Optimal Interleaving for Robust Wireless JPEG 2000 Images and Video Transmission

Daniel Pascual Biosca and Max Agueh

LACSC - ECE Paris, 37 Quai de grenelle,
75015 Paris, France
{biosca,agueh}@ece.fr

Abstract. In this paper we study the impact of interleaving on JPEG2000 images and video transmission through wireless channels. Based on interleaving impact evaluation, we derive a lower bound limit for the successful images decoding rate in wireless environments. Since the successful decoding rate is of central importance to guarantee Quality of Service to wireless clients, we rely on the derived limit to evaluate the performance of near-optimal interleaved frames using a wireless JPEG 2000 based client/server application. This work is a step toward optimal interleaving for robust Wireless JPEG 2000 based images and video transmission.

Keywords: Interleaving, Wireless JPEG2000, Successful decoding rate, Forward Error Correction, Reed-Solomon codes.

1 Introduction

With the development of smart wireless fixed and mobile devices, efficient multimedia transmission over wireless error-prone channels becomes an important issue. Among existing images representation standards, JPEG 2000 1 is one of the most promising to address robust wireless images/video transmission challenges. Actually, JPEG 2000 defines an extension named JPWL [2] [3] (JPEG 2000 for wireless - 11th part of the standard) for reliable transmission of JPEG 2000 based codestreams over error-prone channels. Hence techniques such as Forward Error Correction (FEC) with Reed-Solomon (RS) codes, Unequal Error Protection (UEP) and data interleaving are proposed to increase the robustness of JPEG 2000 codestreams against transmission errors. Although, JPEG 2000 based FEC techniques has been intensively investigated in the literature [4][5][6][7], few works address JPEG 2000 codestreams interleaving issues. In [8], F. Frescura and G. Baruffa propose a backward-compatible JPEG 2000 virtual interleaving which improves the effectiveness of the RS codes. The proposed virtual interleaver guarantees the backward compatibility of JPEG 2000 frames by computing nonconsecutive parity bytes. However, as only parity bytes are interleaved, remaining part of the JPEG 2000 codestreams are still significantly sensitive to transmissions errors.

L. Atzori, J. Delgado, and D. Giusto (Eds.): MOBIMEDIA 2011, LNICST 79, pp. 217–226, 2012.

Since, JPEG 2000 codestreams headers and marker segments are the most important part of the codestreams, a specific emphasis should be taken to integrate them in a overall and more generic interleaving scheme.

In this work we study the impact of interleaving on JPEG 2000 images and video transmission over wireless networks. To the best of our knowledge the present work is the first to rely on interleaving to derive a lower bound limit for successful decoding rate for robust JPEG 2000 images/video streaming over wireless channel. Thus, a straightforward comparison to already implemented interleaving techniques is not possible.

2 Wireless JPEG 2000 Overview and Interleaving Framework

In this section, we present an overview of JPEG2000 Wireless standard and we provide an analysis of interleaved codeword error probability.

2.1 Wireless JPEG2000

Wireless JPEG2000 [2] [3] defines a set of 19 RS codes [2] to protect each part of JPEG 2000 codestreams against transmission errors. A $\boldsymbol{RS(n,k)}$ code can correct up to $\boldsymbol{t=(n-k)/2}$ or symbols. In JPEG 2000 codestreams, redundancy is allocated inside Error Protection Block (EPB) markers segments. A detailed description of JPWL codestream is available in [2]. In figure 1, we present the JPWL codestream structure considered in this work. This codestreams is constituted with *K* tile-parts. Main header is protected with *N* EPBs; The first tile-part is protected with *L* and *M* EPBs respectively for header and bitstream; last tile-part uses *P* and *X* EPBs respectively for its header and its bitstream protection. All EPBs are in packed mode.

2.2 Gilbert-Elliot Channel Model

The Gilbert-Elliot (GE) model is widely used to simulate the burst-error behavior of the wireless channels. The GE model considered in this work is a Markov chain of order 1 and is extensively presented in [9]. This GE model has two states: the state Good, where the channel symbol is correctly transmitted; and the Bad state, where the channel symbol is corrupted. The transition probability from Good state to Bad state is $\boldsymbol{p_{gb}}$, which is generally low; and the transition probability from Bad state to Good state is $\boldsymbol{p_{bg}}$, which is often high. The stationary values for the two states are given by:

$$\boldsymbol{\pi_B = SER = \frac{p_{bg}}{p_{bg}+p_{gb}}}, \tag{1}$$

$$\boldsymbol{\pi_G = 1 - SER = \frac{p_{gb}}{p_{bg}+p_{gb}}} \tag{2}$$

where $\boldsymbol{SER}$ is the Symbol Error Rate.

