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# ERROR SENSITIVITY OF JPEG2000 CODESTREAM FOR EFFICIENT DATA PROTECTION ON UNRELIABLE NETWORKS

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## ABSTRACT

Lossy compressed data, and multimedia content by extension can afford some further losses or degradation in lossy networks without removing its meaning. Still images coded by JPEG2000 exhibit a codestream hierarchically built with codeblock contributions organized in packets across quality layers and resolutions. In this paper we show how the image suffers from missing contributions in accordance with information available in packet header, with the layer inclusion tag especially. Our goal is to determine the level of importance of JPEG2000 packets with the only knowledge of the headers for efficient data protection on unreliable network.

## 1. INTRODUCTION

Still image transport is now a usual traffic on the Internet, using the world wide web for instance. The need to compress these data is crucial in order to decrease the response time, *ie.* the time achieved for data transfer to be completed. However, even using compression the total amount of data carried on Internet remains so large that the response time can be long. In the general case, transmission control protocol (TCP) [1] is used to transmit images on the web. TCP provides both reliable data delivery and good congestion control, but this comes at the cost of a slow response time when packet loss occurs. The use of a partially reliable transport like 2CP-ARQ [2] enables the loss of some data at the expense of an image degradation. The difficulty is then to decide which data are essential in terms of image quality and what can be transmitted with less reliability.

In this paper, we are concerned with error sensitivity in JPEG2000 codestreams. Our goal is to determine the significance level of the different parts of the JPEG2000 contents like the packets, their contributions and their hierarchical link [3]. Such a knowledge allows to select the parts which are the most required in order to adapt the level of reliability in lossy networks when using unequal error protection for example. The core data in a JPEG2000 file is the codestream on which we focus our attention, more precisely on the JPEG2000 packets and the contributions that they carry. The JPEG2000 packets which are associated to a layer, a resolution, a component and a precinct – are often used as the smallest data unit in transmission over networks. JPEG2000 is more than a compression standard since interactive transmission is covered too with JPIP (JPEG2000 Interactive Protocol) [4]. Taubman [5] proposed remote browsing of JPEG2000 images based on per precinct packet transfer, in [6] the per tile transport has been proposed. A JPEG2000 video transmission over RTP has also been proposed in [7] with the JPEG2000 headers and packets as the basic elements of intelligent packetization. Each time, communication is based on JPEG2000 packet transmission and the sent packets are those that are judged the most important with the following criteria: the precinct or the tile (position), the resolution, the layer, and or the component. The same criteria are used to determine the level of importance of JPEG2000 packets for UEP (unequal error protection) transmission for lossy radio channels [8, 9], erasure codes [10], PET (Priority Encoding Transmission) [11].

Our objective is to find the importance of the JPEG2000 contributions as a function of all information available in the packet header, not only the layer, the resolution, the precinct and the component. Our analysis of error sensitivity highlights that the layer inclusion information is a metric that determines efficiently the significance of the contribution. This can be performed without decoding the compressed data as only headers are concerned, so it could be done at low cost and without ability for JPEG2000 decoding.The remainder of the paper is organized as follows: general JPEG2000 layout is covered in section 2, it leads to the analysis of JPEG2000 error sensitivity in section 3 with appearance of losses.

## 2. JPEG2000 ORGANIZATION

The JPEG2000 compression is strongly based on the EBCOT paradigm [12]. Image can be splitted in independent tiles. Samples from a tile are transformed into spatial frequency subbands by Discrete Wavelet Transform (DWT) leading to several resolutions. The smallest resolution $R_0$ contains subband $LL_0$ only whereas resolution $R_i$ with $i \neq 0$ have three subbands ($HL_{i-1}$, $LH_{i-1}$ and $HH_{i-1}$). Each subband is divided into small parts called *code-blocks* which are coded independently. Another level of division is done within a resolution: the *precinct*. A *precinct* is a set of coded *code-blocks* from the same resolution, it can span the entire resolution or a part of it depending on the size of the resolution and of the *precinct*. The *code-blocks* involved in a *precinct* are situated in all the subbands of the given resolution (the same parts of the resolution in the three subbands). Besides the division in resolutions, JPEG2000 allows a decomposition in quality layers. The *bitstream* of each *code-block* is segmented in several parts, each of these parts contributes to one quality layer (a *code-block* may or not contribute to all the quality layers according to the appreciation of EBCOT).

