

EFFICIENT PACKET LOSS PROTECTION FOR JPEG2000 IMAGES ENABLING BACKWARD COMPATIBILITY WITH A STANDARD DECODER

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ABSTRACT

This paper proposes an efficient packet loss protection strategy for transmission of JPEG2000 coded images over a packet erasure channel that backwardly compatible with the JPEG2000 part 1 decoder. The proposed scheme utilizes FEC at packet-level, the JPEG2000 layered structure and its error resilient functionalities. Prior to transmission, packets containing initial layers of the codestream, which is associated to a minimum acceptable image quality, are protected using a packet-level FEC. With a slight modification in the SOT marker segment and careful placement of the redundant packets, the generated codestream that carried redundant data is compliant with a standard decoder.

1. INTRODUCTION

Two distinct approaches are available to recover lost or dropped packets in the networks: Automatic Repeat reQuest (ARQ) and packet-level Forward Error Correction (FEC). ARQ is based on retransmitting the lost packets and has been applied to the TCP (Transmission Control Protocol) for best-effort packet delivery. The idea behind FEC-based packet recovery, however, is to introduce controlled redundancy into the original message prior to transmission. Instead of retransmission, this redundancy is exploited to reconstruct any lost packets at the receiver. Of these two techniques, FEC has been more commonly suggested for real-time application, such as applications using the RTP (Real-time Transport Protocol), due to strict delay requirements. In addition, the amount of redundancy is expected to be minimal, which further reduces transmission delays.

There have been many efforts on packet loss protection for transmission of image and video data using FEC. Since the use of FEC introduces additional packets into the network, most of the previous works such as in [1, 2] have taken the unequal protection scheme into consideration, which assigns an unequal amount of protection to the image data. However, the works in [1, 2] have not considered the existence of the JPEG2000 standard. Thus, many interesting features introduced by the JPEG2000 codestream are not exploited.

Various studies on error protection for JPEG2000 images has been proposed in [3, 4], but these have not dedicated for packet loss environments. Other recent works [5, 6, 7] proposed several approaches to protect the JPEG2000 codestream from packet erasure channels. Unfortunately, backward compatibility with a standard decoder cannot be achieved by them. Furthermore, the proposals are more suitable for short network packets, such as the ATM cells. Other drawbacks with those approaches are they need to receive complete data before loss recovery can be performed. This is because of a part of the codestream that contained coding

elements is spread out into several network payloads and the codestream undergoes interleaving process to increase the robustness. Due to this, partial codestream decoding from the earlier arrived network packets is not possible.

In this paper, we address an efficient scheme of packet loss protection for transmission of JPEG2000 images that backwardly compatible with a standard decoder. This means that, the codestream generated by the proposed encoder is still a valid codestream and thus can be also decoded by the standard decoder. Although our scheme considers unequal protection strategy, it is worth to note that we are not dealing with the optimal assignment of FEC code redundancies to the codestream. Optimal code assignment for scalable image codestream have been extensively studied and interested readers may refer to the literatures as in [8, 9]. On the other hand, our main aim is to offer a simple and useful protection scenario to enable backward compatibility with the standard JPEG2000 decoder, considering the characteristic of the JPEG2000 codestream. Whereas any algorithms regarding to the optimal protection assignment can be applied accordingly.

Since the Motion-JPEG2000 coding algorithm is based on the JPEG2000 still coding scheme [10], our proposal can be applied to both still images and video transmission that is based on the JPEG2000 standard platform.

2. JPEG2000 CODESTREAM STRUCTURE AND FEC BASED PACKET LOSS RECOVERY

2.1. JPEG2000 Codestream Structure

The JPEG2000 standard is mainly based on the discrete wavelet transform and the EBCOT (Embedded Block Coding with Optimized Truncation) algorithm. Before encoding, an image can be regarded as a single tile or partitioned into smaller non-overlapping tiles. The detailed encoding procedure of the standard can be found in [11, 12].

A JPEG2000 codestream can be generated as a single or multiple quality layers. For multiple quality layers coding of a single-tile image, the JPEG2000 codestream is conceptually arranged in the layered structure, as in Fig. 1. The header consists of the main header (MH) and tile-parts header (TH). Each layer includes a part of the coded code-blocks that are collected into *packets*, while each packet consists of a packet header and body (use of the term *packet* here is not to be confused with the term *packet* employed in network transmission. In the next sections, network packets will be referred as *packets*, while packets in the JPEG2000 codestream will be referred as *JP2 packets*). Since the most significant layer (MSL) contains the most significant bit-planes of each code-block, it makes the most significant contribution to image quality and the layers following successively increment image quality.

