Channel Optimized Quantization of Images over Bursty Channels*

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Abstract — A DCT-based combined source-channel coding system is proposed for transmitting grey-level images over a binary channel with additive Markov noise. It consists of a channel optimized quantization scheme that exploits the channel memory by incorporating the characteristics of the correlated noise in the quantizer design. Experimental results show that this simple system – which employs a fixed zonal coding bit allocation technique – provides significant improvements over traditional tandem systems, especially during bad channel conditions. The loss of optimality due to the use of the zonal coding bit allocation method is also examined. The loss is shown to be small for various images; this suggests that a reduction in complexity and bandwidth requirements can further be achieved.

1 Introduction

Traditional tandem source-channel coding is based on Shannon's separation principle [1]; however, in practice its optimality is constrained by the encoder/decoder delay and complexity. Combined source-channel coding has been proposed as an alternative approach and has received considerable attention recently (e.g., [2], [3], [4]). In this approach, a single code is designed with the knowledge of both the source and the channel such that the average distortion of the overall system is minimized.

In this work, we propose a simple combined source-channel coding system for transmitting grey-level images over a binary channel with memory. This scheme which consists of a bank of channel optimized quantizers, exploits the channel memory by incorporating the characteristics of the correlated noise in the quantizers' design.

2 Channel Model

The channel model used is a binary channel with additive stationary ergodic Markov noise. More specifically, it is described by: $Y_i = X_i \oplus Z_i$ for $i = 1, 2, \ldots$, where $\oplus$ represents modulo 2 addition, and X_i, Z_i and Y_i are, respectively, the channel input, noise and output. The input and noise sequences are assumed to be independent of each other. The Markov noise process $\{Z_i\}_{i=1}^{\infty}$ is characterized by a bit error rate (BER) $Pr\{Z_i = 1\} = \epsilon$ and the transition probabilities $Pr\{Z_i = 1 | Z_{i-1} = 1\} = \frac{\epsilon+\delta}{1+\delta}$ and $Pr\{Z_i = 0 | Z_{i-1} = 0\} = \frac{1-\epsilon+\delta}{1+\delta}$, where $\delta > 0$ is the correlation parameter (the noise correlation coefficient is equal to $\frac{\delta}{1+\delta}$). When $\delta = 0$, the channel reduces to the (memoryless) binary symmetric channel (BSC) with crossover probability ϵ. The capacity of this channel is monotonically increasing with δ, and decreasing with ϵ.

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3 A Combined joint source-channel coding system for images

3.1 System description

The proposed image transmission system is briefly described as follows. The image is first subdivided into 8×8 blocks and transformed via the Discrete Cosine Transform (DCT) according to the JPEG standard [5]. Since high frequency DCT coefficients are relatively insensitive to the human visual system, they are zonally masked out [5]. Fixed bit allocation tables are used for each 8×8 image coefficient block. The DCT coefficients are arranged in a zigzag sequence as described in [5] and are subsequently quantized via a bank of Channel-Optimized-Scalar-Quantizers (COSQ). Since the DC coefficient (the coefficient with zero frequency) contains most of the energy in each image block, it is quantized with an 8-bit rate quantizer; as for the AC coefficients, they are quantized at rates that correspond to their level of activity [5]. After quantization, the indexes of the codebook are sent over the binary channel block by block. At the receiver end, they are decoded and the reconstructed image is obtained through the Inverse Discrete Cosine Transform (IDCT). The bank of COSQ's are designed off line using the method described in [4, 6]. The source distribution is assumed to be Gaussian for the DC coefficients and Laplacian for all AC coefficients [7].

