A Hybrid Unequal Error Protection / Unequal Error Resilience Scheme for JPEG Image Transmission using OFDM

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Abstract

This paper combines two major error control coding techniques alongside the highly efficient Orthogonal Frequency Division Multiplexing scheme to provide a sophisticated and reliable framework for JPEG image transmission. The image to be transmitted is first spilt into different quality layers of unequal importance by the use of the progressive JPEG encoding technique. The quality layers are then assigned an Unequal Error Resilience to synchronization loss by unequally allocating the number of headers available for synchronization to them. Following that Unequal Error Protection against channel noise is provided to the layers by the use of Rate Compatible Punctured Convolutional Coding. Finally to provide greater bandwidth efficiency and protection against intersymbol interference, the Orthogonal Frequency Division Multiplexing scheme has been used. The proposed scheme provides a significant gain in image quality over a scheme that uses Equal Error Protection and Equal Error Resilience. The image quality has been evaluated in terms of the Peak to Peak Signal to Noise power Ratio (PSNR) and the Mean Structural Similarity Index (MSSIM) metric.

Keywords: UEP, UER, JPEG Image Transmission, OFDM.

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1. INTRODUCTION

Compression is an almost compulsory component in image processing, storage and transmission due to the massive sizes taken by image data. However one major drawback of image compression is that most image compression algorithms like JPEG or wavelet, have as their final stage an entropy coder which makes use of variable length codes like Huffman. The problem of using a Variable Length Code (VLC) like Huffman is that transmission errors can cause catastrophic error propagation in data streams that have been encoded.

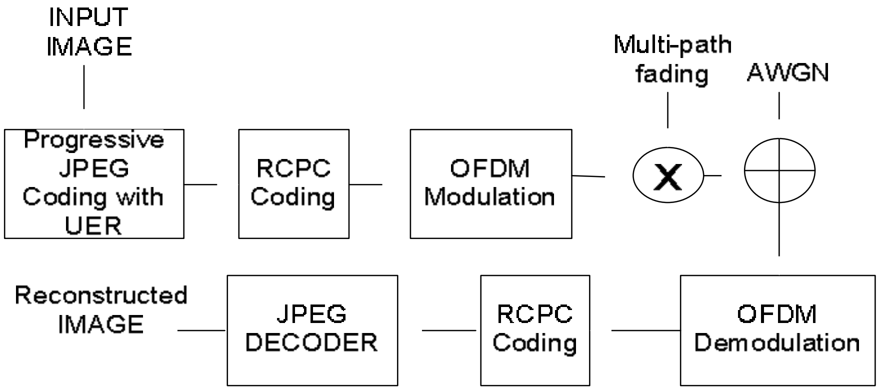
Consequently the transmission of such compressed images over noisy channels can no longer be regarded as a straightforward transmission scheme whereby the error protection scheme is composed of a plain channel code which blindly adds redundancy to the compressed image bit stream.

Channel coding and equalization do provide protection against noise and fading, but cannot alleviate the problem of error propagation in compressed images. With error propagation, a single bit in error can destroy the whole image. Error propagation is normally tackled by error resilient techniques. For example both (Han and Leou 1998) and (Abdat *et al*. 1998) employed frequent restart markers in the image bit stream to limit error propagation in JPEG image transmission. Moreover error-resilient schemes like (Redmill and Kingsbury 1996;Wang and Lin 2002), which directly consider the reliability issues in source coding, by adding controlled redundancy, are also capable of limiting error propagation.

One effective technique of dealing with the transmission of compressed images over noisy channels is Unequal Error Protection. Multiresolution compression algorithms for image decomposition like wavelet decomposition, output different bit streams corresponding to different levels of resolution of the original image. The low resolutions components (or subbands) are extremely important to the visual aspect of the reconstructed image, whereas the human eye is almost insensible to the highest frequency bands. Therefore instead of blindly adding an equal amount of redundancy to the whole image bit stream, a more intelligent use of coding redundancy can be achieved by the use of Unequal Error Protection (UEP). Recently several works have demonstrated the efficiency of this technique. For example in (Wu *et al.* 2002) a UEP scheme was developed for the transmission of JPEG 2000 images. In (Xiang *et al.* 2001) the authors proposed a scheme to unequally protect a JPEG image using Turbo codes by considering an unequal code-rate allocation between the AC and DC layers. UEP has also been used to jointly improve source and channel synchronization in (Fowdur and Soyjaudah 2006).

