An Unequal Power Allocation Scheme for JPEG Image Transmission

Muhammad F. Sabir
Department of Electrical and Computer Engineering,
The University of Texas at Austin
Austin, TX-78705, USA

and

Robert W. Heath Jr.
Department of Electrical and Computer Engineering,
The University of Texas at Austin
Austin, TX-78705, USA

and

Alan C. Bovik
Department of Electrical and Computer Engineering,
The University of Texas at Austin
Austin, TX-78705, USA

ABSTRACT

With the introduction of high data rates in the emerging wireless standards, real-time multimedia communication is becoming common in wireless communication systems. The need for efficient joint source-channel coding (JSCC) and power optimization is growing as these new multimedia services, especially images and videos are introduced in commercial wireless communication systems. These techniques cover a wide range of source coding standards, channel coding and modulation techniques, and optimization methods. In this paper, we present an unequal power allocation scheme (UPA) for progressive JPEG compressed images for transmission over noisy and fading channels. The image is coded in different quality layers, that are transmitted using unequal power with a constraint on the total transmit power over the length of the bitstream. The total power is distributed between the different coded layers in such a way that the total distortion in the reconstructed image is minimized. Such unequal power allocation schemes have not been developed for JPEG compressed images in the past. Results show a peak signal to noise ratio (PSNR) gain of 6.5 dB over an equal power allocation scheme at low values of signal to noise ratio (SNR).

Keywords: Joint Source-Channel Coding, Unequal Error Protection, Distortion Model, JPEG, Unequal Power Allocation.

1. INTRODUCTION

Real-time image and video communication is becoming common in the 3^{rd} generation (3G) wireless systems with the introduction of high data rates. These sources are very sensitive to channel errors and even a small number of channel errors have the potential to introduce significant amounts of perceptual distortion in the reconstructed source. There are many different methods of protecting these sources against channel errors. Channel coding (also known as error protection) and an increase in the transmit power are amongst the most commonly used methods for protecting the transmitted data against channel errors. However, in practical systems, there is always a constraint on available resource, especially bandwidth, data-rate and transmit power. Due to this reason, the use of these resources should be optimized with the goal of minimizing distortion in the reconstructed images and videos. A common way of optimizing the use available bandwidth/data-rate is to perform joint optimization of source coding and channel coding, also known as joint source-channel coding (JSCC) [1–10]. Similarly, joint optimization of source coding and transmit power can also be performed in order to minimize the distortion in the reconstructed data with a constraint on total transmit power. Two such schemes for transmission power management for digital video transmission and vector quantized image transmission are discussed in [11] and [12], respectively.

In this paper, we present a scheme for optimizing the use of total available power for transmission of JPEG compressed images over noisy/fading channels, with the goal of minimizing the distortion. We use the distortion models for DC and AC layers in JPEG compressed images derived in [13] to allocate the total available power unequally between different coefficient layers in JPEG compressed images, in order to minimize the distortion, when transmitted over Rayleigh fading channels.

In Section 2 we outline our system model. In Section 3 we present our unequal power allocation scheme for JPEG compressed images, and present our simulation details and results along with some discussion in Section 4. We conclude the paper in Section 5.

2. SYSTEM MODEL

In this section, we briefly discuss our source encoder/decoder pair along with the channel.

2.1. The Source Coding Model

In our JPEG encoding, we use the progressive discrete cosine transform (DCT) based mode of operation with spectral-selection [14]. In the progressive DCT mode, the data is arranged in different quality layers in such a way that the quality of the decoded image is increased progressively as more and more layers are decoded. In the spectral-selection method, the DCT coefficients are quantized and divided into subbands that are encoded in separate passes. The DC coefficients are DPCM and entropy coded in the first pass, followed by run-length and entropy encoding of AC coefficients for different subbands in subsequent passes. We use Huffman coding for our simulations.

The 64 subbands of DCT coefficients are organized into 64 separate layers: the first one being the DC layer, followed by 63 AC layers. In this way, the resolution and the quality of the decoded image improves as more layers are decoded. Due to the presence of entropy coding, the encoded bitstream becomes highly sensitive to bit errors because of error propagation in codewords. We insert reset (RST) markers in each layer regularly, in order to prevent error propagation, and call the portion of data between two consecutive RST markers in a layer a *segment*. Decoding is reinitialized whenever a RST marker is encountered, and a bit error occurring in a segment only corrupts that segment, and the error is not propagated beyond that segment. In case bit errors occur, we assume that the decoder detects the first bit error (due to loss in synchronization of entropy decoding) and decodes all the coefficients in the rest of the segment as zero.

