Rate Distortion Performance for Joint Source Channel Coding of JPEG Image Over AWGN Channel

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Abstract

This paper presents the rate distortion behavior of Joint Source Channel Coding (JSCC) scheme for still image transmission. The focus is on DCT based source coding JPEG, Rate Compatible Punctured Convolution Codes (RCPC) for transmission over Additive White Gaussian Noise (AWGN) channel under the constraint of fixed transmission bandwidth. Information transmission has a tradeoff between compression ratio and received quality of image. The compressed stream is more susceptible to channel errors, thus error control coding techniques are used along with images to minimize the effect of channel errors. But there is a clear tradeoff between channel coding redundancies versus source quality with constant channel bit rate. This paper proposes JSCC scheme based on Unequal Error Protection (UEP) for robust image transmission. With the conventional error control coding schemes that uses Equal Error Protection (EEP), all the information bits are equally protected. The use of the UEP schemes provides a varying amount of error protection according to the importance of the data. The received image quality can be improved using UEP compared to Equal Error Protection (EEP).

Keywords: JPEG, Convolution Code, Puncturing, JSCC, UEP, EEP

1. INTRODUCTION

With rapid growth of data communication infrastructure, there has been an increasing demand for multimedia communication services involving image communication over wireless channels. Two common problems encountered in multimedia communication services are large bandwidth requirement and noisy transmission channels. Communication channels have limited resources such as bandwidth and power, and multimedia sources usually contain significant amount of redundancy. Therefore data compression (source coding) is necessary [2] [17]. Source coding reduces redundancy and in doing so, it not only introduces distortion in the form of quantization noise, but data dependency is also occurs among the bits from a coded bit stream. This makes the source more sensitive to transmission errors. All the current image coding standards use some form of Variable Length Coding (VLC). To combat the errors introduced by noisy channels, channel coding is often employed to add controlled redundancy.

Error control mechanisms devised for image/video transport can be categorized into four groups: (1) at the source encoder, to make the bit stream more resilient to error (2) at the transport level, including channel coders, packetize/multiplexers (3) Error Concealment at the decoder upon detection of errors, and (4) interaction between the source encoder and decoder, so that the transmitter can adapt its operating based on the loss conditions detected .

According to Shannon's separation theorem [1], source coding and channel coding can be performed separately and sequentially without loss of optimality. However, this does not hold true for practical communication system and one can improve the overall performance by designing the source and channel codes jointly rather than separately, a process called Joint Source-Channel Coding (JSCC). In recent years, extensive research has been carried out in the field of JSCC [3] [4] [10] [15] [20]. It is well known that the theoretical bound for lossless compression is the entropy of the source. In the same way entropy determines the lowest possible rate for lossless compression, Rate Distortion (R-D) theory addresses the same question for lossy compression[18][23].

In 1979 David [3] employs combined source channel approach for 2-D DPCM which has been appropriately matched to the image source. In 1981David and James [4] employs source encoder 2-D block transform coding using the discrete transform (DCT). The approach is an extension of previous work. In 1998 Sherwood and Zegar [6] proposed product channel codes (two dimensional) to protect progressively compressed and packetized images for noisy channels. The main idea is to break the image coder bit stream into packets, encode them with the same Rate compatible punctured convolution code (RCPC) and across packets Reed Solomon (RS) code is used. A nice feature of this particular product code is that decoding the column is unnecessary unless decoding failure. In 2001 Wei Xiang and Steven [5] has presented unequal error protection (UEP) methods to JPEG image transmission using Turbo codes based on importance of data. Simulation results demonstrate the UEP schemes outperforms the equal error protection (EEP) scheme in terms of bit error rate (BER) and peak signal to noise ratio (PSNR). They assume ideal synchronization within the DCT blocks.

In 2005 Yeshan etc. [8] proposed Region of interest (ROI) feature supported by JPEG2000 image compression standard and allows particular region of interest within an image to be compressed at a higher quality than rest of the image. The UEP scheme using Golay code and Hamming code is applied according to importance of data. However ROI feature can useful only specific images. In 2006 Pasteur Poda and Ahmed Tamtaoui [9] proposed UEP scheme using retransmission protocol for JPEG image over Time varying channels. However this proposed solution is not obvious match with real time application. In 2008 Chou Chen etc [10] proposed JPEG image protection using RCPC. To cope up with the synchronization problem, synchronization codeword (Restart marker RM) they periodically inserted after each row into the JPEG image bit stream.

