Estimation of Critical Performance and Optimization of Scalable Joint Source/Channel Coder (SJSCC) For Time Varying Channels

Prof. A. C. Bhagali, Dr. D. D. Shah, Mr. A. L. Wanare

Abstract— **In this paper, we propose the model of Scalable Joint Source/Channel Coding for wireless data transmission where channel is inherently time varying and subject to Rayleigh fading nature. We consider the problem of still image data transmission over time varying channels with two Channel State Information's (CSI) and three bit rates (1, ½ and ¼) for efficient transmission of data. Here, we analyze the effect of CSI availability on the optimal performance analysis of proposed scheme. Our source model is based on two level wavelet image decomposition using Haar mother wavelet with Set Partition In Hierarchical Tree (SPIHT) for significant coefficients for dynamic thresholding and channel coding will be Rate-Compatible Punctured Convolutional (RCPC) Codes. We simulated the new scheme of SJSCC and tried for optimal performance for wireless channels. Further, we show how our optimized SJSCC scheme out performs over Optimized Joint Source/Channel Coder (OJSCC) for channel states as well for various bit rates [2] [3]. In our optimization of SJSCC Scheme, marginal improvement in PSNR of 0.14dB is obtained for both average and worst channels and significant improvements of PSNR values in the order of 2dB is also obtained for all three bit rates over existing OJSCC system. Finally, our proposed SJSCC system performance is compared with RCPC and RCPT for wide range of SNRs and noticed marginal is noticed with RCPC channel coder or RCPT.**

Index Terms— **Wavelet, SPIHT, RCPC, RCPT, OJSCC and SJSCC.**

Prof.A.C.Bhagali Asstt.Prof. & Head, Priyadarshini Institute of Engineering and Technology, Nagpur, M.S., India (phone no.-+91-9371515384, e-mail-acbhagali@rediffmail.com),

Dr.D.D.Shah, Principal, GH Raisoni College of Engineering and Management Pune, M.S. India (phone no.- +91-9975497701, e-mail.- *dilip.d.shah@gmail.com*) ,

Mr.A.L.Wanare, faculty, Priyadarshini Institute of Engineering and Technology, Nagpur, (phone no-+91-9421185834, e-mail- *a.wanare@rediffmail.com)*

I. INTRODUCTION

The field of communications has developed since past 60 years based on the "separation principle". Separation principle states that the source coding and channel coding performed independently. The block diagram of separation principle is shown in Fig. 1.1 the separation approach is to divide a single complex problem in to two simpler problems of designing source coding and channel coding independently. This approach of divide and conquer principle has led many advancements in the design of source coding and channel coding separately and was popular for time-inherent channels. In 1948, Shannon designed and developed only source coding concepts for time-invariant channels without considering channel coding constraints Modern communication.

Systems need heterogeneous design and development of Joint/Source channel coding for "time-Varying" channels Viz. wireless mobile communication and internet access. The performance improvement for mobile and internet access is achieved through "joint source/channel coding" over conventional "Separation principle" design. Thus, the advance theory is essential for characterizing the Joint Source/Channel coding and performance analysis through optimization of communication systems [5] [6] [7] [8].

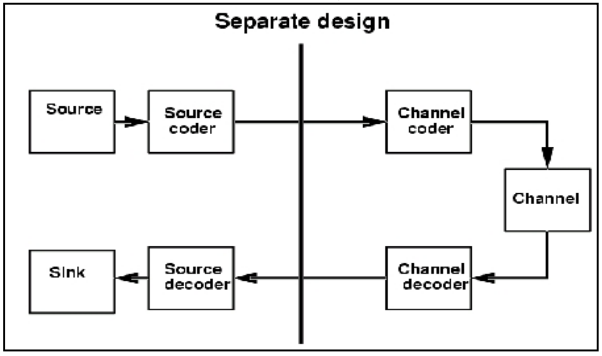


Fig. 1.1: Separation Principle

The communication systems built from independently designed source codes and channel codes may require greater computational resources and cause higher delay of latency than Joint source/channel coding systems. The separation theorem fails in wide array of practical applications and also ignores the imperfections in real time communications systems viz. source coder is designed assuming channel coder corrects all error introduced by the channel and channel coder is designed assuming that all bits generated by the source coder are equally important. Unfortunately, these assumptions may not true in modern communication systems.

