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A Simulation of Image Transmission: Turbo Codes Combined with JPEG Image Compression

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Abstract: An investigation of Unequal Error Protection (UEP) methods applied to JPEG image transmission using turbo codes is presented. The JPEG image is partitioned into two groups, i.e., DC components and AC components according to their respective sensitivity to channel noise. The highly sensitive DC components are better protected with a lower coding rate, while the less sensitive AC components use a higher coding rate. While we use the s-random interleaver and s-random odd-even interleaver combined with odd-even puncturing, we can fix easily the local rate of turbo-code. We propose to modify the design of s-random interleaver to fix the number of parity bits. Simulation results are given to demonstrate how the new UEP schemes outperforms the Equal Error Protection (EEP) scheme in terms of Bit Error Rate (BER) and Peak Signal to Noise Ratio (PSNR).

Key words: JPEG, interleaver, turbo-code, puncturing, BER (Bit Error Rate), Unequal Error Protection (UEP), Peak Signal to Noise Ratio (PSNR)

INTRODUCTION

Visual signals such as compressed still images are very vulnerable to channel noise. Usually, channel coding is utilized to protect the transmitted visual signals. The Joint Photograph Experts Group (JPEG) standard[1] proposed in 1992 is widely used for still image compression and transmission. Turbo codes[2] are suitable for protecting multimedia signals such as images since these visual signals are characterised by a large amount of data, even after compression. In this paper, we address the special case of JPEG still image transmission over noisy channels in which turbo codes are used for channel coding. UEP, which involves data partition with different coding rates, is a method used to protect different components of an image "unequally" according to their respective sensitivity to channel errors. In a JPEG coded image, the coded bits are composed mainly of two types of bits, DC bits and AC bits. There are two justifications in applying UEP to JPEG coded images. First, in the two dimension Discrete Cosine Transform (DCT) adopted by JPEG coding, the DC coefficient is a measure of the average value of the 64 image samples and contains a significant fraction of total image energy. Thus, the DC coefficients are treated separately from the AC coefficients in various source coding stages of JPEG.

Secondly, due to strong correlation in adjacent DC bits, differential coding is applied to DC components. Thus, for DC bits, decoding errors in one block will lead to decoding errors in subsequent blocks. Conversely, for AC bits, decoding errors only affect local blocks. Observing the output bits from a JPEG image encoder, we found AC bit number is around 6-12 times that of DC.

This gives us a large space for applying UEP turbo coding on the output bits of a JPEG source encoder. We allocate a lower coding rate to highly sensitive DC components and a higher coding rate to less sensitive AC components, while keeping the UEP coding rate the same as that of EEP. We will show how sensitive the BER and PSNR of an image is to different protection levels for DC, AC components. Ideal synchronization is assumed in the simulation results.

The transmission chain used for simulations: Figure 1 represents the transmission chain for which we evaluated the Binary Error Rate (TEB) and (PSNR) after decoding. An input image is compressed by JPEG. The binary symbols resulting from the JPEG compressing constitute the sequence of data to be transmitted. The coder of channel receiving these data is a standard turbo-coder of rate 1/3[4]. He is obtained by parallel concatenation of two Recursive Systematic Convolutional codes (RSC), of rate

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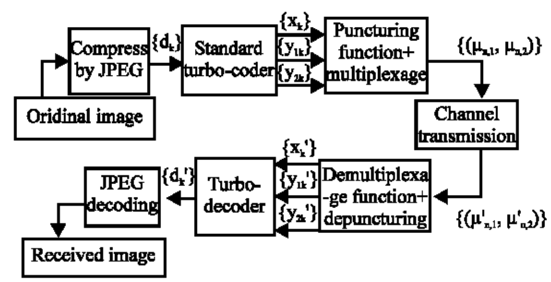

Fig. 1: A block diagram of a communication system

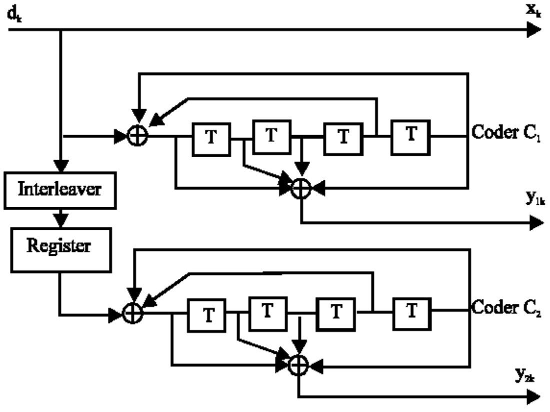

Fig. 2: Standerd turbo-coder structure

1/2, constraint length K = 5 and generating polynomials (23,35), separated by an interleaver Fig. 2. The code RSC, which has these generating polynomials, is powerful within the meaning of the free distance.