2.2. The Channel Model

We transmit the JPEG compressed bitstream using 4-quadrature amplitude modulation (4-QAM) over a quasi-static Rayleigh flat fading channel [15]. We assume that the headers and the markers are transmitted error free, which is a valid assumption since powerful channel codes can be used to transmit the headers and markers (which constitute a small fraction of the total bitstream). No channel coding is used for the transmission of coded data-stream, and no error concealment is considered at the decoder.

2.3. The Distortion Model

We use mean squared error (MSE) as our distortion metric. MSE is converted to PSNR assuming 8 bit unsigned representation for unquantized pixel values using the simple relation $\mathrm{PSNR} = 10\log_{10}\frac{255^2}{\mathrm{MSE}}$, since PSNR is commonly used for image quality assessment.

Our work is based on a combined source-channel distortion model derived in [13]. We use that model to

Group No.	Layers
1	DC Layer
2	AC Layer 1-8
3	AC Layer 9-19
4	AC Layer 20-63

Table 1. Groups of different DCT layers transmitted using unequal power.

estimate the amount of distortion introduced in a set of transmitted images due to quantization and channel bit errors, when transmitted over a noisy/fading channel. MSE is estimated for each layer using our distortion model described in [13], using the source coding rate and the channel bit error rate (BER). The total distortion in the image is then the sum of distortions due to individual layers (recall orthonormality of DCT coefficients).

3. UNEQUAL POWER ALLOCATION

Since different coefficients contribute to total distortion in an unequal manner, it is a natural choice to transmit these different coefficients with different levels of error protection and/or transmit power. Using this idea, in this section, we present an unequal power allocation scheme for transmission of progressive JPEG coded images over Rayleigh flat fading channels.

All the images are coded at 1 bits per pixel (bpp) in 64 layers using the spectral selection mode of operation and Huffman coding. All the headers and markers are assumed to be transmitted error free. The DC layer is kept separate from the AC layers, and the 63 AC layers are then grouped into 3 subgroups to keep the computational complexity of the optimization procedure low. The layers are grouped such that each subsequent group of AC layers has approximately two-third ($2/3$) of the remaining energy of the quantized coefficients (see Table. 1).

These 4 groups of layers are then transmitted using 4-QAM modulation over a Rayleigh flat fading channel using unequal power for different layers, bounded by a total power constraint. We assume that the channel is known at the transmitter, and that it stays constant for a group of layers but varies between different groups of layers. We further assume that each symbol is transmitted in unit time. Then, if E_s is the symbol power (energy), and N_0 is the noise variance, then E_s/N_0 is the SNR per symbol. Since we are using 4-QAM modulation, the average SNR per bit (E_b/N_0) is related to E_s/N_0 as

$$\frac{E_s}{N_0} = \frac{2E_b}{N_0}.$$

If T is the total number of symbols corresponding to the length of the bitstream, then the total power (P_{TOT}) transmitted over the length of the bitstream is E_sT. Our goal is to minimize the expected value of MSE by varying the transmit power for different groups of layers, while keeping the total power constant over the length of the symbol stream. Individual symbols within a group of layers are transmitted with equal power. We represent MSE in terms of E_b/N_0, and formulate and solve the UPA problem numerically as a constrained minimization problem. The relation between the instantaneous BER and E_b/N_0 for a Rayleigh fading channel for 4-QAM modulation [15] is given by:

$$BER = Q\left(\sqrt{2\,|H|^2\,\frac{E_b}{N_0}}\right), \tag{1}$$

where the channel H is a circularly symmetric complex Gaussian random variable with mean 0 and variance 1.

Let $x_i = E_{b_i}/N_0$ ($i = 1..4$) be the SNR per bit for the i^{th} group of layers, $\vec{x} = [x_1\ x_2\ x_3\ x_4]^T$, and $MSE(\vec{x})$ be the corresponding MSE as a function of SNR per bit for individual groups of layers. Then, in accordance with our grouping of layers given in Table. 1, the expected value of MSE can be written as

$$\begin{aligned} E\left(MSE(\vec{x})\right) &= E(MSE_{DC}(x_1)) \\ &\quad + \sum_{n=1}^{8} E\left(MSE_{ACn}(x_2)\right) \\ &\quad + \sum_{n=9}^{19} E\left(MSE_{ACn}(x_3)\right) \\ &\quad + \sum_{n=20}^{63} E\left(MSE_{ACn}(x_4)\right), \end{aligned} \tag{2}$$

where MSE_{DC} and MSE_{AC_n} denote the MSE in the received image due to quantization and channel errors in the DC and the n^{th} AC layers respectively, where $n = 1...63$.

