Transmission of JPEG2000 Code-Streams over Mobile Radio Channels

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***ABSTRACT* - The recent growth in personal wireless communication devices being used for image transmission, have poised a challenge to protect this data against loss over mobile radio channels. The paper addresses this problem investigating error protection schemes in the context of JPEG2000 compressed imagery. More particularly, the results reported in this paper provide coding guidelines concerning the selection of appropriate Turbo Code parameters along with optimized JPEG2000 error resilience tools**.

Keywords – JPEG2000, Mobile Radio Channel, Turbo Codes, unequal error protection

1. INTRODUCTION

This paper is concerned with the development of error protection schemes for JPEG2000 compressed imagery. More particularly, we are interested in evaluating the received image quality in the presence of errors, in a fading channel. Such conditions may be expected in the context of a mobile radio channel.

A new work item of the JPEG2000 project known as JPEG2000 Wireless (ISO/IEC 15444-11 also known as JPWL) [7][8] is standardising tools and methods to achieve the efficient transmission of JPEG2000 imagery over error-prone wireless channels/networks. Number of tools have been developed under this standardization effort, notable among them are: a) error protection capability (EPC) b) error protection block (EPB); and b) error sensitivity descriptor (ESD). These tools specify a number of coding parameters developed on a case study based only on Reed-Solomon (RS) codes. There still remains the need for investigating several error protection techniques based on other error correction codes.

In [3], Hamming codes are used to provide unequal error protection for JPEG2000 code-streams over a binary symmetric channel (BSC). In [6] Turbo Codes are proposed to protect JPEG2000 code-stream over BSC. In [2][4] RS codes are proposed for the prioritised layer protection of JPEG2000 code-streams over a BSC along with optimised JPEG2000 coding parameters. We extend the work done in [2][4] with Turbo Codes evaluating the received image quality over a fading channel. Our selection of Turbo Codes for the present work is motivated by their ability to offer strong protection with modest complexity in practical fading channel environments.

In section 2, we give a brief description of the mobile radio channel. In section 3, properties of Turbo Codes are mentioned. In section 4, relevant features of the JPEG2000 image compression standard are presented. In section 5 we briefly mention the JPWL transcoder structure. Section 6, presents the results and interpretation and section 7 provides conclusion.

2. MOBILE RADIO CHANNELS

In a digital communication system the channel is commonly modelled as an additive white gaussian noise (AWGN) process. Such a model does not take into account the phenomenon of "fading" commonly observed in practical mobile radio channels. The Jakes model [9] is a widely used deterministic method for simulating time-correlated Rayleigh fading waveforms. With this model the channel is then characterized by two parameters namely a) the channel signal to noise ratio (SNR) which determines the channel bit error rate (BER) and b) the Doppler spread which is expressed in terms of the speed of the travelling mobile device. For the purpose of this investigation we consider several case scenarios such as the mobile device travelling at a speed of 3 km/hr, 40 km/hr, 120 km/hr and 300 km/hr (e.g. person walking on the street, car travelling within the city, car on the freeway and a mobile travelling in a high-speed train respectively) and where the user data is transmitted at a rate of 64 kbits/sec with a carrier frequency of 1.9 GHz, such values are commonly encountered in practical mobile radio systems.

3. TURBO CODES

Turbo Codes are a special case of convolutional codes [1]. Recalling that Shannon's channel coding theorem demonstrated that block codes are sufficient to achieve channel capacity only in the limit as the size of the block tends to infinity. Turbo coding is one way of obtaining highly structured infinite length codewords with modest complexity. This explains why Turbo Codes exhibit superior performance than other block codes (e.g. RS codes).

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Figure 1 depicts a standard rate 1/3 Turbo encoder. It consists of two identical binary rate 1/2 recursive systematic convolutional (RSC) encoders, separated by an interleaver. The RSC is characterized by a generator polynomial expressed in octal form, memory length (m) and constraint length (K), where $K=m+1$. In this paper we investigate generator polynomial (37,21) having $K=5$. Rate compatible punctured Turbo Codes [11] used to generate different code rates are also investigated for the prioritised layer protection of JPEG2000 code-stream.

