ROBUST WIRELESS TRANSMISSION OF REGIONS OF INTEREST IN JPEG2000

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ABSTRACT

In this paper, we present a technique to robustly transmit regions of interest in the JPEG2000 framework. The technique assumes a prioritized region-of-interest coding and optimally assigns channel protection to the coded data according to the importance of every packet in the final bit-stream. The mean energy of the transform coefficients contained in a packet and the distance of a packet from the region of interest determine the importance of every packet. The channel protection is achieved by means of a concatenation of a cyclic redundancy check outer coder and an inner rate-compatible convolutional coder. Simulation results performed over a Rayleigh fading channel show an improvement in the visual quality of the reconstructed images.

1. INTRODUCTION

One of the new features of the JPEG2000 is the encoding of regions of interest (ROIs) in an image with a quality better than the background [1]. This feature is useful in several applications where only a specific region of an image is of importance. Such applications include web browsing, image databases and telemedicine. Similarly, transmission applications at low bit-rates may take advantage of the ROI coding feature. By using ROI coding, the information from the regions of interest is placed at the beginning of the bit-stream. This guarantees the reception of the ROIs before the background in the case of transmission failures.

We demonstrated in [2] that it is possible to improve the quality of ROI-encoded images by using packet partition and a prioritization method. Here, we encoded images using small packets and assigned a priority level to each of these packets according to their distance from the center of a ROI. The priority level was used in turn to determine the amount of background information included along with the ROIs. Experimental results showed that the quality of the reconstructed images improves at very low bit-rates compared to the case of no ROI coding, and the two ROI coding methods supported by the JPEG2000 standard (MAXSHIFT and general scaling based method) [3].

We introduced an adaptive unequal channel protection (AUCP) technique in [4] to increase the error resilience of JPEG2000 images. Here, the channel protection is assigned to each packet individually according to their mean energy. The technique was evaluated over a Rayleigh fading channel and proved to increase the quality of the reconstructed images.

In this paper, we extend our earlier work to robustly transmit ROIs over noisy channels at low bit-rates and propose a prioritized adaptive unequal channel protection (PAUCP) technique for JPEG2000 ROI-encoded images. We employ the prioritization method proposed in [4] to encode ROIs and the AUCP technique proposed in [2] to design a method to efficiently protect ROIs at low bit-rates. The objective is to increase the resilience to errors of ROI-encoded images when transmitted over noisy channels, with less sacrifice in ROI quality.

2. REVIEW OF PREVIOUS WORK

In this section we present a brief summary of some of the previous work on ROI coding and channel protection for JPEG2000 images. We first review the two ROI coding methods supported by the standard. We then review a prioritized ROI coding technique and an adaptive channel protection scheme used to increase the resilience to errors of packets in JPEG2000. The algorithms and equations introduced in these two techniques constitute the foundation of the proposed PAUCP technique presented in this paper.

2.1 ROI coding in JPEG2000

JPEG2000 currently supports two methods to encode ROIs: the general scaling based method (GSBM) and the maximum shift (MAXSHIFT) method [1,3].

In GSBM [3], the coefficients associated with the ROI are scaled-up so that the corresponding bits are placed in higher bit-planes. Given the hierarchical structure of the JPEG2000 code-stream, these scaled-up bit-planes are placed in the final bitstream before any bit-planes associated with the background. Depending on the scaling value, some bits of the ROI coefficients may be encoded along with background coefficients. At the decoder side, the ROI is decoded first before the rest of the image. Prior to the start of the coding process, a mask representing the coefficients associated with the ROI is generated.

The MAXSHIFT method [3] scales-up the coefficients associated with the ROI well above the background coefficients and thus eliminates the need of generating the mask at the encoder. In the MAXSHIFT method, the scaling value s is chosen according to the following criteria:

$$s \geq \max\{M_b^i\} \qquad 1 \leq i \leq Q$$

Where, Q is the number of coefficients in the ROI and M_b^i is the number of most significant bit-planes for the ith ROI coefficient. At the decoder, the nonzero ROI and background coefficients are identified by their magnitudes. The coefficients with magnitude less than the *s-th* bit-plane belong to the background. Therefore, there is no need to explicitly transmit the shape information of the ROI. Before the inverse wavelet transform is applied, the background coefficients are scaled-up by s bit-planes.

