Multi-level Priority Transmission of Images Over a Turbo-Coded Channel*

M. Barazande-Pour, J. W. Mark and A.K. Khandani

Dept. of Electrical and Computer Engineering
University of Waterloo, Waterloo, Ontario, Canada N2L 3G1
email:jwmark@bbcr.uwaterloo.ca

ABSTRACT

The application of turbo codes (TC) for multi-level priority transmission of image signals over an AWGN channel is presented. The unequal error protection property of the turbo codes is introduced and matched to the unequal error protection requirement for the transmission of coded image signals. Compared to simply distributing the source bits across the TC block bit positions, the proposed method yields superior performance.

1. INTRODUCTION

Transmission of compressed image signals through low quality communication channels has become an integral part of information exchange. Transmission of these signals requires a high degree of error protection. Depending on the concentration, a small percentage of errors can significantly reduce the quality of the reconstructed image at the receiver. Also, some bits in a compressed image require a higher level of protection compared to others. The quality of the reconstructed image at the receiver is drastically reduced due to the errors in these high error sensitive bits, which require a high degree of error protection.

A suitable error correction coding scheme should be one with a multi-level error protection capability that offers Unequal Error Protection (UEP). In this paper, turbo coding is used to provide unequal error protection for image transmission.

In an additive white Gaussian noise (AWGN) channel the turbo codes [1] exhibit an error correction capability near the Shannon limit. Turbo codes are block codes generated by Recursive Systematic Convolutional (RSC) coders connected in parallel and separated by interleavers. They are block codes in the sense that the trellis of the underlying RSC's is terminated at the end of each block of input data.

The introduction of turbo codes in 1993 [1] has spurted further investigations into different aspects of turbo codes, (e.g., [2, 3, 4]). With the exception of [5], none of them has addressed the unequal error protection property of the turbo codes. In [5] different multiplexing rules are used at the output of rate compatible punctured coders to obtain different error protection capabilities. Our work differs from [5] in that we make use of the inherent unequal error protection property of a turbo code block.

In this paper we investigate the UEP property of turbo codes by transmitting coded image signals over a turbo-coded channel using computer simulation. Our simulation results indicate that, by taking advantage of the UEP property, a significant improvement in the quality of the transmitted image can be achieved.

The paper is organized as follows. Section 2 presents the turbo-coded channel and the communications model used to investigate the unequal error protection property of the turbo codes. Section 3 explains the image compression method used in our simulation and discusses the application of the proposed priority-based mapping method for image transmission. Section 4 presents the multi-level S-random turbo code interleaver design. Finally, Section 5 presents some subjective evaluation in the transmission of the DCT coded Lena image.

2. CHARACTERIZATION OF A TURBO-CODED CHANNEL

To investigate the UEP property of turbo codes, we consider the tandem connection of a turbo encoder, an AWGN channel and turbo decoder. In this work we use a turbo encoder with two component RSC encoders, each characterized by the generator polynomials $G_1 = 37$ and $G_2 = 21$ in octal representation.

The output of a random binary source was transmitted through the turbo-coded channel. At the receiver a two-component turbo decoder was used to decode the received signal. Each component decoder uses the modified BCJR algorithm [6] to perform symbol by symbol decoding. The error vector was obtained by comparing the output of the turbo-coded channel with the source sequence on a block-by-block basis. In the simulation the error vector for 7600 TC blocks are summed to yield an error pattern.

Based on the number of errors in a given bit position, the error patterns are used to classify the bit positions in the TC block into classes of equal sizes. Figure 1 shows the total number of errors at a given bit position in 91200 TC blocks.

It is observed that the error is not uniformly distributed across the block, and the number of errors for each bit depends on the bit position in the block. It is conjectured that the turbo coded channel exhibits a multi-level error protection property. This overall channel can be thought of as a combination of subchannels with different qualities. In general, these subchannels provide an environment for transmission of multimedia signals with different Quality of Service (QoS) requirements. The number of errors at each bit po-

---

This work has been supported by the Natural Sciences and Engineering Research Council of Canada under Grant No. A7779.

