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Layered Unequal Loss Protection for Image Transmission Over Packet Loss Channels with Delay Constraints

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ABSTRACT

In the case of high bit rate image transmission or having lots of packets, the FEC (forward error correction) encoding and decoding processes in the ULP (unequal loss protection) based schemes should be applied to individual packet groups instead of all the packets in order to avoid long processing delay. In this paper, we propose a layered ULP (L-ULP) scheme for fast and efficient FEC allocations among different packet groups and also within each packet group. The numerical results show that the proposed L-ULP scheme is quite promising for fast image transmission over packet loss networks.

Keywords: Progressive image transmission, unequal loss protection, joint source-channel coding, forward error correction, packet loss

1. INTRODUCTION

It is well-known that there exists the problem of packet loss in packet-switching networks such as Internet and ATM networks. For example, if congestion occurs at a network router, the router may discard all newly arrival packets. For some delay constrained applications, if a packet arrives the destination beyond the tolerable delay, it becomes useless. In addition, if there is a wireless link in the transmission path, severe channel impairment in the wireless link can also cause the packet loss. The packet loss remains as one of the most challenging problems in the applications of multimedia communications. In order to achieve a reliable multimedia transmission, error correction schemes are usually employed to combat the packet loss. This is particularly necessary for moderate-to-heavy packet loss cases.

Recently we have seen extensive studies in FEC-based joint source-channel coding (JSCC) for image and video transmission over packet loss channels.[1–5] 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 Ref. 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 Ref. 2 shows 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 unnecessary ULP process. For example, Fig. 1 shows a typical PSNR degradation performance of using the ULP[1] to transmit the Lena image coded by SPIHT[6] at 0.2 bpp with 47 bytes per packet. It can be seen that a considerable portion of the ULP results which is claimed superior to ELP is actually with very low PSNR values (say below 25 dB) and the corresponding reconstructed images are

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of low quality and thus useless for practical applications. By observing this problem, a hybrid ULP and ELP (HLP) scheme is proposed in Ref. 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. 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.

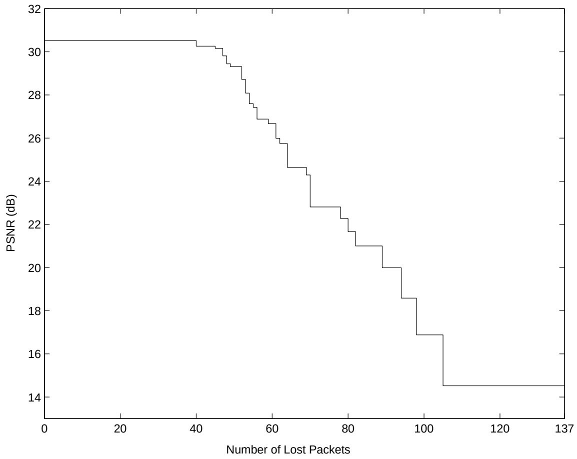

Figure 1. The PSNR performance of using ULP to transmit the Lena image coded at 0.2 bpp with 47 bytes per packet under different numbers of lost packets. The channel loss model is an exponential PMF (probability mass function) with a mean loss rate of 0.2.

So far, the delay problem in the ULP based image transmission has not been addressed much. Most of the ULP schemes consider all the packets of one image entirely for the FEC encoding and decoding processing. This works fine for low bit rate image transmission since the number of packets for one image is quite limited. However, in the case of high bit rate image transmission or having lots of packets, the conventional schemes will cause long delay or slow response to users' requirements since the FEC decoder has to wait until the arrival or the timeout of the last transmitted packet. In this paper, we extend our previous L-ULP work[7] to the case of image transmission with the delay constraint. In particular, in order to satisfy the delay requirement, we divide all the packets into several groups and FEC is applied to each packet group. We formulate the L-ULP framework under such a delay-constrained scenario and propose a two-step approach to find the optimal FEC allocation. Experimental results show that the proposed scheme is able to achieve low-complexity and meet the delay and minimum quality requirements with slight performance degradation.

The paper is organized as follows. Section 2 formulate the problem of applying L-ULP under the delay constraint. Section 3 describes the proposed two-step method. Section 4 presents numerical results and finally concluding remarks are given in Section 5.

2. PROBLEM STATEMENT

Fig. 2 shows the architecture of a general L-ULP scheme. 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. A $(N, N - f_i)$ 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

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

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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,[7] we proposed to divide layers according to source coding R-D (rate-distortion) curves. The basic idea is to let each layer have equal distortion gain while the first layer must satisfy the minimum quality requirement. After such a layer division, the task left for the L-ULP is to find the optimal solutions for f_i.