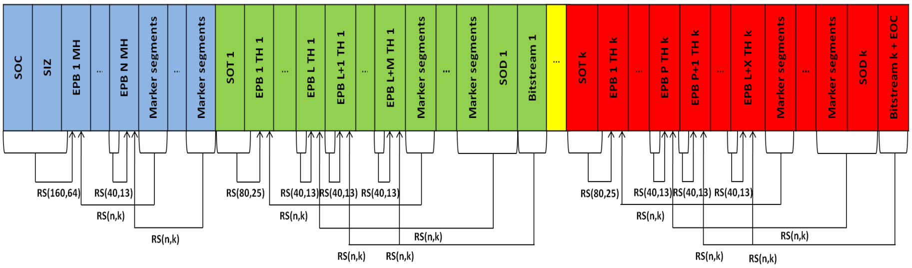

Fig. 1. JPWL codestream protected with EPBs

From [10] the transition probabilities can be expressed as:

$$p_{bg} = (1 - SER)(1 - \rho) \tag{3}$$

$$p_{gb} = SER(1 - \rho) \tag{4}$$

where $\rho = 1 - p_{gb} - p_{gb}$ is the correlation between two consecutive error symbols. Since error bursts may be very harmful for the error correction process, interleaving the protected data before transmitting it through the channel, helps to significantly decrease the decoding error rate. Hence, with interleaving, the correlation between two consecutive error symbols decreases by ρ^I, where I represents the interleaving depth. Then, channel parameters can be expressed as:

$$p_{bg}{}^{I} = (1 - SER) \cdot (1 - \rho^I) \tag{5}$$

$$p_{gb}{}^{I} = SER \cdot (1 - \rho^I) \tag{6}$$

As interleaving increases, the error distribution of the channel becomes more uniform, resulting in a memoryless Binary Symmetric Channel (BSC) with same SER. Indeed $\lim_{I\to\infty} p_{bg} = (1 - SER)$ and $\lim_{I\to\infty} p_{gb} = SER$.

2.3 Impact of Interleaving on Error Probability Reduction

In this section we investigate the impact of interleaving on error probability reduction at the decoder side. In the scenario considered, data is protected with RS codes and transmitted through a GE channel. From [10] the probability of having residual errors in a codeword after RS error correction in a GE channel is:

$$P_{cw}(n, k) = \sum_{m=t+1}^{n} P(m, n) \tag{7}$$

where $P(m, n)$ is the probability of having exactly m errors in n consecutive symbols. A detailed description of $P(m, n)$ is available in [10]. For infinite interleaving, the codeword error probability in a BSC channel [11] can be used:

$$P_{cw-bsc}(n, k) \le \sum_{m=t+1}^{n} \binom{n}{m} SER^m (1 - SER)^{n-m} \tag{8}$$

Figure 2 presents the codeword error probability versus RS codes capability for different interleaving depths. We observe that increasing interleaving depth significantly reduces the codeword error probability. However, for RS codes with low error correction capability, interleaving is inefficient and may become harmful. This is because interleaving reduces the correlation between error symbols but also between error-free symbols. Since the SER remains constant, increasing the interleaving depth reduces the bursts length at the expense of increasing the number of bursts.

3 Successful Decoding Rate

We define the successful decoding rate $\boldsymbol{S_{frame}}$ as the percentage of JPEG 2000 images which are free of errors after error correction in the main header, in any of the tile-part headers, in the EPBs marker segment fields used to protect the bitstreams, and in the End Of Codestream (EOC) marker segment. Hence, we have:

$$\boldsymbol{S_{frame}} \geq (\boldsymbol{1} - \boldsymbol{P_{main}})(\boldsymbol{1} - \boldsymbol{P_{tile\,1}})(\boldsymbol{1} - \boldsymbol{P_{bs\,1}}) \cdots (\boldsymbol{1} - \boldsymbol{P_{tile\,N}})(\boldsymbol{1} - \boldsymbol{P_{bs\,N}})(\boldsymbol{1} - \boldsymbol{P_{eoc}}) \tag{9}$$

where $\boldsymbol{P_{main}}$, $\boldsymbol{P_{tile}}$, $\boldsymbol{P_{bs}}$ and $\boldsymbol{P_{eoc}}$ are respectively the probability of error in the main header, the tile-part headers, bitstreams and EOC marker segment.

