A Compression-Efficient Forward Error Control Mechanism for Image Transmission over ATM Networks

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ABSTRACT

Multimedia services over lossy networks have triggered the development of robust error control and recovery techniques. The main attributes of these techniques include time efficient processing, low amount of additional data overhead, and high resilience to errors in order to efficiently deliver these services. In this work, we propose a Dynamic-Selective FEC with Independent Triangular Interleaving scheme (DS-ITRII) that provides several advantages for multimedia transmission, including efficient compression, fast channel decoding, and low FEC overhead. The proposed scheme is analyzed by simulating a lossy image transmission over an ATM network. We show that for high compression ratios (≤ 0.5 bpp) our scheme after data interleaving and channel encoding perfoms much better than the Baseline JPEG. It also provides high probability for the protected information reaching the receiver error free.

I. INTRODUCTION

Forward Error Correction (FEC) has been widely used for providing high quality data communication in lossy environments. However, there is a general agreement that additional overhead may increase network congestion and hence the network error rate, causing a vicious loop. This is particular true if FEC is applied without data discrimination and without considering current network conditions [1,2,10]. New FEC schemes need to be developed in order to reduce the amount of overhead, while maintaining an acceptable image/video quality at the receiver side. The techniques, such as Unequal Error Protection (UEP) have been applied to video transmission [3,8,9], in which information is layered encoded into base layer and enhancement layers. Each resulting layer receives different amount of protection depending on its contribution to the final quality of the reconstructed information. The most important layer (base layer) receives the maximum FEC benefits, while the less important layers (enhancement layers) receive low protection or none at all. Recent UEP schemes [5,8] are being combined with R-D (rate/distortion) techniques so that the information bit rate (payload and overhead protection) is less than or to the available channel bit rate. This is to alleviate the problem of increase in the channel error rate at the expense of reduced quality of the transmitted information. A common feature in the FEC schemes mentioned above is that the added overhead is used to protect the whole information, or in the case of layered transmissions the base and/or enhancement layers. This implies that the receiver has to wait until it gets all the packets associated with each layer to start the decoding process. Another problem with such schemes is that if the number of cell losses exceeds the FEC protection, the whole layer is indirectly lost because one cannot recover any information from the received cells. This problem is even bigger if the loss is related to the base layer. We propose a Dynamic-Selective FEC with Independent Triangular Interleaving (DS-ITRII) scheme where only specified portions of the transmitted information or layer are protected according to their importance to conceal the errors in the previously sent layers. By doing this, we minimize the effect of FEC on the network load and maintain the probability of survival high for the protected information (that is the probability that the protected information will get the receiver side successfully). With DS-ITRII, large extensions of correlated errors are avoided. Information may be lost during transmission, but sender and receiver cooperatively decide, probabilistically speaking the best loss pattern for the transmitted information, so that errors are recoverable. Since in selective FEC not all the information is protected, the receiver does not have to wait for the whole information to start the decoding process; neither the whole layer is lost when the number of losses exceeds the FEC protection.

We show that the proposed scheme (DS-ITRII) gets compression ratios even better than the Baseline JPEG standard (without FEC protection) for all cell loss rates

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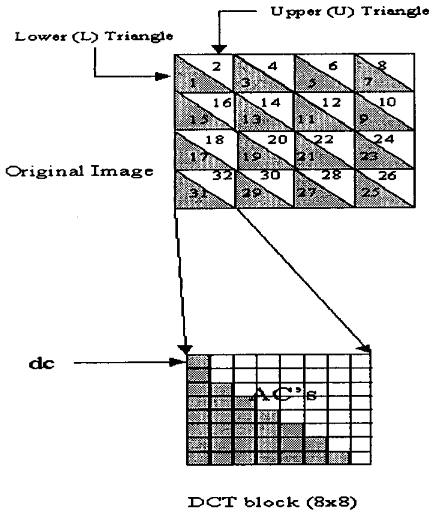

Figure1: DCT block triangular decomposition.

