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Error Protection for JPEG2000-Coded Images and Its Evaluation over OFDM Channel

Khairul MUNADI[†a)], **Masayuki KUROSAKI**[†b)], ***Student Members***, **Kiyoshi NISHIKAWA**[†c)], ***and*** **Hitoshi KIYA**[†d)], ***Regular Members***

SUMMARY In this letter, we propose a new error protection technique for JPEG2000-coded images and also present its evaluation over an OFDM channel. The method exploits the layer structure of the JPEG2000 codestream, a data embedding technique and a forward error correcting code. The main header and data in the top layer are duplicated and protected by the error correcting code. These data are then embedded into the bottom layer for error recovery purposes. Our method offers several features: preserves the same codestream structure as the one in the JPEG2000 part 1 standard, provides multilevel error protection, and can be combined with the existing error resilience technique. Hence, the method accommodates the new requirements for wireless JPEG2000 (JPWL/JPEG2000 part 11).

key words: *JPEG2000, error protection, OFDM*

1. Introduction

The latest image compression standard, JPEG2000 [1], is known to offer many new features and superior compression performance compared with its predecessor (JPEG) [2]. Undoubtedly, it will soon gain wide acceptance in diverse application areas, including the one of modern multimedia communications.

One of the desired features in recent multimedia communications is image transmission over a wireless channel. However, wireless communications systems, such as CDMA (Code Division Multiple Access), GSM (Global System for Mobile communications), and OFDM (Orthogonal Frequency Division Multiplexing), are vulnerable to the fading phenomenon that generate severe channel errors. These errors, if not handled properly, may produce images with a catastrophic degradation.

To lessen the error impact, the JPEG2000 part 1 standard incorporates error resilience tools (ERT) in its features [3]. The adopted tools can be classified based on the following strategies: data partitioning and resynchronization, error detection and concealment, and quality of services (QoS) transmission based on priority [1]. The tools can detect errors, discard the rest of data, and resynchronize the decoding process. However, they are not able to correct error data. As a result, when the critical part of the codestream (like the main header and data in the most significant layer) is affected by errors, the JPEG2000 ERT do not provide enough protection. Hence, the erroneous codestreams may yield images with high deterioration if not being undecodable.

In this letter, we propose a new method of error protection for JPEG2000-coded images, which employs the JPEG2000 layer structure, a data embedding technique and a forward error correcting (FEC) code. The method is an extension of the work in [4]. However, the previous work did not provide any protection to the main header. Therefore, when an error exists in the main header, it renders the entire codestream undecodable. Besides, it considered only random error. Other recent studies for JPEG2000 error protection have been reported in [5]–[7]. Unfortunately, all methods in these studies could not preserve the same codestream structure as the one in the JPEG2000 part 1 standard, thus causing the standard decoder unable to perform the decoding task. Moreover, none of the studies utilized the layer structure and a data embedding technique. Hence, we offer a different approach from them. Lastly, the methods in [5]–[7] also assumed that the main header part of the codestream remains intact during transmission process, which is not always the case in a real application.

Instead of using a uniform error model, either random or burst error, we evaluated the performance of the proposed method over an OFDM transmission system that is one of the potential candidates for future wireless communication.

The significant features of the proposed method are: it maintains the same codestream structure as the one in the JPEG2000 part 1 standard and offers multilevel error protection. The former enables the JPEG2000 part 1 decoder to decode the resulting bitstream and the latter provides error protection not only to the image data but also to the main header of the codestream.