3.1 Basis Assumption

Since Successful decoding rate is an important metric for our interleaving methodology, we first make the assumption that $\boldsymbol{S_{frame}}$ is only constituted of images with error free headers and markers segments. In other words we make the hypothesis that $\boldsymbol{S_{frame}}$ has a lower bound whose estimation is of central importance for practical implementation of JPEG 2000 frames interleaver. We then validate this assumption by simulation using JPEG 2000 codestreams.

Actually, our hypothesis is justified by two reasons. First, residual errors in marker segment fields may look like valid values defined by the standard and thus could not be detected and corrected by the decoder. Hence, those errors may significantly reduce decoded images quality and this leads us to consider them as unsuccessfully decoded images. However, even if those undetected errors are not corrected by the decoder, the bad quality of resulting images will lead to straightforwardly discard these images using the method proposed in [12]. Secondly, the number of bytes to protect with an RS code, may not be multiple of the codeword length, thus byte padding is used up to fill the codeword. If by chance the residual errors fall only inside padding data, the decoding rate will not be affected.

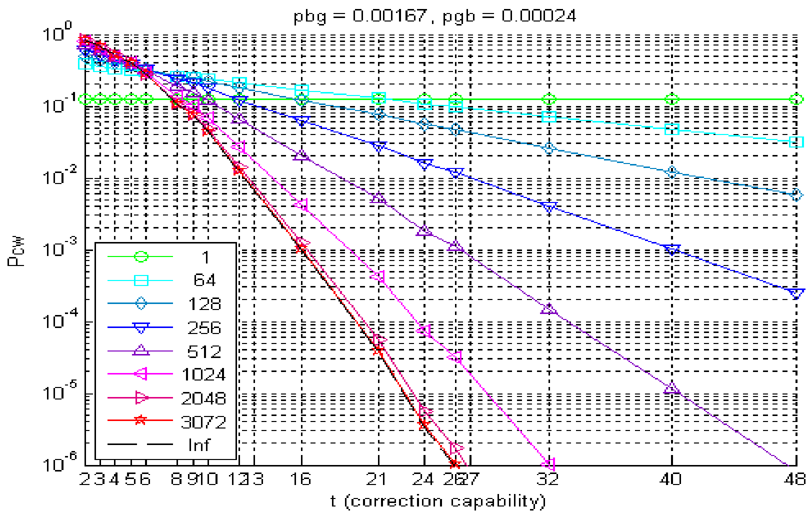

Fig. 2. Codeword error probability for RS codes in a GE channel with $\boldsymbol{p_{bg}} = \mathbf{0.00167}$ and $\boldsymbol{p_{gb}} = \mathbf{0.00024}$

3.2 Residual Error Probability Estimation

The probability of having residual errors in the main header is:

$$\boldsymbol{P_{main}} = \mathbf{1} - [\left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{160}, \mathbf{64})\right)\left(\mathbf{1} - \boldsymbol{P_{cw}}(\boldsymbol{n_a}, \boldsymbol{k_a})\right)^{\boldsymbol{a}} \\ \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{40}, \mathbf{13})\right)\left(\mathbf{1} - \boldsymbol{P_{cw}}(\boldsymbol{n_b}, \boldsymbol{k_b})\right)^{\boldsymbol{b}} \cdots] \tag{10}$$

where $\boldsymbol{a}$ is the number of codewords in the first EPB protected with $\boldsymbol{RS}(\boldsymbol{n_a}, \boldsymbol{k_a})$, $\boldsymbol{b}$ is the number of codewords in the second EPB protected with $\boldsymbol{RS}(\boldsymbol{n_b}, \boldsymbol{k_b})$ and so on. In the same way, the probability of having residual errors in a tile-part header is:

$$\boldsymbol{P_{tile}} = \mathbf{1} - [\left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{80}, \mathbf{25})\right)\left(\mathbf{1} - \boldsymbol{P_{cw}}(\boldsymbol{n_c}, \boldsymbol{k_c})\right)^{\boldsymbol{c}} \\ \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{40}, \mathbf{13})\right)\left(\mathbf{1} - \boldsymbol{P_{cw}}(\boldsymbol{n_d}, \boldsymbol{k_d})\right)^{\boldsymbol{d}} \cdots] \tag{11}$$

