Increasing Watermarking Robustness using Turbo Codes

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Abstract **– In this paper we present a watermarking system that uses the biorthogonal discrete wavelet transform, DWT and the message is encoded before embedding. The proposed watermarking method is very simple, implying four steps: turbo coding of the watermark message, embedding the turbo coded watermark into the host image using a perceptual mask, extraction of the turbo coded watermark from the watermarked, possibly corrupted image, and turbo decoding of the watermark. The goal of this paper is the association of the DWT and duo-binary turbo codes. Some simulation examples prove the performance of the proposed watermarking method.**

Keywords **– Watermarking, Discrete Wavelet Transform, Turbo codes, Duo-binary turbo codes.**

I. INTRODUCTION

Watermarking has been proposed as a means of identifying the owner, by secretly embedding an imperceptible signal into the host signal [1]. Important properties of an image watermarking system include perceptual transparency, robustness, security, and data hiding capacity [2].

Robustness can be assured by using some sort of encoding of the watermark, usually a repetition code or an error correcting code. Despite of their efficient use in telecommunications, turbo codes have been rarely used in watermarking, [3-5]. As seen in [4], the association between watermarking and turbo codes is effective in the wavelet domain.

In this paper we present a watermarking system that uses the biorthogonal discrete wavelet transform, DWT and the message is encoded before embedding. The operations made are the following: 1. turbo coding, 2. embedding the turbo coded message into the host image using a perceptual mask proposed by the authors, 3. extraction of the turbo coded message from the watermarked, possibly corrupted image, and 4. turbo decoding. The paper has the following structure. Section II presents the insertion and extraction of the watermark. Section III presents the turbo encoder and turbo decoder used. Section IV contains simulations using the new technique. Conclusions and future research directions are presented in the last section.

II. WATERMARKING IN THE DWT DOMAIN

The watermark is either embedded in coefficients of known robustness (which are usually large coefficients) or in perceptually significant regions [1], such as contours and textures of an image. This can be done empirically, selecting larger coefficients [2] or using a thresholding scheme in the transform domain [6, 7]. Another approach is to insert the watermark in all coefficients of a transform, using a variable strength for each coefficient [8]. Hybrid techniques, based on compression schemes, embed the watermark using a thresholding scheme and variable strength [6].

In our system, the watermark is masked according to the characteristics of the human visual system (HVS), taking into account the texture and the luminance content of all the image subbands, in all resolution levels of the DWT, except the low frequency one. For coefficients corresponding to contours of the image a higher strength is used, for textures a medium strength is used and for regions with high regularity a lower strength is used, in accordance with the analogy water-filling and watermarking proposed in [9].

The image I, of size $2M \times 2N$, is decomposed into 4 levels of the DWT, where I_l^θ is the subband from level $l \in \{0,1,2,3\}$, and orientation $\theta \in \{0,1,2,3\}$ (horizontal, diagonal and vertical detail subbands, and approximation subband). A binary watermark message m is turbo coded and the result is casted on subbands on different levels of resolutions, $x_l^\theta(i,j)$. The turbo coded watermark $x_l^\theta(i,j)$ is embedded in the wavelet coefficients of the l^{th} level, having the magnitude higher than a threshold T:

$$\tilde{I}_l^\theta(i,j) = I_l^\theta(i,j) + \alpha w_l^\theta(i,j) x_l^\theta(i,j), \text{ if } \left|I_l^\theta(i,j)\right| > T \quad (1)$$

where α is the embedding strength, $w_l^\theta(i,j)$ is a weighing function, which is a half of the quantization step $q_l^\theta(i,j)$. The quantization step of each coefficient is computed as the weighted product of three factors:

$$q^\theta(i,j) = \Theta(l,\theta)\Lambda(l,i,j)\Xi(l,i,j)^{0.2}, \quad (2)$$

and the embedding takes place in all resolution levels, $l \in \{0,1,2\}$, except the coarsest resolution level.