This paper employs both Unequal Error Protection and Unequal Error Resilience (UER) to provide a robust image transmission scheme over a very hostile channel where both Additive White Gaussian Noise (AWGN) and multi-path fading is present. OFDM modulation is used to combat the distortion due to multi-path fading instead of using high speed equalizers. Moreover two algorithms are proposed to firstly unequally allocate the coding redundancy for UEP, and secondly to unequally allocate the number of headers for UER. The proposed hybrid UEP/UER scheme provides a gain of 6dB in PSNR and about 15 percent in MSSIM over a conventional scheme employing Equal Error Protection (EEP) and Equal Error Resilience (EER).

The organization of this paper is as follows. Section 2 describes the complete system model. Section 3 describes the image quality assessment metrics used. Section 4 presents the simulation results and Section 5 concludes the paper.


INPUT IMAGE
Multi-path fading
AWGN
Progressive JPEG Coding with UER
RCPC Coding
OFDM Modulation
X
Reconstructed IMAGE
JPEG DECODER
RCPC Coding
OFDM Demodulation

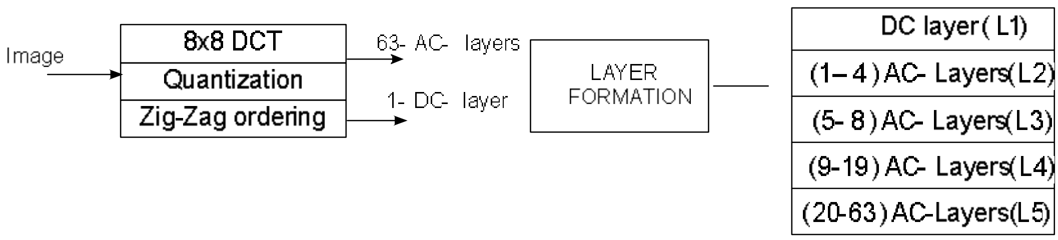


Image
8x8 DCT
Quantization
Zig-Zag ordering
63- AC- layers
1- DC- layer
LAYER FORMATION
DC layer(L1)
(1– 4) AC- Layers(L2)
(5- 8) AC- Layers(L3)
(9-19) AC- Layers(L4)
(20-63) AC-Layers(L5)

$$L4 = \sum_{i=1}^{N} \sum_{x=9}^{19} B_i\left(Z(x)\right) \tag{3}$$

$$L5 = \sum_{i=1}^{N} \sum_{x=20}^{63} B_i\left(Z(x)\right) \tag{4}$$

Where
L2,L3,L4 and L5 are the four different AC – quality layers obtained.
N is the total number of 8x8 blocks in the image.
x is the coefficient number
B_i is the ith 8x8 block
Z is a zig-zag ordering function which determines the order in which the coefficients are taken from the 8x8 blocks.

The following convention has been used:

The summation sign $\sum$ in the above equations represents a collection of elements and not a sum. Suppose an array, A, has the following elements A = [2 3 4 6 7 9], then with the modified notation for the $\sum$ sign, if an array B is given as : $B = \sum_{i=1}^{3} A(i)$
Then B = [2 3 4], that is it will be an array containing the first 3 elements of array A.

After obtaining these 5 layers, the next step is to provide UER against error propagation to these layers. If a whole layer is Huffman coded into a single bitstream, then even a single error in the bitstream can cause a complete loss of synchronisation at the VLC decoder and the error could propagate through the whole layer. This problem can be tackled by employing an error resilient scheme to reduce the error propagation length of the VLC bitstream.

The error resilient scheme used is as follows. Instead of encoding a whole layer of N coefficients into a single VLC bit stream, the layer is split into blocks of K coefficients and each block is encoded into a VLC packet of n bits. This scheme is depicted in Figure 3.