3.2 Experimental results

Experimental results for this proposed system indicate that large improvements over usual tandem schemes can be achieved. Two images with different sizes are used, Baboon (256×256) and Lena (512×512). In Tables 1–4, the average PSNR of the reconstructed images are displayed for various values of the channel correlation δ, BER ϵ, and overall operational rate in bits-per-pixel (bpp). The results were averaged over 25 experiments. Subjective performance improvements can also be observed in Figure 1. Two reference tandem systems are used for comparison: SQ and SQ-IL. SQ denotes the Lloyd-Max quantizer with Natural Binary Code (NBC) codeword assignment over the Markov channel; SQ-IL denotes the Lloyd-Max quantizer with NBC codeword assignment over an interleaved Markov channel. In this case, we assume that the Markov channel has been rendered memoryless (i.e., $\delta = 0$) via an ideal interleaver. COSQ denotes our proposed scheme. As shown from the PSNR tables, the COSQ system outperforms the two reference systems in all cases, especially in very noisy channel environments with high noise correlation. More specifically, the improvements can be as high as 5 dB for Baboon and 12 dB for Lena when $\epsilon = 0.1$ and $\delta = 10$ at 1.19 bpp. Finally, it can be observed that for a fixed ϵ, the performance of the COSQ scheme improves as the channel correlation parameter increases from $\delta = 0$ to $\delta = 10$ (the best gain occurs in Table 1 at $\epsilon = 0.1$.) This is due to the fact that the COSQ exploits the noise memory when $\delta > 0$.

4 Loss of optimality due to zonal coding

Bit allocation addresses the proper distribution of the available bits to the transform coefficients. It determines which coefficients should be kept for coding and transmission and how coarsely the retained coefficients should be quantized [5]. It can be performed either with fixed (global) zonal coding or adaptive threshold coding (which is recommended in the JPEG standard [5]). The zonal coding technique is based on the assumption that the transform coefficients with the largest variances carry most of the information; it provides a *fixed* bit allocation table that is globally applied to each image block. The advantage of zonal coding over adaptive threshold coding is that it does not require overhead information; this results in a reduction in complexity and bandwidth requirements. We herein evaluate the loss of optimality due to the incorporation of the zonal coding bit allocation method in our proposed system. This is achieved by comparing it to a similar system that employs an optimal bit allocation scheme which minimizes the overall distortion. The method for calculating the optimal bit allocation table is described in [2]. A constraint of allocating a maximum of 8 bits is applied for each transform coefficients. The optimal bit allocation method used in this work differs from [2] by the facts that we consider a Markov channel instead of a BSC, and that the DC and AC coefficients are modeled using different distributions.

Simulation results for the transmission of Baboon using the two systems are presented in Tables 5–6 for two different values of the overall rate (1.19 bpp and 0.375 bpp). COSQ-OPT denotes the scheme using the optimal bit allocation table and COSQ-FIX denotes the zonal coding-based scheme described in the previous section. Our results show that the loss of optimality by using the fixed (zonal coding) bit allocation table is only about 1.0 dB; this gap narrows as the channel conditions deteriorate. A similar behavior was observed for various other images.

5 Conclusion

In this work, we propose a DCT-based combined source-channel coding system for the reliable communication of grey-level images over binary bursty channels. This system consists of a channel optimized quantization scheme that exploits the channel memory. Experimental results demonstrate considerable objective and subjective performance improvements over other tandem coding schemes. The loss of optimality due to zonal coding is also studied; it is observed that such loss is relatively small. This suggests the possibilities for reducing the system complexity/bandwidth.

Future work will address the design and implementation of channel optimized quantizers for the Gilbert channel. This will be achieved by modeling the Gilbert channel using an M'th order Markov channel model, and using the Markov channel parameters in the design of the channel optimized quantizers. The usefulness of the Markov channel model will be manifested through the transmission performance of both ideal and real images over the Gilbert channel.

References

[1] C. E. Shannon, "A mathematical theory of communication," *Bell Syst. Tech. J.*, vol. 27, pt. I, pp. 379–423, 1948; pt. II, pp. 623–656, 1948.

[2] V. Vaishampayan and N. Farvardin, "Optimal block cosine transform image coding for noisy channel," *IEEE Trans. Commun.*, pp. 327–336, Mar. 1990.