Compressed data from each precinct is collected into so-called *packets*. Note that this denomination has a different meaning from that concerning packets of a network traffic.

A packet has two parts: a header and a body, see figure 1. It contains *code-block* contributions related to one quality layer, one resolution, one component and one *precinct*. Information carried by the packet header are for each code-block contribution within the packet body: the first layer for which the code-block contributes (layer inclusion), the number of most significant bit-planes to zero (actually these bit-planes are unsignificant), the number of coding passes included and the contribution length in bytes. In order to decode the packet header, the parser needs to know what to expect. These required elements like the type of progression used, the number of resolutions, of quality layers, of components and *precinct* size are stored in the main header of the codestream. Using these data, it is possible to know which (layer,resolution,component,precinct) tuple a given packet belongs to given its rank in the codestream and how many *code-blocks* contributions are in the packet. Consider a tile with $l$ quality layers, $r$ resolutions, $c$ components and $p$ *precincts*, then the rank $N$ of the packet that is related to the layer $L_i$, the resolution $R_j$, the component $C_k$ and the *precinct* $P_m$ is determined by (1) in the case of the LRCP progression.

$$N = i(rcp) + j(cp) + k(p) + m \quad (1)$$

Conversely, from the rank, (2) gives $(i, j, k, m)$ where $i$ is the layer, $j$ the resolution, $k$ the component and $m$ the *precinct* $m$.

$$\begin{aligned} i &= \left\lfloor \frac{N}{rcp} \right\rfloor \\ j &= \left\lfloor \frac{N - i(rcp)}{cp} \right\rfloor \\ k &= \left\lfloor \frac{N - i(rcp) - j(cp)}{p} \right\rfloor \\ m &= N \ mod \ p \end{aligned} \quad (2)$$

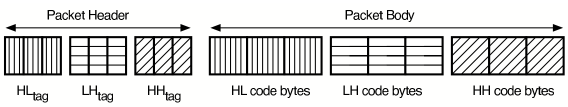



Figure 1: JPEG2000 packet structure.

Thus in LRCP the closest to the beginning of the packstream a packet is, the more essential its layer is. A trivial approach would be to consider the packets in the order of importance. Figure 3(a) shows that packets have not a strictly decreasing impact when the rank increases, then it is not so simple.

JPEG2000 still images are usually stored in files with jp2 extension which is the base file format described in the standard [3]. This file format is made of boxes which embed the JPEG2000 codestream resulting from the image compression and some additional color management information like color profile which is not required for simple decoding. The compressed data and necessary information to decode them lie in the codestream (see figure 2). Indeed an image can be compressed and written as a pure codestream file for further decoding with JJ2000 for example [13]. JPEG2000 codestream contains parts delimited by two-byte tags (FFxx) [14]. Some parts are required for decoding but there is some pieces of information that can be altered without preventing decoding.

The goal of the following section is to define the required data without which the decoding is impossible on the one hand, and how to determine the level of meaning of the data that can be missing on the other hand. Simulation of losses have been performed and impact on the PSNR are analysed regarding the information available in the main header and in the packet header in order to achieve this goal.

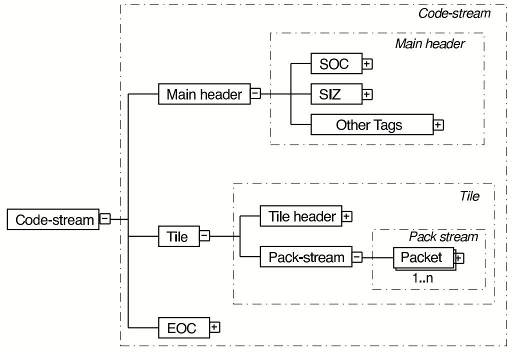



Figure 2: Composition of JPEG2000 codestream.

