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AN EEP TRANSMISSION SYSTEM USING RCPT CODES AND JPEG2000

Abdelmounaim Moulay Lakhdar

Département de Génie Mécanique, Centre Universitaire de Béchar
Béchar 08000, Algérie

Rachida Méliani, Malika Kandouci

Département d'Electronique Faculté des Sciences de l'Ingénieur
Université Djillali Liabès BP 89, Sidi Bel Abbes 22000, Algérie

Abstract. This work describes a method for providing robustness to errors from a binary symmetric channel for the JPEG2000 image compression. The source rate and channel rate are jointly optimized by a stream of fixed-size channel packets. Punctured turbo codes are used for the channel coding, providing stronger error protection than previously available codes. We use a subset of the puncturing patterns that are well chosen and that leads to the best source rate. The rate allocation scheme presented obtains all necessary information from the JPEG2000 encoder, and does not require image decompression.

Keywords: JPEG2000, Turbo-code, puncturing, rate allocation, Peak Signal to Noise Ratio (PSNR).

1. Introduction

One of the most successful and practical image coders today for the noiseless channel was originally developed by Shapiro [1] and later refined by Said and Pearlman [2]. Their schemes achieve a "progressive" mode of transmission, namely that as more bits are transmitted, better quality-reconstructed images can be produced at the receiver. The receiver needs not wait for all of the bits to arrive before decoding the image; in fact, the decoder can use each additional received bit to improve somewhat upon the previously reconstructed image.

These wavelet-based encoders have been shown to perform better than almost any other existing compression scheme. In addition, they have the nice features of being progressive and computationally simple. However, to obtain the high-quality compression that they achieve, variable-length coding is used with significant amounts of "state" built into the coder. The result is that channel errors can cause a nonrecoverable loss of synchronization between the encoder and decoder. Total collapse of the reconstructed image often results from loss of synchronization. In fact, vast majority of images transmitted using this progressive wavelet algorithm will frequently collapse if even a single transmitted information bit is incurrectly decoded at the receiver.

One approach to circumventing loss of synchronization on noisy channels is to use fixed-rate image compression techniques, and those not based upon finite state algorithms. However, some of these techniques have the disadvantages of not being progresssive, not performing as well for good quality channels, or having extremely high computational complexity. Two of the most competitive techniques for protecting images from channel noise are found in [3] and [4].

Another approach to protecting image coders from channel noise is to divide the transmitted bitstream into two classes, the "important" bits and the "unimportant" bits, based upon the effects of channel errors on these bits. The important bits can then be sent as header information using good error control codes and the remaining bits can be sent with weaker channel codes. This type of technique was used in [5] and [6].

A more traditional approach to protecting source coder information from the effects of a noisy channel is to cascade the source coder with a channel coder. Analytical results have recently been obtained in [7] as guidance in choosing the optimal trade-off between source coding and channel coding. In [8], the progressive nature of the embedded bit stream produced by the The Joint Photographic Experts Group (JPEG2000) image coding algorithm [2] is exploited to provide a channel robustness far superior to anything else in the literature at that time. In fact, these results roughly follow those that we use in the present system. The work by [8] provides equal error protection to all of the image data. Later work [9, 10,11] extended these results by providing unequal error protection.

However the design of the optimal code rates for each component code is very complicated.

In this paper, we present a low-complexity technique that preserves the encoding power of the progressive wavelet schemes of Shapiro–Said–Pearlman, preserves the progressive transmission property, and is simple to implement in practice. We focus on binary symmetric channels with large bit error probabilities.

One nice feature of the proposed coding system is that its performance for a given image remains constant with probability near one over all possible received channel error patterns. Effectively, no degradation due to channel noise can be detected because we use a subset of the puncturing patterns that are well chosen. In fact, the effect of channel noise is to force the transmitter to encode the image at a lower source coding resolution and devote more bits to channel coding. Thus, on very noisy channels, the reconstructted image quality will be that of the noiseless channel encoder, but at a lower source coding rate. The system does not have to be designed for any particular transmission rate, and, in fact, works quite well over a broad range of transmission rates. One goal of this note is to present state-of-the-art numerical results for noisy channel image transmission systems that can be useful for future comparisons.

2. System description

Consider the following model (Figure 1). An embedded (progressive in accuracy) source bit stream is partitioned into cells, denoted as C_1, C_2, C_3,… If the first k-1 cells are received with no errors, and the k^{th}cell is in error, then the decoder decodes using only the bits from the first k-1 cells, resulting in a distortion of D_{k-1} . Let $D_0 = \sigma_x^2$ where σ_x^2 is the source variance.

