

An Effective Joint Source-Channel Coding with Unequal Error Protection using Asymmetric Turbo Codes

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Abstract-- In this paper, we firstly present a novel interleaver to improve the error correction performance of turbo codes. Secondly, we devise two types of asymmetric turbo codes to optimize the bit error rate of both water fall and error floor. Finally, we propose an efficient joint source-channel coding scheme based on unequal error protection technology using asymmetric turbo codes. The proposed scheme can adaptively adopt different coding strategies, different interleavers of turbo codes, various decoding algorithms and appropriate decoding iterative numbers in terms of the different significant levels of image data streams and the varying conditions of estimated channel state information. This scheme can also dynamically adjust the source and channel code rates according to the calculated peak signal to noise ratio of reconstructed images and the estimated channel states. The experimental results show that the proposed scheme can evidently increase the peak signal to noise ratio of the reconstructed images and improve the visual effect of the images but with no additional bandwidth, the scheme is more adaptive and feasible.

Keywords-- Joint source-channel coding; Unequal error protection; Asymmetric turbo codes; Interleaver; Peak signal to noise ratio

I. INTRODUCTION

Recently, the fast growing consumer demand for multimedia communication products in wireless services and the internet has spurred interest in the image and video data transmission over noisy channels. To enhance the transmission efficiency and insure better qualities of reconstructed image and video, source data compression and channel errors correction technologies are two promising approaches in the digital multimedia communication. On the one hand, the source data have numerous redundant information which require to be processed. Compressed image data are very sensitive to channel errors because their most redundant data are removed. Sometimes a few errors may destroy the entire image bit streams and thus affect the quality of restored image. On the other hand, a large amount of bit errors could occur due to the poor wireless channels whose capacities are limited and time-varying. Considering the characteristics of both source data streams and channel state information (CSI), joint source-channel coding (JSCC) is a promising approach to achieve better performance in limited bandwidth and power system. JSCC technique has been attractive in delay-sensitive

multimedia transmission system, especially in heterogenous networks where users may have different quality of service (QoS) requirements [1]. Unequal error protection (UEP) is an effective solution for JSCC. In recognition of the fact that the effects of bit errors in encoded sources are usually more detrimental in some groups of bits than in others, several UEP schemes for image transmission using turbo codes are reported according to the significant levels of the image data streams and varying channel characteristic [2], [3], [4]. But most of them mainly focus on UEP with conventional symmetric turbo codes (STC). However, STC evidently exist some defects that they have either a good water fall performance at low signal to noise ratio (SNR) or a good error floor at high SNR, but not both over the entire range of SNR [5]. Asymmetric Turbo codes (ATC) are the better choice among the improvement of performance, the overall time delay and the computational complexity of decoding algorithms. Several ATC are investigated to improve bit error rate (BER) in the whole SNR ranges compared with STC [6], [7].

This paper presents an effective JSCC design based on UEP using ATC, which can adaptively adopt different coding strategies, different interleavers of turbo codes, various decoding algorithms and appropriate decoding iterative numbers in terms of the different significant levels of image data streams and the varying conditions of estimated CSI. This scheme can also dynamically adjust the source and channel code rate according to the calculated peak signal to noise ratio (PSNR) of the reconstructed images and the estimated channel conditions. The proposed scheme can evidently increase PSNR of the reconstructed images and improve the visual effect of the images but with no additional bandwidth. The remainder of the paper is organized as follows. In section 2, we present a novel interleaver named unequal row column cyclic cross (URCCC) interleaver, it could improve the error correction performance of turbo codes effectively. In section 3, we devise two types of ATC to optimize the BER of both water fall and error floor for turbo codes. In Section 4, focusing on the characteristic that the image data streams compressed by set partitioning in hierarchical trees (SPIHT) algorithm have different sensitivity to channel bit errors [8], we propose an efficient JSCC scheme based on UEP using the designed ATC. The simulation results for JSCC are shown in section 5 and the conclusions are drawn in the last section.

II. UNEQUAL ROW COLUMN CYCLIC CROSS INTERLEAVER

The interleaver is an essential component and plays an important role in determining the performance and decoding computational complexity for turbo codes. Considering the drawbacks of both block and random interleavers which can not eliminate the more information correlation or not permute the low weight codeword sequence effectively, we present a novel interleaver, i.e. URCCC. This new interleaver can eliminate the more information correlation than block and random interleaver, it can also permute the low weight codeword sequence. The algorithm is described as follows:

Step1: Information bit data are written into $m \times n$ block interleave matrix row by row.

