A wireless Motion JPEG2000 video streaming scheme with a priori channel coding

Max Agueh, Francois-Olivier Devaux, and Jean-Francois Diouris

Abstract—In this work, we present a wireless image/video streaming system for robust transmission of JPEG2000 codestreams over wireless systems. The proposed architecture, based on a priori Forward Error Correction rate allocation allied to layered Unequal Error Protection (UEP), is implemented according to the main recommendations of Wireless JPEG2000 standard final draft. We highlight the effectiveness of the proposed scheme by presenting results from JPEG2000 frames streaming over memoryless Binary Symmetric Channel and Gilbert-Elliot channel (based on Markov chain of order 1). Going straightforward we derived interesting results from Motion JPEG2000 video streaming over real wireless channel traces.

This application, developed within the European IST WCAM project, validates wireless JPEG2000 standards recommendations and is a contribution to reliable JPEG2000 based data streaming over wireless systems.

***Index Terms*—A priori Forward Error Correction (FEC), layered Unequal Error Protection (UEP) with Reed-Solomon codes, wireless channel models, wireless JPEG2000 (JPWL), wireless video streaming.**

I. INTRODUCTION

Nowadays, more and more multimedia applications integrate wireless transmission functionalities. Wireless networks are suitable for those types of applications, due to their ease of deployment and because they yield tremendous advantages in terms of mobility of User Equipment (UE). However, wireless networks are subject to a high level of transmission errors because they rely on radio waves whose characteristics are highly dependent of the transmission environment.

In wireless video transmission applications like the one considered in this paper and presented in Figure 1, effective data protection is a crucial issue.

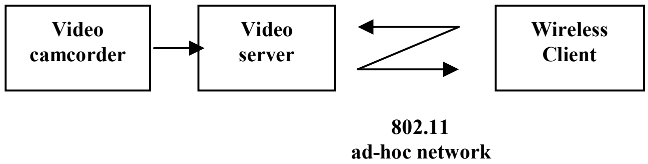

Fig 1: Wireless video streaming system

JPEG2000, the newest image representation standard, addresses this issue firstly by including predefined error resilient tools in his core encoding system (part 1) and going straightforward by defining in its 11th part called wireless JPEG2000 (JPWL) a set of error resilient techniques to improve the transmission of JPEG2000 codestreams over error-prone wireless channel.

In [1], JPWL system description is presented and the performance of its Error Protection Block (EPB) is evaluated. A fully JPEG2000 Part 1 compliant backward compatible error protection scheme was proposed in [2] where a memoryless Binary Symmetric Channel (BSC) is used for simulations. As packets errors arrive in burst in wireless channel the channel model used in [2] is not realistic. Moreover JPEG2000 codestream interleaving is not considered in [2].

The wireless JPEG2000 system presented in this paper aimed at highlighting the importance of protecting JPEG2000 codestream according to JPWL specifications. Hence, JPWL main ideas such as Forward Error Correction and data interleaving are addressed.

To the best of our knowledge the present work is the first to present results derived from JPEG2000 image/video streaming over realistic wireless channel model (Gilbert-Elliot) and real wireless channel traces.

The paper is arranged as follows. In section II, an overview of JPEG2000 is presented with a focus on JPWL (JPEG2000 11th part). Then the proposed JPWL based system is described in section III with details on its main modules. One subsection is dedicated to a priori protection of the JPEG2000 codestream with Reed-Solomon codes. In section IV, experimental results are derived from JPEG2000 frames transmission over simulated channel models and real wireless channel traces. Finally, some conclusions are provided in section V.

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II. JPEG2000 AND WIRELESS JPEG2000 (JPWL) OVERVIEW

JPEG2000 is the newest image compression standard completing the existing JPEG standard [3].

The interest for JPEG2000 is growing since the Digital Cinema Initiatives (DCI) has selected JPEG2000 for future distribution of motion pictures.

Its main characteristics are: lossy or lossless compression modes; resolution, quality and spatial scalability; transmission and progressive image reconstruction; error resilience for low bit rate mobile applications; Region Of Interest (ROI) functionality, etc.