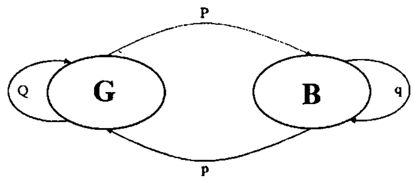

Figure 2: Gilbert Model (two states Markov model).

(CLR) considered. The proposed scheme considerably improves our previous results as well (DS-TRII [4]).

II. Dynamic and Selective ITRII (DS-ITRII)

The proposed DS-ITRII scheme can be divided into two parts: a Independent Triangular interleaving scheme (ITRII) [7] to de-correlate information inside the blocks, and a 4-state Markov chain (4-MC) that predicts, the amount of FEC overhead needed for protection, based on the current channel cell loss rate. The ITRII scheme de-correlates information inside the blocks (8x8 pixels) and between consecutive cells. In this scheme, every DC transformed and quantized block is diagonally divided into two independent triangular components, the upper (U) and the lower (L) components (as shown in Figure 1). The DC term is treated as an independent component and is grouped together with the rest of the DC terms to form the *base layer*. In order to have two independent triangular regions per block, an additional EOB per block is required. Since this addition increases the encoded information by $4*N_b$ bits, (where N_b is the number of blocks in the input image, and 4 is the number of bits per EOB), we proposed a JPEG compliant variable EOB (V-EOB) scheme to reduce its effect on the final compression ratio [7]. In this scheme, considering all the triangular components in the image, a frequency table is computed over the number of AC coefficients per component and Huffman code is then applied to get the binary bit code for each EOB. This scheme has been tested on several input images under different compression ratios and the results show that ITRII with V-EOB outperforms JPEG compression standard at all levels, yielding a total average gain of 6.3%. After diagonalization, the lower and upper triangles are grouped into two layers (which can be considered as the *Enhancement Layers*) such that if lower triangle of block *i* is in layer 1 then the upper triangle of the same block is in layer 2 and vice versa. The above interleaving process produces 3 different layers, DC, L_1, and L_2 layers. An important thing to point out here is that L_1 and L_2 are complementary layers that are needed to fully restore the original information of every single block. If L_1 or L_2 is missing during transmission, half of the information will be present in each block.

Our dynamic selective FEC scheme is based on the assumption that in general cell losses are correlated and occur in bursts [6]. This process can be approximated by considering a two-state (on-off) Markov model with state transition probabilities as shown in Figure 2. The states *G* and *B* represent the *Good* (no cell loss) and *Bad* (cell loss) behavior, respectively. The quantity *P* represents the transition probability to go from *G* to *B*, and *p* from *B* to *G*. The quantity Q represents the probability to stay in good state (*G*), while q represents the probability to stay in bad state (B). As transition probabilities, $P + Q = p + q = 1$. The cell information is organized in such a way that highly correlated blocks (neighboring blocks) do not be share the same cell nor *l* consecutive number of cells. The value of *l* depends on the actual cell loss behavior of the network, heavier the congestion, bigger the number *l*.

During data transmission, L_1 layer is first transmitted without FEC overhead and feedback is awaited from the receiver as to which cell has been lost in L_1. While the sender is waiting for the feedback, it is also sending at the same time the DC layer labeling as a high priority layer. If there was no loss in the first layer, it transmits the second layer L_2 without FEC protection (no errors, no FEC) otherwise FEC is then applied to protect only the information in L_2 whose complement has been lost in L_1. This protection scheme increases the probability that some coefficients in every DCT block will reach the receiver side. The amount of FEC overhead added for the protection of L_2 depends basically on the network cell loss rate during the transmission of L_1, and it is computed by using the stationary probabilities of a 4-states Markov model, as described next. When losses occur in L_1, cells in L_2 carrying the complementary information have to be protected. The number of FEC cells to be added for protection is computed by considering the probability of loosing cells from both layers (1 and 2) at the same position. For instance, state (B,B) means that we lose complementary cells (this is the state that we want to avoid), and (G,B) means that there are no loss in L_1, only in L_2. Assuming that the cell loss pattern in L_1 does not influence the loss pattern in L_2 (independence property), the probability to go from (B,B) to (G,B) is *pq*. By using this reasoning, the problem can be re-stated as a 4-MC represented by S = [(G,G), (G,B), (B,G), (B,B)], with transition probabilities represented as