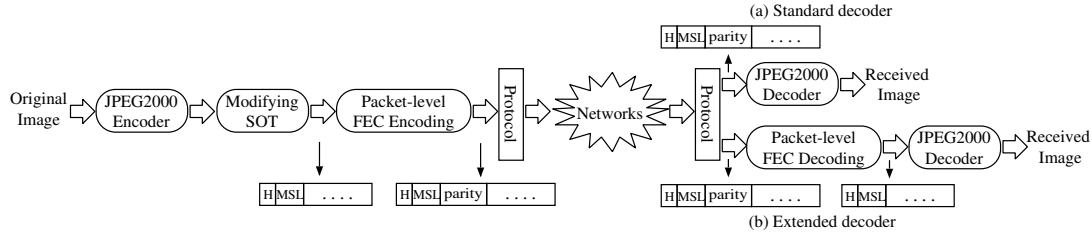


Fig. 2. Transmission scheme overview.



Fig. 3. Modification of SOT marker segment in tile-part header.

Fig. 1. Structure of JPEG2000 part 1 codestream for single-tile image with multiple quality layers.

2.2. FEC Based Packet Loss Recovery

As previously mentioned, FEC based packet loss recovery involves addition of redundant (parity) packets, that are used in reconstructing any lost or dropped packets at the receiver. An erasure is declared whenever a packet is lost or does not arrive in time and the lost position is normally known. Redundant data can be obtained from original data using techniques derived from coding theory, such as simple exclusive OR (XOR) operation or Reed-Solomon (RS) erasure codes. In the present work, we applied only the latter one.

The RS(n, k) erasure code takes k original packets and generates $n - k$ redundant or parity packets. Given the position of the lost packets, the RS decoder can reconstruct lost packets up to $n - k$ packets out of n packets. When the code is systematic, the first k of the n encoded packets are the original packets and the remaining $(n - k)$ packets are redundancy. The detail scenario on how the RS erasure code works and its implementation issues can be found in [13].

3. PROPOSED METHOD

Our basic idea is to effectively protect packets that contain the most important image data while maintaining backward compatibility with the JPEG2000 part 1 decoder, which will be referred here also as standard JPEG2000 decoder. We consider a codestream has been generated from a single-tile image with the inclusion of SNR scalability and the packet-level FEC is used.

3.1. System Overview

Figure 2 depicts the framework of the proposed transmission system. Image or video sequence input goes to the JPEG2000 encoder to form the codestream. After packet-level FEC encoding, the FEC-encoded codestream is transmitted to the network. The codestream arriving from the network is either passed to the standard JPEG2000 decoder (a) or the extended JPEG2000 decoder (b). From this figure, we expect that the protected codestream at the receiver end, i.e., the codestream containing parity packets, can be decoded either by our proposed decoder (b) or by the standard decoder (a). Here, the standard decoder is expected to skip the parity

data and can properly go through the decoding process.

3.2. Pre-transmission Process

The following steps are carried out at the transmission side.

Step 1: *JPEG2000 Encoding*. The original image is encoded into a number of quality layers with the single-tile option, where some portions of bit rate that corresponds to minimum acceptable image quality at the receiver is assigned to the MSL of the codestream. The desired bit rate can be assigned arbitrarily during the JPEG2000 encoding process. The option to include the SOP (Start of Packet) marker segment into the codestream is enabled during encoding. By this way, we invoke the error resilient tools at JP2 packet level. Other resilient tools at the entropy coding level can be also enabled to prevent misreading of compressed data following the lost packets.

Step 2: *Modification of SOT Marker Segment*. The SOT (start of tile) marker segment, signalled by the 0xFF90, in the tile-part header of the encoded codestream is then modified as outlined in Fig. 3, where the *Psot* field is set to 0x0000. For a single-tile image, by modifying the “*Psot*” to 0x0000, we relax the total length of the codestream. In other words, if the “*Psot*” is 0x0000, the tile-part is assumed to contain all data until the EOC (End of Codestream) marker is found [11], thus enabling us to insert any desired amount of data into the codestream.