The first factor in (2) is the sensitivity to noise depending on the orientation:

$$\Theta(l,\theta) = \begin{Bmatrix} \sqrt{2}, & \theta = 1 \\ 1, & \text{otherwise} \end{Bmatrix}. \quad (3)$$

The 2nd factor takes into account the local brightness based on the gray level values of the approximation image from level l, where the watermark is embedded, I_l^3:

$$\Lambda(l,i,j) = 1 + L'(l,i,j), \quad (4)$$

where

$$L'(l,i,j) = \begin{Bmatrix} 1 - L(l,i,j), & L(l,i,j) < 0.5 \\ L(l,i,j), & \text{otherwise} \end{Bmatrix}, \quad (5)$$

and

$$L(l,i,j) = \frac{1}{256} I_l^3(i,j). \quad (6)$$

The third factor represents the texture activity around a pixel:

$$\Xi(l,i,j) = \sum_{k=0}^{3-l} \frac{1}{16^k} \sum_{\theta=0}^{2} \sum_{x=0}^{1} \sum_{y=0}^{1} \left[I_{k+l}^\theta \left(y + \frac{i}{2^k}, x + \frac{j}{2^k} \right) \right]^2 \cdot \frac{S_l^3(i,j)}{U_l^3(i,j)} \quad (7)$$

This term is the product of the local mean square value of the DWT coefficients in all detail subbands and the local standard deviation of the image, compressed in the wavelet domain and normalized to its mean [10]. The first contribution is the distance from the edges, whereas the second one the texture. In [8], the second term of eq. (7) was initially the local variance of the low-pass subband, computed in a small 2×2 window centered on the pixel (i,j). This local variance estimation was computed with a low resolution. The reader is referred to [8] for details on the implementation of the original algorithm.

The detection requires the original watermark and the original image, or some significant vector extracted from its wavelet transform, specifically in this case, the detail coefficients with an absolute value above the threshold T. The watermark bit is obtained from the wavelet coefficient $\hat{I}_l^\theta(i,j)$ of the possibly distorted image $\hat{I}^w$, and the original wavelet coefficient $I_l^\theta(i,j)$:

$$\hat{x}_l^\theta(i,j) = \frac{\hat{I}_l^\theta(i,j) - I_l^\theta(i,j)}{\alpha w_l^\theta(i,j)}, \text{ if } \left| I_l^\theta(i,j) \right| > T \quad (8)$$

The estimate of the encoded message is decoded and the watermark message $\hat{m}$ is obtained. We compute at the output the bit error rate between the original watermark message m and the received watermark message $\hat{m}$:

$$BER = \frac{\text{number of erroneous bits}}{\text{number of bits}}, \quad (9)$$

which gives a measure of the performance. In the following section, we explain the architecture of the chosen turbo code.

III. DUO-BINARY TURBO-CODES

Turbo codes [11, 12] are characterized by their powerful error correcting capability while maintaining reasonable complexity and flexibility in terms of coding rates. A few years ago, Douillard and Berrou have proposed a new family of turbo codes with multiple inputs [13]. Particularly, they show by means of simulations that a parallel concatenation of two binary recursive systematic convolutional (RSC) codes based on multiple-input (r-inputs) linear feedback shift registers (LFSRs) provides a better overall performance than turbo codes with single input over AWGN channel.

Multi-binary turbo codes (MBTC) have been adopted in the digital video broadcasting (DVB) standards for return channel via satellite (DVB-RCS) and the terrestrial distribution system (DVB-RCT), and also in the 802.16 standard for local and metropolitan area networks.

A parallel concatenation of two identical r-ary RSC encoders with an interleaver (ilv) is presented in Fig. 1 [14], where u, c^1 and c^2 represent the encoder outputs.

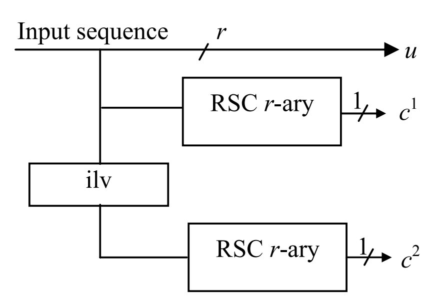

Figure 1. The r-ary turbo-encoder.

The scheme of the 8-state duo-binary RSC encoder, with polynomials 15 (feedback) and 13 (redundancy) in octal form, is shown in Fig. 2, where S_1, S_2 and S_3 denote the encoder states.

In this paper, we consider the particular case of MBTC, namely, the duo-binary turbo codes (DBTC). The trellis of the first encoder is closed to 0 and the trellis of the second encoder is unclosed. The rate of the DBTC is ½.