Some of the main disadvantages of the GSBM and MAXSHIFT method are the need to transmit the shape information of the ROI and the inability to decode the background coefficients along with the ROI. We demonstrated in [2] that these disadvantages can be overcome by taking advantage of the packet partition feature of the standard. This technique is reviewed in the following section.

0-7803-8554-3/04/$20.00

2.1.1. Prioritized ROI coding

JPEG2000 uses a packetization approach to compress and organize the information in the final bit-stream [1]. A packet describes a specific region of the image at a specific resolution. If the number of packets is consistent across the different decomposition levels, pyramid decomposition is achieved. In pyramid decomposition, a region of size $m \times n$ and position $\{i, j\}$ at decomposition level k is related to a region of size $2m \times 2n$ and position $\{2i, 2j\}$ at decomposition level $k\text{-}1$, where $k=1$ is the first decomposition level. By using pyramid decomposition, a ROI can be defined by rearranging the position of the packets in the final bit-stream. Moreover, a priority level can be assigned to each packet according to their distance from the center of a ROI and their position in the final layered bit-stream. In this way, packets within a ROI receive the highest priority and are placed in the initial layers, whereas the surrounding packets receive a priority inversely proportional to their distance measured from the center of the ROI and are placed in later layers [2]. This priority level can be used to increase the amount of background information included with the ROIs. For an image with L quality layers and M packets per layer, packet m in layer l receives a priority level, $p_{m,l}(r)$, according to the following equation [2]:

$$p_{m,l}(r)=\begin{cases} \dfrac{\mathrm{P}_{ROI}}{L}\cdot\left(L-l+1\right) & \text{if packet} \in ROI \\ \dfrac{\mathrm{P}_{ROI}\cdot 2^{-(r/R)^2}}{L}\cdot\left(L-l+1\right) & \text{if packet} \notin ROI \end{cases}$$

where, P_{ROI} is the priority level assigned to the ROI, r is the distance between the centers of the ROI and the region represented by packet m, L is the number of layers used to compress the image and R (the shape parameter) is defined as the radius at which the priority drops to one-half its maximum value. The shape parameter may be changed to increase or decrease the priority level of packets surrounding a ROI. The value of R is limited to the range $[0,2S]$; where, S is the diagonal length of the image (measured in pixels) defined as [2]:

$$S=\sqrt{H^2+V^2}$$

where H and V denoting the horizontal and vertical size of the image, respectively.

2.2. Error-resilience in JPEG2000

Smaller units called code-blocks compose each packet in JPEG2000 [1]. JPEG2000 uses a bit-plane context based arithmetic entropy coder to compress the discrete wavelet transform coefficients in each code-block. Even though the arithmetic entropy coder has good compression performance; the resulting coded data is prone to bit-errors [5,6]. A set of error resilient tools has been included in the JPEG2000 standard to reduce the impact of transmission errors on compressed images. The error resilient tools reduce the error propagation to which variable length coding is highly sensitive. This reduction is achieved by independently coding the code-blocks, inserting markers in the code stream and terminating the arithmetic coder after each coding pass [1,5,6].

Since a code-block is the basic unit of a packet, we first analyze the contributions of bit-errors in a code-block to the overall mean-square error (MSE) of the image. The effect of channel errors, in terms of the MSE, in code-blocks and packets may be computed according to the expressions in [4]. Hence, the maximum MSE (MMSE), for a code block b in sub-band s (hereafter referred to as code-block (b, s)) can be expressed as:

$$\mathrm{M}_{b,s}=\frac{(\Delta_{b,s})^2}{N_{b,s}}\cdot\sum_{n=1}^{N_{b,s}} C_n{}^2 \qquad (1)$$

Where, C_n is the nth quantized coefficient in code-block b in sub-band s, $N_{b,s}$ is the total number of samples in code-block (b, s) and $\Delta_{b,s}$ is the quantization step for code-block (b, s).