II. APPLICATION AREAS.

A modern communication systems in which source coder and channel coders are designed in a dependent fashion and operating in cooperative optimization of communication system components is referred as "Joint Source/Channel Coder (JSCC)"[13][14][15]. Advantages of JSCC are as follows

Better performance is achieved for the systems with critical resource constraints viz. rate of data transmission, complexity, power and delay.

Potential performance is achieved for high multi-user systems

And shared channels viz. wireless systems and internet data.

Significant performance is achieved for multi-user systems with heterogeneous source, channel and topologies.

Source heterogeneity: Different data types traveling a single communication system have different sensitivities to loss, corruption of data and delay.

Channel heterogeneity: Different channels within single network may have different noise characteristics, rates, packet size, delay etc.

Topology heterogeneity: Some networks can be used simultaneously for point-to-point, broadcast and multiple access communication systems.

Significant gains are obtained for the applications characterized by unknown or time-varying sources, channels or networks.

III.SPIHT

It has been explained that an alternative principle of operation of the previous EZW algorithm to better understand the conceptual reasons of its excellent performance. According to SPIHT, partial ordering by magnitude of the transformed coefficient with a set partitioning sorting algorithm, ordered bit plane transmission of refinement bits, and explanation of self similarity of the image wavelet transform across different scales of and image are the three concepts. In addition, a new and more effective implementations of the modified algorithm based on SPIHT [1] it is explained that scheme for progressive transmission of the coefficient values that incorporates the concepts of ordering the coefficients by magnitude and transmitting the most significant bits first. There is used uniform scalar quantizer and claim ordering information made this simple quantization method more efficient than expected. An efficient way to code the ordering information is also proposed according to above, result from the SPIHT coding algorithm in most uses surpass those obtained from previous algorithm. One important fact used in the design of the sorting algorithm is that we do not need to sort all coefficients actually, we need an algorithm that simply select the coefficients such than $2^n \le |Ci,j| < 2^{n+1}$ with n decremented in each pass.

Given n, if $|Ci,j| \ge 2^n$ then we say that a coefficient is significant; otherwise is called in significant

To make clear relationship between magnitude comparisons and message bits, we can be use the function

$$S_n(p) = \begin{cases} 1 & \text{Max } (Ci,j) \ge 2^n \\ 0 & \text{Otherwise} \end{cases}$$

To indicate the significance of a set of coordinates P. simply the notation of single coefficient sets Sn(i,j).

Step 1: calculate the 'n' to select the threshold level :n = $\log_2 (\max(i,j) (Ci,j))$

Step 2: for sorting purpose; followed by the pixel coordinates m(k) and sign each of the coefficients such that $2^n \le |Cm(k)| < 2^{n+1}$ (Sorting Pass)

Step 3: output the n^{th} most significant bit of all the coefficients with $|C_{i,j}| \ge 2^{n+1}$ if required, those that had their coordinate transmitted in previous sorting passes

Step 4 : Decrement n by one and to go to step 2.

The above steps that can be implemented and stop at the desired the rate or distortion normally, good quality images can be recovered after a relatively small amount of the coefficients are transmitted. In a practical implementation purpose the significance information is stored in three-ordered list as.

i) **LIS:** List of insignificant set contains sets of discrete cosine transform coefficients which are defined by tree structures [16][18] and which had been found have magnitude smaller than the threshold (insignificant)
ii) **LIP:** List of insignificant pixels contains individual coefficients that have magnitude smaller than the threshold.
iii) **LSP:** List of significant pixels found to have magnitude larger that the threshold (significant according to above tree ordered we can be performed for coding purpose for 8x8 block of image which is transformed by DCT [17] (Discrete cosine transform).

According to SPIHT, the compression takes place mainly because after the transformation most of the energy of the image is concentrated in low frequency coefficients that is DC coefficients and rest of the coefficients have very low values [3]. This means that there are many zeros in the most significant bit planes of the coefficients, until the first significant bit of a certain coefficient is found, it contains more information. If largest magnitude coefficient is there, then we get first non-zero bit. For each coefficient we call its first one bit (non-zero bit) starting from most significant to less significant bits (MSB to LSB) as the first significant bit (FSB). And the bits of coefficients prior to the first significant bit will be referred to as the zero bit (ZBS). The sign information is represented by the sign bit (SB), while the rest of the bits after the first significant bits are called row bits (RBS). According to above definitions, coding starting with bit plane. In each bit plane the coding will be form the lowest frequency coefficient (DC coefficients) to highest frequency coefficients (AC coefficients).SPIHT encoder uses these principles to progressively transmit DCT (Discrete cosine transform) coefficients starting with the most important information. The coefficients are sorted and the sorting information is contained in set of elements m (k) contains the (i,j) coordinates of a coefficient (Ci,j) and such that $\lvert Cm(k) \rvert \geq \lvert Cm(k+1) \rvert$ for all values of k.[16]