2. SYSTEM OVERVIEW

The standard image transmission model considered for this work is given in Fig 2.1. It consists of source encoder, channel encoder, transmission channel, channel decoder, and source decoder. The source encoder reduces or eliminates any redundancies in the input image, which usually leads to bit savings. The source coded signal is then encoded further using channel encoder to add error protection prior to transmission over a channel and hence increases noise immunity of source encoder's output. At the receiver, channel decoder detects and/or corrects transmission errors and source decoder decompresses the signal. Most of the practical standards for image compression are lossy, i.e. the volume of data is compressed at the expense of visual quality.

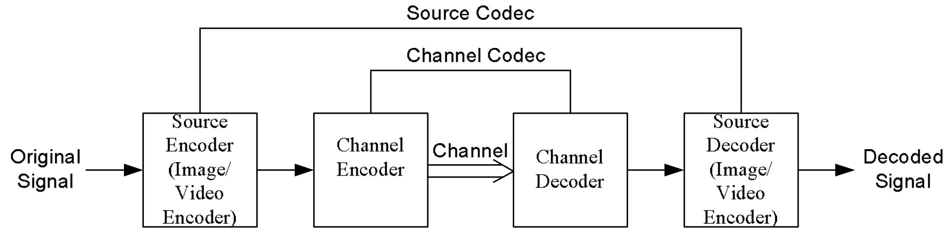

FIGURE 2.1: Image Transmission System

In this paper section III describes design of Source Encoder Decoder used in this simulation. The encoded bit stream is partitioned into two groups, DC and AC coefficients. Section IV describes design of Channel Encoder Decoder. Section V discusses design first for equal error protection using JSCC and Rate Distortion performance to obtain optimum solution. Secondly, joint source-channel coding (JSCC) based on UEP is applied in which RCPC channel encoder applies different channel coding rates to DC and AC coefficients. Highly sensitive DC coefficients are better protected with a lower code rate, while less sensitive AC coefficients higher code rate.

3. JPEG ENCODER DECODER

The Joint Photographic Experts Group (JPEG) standard (1992) is widely used for coding still images (such as photographs). Its main application is storage and transmission of still images in a compressed form, and it is widely used in digital imaging, digital cameras. An overview of image compression standard JPEG is discussed in detail [2] [21]. DCT is widely used in JPEG because of two important properties; high de correlation and energy compaction [25]. Fig. 3.1 shows the basic block diagram of JPEG Encoder.

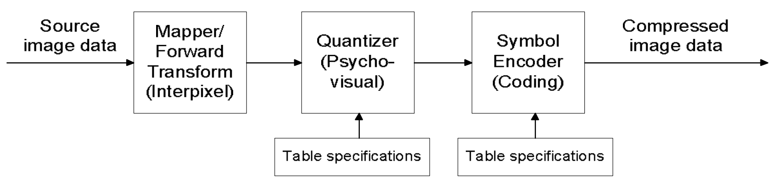

FIGURE 3.1: JPEG Source Codec

JPEG encoder-decoder consists the following steps [17]:

- Converting the base image to 8x8 matrices
- Level shifting by subtracting 128 from each pixel
- DCT transform
- Quantizing and normalizing
- DPCM coding of DC coefficient and Huffman encoding
- Zigzag scanning , Run length encoding and Huffman encoding of AC coefficients
- Denormalization and Dequantization
- Inverse DCT and Level shifting back by adding 128 to each pixel

In our simulation, we have used symbols and specification as given in Table 3.1:

Original File	'cameraman.tif '
Original File Size (S)	256X 256
Bits per pixel of Original file (BPP_O)	8 bits/pixel
Total bits after JPEG encoding (Bs)	Depends on Quality factor
Source Encoder Rate (Rs) bits/pixel	Bs/S
Compression Ratio (CR)	(BPP_O X S)/ Bs