Next, assume that the length of a packet is fixed, where a packet is comprised of a cell and redundant bits. If the packet is of length R, and the i^{th} cell is of length R_i, then the number of redundant bits, C_i , is given by $R_i+C_i=R$, so specifying R_i is equivalent to specifying the channel coding rate for packet i. In [10] each cell contains (R_i-24) bits of data from the J2K bit stream, 8 bits for specification of the next packet's channel coding rate, and 16 bits for a cyclic redundancy check code (CRC). However, in this work each cell contains (R_i-16) bits of data from the JPEG2000 bit stream, no bit for specification of the next packet's channel coding rate because R_i is fixed for given channel BER, and 16 bits for a CRC.

Let $P_e(R_i, P_b)$ be the probability of at least one error in the i^{th}decoded packet, where P_b is the probability of a bit error from the BSC, and R_i is the number of information bits in the i^{th} cell. The expected distortion can then be computed as:

$$D = D_0 P_e(R_1, P_b) + \sum_{i=2}^{N+1} D_{i-1} P_e(R_i, P_b) \prod_{j=1}^{i-1} \left[1 - P_e(R_j, P_b)\right], \quad (1)$$

where N is the number of transmitted packets and $P_e(R_{N+1}, P_b) = 1$. The total rate is $\sum_{i=1}^{N}(R_i + C_i)$. Since we use an equal error protection (EEP), R_i= R_1 = constant, $\forall i$. So (1) can then be simplified to:

$$D = P_e(R_1, P_b) \sum_{i=1}^{N+1} D_{i-1} [1 - P_e(R_1, P_b)]^{i-1}, \quad (2)$$

and the useful rate of reconstruction is:

$$URR = P_e(R_1, P_b) \sum_{i=1}^{N+1} URR_{i-1} [1 - P_e(R_1, P_b)]^{i-1}. \quad (3)$$

The rate allocation problem is to $\min_{R_1} D$.

Or $\max_{R_1} URR$ such that all N packets are used, assuring the total rate is NR.

The advantage of the second method is that it does not use the functions characterizing the performance of the source coder in the case of the image in question (function $PSNR(i)$ for example), and does not require image decompression.

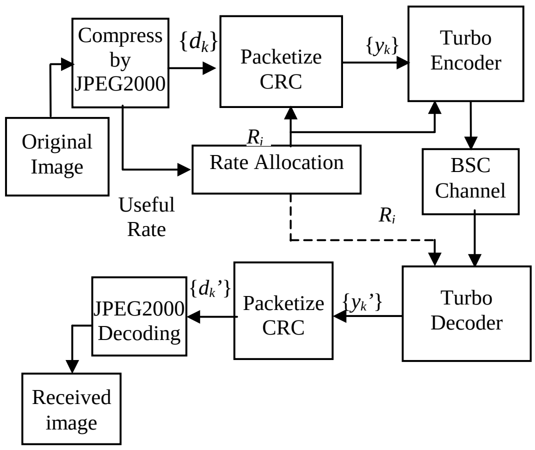

Figure 1. System Overview

In practice, each packet uses a 16-bitCRC outer code [13] for detection of packet errors, concatenated with an inner turbo code for error correction on the BSC. The turbo code employs the punctured parallel-concatenated recursive convolutional codes (RTCP) of [14], where each of the two 8-state component encoders has feedback/feedforward generator polynomials 15,11 (octal). We use a subset of the puncturing patterns recommended in [14] to obtain code rates {8/10, 8/11, 8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18, 8/19, 8/20, 8/21, 8/22, 8/23, 8/24}. $P_e(R_1, P_b)$ can then be tabulated, from extensive simulations, for each permissible channel code rate, R_i, and for the specified channel bit error rate, P_b. The probability of a 517 byte block having a bit error after 20 turbo decoder iterations is presented in Table 1.

The probabilities $P_e(R_1, P_b)$ are independent of the source, depending only upon the BSC bit error rate, P_b, and selected channel coding rate, R_1. $P_e(R_1, P_b)$ can be tabulated, from extensive simulations, for each permissible channel code rate, R, and for the specified channel bit error rate, P_b. The probability of a 517 byte block having a bit error after 20 turbo decoder iterations is presented in Table 1, based on Monte-Carlo simulations using 10 000 blocks.