Part 1 of the standard defines different tools allowing the decoder to detect errors in the transmitted codestream, to select the erroneous part of the code and to synchronise the decoder in order to avoid decoder crash. Even if those tools give a certain level of protection from transmission errors, they become ineffective when the transmission channel experiences high bit error rate. Wireless JPEG2000 (JPEG2000 11th part) addressed this issue by defining techniques to make JPEG2000 codestream more resilient to transmission errors in wireless systems.

Wireless JPEG (JPWL) which is still in standardization process, specifies error resilience tools such as Forward Error Correction, interleaving, unequal error protection.

In this paper we present a wireless JPEG2000 video streaming system based on the recommendations of JPWL final draft [4].

III. A WIRELESS JPEG2000 IMAGE/VIDEO STREAMING SYSTEM

A. System functionalities:

The functionalities of the proposed JPWL based system are presented in figure 2. The aim of this system is to efficiently transmit a Motion JPEG2000 (MJ2) video sequence through a wireless channel.

The considered wireless channel models are the BSC and Gilbert-Elliot channel models and finally a channel based on real traces.

1)Description : The input of the JPWL codec is a Motion JPEG2000 (MJ2) file. The JPEG2000 codestreams included in the Motion JPEG2000 file are extracted and indexed.

These indexed codestreams are then transmitted to the JPWL encoder ([4] presents a more accurate description of the JPWL encoder and decoder used) which applies FEC at the specified rate and adds the JPWL markers in order to make the codestream compliant to the Wireless JPEG2000 standard. At this stage, the frames are still JPEG2000 part 1 compliant, which means that any JPEG2000 decoder is able to decode them.

To increase the JPWL frames robustness, an interleaving mechanism is processed before each frame transmission through the error-prone channel. This is a recommended mechanism for transmission over wireless channel where errors occur in burst (contiguous long sequence of errors). Thank to the interleaving mechanism the correlation between errors is reduced.

The step following the JPWL frames interleaving is the RTP packetisation. In this process, JPEG2000 codestream data or other types of data are incorporated into RTP packets as described in [5].

RTP packets are then transmitted through the wireless channel which is first modelled by a memoryless BSC or a memory Gilbert-Elliot (GE) channel model. These two channel models will be further presented.

At the decoder side, after the depacketisation process, the JPWL decoder corrects and decodes the received JPWL frames and rebuilds the JPEG2000 frames. At this stage, parameters such as Packet Error Rates (PER) are extracted and give information on the channel state. The decoder sends this information back to the JPWL encoder via the Up link.

The last process of the transmission chain is the evaluation of the Peak Signal to Noise Ratio (PSNR) which measures the distortion between the transmitted and the decoded image/video.

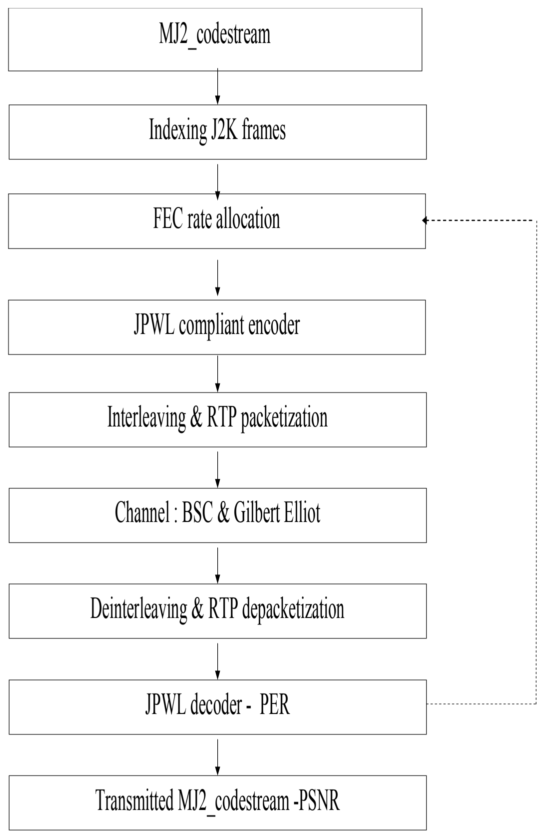

Fig 2: JPWL based system functionalities

2) Wireless channel modeling: When designing the JPWL encoder, different channel models where studied to enhance the protection mechanism. A special interest was dedicated in this work to wireless channel modeling. In the first step the channel was modeled as a memoryless BSC. This type of channel is characterized by uncorrelated error occurrences which are not really representative of real wireless channel. Indeed, wireless channels experience burst errors leading to a correlated repartition of errors. So, the second channel model considered in our work is the Gilbert-Elliot model. This model is based on first order Markov chains and is a packet level model emulating the correlated error characteristics of wireless channel.