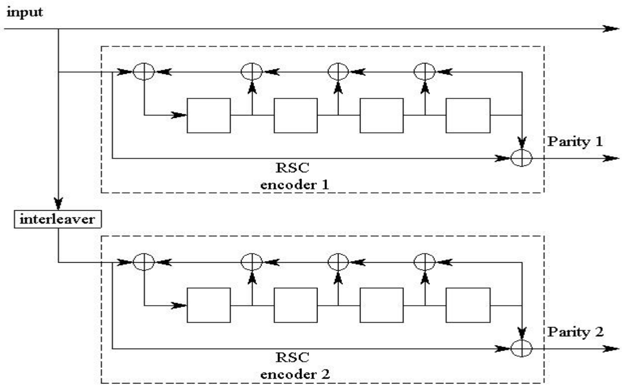

Figure1: A rate 1/3 turbo encoder with generator polynomials (37,21) in octal form.

Turbo Codes are characterized by the interleaver length and their performance improves with increasing interleaver length. A number of interleaving techniques have been proposed in the past, from which an appropriate design may be selected. In this paper we use a random interleaver design so that the parity bits generated at the output of the Turbo encoder are uncorrelated. This tends to increase the error correction capability of the Turbo Code.

4. JPEG2000

In this section, we describe some of the most relevant features of the JPEG2000 image compression standard [5]. The JPEG2000 standard employs a dyadic multi-resolution transform, known as the Discrete Wavelet Transform (DWT) to analyze the image into a collection of subband images, each of which contains information from different spatial frequency bands. The DWT coefficients in each subband are further sub-divided into code-blocks, each of which are independently encoded. The encoded code-block bit-streams are then grouped into bins called *precincts*. Each precinct contains a number of corresponding code-blocks from every subband of a single resolution level. Precincts form the base for the creation of the final compressed bitstream.

To allow quality progressive refinement of the image representation, the encoded data associated with each code-block is spread over a number of *layers*. This is generally done by an optimization procedure, which aims to uniformly increase the image quality by similar perceptual increments in each successive layer. The final JPEG2000 bitstream is constructed by concatenating a list of co-called *JPEG2000 packets* (the use of the term packet here is not to be confused with the packets which might be employed by a network transport layer), where each packet represents the compressed data contributions to a single layer, from code-blocks belonging to a single precinct. Thus, each precinct contributes one packet for each layer.

A complete JPEG2000 code-stream commences with a sequence of marker segments, each of which commences with a specific marker code and contains parameters describing the coding options, which have been employed. The last of these marker segments is followed by a concatenated list of code-stream packets. For the purpose of this investigation we assume that all of the marker segments which precede the concatenated list of code-stream packets remain intact. As these marker segments contain crucial information, without which nothing can be decoded.

5. JPWL TRANSCODER

Figure 2 illustrates the system organization. As seen in the figure, we consider a JPEG2000 Part 1 compliant code-stream at the input and output of our implementation.

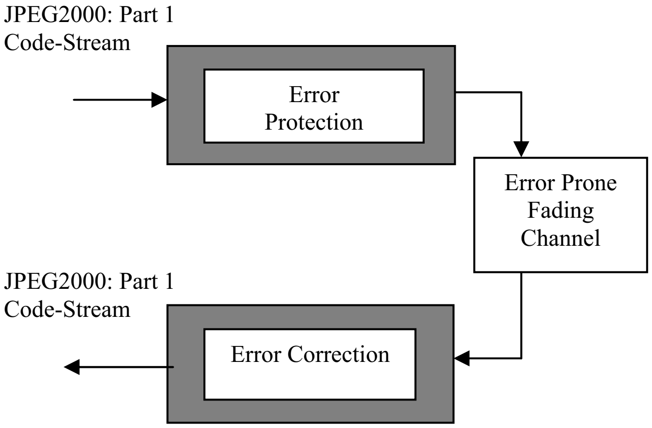

Figure 2: Typical JPWL Transcoder.

To investigate the impact of various Turbo Coding parameters on JPEG2000 compressed imagery in a fading channel, we consider a six layered JPEG2000 code-stream having cumulative sizes corresponding to an overall image bit-rates of 0.03125, 0.0625, 0.125, 0.25, 0.5 and 1.0 bits per sample. We also employ error resilience tools such as the error detection (i.e. SEGMARK), error concealment (i.e. ERTERM) mechanisms along with resynchronisation markers (SOP). These tools provide some degree of protection against errors as investigated in [2] and [4].