2. Overview of JPEG2000 and OFDM System

2.1 JPEG2000 Encoding and Codestream Structure

In the JPEG2000 coding, an input image is decomposed into its sub-bands by the aid of the DWT (Discrete Wavelet Transform) and the wavelet coefficients of each sub-band are quantized. The quantized coefficients are then coded using the EBCOT (Embedded Block Coding with Optimized Truncation) algorithm [8]. In this algorithm, each sub-band is divided into rectangular blocks (i.e., 64×64) called code-

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[†]The authors are with the Department of Electrical Engineering, Tokyo Metropolitan University, Hachioji-shi, 192–0397 Japan.
a) E-mail: munadi@isys.eei.metro-u.ac.jp
b) E-mail: kurosaki@isys.eei.metro-u.ac.jp
c) E-mail: kiyoshi@eei.metro-u.ac.jp
d) E-mail: kiya@eei.metro-u.ac.jp

blocks, which form the independent input to coefficient bit modelling based on a bit-plane and arithmetic coding. A comprehensive description about the JPEG2000 encoding procedure is given in [9].

The JPEG2000 codestream is conceptually arranged in the layer structure that imparts quality scalability, as illustrated in Fig. 1. It consists of a main header and a sequence of layers, starting from the most significant layer (MSL) to the least significant layer (LSL). The main header part contains crucial coding parameters and therefore should be error free during any processes, otherwise nothing can be decoded by the decoder. Each layer includes a part of coded code-blocks that collected into packets. The MSL comprises the most significant contribution to image quality and the following layers increment image quality successively. In other words, the most important data is placed in the MSL, while the least important one is put in the LSL. It is worth pointing out that the number of layers and the length of each layer can be assigned arbitrarily in the encoding process.

2.2 OFDM System Architecture

A schematic diagram of an OFDM baseband system is depicted in Fig. 2. In the transmitter, the binary input data are first channel coded. The encoded data is then interleaved and mapped onto desired modulation scheme. A serial-to-parallel (S/P) converter transforms the serial modulated data into parallel data before performing the IFFT (Inverse Fast Fourier Transform). This parallel data is then converted back into its serial form using a parallel-to-serial converter (P/S). We referred to this data as an OFDM symbol. To obtain robustness against multipath fading, a cyclic prefix is inserted as a guard interval (GI) between symbols before entering a transmission channel.

In the receiver, inverse operations are performed starting from cyclic prefix removal, FFT (Fast Fourier Transform), demodulation, deinterleaving, and channel decoding, accordingly. A more detail explanation about the OFDM can be found in [10].

3. Proposed Method and Its Features

3.1 Proposed Method

The prime idea is to provide high error protection for the main header and the MSL of the codestream because they contain the most important data of the compressed image. In an OFDM transmission system, the proposed methods are considered as pre- and post-transmission processes as illustrated in Fig. 3. It should be noted that our methods can be independently attached to other transmission systems.

A. Pre-transmission

The input image is first compressed by the JPEG2000 encoder and formed into a certain number of quality layers. The compressed data is then pre-transmission processed as in Fig. 4, where the main header and the MSL are duplicated and protected by an FEC code.Two scenarios are proposed:

1. *Equal Protection (EP)*
   The main header and the MSL are protected by the same strength of error correcting code.
2. *Unequal Protection (UP)*
   The main header is protected by a more powerful correcting code than the MSL.

In this work, we utilized the Reed-Solomon (RS) code [11] as the correcting code. The choice of any RS codes for

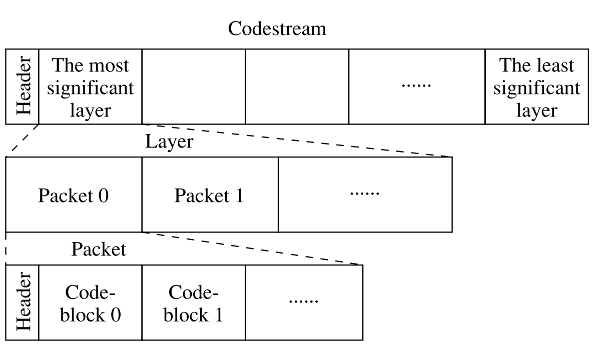

Fig. 1 Structure of a JPEG2000 codestream.