Memoryless Binary Symmetric channel: A BSC model represented in figure 3 is an idealised communication channel with binary input and binary output where

$$p(y=0 \mid x=1) = p(y=1 \mid x=0) = p$$

The probability that a bit sent over a BSC is correctly received is (1-p) and is independent of the previous transmission, meaning that errors are uncorrelated. This assumption is no more justified in wireless channel where errors are correlated and arrive in burst.

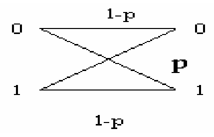

Fig 3: Binary Symmetric Channel

For simplicity, we use this model in the first step of our work but we then developed a more realistic wireless channel model, the Gilbert-Elliot channel model, which is based on the first order Markov chain.

Markov based Gilbert-Elliot channel model: The wireless channel is modelled to have two states: good and bad [6]. In the good state (g), the channel provides a constant and low bit error probability (e_G) whereas in the bad state (b), the channel experiences a high bit error probability (e_B). Hence, $e_G << e_B$.

Therefore, our wireless channel is modelled as a two state Markov process (figure 4).

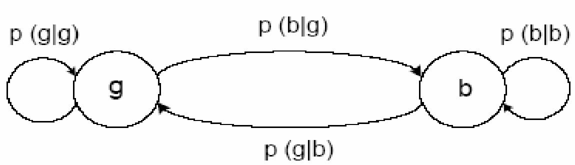

Fig 4: Two-state Markov process scheme

With this model the channel will produce error bursts. This is because while in bad state the probability of staying in it is greater than the probability of returning to good state.

This Markov process is applied for each bit of codestream, and to compute the bit error rate (BER), we consider the probability of staying in bad state (p(b)).

Of course, applying conditional probability, we have:

$$(p(g|g) + p(b|g) = 1 \text{ and } p(g|b) + p(b|g) = 1$$

And

$$p(g) = p(g|g) \cdot p(g) + p(g|b) \cdot p(b) \qquad (1.1)$$

$$p(b) = p(b|g) \cdot p(g) + p(b|b) \cdot p(g) \qquad (1.2)$$

We obtain the expected p(b) as follows:

$$p(b) = [1 - p(g|g)] / [2 - p(g|g) - p(b|b)] \qquad (1.3)$$

A comprehensive description of the Markov modelling for wireless channel is explained in [6].

B. *The protection strategy*

In order to make JPEG2000 codestreams resilient to transmission errors, Unequal Error Protection (UEP) is applied on the codestreams and Forward Error Correction with a priori assignment of Reed-Solomon (RS) codes is used.

In the "a priori protection strategy" we empirically defined a set of RS codes for each image quality layer. So for an image with L quality layers we chose a set of L Reed-Solomon codes between the RS default codes registered by the JPWL Registration Authority. The most powerful of the L Reed-Solomon codes is assigned to the first layer and the other codes are assigned by decreasing order of power to the other quality layers. By this way all the image content is protected by decreasing order of importance in other words this protection strategy could be seen as a layered unequal error protection with fixed RS codes.

IV. JPEG2000 IMAGES/VIDEO STREAMING RESULTS

The interest of this section is to show the results achieved when using channel models and highlight the practical interest of the proposed JPWL based system by using real wireless channel traces.

The video sequence used is the *speedway.mj2* [7] containing 200 JPEG2000 frames and when dealing with a single image streaming, the corresponding image is *speedway_130.j2k* (576x720, 3 components, 3 layers) compressed at an overall quality of 0.2 bpp (bit per pixel) with 0.05 bpp for base layer, 0.1 bpp for the second layer and 0.2 bpp for the third layer.

As error occurrence in the transmission channel is a random process, different runs were made for each simulation and the Mean Square Error (MSE) between the original image (I_o) and the decoded image (I_d), is averaged over all the runs in order to have statistically representative metrics.