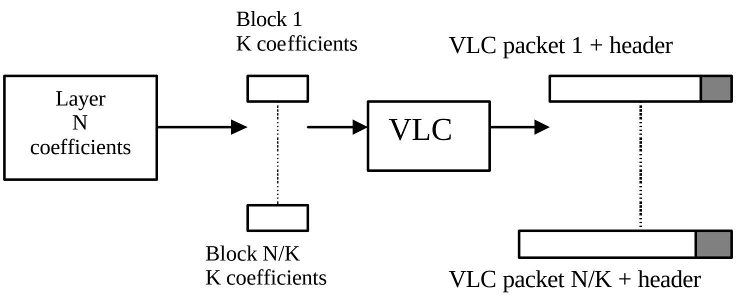


Figure 3 : Error resilient scheme

Each VLC packet contains K coefficients encoded in n bits. The header (shown shaded in Figure 3) attached to each packet specifies the number of bits in the packet. In general this scheme reduces the error propagation length from N to only K coefficients. When this error resilient scheme is used, the smaller the block size into which the layer is split, the smaller is the error propagation length. However, small blocks require huge overheads in terms of the number of headers that will have to be transmitted. Therefore one solution is to unequally allocate the headers to the different layers of an image based on the importance of the layer.

In this work the variance of the layer is used as the criteria to determine the layer's importance. The following Variance-based header allocation algorithm is proposed to unequally allocate the number of headers to the layers of the JPEG image.
Consider the following terms used to formulate the algorithm:

S_i , i = 1,2,3,4,5, is the size in number of coefficients of each layer.
B_{max} = maximum possible block size a layer can be divided into.
B_{min} = minimum possible block size a layer can be divided into.
H_T = Total number of headers available.
$H_R = \sum_{i=1}^{5} \frac{S_i}{B_{max}}$ where H_R is the number of headers required for a block size of B_{max}.
Number of headers left for unequal allocation, $H_L = H_T - H_R$.
The maximum number of headers that can be allocated to a layer is given as

$H\max(i) = \frac{S_i}{B_{min}}$ where i = 1,2,3..5

The minimum number of headers that can be allocated to a layer is given as

$H\min(i) = \frac{S_i}{B_{max}}$ where i = 1,2,3..5

V_i , i = 1,2,3,4,5 is the variance of the ith layer.

Algorithm :

n = 1;
while n <= 5

$T_{var} = \sum_{i=1}^{5} V_i$ where T_{var} is the total variance of the 5 subbands.

$HVR = \frac{H_L}{T_{var}}$ where HVR is the number of headers per unit variance.

HA_n = HVR x V_n where HA_n is the number of headers allocated to the nth layer.

if (HA_n > Hmax(n))
HA_n = Hmax(n)
End

$H_{remaining} = H_L$ - (HA_n + Hmin(n))
$H_L = H_{remaining}$

If (H_L > = 1)
n = n+1
else
break
end

Endwhile

Following the allocation of headers to the quality layers of the image, the layers are split into blocks of different sizes. The block size into which a layer is split depends on the number of headers allocated to it. Finally the blocks from each quality layer are coded into bits according to the JPEG Huffman coding standard for AC and DC layers and they are then transmitted as packets with a header assigned to each packet to indicate its size.

2.2 UEP with RCPC Coding

At the channel coding stage RCPC codes (Hagenauer 1988) are used to allocate different levels of coding redundancy (or code rates) to the different layers based on their level of importance. In our work we have used a family of 8 RCPC codes derived from a mother code of rate ½, constraint length, K=3, and connection vectors g1 = [101] and g2 = [111], with a puncturing period of 8. The different code rates used are 1/2, 8/15, 8/14, 8/13, 8/12, 8/11, 8/10 and 8/9. A variance-based rate allocation algorithm is proposed to unequally allocate the coding redundancy to the different quality layers of the image. Consider the following terms used to formulate the algorithm:

S_i , i = 1,2,3,4,5, is the size in number of bits of each layer.
R_{max} = maximum code-rate a layer can be assigned.
R_{min} = minimum code-rate a layer can be assigned.
R_{EEP} = code-rate used for equal error protection.
V_i , i = 1,2,3,4,5 is the variance of the ith layer.

