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Improving Image Quality in Remote Sensing Satellites using Channel Coding

H. M. Behairy, and M. S. Khorsheed

***Abstract*— Among other factors that characterize satellite communication channels is their high bit error rate. We present a system for still image transmission over noisy satellite channels. The system couples image compression together with error control codes to improve the received image quality while maintaining its bandwidth requirements. The proposed system is tested using a high resolution satellite imagery simulated over the Rician fading channel. Evaluation results show improvement in overall system including image quality and bandwidth requirements compared to similar systems with different coding schemes.

***Keywords*— Image Transmission, Image Compression, Channel Coding, Error-Control Coding, DCT, Convolution Codes, Viterbi Algorithm, PCGC.

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I. INTRODUCTION

IMAGE transmission over error prone channels is a tradeoff between transmission delay and received image quality. Usually, it is acceptable to have a received image slightly different than the original. However, when the receiver can not understand the received image due to severe degradation in the transmitted image it demands a retransmission. The number of retransmissions is proportional to the channel noise and, consequently, to the transmission delay [1].

Limitation in channel bandwidth necessitates implementing compression techniques to reduce the amount of information to be transmitted. Image compression applies coding schemes to remove spatial, temporal, or spatio-temporal redundancy among pixels. While the bit rate reduction is achieved, a strong data dependency is created between pixels. This increases image sensitivity to channel noise and, consequently, affects the image quality greatly [2], [3].

Channel coding techniques can achieve improvements in the performance of satellite communication systems by expanding the bandwidth. An important part of error control coding is the incorporation of redundancy into the transmitted image. The number of bits transmitted as a result of the error control code is therefore greater than that needed to represent the image. Without this, the code would not even allow us to detect the presence of errors and therefore would not have any error controlling properties. This means that, in theory, any incomplete compression carried out by a source encoder could be regarded as having error control capabilities. In practice, however, it will be better to compress the source information as completely as possible and then to re-introduce redundancy in a way that can be used to best effect by the error correcting decoder [4].

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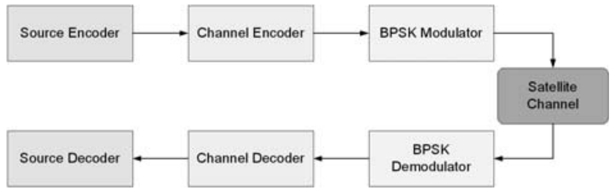

Fig. 1 System block diagram

In this paper, we present a system that uses image compression techniques along with error control codes to achieve high throughput transmission of still images. High throughput of the satellite channel is achieved by minimizing the number of retransmissions needed for an acceptable image quality reconstruction at the receiver side. The error correcting capabilities ensures high reliability when transmitting images over noisy satellite channels. The reduction of the bandwidth achieved by compressing the image is reinstated as controlled redundancy by the error control encoder. This way, the overall image bandwidth is maintained the same.

The remainder of this paper is organized as follows: Section II describes the process of image compression, using error control codes in image transmission, and the most common channel model used in satellite communication. Section III illustrates the simulation results and discusses it. Finally we conclude.

II. SYSTEM MODEL

Satellite images are usually composed of large number of pixels. Transmitting such huge images over bandlimited channels in real-time is a challenge. Alternatively, the original image may be transformed using a global transformation technique into a set of transform coefficients, which are then quantized and coded. Those coefficients could be coarsely quantized in order to reduce the transformed image size with little image distortion. However, the resulting encoded image becomes more sensitive to channel noise which necessitates using error control techniques for designing practical image communication systems.

A satellite communication system is simulated using MatLab V.7. The model, shown in Fig 1, consists of a source encoder which accepts an image as input, and goes through all the steps described in Section II-A, a channel encoder that takes a stream of data bits as input and produce codeword symbols that consists of the original data bits and parity-check bits. The output of the encoder is then interleaved and passed on to the modulator where the codeword is modulated.