0-7803-3905-3/97/$10.00

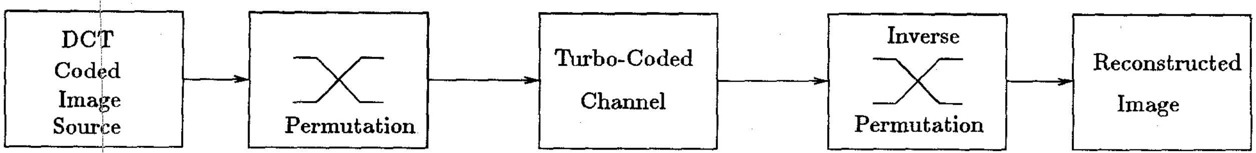

Figure 2: Image transmission system using priority-based mapping

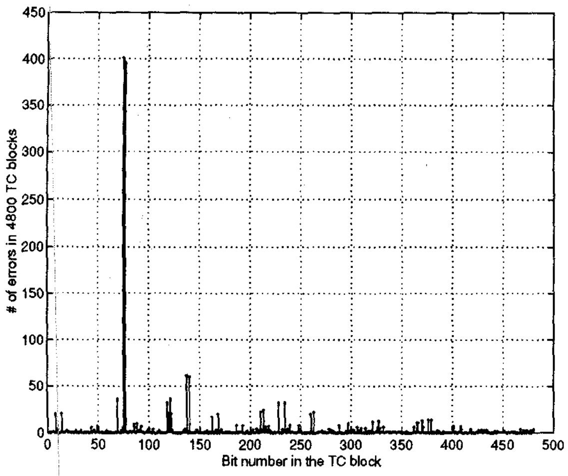

Figure 1: Non-uniform distribution of errors in 91200 TC blocks

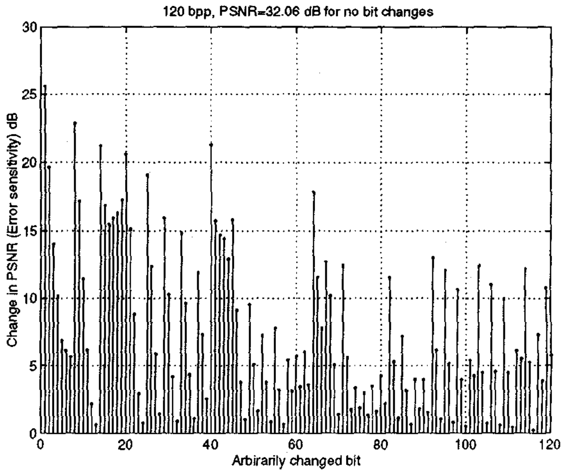

Figure 3: Error sensitivity of different bits in DCT blocks

sition is used for classification. Figure 1 shows that for the TC block of 480 bits, 256 of the bit locations exhibit zero errors, 99 bit locations show one error and 125 bit locations show more than one error. We have selected 160 of the 256 zero-error locations as the first class, the remaining zero-error locations and 64 single error locations as the second class, and the remaining 160 locations of the TC block as the third class. In this paper, we are concerned with using the TC channel for transmission of compressed image signals with different error protection requirements for different bits in DCT coded blocks. In the next section the unequal error protection requirement for image transmission is discussed. A permutation block is designed to match the unequal error protection of images to the UEP property of turbo codes.

3. TRANSMISSION OF DCT CODED IMAGES USING PRIORITY-BASED MAPPING

Figure 2 shows the functional block diagram used in our simulation. The input image is divided into 8 × 8 blocks. Each block is DCT coded and the DCT coefficients are quantized using a Lloyd-Max quantizer. A natural binary code is used to index the quantizer coefficients. At the receiver the quantizer indices are mapped onto reconstruction levels for the DCT coefficients. Each 8 × 8 block is inverse DCT transformed and the output image is reconstructed. An integer programming approach is used for bit allocation [7].