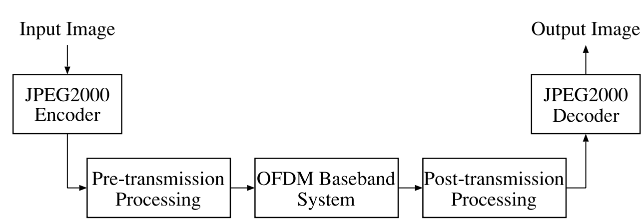

Fig. 3 Proposed method in JPEG2000-coded image transmission over OFDM system.

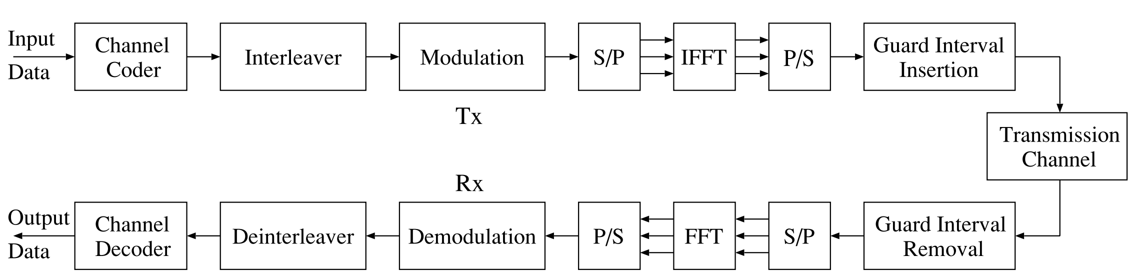

Fig. 2 OFDM baseband system architecture.

both scenarios should consider the size of the LSL, where the size of the protected MSL and its parity should be equal or less than the LSL size. It is worth reemphasizing that the length of the MSL and LSL can be assigned arbitrarily during the encoding process. The codes and their strengths (i.e., correctable errors) applied by the proposed methods are shown in Table 1.

Then, the protected data are embedded into the LSL. The method of extracting and embedding data in the JPEG2000 codestream is explained in [12], [13].

B. Post-transmission

In the receiver side, the codestream is post-transmission processed before decoding, as shown in Fig. 5. After extracting and performing the FEC decoding, the embedded data becomes nearly error free and can be utilized to redeem the error data in the MSL. After error recovery, the last layer is discarded, and the codestream can be decoded. The effect of discarding the last layer to image quality is very small and can be reasonably neglected as previously studied in [4].

3.2 Features of Proposed Method

Several features offered by the proposed method are as follows. First, our method preserves the same codestream structure as the standard one. Hence, the resulting codestream can also be decoded by the JPEG2000 part 1 decoder. This benefit conforms to one of the currently issued requirements aiming at the extension of the JPEG2000 standard for wireless application (JPWL or JPEG2000 part 11) [14]. Secondly, the method provides multilevel error protection since the main header and data in the top layer can be differently protected. Furthermore, the method can be combined with the existing JPEG2000 ERT.

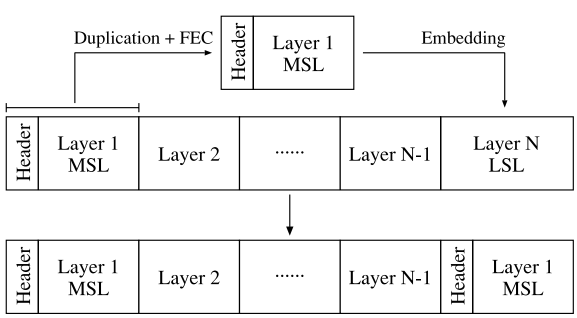

Fig. 4 Pre-transmission scheme.

Table 1 Error correcting codes used by proposed method.

Scenarios	Protected Data	RS Code and Its Strength
EP	Main header	RS(255,239), 8-bytes
	MSL	
UP 1	Main header	RS(255,231), 12-bytes
	MSL	RS(255,243), 6-bytes
UP 2	Main header	RS(255,231), 12-bytes
	MSL	RS(255,239), 8-bytes

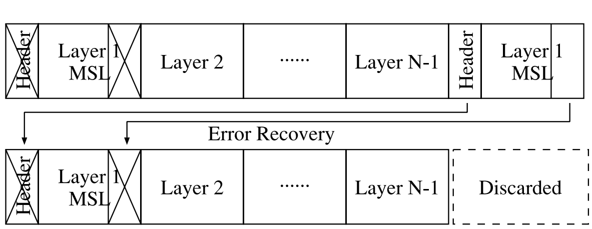

Fig. 5 Post-transmission scheme.