where $\boldsymbol{c}$ is the number of codewords in the first EPB protected with $\boldsymbol{RS}(\boldsymbol{n_c}, \boldsymbol{k_c})$, $\boldsymbol{d}$ is the number of codewords in the second EPB protected with $\boldsymbol{RS}(\boldsymbol{n_d}, \boldsymbol{k_d})$ and so on. The probability of having residual errors in the bitstream EPBs is:

$$\boldsymbol{P_{bs}} = \mathbf{1} - \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{40}, \mathbf{13})\right)^{\boldsymbol{N_p}} \tag{12}$$

where $\boldsymbol{N_p}$ is the number of EPBs used in the tile-part. Finally, the error probability for the EOC marker segment is given by:

$$\boldsymbol{P_{eoc}} = \boldsymbol{P_{cw}}(\boldsymbol{n_{last}}, \boldsymbol{k_{last}}) \tag{13}$$

3.3 Assumption Validation

In order to validate our basis assumption, we use Structural Similarity (SSIM) metric 13 to study the effect of residual errors in marker segments of a Lena 2k image. The characteristics of the lena.j2k images are: resolution 352x288; size off codeblocks 64x64; precinct 1; tile 1 (no offset used); component 1 ; resolution levels 6; quality layers 3 (compression rate 20, 10 and 5 respectively); JPEG 2000 data packets 18;

We observe from figure 3 and figure 4 that errors in headers are extremely harmful in terms of quality and successful decoding. Actually, JPEG 2000 images quality decreased significantly when transmission errors occur in the marker segments.

The current work is the first which investigates the JPEG 2000 marker segments sensitivy to wireless transmission errors. It's worth noting the proposed normalized residual error ratio allows comparison between different types of marker segments.

We notice from figure 3 and figure 4 that in the case of header or marker segment corruption, measured MSSIM is under 0.5 and successful decoding rate is under 50% (which is intolerable) whatever the marker. Our assumption which consists to consider only error free header and marker free decoded JPEG 2000 frames in S_{frame} estimation is valid.