6. RESULTS AND INTERPRETATION

To study the impact of various Turbo Code parameters on different fading channel scenarios, we work with Kakadu v3.2. The 256×256 monochrome test image "Lenna" is encoded to a total size corresponding to 1.0 bits per sample together with JPEG2000 error resilience tools such as resynchronisation markers (SOP), error detection (SEGMARK) and error concealment (ERTERM) mechanism. This code-stream is then encoded with an appropriate Turbo Code rate. The channel signal to noise ratio (SNR) is measured in terms of E_p/N_0 where E_p is the energy per image sample and N_0 is the channel's spectral noise density. We simulate a fading channel having $E_p/N_0 = 5.5$ dB and Doppler spread expressed in terms of the mobile device travelling at a speed of 3 km/hr, 40 km/hr, 120 km/hr and 300 km/hr. Such values are typical in mobile radio communication systems. All noisy simulations are repeated 100 times for each set of test conditions. Image quality is assessed in terms of Mean Square Error (MSE), taken over all 100 simulation runs, and expressed in terms of PSNR[1].

We may categorize error protection schemes as either Equal Error Protection (EEP) or Unequal Error Protection (UEP) schemes. EEP schemes assign the same amount of protection to the entire code-stream. On the other hand UEP schemes provide different levels of protection to different elements in the code-stream; data which is more sensitive to errors is protected more heavily than the less sensitive data. We also categorize fading channels as slow fading channel, moderately fast, fast and very fast fading channel.

Table 1 shows the results of our simulations for two possible interleaver lengths in which a rate 1/3 Turbo Code is applied to all packet data uniformly with an interleaver length N= 63944 (which is the length of the entire compressed image in bits) and N=7993. From Table 1 we can clearly see that having a longer interleaver has a considerable impact on the reconstructed image quality and that image quality definitely improves with increasing interleaver length.

Table 1: PSNR (dB) results for test image "Lenna" for interleaver size "N" expressed in bits for different fading channel scenarios after 2 turbo decoder iterations and E_p/N_0= 5.5 dB.

Doppler Spread (Km/hr)	N=7993	N= 63994
3	30.28 dB	33.81 dB
40	30.28 dB	31.37 dB
120	26.86 dB	35.01 dB
300	35.01 dB	35.14 dB

As noted earlier [2], we could benefit from prioritized protection of JPEG2000 code-stream, by protecting higher quality layers more strongly then the lower quality layers. We decide to code the image to a total size of 1.5 bits per image sample including the additional cost of Turbo Coding of 0.5 bits per image sample. With this new constraint, the maximum code rate for the EEP scheme would then be a rate 2/3 Turbo Code applied uniformly to all packet data. On the other hand, for the UEP schemes we select an appropriate rate compatible punctured Turbo Code for each layer based on the scheme under consideration, while keeping the constraint of 0.5 bits per image sample as the overall overhead due to Turbo Coding as mentioned earlier.

Table 2 shows the results for our simulations for three UEP schemes and the EEP scheme. From Table 2 we observe that all three UEP schemes (i.e. *Scheme 1, Scheme 2 and Scheme 3)* clearly outperform the EEP scheme.

In *Scheme 1* we apply a rate 1/3 Turbo Code for the protection of the first two layers, rate 2/5 Turbo Code for the next two layers, while the last two layers are protected with a rate 5/6 Turbo Code. In *Scheme 2* we apply rate 1/3 Turbo Code for the protection of the initial three layers, rate 1/2 for the fourth layer, rate 2/5 for the fifth layer and rate 7/8 Turbo Code for the last layer. Finally in *Scheme 3* we code the first four layers with rate 1/3 Turbo Code, rate 7/8 for the fifth layer and rate 9/10 Turbo Code for the last layer. In the above mentioned EEP and UEP schemes we obtain the 2/3, 2/5, 5/6, 1/2, 7/8 and 9/10 rate Turbo Codes by puncturing the 1/3 Turbo Code appropriately. For all UEP schemes, the length of the interleaver is equal to the length of the layer/layers being encoded with the respective Turbo Code rate.