$SC_i = \frac{S_i}{R_{\max}}$, where i = {1,2,3,4,5} and SC_i is the size in number of bits of layer i after it has been encoded with a rate of R_{min}.

$L_i = \frac{S_i}{R_{\min}} - S_i$, where i = {1,2,3,4,5} and L_i is the maximum number of coded bits that can be assigned to layer i.

$T_{bits} = \frac{\sum_{i=1}^{5} S_i}{R_{EEP}} - \sum_{i=1}^{5} SC_i$, where T_{bits} is the total number of extra channel coding bits that can be allocated to the 5 layers after each layer has been coded with the maximum rate of R_{max}.

The algorithm is formalized as follows:

n = 1
While n <= 5

$T_{\text{var}} = \sum_{i=1}^{5} V_i$ where T_{var} is the total variance of the 5 subbands.

$BVR = \frac{H_L}{T_{\text{var}}}$ where BVR is the number of bits per unit variance that can be allocated.

SA_n = Vn x BVR , which is the number of channel coding bits allocated to layer n.

if (SA_n < = L_n)

$RA_n = \frac{S_n}{SA_n + SC_n}$ where RA_n is the code-rate allocated to layer n.

else

$SA_n = L_n$
RA_n = ½

End

$B_{consumed} = \frac{S_n}{RA_n} - SC_n$ where $B_{consumed}$ is the additional number of bits consumed by layer S_n when it is allocated a code-rate of RA_n.

$B_{remaining} = T_{bits} - B_{consumed}$
$T_{bits} = B_{remaining}$

SA_{min} ? $SC_{n?1}$? $S_{n?1}$ where SA_{min} is the minimum number of bits needed to increase the code-rate of layer n+1 by R_{max}.

if (T_{bits} > = SA_{min})
n = n+1
else
break
end

Endwhile

2.3 OFDM

OFDM is a modulation technique where multiple low data rate carriers are combined by a transmitter to form a composite high data rate transmission. In a conventional serial data system, symbols are transmitted sequentially, with the frequency of each data symbol allowed to occupy the entire bandwidth. OFDM provides the following two advantages over a conventional serial data transmission system :

1. It mitigates the effect of Inter-Symbol-Interference in a multi-path environment, especially in the presence of frequency selective fading. This eliminates the need for high speed equalization. OFDM provides this robustness to multi-path environments by splitting the information to be transmitted over a large number of carriers in such a way that the signaling rate on each of them becomes significantly lower than the coherence bandwidth of the channel. Each carries thus operates at a low bit-rate, which implies that the corresponding symbol duration can be increased to the point where it is much larger than the delay spread of the channel. However, even when the delay spread is less than one symbol period, a degree of ISI from the previous symbol remains. This can be eliminated by making the period for which each symbol is transmitted longer than the period over which the receiver integrates the signal. Guard bands are used to achieve this increase in symbol period.

2. It allows carriers to be packed as closely as possible without causing Inter-Carrier-Interference, thereby leading to greater bandwidth efficiency. OFDM makes this possible by imposing an orthogonality constraint on the carriers. Orthogonality in the frequency domain is achieved by allocating each of the separate information signals onto different subcarriers. OFDM signals are made up from a sum of sinusoids, with each corresponding to a subcarrier. The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol. As a consequence the subcarriers are orthogonal to each other (Fernando and Rajatheva 1998; Lawrey 1997; Cosby 2001).

Two periodic signals are *orthogonal* when the integral of their product, over one period, is equal to zero. The carriers of an OFDM system are sinusoids that meet this requirement because each one is a multiple of a fundamental frequency. Each one has an integer number of cycles in the fundamental period. This is shown by equation 5 :

$$s(n) = \sum_{m=1}^{M} \sum_{n=0}^{N-1} \cos\left(\frac{2\pi mn}{N} + \theta_m\right) \tag{5}$$

Where
n = sample time, m = OFDM carrier, N = IFFT bin size, M = total number of carriers and θ_m is the phase modulation of OFDM carrier m.
The block diagram for a typical OFDM system is shown Figure 4.