[3] W. Xu, J. Hagenauer and J. Hollmann, "Joint source-channel decoding using the residual redundancy in compressed images," *Proc. Int. Conf. Commun.*, Dallas, TX, June 1996.

[4] N. Phamdo, F. Alajaji and N. Farvardin, "Quantization of memoryless and Gauss- Markov sources over binary Markov channels," *IEEE Trans. Commun.*, to appear, June, 1997.

[5] A. M. Tekalp. *Digital video processing.* Prentice Hall, Upper Saddle River, NJ, 1995.

[6] N. Farvardin and V. Vaishampayan, "On the performance and complexity of channel-optimized vector quantizers," *IEEE Trans. Inf. Theory*, vol. 37, pp. 155–160, Jan. 1991.

[7] R. C. Reinger and J. D. Gibson, "Distributions of the two-dimensional DCT coefficients for images," *IEEE Trans. Commun.*, vol. 31, pp. 835–839, 1983.

δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ	32.33	30.42	29.50	25.18	22.42
0	SQ	32.33	27.30	24.99	18.59	15.69
0	SQ-IL	32.33	27.30	24.99	18.59	15.69
5	COSQ	32.33	31.06	30.32	27.43	25.87
5	SQ	32.33	27.24	24.85	18.49	15.59
5	SQ-IL	32.33	27.30	24.99	18.49	15.69
10	COSQ	32.33	31.41	30.83	28.98	27.74
10	SQ	32.33	27.23	24.97	18.53	15.63
10	SQ-IL	32.33	27.30	24.99	18.59	15.69

Table 1: Average PSNR (dB) of decoded Lena over the Markov channel with BER ϵ and correlation parameter δ using a fixed bit allocation table at 1.19 bpp.

δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ	21.78	21.65	21.55	20.87	20.17
0	SQ	21.78	21.33	20.88	18.43	16.51
0	SQ-IL	21.78	21.33	20.88	18.43	16.51
5	COSQ	21.78	21.69	21.63	21.34	21.04
5	SQ	21.78	21.34	20.88	18.28	16.33
5	SQ-IL	21.78	21.33	20.88	18.43	16.51
10	COSQ	21.78	21.73	21.69	21.51	21.34
10	SQ	21.78	21.32	20.91	18.26	16.38
10	SQ-IL	21.78	21.33	20.88	18.43	16.51

Table 2: Average PSNR (dB) of decoded Baboon over the Markov channel with BER ϵ and correlation parameter δ using a fixed bit allocation table at 1.19 bpp.

δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ	21.50	21.06	20.99	20.46	19.89
0	SQ	21.50	20.80	20.44	18.28	16.45
0	SQ-IL	21.50	20.80	20.44	18.28	16.45
5	COSQ	21.50	21.08	21.04	20.82	20.60
5	SQ	21.50	20.77	20.38	18.12	16.37
5	SQ-IL	21.50	20.80	20.44	18.28	16.45
10	COSQ	21.50	21.11	21.08	20.95	20.83
10	SQ	21.50	20.76	20.40	18.10	16.41
10	SQ-IL	21.50	20.80	20.44	18.28	16.45

Table 3: Average PSNR (dB) of decoded Baboon over the Markov channel with BER ϵ and correlation parameter δ using a fixed bit allocation table at 0.90 bpp.

δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ	19.95	19.91	19.88	19.61	19.18
0	SQ	19.95	19.70	19.44	17.95	16.55
0	SQ-IL	19.95	19.70	19.44	17.95	16.55
5	COSQ	19.95	19.92	19.90	19.79	19.66
5	SQ	19.95	19.72	19.48	17.84	16.46
5	SQ-IL	19.95	19.70	19.44	17.95	16.55
10	COSQ	19.95	19.93	19.92	19.86	19.80
10	SQ	19.95	19.71	19.48	17.86	16.47
10	SQ-IL	19.95	19.70	19.44	17.95	16.55

Table 4: Average PSNR (dB) of decoded Baboon over the Markov channel with BER ϵ and correlation parameter δ using a fixed bit allocation table at 0.375 bpp.