Table 2: PSNR (dB) results for test image "Lenna" with interleaver size equal to the size of the layer being coded for different fading channel scenarios after two 2 turbo decoder iterations and E_p/N_0= 5.5 dB.

Doppler Spread (Km/hr)	Scheme 1	Scheme 2	Scheme 3	EEP Scheme N = 63944
3	21.85 dB	26.25 dB	27.42 dB	17.47 dB
40	24.57 dB	25.25 dB	26.28 dB	14.87 dB
120	24.12 dB	24.85 dB	25.84 dB	14.52 dB
300	23.80 dB	24.63 dB	25.56 dB	14.47 dB

From Table 2 we see that for the slow fading channel (i.e. Doppler Spread of 3km\hr) *Scheme 1* performs poorly as compared to other UEP schemes. Upon closer investigation we find that in the case of a slow fading channel the channel is reliable for majority of time, but when it deteriorates, the time interval is large, so a small interleaver size (and therefore a small codeword length) does not provide sufficient error protection. Thus, it is important that the higher quality layers, which contain much fewer bytes than the lower quality layers, be protected not only with the strongest code but also be distributed over a longer interleaver length as demonstrated by *Scheme 2* and *Scheme 3*. But counter-intuitively for moderately fast, fast and very fast fading channels (i.e. Doppler Spread of 40, 120 and 300 km/hr respectively), protecting higher quality layers with a longer inteleaver length does prove to have a significant impact as neither of the UEP schemes perform dramatically worse than each other. Upon closer investigation we find that such channels deteriorate for a considerably smaller interval of time but more frequently than a slow fading channel, thus having a longer interleaver length (and therefore a longer codeword length) does not dramatically aid in improving the

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[1] PSNR (Peak Signal to Noise Ratio) is defined as $10\log_{10}(P^2/MSE)$, where P is the peak-to-peak signal amplitude. In this case, P=255, since we are working with 8-bit images.

received image quality. Here we note that the phenomenon of fading plays an important role on the performance of any particular coding scheme.

In compiling results presented in Table 1 and Table 2 we also consider two types of generator polynomials a) with $K=5$ namely (35,23) & (23,31) and b) with $K=4$ namely (17,15) and (15,11). In the case of EEP schemes none of them shows a significant impact on increasing image quality to warrant a conclusion that these generator polynomials are beneficial. But in the case of UEP schemes we observe that generator polynomials with $K=5$ tend to outperform generator polynomials with $K=4$. Upon closer investigation we find that generator polynomials with increasing constraint length (K) tend to maximize the Hamming distance between two codewords and thus aid in increasing the error correction capability of the Turbo Code.

Figure 3 shows the actual visual quality metric assessment for *Scheme 3* for the various fading channel scenarios considered in this investigation.

7. CONCLUSION

In this paper we have investigated the use of different Turbo Code parameters for the robust transmission of JPEG2000 code-streams under various fading channel scenarios.

Firstly, we examined that the length of Turbo Code interleaver has a considerable impact on the reconstructed image quality and that the image quality definitely improves with increasing interleaver length.

Next we examined that by using a family of rate compatible Turbo Codes, the JPEG2000 code-stream can be made substantially resilient to errors and unequal error protection of quality layers is definitely beneficial.

We also find that the optimal configuration of the unequal error protection scheme strongly depends on the fading channel characteristics, particularly noting that the use of longer Turbo Code interleaver's is only beneficial in case of slow fading channel conditions.

Somewhat counter-intuitively, we have not found the use of longer Turbo Code interleaver's to be of significant benefit in context of moderately fast, fast and very fast fading channels.

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a) PSNR: 27.42 dB **b)** PSNR: 26.28 dB

c) PSNR: 25.84 dB **d)** PSNR: 25.56 dB

Figure 3: PSNR (dB) results for test image "Lenna" coded with Scheme 3 for Doppler spread a) 3 Km/hr, b) 40 Km/hr, c) 120 Km/hr and d) 300 Km/hr and with 2 turbo decoder iterations for E_p/N_0= 5.5 dB