The MMSE for code-block (b, s) on a per pixel basis (*i.e.*, over the entire image) can be calculated as [4]:

$$\overline{\mathrm{M}}_{b,s}=\frac{s_{b,s}}{B_s\cdot S}\cdot w_s\mathrm{M}_{b,s}=\frac{2^{-2r_{b,s}}}{B_s}\cdot w_s\mathrm{M}_{b,s} \qquad (2)$$

Where, S is the total number of image pixels, $r_{b,s}$ is the resolution of sub-band s ($r=1$ corresponds to the first level of decomposition), $s_{b,s}=S/2^{2r_{b,s}}$ is the number of coefficients in sub-band s, B_s is the number of code-blocks in the sub-band (the code-blocks are of equal size) and w_s is the weighting factor of sub-band s used to compensate for the non-energy preserving characteristics of bi-orthogonal wavelets. The weighting factor is a function of the specific wavelet filters used for reconstruction and can be easily calculated from the filter coefficients [7].

Assuming error resilient tools are used, channel protection may only be assigned to those packets that contain any code-block data for the first time [4]. The MMSE in packet p with coded data from S sub-bands, each sub-band having B_s code-blocks, can then be expressed as follows:

$$\overline{\mathrm{M}}_p\approx\sum_{s=1}^{S}\sum_{b=1}^{B_s}\left(\overline{\mathrm{M}}_{b,s}\cdot\psi(b)\right) \qquad (3)$$

Where, $\psi(b)$ is 1 if the coded data for the bth code-block is included in packet p for the first time (otherwise it is zero), and $\overline{\mathrm{M}}_{b,s}$ is as given in Eq. (2).

3. PROPOSED TECHNIQUE

A JPEG2000 ROI-coded image has the property that the data describing a ROI appears in the first layers of the final bit-stream. In applications with bandwidth constraints, it is desirable that the initial layers are transmitted efficiently and are error-free. Since the later layers only provide the background information, it is possible to sacrifice the quality of this data in order to increase the resilience to errors of the ROIs. In this section, we apply channel protection to ROI-coded images by using the AUCP technique proposed in [4] and taking into account the prioritization process to encode ROIs described in Section 2.1. We first introduce some modifications to the equations used to realize the AUCP technique to extend the protection to ROI-coded images. The result is an efficient channel protection technique that assigns protection to every packet according to their mean energy and priority level.

3.1. Effect of bit-errors in packets

In order to increase the channel protection of packets that describe a ROI, we have defined a MMSE for prioritized ROI-coding ($\mathrm{MMSE}_{\mathrm{ROI}}$ hereafter). The $\mathrm{MMSE}_{\mathrm{ROI}}$ takes into account the position of a packet with respect to a ROI. Packets within a ROI must receive the strongest channel protection while packets in the periphery must be assigned a weaker channel protection. To achieve this, we have added a weighting factor to the MMSE in Eq. (3). This weighting factor R_p, is equal to the priority level $p_{m,l}(r)$ for packet m in layer l used to encode ROIs (see Eq. (1)). Therefore, the $\mathrm{MMSE}_{\mathrm{ROI}}$ of packet p can be expressed as follows:

$$\overline{\mathrm{M}}_{p_{ROI}} \approx R_p \cdot \overline{\mathrm{M}}_p \tag{4}$$

where, $\overline{\mathrm{M}}_p$ is as given in Eq. (3). The weighting factor R_p varies between 0 and 1; where a weighting factor of 1 implying packet p is in the ROI.

3.2 Overall Distortion of the Reconstructed Image

The overall distortion D_{ROI} of an image encoded with ROIs can then be expressed as the summation of the individual distortions associated to each packet p multiplied by the probability of error $\mathrm{P_e}$ of every packet [4]. The probability of error $\mathrm{P_e}$ assumes a concatenation of a cyclic redundancy check (CRC) code and a rate compatible punctured convolutional (RCPC) code [8,9]. For an image with K packets, the overall distortion (taking into account discarded packets to meet bit-rate constraints) can be computed as [2]:

$$\begin{aligned} D_{ROI} &= \sum_{p=1}^{K} \overline{\mathrm{M}}_{p_{ROI}} \cdot \mathrm{P}_e \cdot \phi(p) + \sum_{p=1}^{K} m_p \cdot R_p \cdot \left[1-\phi(p)\right] \\ &= \sum_{p=1}^{K} \phi(p) \cdot R_p \cdot \left[\overline{\mathrm{M}}_p \cdot \mathrm{P}_e - m_p\right] + \sum_{p=1}^{K} m_p \cdot R_p \\ &= \sum_{p=1}^{K} \phi(p) \cdot R_p \cdot \left[\overline{\mathrm{M}}_p \cdot \mathrm{P}_e - m_p\right] + \bar{\varepsilon}_{C_{ROI}} \end{aligned} \tag{5}$$