Step 3: *Packet-level FEC Encoding*. After a slight modification in the SOT marker segment, the MSL of the codestream is FEC coded using the desired erasure code, resulting the parity packets. To enable the minimum decoder skipping these parity packets, they should be placed in between the two JP2 packets in the codestream. This can be easily done since the SOP marker option has been enabled during encoding (step 1). This situation is depicted in Fig. 4, in which the MSL is protected using RS(7, 4). However, care should be taken. The parity sections should not contain any of the restricted markers already defined for the JPEG2000 standard [11], those are the two consecutive data byte in the range 0xFF90 to 0xFFFF. Otherwise, it may cause confusion at the standard decoder side. To overcome this, one may insert a 0 bit in between the ‘0xF’ and ‘0xF’, (i.e., ‘11111111’ becomes ‘11110111’) when the restricted markers are found in the parity packets. This may lead to a small increase in the length of the parity packets. However, our solution is simpler than the bit packing strategy proposed in [3], where the parity bits are collected into multiple of 7 and packing each such multiple into a

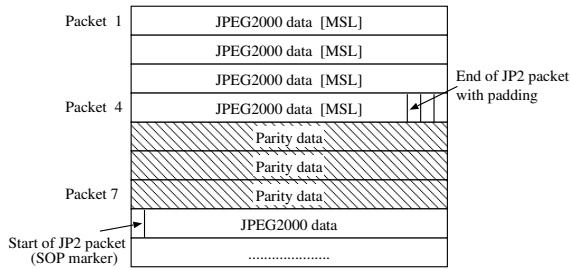


Fig. 4. Protection of MSL data using packet-level FEC, RS(7, 4), and parity data position.

whole packet data byte, whose most significant bit is 0. The final step is to packetize the protected codestream into the network payload. In case of any 0 bit insertions, the payload length for the parity data is slightly different from the one for the JPEG2000 data.

3.3. Post-transmission Process

The following steps are carried out at the receiver equipped with an extended decoder.

Step 1: Packet-level FEC Decoding. The received data from the network is FEC decoded before feeding it into the JPEG2000 decoder. Any lost MSL data packets are reconstructed through FEC decoding. The parity packets are then excluded from the codestream.

Step 2: JPEG2000 Decoding. After packet-level FEC decoding, the received data is then JPEG2000-decoded to reconstruct the image.

3.4. Backward Compatibility with Standard Decoder

At a receiver that is only equipped by a standard JPEG2000 decoder (without packet-level FEC decoding capability), however, image decoding is done by skipping the redundant data. In this case, any lost MSL packets will become unrecoverable. Here, we shortly explain how the skipping process can be done. Note that, when the codestream that processed according to the procedure in Section 3.2 is available at the receiver, the parity packets have been included in between the two JPEG2000 packets and the SOP marker have been invoked. When the received codestream is inputted to the standard JPEG2000 decoder, the decoder will identify the SOP marker and read the related information in the JPEG2000 packet header, such as the packet length information, etc. By this way, all valid data in one JPEG2000 packet can be determined. Then, the decoder continues to find the next SOP marker. Since the parity packets are not preceded by the SOP marker, they will be skipped and completely ignored until the next SOP marker is found.

3.5. Features of Proposed Scheme

There are several features that the proposed scheme offers and these are as follows. First, by taking advantages of JPEG2000 codestream syntax and error resilient functionalities, it provides backward compatibility with a standard decoder. In other words, a standard decoder can do normal decoding by skipping redundant information. This feature is important because it enables us to differentiate the quality of service (QoS) among users. Second, since only the most important layer that is related to a predetermined bit rate is protected, the scheme only introduces a small number of redundancies and less delay. Furthermore, any packet-level FEC techniques that are optimized with respect to the mean packet loss rate can be used with the proposed scheme.

Table 1. Simulation parameters.

	Image	Video
Source Data	LENA (8bpp)	MOBILE (8bpp)
Compression Rate	1 bpp	
Number of layers	20	
Bit rate of MSL	0.05 bpp	0.05 bpp
PSNR of MSL	27 [dB]	25 [dB]
Erasure Code	RS(7, 4)	
Length of Packet	500 [bytes]	700 [bytes]

Table 2. Total number of redundant packets when RS(7, 4) erasure code applied for packet loss protection.

Image/Sequence	Number of Redundant Packets	
	MSL	Whole Codestream
LENA	3 packets	51 packets
MOBILE (40 frames)	3×40 packets	57×40 packets

4. SIMULATIONS

4.1. Simulation Conditions

Table 1 lists the simulation parameters. Here, we assumed the minimum acceptable quality for still image and video sequences are related to 0.05 bpp, which results 27 dB for LENA image and close to 25 dB for each frame of the MOBILE & CALENDAR sequences. This 0.05 bpp data was then packetized into four packets and protected by RS(7, 4) erasure code, resulting in three redundant packets. We considered that the images were transmitted over an unreliable protocol, such as the RTP over UDP (the User Datagram Protocol), where retransmission is not permitted. The loss of a packet was assumed to be an independent event, occurring randomly and could be detected at the receiver. We assumed also that there was no out of order delivery during transmission. The mean packet loss rates under consideration were in the range of $0 \leq p \leq 0.25$. All information about the packetization, the chosen FEC and other related information were assumed to be known by the extended decoder. In practice, these information can be placed into the “COMMENT” area either in the main header or the tile-part header of the codestream.