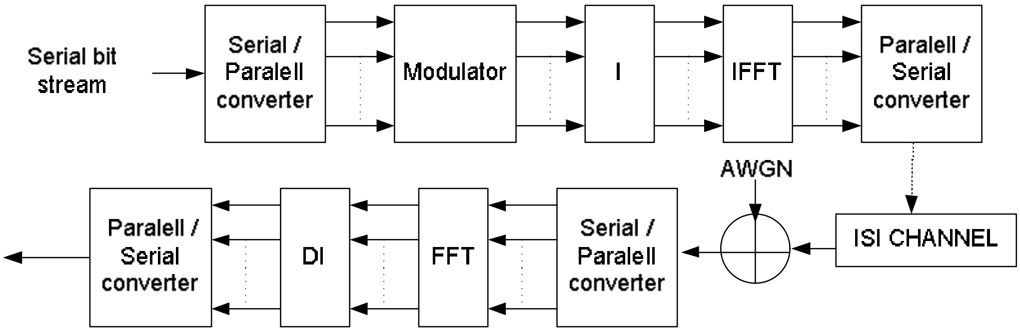


Figure 4 : OFDM System Model

OFDM modulation proceeds as follows. The serial bit stream is first converted to a parallel stream followed by modulation, interleaving and IFFT. Finally the parallel IFFT symbols are converted to a serial symbol stream and transmitted over the channel. The receiver performs the reverse steps to demodulate the received OFDM signal.

3 IMAGE QUALITY ASSESSMENT

The simplest and most widely used full-reference image quality assessment metric is the mean squared error (MSE) given as:

$$MSE = \frac{1}{x.y} \sum_{i=1}^{x} \sum_{j=1}^{y} [R(i,j) - D(i,j)]^2 \tag{6}$$

Where, x and y represent the number of pixels in the x and y-directions of the image. R and D are the reference and distorted images respectively.
The related quantity of peak signal-to-noise ratio (PSNR) which is given as:

$$PSNR = 10Log_{10}[\frac{255^2}{MSE}] \tag{7}$$

The above equation for PSNR applies for the case where the maximum value of an image pixel is 255.These metrics are appealing because they are simple to calculate, have clear physical meanings, and are mathematically convenient in the context of optimization. But they are not very well matched to perceived visual quality (Wang *et.al.* 2004).

The Structural Similarity Index Metric (SSIM) is a more direct way to compare the structures of the reference and the distorted signals (Wang *et.al.* 2004). It is based on the assumption that the human visual system is highly adapted to extract structural information from the viewing field. It follows that a measure of structural information change can provide a good approximation to perceived image distortion. Therefore the authors in (Wang *et.al.* 2004) devised a Structural Similarity Index Metric which is given as follows and the different parameters are as per (Wang *et.al.* 2004). This metric can be implemented with the code obtainable from (ssim).

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_x^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \qquad (8)$$

Where

μ_x, μ_y are the mean intensities of signals x and y, σ_x, σ_y are the standard deviations of x and y and are used as estimates of the signal contrast, σ_{xy} is the correlation coefficient and C_1,C_2 are stabilization constants.

A mean SSIM (MSSIM) index to evaluate the overall image quality can therefore be used:

$$MSSIM(D,R) = \frac{1}{M}\sum_{j=1}^{M} SSIM(x_j, y_j) \qquad (9)$$

Where, D and R are the distorted and the reference images, respectively; x_j and y_j are the image contents at the *j*-th local window; and *M* is the number of local windows in the image.

4 SIMULATION RESULTS AND ANALYSIS

The performance of the following two schemes are compared :

1. The proposed hybrid UEP/UER with OFDM modulation.
2. A scheme employing EEP and EER with OFDM modulation.

The constraint on the overall transmission rate, R_{OVR} is set to R_{OVR} = 1.56 bits/pixel and the total number of headers is 1024 for both schemes. The programming platform is MATLAB 6.5 and the test image used is the 256x256 Lena image, which is one of the most used patterns in image processing. The image is transmitted over a composite channel with both multi-path fading and AWGN. The multi-path fading channel consists of 7 paths and causes very severe fading.