TABLE 3.1: Symbols and Specification of JPEG Encoder and Decoder

As Quality Factor (QF) changes the number of nonzero element in each 8X8 block of DCT after quantization varies. This affects finally reconstructed image. In JPEG, stream is partitioned into DC coefficients and AC coefficients. The simulation results for the test image cameramen for different QF are shown in Table 3.2**.**

QF	Bs	Rs =Bs/S Bits/pixel	MSE	PSNR(dB)	CR	Perceptual Quality
1	7758	0.11	1383	16.72	67.58	Not accept
2	9137	0.13	566.82	20.6	57.38	Not accept
5	13235	0.2	252.64	24.1	39.62	Not accept
10	19711	0.3	154.51	26.24	26.59	Not accept
15	25376	0.38	114.98	27.52	20.66	accept
20	30579	0.47	93.19	28.43	17.14	accept
30	39533	0.63	68.79	29.75	13.26	accept
40	47301	0.72	54.5	30.77	11.08	good
50	55134	0.84	44.64	31.63	9.5	good
60	63003	0.96	36.15	32.54	8.32	good
70	74557	1.13	27.17	33.79	7.03	good
90	139454	2.12	6.74	39.84	3.75	good

TABLE 3.2: Evaluation parameters for various QF

Source rate Rs approximately exponentially increases with QF increases as shown in Fig .3.2. The source Rate Distortion (RD) curve for Cameramen image is shown in Fig. 3.3. From the source RD curve it is concluded that as QF increases the source bits rate (R_s bits/pixel) increases, so distortion (MSE) in received image is reduces. Higher compression can be achieved at the cost of visual quality. This curve varies from image to image.

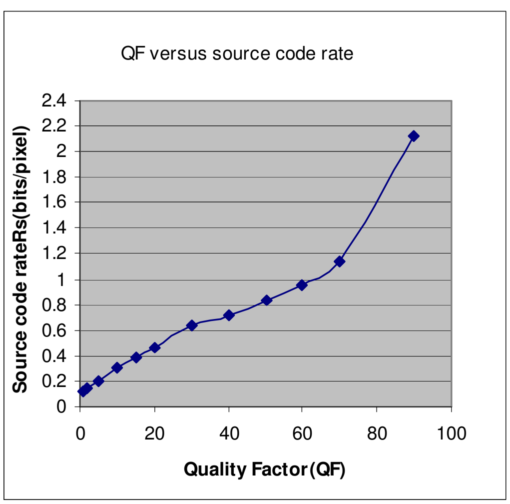

FIGURE 3.2: QF versus Rs

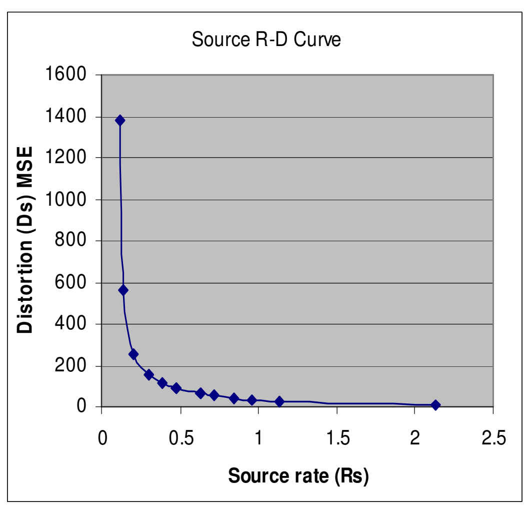

FIGURE 3.3: Source Rate Distortion (RD) curve

4. CHANNEL CODING

The bit stream for compressed image is more susceptible to channel errors. Thus error control coding techniques are used along with compressed image bit stream to minimize the effect of channel errors. Various Error Control Techniques are Automatic Repeat Request (ARQ), Forward Error Correction (EFC), Interleaving, Layered Coding with Unequal Error Protection and Error Concealment. Cyclic Redundancy Check (CRC-16) code is already proposed for error detection and Rate Compatible Punctured Convolution (RCPC) [11] [12] [13] [14] code for error correction. When the same protection is given to all encoded source bits regardless their channel error sensitivity, the method is called Equal Error Protection (EEP). The method of modulating the amount of channel coding based on the required level of protection is known as Unequal Error Protection (UEP). UEP scheme allows us to protect significant bits by allocating a lower channel code rate and less significant bits at a higher channel code rate.