We considered an *S*-interleaver [15], which is semi-random and exhibits excellent performance since it has very high minimum distances even for moderate block sizes. Thus, for the block size of 768 bits, the *S*-interleavers designed in [16] (see [17] for a more detailed analysis) yields minimum distances of 20. The minimum distance can be further increased [15]. The design of the interleaver is based on a random selection with the following constraint:

$$d\left(i,j\right)=\left|\pi\left(i\right)-\pi\left(j\right)\right|+\left|i-j\right|\geq S \qquad (10)$$

where π represents the fully random permutation function and $d(i,j)$ represents the interleaving distance between the positions i and j, $i,j=1,\ldots,n$. Here, n denotes the codeword size. Based on this design method, the interleaver used in this paper has a minimum distance of 28 for a block size of 768 bits. The length of the coded sequence is 2×768=1536 bits.

For decoding we used the Max-Log-MAP algorithm [18]. This suboptimal version is preferred in practice due to its low computational complexity while keeping near-optimal performance [13]. The scaling factor of the extrinsic information is equal with 0.75 [19]. We assume at the decoder a number of 15 iterations with a stopping criterion.

In Fig. 3 a) and b), bit error rate (BER) and frame error rate (FER) performance of the uncoded case and of the DBTC are plotted for rate ½. In our simulations we considered the AWGN channel.

For a SNR=1.6 dB the bit error rate is $BER=1.5\cdot10^{-6}$. For a $FER=2\cdot10^{-4}$, DBTC performs as close as 0.8 dB from the Shannon limit.

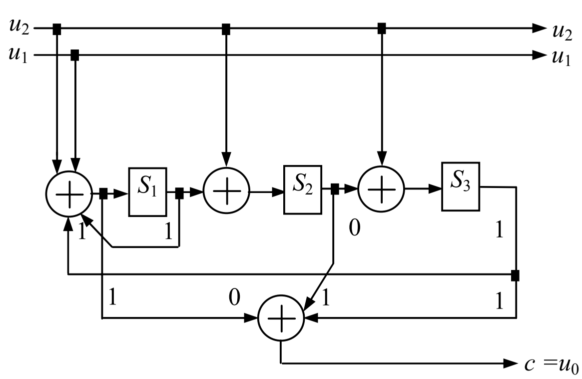

Figure 2. Scheme of the 8-state duo binary RSC encoder with the rate 2/3. Encoder polynomials: 15 (feedback) and 13 (redundancy) in octal form (DVB-RCS constituent encoder for *r*=2).

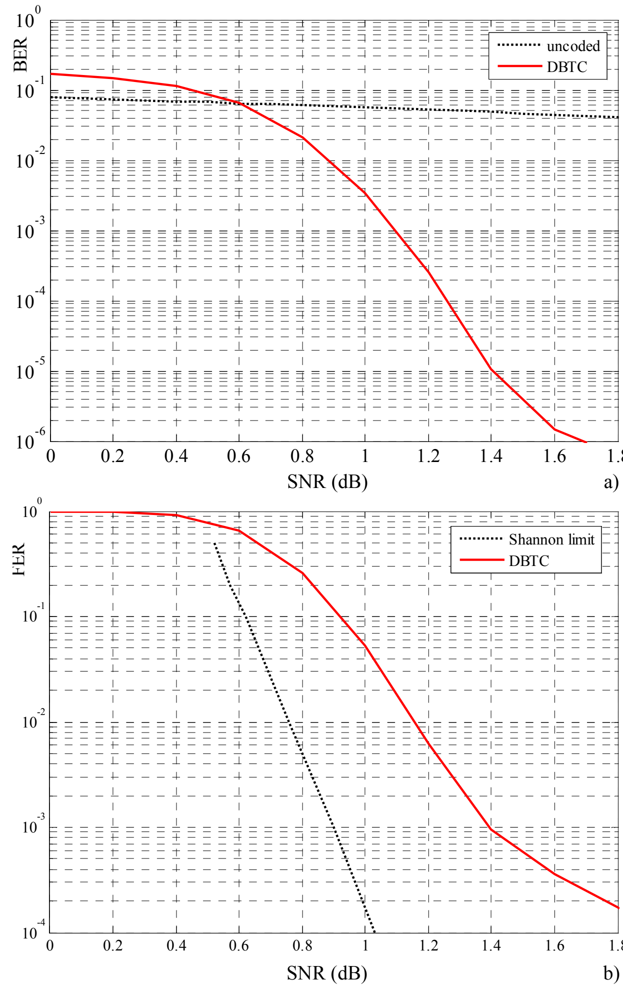

Figure 3. Bit Error Rate (a)) and Frame Error Rate (b)) performance for uncoded case and 1/2 rate Duo-Binary Turbo Coded (DBTC) transmission over AWGN channel, is plotted as function of SNR.

