Robustness Improvement of Known-Host-State Watermarking Using Host Statistics

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ABSTRACT

In this paper we consider the problem of performance improvement of known-host-state (quantization-based) watermarking methods undergo Additive White Gaussian noise (AWGN) and uniform noise attacks. We question the optimality of uniform high-rate quantizer based design of Dither Modulation and Distortion Compensated Dither Modulation methods from their robustness to these attacks point of view in terms of bit error rate probability. Motivated by the superior performance of the uniform deadzone quantizer over the uniform one in lossy source coding, we propose to replace the latter one by the former designed according to the statistics of the host data. Based on the suggested modifications we obtain analytical expressions for the bit error rate probability analysis of quantization-based watermarking methods in AWGN and uniform noise channels. Experimental results of computer simulations demonstrate significant performance enhancement of known-host-state watermarking techniques in comparison to the classically elaborated schemes.

Keywords: information hiding, known-host-state watermarking, quantization-based watermarking, high-rate quantization, uniform quantizer, uniform deadzone quantizer, bit error rate probability.

1. INTRODUCTION

Digital watermarking is targeting at reliable communications of information through some kind of media. Therefore, one of the possible criteria for the comparison of different data-hiding technologies is the analysis of their information-theoretic performance limits .[1, 2]

Another criterion based on the consideration of data hiding systems from the point of view of practical communications was recently proposed by Perez-Gonzalez *et al.*[3] where the analysis is performed using bit error rate probability. The obtained results demonstrate the behavior of some known-host-state and known-host-statistics methods under certain channel distortions (AWGN attack and uniform noise attack). They also allow to conclude that for high Watermark-to-Noise ratios quantization-based methods outperform spread-spectrum based ones while at low Watermark-to-Noise regime the situation is the opposite one. The performed analysis is based on the assumption borrowed from source coding that in case of high-rate quantization the uniform quantizer is optimal and quantization noise is independent from the host signal .[4]

Several investigations have been performed targeting at establishing the possible ways of uniform quantizer performance improvement for real images in the transform domain when Laplacian or Generalized Gaussian (GG) pdf are used as a stochastic image model .[5] As a possible solution one consists in preservation of the quantizer uniformity everywhere but not in the vicinity of zero where the bin width (the width of the deadzone) is larger than the width of all other bins. This simple modification leads to the superiority of the rate-distortion characteristics of this Uniform Deadzone Quantizer (UDQ) for independent identically distributed (i.i.d.) Laplacian and GG data versus uniform one.

Motivated by this promising result we formulate the goal of this paper as answering the following question: is it possible to achieve better performance for DM and DC-DM designed based on the UDQ in terms of bit error rate probability in AWGN and uniform noise channels?

In our previous work, we have shown that taking into account the host pdf one can considerably increase the achievable rate at low watermark-to-noise ratio (WNR) regime[6] contrarily to the uniform assumption of

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Eggers *et al.*[1] using uniform quantizers. Moreover, practically designed scheme based on non-uniform quantizer taking into account host pdf has outperformed all existing techniques for low-WNR regime under AWGN attack benchmark.[7] Here we extend our results to both AWGN and uniform noise and demonstrate that even without the optimization of compensation parameter in the DC-DM, the proposed scheme has superior performance in comparison with previously reported results.

The paper is organized as follows. In Section 2 we present an overview of known-host-state watermarking. Section 3 contains bit error rate probability bounds for the DM and DC-DM designed using UDQ. In Section 4 benchmarking results for the deadzone-based DM and DC-DM are presented versus performance of the classical schemes. Finally, Section 5 concludes the paper.

Notations. We use capital letters to denote scalar random variables X and regular letters x to designate the realizations of scalar random variables. We use $X \sim f_X(x)$ or simply $X \sim f(x)$ to indicate that a continuous random variable X is distributed according to $f_X(x)$. The variance of X is denoted by σ_X^2. The set of integers is designated by $\mathbb{Z}$.