Our objective is to minimize $E\left(MSE(\vec{x})\right)$

$$\min_{\vec{x}} E\left(MSE(\vec{x})\right),$$

with the equality constraint

$$g(\vec{x}) = \sum_{i=1}^{4} l_i x_i = P_{TOT}, \tag{3}$$

where l_i is number of bits in the i^{th} group of layers. In Eq. (3), we have assumed $N_0 = 1$, without loss of generality.

4. SIMULATIONS AND RESULTS

We minimize MSE using our model for 500 channel realizations over a set of 200 natural grayscale images at each *average* SNR per bit, given as

$$\left(\frac{E_b}{N_0}\right)_{avg} = \frac{\sum_{i=1}^{4} l_i x_i}{\sum_{i=1}^{4} l_i} \tag{4}$$

and then take the average of these MSE values. These results are shown in Fig. 1 with PSNR plotted against $(\frac{E_b}{N_0})_{avg}$. Note that this SNR is the average SNR per bit for the entire bitstream, whereas the actual SNRs per bit associated with individual groups of layers can be different based on the group's contribution to the total MSE. For comparison, PSNR curve for an equal power allocation (EPA) scheme is also shown. To observe a fair comparison, the bitstream used for EPA is derived from 'baseline' JPEG coded images. Using progressive DCT with EPA would not be a fair comparison since for progressive streams the importance of bits decreases with distance from the start of the bitstream. We use baseline coding for EPA because in baseline mode there is no layering as opposed to the progressive DCT based mode, and hence all the parts of the bitstream have roughly equal importance. The source coding rate for the baseline JPEG is kept the same as that of the progressive DCT coded images. The total number of RST markers is also same for both the cases.

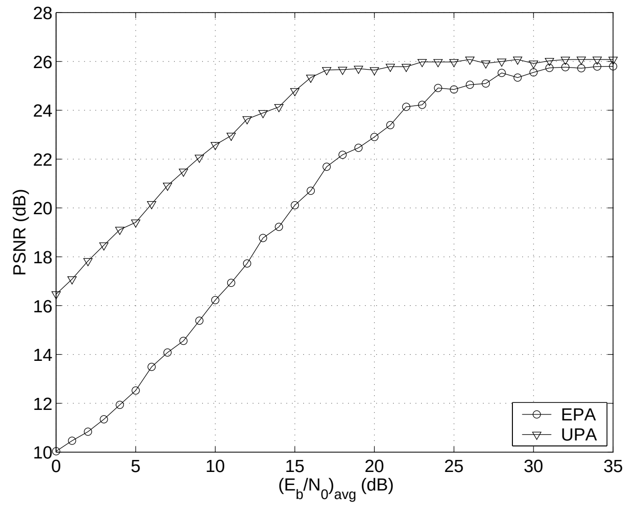

Fig. 1. PSNR comparison for unequal power and equal power allocation schemes at 1 bits per pixel source coding rate and different average signal to noise ratios.

Fig. 1 shows average PSNR curves for UPA and EPA at different average SNRs. The curve for UPA is constructed using our distortion model in [13] and the UPA strategy presented in this paper, whereas the curve for EPA is obtained using simulations, since we did not derive a model for the baseline case.

In the case of UPA, at lower SNRs, it is sometimes optimum to transmit only a few groups of layers. Hence in such cases, all the power is allocated to these groups of layers and the remaining groups of layers are not transmitted. Hence nothing is transmitted for the remaining length of the symbol stream in these scenarios and P_{TOT} is kept constant. As shown in Fig. 1, by using the UPA scheme, we get a PSNR gain of around 6.5 dB at 5 dB $(E_b/N_0)_{avg}$ as compared to EPA. This is a significant gain in terms of image quality. This gain reduces as we move towards higher SNR. For example, at 20 dB $(E_b/N_0)_{avg}$, the PSNR gain is around 2.5 dB. This is because at high SNR there are almost no channel errors and all the distortion is mostly due to quantization errors. Note that both schemes use the same source coding rate and the same number of markers.

5. CONCLUSION

In this paper, we presented an unequal power allocation scheme for transmission of progressive JPEG compressed images over Rayleigh fading channels. Different layers in the JPEG image are transmitted using different power levels, where as the total power transmitted over the length of the bitstream is kept constant, such that the total distortion in the reconstructed image is minimized. Results show that using UPA, a PSNR gain of up to 6.5 dB over EPA is obtained at low SNRs which reduces as we move towards high SNR regions. This shows that the quality of the reconstructed images can be improved significantly if the transmit power is allocated between the different coefficient layers in an intelligent unequal manner rather than transmitting all the layers with equal power. In future, we plan to devise optimal joint source-channel coding and unequal error protection schemes for different video coding standards.

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