The parameters for the OFDM modulation are as follows:

IFFT bin size = 64. Number of carriers = 48. Number of symbols/carriers = 20.
Guard time = 16 (Cyclic prefix extension)
For the EEP/ EER scheme, all the 5 layers are given a code-rate of 8/11 and all of them are split into blocks of 64 coefficients. The parameters for the hybrid UEP/UER scheme are shown in Table1. These are obtained using the variance-based header and variance-based rate allocation described in sections 2.1 and 2.2.
Figure 5 shows the graph of PSNR against Eb/No (ratio of bit energy to noise power spectral density) for both schemes. A gain of about 7 dB is achieved by the hybrid UEP/UER scheme over the conventional EEP/EER scheme.

Table1: Parameters for UEP/UER scheme

Layer	L1	L2	L3	L4	L5
Code-rate	1/2	8/13	8/11	8/9	8/9

Block-size	8	12	38	120	128

Figure 6 shows the graph of MSSIM against Eb/No for both schemes. The hybrid UEP/UER scheme achieves a gain of over 15% in MSSIM. In terms of image quality these gains are significant as can be observed from the decoded images in Figure 7, which shows the images decoded at Eb/No values of 9 and 15 dB.

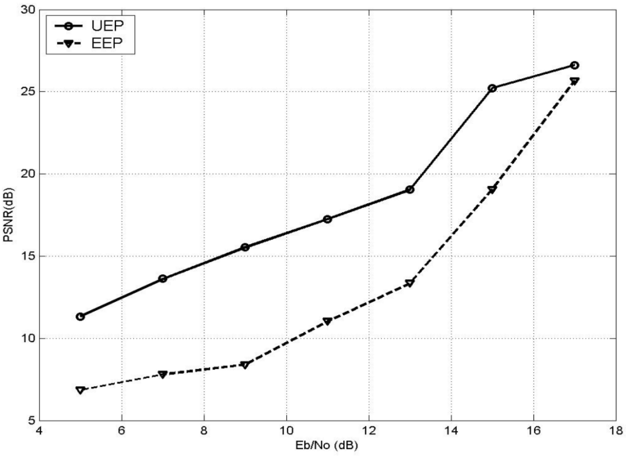


Figure 5 : Graph of PSNR against Eb/No

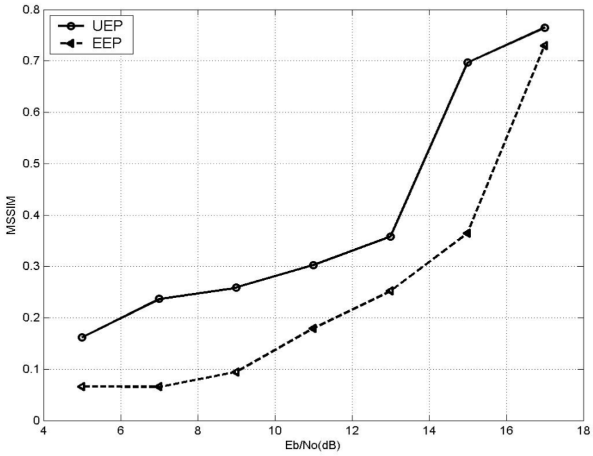


Figure 6 : Graph of MSSIM against Eb/No

ORIGINAL IMAGE

Scheme: UEP; Eb/No = 9 dB
PSNR = 15.53; MSSIM = 0.259

Scheme: UEP; Eb/No = 15 dB
PSNR = 25.22; MSSIM = 0.697

Scheme: EEP; Eb/No = 9 dB
PSNR = 6.85; MSSIM = 0.0662

Scheme: EEP; Eb/No = 15 dB
PSNR = 19.06; MSSIM = 0.3649

Figure 7 : Decoded images

5. CONCLUSION

A new hybrid UEP/UER scheme has been proposed and implemented for progressive JPEG image transmission with OFDM. A simple but fast algorithm has been developed to unequally allocate transmission parameters like channel code-rate and number of headers. The performance of the scheme was tested over a very hostile channel comprising of both AWGN and multi-path fading. Major performance gains in terms of PSNR and MSSIM were obtained with the proposed scheme. The scheme is suitable for applications involving image transmission over wireless mobile networks or Wireless Local Area Networks.

6. ACKNOWLEDGEMENTS

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