Step2: Odd row data are rearranged as follow formula 1 and even row data are reordered as follow formula 2, respectively. C_i denotes interleave table, i is column number, n is column length, mod denotes modular arithmetic, k and p are adjustable parameters, $k < n$, $p < n$, k and p are relatively prime to n , $k \neq p$.

$$C_i = (k \times i) \pmod{n} + 1, \quad 0 < i \leq n \quad (1)$$

$$C_i = (p \times i) \pmod{n} + 1, \quad 0 < i \leq n \quad (2)$$

Step3: Odd column data are rearranged as follow formula 3 and even column data are reordered as follow formula 4, respectively. C_j is interleave table, j is row number, m is row length, a and b are adjustable parameters, $a < m$, $b < m$, a and b are relatively prime to m , $a \neq b$.

$$C_j = (a \times j) \pmod{m} + 1, \quad 0 < j \leq m \quad (3)$$

$$C_j = (b \times j) \pmod{m} + 1, \quad 0 < j \leq m \quad (4)$$

Step4: The interleaved bit data are read out from interleave matrix column by column.

The performance of URCCC interleaver used in turbo codes is shown in Fig.1. In simulations experiment, information data size is 378 bits, generator polynomials of two component codes for turbo code are 13 and 15 (in octal), one half code rate, 4 iteration number for log-MAP algorithm, BPSK modulation, AWGN channel. It is observed that URCCC interleaver outperform conventional block and random interleavers.

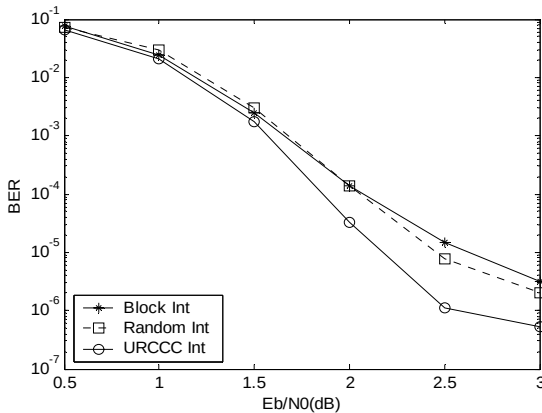


Figure 1. BER versus E_b/N_0 for URCCC interleaver in turbo code

III. ASYMMETRIC TURBO CODES

Turbo codes are composed of two parallel concatenated recursive systematic convolutional (RSC) constituent encoders which are separated by an interleaver. There are a number of key design parameters involved in determining the performance of turbo codes, such as the choice of component encoders and the types of interleaver, etc. Compared with STC, constraint lengths or generator polynomials of two RSC component codes are different for ATC. Here, we focus on using the non-identical component codes with different constraint lengths and different types of generator polynomials to devise ATC.

On the one hand, the constraint lengths of the constituent code determine the performance and decoding computational complexity. The longer constraint lengths can achieve bigger free distance and better error floor performance, but the computational complexity will increase correspondingly. To obtain good performance and reduce complexity, it is necessary to decrease the constraint lengths of one of the constituent encoders of RSC. Then we can construct ATC using two different constraint lengths component codes. On the other hand, the types of generator polynomials of component encoder are a key factor for ATC design. The primitive feedback generator polynomials for component code are able to enlarge the free distance to improve error floor at high SNR, but at a cost of degrading water fall at low SNR. On the contrary, the non-primitive generator polynomials would optimize the distance spectrum to enhance water fall performance at low SNR, but reduce error floor at high SNR. For this reason, we can also create ATC using two component codes with mixed types of primitive and non-primitive polynomials.

Our proposed ATC with the different constraint lengths and mixed types of the generator polynomials are listed in Tab.1. Here, K1 and K2 denote constraint lengths of two component codes RSC1 and RSC2, respectively; G1 and G2 (in octal) denote generator polynomials of RSC1 and RSC2, P and NP denote primitive and non-primitive polynomial, suffix 1, 2 of P and NP are corresponding to RSC1 and RSC2.