The first coefficient Cm (i) =C(2,3) is s100…………. The second coefficient Cm (2) = C (3,4) is s100……….and so on. The sorting information that the encoder has to transmit is the sequence m (k) or (2, 3) (3, 4).. In addition. It has to transmit the 8 signs and 16 coefficients in order of significant bits. A direct transmission would send the 16 numbers. SSSSSS………..SS, 110000...00; but this clearly wasteful. Instead of that, it can be performed by technique for iteration a sorting purpose. In the first iteration it transmits the two coefficients (whose MSB is one) as shown in figure, number of coefficients Ci,j in figure2 that satisfy $2^7 \leq \lvert Ci,j \rvert\, 2^8$ followed by two pairs of coordinates (2,3) and (3,4) according to our figure. And by the signs of the first two coefficients. Coefficients C23 and C3,4 are constructed as 8 bit numbers s1000…….0. But it can be recover by transmitting MSB and remaining 14 coefficients are constructed as all zero. The most significant bits of the largest coefficients are transmitted first according to dynamic thresholding [6].

IV. WORKING OF THE SYSTEM.

The block diagram of Joint Source/Channel Coder is shown in Fig. 3.1. The proposed scheme of Joint Source/Channel Coding is developed for transmitting data and image streams over wireless Rayleigh channel. The channel state is estimated and optimum bits are allocated to quantizer and channel coder jointly for improvement in PSNR and better visual quality of reconstruction of images. The trade-off between source coding rate and channel coding is achieved through Joint Source/Channel Rate-Distortion function. The data stream is decorrelated through multilevel and multiresolution discrete wavelet transform (DWT) using Haar and Daubechies mother wavelets. Each subband is reshaped to Gaussian distribution by suitable filter. Each sample of subband is then quantized with Lloyd max non-linear quantizer. The output of quantizer is then protected through unequal protection by channel coder. The receiver performs exactly inverse process as per the channel states used for transmission [4][5][9]. The graphical representation of general rate distortion (R-D) function of Joint Source/Channel Coder is as shown in Fig.3.2.

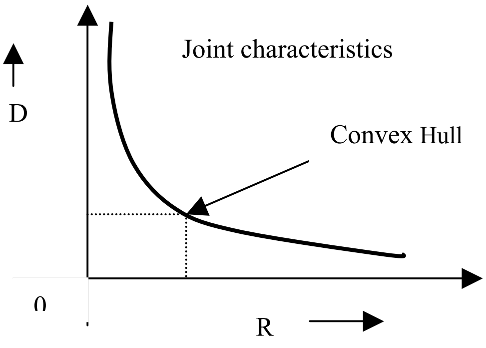


Fig. 3.2: Graphical representation of Joint Source/Channel Coder

The rate distortion (R-D) function for memoryless channel is expressed in equation no-1.

$$D = \sum_{i=0}^{N-1} \frac{S_i}{S}\left[E_{i,m_i} + \sum_{j=0}^{m_i} A_i^{(j)} P_i^{(j)} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, N is the number of sub bands, S is the total number of pixels in the original image, S_i is the number of pixels in the i^{th} subband, $E_{i,m}$, is the distortion caused by m_i bit quantization for the i^{th} subband and $A_i^{(j)}, P_i^{(j)}$ are bit error sensitivity and channel bit error rate after channel coding for the jth bit of the ith subband.

V. RATE COMPATIBLE PUNCTURED CONVOLUTIONAL CODES (RCPC)

For wireless communication in real world different channel code rates are essential for providing different channel error protection. Hence different code will certainly allow different channel rates. We selected different channel rates simply by selecting different punctured bits to facilitate various rates ie. RCPC. The channel code RCPC will allow very precise and accurate prediction of the expected BERs for specified channel conditions and given channel code rates [11] [12] [15] [16]. RCPC codes will provide reasonably accurate BER Vs PSNR values which will certainly provide the overall analysis of Scalable Source/Channel coder performance.

