULP and the L-ULP without the pre-interleaving use the same FEC allocation method and thus their corresponding complexity and P_f values are the same. From Table 1, we can see that the complexity of the proposed IL-ULP, in the order of 10^2, is much lower than that of the HLP, in the order of 10^6. In addition, the IL-ULP also achieves smaller probability of failure image transmission in most of the cases.

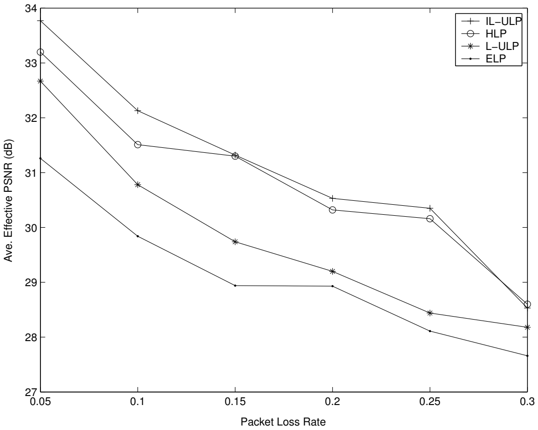

Fig. 2. The PSNR performance comparison between IL-ULP, HLP, L-ULP and ELP at 0.488 bpp.

5. CONCLUSION

The contribution of this paper is twofold. First, we have integrated the pre-interleaving with our previous L-ULP scheme which is able to delay the occurrence of the first unrecoverable loss in the source progressive bitstream while still keeping the original priorities among different layers. Second, we have solved the optimal FEC selection by gradient search instead of exhaustive iterative search, which greatly reduces the system complexity. Experimental results have demonstrated the proposed joint L-ULP and pre-interleave system can satisfy the low-complexity and minimum quality requirements with only slight performance loss. Therefore, it is very suitable for practical fast image transmission over packet loss networks.

Table 1. The complexity and P_f comparison between the HLP and the IL-ULP for the Lena image coded at 0.488 bpp.

Average Packet Loss Rate	Number of Loops		$P_f(\%)$	
	HLP	IL-ULP	HLP	IL-ULP
0.05	2686976	808	0.22	0.15
0.1	5242880	743	0.37	0.33
0.15	3801088	711	0.45	0.4
0.2	1769472	741	0.68	0.6

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