2. KNOWN-HOST-STATE WATERMARKING

2.1. Dither Modulation

Originally introduced in,[8] binary Dither Modulation (DM) refers to the embedding of the binary value b quantizing the host image using one of two uniform quantizers (a generalization to M-ary DM is possible but this aspect is outside of the scope of this paper). The centroids of the $Q_{-1}(.)$ and $Q_1(.)$ of the quantizers (Figure 1, a) belong to the unidimensional lattices[3]:

$$\Lambda_{-1} = 2\Delta\mathbb{Z}, \tag{1}$$

$$\Lambda_1 = 2\Delta\mathbb{Z} + \Delta. \tag{2}$$

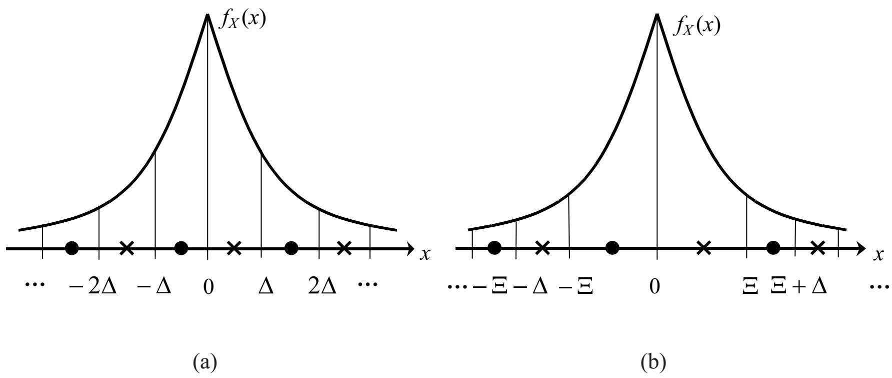


Figure 1. Quantization of the Laplacian pdf: (a) uniform quantizer case, (b) the UDQ case.

Therefore, the stego image y' is obtained as a quantized version of the host data:

$$y' = Q_b(x) = x + w, \tag{3}$$

where the watermark w is equivalent to the quantization error:

$$w = Q_b(x) - x. \tag{4}$$

Supposing that high-rate quantization conditions are preserved,[4] the following assumptions are valid:

a) the watermark and the host signal are independent;

b) quantization error is uniformly distributed within the interval (-Δ; Δ];

c) embedding distortions are determined by $\sigma_W^2 = \Delta^2/3$.[3]

The DM decoder performs the minimum distance decoding:

$$\hat{b} = \arg \min_{b \in \{-1,+1\}} \|y - Q_b(y)\|^2, \tag{5}$$

where y is the input of the decoder.

2.2. Distortion Compensated Dither Modulation

In case of the DC-DM the watermark (4) is scaled by a certain constant $\nu \in [0; 1]$ (for ν=1 the DC-DM reduces to the DM)[8]:

$$w = \nu(Q_b(x) - x), \tag{6}$$

$$y' = x + w = x + \nu(Q_b(x) - x). \tag{7}$$

Therefore, the error of quantization is uniformly distributed on the interval (-$\nu\Delta$; $\nu\Delta$] and the embedding distortions are given by $\sigma_W^2 = \nu^2\Delta^2/3$ and decoding is also performed using the minimum distance rule (5).

As it was pointed out in the Introduction, in the field of lossy image compression uniform quantizer rate-distortion performance improvement can be obtained for the case of Laplacian or GGd pdfs using a simple modification of the central bin (deadzone) $\left(-\frac{\Xi}{2}; \frac{\Xi}{2}\right]$ of the midtread quantizer.[5]

Assuming i.i.d. Laplacian distribution of the host image that was successfully used in lossy wavelet based image compression,[9] one might expect a performance enhancement of DM and DC-DM providing better conditions for near-zero magnitude coefficients using wider deadzone in comparison with the regular bin width (Figure 1). The improvement is coming from the enlargement of the minimum code width for the most often appearing host elements.