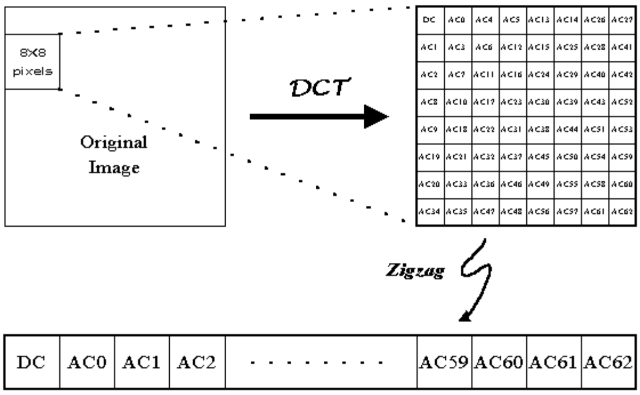

Fig. 2 Ordering DCT coefficients

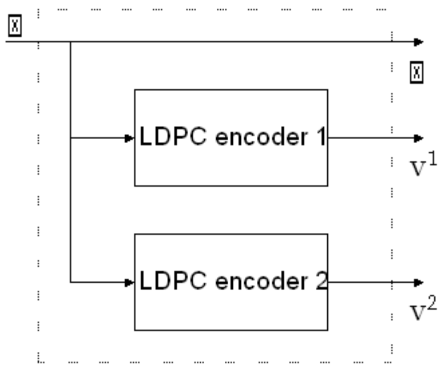

Fig. 3 PCGC Encoder

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At the receiver side, the signal is demodulated and sent to the decoder after deinterleaving it. The channel decoder decodes the received sequence and outputs the best estimate of the transmitted data which can be forwarded to the source decoder to reconstruct the image.

A. *Image Compression*

Image compression eliminates interpixel redundancies in the original image. This is achieved by using the Discrete Cosine Transform (DCT) [5]. The original image is first divided into 8×8 pixel blocks. Each of these 8×8 pixel blocks is transformed by a DCT into its frequency domain equivalent. After the transform stage, each frequency component is quantized to reduce the amount of information which needs to be transmitted. These quantized values are then encoded using Binary Fixed Length Codes (BFLCs). BFLCs are more tolerant to channel noise than Variable Length Codes (VLCs) in which fewer bits are assigned to the more probable gray levels than to the less probable ones. VLCs are core components of any image compression system. The main drawback of VLCs is their high sensitivity to channel noise: bit errors may lead to dramatic decoder desynchronization problems.

Fig 2 shows how the DCT coefficients are organized in 64 subbands. The first is the DC coefficient followed by 63 AC coefficients. When reconstructing the image, the more subbands used for decoding, the better the image quality is. All the 64 DCT-coefficients are quantized using a quantization table which consists of 64 elements. After quantization, every 64 element block is converted to a vector by gathering elements in zigzag fashion. This method has the advantage that low-frequency coefficients are placed first, while high frequency components come last in the array.

At the ground segment, the source decoder decodes the quantized DCT coefficients, computes the inverse DCT of each 8×8 pixel block and groups different blocks into a single image.

B. *Channel Coding*

Error control coding or alternatively channel coding, is concerned with methods of delivering information from a source to a destination with a minimum of errors. Historically, error control codes have been classified into block codes and convolutional codes. An (n, k) block code is generated by appending $n - k$ redundant parity bits to a block of k data bits, producing a codeword consisting of n coded bits, where the ratio $R = \frac{k}{n}$ is defined as the code rate [6] [7].

Convolutional codes [6] are generated by the discrete-time convolution of the input data sequence with the impulse response of the encoder. The memory of the encoder is measured by the duration of the impulse response. They achieve their best performance when decoded using the soft decision Viterbi decoding algorithm. In convolutional codes, each block of k bits is mapped into a block of n bits to be transmitted over the channel. These n bits are not only determined by the present k information bits, but also by the previous information bits.

Parallel Concatenated Gallager Codes (PCGCs) [8], are a class of concatenated codes built from the direct parallel concatenation of Low-Density Parity-Check (LDPC) codes. The motivation is to use the good LDPC codes in the well known turbo code structure to break the fairly complex decoding of a long code into steps while maintaining the information flow between the component decoders and minimizing any information loss between the decoding steps. PCGCs have good error correcting capabilities in both AWGN and Rician fading channels. The good performance of PCGCs reduces the amount of power needed for reliable image transmission, while the reduced encoding and decoding complexity of such codes keep the signal processing delays within a reasonable limit.