## 3. ERROR SENSITIVITY

The key information is stored and distributed within all the headers, so it is needed to keep them unchanged at the risk of a non decodable codestream. On the other hand, the packet body can be modified subject to not changing the length of the data (in agreement with that specified in the header). We have experimented the alteration of JPEG2000 codestream (in the packet bodies) with several .jp2-compliant decoders and their behavior is different according to the way packet bodies are modified. When the data are removed or changed without respect of the length, then some applications cannot decode anything (JJ2000, IrfanView) whereas some other decoders may lead to different results if they do not fail to decode (jasper, Preview). This depends on the implementation which handles the resync markers (SOP and EPH if present) or not with more or less success. However in any case, when the data in a packet body are subtituted by something having the same length, all the decoders produce the same result.

The degradation of PSNR that implies such a ”loss” of packet body or codeblock contribution substitution is presented in the next sections. The factors retained for analysis are information available in the main header (SIZ and COD: layer, resolution, component) and those of packet header (codeblock, subband, zero bit-planes, layer inclusion, coding passes, length of contribution).

### 3.1 Experiments

We have measured the degradation of image quality provoked by the deletion of data in each packet body. Actually, the missing data is substituted by the same number of bytes at 0x00 for the obvious reason of decoding cited in section 3 and then the volume of the ”missing” data can be deduced since the length of the contributions is given by the packet

| P | L | R | C | S | Cb | Li | Cp | Z | l | $\Delta_{PSNR}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 375 | -13.9 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 3 | 488 | -15.7 |
| : | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 10 | 1 | 0 | 1 | 0 | 3 | 0 | 4 | 4 | 367 | -0.9 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 24 | 2 | 2 | 0 | 2 | 13 | 2 | 3 | 4 | 17 | -1.7 |

Table 1: Sample of code-blocks contributions. Data collected are from left to right: packet in where the contribution is, layer, resolution, component, subband, layer-inclusion, coding passes, bit-planes to zero, length in bytes and PSNR degradation in dB.

header. All measures have been done on the famous Lena $512 \times 512$ pixels, color and gray-level versions. All the images have been encoded with JJ2000 with given target bitrate, number of layers and number of resolutions with the progression order LRCP.

At this stage, it could be expected that the most important contributions in terms of PSNR are in the first quality layers, *ie.* in the first packets in LRCP order, or that the packet of layer $l$ is always more significant than a packet of layer $l+1$ but we show that it is not that systematic.

### 3.2 Impact of missing packets

The image Lena gray-level (1 component) is encoded at 0.5 bit per pixel, 5 quality layers, 3 resolutions, 1 precinct, 1 tile with a PSNR of 36.73 dB. Its codestream exhibits 15 packets ($5 \times 3 \times 1 \times 1$) while the color version is at 0.5 bpp, 3 layers, 3 resolutions, 3 components, 1 precinct, 1 tile (27 packets) with a PSNR of 31.44dB. All the results are expressed in terms of fall of PSNR ($\Delta_{PSNR}$).

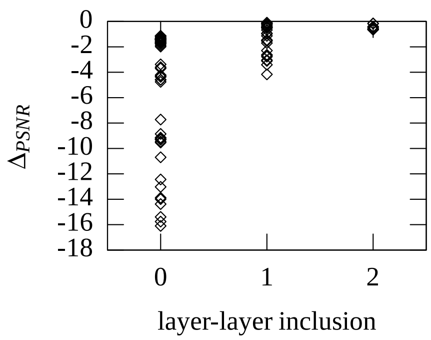
The general tendency of the degradation which implies the packet loss is decreasing with the increase of the layer, however the packet loss concerning a given layer is not necessarily more harmful than the loss in the following layer in the graylevel case. Color image exhibits the same behavior. Figure 3 shows that the significance of a JPEG2000 packet is not ruled by its layer only (figure 3(b)), nor its resolution only (figure 3(c)), nor its rank in a LRCP order (progression by quality) only (figure 3(a)).