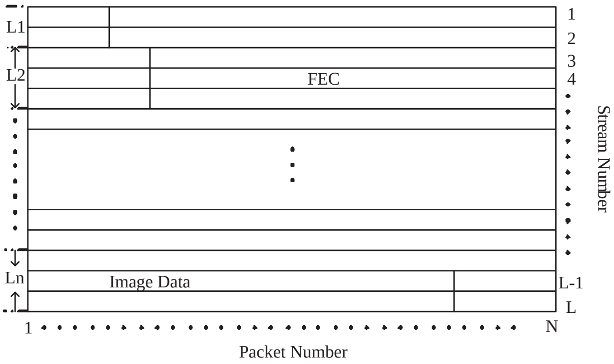

Figure 2. A general layered ULP structure.

In the case with the delay constraint, we consider there are multiple independent rectangles. Each rectangle consists of a group of packets. The size of a rectangle is limited by the delay constraint. The expected distortion in this case can be written as

$$D = d_0 - \sum_{i=1}^{m} \sum_{j=1}^{n_i} \Delta d_i^j \cdot C_i^j, \tag{2}$$

where m is the number of rectangles, n_i is the number of layers in the the i-th rectangle, C_i^j is the probability of correctly decoding the j-th layer in the i-th rectangle, and Δd_i^j is the corresponding distortion gain. Suppose n_i is pre-chosen according to users' requirements or network configuration, which is typically a small value in order to keep low complexity. The L-ULP problem under the delay constraint can be summarized as: given all the values of n_i, how to find the optimal f_i^j and L_i^j so that the expected distortion shown in Eqn. (2) can be minimized.

3. L-ULP FOR DELAY-CONSTRAINED TRANSMISSION

Regarding to this problem of applying L-ULP under the delay constraint, we propose a two-step approach to perform the FEC allocation and the layer division. In particular, in the first step we consider the FEC allocation among rectangles. In other words, we only consider one layer in one rectangle at the first step. After we obtain the average FEC amounts for each rectangle, we can apply our previous proposed L-ULP scheme[7] directly to obtain the FEC allocation and the layer division in each rectangle. The basic idea here is to reduce the dependency of FEC allocation among different rectangles so that L-ULP can be processed in a fast manner. We believe such an approach can achieve sub-optimal performance which is close to that of global optimization using iterative search. This is because many studies show that under channel matching conditions the minimum distortion achieved by the ULP is only slightly better than that of the optimal ELP. Our numerical results in the next section also provide very supportive evidence for the effectiveness of our proposed scheme. In the following, we describe the proposed two-step approach in detail.

- Step 1: We consider only one layer in one rectangle and use the iterative search method to find the optimal

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FEC allocation $\overrightarrow{F}$ among the m rectangles which minimizes

$$D(\overrightarrow{F}) = d_0 - \sum_{i=1}^{m} \Delta d_i(\overrightarrow{F}) \cdot C_i(\overrightarrow{F}), \tag{3}$$

where $\overrightarrow{F} = \{\bar{f}_1, \bar{f}_2, \ldots, \bar{f}_m\}, \bar{f}_1 \geq \bar{f}_2 \geq \ldots \geq \bar{f}_m$. Note that although we use iterative search at this step, the complexity is very low since m is usually a small number. d_0 and Δd_i can be obtained according to source coding R-D curves $D_s(R_s)$. The source coding R-D curves $D_s(R_s)$ of a progressive image coding scheme such as SPIHT can be obtained by extracting some R-D points such as the end points of each bitplane during the encoding process followed by linear interpolation between neighbor R-D points. $C_i(\overrightarrow{F})$ can be derived as

$$C_i = \prod_{j=1}^{i} [\sum_{k=0}^{\bar{f}_j} P(N_j, k)], \tag{4}$$

where $P(N_j, k)$ is the probability of having k lost packets out of the total N_j packets. $P(N_j, k)$ can be calculated according to the given packet loss model. In this research, we use the packet loss model with the exponential probability mass function (PMF) the same as that in Ref. 1.

- Step 2: Based on the obtained $\overrightarrow{F}$, we perform the layer division and the FEC allocation in each rectangle independently. In particular, we divide layers according to source coding R-D curves $D_s(R_s)$. The basic idea of the proposed layer division is to let each layer in one rectangle have equal distortion gain while the first layer in the first rectangle must satisfy the minimum quality requirement. For example, the layer division for the i-th ($i \neq 1$) rectangle can be described as

$$b_i^j = \begin{cases} L(N_i - \bar{f}_i) + b_{i-1}^{n_{i-1}} & \text{if } j = n_i \\ D_s^{-1}(d_i^h - j\Delta d_i) & \text{if } j = 1, 2, \ldots, n_i - 1 \end{cases} \tag{5}$$

where d_i^h, $d_i^h = d_{i-1}^l$, and d_i^l, $d_i^l = D_s(b_i^{n_i})$, are the highest and lowest distortions associated with the i-th rectangle, respectively, and $\Delta d_i = \frac{d_i^h - d_i^l}{n_i}$. Note that the actual value of b_i^j may need to change a little during the implementation due to byte alignment and channel block alignment.