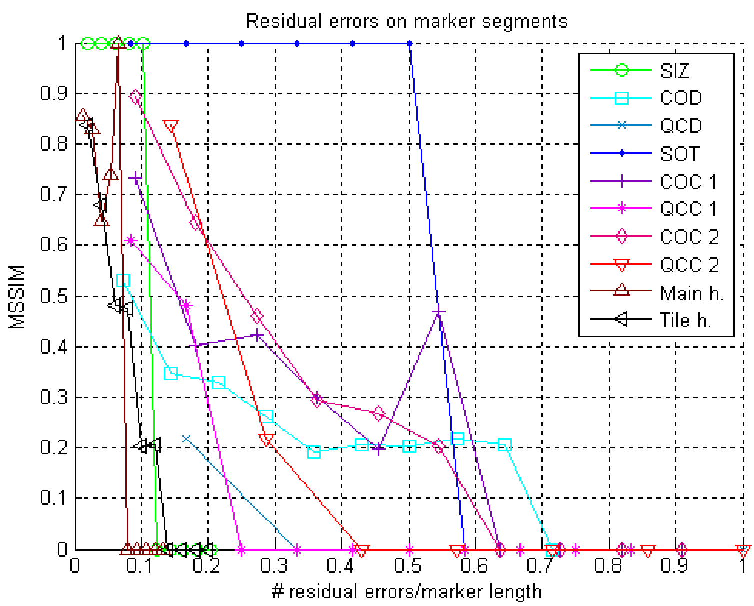

Fig. 3. Normalized residual errors ratio versus SSIM

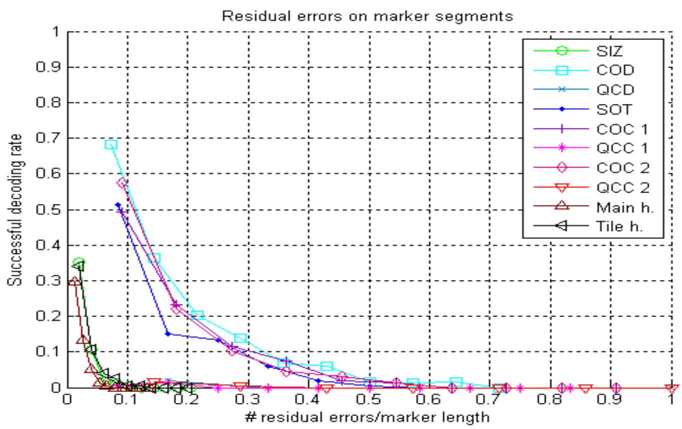

Fig. 4. Normalized residual errors ratio versus successful decoding rate

4 Wireless Performance of Interleaving on Our Wireless JPEG 2000 Transmission System

The video sequence used in this work is *speedway.mj2* video 14 which is constituted by 200 JPEG 2000 frames. The 352 x 288 video is transmitted through a GE channel using the JPWL based transmission system presented in [7]. RTP packet lengths of 512 and 768 are used . The packet traces are derived from real IEEE 802.11 wireless channel traces 15. JPEG 2000 frames marker segments are protected with the predefined RS codes. Equal Error Protection (EEP) is used to protect the whole codestream up to reaching the bandwidth constraint.

The generated GE channel characteristics are: $\boldsymbol{p_{bg}} = \mathbf{0.05227}$ and $\boldsymbol{p_{gb}} = \mathbf{0.00024}$ and the available bandwidth is 10 Mbps. In this scenario, $\boldsymbol{S_{frame}}$ is given by:

$$\boldsymbol{S_{frame}} \geq \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{160}, \mathbf{64})\right)^{\mathbf{3}} \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{80}, \mathbf{25})\right)^{\mathbf{2}} \left(\mathbf{1} - \boldsymbol{P_{cw}}(\mathbf{40}, \mathbf{13})\right)^{\mathbf{18}} \left(\mathbf{1} - \boldsymbol{P_{cw}}(\boldsymbol{n_{last}}, \boldsymbol{k_{last}})\right) \tag{14}$$

In figure 5 and figure 6 the successful decoding rate is plotted for different interleaving depths (named as *Real*) along with the rate of frames without errors in the marker segments (named as *Minimum simulated*). We observe from figure 5 that the best results (more than 90% of successfully decoded images) are achieved for the interleaving depth overcome RTP packet length (here 512 bytes). However when RTP packet length increases the needed interleaving depth to achieve good performance seems to be a multiple of the RTP packet length. An interesting extension to this work could be to derive an optimal interleaving.

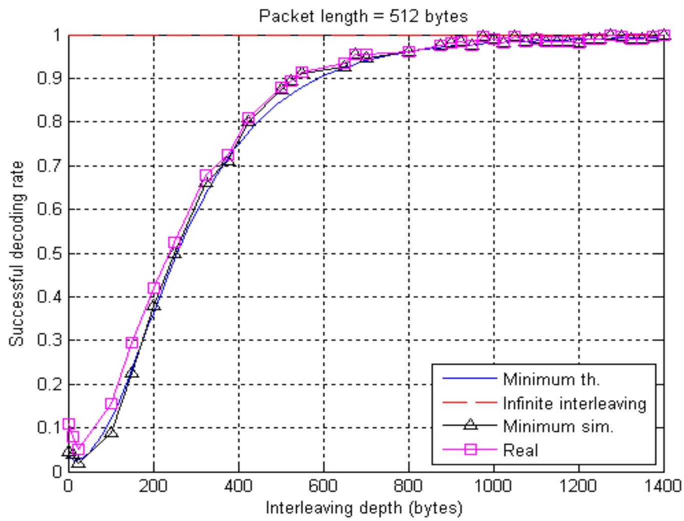

Fig. 5. Interleaving depth versus successful decoding rate – RTP packet length = 512 bytes

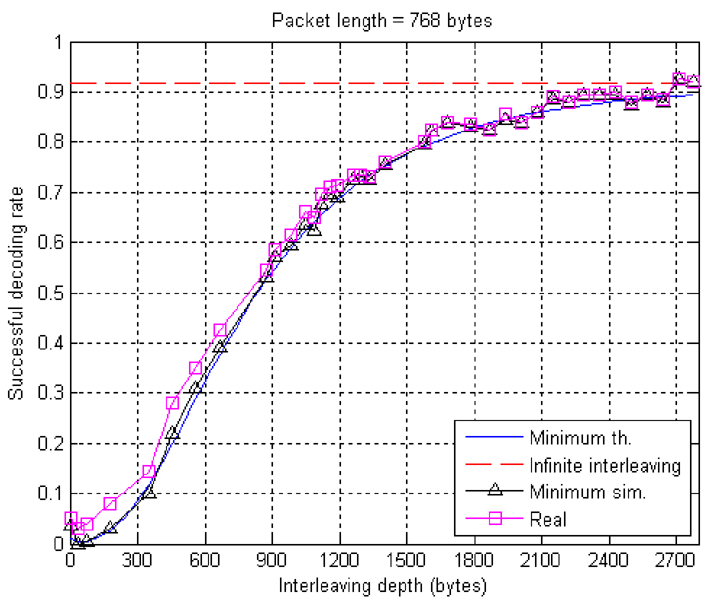

Fig. 6. Interleaving depth versus successful decoding rate – RTP packet length = 768 bytes