Two parameters were assessed, i.e.: decoding probability and image quality. The former reveals the JPEG2000 decoder ability to decode the codestream when packet loss occurred in the network. Note that arrival of the first packet at the receiver guarantees correct decoding since it includes also the JPEG2000 header. The latter indicates the quality of decoded images that were measured in terms of the peak signal-to-noise ratio (PSNR). All simulations were repeated up to a total of 100 realizations.

4.2. JPEG2000 Codecs Used in Simulations

We tested the proposed scheme by employing three different software implementation of JPEG2000 codecs, namely: VM8.6 [14], Kakadu v4.02 [15] and Jasper v1.701.0 [16]. The proposed scheme worked well with VM8.6 and Kakadu, while the Jasper decoder could not perform normal decoding. We believed this due to the imperfect implementation of the standard, particularly related to the issue of error resilient functionality at the JP2 packet level (resync marker). In the following, we present the simulation results obtained when using VM8.6.

4.3. Simulation Results

As mentioned earlier, a scheme that only introduces a small number of redundancies is preferred for lower delays in transmission. Table 2 lists the number of redundancies when we applied the RS(7, 4) based packet loss protection only to the MSL and to the

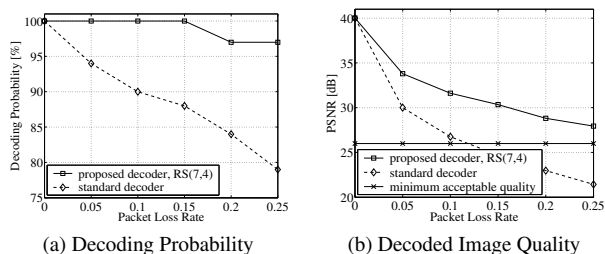


Fig. 5. Performance of proposed scheme for still image.

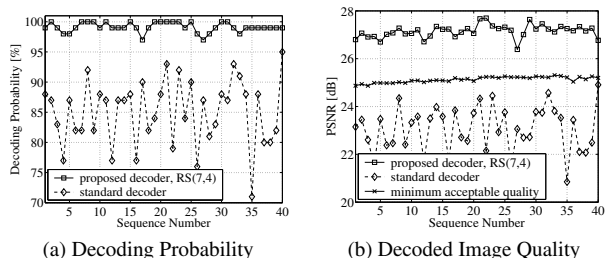


Fig. 6. Performance of proposed scheme for video sequence transmission, packet lost rate $p = 0.15$.

whole codestream for LENA and MOBILE & CALENDAR images. As can be seen, the idea to protect just the MSL considerably reduces the number of redundant packets.

4.3.1. Transmission of Still Images

Figure 5 plots the simulation results for transmitting the LENA still image in a common packet loss rates. From Fig. 5(a), we can see that the decoding probability offered by the proposed method is considerably high. This reveals that most lost packets in the first transmission can be reconstructed by means of packet-level FEC. We can even provide more protection by applying a stronger FEC code. Due to this, we are able to guarantee that the received codestream can be perfectly decoded. Figure 5(b) plots the decoded image quality at various common packet loss rates. As can be seen, the proposed scheme results in image quality over the minimum acceptable image quality, in this case 27 dB. When there is no packet loss, the PSNR value at the standard decoder is exactly the same as at the extended decoder because the parity data can be skipped.

4.3.2. Transmission of Video Sequences

The Motion-JPEG2000 codec is an intra-frame based coding system and utilizes the same coding engine as the still JPEG2000 [10]. Therefore, in this experiment, FEC based packet loss recovery was employed on a frame-by-frame basis. Figure 6 plots the simulation results for transmitting MOBILE & CALENDAR sequences at a packet loss rate of $p = 0.15$. As we can see from Fig. 6(b), the quality of all received video frames is higher than the minimum acceptable quality. The decoding probability for all video frames is also considerably higher as we can see from Fig. 6(a).

5. CONCLUSION

We showed that the advantages of the layered structure, the richness of JPEG2000 codestream syntax and its error resilient functionalities could be utilized to provide efficient packet loss protection for transmission of the JPEG2000 encoded images. The codestream generated by the proposed scheme is backwardly compatible with the standard JPEG2000 decoder.

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