Convolution codes are a powerful class of error correcting codes, providing equal error protection over the information bit stream [18]. Punctured convolution codes were first introduced by Cain, Clast and Geist [11]. Puncturing is the process of deleting (puncturing) some parity bits from the output codeword of lower code rate coder according to a puncturing matrix so that fewer bits are transmitted than in the original coder and hence leading to higher code rate. For a rate 1/N mother code rate encoder, the puncturing pattern can be represented as an N x *P* matrix, where P is a matrix whose elements are 1's and 0's, with a 1 indicating inclusion and a 0 indicating deletion of bit. In 1988 Hagenauer [13] extended the concept of punctured convolution codes by puncturing a low rate 1/N code periodically with period *p* to obtain a family of codes with rate *p/(p+l)* where *l* can be varied between 1 and (N-1)*p*.

Fig.4.1 shows convolution code of rate = 1/3 with memory M = 6 and code generator matrix [133 171 145]. The specification for RCPC code is given in Table 4.1.

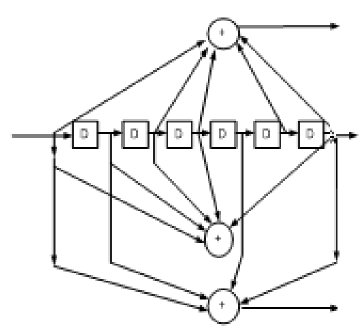

FIGURE 4.1: RCPC Code Generator

Mother code rate (1/N)	1/3
Punctured Code rates, Rc = (*p/p+l)*	8/9, 8/10, 812, 8/14, 8/16, 8/18, 8/20, 8/22, 8/24
Puncture period *p*	8
Decoder	Soft decision
Memory	6
Code Generator	[133, 171, 145]
Channel type	AWGN
Modulation	BPSK

TABLE 4.1: Specification of RCPC Code

The performance of selected RCPC codes on a Gaussian channel states with soft decision under different values of Es/No are simulated and results are given in figure 4.2. Lower code rate makes lower bit error probabilities, which means better protection for combating the channel errors.

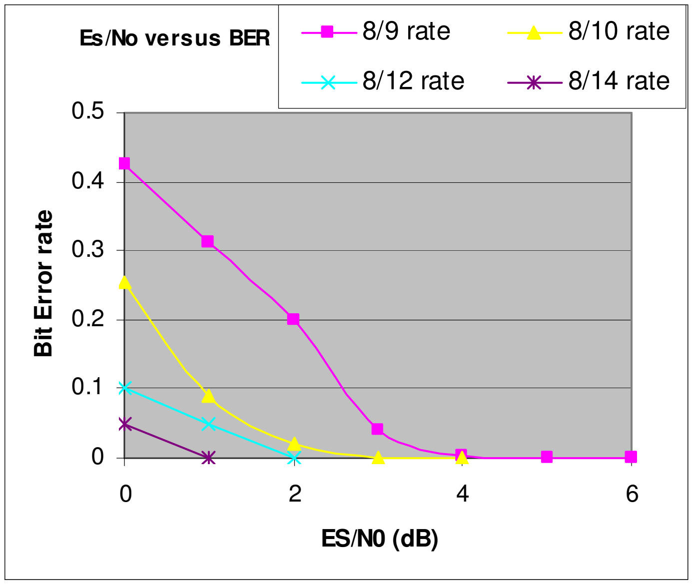

FIGURE 4.2: performance of RCPC Code family

5. SIMULATION RESULT FOR JOINT SOURCE CHANNEL CODING(JSCC)

The goal of JSCC is to distribute the source bits and the channel bits between source coder and channel coder so that the resulting end-to-end distortion is minimized. JSCC has gained significant research attention during the last decade, particularly since the Internet revolution.