The JPEG source encoder used in this study partitions the output bits into two groups of bits, i.e., DC bits and AC bits. Both are sent into a multi-rate turbo encoder. The multi-rate turbo encoder applies different coding rates to the DC and AC bits according to the particular UEP scheme. We assume that the channel is a binary input channel with Additive White Gaussian Noise (AWGN). QPSK modulation is used. The turbo decoder decodes the UEP coded bits from the noisy channel output. The JPEG image decoder integrates the two groups of DC and AC bits into a standard image coded stream and outputs the reconstructed image.

The puncturing: Thanks to the technique of puncturing, it is possible to provide a whole of turbo-coders of various rate, starting from only one standard code whitch rate is generally equal to 1/3. The codes thus obtained present performances very close to those obtained with optimal codes (non-poinçonés) of the same rate, in condition however that the puncturing matrix are quite selected. This technique of puncturing makes it possible to simplify the trellis since in each state converges, only, two branches and not 2^M branches as for an optimal code of rate M/N. This decreases the complexity of decoding using the Soft Output Viterbi Algorithm (SOVA). Moreover, the same turbo-decoder can then be used for a whole of compatible punctured codes.

A puncturing matrix P of period p applied to a turbo code having N output branches can be represented by:

$$P = \begin{bmatrix} g_{11} \cdots g_{1p} \\ \cdots g_{ik} \cdots \\ g_{N1} \cdots g_{Np} \end{bmatrix} \tag{1}$$

Where every row corresponds to one output branch, i.e., the first row corresponds to the systematic branch $\{d_k\}$ Fig. 2; the second row corresponds to the first parity branch $\{y_{1k}\}$ and so on. Note that g_{ik} where 0 implies that corresponding bit is punctured. The degree of freedom in controlling the code rate can be gained by increasing p. Note that in our case N = 3.

If w (.) the Hamming weight operator, then the rate of the code after puncturing with the puncturing matrix P is:

For the unpunctured case: w(P) = N.p and (2) reduces to: R = 1/N.

A simple method consists to puncture only the parity bits which differs from the information bits, which amounts to choosing a puncturing matrix which coefficients associated with the sequence of information bits $\{d_k\}$ Fig. 2 are always equal to 1. Such a matrix is known as "invariant" and this technique of puncturing is called " puncturing of the parity data", noted PPD will be adopted during the simulation of the transmission chain described previously. The matrix of puncturing odd-even (EEP) used in our simulation to obtain a code of rate 1/2 is as follows:

$$P = \begin{bmatrix} 1 & 1 \\ 0 & 1 \\ 1 & 0 \end{bmatrix} \tag{3}$$

with p = 2.

Several work showed the improvement of the performances in these turbo-codes by using an interleaver having the property odd-even.

The interleaving: There are two families of interleavers: block interleaving and convolutionnel interleaving. For example, the family of block interleaving gathers several types of interleaving like the classical interleaver (uniform), pseudo-random (Berrou-Glavieux), random... etc. We are mainly interested in block interleaving. To have more details, we will be able to refer to[5].

The random interleaver is generated using a purely random vector[6]. The S-random interleaver is a random interleaver with a restriction of his dispersion capacity[5,6]. For the turbo-code of rate R = 1/2 (with puncturing), the odd-even interleaver makes an improvement of the performances[6]. He is generated with the following condition: The bits having odd positions (respectively even) are permuted to odd positions (respectively even).

UEP schemes: The multi-rate turbo encoder used for UEP is capable of implementing two different code rates for the DC and AC components. Two different interleavers were examined. We denote DC bit number and AC bit number in a JPEG image by L_{DC} and L_{AC}, respectively. In the structure of image bits stream, the DC and AC blocks are joined together to form a single block of the same size as that of the EEP scheme. The overall block has its same interleaver. Figure 3 shows the structure of image bits stream.