$$P_{i,j} = \begin{pmatrix} Q^2 & QP & PQ & P^2 \\ Qp & Qq & Pp & Pq \\ pQ & pP & qQ & qP \\ p^2 & pq & qp & q^2 \end{pmatrix} \qquad (1)$$

where $P_{i,j}$ is the probability to go to state *j* given that we are in state *i*, and $i, j \in$ S. The parameters *Q*, *P*, *p*, and *q* are calculated based on the information received from the sender. The stationary probabilities can be calculated by solving the following system of equations:

$$\pi_j = \sum_{i \in S} \pi_i P_{ij} \ , \qquad \sum_i \pi_i = 1 \qquad (2)$$

where π_i represents the long term probability to be in state $i \in$ S. As we mentioned above, we are particularly interested in the value of $\pi_{(B,B)}$, which represents the proportion of cells in L_2 that are likely to be in state (B,B). From this value, we can compute the number of cells needing protection by using the following relation:

$$F_c = \pi_{(B,B)} N_2 \qquad (3)$$

where N_2 is the number of cells in L_2. Since we are to sending F_c additional cells in L_2, these cells are also subject to probabilistic losses and the amount of loss is given by $(\pi_{(B,B)} + \pi_{(G,B)})F_c$. Therefore, the total number of cells needing protection can be represented as:

$$\begin{aligned} F_c &= \pi_{(B,B)} N_2 + (\pi_{(B,B)} + \pi_{(G,B)})F_c \\ F_c &= \pi_{(B,B)} N_2/(1 - \pi_{(B,B)} - \pi_{(G,B)}) \qquad (4) \end{aligned}$$

For the purpose of our simulation results, we have used F_c and its variance over different cell loss ratios to compute the total amount of overhead required for protection.

III EXPERIMENTAL RESULTS

In this section we present the performance results of DS-ITRII using Lenna (512x512) at 0.5, 0.45, 0.4, 0.35, 0.3, 0.25 bpp under different cell loss rates (5%, 10%, 15%, 20%, and 25%) and a burstiness of q=0.4. The DC layer remains unmodified by using high priority transmission, and only the first and second layers are subject to errors. The same error rate was considered to simulate the cell loss in both layers, L_1 and L_2.

Figure 3 compares the FEC overhead generated by the proposed method (DS-ITRII), with other FEC schemes such as constant FEC [1,2,8,10], Linear FEC (joint/source coding) [3,9], and DS-TRII [4] (which does not use V-EOB and instead creates new blocks using complementary triangles of neighboring blocks). Two versions of DS-ITRII are presented in Figure 3: Linear scheme, in which the number of FEC cells in L_2 equals the number of cells lost in the L_1, and the 4-MC (described in section II). For lower values of CLR, DS-ITRII and DS-TRII have comparable overhead but for larger CLRs, the DS-ITRII scheme outperforms all the other schemes considered.

Figure 4 shows the difference in total number of cells produced by DS-TRII and DS-ITRII with respect to JPEG standard without FEC, using the same quantization matrix (Q). The values of Q were chosen such that the JPEG compressed image is represented at 0.5, 0.45, 0.4, 0.35, 0.3, 0.25, 0.2 bpp. Since DS-ITRII outperforms DS-TRII in all the cases under consideration, for DS_TRII we only show the result at 0.5 bpp. The difference is computed as follow, if JPEG standard produces 10 cells for a certain input image at a given bpp, and TRII produces 15 (including FEC) using the same Q, then the extra overhead that has to be transmitted by using TRII with respect to JPEG is ((15-10)/10)*100. However in TRII, the extra overhead has a minimum value of 12% at 5% CLR and a maximum of 24% at 25% CLR. These relatively high values of overhead are due to two reasons: 1) The effect of TRII on the compression ratio, which is 2% higher than JPEG; and 2) the fact that the number of cells lost in L_1, in general, doubles the number of cells that needs protection in L_2. The reason is that the complementary information in L_1 and L_2 is not necessarily confined to the same cell boundaries. This implies that a 1cell loss in L_1 may require 2 or more cells that may need protection of the cell in L_2. We address this problem in the proposed DS-ITRII scheme by independently encoding and protecting the complementary components in L_2, so that the difference between the number of cells lost in L_1 and the number of cells protected in L_2 is minimized (the protected information can be shuffled with the unprotected cells, so that they can serve as a shield for correlated cell losses).

