LDPC CODES FOR
ROBUST TRANSMISSION OF IMAGES OVER WIRELESS CHANNELS

C. Zhong and J. P. Havlicek

School of Electrical and Computer Engineering
University of Oklahoma
Norman, OK 73019-1023, USA

ABSTRACT

We propose a novel scheme based on low density parity check (LDPC) codes for channel coding in a robust wireless image transmission system. These codes, which have received intense research attention recently, can achieve reliable transmission at rates approaching the channel capacity. Moreover, they offer an implementation advantage over Turbo codes in terms of decoder complexity. To minimize latency in image reception, we consider the case where the image has been source coded using baseline JPEG. An additional level of unequal error protection is provided by applying Reed-Solomon codes to the JPEG header and marker segments. Finally, we present examples and simulation results that characterize the system performance for SNR per bit ranging from 1.6 to 2.1 dB.

1. INTRODUCTION

Proliferation of the World Wide Web and recent advances in both wireless communication technology and low-cost personal computing and communication devices have lead to an increasingly urgent need for robust, reliable, and inexpensive transmission of multimedia data over wireless channels. In this paper, we propose a novel channel coding scheme to address this need and demonstrate its application for the transmission of gray scale images.

Constraints on bandwidth, power, and latency in wireless applications prohibit transmission of uncompressed images, so there is always a tradeoff in system design between the conflicting goals of source coding to reduce the source information rate and channel coding to provide robustness against transmission errors. Typical compressed image representations are highly sensitive to bit errors arising from, *e.g.*, noise, fading and interference. Thus, effective channel coding is especially important in wireless systems, which are characterized by high bit error probabilities, since even a single bit error has the potential to render a received image undecodable if source coding has been applied. In particular, bit errors occurring in crucial header segments often cause catastrophic failures at the decoder. Broadly speaking, three error-handling methods are available to counteract these effects: forward error correction (FEC), error resilience, and error concealment [1].

In this paper, we consider a wireless transmission system for images coded using baseline JPEG and propose a novel FEC scheme based on low density parity check (LDPC) codes. We provide an additional level of unequal error protection (UEP) for the critical header and marker segments within the JPEG interchange format by applying a Reed-Solomon (RS) encoder prior to LDPC encoding. Using this approach, we demonstrate high quality image transmission at message bit error rates (BER) on the order of 10^{-4}, where the required message SNR per bit E_b/N_0 is within 2 dB of the Shannon limit for the additive white Gaussian noise (AWGN) channel. Via simulation, we also obtain the BER and peak signal-to-noise ratio (PSNR) as a function of E_b/N_0.

Although JPEG 2000, the new ISO/ITU-T standard is about to be finished [2], we focus our attention in this paper on baseline JPEG for its simplicity and popularity. A recent result [3] has shown that, for still images, the wavelet transform (on which JPEG 2000 is based) typically outperforms the discrete cosine transform (DCT) by only about 1 dB in terms of PSNR. Moreover, much of the performance gain is actually obtained through careful design of quantizers that are tailored to the transform structure rather than begin a consequence of inherent differences between the two transforms.

We believe that this paper is the first time that LDPC codes have been applied in a UEP channel coding scheme to achieve practical image transmission through the wireless channel. This is significant since, in comparison with another well-known, popular family of channel codes, *viz.*, the turbo codes, the sum-product decoding algorithm for LDPC codes is less complex than the BCJR algorithm for turbo codes [4] and allows parallel implementation in hardware. In Section 2, we give a brief

0-7803-7147-X/01/$10.00©2001 IEEE

overview of LDPC codes. An overview of the proposed communication system is presented in Section 3, and simulation results appear in Section 4.

2. BRIEF OVERVIEW OF LDPC CODES

Although LDPC codes were invented by Gallager in the early sixties [5], their importance as capacity-approach codes has emerged only recently [6]. Code construction and performance analysis issues are currently being addressed in the coding community, and applications including, *e.g.*, in the magnetic recording channel, have just begun to appear [4].

While the theory of LDPC codes is beyond the scope of this paper, interested readers can refer to [5] and [6]. Basically, LDPC codes are linear block codes with a very sparse parity check matrix H (N columns and M rows). Typically, the matrix H is generated by applying random perturbations to the zero matrix until a specified number of ones appear in every column and roughly fixed equal number of ones appear in each row. The associated generator matrix G can be obtained by Gaussian elimination of H, where G is not necessarily sparse. The sparseness of H facilitates the decoding of such codes. The pseudo-random parity check matrix also leads to LDPC codes that have random-like properties parsimonious with the Shannon Channel Coding Theorem conditions, but still possess a structure that facilitates practical decoding.

It was demonstrated in [6] that these codes could be used to transmit information reliably at rates very close to channel capacity. The decoding of LDPC codes can be tackled with the sum-product algorithm (also known as *message passing* and *belief propagation*). This is an iterative probabilistic decoding algorithm that begins with H and a set of prior probabilities for the N bits. It then iteratively updates these based on the M parity checks until all of the parity checks are satisfied. In case all parity checks cannot be satisfied after some predetermined maximum number of iterations, the decoder fails. In practice, this algorithm works well provided H does not contain patterns where two columns have two or more check positions in common.