The image coding usually involves a rate-distortion trade off. That is, when more bits are spent on coding a picture, less distortion will occurs. Conversely, when fewer bits are spent, more distortion will be observed. The rate-distortion trade off curve is useful in situations when the bit budget is a constrain. Generally the Joint Source Channel Coding (JSCC) schemes achieve the optimal bit allocation between source and channel. In a traditional image coder, the optimization algorithm only considers the distortion caused by quantization of DCT coefficients. However, in a JSCC framework, the rate-distortion tradeoff is extended to include the distortion coming from quantization and channel errors.

(A) Equal Error Protection (EEP) Scheme:

The JPEG encoder output bit stream is partition into DC coefficient and AC coefficient bit stream. These streams are partitioned into consecutive blocks of length B. Then a collection of C no of total CRC bits are derived based only on these B bits (C= 16) are appended with B data bits. Finally M zero bits, where M is the memory size of the convolution coder (M=6), are appended to the end. The purpose of adding M bits is to flush the memory and terminate the trellis to zero state. The resulting block of B + C + M bits is then passed through a Rate Compatible Punctured Convolutional (RCPC) coder. Equal Error Protection (EEP) defined by RCPC code rate is same for both DC and AC Coefficients. The Various parameters analyzed for this system are given below.

(i) If we fixed punctured convolution code rate Rc=8/9 and change the parameter E_S/N_O from 4 dB to 6dB the received image quality can be improved as shown in Fig.5.1.In this simulation the source rate is fixed Rs = 0.47 Bits Per Pixel(QF=20).

(ii) If we fixed QF =20 and E_S/N_O=2dB, variation in channel code rate Rc the required bit budget will change as given in Table 5.1. Here the simulation is done using fixed packet size 256. Total bit budget at input of channel is defined as R_{Total}.

QF=20, PSNR=19.3918, CR=17.1454

QF=20, PSNR=28.4367, CR=17.1454

FIGURE 5.1: Rate = 8/9 (a) Es/No = 4dB (b) Es/No = 6dB

Channel Code Rate(Rc)	Packet Length in Bits (B)	Total Packet(P) =30579/B	Total Bits Bc (Px256)	R_{Total} = Bc/S Bits/Pixel	PSNR	Bit Error Rate(BER)	MSE
8/9	205	150	38400	0.58	4.94	0.2358	2.08E4
8/10	183	168	43008	0.65	6.66	0.0248	1.4E4
8/12	149	206	52736	0.8	28.593	0	89.90
8/14	124	247	63232	0.96	28.593	0	89.90
8/16	106	289	73984	1.13	28.593	0	89.90
8/18	92	333	85284	1.3	28.593	0	89.90
8/20	80	383	98048	1.5	28.593	0	89.90
8/22	71	431	110336	1.7	28.593	0	89.90
8/24	64	478	122368	1.87	28.593	0	89.90

TABLE 5.1 QF=20, Es/N0=2dB, packet size 256

As channel code rate reduces, more number of redundancy bits is added. So for fixed QF, bits per pixel of source (Rs) are fixed, but total transmitted number of bits increasing. As code rate reduces BER performance also improves. At channel code rate (8/12) bit error rate (BER) becomes zero and lower than that the entire code rate, PSNR becomes constant for same channel condition (E_S/N_O=2 dB) . This can be considered as optimum channel code rate to generate highest of PSNR.

(B) Optimum JSCC Design for Fixed bit budget (R_{Total}) Using RD performance:

For fixed total bit rate R_{Total} , EEP algorithm searches all possible combinations of source bit rate (R_S) and channel code rate (R_C) to find the best one that minimizes the end-to-end distortion D_{Total}. End to end distortion D_{Total} is measured in terms of Mean Square Error (MSE), it includes both source distortion and channel distortion. With R_{Total} = 1.5 bits/pixel, Es/No = 2 dB, Packet size = 256 bits, CRC size = 16 bits, the simulation results are given in Table 5.2 .The operational RD curve is plotted in Fig. 5.2. Initially as Rs increases, channel code rate is sufficient for correcting channel errors up to Rc =8/12. Up to Rc=8/12 rate channel error can be corrected ,so visual quality improve as Rs increases .But after this point as Rs increases, source distortion decreases but channel noise immunity also decreases, so total distortion increases. There exist optimal points for which allocation of the available fixed transmission rate bits are optimally allotted between source and channel such that end to end distortion is minimum. From the graph, optimal point (highlighted in Table 5.2 by color) is obtained at R_S = 0.87 Bits/pixel (QF = 54) and R_C channel code rate = 8/12. In other words, to obtain minimum distortion, source should be coded at QF=40 and 8/12 rate RCPC code should be used for channel coding for fixed R_{Total} =1.5 and Es/No=2dB. The simulation results can be repeat for another value of Es/No.

