SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 5, No.2, November 2008, 353-360

Robust Image Transmission Performed by SPIHT and Turbo-Codes

Abdelmounaim Moulay Lakhdar[1],
Rachida Méliani[2], Malika Kandouci[2]

Abstract: This work describes the method for providing robustness to errors from a binary symmetric channel for the SPIHT 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 the most appropriate set of puncturing patterns that ensure the best source rate. The presented rate allocation scheme obtains all necessary information from the SPIHT encoder, without requiring image decompression.

Keywords: SPIHT, Turbo-code, Puncturing, Rate allocation, Peak signal to noise ratio (PSNR).

1 Introduction

One of the most successful 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, i.e. the more bits transmitted the better quality of reconstructed images produced at the receiver. The receiver need not wait for all bits to arrive before decoding the image; in fact, the decoder can use each additional received bit to make slight improvements on previously reconstructed image.

These wavelet-based encoders have come out to perform better than almost any other existing compression scheme. In addition, they are progressive and computationally simple. However, for achieving high-quality compression they use variable-length coding with significant amounts of “state” built into the coder. As the result, channel errors can cause non-recoverable loss of synchronization between the encoder and decoder. The total collapse of the reconstructed image often results from the loss of synchronization. In fact, vast majority of images transmitted by this progressive wavelet algorithm will frequently collap-

---

[1] Département de Génie Mécanique, Centre Universitaire de Béchar, Béchar 08000, Algérie
E-mail: Moulaylakhdar78@yahoo.fr
[2] Département d’Electronique Faculté des Sciences de l’Ingénieur Université Djillali Liabès BP 89, Sidi Bel Abbes, Algerie

se even if a single transmitted information bit is incorrectly decoded at the receiver.

In order to avoid circumventing loss of synchronization on noisy channels the application of fixed-rate image compression techniques are recommended as well as those not based on finite state algorithms. However, some of these techniques have the disadvantages of not being progressive, not performing as well as high-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 bit stream into two classes, "important" bits and "unimportant" ones, based upon the effects of channel errors on these bits. 'Important' bits can then be sent as header information using good error control codes and the remaining ones can be sent with weaker channel codes. This 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. The analytical results have recently been obtained in [7] as a guide in choosing the optimal trade-off between the source coding and the channel coding. In [8], the progressive nature of the embedded bit stream produced by the set partitioning in hierarchical trees (SPIHT) image coding algorithm [2] is exploited to provide channel robustness far superior to anything else available in the contemporary literature. 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 [9–11] 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. Being easily implemented in practice, this technique also ensures the progressive transmission.

In this paper, we have been focused on binary symmetric channels with large bit error probabilities.

The distinctive 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 the channel noise can be detected as 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 reconstructed image quality will be that of the noiseless channel encoder, though at a lower source coding rate. The system need not be designed for any particular transmission rate, as it actually works quite well over a broad range of transmission rates. One of the objectives this paper is to present the state-of-the-art numerical results for the noisy channel image transmission systems that can be useful for future comparisons.

2 System Description

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

In the following step, let us 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 SPIHT bit stream, no bit for specification of the next packet channel coding rate because R_i is fixed for given channel BER, and 16 bits for a CRC.

Let $P_e\left(R_i, P_b\right)$ 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:

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

N stands for the number of transmitted packets and $P_e\left(R_{N+1}, P_b\right) = 1$. The total rate is $\sum_{i=1}^{N} R_i + C_i = NR$. Since we use an equal error protection (EEP), $R_i = R_1 = \text{const.}$ for every i. Thus (1) can then be simplified as:

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

The useful rate of the reconstruction is:

$$URR = P_e\left(R_1, P_b\right) \sum\nolimits_{i=1}^{N+1} URR_{i-1} \left[1 - P_e\left(R_1, P_b\right)\right]^{i-1} . \tag{3}$$

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

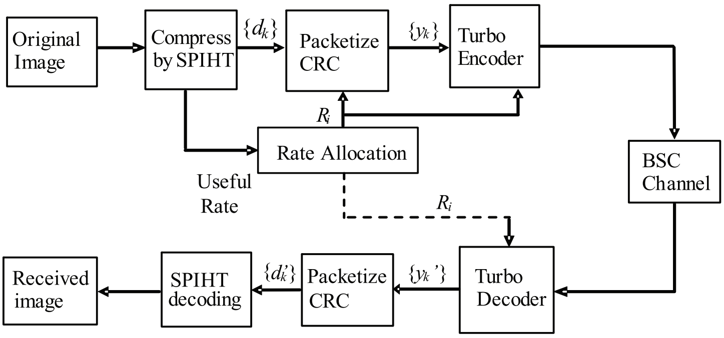

Fig. 1 – *System Overview.*

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 we do 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.