The channel coder rate is expressed for j^{th} position and selected i^{th} Subband of the image decomposition will be expressed as;

$$R_{c,i} = \frac{n_i}{\sum_{j=1}^{n_i} 1/R_{i.j}} \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots\ 1$$

Where j is bit position of i^{th} subband of decomposition. The overall channel rate can be expressed as:

$$R_c = \frac{\sum_{i=1}^{K} n_i.s_i}{\sum_{i=1}^{K} [(n_i.s_i)/R_{c,i}} = \frac{\sum_{i=1}^{K} n_i.s_i}{\sum_{i=1}^{K} s_i.\sum_{j=1}^{n_i}(1/R_{i,j})} \ldots\ldots 2$$

Where $s_i = S/2^r$, S is total number of pixels in the original image, s_i is the number of samples per subband , r representing the resolution of i^{th} subband and K is number of different sub bands and n_i is the codeword of i^{th} subband.

Joint Source/Channel rate:

The combined rate of source/channel is denoted as R_{s+c} and expressed by

$$R_{s+c} = (R_s/R_c).(1/\log_2 M) \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where M is modulation order as 2, 4,8,16.

$$R_{s+c}.\log_2 M = \frac{1}{S}\sum_{i=1}^{K} s_i.\sum_{j=1}^{n_i}(1/R_{i,j})$$

$$R_{s+c}.\log_2 M = \frac{1}{S}\sum_{i=1}^{K}\frac{n_i.s_i}{R_{c,i}} = \frac{1}{S}\sum_{i=1}^{K} s_i.R_{s+c,i} \ldots\ldots\ldots\ldots\ldots\ldots 4$$

we are concerned to allocate the bits for overall rate of joint source/channel coder R_{s+c} for minimum distortion and hence the MSE.

VI. RESULTS.

Results obtained by our Scalable Joint Source/Channel Coder are shown in Table-1 for two channel states and three BERs.

JSCC scheme	BER 10^{-3}		10^{-2}		5 x 10^{-2}	
	AVG (PSNR)	worst	avg	worst	avg	worst
OJSCC	33.01	32.75	31.92	31.86	30.28	30.17
SJSCC	33.02	32.8	31.96	31.9	30.42	30.28

Table-1:PSNR Result of SJSCC

Graphical representation as shown in fig 6.1 are results of SJSCC and will be clearly indicating marginal improvement by SJSCC over other optimized JSCC schemes for wireless channels

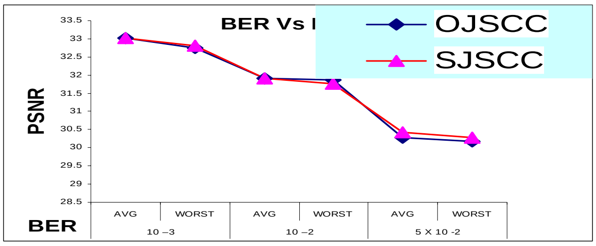
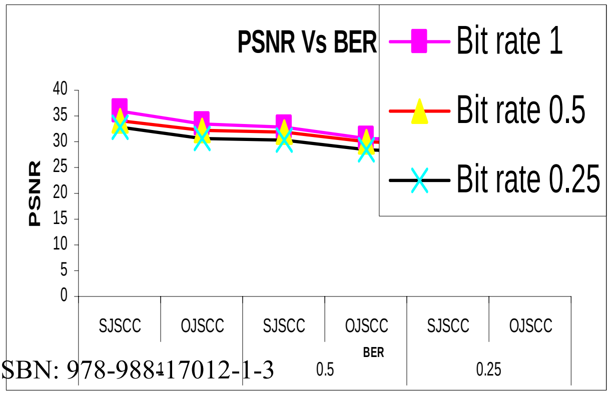


Fig 6.1: Result of SJSCC BER vs PSNR over OJSCC.