IV. SIMULATION RESULTS

In this section, simulation results obtained using the image Lena (512×512) are reported. The image is decomposed into a four level decomposition with a biorthogonal mother wavelet. As suggested in [20], the biorthogonal mother wavelets used in the JPEG2000 standard are most suitable. Hence, in our experiments, we use the mother wavelet Biorthogonal 2.2 (bior2.2). A pseudo-random binary message m with values $\{-1,1\}$ is turbo coded using a DBTC, resulting in a coded watermark message. The block size is 768 bits and the number of blocks for the image Lena is 7. The coded watermark is embedded into each subband in coefficients with the magnitude greater than a threshold T, for levels 0, 1 and 2, using eq. (1). In all simulations, this threshold was experimentally set to the value 10. The embedding strength is set to $\alpha=9$, resulting in a watermarked image with the peak signal-to-noise ratio PSNR=29.95 dB. Two experiments were performed: addition of white Gaussian noise (AWGN) and JPEG compression.

In the first experiment, we added noise with mean 0 and variance σ^2 to the watermarked image. We repeated the experiment for σ ranging from 3.25 to 15 with step 0.25; we plotted BER, without coding the watermark, and with a DBTC. Fig. 4 presents the values of the BER computed for different values of σ, while Fig. 5 presents BER as a function of the PSNR between the attacked image and the watermarked image, for the uncoded sequence as well the coded sequence. For values of σ inferior to 8, the noise addition doesn't degrade the image too much and the PSNR value is still high. For a PSNR superior to 29 dB, the watermark is reconstructed without error, using turbo decoding. For PSNR values inferior to 29 dB, the attacked images are visually impaired by the noise addition, making the attacked images useless.

Next we studied the robustness of the watermark using the JPEG compression attack. We have compressed the watermarked image using different quality factors, Q from 100 to 10, and we have plotted the BER with and without turbo coding the watermark. Fig. 6 presents the values of the BER computed for different values of the quality factors, for the uncoded sequence as well the coded sequence. For a quality factor higher than 50, the reconstruction of the watermark is almost perfect. Fig. 7 presents BER as a function of the PSNR between the attacked image and the watermarked image.

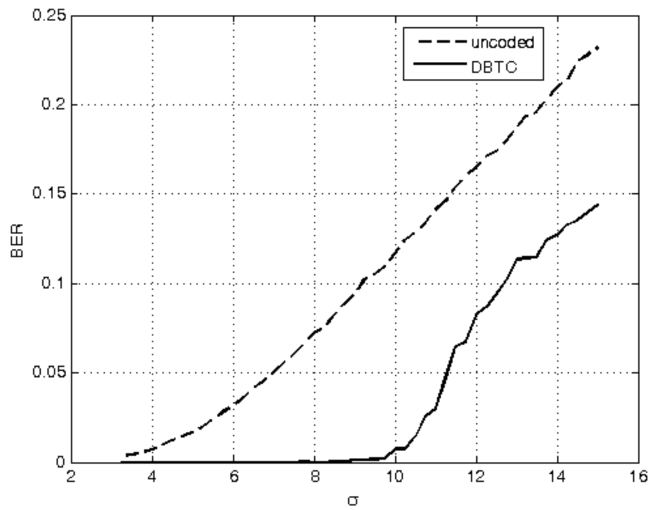

Figure 4. BER versus standard deviation obtained without coding the watermark and using a DBTC for the AWGN attack.

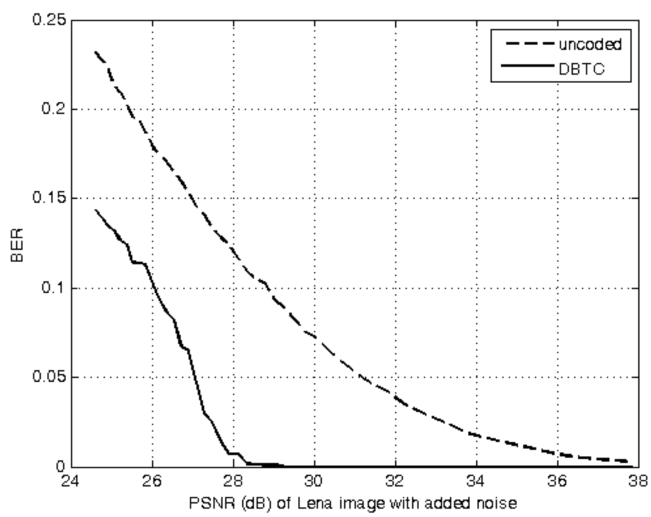

Figure 5. BER versus the PSNR obtained without coding the watermark and using a DBTC for the AWGN attack.