In practice, each packet uses a 16-bit CRC 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 convolution 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}. $P_e\left(R_1, P_b\right)$ is independent of the source, depending only upon the BSC, and the selected rate. $P_e\left(R_1, P_b\right)$ 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 $P_e\left(R_1, P_b\right)$ are independent of the source, depending only upon the BSC bit error rate, P_b, and selected channel coding rate, R_1. $P_e\left(R_1, P_b\right)$ 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 10000 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	$1.5 \cdot 10^{-3}$

3 Results

All results are based on the 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 SPIHT 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 SPIHT 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 SPIHT encoder or decoder, hence our protection scheme is standard compliant.

Table 2 and **Table 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.

Overall Rate (bpp)		Channel BER					
		0.01		0.03		0.1	
		psnr	Rate	psnr	Rate	psnr	Rate
0.252	Proposed system	32.41	0.72 8/11	31.64	0.61 8/13	29.71	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
0.505	Proposed system	35.26	0.72 8/11	34.51	0.61 8/13	32.55	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	38.17	0.66 2/3	37.50	0.57 4/7	35.56	0.38 8/21
	[8]	38	0.66	ND	ND	34.2	0.28
	[12]	ND	ND	ND	ND	ND	ND

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	29.36	0.72 8/11	28.84	0.61 8/13	27.64	0.4 2/5
	[8]	29	0.66	ND	ND	26.7	0.28
0.505	Proposed system	31.5	0.72 8/11	30.92	0.61 8/13	29.42	0.38 8/21
	[8]	31.2	0.66	ND	ND	28.6	0.28
0.994	Proposed system	34.13	0.66 2/3	33.46	0.57 4/7	31.61	0.38 8/21
	[8]	34	0.66	ND	ND	30.7	0.28

4 Conclusion

A novel image transmission scheme was proposed for the communication of compressed SPIHT 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.

5 References

[1] J.M. Shapiro: Embedded Image Coding using Zerotrees of Wavelet Coefficients, IEEE Trans. Signal Processing, Vol. 41, No 12, Dec. 1993, pp. 3445 – 3462.

[2] A. Said, W.A. Pearlman: A New, Fast, and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees, IEEE Trans. Circuits Syst. Video Technol., Vol. 6, No. 3, June 1996, pp. 243 – 250.

[3] N. Tanabe, N. Farvardin: Subband Image Coding using Entropy-coded Quantization Over Noisy Channels, IEEE J. Select. Areas. Commun., Vol. 10, No. 5, June 1992, pp. 926 – 943.

[4] Q. Chen, T.R. Fischer: Robust Quantization for Image Coding and Noisy Digital Transmission, In Proc. DCC'96, Mar/Apr 1996, pp. 3 – 12.

[5] T.P. O'Rourke, R.L. Stevenson, Y.F. Huang, D.J. Costello Jr.: Improved Decoding of Compressed Images Received Over Noisy Channels, In Proc. ICIP-95, Vol. 2, Oct. 1995, pp. 65 – 68.

[6] D.W. Redmill, N.G. Kingsbury: Still Image Coding for Noisy Channels, In ICIP-94, Vol. 1, Nov. 1994, pp. 95 – 99.

[7] B. Hochwald, K. Zeger: Tradeoff Between Source and Channel Coding, IEEE Trans. Inform. Theory, Vol. 43, No. 5, Sept. 1997, pp. 1412 – 1424.

[8] P.G. Sherwood, K. Zeger: Progressive Image Coding on Noisy Channels, Proceedings DCC '97. Data Compression Conference, Mar. 1997, pp. 72 – 81.

[9] V. Chande, N. Farvardin: Joint Source-channel Coding for Progressive Transmission of Embedded Source Coders, In Proc. Data Compression Conference (DCC'99), Mar. 1999, pp. 52 – 61.

[10] B.A. Banister, B. Belzer, T.R. Fischer: Robust Image Transmission using JPEG2000 and Turbo Codes, Proceedings of the International Conference on Image Processing, Vol. 1, 2000, pp. 375 – 378.

[11] N. Thomos, N.V. Boulgouris, M.G. Strintzis: Wireless Image Transmission using Turbo Codes and Optimal Unequal Error Protection, IEEE Trans. on Image Processing, Vol. 14, No. 11, Nov. 2005, pp. 1890 – 1901.

[12] L. Yao, L. Cao: Interleaved Turbo Codes Protection for Progressive Image Transmission with Efficient Rate Allocation, Proceedings of the International Conference On Communications And Mobile Computing, Honolulu, Hawaii, USA, August 2007, pp. 618 – 622.

[13] G. Castagnoli, J. Ganz, P. Graber: Optimum Cyclic Redundancy-Check Codes with 16-Bit Redundancy, IEEE Trans. on Communications, Vol. 38, No. 1, Jan. 1990, pp. 111 – 114.

[14] Ö. Açikel, W. Ryan: Punctured Turbo-Codes for BPSK/QPSK Channels, IEEE Trans. on Communications, Vol. 47, No. 9, Sept. 1999, pp. 1315 – 1323.