Rate	Schemes	BER 0	10^{-3}	10^{-2}	5 X 10^{-2}
1	SJSCC	36.21	35.84	34.06	32.72
	OJSCC	33.7	33.51	32.34	30.72
0.5	SJSCC	33.01	32.76	31.93	30.28
	OJSCC	31.2	30.63	30.02	28.52
0.25	SJSCC	30.39	30.2	29.42	27.93
	OJSCC	28.92	28.58	28.02	26.9

Table-2 : Result of SJSCC Over OJSCC for various Bit Rates

Results obtained for three bit rates 1, 0.5 and 0.25 by the proposed Scalable Joint Source/Channel Coder is shown in Table-2 for various BER values.
Graphical representation of results in table 2 is as shown in fig 6.2. Results of SJSCC for three bit rates are clearly indicating marginal improvement by SJSCC over other optimized JSCC Schemes for wireless channels.



Results of SJSCC for three channel SNRs is indicated in Table-3. The optimal source and channel rates noticed for four bands. Optimal variations of source and channel rates as shown in figure 6.3.

Sub bands	Channel SNR 1dB		Channel SNR 4dB		Channel SNR 8 dB	
	R_S	Rc	R_S	Rc	R_S	Rc
Band 0	8	0.33	8	0.33	8	0.57
Band 1	1.5	0.33	2.25	0.57	3	0.8
Band 2	0	0	2.25	0.57	3	0.8
Band 3	0	0	0	0	2.25	0.8

Table-3: Sub bands with various source channel Rates

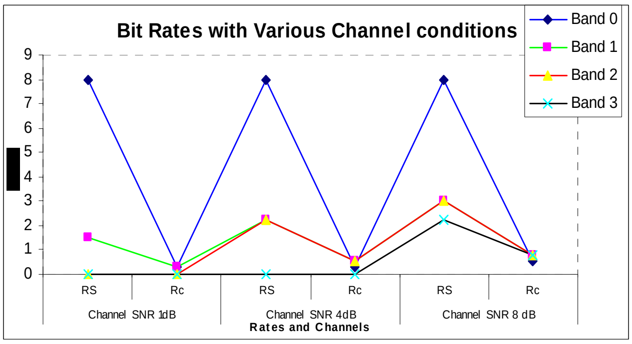
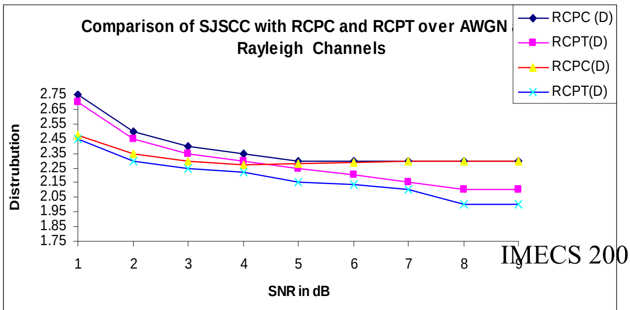


Fig 6.3: Sub bands with various source channel Rates

Channel SNR in dB	Rayleigh Channel		AWGN Channel	
	RCPC (D)	RCPT (D)	RCPC (D)	RCPT (D)
5	2.75	2.7	2.47	2.45
10	2.5	2.45	2.35	2.3
15	2.4	2.35	2.3	2.25
20	2.35	2.3	2.27	2.22
25	2.3	2.25	2.28	2.15
30	2.3	2.2	2.29	2.14
35	2.3	2.15	2.3	2.1
40	2.3	2.1	2.3	2.0
45	2.3	2.1	2.3	2.0

Table-4: Comparison of SJSCC

Results of SJSCC for wide range of SNRs are obtained for both Raleigh & AWGN channels. The distributions for both RCPC & RCPT are plotted in fig 6.4 for all SNRs. The results of RCPC is proved to be better than RCPT results.



VI. CONCLUSIONS.

We have modeled the Scalable Joint Source/Channel Coder (SJSCC) for wireless channels and extensive simulations are carried out for various channel states and bit rate. The results obtained are marginally improved with RCPC Channel Coder over existing Optimized Joint Source/Channel Coder (OJSCC). Overall improvement of PSNR in the order of 0.14dB is noticed in our developed model of SJSCC for two channel states and three BER values. Results of SJSCC for three channel SNRs obtained for source and channel rates are seems to be optimal and analyzed for four subbands. Results are obtained for distributions of RCPC and RCPT for channel SNRs ranging from 5dB to 45dB and are marginally improved over RCPT for low bit rates and for both Rayleigh and AWGN channels. Finally, we claim the improvement in PSNR and SNR values ranging from 0.14db to 2dB for various combinations of source and channel coder and also for various bit rates.

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