It is well known that the error protection requirement for the output stream of an image coder using block DCT is not the same for all the bits. In general, the DC components of the DCT block require a higher degree of error protection compared to the AC components. For each coefficient the most significant bits (MSBs) have higher error protection requirements. In this paper, instead of blindly transmitting image bit streams by turbo codes, we attempt to map the bits with higher error protection requirement to the locations in the TC block which exhibit fewer errors.

In order to find the error protection requirements for the individual bits of a DCT block, we intentionally change each bit separately and calculate the peak signal-to-noise ratio (PSNR) at the output of the image decoder. Figure 3 shows the effect of the individual bit errors on PSNR of the compressed Lena image with 120 bits per DCT block. It is observed that the error in some bits will adversely affect the PSNR of the reconstructed image. Compared to the less error-sensitive bits, a higher degree of error protection should be used for these bits.

We classify the source coder bits of the DCT blocks into three equal-size classes. The first class is the "most important" class, for which an error in any individual bit will have the highest reduction in the output PSNR. The elements of this class have the highest sensitivity to the bit error and require the highest degree of error protection. The second and third group of bits are the "important" and "least important" bits. An individual error in the last group has the least effect on the PSNR.

The information derived from the classification of the DCT bits based on UEP requirements and the classification of TC bits based on UEP provided by the turbo-coded channel is used to design the permutation block. In the permutation block, the highest error-sensitive bits of the image coder are mapped to the first class of the TC bits which provide the highest error protection. We refer to the mapping of DCT block bits into proper bit positions of the TC block as the **multi-level priority-based mapping** method. The following subsection describes the proposed priority-based mapping method in more details.

3.1. Multi-level Priority-Based Mapping Method

Each TC block is comprised of 4 DCT blocks of size 120 bits of the compressed image. Let DCT_UEP and TC_UEP be vectors containing the information of UEP requirements for the DCT block-coded bits and the UEP provided by the TC blocks, respectively. $DCT\_UEP[0]$ contains the position of the most important bit of a DCT coded block. An error in this location causes the maximum change (i.e., reduction) in the PSNR of the reconstructed image. The bit locations are sorted according to their sensitivity to the error. $TC\_UEP[0]$ contains the best position of a bit in TC block with the minimum number of errors. For $TC\_UEP[0]$, the bit positions are sorted according to their error performance.

The index $i = 0, 1, \cdots, 119$ is used to find the ith most important bits in the DCT blocks, using DCT_UEP. This index also uses the TC_UEP to find the locations in the TC block to which the corresponding DCT coded bits should be mapped.

Our priority-based permutation block is placed before the TC block in the system. The output of the TC block is inverse permuted using the inverse of the priority-based permutation block.

4. MULTI-LEVEL S-RANDOM TURBO CODE INTERLEAVER DESIGN

In the previous sections, we performed a large number of simulations to specify the error protection capability of different bit positions in a turbo block. The bit positions with a large number of errors correspond to the positions of 2-weight input sequences which result in code words with small Hamming distance. The results of these simulations are only valid for a specified interleaver. In this section we present a method for designing the interleaver for a turbo coder with multi-level error protection capability, using S-random interleavers. S-random interleaver was first proposed by Divsalar et al. in [8]. The algorithm for designing S-random interleaver is as follows. A random integer in the range of 1 to N is generated. Each non-repeated integer is compared to the S previously selected integers. If the current number is within $\pm S$ distance of these numbers, the new integer is rejected, otherwise it is accepted. The process is repeated until all N integers are selected. The problem with S-random is that the searching time for this algorithm increases with S, and it is not guaranteed to finish successfully, and the parameter S is fixed for the turbo code block.

In a multi-level S-random interleaver first we select a large value for S and then decrease its value as we proceed through the interleaver design. As an example we have chosen S equal to 18 for the first 160 bits of a 480-bit turbo code block and then S equal to 6 and 1 for the second and third 160 bits of the block, respectively. By using a multi-level S-random interleaver it is expected that for this example the first 160-bit positions provide the best error protection capability across the block. In a simulation of 45600 blocks of size 480 we observed that only 10 errors has occurred on the first 160 bit positions and 27 in the second part and 88 in the third part.