5 Conclusion

In this paper, we first investigate the impact of interleaving on robust wireless JPEG 2000 image and video transmission over wireless channels. Then, we derive a lower bound expression for successful decoded frames in wireless transmission of JPEG2000 images and video.

Our derived expression fits very well with JPEG 2000 based decoding images which are empirically estimated. We validate our expression using a wireless JPWL based client/server application. Since, successful decoding rate is significantly impacted by interleaving depth, our work could be considered as a valid step toward optimal interleaving for robust JPEG 2000 images and video transmission through wireless channels.

References

1. Information Technology-JPEG 2000-Image Coding System-Part 1: Core Coding System, ISO/IEC 15 444-1 (2000)
2. Information Technology-JPEG 2000-Image Coding System-Part 11: Wireless, ISO/IEC 15 444-1 (2005)
3. Nicholson, D., Lamy-Bergot, C., Naturel, X., Poulliat, C.: JPEG 2000 backward compatible error protection with Reed-Solomon codes. IEEE Transactions on Consumer Electronics 49(4), 855–860 (2003)
4. Agueh, M., Devaux, F.O., Diouris, J.F.: A Wireless Motion JPEG 2000 video streaming scheme with a priori channel coding. In: Proceeding of 13th European Wireless 2007 (EW 2007), Paris France (April 2007)
5. Guo, Z., Nishikawa, Y., Omaki, R.Y., Onoye, T., Shirakawa, I.: A Low-Complexity FEC Assignment Scheme for Motion JPEG 2000 over Wireless Network. IEEE Transactions on Consumer Electronics 52(1), 81–86 (2006)
6. Agueh, M., Diouris, J.F., Diop, M., Devaux, F.O.: Dynamic channel coding for efficient Motion JPEG 2000 streaming over MANET. In: Proceeding of Mobimedia 2007, Nafpaktos, Greece (August 2007)
7. Agueh, M., Diouris, J.F., Diop, M., Devaux, F.O., De Vleeschouwer, C., Macq, B.: Optimal JPWL Forward Error Correction rate allocation for robust JPEG 2000 images and video streaming over Mobile Ad-hoc Networks. EURASIP Journal on Advances in Signal 2008; Proc., Spec. Issue Wireless Video
8. Frescura, F., Baruffa, G.: Backward-Compatible Interleaving Technique for Robust JPEG 2000 Wireless Transmission. In: Atzori, L., Giusto, D.D., Leonardi, R., Pereira, F. (eds.) VLBV 2005. LNCS, vol. 3893, pp. 44–50. Springer, Heidelberg (2006), doi:10.1007/11738695_7
9. Elliot, O.: Estimates of error rates for codes on burst-noise channel. Bell SystemTechnical Journal 42, 1977–1997 (1963)
10. Yee, J.R., Weldon Jr., E.J.: Evaluation of the performance of error-correcting codes on a Gilbert channel. IEEE Trans. on Communications 43(8), 2316–2323 (1995)
11. Proakis, J.G.: Digital Communications, 3rd edn. McGraw-Hill, New York (2001)
12. Nishikawa, K., Munadi, K., Kiya, H.: No-Reference PSNR Estimation for Quality Monitoring of Motion JPEG 2000 Video Over Lossy Packet Networks. IEEE Transactions on Multimeda 10(4), 637–645 (2008)

13. Wang, Z., Bovik, A.C., Sheikh, H.R., Simoncelli, E.P.: Image Quality Assessment: From Error Visibility to Structural Similarity. IEEE Transactions on Image Processing 13(4), 600–612 (2004)
14. Speedway video sequences have been generated by UCL, http://euterpe.tele.ucl.ac.be/WCAM/public/Speedway%20Sequence
15. Loss patterns acquired during the WCAM Annecy 2004 measurement campaigns IST-2003-507204 WCAM. Wireless Cameras and Audio-Visual Seamless Networking (2004), http://www.ece.fr/~agueh/wcam_patterns