The measured Peak Signal to Noise Ratio (PSNR) is obtained as follows:

$$MSE(I_o, I_d) = \frac{1}{M.N} \sum_{x=1}^{M} \sum_{y=1}^{N} |I_o(x,y) - I_d(x,y)|^2$$

$$\overline{MSE} = \frac{MSE}{N_{frames}}$$

$$PSNR = 10 * \log_{10} \left(\frac{255^2}{\overline{MSE}} \right)$$

Where $\overline{MSE}$ is the Mean Square Error over all the N_{frames} images considered. In the case of Motion JPEG2000 streaming, N_{frames} represents the 200 JPEG2000 frames constituting the video sequence and in the single image transmission case N_{frames} represents the number of trials needed to have a statistically representative metric. In the last case, each PSNR measure is associated to a decoding rate metric which corresponds to crash estimation on the basis of 1000 transmission trials. Considering more realistic image quality metrics like Structural Similarity Index (SSIM) or Mean Opinion Score (MOS) could be an interesting extension to this work.

The overall protection rate is $R = 2/3$ and the selected Reed-Solomon codes used for all image/video streaming tests are: RS (48, 32) for base layer, RS (40, 32) for layer 2, RS (37, 32) for layer 1.

A. JPEG2000 image transmission over memoryless Binary Symmetric Channel model:

Figure 5 shows Peak Signal to Noise Ratio (PSNR) versus Bit Error Rate (BER), when transmitting a JPEG2000 image (*speedway_130.j2k)* through a channel modelled as a memoryless BSC along with the decoding rate associated to the image transmission trials.

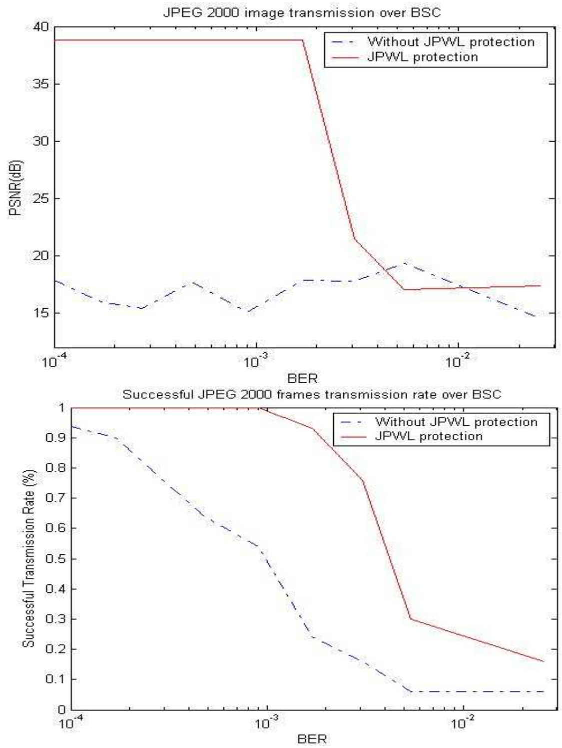

Fig 5: JPEG2000 image transmission over BSC

From figure 5 we observed that when transmitting JPEG2000 frames over memoryless BSC without a priori FEC the mean PSNR is very low (under 20dB) whereas the proposed scheme significantly improved the quality of the transmitted frames and considerably reduced the decoder crashing rate.

When compared to the non JPWL compliant layered Unequal Error Protection presented in [2], our JPWL based scheme yields an improvement of 10 dB for $BER \leq 1.10^{-3}$. Above this value the performances quickly degrade due to the suboptimal protection rate allocation mechanism.

B. JPEG2000 frames transmission over Gilbert-Elliot Channel:

Gilbert-Elliot channels with different BER were emulated by deriving from equation (1.3) the corresponding set of values of $P(g/g)$ and $P(b/b)$ respectively the probability to stay in a good state and the probability to stay in a bad state.

Figure 6 indicates the Peak Signal to Noise Ratio (PSNR) versus BER with the associated successful decoding rate curve.