In this research we assume the alignment issues can be neglected and we re-formulate the expected distortion for the i-th rectangle after the layer division as

$$D_i(\overrightarrow{F}_i) = d_i^h - \Delta d_i^1 \cdot C_i^1(f_i^1) - \Delta d_i \sum_{j=2}^{n_i} C_i^j(f_i^j), \tag{6}$$

where $\overrightarrow{F}_i = \{f_i^1, f_i^2, \ldots, f_i^{n_i}\}, f_i^1 \geq f_i^2 \geq \ldots \geq f_i^{n_i}$ and $C_i^j(f_i^j) = \sum_{k=0}^{f_i^j} P(N_i, k)$. Here, the reason we separate the first layer out is that the first layer in the first rectangle is divided according to the minimum quality requirement. From Eqn. (6) we can see that the expected distortion can be separated into the n_i independent units and Δd_i^j is independent of the choice of $\overrightarrow{F}_i$. Thus, the problem of finding the optimal FEC allocation is the same as optimal bit allocation among n_i independent units, which can be solved by processing the falling convex hull of the R-D slopes. Details can be found in Ref. 8, 9.

4. NUMERICAL RESULTS OF L-ULP WITH DELAY CONSTRAINTS

The standard 512x512 Lena image with 8 bits per pixel is used as the test image. We choose the packet size of 100 bytes and use the exponential PMF packet loss model. 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. We compare our proposed L-ULP extension scheme with the HLP[3] and the optimal ELP scheme. The HLP considers each row in one rectangle as a layer and uses iterative search to find the optimal FEC allocation f_i^j which minimizes the overall distortion based on Eqn. (2) while it limits the foremost several rows

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in the first rectangle with equal loss protection in order to satisfy the minimum quality requirement. Therefore, the performance of the HLP should be the upper bound for our proposed L-ULP extension scheme.

Fig. 3 shows the comparison of the average PSNR performance of transmitting the Lena image under different packet loss rates. The size of each rectangle is limited to 80 packets and there are totally 160 packets. This corresponds to a total bandwidth about 0.488 bpp. In our proposed L-ULP extension scheme, we choose a simple layer configuration $(5, 5)$, i.e., five layers in each rectangle. It is shown in Fig. 3 that our proposed L-ULP extension scheme outperforms the ELP, up to 1.8 dB gain, while it is not as good as the HLP, around 0.18 dB to 0.37 dB degradation which is not significant.

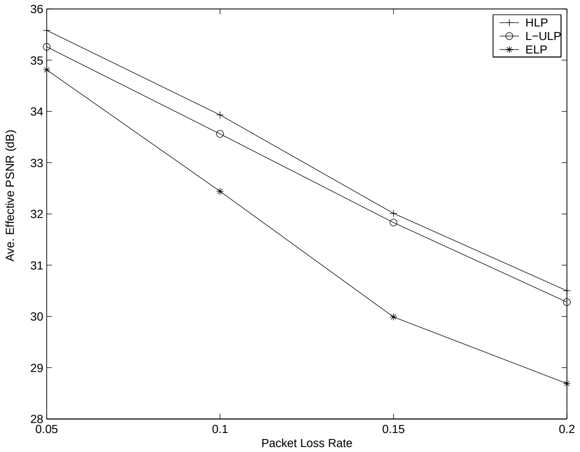

Figure 3. The comparison of the average effective PSNR of different unequal loss protection schemes under the delay constraint. The total bandwidth is 0.488 bpp and there are two independent packet groups.

We also compare the complexity and the probability of failure image transmission P_f between our proposed L-ULP extension scheme 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 allocation algorithms since the optimal FEC allocation is the most time-consuming portion in all the ULP schemes. For the HLP, the number of loops is considered as the number of times calculating the distortion in Eqn. (2). While for the L-ULP extension scheme, the number of loops is considered as the number of times calculating a R-D slope. From Table 1, it can be observed that our proposed L-ULP extension scheme achieves lower P_f values, and the complexity of the proposed L-ULP, in the order of 10^2, is much lower than that of the HLP which is in the order of 10^5 or 10^6.

Table 1. The complexity and P_f comparison between the HLP and the L-ULP under the delay constraint.

Packet Loss Rate	Number of Loops		$P_f(\%)$	
	HLP	L-ULP	HLP	L-ULP
0.05	408259	510	0.0085	0.001
0.1	1775349	830	0.058	0.034
0.15	1809735	911	0.32	0.176
0.2	2509776	956	0.61	0.553

5. CONCLUSION

In this paper, we have presented the L-ULP scheme for progressive image transmission over packet loss channels with delay constraints. In particular, we proposed a two-step approach to perform the FEC allocation among

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individual packet groups and also within each packet group. By smartly choosing layers, we solved the FEC allocation problem within one packet group by gradient search instead of exhaustive iterative search. Numerical results have demonstrated that the proposed L-ULP scheme can satisfy the delay and minimum quality requirements, and can achieve comparable performance with very low complexity. Therefore, it is very suitable for practical fast image transmission over packet loss networks.

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