Puncturing matrix: The puncturing matrix has a period $p = L_{DC} + L_{AC}$ and N = 3 represented by:

$$P = \begin{bmatrix} g_{11} \cdots g_{1LDC} \cdots g_{1p} \\ g_{21} \cdots g_{2LDC} \cdots g_{2p} \\ g_{31} \cdots g_{3LDC} \cdots g_{3p} \end{bmatrix} \quad (4)$$

$$P_1 = g_{11} \cdots g_{1LDC} \cdots g_{1p} = [1111111 \ldots 1111] \quad (5)$$

$$P_3 = g_{31} \cdots g_{3LDC} \cdots g_{3p} = [010101 \ldots 0101] \quad (6) \quad (6)$$

$$P_2^{DC} = g_{21} \cdots g_{2LDC} \quad (7)$$

$$P_2^{AC} = g_{2\ LDC+1} \cdots g_{2p} \quad (8)$$

And the first parity branch (P_2) depend on the local rate of DC bits and AC bits: R_{DC} and R_{AC} respectively. For example:

$$P_2^{DC} = [1\ 1\ 1\ 1\ 1\ 0\ \ldots 111110\ ]$$

and

$$P_2^{AC} = [\underbrace{00101010\ \ldots 10101000}_{48\text{ bits}} \ldots \underbrace{00101010\ \ldots 10101000}_{48\text{ bits}}]$$

for R_{DC}= 0.4285 and R_{AC}= 0.5055. We will use tow type of interleavers:

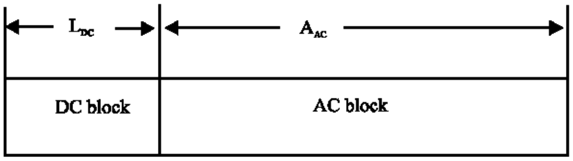

Fig. 3: The structure of image bits stream

a- In the case of S-random odd-even interleaver: The number of coded bits associated with DC information bit is: $L_{DC}/2$ for the second parity branch because only the even positions information bits are interleaved towards even positions. And these positions have no null bits of parity.

b-In the case of S-random interleaver: we added in the design of interleaver the following constraint:

The half number of DC bits ($L_{DC}/2$) must interleaved towards even positions. These $L_{DC}/2$ bits are selected randomly. Thus the number of coded bits associated with DC information bit is: $L_{DC}/2$ for the second parity branch.

So in the tow case R_{DC} and R_{AC} depend on the first parity branch: w (P^{DC}_2) and w (P^{AC}_2), respectively. We have:

$$w(P_3) = \frac{L_{DC} + L_{AC}}{2}$$

then the local rate

$$R_{DC} = L_{DC} / (L_{DC} + w(P_2^{DC}) + \frac{L_{DC}}{2})$$

and

$$R_{AC} = L_{AC} / (L_{AC} + w(P_2^{AC}) + \frac{L_{AC}}{2})$$

RESULTS

We present some simulation results from transmitting JPEG coded "Lena" over the AWGN channel. In JPEG image source coding, quality factor Q is used to control the compression ratio and thus the compressed image quality. A 16 state multi-rate systemetic turbo codec with codes 35/23 in octal notation is used in the simulations. S-random and S-random odd-even interleaving is used. The PSNR of "Lena" 64 x 64 image are 34,64. He is the highest PNSR the receiver can obtain without any transmission errors. Synchronisation is an issue when Variable Length Coded (VLC) signals such as JPEG images are transmitted through noisy channels. In order to distinguish synchronisation errors from decoding errors, we assume ideal synchronisation within the DCT operational 8x8 subblock in our simulations.

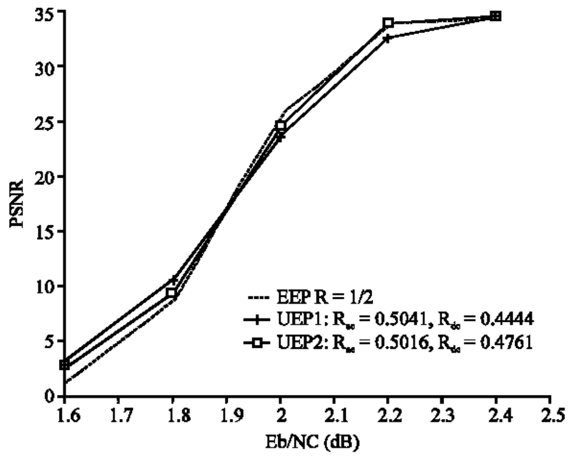

Fig. 4: PSNR performance comparison of EEP and UEP scheme for S-random interleaver

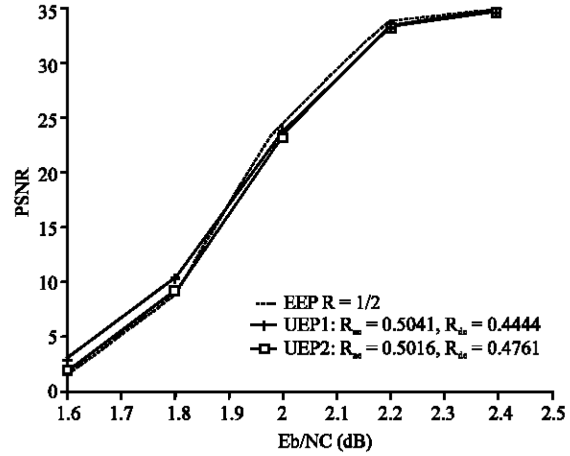

Fig. 5: PSNR performance comparison of EEP and UEP scheme for S-random odd-even interleaver