Table 1. Proposed ATC with different constraint lengths and mixed types of generator polynomials

Constraint lengths	Generator polynomials			
	P1-P2	NP1-NP2	NP1-P2	P1-NP2
K1=3 K2=5	G1=[7, 5] G2=[23,35]	G1=[5, 5] G2=[37,21]	G1=[5, 5] G2=[23,35]	G1=[7, 5] G2=[37,21]
K1=5 K2=3	G1=[23,35] G2=[7, 5]	G1=[37,21] G2=[5, 5]	G1=[37,21] G2=[7, 5]	G1=[23,35] G2=[5, 5]
K1=4 K2=5	G1=[13,17] G2=[23,35]	G1=[15,17] G2=[37,21]	G1=[15,17] G2=[23,35]	G1=[13,17] G2=[37,21]
K1=5 K2=4	G1=[23,35] G2=[13,17]	G1=[37,21] G2=[15,17]	G1=[37,21] G2=[13,17]	G1=[23,35] G2=[15,17]
K1=5 K2=5	G1=[23,35] G2=[23,35]	G1=[37,21] G2=[37,21]	G1=[37,21] G2=[23,35]	G1=[23,35] G2=[37,21]

The simulation results of ATC are shown in Fig.2 and Fig.3. In simulations, per frame size is set to 378 bits, one half code rate, URCCC interleaver, 4 iteration number for log-MAP algorithm, BPSK modulation, AWGN channel.

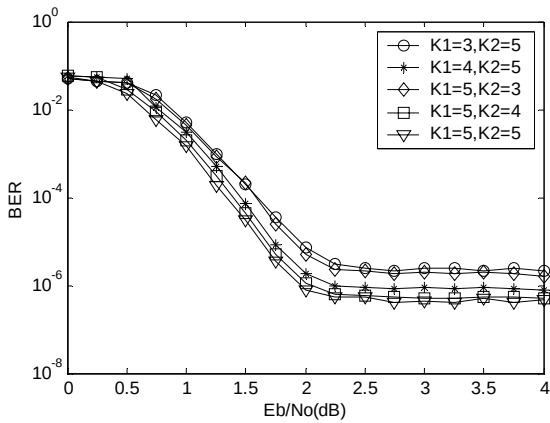


Figure 2. BER versus E_b/N_0 for P1-P2 ATC with different constraint lengths

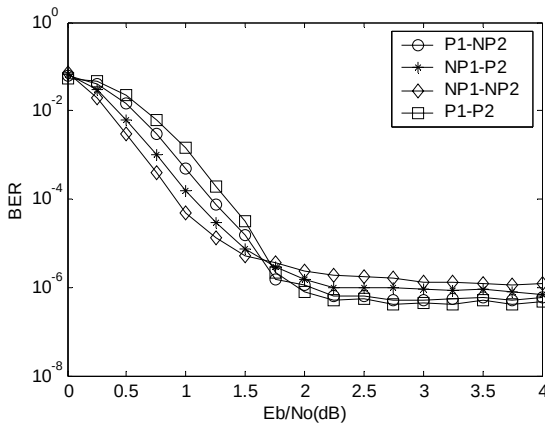


Figure 3. BER versus E_b/N_0 for ATC with mixed types of primitive and non-primitive generator polynomials

Fig.2. shows BER versus E_b/N_0 for P1-P2 ATC with different combination of the constraint lengths $K=3, 4, 5$ and P1-P2 STC with the same constraint length $K=5$. It is apparent that the water fall and error floor performances of ATC are all deteriorated by decreasing the constraint lengths of one of the constituent codes. However, the decoding computational complexity can be reduced. This kind of ATC can get a favorable trade off between the performance and complexity. It is also seen that the performance of ATC with $K_1=4, K_2=5$ or $K_1=5, K_2=4$ is slightly inferior to STC with $K_1=K_2=5$. Especially, ATC with $K_1=5, K_2=4$ is nearly close to STC but with a reduced computational complexity. In addition, ATC with $K_1=5, K_2=4$ is superior to those with $K_1=4, K_2=5$. Similarly, ATC with $K_1=5, K_2=3$ is superior to those with $K_1=3, K_2=5$. For this reason, reducing the constraint lengths of RSC2 component code is a good scheme for ATC with the different constraint lengths.

Fig.3 shows BER versus E_b/N_0 for ATC with mixed types of primitive and non-primitive generator polynomials and the same constraint lengths $K_1=K_2=5$. It is observed that the error floor performance of P1-P2 STC is good at high SNR, but its water fall is poor at low SNR. On the contrary, the water fall of NP1-NP2 STC is superior at low SNR, but its error floor is inferior at high SNR. It can also be noticed that the water fall of NP1-P2 and P1-NP2 ATC is superior to P1-P2 STC but

inferior to NP1-NP2 STC at low SNR. However, the error floor of NP1-P2 and P1-NP2 ATC is inferior to P1-P2 STC but superior to NP1-NP2 STC at high SNR. These results show that ATC is trade off scheme over the entire ranges of SNR.