3. SYSTEM OVERVIEW

Fig. 1 shows a block diagram of the proposed wireless image transmission system. The image source encoder compresses the image using the JPEG baseline DCT process. To facilitate error recovery at the decoder, the JPEG encoder inserts two restart markers (RST) per image block row. After JPEG encoding, the header and marker segments of the coded bitstream are separated from the entropy coded image blocks (MCU's) for RS encoding.

The RST markers are modified in the following way: the leading 0xFF byte of each marker is replaced with an integer count giving the number of bytes in the preceding entropy coded data segment, which varies from segment to segment due to the variable length entropy coding employed by the JPEG standard. Since the RST markers are RS coded with the image header in contiguous blocks, these byte counts enable the decoder to determine the appropriate positions within the entropy coded bitstream of MCU data where the RST marker segments should be reinserted.

Our UEP coding approach is similar to the one described in [7]. We partition the header/markers bitstream into fixed length blocks and apply an RS (n,k) code [8]. Where necessary, the last block is padded with zeros. At the receiver, RS decoding is performed using the well-known Berlekamp-Massey algorithm [8]. Subsequent to RS encoding the header/markers and MCU bitstreams are simply concatenated. While improved performance could certainly be obtained by inserting an interleaver prior to the LDPC encoder, that possibility will not be explored in this paper. LDPC coding is applied to the concatenated bitstream which is then fed to a digital modulator for transmission through the AWGN channel.

As indicated in Fig. 1, an LDPC decoder is applied to the received signal subsequent to demodulation to retrieve the concatenated bitstream. RS (n,k) decoding is then applied to blocks of length n bytes until the header and marker segments are successfully decoded. At this point, the byte lengths stored in the modified RST markers enable the decoder to reintegrate the RST markers back into the entropy coded bitstream and concatenate this with the decoded header to construct the received compressed image in JPEG interchange format. Finally, the received image is obtained at the output of the JPEG decoder.

In this paper, we apply a basic LDPC code to the compressed image transmission to obtain preliminary validation of our proposed channel coding approach. We use a rate ½ (2000, 1000) LDPC code with three "1"s in every column and roughly six "1"s in each row of the parity check matrix. Alternative LDPC codes, *e.g.*, high rate, irregular, and non-binary codes will be considered in our future research to improve system BER, throughput, and latency performance.

We use the AWGN model to simulate the wireless channel. More complex model, such as Rayleigh and Rician fading channels, could be but will not be considered here in the interest of brevity and simplicity.

4. RESULTS

Fig. 2 shows the familiar 256×256 grayscale image *lenna*, where each pixel takes gray levels in the range [0, 255] (one byte per pixel). Fig. 3 shows the image obtained after JPEG encoding and decoding with a quality factor of 50. This results in a bit rate of 0.954 bits per pixel (bpp) with PSNR = 32.77 dB for the JPEG process. As discussed above, two restart markers are inserted in each image block row. This increases the size of the compressed image by 2% and the bit rate is slightly increased to 0.975 bpp. However, the PSNR remains unchanged.

RS (255, 231) encoding was applied to the header/markers bitstream, which resulted in two RS coded blocks. This RS code can correct up to 12 bytes per codeword. The resulting header data expansion was immaterial (0.6%) and the bit rate for the *lenna* image JPEG and RS coding was 0.981 bpp. The rate ½ (2000, 1000) LDPC encoding was then applied to the concatenated header/markers and MCU bitstreams.

As a benchmark, we calculated a value of 0.19 dB for the theoretical minimum SNR per message bit E_b/N_0 required to achieve the AWGN channel capacity for the rate ½ antipodal input. With iterative decoding, we evaluated the system BER for values of E_b/N_0 ranging from 1.6 to 2.1 dB. These results are shown graphically in Fig. 4, where each point was obtained by averaging 1000 simulated image transmissions. Average PSNR values for the decoded images are summarized in Table 1 below. Note that, in the E_b/N_0 = 2.1 dB case, the PSNR of the decoded image is precisely equal to that obtained by direct JPEG encoding and decoding, indicating that no uncorrectable errors occurred during wireless transmission of the image in this case.

Table 1. Recovered image PSNR (dB) vs. E_b/N_0 (dB)

E_b/N_0	1.6	1.7	1.8	1.9	2.0	2.1
PSNR	20.05	21.74	26.50	27.65	28.76	32.77

To demonstrate the type of decoding errors one expects to incur at very low SNR, Fig. 5 shows the recovered image for E_b/N_0 = 1.9 dB. We find that the image is for the most part recovered perfectly. A few block-like artifacts are clearly visible from uncorrectable bit errors in the MCU data stream, however. Note that we are only about 1.7 dB away from the channel capacity in this case, which is quite amazing by conventional wireless communications standards. The blocking artifacts arise from two sources [9]: (1) errors in the DCT coefficients produce block-like artifacts with sharp annoying edges; (2) End of Block (EOB) codes in the JPEG interchange format are missed or falsely detected, leading to misinterpretation of the following bits.