In PCGC two distinct LDPC codes, each of length L and rate $\frac{1}{2}$, are used in parallel concatenation to build a PCGC of rate $\frac{1}{3}$ and length N as shown in Fig 3, where x denotes the systematic information bits, while v^1 and v^2 are the parity bits generated by the first and the second encoders, respectively.

Consider an M rows parity-check matrix, where

$$\lambda(x) := \sum_{i=1}^{M} \lambda_i x^i \qquad (1)$$

specifies the column weight distribution with a maximum column weight of M. More specifically, λ_i represents the

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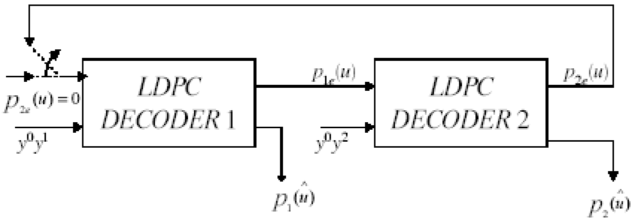

Fig. 4 PCGC Decoder

fraction of columns of weight i in the matrix, while

$$\text{MCW} = \sum_{i=1}^{M} i\lambda_i \tag{2}$$

(MCW) is the Mean Column Weight of the matrix.

We consider LDPC codes constructed randomly based on the MCW of the parity-check matrix as component codes in PCGC. The resultant code is then described by three parameters: frame length, MCW1, and MCW2. Engineering of the optimum PCGC relies mainly on choosing the best parameters of the overall code.

Decoding PCGC follows the scenario of turbo decoding with the exception that an interleaver is not present between the component decoders. The component LDPC decoders compute the *a posteriori* probability as described in [9] using the sum-product algorithm with modifications to accommodate the *a priori* information [10].

Let $U \in \{+1, -1\}$, and y^0 denotes the received sequence corresponding to the systematic information bits, while y^1 and y^2 denote the received sequences corresponding to the parity bits of the first and second component codes, respectively. We define a *super iteration* as an iteration when the two component decoders exchange information among themselves. The PCGC decoder (one *super iteration* step) is illustrated in Fig 4. Note that each component decoder itself performs a number of *local iterations* before passing any information to the other component decoder.

In the first *super iteration,* the first decoder computes the *a posteriori* probability of the L coded bits $p_1(\widehat{u})$ using received sequences y^0 and y^1 with no *a priori* information since the information bits are equally likely to be a -1 or a 1. The second decoder now computes the *a posteriori* probability $p_2(\widehat{u})$ using the received sequences y^0 and y^2 along with the *extrinsic* information $p_{1e}(u)$ available from the first decoder as *a priori* information. On subsequent iterations, the first decoder uses the *extrinsic* information generated by the second decoder $p_{2e}(u)$ as *a priori* information to compute the *a posteriori* probability. The process of exchanging information between the component decoders is continued until both decoders converge to valid codewords, or a maximum number of *super iterations* is reached. In the latter case, output from the second component decoder is declared as the best estimate of the transmitted sequence.