IV. JOINT SOURCE AND CHANNEL CODING WITH UEP USING ASYMMETRIC TURBO CODES

In image communication system, the sensitivity of the image data streams to channel errors is generally not uniform, the reconstructed image is insensitive to errors affected by insignificant data streams (e.g. high frequency components of image), while it is rather sensitive to errors caused by significant bits (low frequency components of image), i.e., the sensitivity of the significant bits to errors is far greater than the insignificant bits. Thus, we can classify source data into several classes and use UEP encoder to strongly protect the significant classes in poor receiving channel conditions and weakly protect the insignificant classes in rich channel. The block diagram of our proposed JSCC scheme based on UEP using ATC is shown in Fig.4.

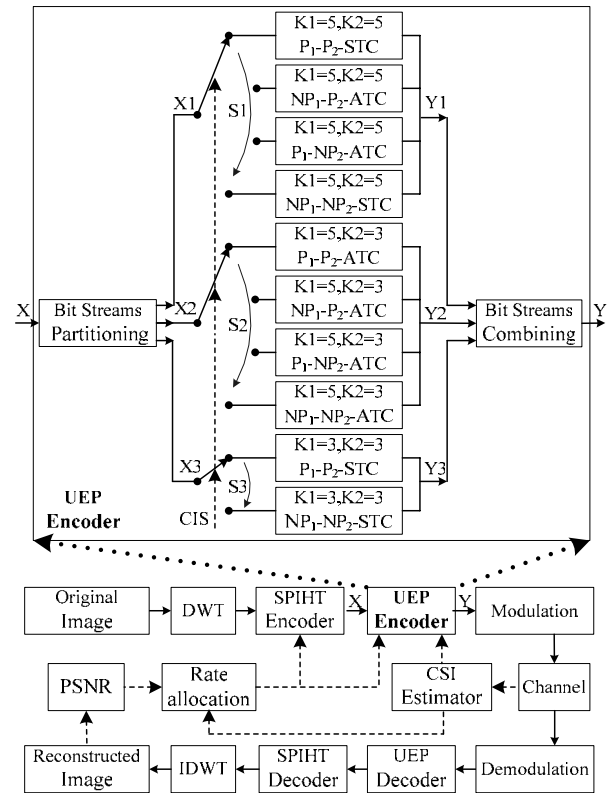


Figure 4. Block diagram of proposed JSCC scheme based on UEP using ATC

Original image is firstly decomposed by discrete wavelet transformation (DWT) and compressed by SPIHT encoder. As the importance levels of the compressed bit streams X trend towards decreasing progressively, i.e., the significant bit streams locate the nearer front and the insignificant bit streams are behind, we would partition X into three classes block, X_1 , X_2 and X_3 . Then they are encoded with UEP encoder

hierarchically so that the significant information can obtain strong protection. X1 is called most significant bit streams. X2 names more significant bit streams. X3 denotes insignificant bit streams. After UEP, the coded bit streams are combined to Y and modulated, then transmitted into the noisy channel. In receiver end, the received data streams are correspondingly demodulated, UEP decoded, SPIHT decoded, inverse DWT (IDWT) and the image would be reconstructed.

In terms of different importance classes of source bit streams, the UEP encoder can adaptively adopt different types of turbo codes. For most significant bit streams X1, ATC or STC with constraint lengths $K=5$ are selected because they have strong error correction. For more significant X2, ATC with constraint lengths $K_1=5$ and $K_2=3$ are adopted due to their relative low complexity. For insignificant X3, STC with constraint lengths $K=3$ are chosen because of their more low complexity.

Considering the conditions of CSI from channel estimator, UEP encoder can also dynamically adjust coding strategies through the switch S1-S3. If the CSI condition is good, i.e. high SNR, then the encoder chooses P1-P2 turbo codes. If the CSI is slightly inferior, i.e. medium SNR, then selects NP1-P2 or P1-NP2 turbo codes. If the CSI is worst, i.e. low SNR, then adopts NP1-NP2 turbo codes.

To received data streams, the UEP decoder can be adapted to adopt various decoding algorithms and appropriate decoding iterative numbers. For received most significant data streams, UEP decoder chooses Log-MAP algorithm because of its good error correction ability. Meanwhile, properly increases decoding iterative numbers to strongly protect most significant data. For more significant data, adopts low complicated Max-Log-MAP algorithm and moderate of the iteration numbers to reduce decoding complexity. For insignificant streams, selects lowest complexity SOVA algorithm and suitably reduces iteration numbers to further reduce computational complexity and time delay.