5. CONCLUSIONS

For the first time, we have proposed a robust UEP channel coding technique combining RS codes with novel, powerful LDPC codes for robust wireless image transmission. LDPC codes have been popularized recently for their capability to approach the channel capacity. The main advantage that LDPC codes offer over Turbo codes is efficient hardware implementation of the decoder. Our simulations show that the proposed technique is capable of delivering viewable images at typical wireless communications BER when E_b/N_0 is as close as 1.7 dB to the theoretical channel capacity.

Although our results are certainly encouraging, this research is its infancy and an exciting array of issues remains to be further investigated. As we mentioned in Section 3, high rate, irregular, and non-binary LDPC codes can be developed that will improve the system performance. Fading channels definitely need to be investigated.

In addition, we are particularly interested in the following two issues. First, since many images of practical interest are Markovian, a (soft) Viterbi algorithm could be used for source decoding. This could be combined with LDPC channel codes with iterative soft decoding to implement a joint source-channel coding scheme. Second, although we have employed a UEP scheme in this paper, reliability information regarding the decoding of RS codes and LDPC codes could be further exchanged between the two decoders if the RS decoding algorithm were implemented in a soft-decision mode [10].

6. REFERENCES

[1] Special Issue on Error-Resilient Image and Video Transmission, *IEEE J. Select. Areas Commun.*, vol. 18, no. 6, June 2000.

[2] M. J. Gormish, D. Lee, and M. W. Marcellin, "JPEG 2000: overview, architecture, and applications," in *Proc. IEEE Int. Conf. Image Processing*, 2000.

[3] Z. Xiong, K. Ramchandran, M. T. Orchard, and Y. Q. Zhang, "A comparative study of DCT- and Wavelet-based image coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol., 9, pp. 692-695, Aug. 1999.

[4] J. L. Fan, A. Friedmann, E. Kurtas, and S. McLaughlin, "Low density parity check codes for magnetic recording," in *Proc. Allerton Conf. on Commun. and Control*, 1999.

[5] R. G. Gallager, *Low-Density Parity-Check Codes*, MIT Press, 1963.

[6] D. J. C. MacKay, "Good error-correcting codes based on very sparse matrices," *IEEE Trans. Inform. Theory*, vol. 45, pp. 399-431, Mar. 1999.

[7] J. He, D. J. Costello, Y. F. Huang, and R. L. Stevenson, "On the application of turbo codes to the robust transmission of compressed images," in *Proc. IEEE Int. Conf. Image Processing*, 1997.

[8] S. B. Wicker, *Error Control Systems for Digital Communication and Storage*, Prentice Hall, 1995.

[9] D. W. Redmill and N. G. Kingsbury, "Still image coding for noisy channels," in *Proc. IEEE Int. Conf. Image Processing*, pp. 95-99, 1994.

[10] R. Koetter and A. Vardy, "Algebraic soft-decision decoding of Reed-Solomon codes," in *Proc. IEEE Int. Symp. Inform. Theory*, 2000.

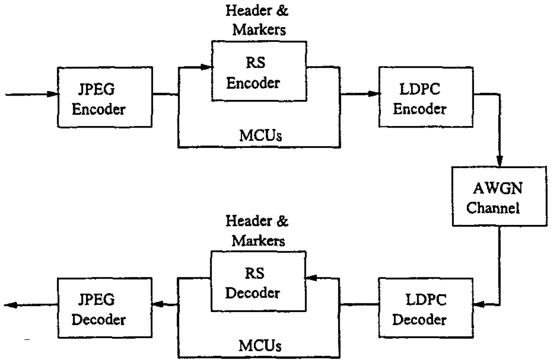

Fig. 1. Block diagram of system for wireless image transmission.

Fig. 2. Original *lenna* image.

Fig. 3. Recovered image after JPEG encoding and decoding.

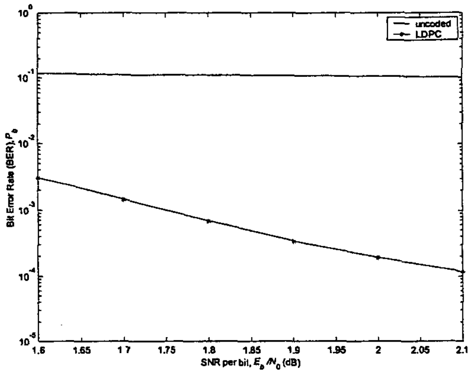

Fig. 4. Bit error rate vs. E_b/N_0 for LDPC codes.

Fig. 5. Recovered *lenna* image with $E_b/N_0 = 1.9$ dB.