Quality Factor (QF)	Source BPPs (R_S)	Channel Code Rate (Rc)	(R_{Total})	Distortion Es/N0=2dB	Distortion Es/No=2dB (dB)	PSNR
14	0.37	8/24	1.5	115	41.26	27
20	0.47	8/20	1.5	89.9	39.07	28.59
32	0.63	8/16	1.51	63.08	35.99	30.13
40	0.72	8/14	1.49	52.9	34.47	30.89
54	0.87	8/12	1.5	40	32.14	32.05
67	1.07	8/10	1.51	1.09E4	85.61	5.32
73	1.21	8/9	1.5	2.21E4	86.90	4.67

TABLE 5.2: Experimental Results of Optimal Bit Allocation with EEP Scheme

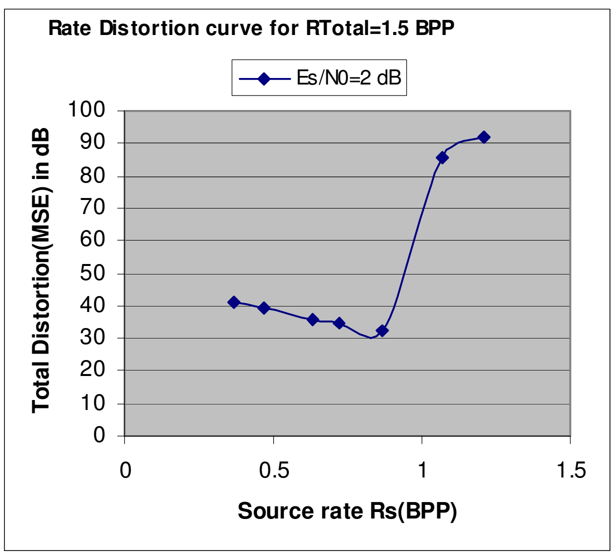

FIGURE 5.2: Operational RD curve

C) Simulation of Unequal Error Protection (UEP) Scheme

In UEP both the DC and AC coefficients have applied different protection channel code rate according to their importance. From Table 5.3.it is concluded that UEP scheme outperforms EEP in terms of end to end distortion for fixed R_{Total}.

R_{Total} (BPP)	CASE	Rs	R_{DC}	R_{AC}	D_{total} (MSE)	PSNR (dB)
1.5	UEP	0.85	8/14	8/12	48.29	31.20
	EEP	0.47	8/20	8/20	89.9	28.59
	EEP	0.63	8/16	8/16	63.03	30.13

TABLE 5.3: EEP and UEP comparison

6. CONCLUSION

Joint source channel coding approach for digital data communications, mainly for information sources like images and video, has registered a great success and is more and more passing to be conventional nowadays. There is a clear tradeoff between channel coding redundancies versus source coding resolution. When few channel redundancy bits carrying quantization information, there is little channel error correction. Though source coding or quantization distortion is small it will cause unacceptable higher distortion due to uncorrected channel errors. On the other hand more redundancy bits at the channel will leave insufficient bit rate to describe the source In this case the channel error correction capability is higher, but the source coding distortion is relatively high, thus again possibly yielding a large total distortion. Between these two extremes there exist optimal choice of a channel code rate and source code rate that minimize the distortion. The optimum point will be shift as channel condition changes. We allocate lower coding rate to higher sensitive DC coefficients bit stream and higher channel coding rate to AC coefficients bit stream for exploiting different sensitivity of source bits.

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