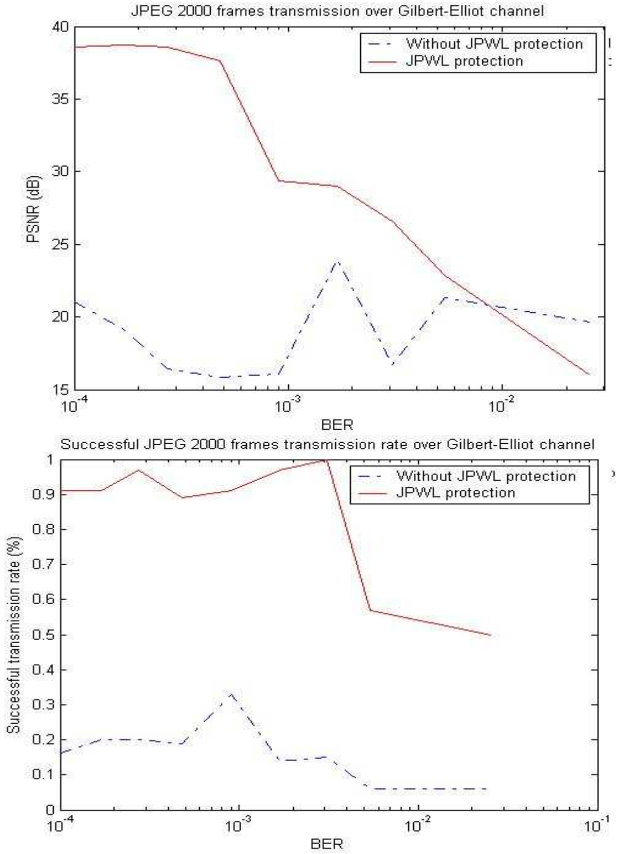

Fig 6: JPEG2000 image transmission over GE channel

In this case, the Peak Signal to Noise Ratio (PSNR) improvement is also obvious. It is worth noticing that for a Gilbert-Elliot channel the successful decoding rate is very low when compared to the BSC due to the fact that errors occur in bursts.

Hence, when the BER is increased (beyond 1.10^{-3}) the decoded images quality drastically decreased inferring the necessity of building an optimal FEC rate allocation mechanism based on a dynamic adaptation to channel conditions. This could be an interesting extension to our work

From those tests we concluded that the a priori FEC protection strategy yields tremendous improvement in terms of PSNR and considerably reduced decoding crashes. However this protection strategy is effective as far as the selected RS codes leads to a good compromise in terms of protection rate/distortion ratio.

C. JPEG2000 codestreams interleaving for transmission over Gilbert-Elliot Channel:

In this section JPEG2000 codestreams interleaving is evalutated. The considered channel is a Gilbert-Elliot channel emulated with a $BER = 1{,}195.10^{-3}$ and the interleaving degrees are 1, 2, 4, 8 , 16 , 32, 64 and 128. Table 1 shows the PSNR evolution as function of interleaving degree I .

TABLE 1: INTERLEAVING DEGREE AND ASSOCIATED IMAGE PSNR

Interleaving degree I	PSNR(dB)	Successful decoding rate (%)
I=1	18.4149	0.770
I=2	20.3488	0.904
I=8	22.5024	0.936
I=16	22.7078	0.928
I=32	23.0597	0.94
I=64	23.7704	0.924
I=128	23.1956	0.921

The interest of interleaving is shown in table 1 in the sense that the PSNR is increasing with the interleaving degree I . The results presented in table 1 are valid for a Gilbert-Elliot channel with a specific error correlation factor and are no longer the same when this factor changes. For the considered channel, we can observe that for $I \le 8$, interleaving has no noticeable impact because the interleaving degree I is smaller than the average error burst length (estimated to 6 bytes in this case). It is worth noticing that higher values of I (128) yield only slight improvement in terms of PSNR while consuming considerable memory resources leading to the conclusion that reasonable interleaving degrees (typically $I = 16$ or $I = 32$) are a good compromise.

D. Wireless Motion JPEG2000 video transmission over real wireless channel traces :

Thanks to the wireless multimedia system proposed in figure 7, the effectiveness of the JPWL codec is evaluated by computing the PSNR at the output of the system. Through a client/server application the JPEG2000 frames extracted from the Motion JPEG2000 (MJ2) file are transmitted to the receiver which represents the wireless client.