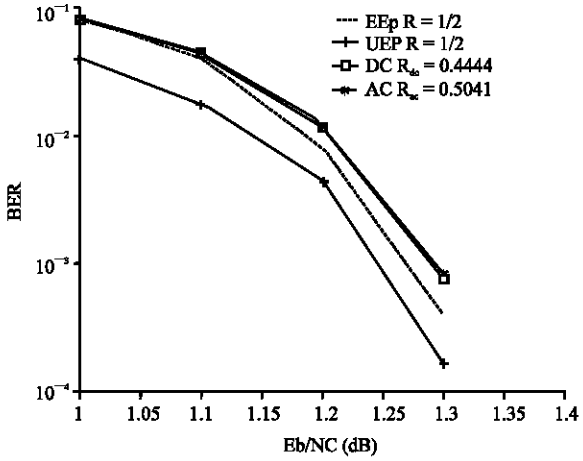

Fig. 6: BER performance comparison of EEP and 1st UEP scheme for S-random interleaver

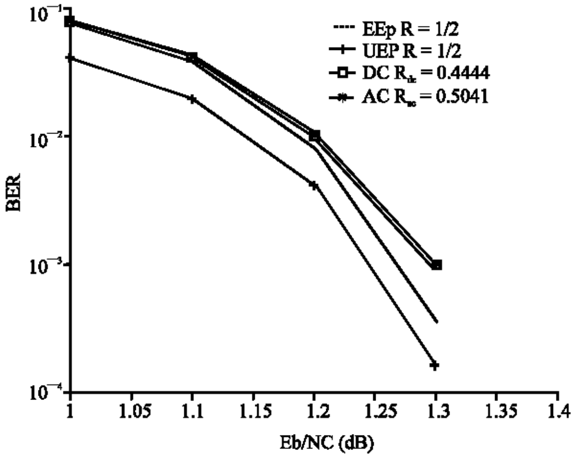

Fig. 7: BER performance comparison of EEP and 1st UEP scheme for S-random odd-even interleaver

In[3], the authors investigated the UEP method applied to header bits and all the other image bits. In this study, we assume all the header bits are transmitted correctly. And in[7], the authors investigated the UEP method witch interleaver structure design is to break the larger interleaver of size $L_{AC}+L_{DC}$ into smaller pieces without changing the order of the bit stream image before coding by the turbo coder, each having an identical size of bits and the interleaving is applied separately to DC bits then to AC bits. In this study, the interleaving is applied once to all the bits of image (L_{AC} and L_{DC}).

UEP schemes were simulated for the 64×64 "Lena" image. L_{DC} is 728 and L_{AC} is 11182. Tow different coding rate allocations for DC and AC components were tried while keeping the total turbo coded bits the same as in the EEP case, i.e., overall rate 1/2 coding regardless of the code rate allocation between the DC and AC components.

Figure 4 to 5 gives PSNR performances comparisons for tow different interleavers: S-random and S-random odd-even while Fig. 6 to 7 give BER performance comparisons. From these Fig. we can see that the average PSNRs of UEP2 outperform that of EEP for low Eb/No, but is worse than that of EEP for high Eb/No for the S-random odd-even interleaver and slightly worse for the S-random interleaver for high Eb/No. The underlying justification is that the S-random odd-even interleaver is very adapted with the odd-even puncturing (EEP) according to their definition. This is obvious on the graphs of BER in Fig. 6 and 7: UEP BER is superior than EEP BER for high Eb/N0 especially for S-random odd-even.

CONCLUSION

UEP methods applied to JPEG image transmission using turbo codes are investigated in this study. The DC and AC components are protected with different coding rates. Different UEP schemes are compared to that of EEP in terms of both BER and PSNR. The simulation results revealed:

- For very noisy channels, where Eb/No is relatively low: The BER of highly sensitive DC bits is very sensitive to channel coding rate allocation. A slightly lower coding rate for DC components will lead to significant DC BER drop while keeping the corresponding AC BER close to that of EEP. the average BER of the most important DC component is much lower than that of EEP. UEP schemes are better than EEP in terms of BER and PSNR.
- For higher Eb/No: The average PSNR of UEP schemes is worse than that of EEP for the S-random odd-even interleaver but slightly worse for the S-random interleaver.

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