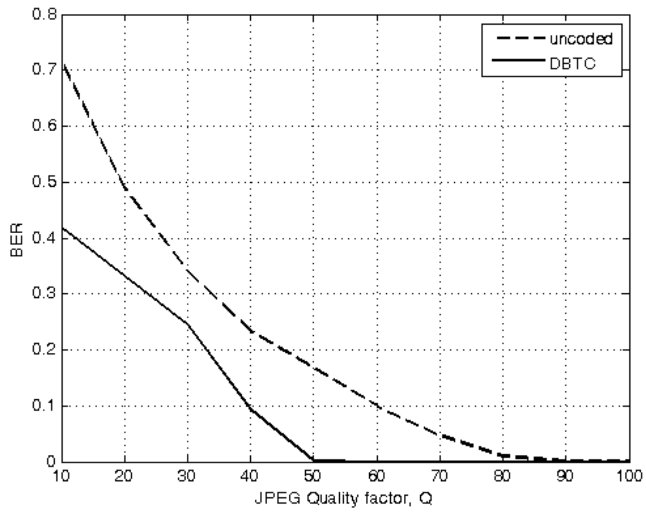

Figure 6. BER versus quality factor obtained without coding the watermark and using a DBTC for JPEG compression.

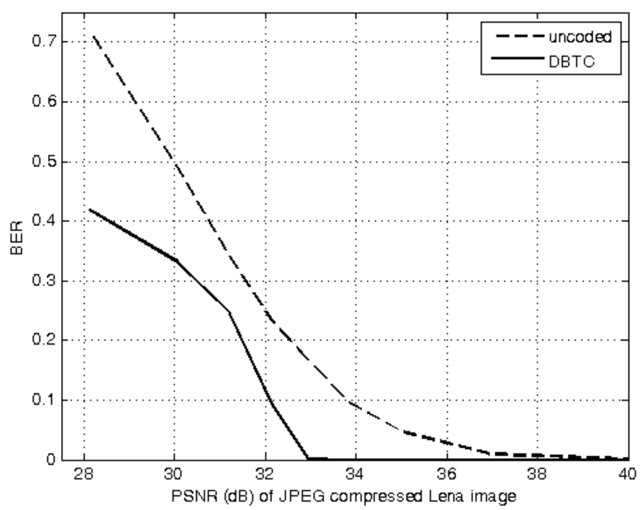

Figure 7. BER versus PSNR obtained without coding the watermark and using a DBTC for JPEG compression.

TABLE I. A BER BASED COMPARISON OF THE CODED AND UNCODED APPROACH.

Attack vs. BER	BER	
	Uncoded	DBTC
JPEG compression, Q=50, PSNR=32.94 dB	0.167132	0.001488
AWGN, σ=8, PSNR=29.29 dB	0.0885	$3.25 \cdot 10^{-4}$

Table I shows numerical values of the BER for the uncoded and for the coded case for each attack. We can see the performance of turbo coding in watermarking in the decrease of the bit error rate. For less severe attacks, the watermark is perfectly reconstructed. This is the case when the attack on the watermarked image can be modeled like an AWGN transmission channel, with a high value of the SNR. It is to be noted that the coding gain brought by the use of the DBTC is superior to 2 dB.

V. CONCLUSION

Analyzing the simulation results the advantages of the use of turbo coding in data embedding are obvious. The simulation results presented in this paper illustrate the decrease of the bit error rate of the message extracted from the watermarked image attacked with two types of attacks.

For less severe attacks, the watermark is perfectly reconstructed if turbo codes are used. This is the case when the attack on the watermarked image can be modeled like an AWGN channel, with a high value of the SNR, needed for a successful decoding for the Max-Log-MAP algorithm.

For severe attacks the images obtained are visually impaired, making them useless.

It is to be noted that the coding gain brought by the use of the DBTC is higher than 2 dB.

In the future, we shall concentrate on the increase of the coding gain. Other future research directions are: the application of the proposed algorithm using an image database to refine the analysis of the robustness with the aid of some statistical tools and the diversification of the set of attacks by the addition of some new attacks like: resizing, median filtering, gamma correction, geometrical transformations, and so on.

REFERENCES

[1] I. Cox, "Robust watermarking", *ECRYPT Summer School on Multimedia Security*, Salzburg, Austria, Sept. 22, 2005.