Table 1. Probability of block error vs. channel BER, block length=517 bytes, 20 turbo decoder iterations

Turbo code Rate	Channel BER				
	0.1	0.08	0.05	0.03	0.01
1/3	0	0	0	0	0
8/23	0	0	0	0	0
4/11	0	0	0	0	0
8/21	0	0	0	0	0
2/5	1.5 10^{-4}	0	0	0	0
8/19	8 10^{-4}	0	0	0	0
4/9	2 10^{-2}	10^{-4}	0	0	0
8/17	4 10^{-1}	2 10^{-3}	0	0	0
1/2	1	10^{-2}	10^{-4}	0	0
8/15	1	3 10^{-1}	2 10^{-4}	0	0
4/7	1	6 10^{-1}	5 10^{-4}	0	0
8/13	1	1	2 10^{-3}	10^{-4}	0
2/3	1	1	6 10^{-1}	6 10^{-4}	0
8/11	1	1	1	2 10^{-2}	10^{-4}
4/5	1	1	1	1	1.5 10^{-3}

3. Results

All results are based upon a packet length of 517 bytes. The packet size (517 bytes) is typical for user datagram protocol (UDP) packets sent over the Internet. Padding is used as needed to assure all packets are of the same length. One exception is for the channel code rate of 1/3 where the last parity bit from encoder 2 is dropped to fit in 517 bytes. The number of JPEG2000 bytes used for each channel rate is 394, 357, 326, 299, 276, 257, 240, 225, 211, 199 188, 178, 169, 161, and 154 respectively for rates of {8/10, 8/11, 8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18, 8/19, 8/20, 8/21, 8/22, 8/23, 8/24}. The JPEG2000 encoder uses default options, except for the explicit specification of the progressive by accuracy bitstream. No changes have been made to the functionality of either the JPEG2000 encoder or decoder, hence our protection scheme is standard compliant.

Tables 2 and 3 present coding results (in dB PSNR) for Lena and Goldhill (8-bit monochrome) images, respectively, and tree channel bit error rates (BERs). Where possible, our results are compared to those reported in [8,12], where not possible we put 'ND' in the case. The proposed method provides about 0.4 dB and 0.2dB improvement over [8] and [12], respectively, at 0.01 BER, and an improvement of 1.4 dB and 0.2 dB at 0.1 BER. For images Lena and Goldhill at 0.1 BER, the improvement over [8] is due to superior channel codes and turbo code performances.

Table 2. Expected distortion (PSNR in decibels) for Lena 512×512 image transmitted over a BSC at total rate 0.252, 0505, 0.994 bpp. Result from [8, 12] appear in the table

Overall rate (bpp)		Channel BER					
		0.01		0.03		0.1	
		psnr	Rate	psnr	Rate	psnr	rate
0.252	Proposed system	32.21	0.72 8/11	31.26	0.61 8/13	29.81	0.4 2/5
	[8]	32	0.66	ND	ND	28.4	0.28
	[12]	32.25	0.69	ND	ND	29.63	0.38
0505	Proposed system	35.51	0.72 8/11	35.01	0.61 8/13	32.58	0.38 8/21
	[8]	35.2	0.66	ND	ND	31.1	0.28
	[12]	35.11	0.68	ND	ND	32.32	0.36
0.994	Proposed system	37.17	0.66 2/3	37.39	0.57 4/7	36.04	0.38 8/21
	[8]	38	0.66	ND	ND	34.2	0.28
	[12]	ND	ND	ND	ND	ND	ND

4. Conclusion

A novel image transmission scheme was proposed for the communication of compressed JPEG2000 image streams over BSC channels. The proposed scheme employs turbo codes and CRC codes in order to deal effectively with errors. A novel methodology for the optimal EEP of compressed streams was also proposed and applied in conjunction with an inherently more efficient rate for the RTCP codes. The resulting system was tested for the transmission of images over BSC channels. Experimental evaluation showed the superiority of the proposed schemes in comparison to well-known robust coding schemes.

Table 3. Expected distortion (PSNR in decibels) for Goldhill 512×512 image transmitted over a BSC at total rate 0.252, 0505, 0.994 bpp

Overall rate (bpp)		Channel BER					
		0.01		0.03		0.1	
		psnr	Rate	psnr	Rate	psnr	rate
0.252	Proposed system	29.1	0.72 8/11	28.34	0.61 8/13	28.55	0.4 2/5
	[8]	29	0.66	ND	ND	26.7	0.28
	[12]	ND	ND	ND	ND	ND	ND
0505	Proposed system	30.6	0.72 8/11	30.7	0.61 8/13	29.88	0.38 8/21
	[8]	31.2	0.66	ND	ND	28.6	0.28
	[12]	ND	ND	ND	ND	ND	ND
0.994	Proposed system	34.01	0.66 2/3	33.33	0.57 4/7	32.04	0.38 8/21
	[8]	34	0.66	ND	ND	30.7	0.28
	[12]	ND	ND	ND	ND	ND	ND

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