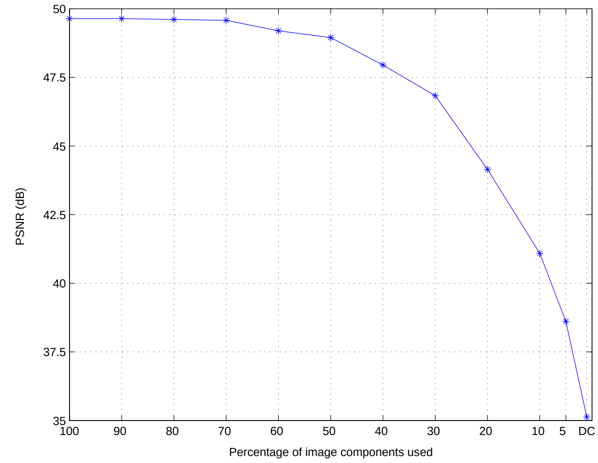

Fig. 5 Performance in noiseless channel

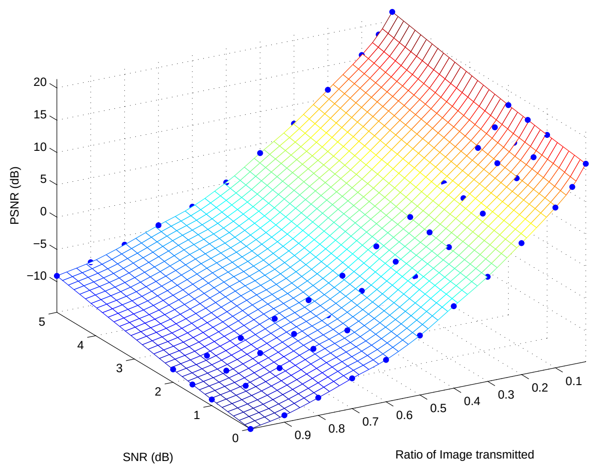

Fig. 6 Performance in Rician fading channel

C. Channel Model

Thermal noise is the most common impairment in satellite communication systems. There are three general sources: 1) The noise that enters the antenna with the signal. 2) The noise generated due to ohmic absorption in the various passive hardware components. 3) Noise produced in amplifiers through thermal action within semiconductors. This type of noise is characterized statistically as a Gaussian noise process. Hence, the resulting mathematical model for the channel is usually called the additive Gaussian noise channel (AWGN) [6].

Fading is another major source of noise in satellite communication. It is caused by multipath reception. This occurs when the ground segment antenna receives a large number of reflected and scattered waves. Because of wave cancelation effects, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna. This may be simulated using Rician random variables.

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III. SIMULATION AND ANALYSIS

To assess the performance of the proposed system, a high resolution satellite imagery of Riyadh city, the capital of Saudi Arabia is used as a testbed. The image is taken from IKONOS satellite of pixel size 512×512.

As a performance measurement, the Peak Signal-to-Noise Ratio (PSNR) is calculated for the reconstructed images at the receiver side. PSNR is metric used to compare two images, the more pixel difference between the images, the less the PSNR value. It is useful to know that the human eye does not have enough sensitivity to detect changes in visual data for PSNR measurements above approximately 50 dB, although this may vary in a minor way for each person.

At the receiving side, the recovered DC and AC components are used to reconstruct the image. When channel noise is not considered, the image quality keeps improving, in terms of its PSNR value, as we use more AC components, as shown in Fig 5. However, to achieve some degree of compression, some of the AC components, those that correspond to the high frequencies in the image, can safely be excluded when reconstructing the image. In fact, only 30% - 40% of the components are enough to reconstruct the image with highly acceptable quality.

Under noisy conditions, the image components suffer greatly, and using them at the receiving side to reconstruct the image becomes tricky. In our simulations, contradictory to the noiseless case, we have observed that the image quality keeps degrading, in terms of its PSNR, as we use more AC components, as shown in Fig 6. This is due to that all DCT-coefficients contribute to the caluculation of each of the image pixel values as shown below ($0 \leq x, y, u, v < N$):

$$Im(x,y) = \sum_{u=0}^{N-1}\sum_{v=0}^{N-1}\Big\{\alpha(u)\alpha(v)C(u,v) \cos[\frac{(2x+1)u\pi}{2N}]\cos[\frac{(2y+1)v\pi}{2N}]\Big\} \quad (3)$$

accordingly, reseting the DCT-coefficient values has by far less negative impact on pixels than using corrupted coefficients. This suggests that under severe noise conditions, sending all AC components is not necessary since using them at the receiver side will only degrade the image quality.

Figs $7a$ and $7b$ show the reconstructed images of Riyadh using 100% and 33% of the components, respectively. The difference in quality between the two images is barely noticeable. This visually shows that in a noiseless channel, a portion of the components is enough for satisfactory reconstruction.

A reconstruction of an image transmitted on a Rician fading channel with $SNR = 10$ dB is shown in Fig $7c$ when 100% of the image components were used, and Fig $7d$ when 33% of the image components were used. This illustrates how severely the image is degraded when exposed to channel noise. Note how the image quality degraded when 100% of the components were used to reconstruct the image, comparing to the case when only 33% of the components were used. This suggests that even expanding the bandwidth or increasing the signal power cannot completely overcome the channel effects when the noise is severe.