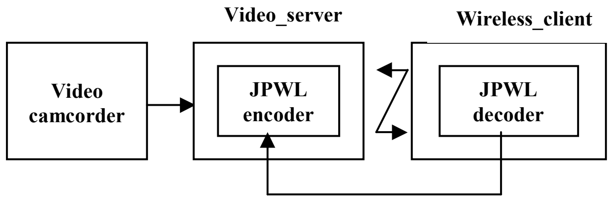

Fig 7: Wireless multimedia system

The wireless channel is emulated by wireless channel traces [8]. Those traces are a set of loss patterns covering different transmission scenarios (mobile or static). They where generated by connecting two laptops in ad-hoc network using two PCMCIA IEEE 802.11b/g cards (at 2,4 GHz).

The video sequence is streamed over the generated loss patterns. Each pattern corresponds to a specific Carrier to Noise ratio $\frac{C}{N}$ ($\frac{C}{N}$ is the ratio between the desired signal and the total received noise power). The considered loss patterns had a $\frac{C}{N}$ varying between 11dB and 21 dB corresponding to Bit Error Rate between 0.0001 and 0.025. The used mode at the physical layer of the wireless link is the mode 4 where the modulation is QPSK , the coding rate is 3/4 and the Nominal Data Rate $R_{Nominal}$ is 18Mbit/s.

As the previous section already demonstrates the necessity of using JPWL protection for a robust transmission of JPEG2000 streams, video transmission without JPWL features is not considered in this part. Figure 8 shows the PSNR of the decoded video sequence when applying a priori FEC rate allocation with layered unequal error protection.

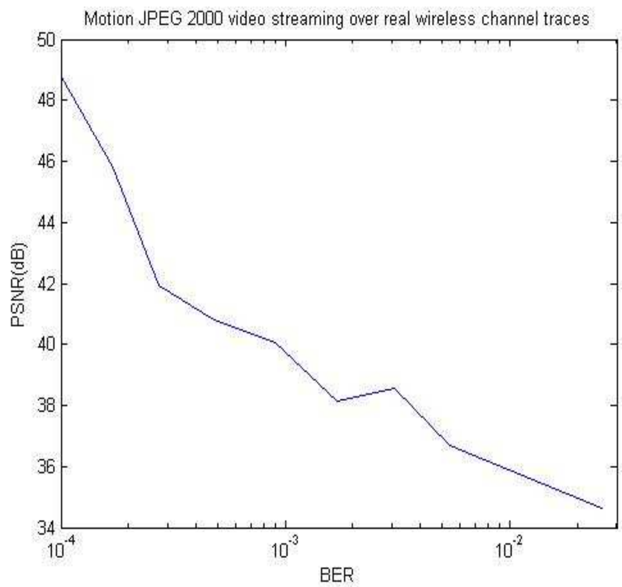

Fig 8: Wireless Motion JPEG2000 video streaming

We observed that thanks to a good a priori FEC rate allocation and interleaving compromise ($I = 32$ suggested by previous section), the proposed protection strategy, yields excellent results in terms of PSNR for JPEG2000 video streaming.

V. CONCLUSION

In this paper, a JPWL compliant system for robust transmission of JPEG2000 images/video over wireless system is presented.

The paper started by an overview of the different characteristics and features of JPEG2000 and Wireless JPEG2000 (JPWL) defined in Part 11 of JPEG2000 standard and then described the proposed system architecture.

We then introduced the wireless channel models used when designing the system: a memoryless BSC and a more realistic memory channel based on the first order Markov chain (Gilbert-Elliot channel model).

We used a priori FEC with layered Unequal Error Protection (UEP) as codestreams protection strategy. Interesting results are then presented to demonstrate the effectiveness of the proposed scheme when transmitting image through BSC and Gilbert-Elliot channels and the impact of data interleaving is also addressed. Then the proposed system is validated by a test of motion JPEG2000 video streaming over real wireless channel traces.

Summarizing we can say that JPEG2000, including the JPWL features, is a good point of departure to achieve robust video transmissions over noisy channels. Hence, we consider the proposed JPWL compliant system based on a priori FEC rate allocation with layered Unequal Error Protection, as a valid foundation to accomplish JPEG2000 based wireless multimedia transmissions.

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