To achieve a thinner granularity level, the test is now done on the codeblocks contributions rather than the packet bodies. It will enable to highlight any correlation between $\Delta_{PSNR}$ and parameters of the contributions.

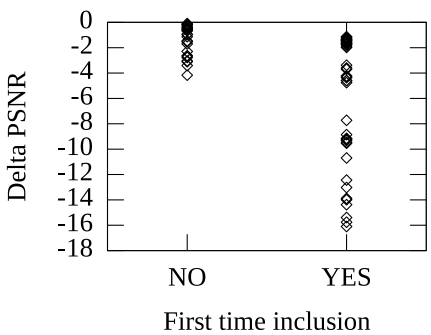
### 3.3 Impact of missing contributions

JPEG2000 packets are formed with codeblocks contributions of the concerned layer/resolution/precinct/component. After decoding the packet headers, the contributions can be altered independently. Table 1 shows a sample of the results associated to the color version of the Lena image but the gray-level image gives similar results.

From the measures it appears that the the length of the contribution does not have a great influence on $\Delta_{PSNR}$, figure 4(a) does not exhibit that longest contributions are crucial. The same can be said about the number of coding passes (more coding passes means more bytes generally), zero bitplanes and subbands (but $LL_0$ of course).




(a) $\Delta_{PSNR}$ vs. farness from the first inclusion.




(b) $\Delta_{PSNR}$ vs. the first inclusion of a CB.

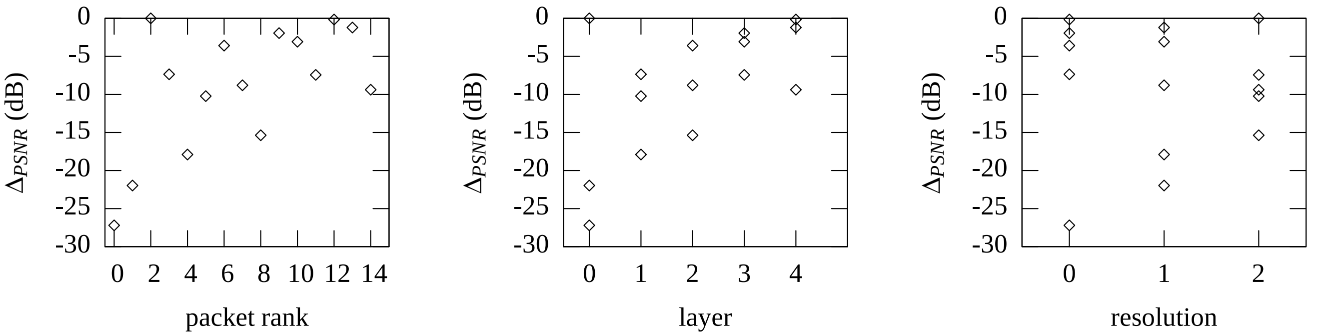
Figure 5: Importance of layer inclusion information.

The layer and the resolution to which belongs a contribution are important indicators on the level of importance (figures 4(b) and 4(c) respectively), the first layers and smallest resolutions tend to produce the biggest degradation with losses appearance but as it is the case for the whole packet bodies, there are contributions which have few significance although in more important layers/resolutions and conversely. When taking into account other parameters, the layer inclusion (LI) is essential. LI means the first layer where the codeblock contributes. The more a CB has already contributed many times, the less its next contribution is essential for the quality as shown on figure 5(a). It appears that the most important contributions are the first contributions of code-blocks, see figure 5(b).