Where, $\overline{\mathrm{M}}_{p_{ROI}}$ is as given in Eq. (4), m_P is the amount of MSE that will be added to the overall distortion if packet p is discarded, and $\phi(p)$ is 1 if the *pth* packet is included in the code stream (otherwise it is zero). Note that the term m_P in Eq. (5) has been weighted by the factor R_p and $\bar{\varepsilon}_{C_{ROI}}$ denotes the mean energy of the compressed image when the weighting factor R_p is used.

In order to assign an optimal channel protection in the proposed PAUCP technique, the distortion as given in Eq. (5) is minimized subject to the following rate constraint:

$$\frac{S_M}{R_M} + \sum_{p=1}^{K} \frac{S_p}{R_p} \le R_T \tag{6}$$

Where, R_M is the channel code rate for the main header, R_p is the channel code rate for packet p, S_M is the number of bits in the main header and S_p is the number of source bits in packet p. The left side of Eq. (6) is the actual bit-rate whereas R_T is the specified overall bit rate. When a packet receives no channel protection, the channel code rate is equal to one.

By adding a weighting factor to Eqs. (4) and (5) we have realized an efficient channel protection for ROI-coded images with two important advantages:

a. The channel protection is assigned taking into account the mean energy of a packet and its priority level with respect to the ROIs. This guarantees more channel protection to those pockets with a significant amount of mean energy and within a ROI.
b. The importance of a ROI is maintained even after applying the channel protection. This guarantees the reception of a ROI with a better quality even at low bit-rates and poor channel conditions.

4. SIMULATION RESULTS

The PAUCP technique has been evaluated over a Rayleigh fading channel with FSK modulation, a carrier frequency of $900\,MHz$, a data rate of $15\,Kbits/s$ and a mobile speed of $3.6\,Km/h$ [10]. The gray level 512 x 512 Lena image was encoded using lossless compression with five levels of decomposition, ten quality layers, a precinct size of 64 x 64 (for the first level of decomposition), and the error resilient tools proposed by the standard [1,5]. A single ROI encircling the face area was defined as described in Section 2.1. The shape parameter R was varied in each decomposition level to change the amount of background included in the layers containing the ROI. Table I shows the shape parameters assigned to the ROI at each decomposition level.

Table I: *Shape parameters for the five decomposition levels of Lena image. The first decomposition level corresponds to the highest frequency subband.*

Decomposition level	R parameter
1	$S/4$
2	$S/2$
3	S
4	$1.5S$
5	$2S$

In order to obtain different rates, we punctured the convolutional mother code of rate ¼ and generator matrix g=[23 35 27 33], in octal notation, with a period of 8. The decoding process was performed using the Viterbi algorithm. We divided the main header and the data packets to be channel-protected into blocks of 384 bits. Each block was first protected by an outer 16-bit CRC code defined by the polynomial 210421 (in octal notation), followed by an inner RCPC code. No puncturing matrix was used to protect the blocks in the main header and a convolutional interleaver of depth 60 was used on the protected information before transmission. The information regarding the channel coder rate and number of protected packets is assumed to be common knowledge to both the encoder and decoder and no extra information needs to be transmitted.

Figure 1 shows the reconstructed images after transmission at different low bit-rates and channel conditions. Channel conditions are determined by the average signal-to-noise ($\overline{SNR}$) ratio of the channel. A low $\overline{SNR}$ indicates poor channel conditions, while a high $\overline{SNR}$ indicates better channel conditions. The PAUCP technique was compared with the AUCP technique, where no priority level is assigned to the packets. The AUCP technique has already been proven to have better performance compared to the case of no channel protection and ordinary equal and unequal channel protection techniques [4,11]. Images in Fig. 1 show the average quality for the two channel protection techniques according to the overall distortion as expressed by Eqs. (5) and (6).