In the case of DS-ITRII, the total amount of transmitted cells (FEC and payload) is much less than the Baseline JPEG (6.3 % on the average) for all CLR and bpp's, as shown in Figure 4.

Figure 5 shows the received Lenna image at 0.5 bpp and CLR of 15% for the DS-ITRII scheme. The damaged blocks have lost half of the information, which, is relatively easy to reconstruct due to the availability of correlated information in the surrounding. Figures 4 and 5 show very important results, highlighting several properties of the proposed scheme. These include: a) novel interleaving that spreads out the effect of errors over the entire image, b) new FEC protection for full error recovery using very small FEC overhead, and c) implicit significant reduction in the network errors because less information is being transmitted.

IV. CONCLUSSIONS

We have introduced a new dynamic and selective FEC scheme with independent triangular interleaving (ITRII) that improves error resilience and bandwidth usage in lossy networks at all simulated compression levels and CLR's. It has been shown that the combination of ITRII and dynamic-selective FEC (DS-ITRII) gives even better compression ratio than the Baseline JPEG standard (4.7% gain on the average). Also, the DS-ITRII shows remarkable reduction in FEC cells compared to DS-TRII, constant FEC, and Joint/source channel coding Linear FEC, without compromising its responsibility to robustly protect the transmitted information.

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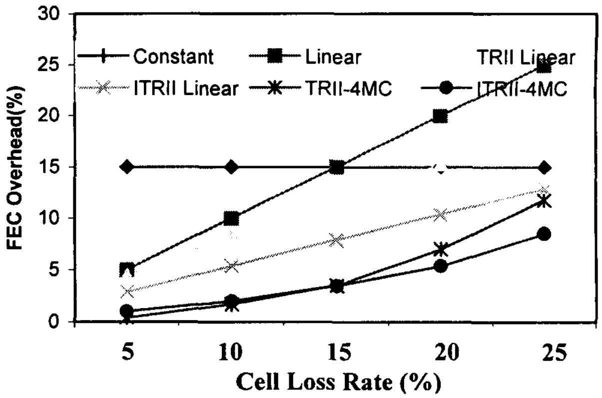

Figure 3: Amount of FEC overhead respect to JPEG standard.

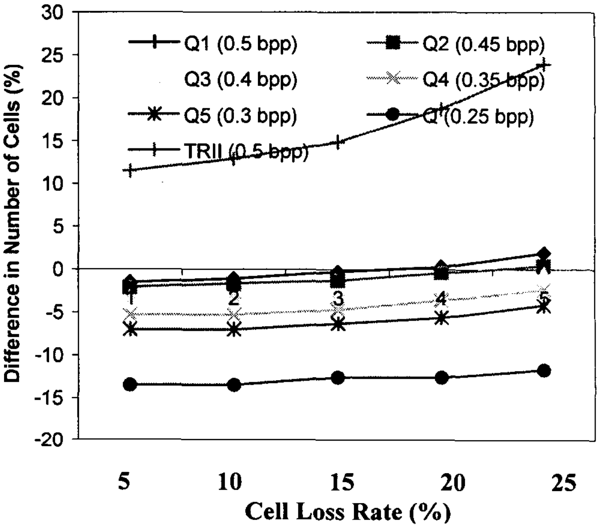

Figure 4: The difference in number of cells transmitt compared to Baseline JPEG standard

Figure 5: DS-ITRII coded Lenna at 15% CLR.