Using error control coding to protect the transmitted image greatly enhance its quality. In our model we compare the performance of a systematic convolutional code [6] of $R = \frac{1}{3}$, and memory $L = 8$ with the following generators in octal $g(1) = [111]$, $g2 = [225]$, $g3 = [331]$ to a PCGC of the same rate and of length $N = 1920$ [8]. The introduced redundancy from the channel encoder causes some bandwidth expansion. However, when combining image compression with channel encoding, the expansion in bandwidth is compensated for by the reduction in the image size achieved by not sending all the AC components.

To show how the image quality can be substantially improved by using forward error correction, an image that was transmitted on a Rician fading channel and reconstructed using 33% of its components is shown in Fig $7e$ when convolution codes are used at SNR=2.8 dB, and Fig $7f$ when PCGCs are used at SNR=2.8 dB. When using PCGC, we were able to recover the exact transmitted image with only 2.8 dB SNR comparing to an improved but not perfect performance of the convolution code even at 2.8 dB SNR. Comparing Fig $7c$, Fig $7e$, and Fig $7f$ all transmitted images are of the same size (due to using only 33% of the components), and therefore occupied the same bandwidth when transmitted. Nevertheless, the difference in quality is substantial in favor of the case when channel coding was implemented in the system. In addition to the improved quality achieved when using channel coding, a substantial reduction in the transmitted signal power can be achieved when using PCGCs.

IV. CONCLUSION

Under noiseless conditions, a portion of a DCT transformed image is enough for satisfactory reconstruction at the receiving end, while the quality keeps improving as more components are used for reconstruction. When the image is transmitted in noisy conditions image components can suffer greatly, and using them at the receiving side to reconstruct the image becomes tricky. In our simulations, contradictory to the noiseless case, we have observed that the image quality keeps degrading, in terms of its PSNR, as we use more AC components. Using error control coding to protect the transmitted image greatly enhance its quality. In addition to the improved quality achieved when using channel coding, a substantial reduction in the transmitted signal power can be achieved when using PCGCs.

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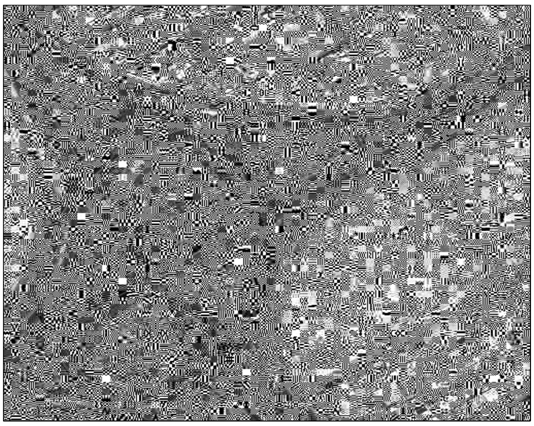
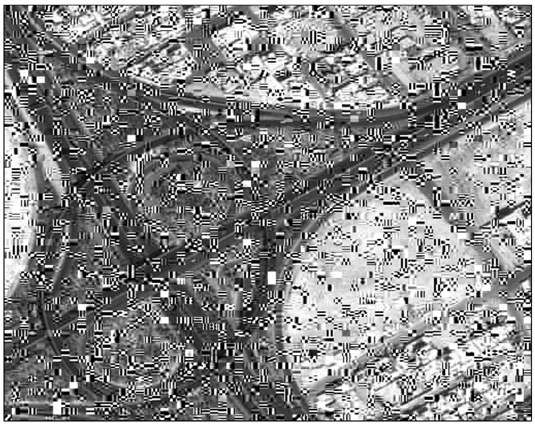
(a) 100%

(b) 33%



(c) 100%, $SNR = 10dB$



(d) 33%, $SNR = 10dB$

(e) 33%, $SNR = 2.8dB$ with Convolution coding.

(f) 33%, $SNR = 2.8dB$ with PCGC.

Fig. 7 Reconstruction of Riyadh city satellite imagery, using a percentage of DCT coefficients: (a) and (b) data were transmitted over a noiseless channel, (c), (d), (e) and (f) data were transmitted over a Rician fading channel.

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