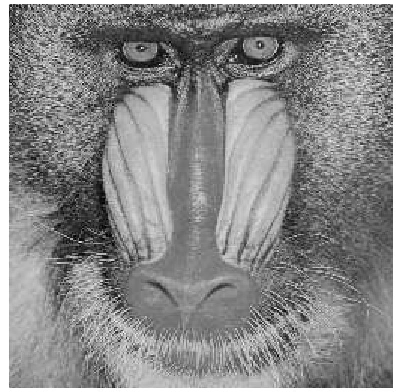
δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ-OPT	23.72	23.29	23.02	21.52	20.47
0	COSQ-FIX	21.78	21.65	21.55	20.87	20.17
5	COSQ-OPT	23.72	23.47	23.25	22.29	21.63
5	COSQ-FIX	21.78	21.69	21.63	21.34	21.04
10	COSQ-OPT	23.72	23.51	23.36	22.59	22.06
10	COSQ-FIX	21.78	21.73	21.69	21.51	21.34

Table 5: Performance comparison between COSQ systems using fixed and optimal bit allocation tables; PSNR (dB) of decoded Baboon over the Markov channel with BER ϵ and correlation parameter δ at 1.19 bpp.

δ	System	ϵ=0	ϵ=0.005	ϵ=0.01	ϵ=0.05	ϵ=0.1
0	COSQ-OPT	20.84	20.62	20.51	19.90	19.35
0	COSQ-FIX	19.95	19.91	19.88	19.61	19.18
5	COSQ-OPT	20.84	20.71	20.51	20.25	19.97
5	COSQ-FIX	19.95	19.92	19.90	19.79	19.66
10	COSQ-OPT	20.84	20.74	20.68	20.39	20.19
10	COSQ-FIX	19.95	19.93	19.92	19.86	19.80

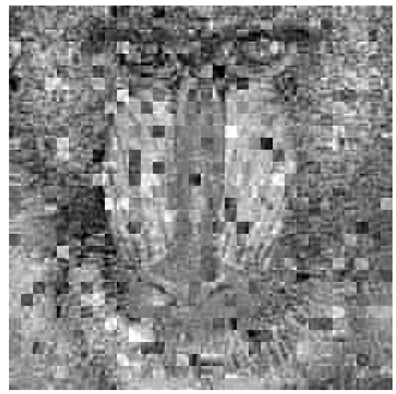
Table 6: Performance comparison between COSQ systems using fixed and optimal bit allocation tables; PSNR (dB) of decoded Baboon over the Markov channel with BER ϵ and correlation parameter δ at 0.375 bpp.

Original Lena(512×512)



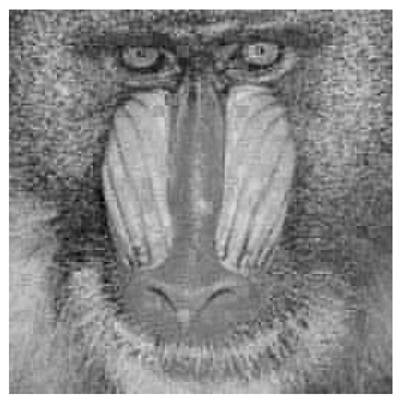
Original Baboon(256×256)

Decoded Lena with SQ-IL, $PSNR = 15.84$ dB



Decoded Baboon with SQ-IL, $PSNR = 16.52$ dB

Decoded Lena with COSQ, $\delta = 10.0$, $PSNR = 27.88$ dB



Decoded Baboon with COSQ, $\delta = 5.0$, $PSNR = 21.10$ dB

Figure 1: Overall rate is 1.19 bpp; Markov channel with $\epsilon = 0.1$