[2] I. Cox, J. Killian, T. Leighton, T. Shamoon, "Secure Spread Spectrum Watermarking for Multimedia", *IEEE Trans. Image Processing*, 6, 12, 1997, 1673-1687.

[3] N. Abdulaziz, A. Glass, K.K.Pang, “Embedding Data in Images Using Turbo-Coding”, *6th Symposium on DSP for Communication Systems*, 28-31 Jan. 2002, Univ. of Wollongong, Australia.

[4] C.V. Serdean, M.A. Ambroze, M. Tomlinson and J.G. Wade, DWT-based high-capacity blind video watermarking, invariant to geometrical attacks, *IEE Proc.-Vis. Image Signal Process*., 150, 1, Feb. 2003.

[5] Felix Balado and Fernando Perez-Gonzalez, Coding at the Sample Level for Data Hiding: Turbo and Concatenated Codes, *SPIE Security and Watermarking of Multimedia Contents*, San Jose CA, 22-25 Jan. 2001, San Jose CA , USA, 2001, 4314, 532-543.

[6] C. Podilchuk, W. Zeng, "Image-Adaptive Watermarking Using Visual Models", *IEEE JSAC*, 16, 4, May 1998, 525-539

[7] C. Nafornita, A. Isar, M. Borda, "Image Watermarking Based on the Discrete Wavelet Transform Statistical Characteristics", Proc. *IEEE EUROCON 2005*, Serbia & Montenegro, 943-946.

[8] M. Barni, F. Bartolini, A. Piva, "Improved wavelet-based watermarking through pixel-wise masking", *IEEE Trans. Image Processing*, 10, 5, May 2001, 783 – 791.

[9] D. Kundur, "Water-filling for Watermarking?", Proc. *IEEE Int. Conf. On Multimedia and Expo*, NY, 1287-1290, Aug. 2000.

[10] C. Nafornita, A. Isar, M. Borda, "Improved Pixel-Wise Masking for Image Watermarking", in *Multimedia Content Representation, Classification and Security*, September 11-13, 2006, Istanbul, Turkey, LNCS, 90-97.

[11] C. Berrou, A. Glavieux, P. Thitimajshima , "Near Shannon limit error-correcting coding and decoding: Turbo-codes", *Proc.ICC’93*, Geneva, Switzerland, May 1993, 1064 – 1070.

[12] C. Berrou, A. Glavieux, "Near Optimum Error Correcting Coding and Decoding: Turbo-Codes", *IEEE Trans. on Communications*, 44, 10, Oct. 1996.

[13] C. Douillard, C. Berrou, "Turbo Codes With Rate-m/(m+1) Constituent Convolutional Codes", *IEEE Trans. on Communications*, 53, 10, Oct. 2005, 1630-1638.

[14] M. Kovaci, H. Balta, M. Nafornita, "Performance of Multi Binary Turbo Codes on Rayleigh Flat Fading Transmission Channels", *Annals of University from Oradea*, *Romania,* Sect. Electronic, 2006, 64-67.

[15] S. Crozier, "New High-Spread High-Distance Interleavers for Turbo-Codes", 20th *Biennial Symposium on Communications*, Kingston, Ontario, Canada, May 28-31, 2000, 3-7.

[16] S. Dolinar, D. Divsalar, "Weight Distributions for Turbo Codes Using Random and Nonrandom Permutations", *The Telecommunications and Data Acquisition Progress Report*, TDA PR 42-122, Aug. 1995, pp. 56-65.

[17] M. Kovaci, H. Balta, M. Nafornita, "The Performance of Interleavers used in Turbo Codes", *Proc. Int. Symp. Signals, Circuits and Systems, ISSCS 2005*, Iasi, July, 14-15, 2005, 363-366.

[18] J. Vogt, A. Finger, "Improving the Max-Log-MAP Turbo Decoder", *Electron. Lett*., 36, 23, 1937–1939, Nov. 2000.

[19] M. Kovaci, H. Balta, A. De Baynast, M. Nafornita, "Performance Comparison of Punctured Turbo Codes and Multi Binary Turbo Codes", *Proc. International Symposium on Signal, Circuits and Systems, ISSCS 2007*, Iasi, Romania, July, 12-13, 2007, 485-488.

[20] C. Nafornita, A. Isar, "On the Choice of the Mother Wavelet for Perceptual Data Hiding", *Int. Symp. Signals, Circuits and Systems*, *ISSCS 2009,* Iasi, 2009, in press.