4. Simulations

4.1 Simulation Conditions

Using the parameter in Table 2, we employed the OFDM model in Fig. 2 as a transmission system in evaluating the performance of the proposed methods. The OFDM receiver was assumed to be perfectly synchronized. We also assumed that all information related to the protection of the main header and the MSL (i.e., RS code and the resulting parity number) are known both by the JPEG2000 encoder and decoder.

The input data was a standard image "Lena" (grayscale 512 $\times$ 512, 8 bits/pixels) that compressed by the JPEG2000 verification model 8.6 [15] with a target bit rate of 1.0 bits/pixel (bpp) and formed into 20 layers. Accordingly, each layer contributed to 0.05 bpp. In case of using the JPEG2000 ERT, the size of the main header, the MSL and the LSL after compression were 110, 1510 and 1820 bytes, respectively. Since the main header contains only a few data, it is apparent that protecting it with the stronger RS codes only introduce a very slight increase in redundancy. Note that, the embedded data sizes that were resulted by the scenarios in Table 1 were less than the available space in the LSL. All simulations were repeated over 100 independent trials.

The average bit error rate (BER) of the simulated OFDM model with various channel delays is plotted in Fig. 6. As expected, when the channel delay is within the GI, the channel error rate is relatively low. On the contrary, when the delay is exceeding the GI, the error rate is significantly increased. This condition may happen in the single frequency networks (SFN) of an OFDM based broadcasting system where the signals from different transmitters with the same frequency are received simultaneously by a receiver [16], [17]. The performance of the proposed method was

Table 2 Simulation parameters of OFDM baseband system.

Parameter	Description
Modulation	BPSK
FFT Size	2048
Guard Interval (GI)	25% (512 Samples)
Channel Coding	Reed-Solomon, RS(255, 247)
Interleaver / Deinterleaver	Convolutional, depth = 13
Transmission Channel Model	Two-path AWGN (with second path 3 [dB] less)
SNR [dB]	12

evaluated when the channel delay both within and outside the GI, as shown in Table 3.

Two parameters were assessed, namely: decodable rate and image quality. The former shows the JPEG2000 decoder capability to decode the erroneous codestreams. The latter indicates the quality of decoded images that was measured in terms of peak signal-to-noise-ratio (PSNR) between the original and the decoded images.

4.2 Performance of JPEG2000 Error Resilience

The performance of the JPEG2000 ERT without using the proposed method, which is referred as No Protection (NP), can be evaluated by comparing the simulation results in column (a) with column (e) of Table 3. It is clearly shown that using the JPEG2000 ERT we can obtain higher image quality, thus offers an advantage in minimizing the error impact. However, this advantage becomes meaningless if the error occurs in the MSL. Because it will discard the rest of the data and hence substantially reducing the image quality. Furthermore, no protection can be provided if the error corrupts the main header and results the undecodable codestreams. This is shown by the decodable rate below 100% even in the low channel error rate and the delay was within the GI.

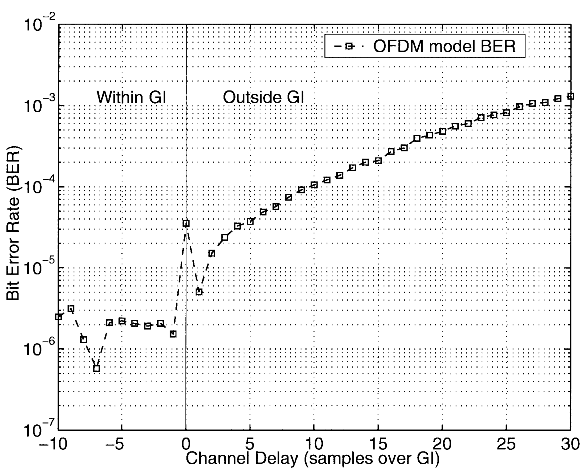

Fig. 6 Channel delay vs. BER in the simulated OFDM system.