5. SUBJECTIVE EVALUATION

For comparison purposes, Figure 4 shows the reconstructed Lena image when 120 bits were allocated to each 8 × 8 DCT block and error-free transmission was assumed. Figure 5 shows the the output of the turbo decoder when no priority-based mapping is used. The artifacts in this image are due to channel error. The decoder output image with the priority-based mapping is shown in Figure 6. By comparing figures 5 and 6, it is observed that priority-based mapping method significantly enhances the subjective quality of the reconstructed image at the receiver. By looking at the TC error pattern in Figure 1, it is observed that a large number of errors occurred around the 75th bit of the TC block. To further improve the performance of the system we may just not send any source bits on these high error rate locations. In Figure 7, we have reduced the number of allocated bits per block from 120 to 110 bits and have not used the TC bit locations with high error rate for transmission. Figure 8 shows the results of our simulations using mutilevel S-random interleaver. In general, by comparing the results of our simulations, it is observed that the priority-based method provides much better subjective image quality compared to the conventional mapping method.

6. CONCLUDING REMARKS

In this paper we have examined the error characteristics of a turbo-coded channel. A multi-level priority transmission scheme to achieve unequal error protection was proposed. Our transmission method is based on the unequal error protection distribution exhibited by turbo codes. It is shown that multi-level priority transmission of coded image signals provides good subjective quality. It is conjectured that this method can be used for transmission of multimedia signals with different QoS requirements.

7. REFERENCES

[1] C. Berrou, A. Glavieux, and P Thitimajshima. "Near Shannon Limit Error-Correcting Coding and Decoding; Turbo Codes (1)". *In ICC'93 Conference Record, Geneva, Switzerland,*, pages 1064–1070, May 1993.

[2] J. D. Anderson. "The TURBO Coding scheme". *International Symposium on Information Theory (ISIT'94), Trondheim, Norway*, June May 1994.

Figure 4: Decompressed Lena image (120 bpb, PSNR=32.06dB)

Figure 5: Turbo Decoder Output NOT Using the Priority based Mapping Method (120 bpb, PSNR=27.60 dB)

[3] O. Joerssen and H. Meyer. "Terminating the Trellis of Turbo-Codes". *Electronic Letters*, vol. 30:pp. 1285–1286, August 1994.

[4] P. Robertson. "Illuminating the Structure of Code and Decoder of Parallel Concatenated Recursive Systematic (Turbo) Codes". *In GLOBECOM'94 Conference Record, San Francisco, California*, pages 1298–1303, December 1994,.

[5] A.S. Barbulescu and S.S. Pietrobon. "Rate Compatible Turbo Codes". *Electronics Letters*, vol. 31(No. 7):pp. 535–536, March 1995.

[6] L. R. Bahl, J. Cocke, F. Jelinek, and J. Raviv. "Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate". *IEEE Transactions on Information Theory*, vol. IT-20:pp. 284–287, March 1974.

[7] Edwin Vai-Hou Iun. " Combined Source-Channel Coding for the Transmission of Still Images over Code Division Multiple Access (CDMA) Channel ". *M.Sc Thesis, University of Waterloo, Waterloo, ON, Canada*, 1996.

[8] D. Divsalar and F. Pollara. "Turbo Codes for PCS Applications". *In ICC'96 Conference Record, Seattle, WA*, pages 54–59, June 1995.

Figure 6: Turbo Decoder Output Using the Priority based Mapping Method (120 bpb, PSNR=30.23 dB)

Figure 7: Turbo Decoder Output Using the Priority based Mapping Method (110 bpb, PSNR=30.85 dB)

Figure 8: Turbo Decoder Output Using Multilevel S-random Interleaver (120 bpb, PSNR=30.84 dB)