Our scheme can also optimally allocate the source and channel code rates according to the calculated PSNR value of the reconstructed image and the estimated CSI condition while fixing the overall code rates. If the PSNR value is small or SNR is low, then properly increase SPIHT code rate to preserve more image details and decrease UEP code rate to protect them strongly. If the PSNR is big or SNR is high, then timely reduce SPIHT code rate and increase UEP code rate.

V. SIMULATION RESULTS AND ANALYSIS

The proposed JSCC scheme is applied to digital image transmission system. Experiments are performed on 128×128 gray-scale image Lena at 0-1 bpp rates, using 5-level wavelet decomposition based on the 9/7 tap filters, the reliability and effectiveness of the proposed scheme was evaluated. In the transmitter, if SNR is 0-1dB, i.e. worst CSI, X1 adopts NP1-NP2-STC with $K_1=K_2=5$, X2 adopts NP1-NP2-ATC with $K_1=5$, $K_2=3$, X3 adopts NP1-NP2-STC with $K_1=K_2=3$. If SNR is 1-2dB, i.e. medium CSI, X1 adopts NP1-P2-ATC with $K_1=K_2=5$, X2 adopts NP1-P2-ATC with $K_1=5$, $K_2=3$, X3 adopts NP1-NP2-STC with $K_1=K_2=3$. And if SNR is

2-3dB, i.e. good CSI, X1 adopts P1-P2-STC with $K_1=K_2=5$, X2 adopts P1-P2-ATC with $K_1=5$, $K_2=3$, X3 adopts P1-P2-STC with $K_1=K_2=3$. In the receiver, for received most significant data, the decoder chooses Log-MAP algorithm and 5 iterative. For more significant data, chooses Max-Log-MAP algorithm and 4 iteration numbers. For insignificant data, selects SOVA algorithm and 3 iteration numbers. For comparison, two equal error protection (EEP) schemes using STC are also performed. In EEP, three significant classes bit streams all adopt NP1-NP2-STC with $K=5$ constraint lengths and 4 iteration decoding, while the decoder selects Max-Log-MAP algorithm for EEP1 and SOVA for EEP2. The simulation results for PSNR of JSCC with UEP and EEP in various source rates and channel SNR value are listed in Tab.2. The reconstructed images for JSCC with UEP and EEP in rate=0.5bpp and SNR=1.5dB are shown in Fig.5.

Table 2. PSNR (dB) of JSCC with UEP and EEP in various source rates(bpp) and channel SNR(dB)

Rate(bpp)	SNR(dB)	PSNR(dB)		
		UEP	EEP1	EEP2
0.25	0.50	24.51	19.87	18.05
	1.50	28.84	24.65	22.32
	2.50	31.62	28.02	25.88
0.5	0.50	26.79	22.11	20.33
	1.50	31.10	27.38	25.40
	2.50	34.55	31.25	29.28
0.75	0.50	29.13	25.21	22.73
	1.50	33.22	29.80	27.69
	2.50	36.81	33.65	31.44



Figure 5. Reconstructed images with rate=0.5bpp and SNR=1.5dB
(a) UEP (b) EEP1 (c) EEP2

From Tab.2, it is obvious that the PSNR of reconstructed image for JSCC scheme with UEP using ATC is superior to EEP1 and EEP2 because the significant bit streams are strongly protected in UEP program. We can also see that PSNR will be better in relative higher source rates with the same SNR condition and PSNR become worse in lower SNR with the same source rates. So, our JSCC scheme can optimally adjust the source and channel code rates according to the calculated PSNR of the reconstructed image and the estimated SNR value.

It can be seen from Fig.5 that the reconstructed image qualities for JSCC with UEP using ATC are obviously improved and superior to EEP1 and EEP2. Whether objective PSNR evaluation criterion or subjective visual perception standard, the proposed JSCC scheme is effective and feasible.

VI. CONCLUSIONS

This paper presents an efficient JSCC design based on UEP

using ATC, which can adaptively adopt different coding strategies, different interleavers of turbo codes, various decoding algorithms and appropriate decoding iterative numbers according to the different significant levels of image data streams and the varying conditions of estimated channel CSI. This scheme can also dynamically adjust the source and channel code rates according to the calculated PSNR of reconstructed images and the estimated CSI. The proposed JSCC scheme can not only evidently improve the reconstructed image qualities but also enhance the reliability of the transmission system but with no additional bandwidth, our scheme is more adaptive and robust.

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