4.3 Performance of Equal Protection Method

Using the EP method, as can be seen in columns (b) and (f) of Table 3, in a low and moderate channel error rate all of the erroneous codestreams are becoming decodable regardless of the use of the JPEG2000 ERT. This is because the proposed methods is capable of securing the main header and the critical data in the MSL. However, in a higher error rate, the EP method cannot completely secure the main header part. Thus, some undecodable codestreams still ex-

Fig. 7 Decoded images from the simulated OFDM with channel delay 20 samples exceeding the GI. (a) Decoded using JPEG2000 ERT only, PSNR = 20.53 [dB]. (b) Decoded using JPEG2000 ERT and equal protection method, PSNR = 31.23 [dB].

Table 3 Performance of JPEG2000 error resilience tools and proposed method.

Parameters	Without JPEG2000 ERT				With JPEG2000 ERT				Channel Delay [samples over GI] / (Average BER)	Remarks
	(a) NP	(b) EP	(c) UP 1	(d) UP 2	(e) NP	(f) EP	(g) UP 1	(h) UP 2		
Decodable Rate [%]	100	100	100	100	100	100	100	100	-10 / (2.4858E-6)	Within GI
PSNR [dB]	39.729	39.621	39.621	39.621	39.888	39.598	39.598	39.598		
Decodable Rate [%]	98	100	100	100	99	100	100	100	0 / (3.5414E-5)	
PSNR [dB]	34.684	35.902	35.902	35.902	37.075	37.631	37.631	37.631		
Decodable Rate [%]	81	100	100	100	96	100	100	100	10 / (1.0571E-4)	Outside GI
PSNR [dB]	15.485	31.206	30.581	31.206	27.883	37.307	37.012	37.307		
Decodable Rate [%]	89	100	100	100	89	100	100	100	20 / (4.8261E-4)	
PSNR [dB]	10.836	22.467	21.575	22.879	19.543	30.669	26.601	30.678		
Decodable Rate [%]	80	99	100	100	79	94	100	100	30 / (1.3074E-3)	
PSNR [dB]	9.012	16.263	14.849	15.809	16.404	24.291	23.873	26.618		

ist. Therefore, it is reasonable to provide a more powerful protection to the main header than the MSL. Besides, the quality of the decoded images becomes considerably high when the method is combined with the JPEG2000 ERT, as shown by the average PSNRs in column (f) of Table 3.

4.4 Performance of Unequal Protection Method

The UP method increases the immunity of the main header to the errors by providing a stronger protection to it using a more powerful error correcting code. Therefore, the UP is suitable to deal with a high error rate channel. The performance of this method can be seen in columns (c), (d), (g) and (h) of Table 3. Although in a severe channel error, the method can perfectly isolate the main header from error. Thus, all the decodable rates are becoming 100%. After protecting the main header with an adequate FEC code, the quality of the image is determined by the strength of RS code that used to protect the MSL. As can bee seen, the stronger code (UP 2) provides better image quality than the UP 1. Moreover, the quality of the decoded images is also increased significantly when the method is combined with the JPEG2000 ERT, as shown by the higher PSNRs in column (h) of Table 3.

Some of the decoded images that obtained from the simulated OFDM with channel delay 20 samples exceeding the GI can be seen in Fig. 7(a) and Fig. 7(b). As shown, our method increased the image quality by more than 10 [dB].

5. Conclusion

A new method of error protection for the JPEG2000 coded-images has been described and evaluated over an OFDM channel. It employs the layer structure, a data embedding technique and an FEC code. The method preserves the same codestream structure as the standard one, provides multi-level error protection and offers high image quality when combined with the JPEG2000 error resilience tools.

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