### 3.4 Impact of cumulative losses

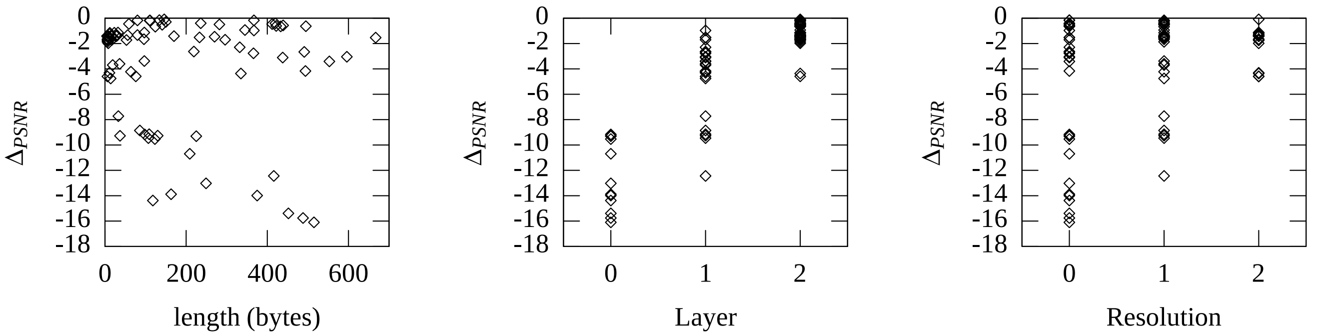
Packet analysis of JPEG2000 packet loss (section 3.2) and of codeblock contributions (section 3.3) are done for single loss and do not take into account the existing hierarchical links between contributions.

Actually a codeblock contribution matches a square area of the image. Depending on the sizes of the CB and of the resolution, the area can cover the whole image, or just a part. As the CBs are encoded independently, their loss affect their spatial area only. Thus the loss of two CBs of the same precinct (recall that in our samples there is one precinct per resolution/component) has cumulative effects. Figure 6 show the degradation after the loss of contributions for CBs 2 and 3 in layer $Q_0$, resolution $R_1$ and subband 1. Essential contributions are lost here for exhibition purpose, $\Delta_{PSNR}$ is extremely severe (-19.74dB) and the two zones are visible (a




(a) $\Delta PSNR$ vs. the rank of the substituted packet. (b) $\Delta_{PSNR}$ vs. the layer of the substituted packet. (c) $\Delta_{PSNR}$ vs. the layer of the substituted packet.

Figure 3: Lena gray-level: impact of the data substitution in each packet body.




(a) $\Delta_{PSNR}$ vs. length of the lost contribution. (b) $\Delta_{PSNR}$ vs. the layer of the touched packet. (c) $\Delta_{PSNR}$ vs. the layer of the touched packet.

Figure 4: Lena color: impact of the data substitution in each code-block contribution.

CB of $64 \times 64$ samples represents the quarter of the resolution 1).

Figure 6: cumulative losses of different CBs.

However the loss of contributions of the same CB is not cumulative, contribution at a given layer needs the contributions of the CB at all previous layers to be decoded. In such a case, a sender does not have to transmit contributions following the loss of the CB at a previous layer.

Our analysis shows that the difference between the layer and the layer inclusion information is a pertinent criterion to determine whether a contribution is crucial in terms of PSNR. This allows to work at a smaller level of granularity than the packet but as packets are formed by contributions, their impact can be also evaluated if protection is done at packet level. The knowledge of the layer inclusion information needs header decoding only, no need to decode contribution. This can help to adapt the protection policy for lossy channel transmission: both FEC (forward error correction) with turbo codes, or partially reliable transport with ARQ mechanism could have improved performance with a protection policy in equivalence with the significance of the data.

## 4. CONCLUSION

Although the layer and the resolution have obviously a great role for deciding the level of significance of JPEG2000 packets, we highlight that it is not sufficient. Therefore performing further analysis at the code-block contribution level is required. It shows the importance of parameters like layer inclusion and helps to decide whether a contribution is important from the point of view of the image quality. This analysis can be performed without decoding the compressed data as only headers are concerned, so it could be done quickly with few computing power and without ability for JPEG2000 decoding. This stage is the first step for adapting an UEP policy for transmission over lossy channels, but it can improve the decoding at the receiver side with a ”loss-aware decoding” too. In the future we will focus on the data analysis in order to develop a statistical model. Planned work concerns the adaptation of the protection policy for partially reliable transport of JPEG2000 with our 2CP-ARQ protocol [2].

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