Because it is difficult to measure the quality of ROI-coded images objectively, subjective evaluation was performed. Fifty graduate students from different areas of science and engineering (including image processing) were asked to choose the images with the best visual quality for each bit-rate and channel condition. The results are shown in Fig. 2 as a percentage of times each channel protection technique was chosen. These results show that for bit-rates higher than 0.05 bpp, the images protected with the PAUCP technique were preferred in more than 95% of the times. However, for a bit-rate of 0.05 bpp and poor channel conditions (e.g. $\overline{SNR} = 8dB$), the percentage of times images protected with the PAUCP technique were chosen decreased. At 0.05 bpp and poor channel conditions, both techniques provide similar visual quality. This is mainly because of the high amount of packets that are discarded to accommodate the channel protection leaving only a few packets to be transmitted. These remaining packets receive similar channel protection.

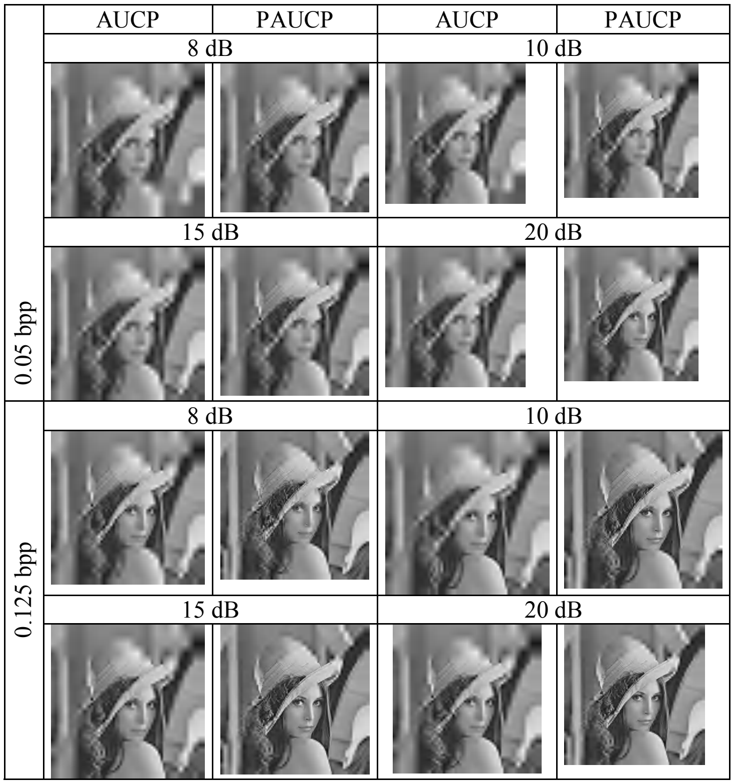

Fig. 1: *Visual results at different bit-rates over a Rayleigh-fading channel conditions. PAUCP=Prioritized Adaptive Unequal Channel Protection, AUCP= Adaptive Unequal Channel Protection.*

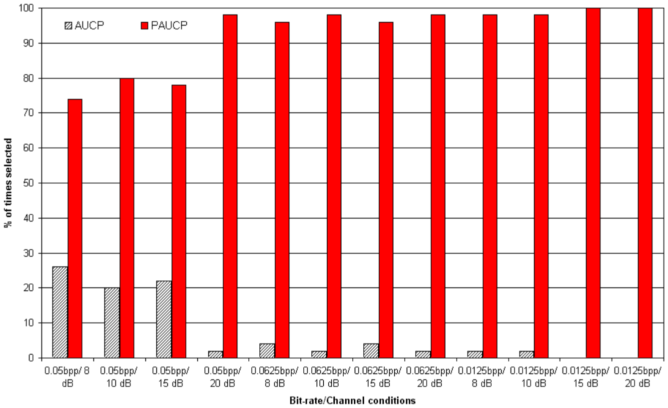

Fig. 2: *Subjective evaluation of the channel protection techniques.*

5. CONCLUSIONS

We presented a prioritized adaptive unequal channel protection technique designed for JPEG2000 ROI-coded images. The technique takes advantage of the feature of convolutional codes to create different channel coding using the same encoder/decoder. The channel protection is assigned to packets according to their mean energy and priority level with respect to a ROI. Simulation results over a Rayleigh fading channel at different bit-rates proved that the proposed PAUCP technique provides better visual quality at low bit-rates compared to regular adaptive unequal channel protection techniques.

ACKNOWLEDGEMENT

This work has been supported by financial grants from the *National Science and Engineering Research Council (NSERC) of Canada* and *Alberta Science and Research Authority (ASRA)*.

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