Several investigations have been carried out in source coding to determine the optimal deadzone-to-regular bin width (Ξ/Δ) ratio.[10, 11] It was shown that it should be in range between 1.5 and 2. In our case we select Ξ/Δ=2 and take the same quantizer structure for both symbols (Figure 2,b). We will refer to the quantization-based watermarking systems that use the UDQ as to the *deadzone-based DM* (DDM) and *deadzone-based DC-DM* (DDC-DM), respectively. Obviously, the optimal selection of this ratio can be a subject of separate investigation in data-hiding applications.

3. PERFORMANCE ANALYSIS OF DDM AND DDC-DM WATERMARKING

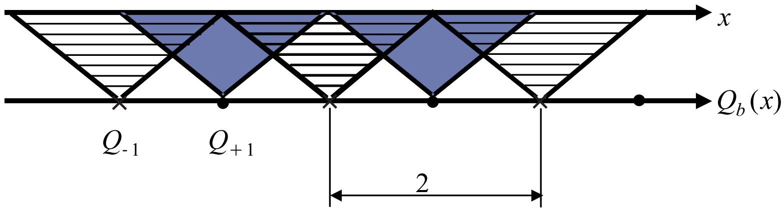
The performance analysis of deadzone-based known-host-state methods will be accomplished for the cases of uniform noise and AWGN attacks, assuming i.i.d. Laplacian distribution of the host image, and is based on the methodology developed in.[3]

Assuming that the stego image y' is corrupted by some additive noise Z with a pdf $f_Z(z)$ that is $y = y' + z = x + w + z$. In this case, referring to $\mathcal{G}_{-1}$ and $\mathcal{G}_{+1}$ as to the decision regions associated to $\hat{b}$=-1 and $\hat{b}$=+1, respectively, the bit error rate probability is determined by the following expression:

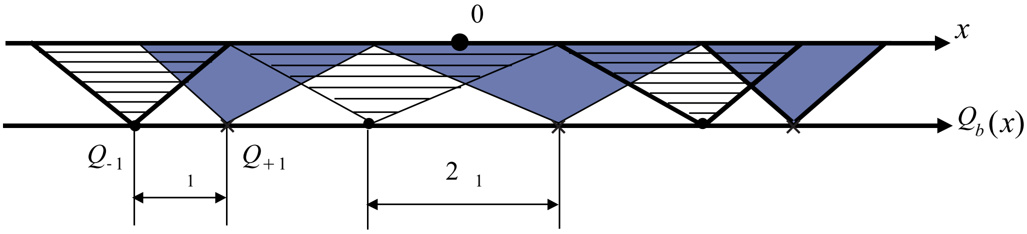
$$P_e = P\{\|y - Q_{+1}(y)\|^2 < \|y - Q_{-1}(y)\|^2 | b = -1\} = P\{y \in \mathcal{G}_1 | b = -1\}, \tag{8}$$

and can be calculated in the following way:

$$P_e = \int_{\mathcal{G}_1} f_Y(y|b = -1) = \int_{\mathcal{G}_1} f_\Phi(\phi) d\phi, \tag{9}$$



(a)



(b)

Figure 2. DM watermark signaling: (a) classical system based on uniform quantizer, (b) UDQ-based system.

where $f_\Phi(\phi)$ is the equivalent noise pdf that depends on both embedding and attacking strategies and is determined by a convolution of the "self-noise" pdf with the pdf of the attack.[3]

The difference between classical methods and DDM and DDC-DM consists in the dependence of this probability on the bin $Q_{-1}(.)$ where x lies. Therefore, for proper analysis it is now necessary to determine the UDQ parameters and compute this probability for all the bins where x can be located.

This is a crucial difference with the previously performed analysis[1,3] under uniform assumption of host pdf, where probability of error is invariant to the bin index (probability of the corresponding symbol appearance defined by the host pdf).

To have fair comparison conditions, we conduct the analysis for the WNR within [-5, 10] dB, ($WNR = 10\log_{10}\left(\frac{\sigma_W^2}{\sigma_Z^2}\right)$). All the justifications are performed based on the assumption that high-rate quantization conditions are preserved within the deadzones.

3.1. Determination of the UDQ parameters

According to the selection made in Section 2.2, the ratio of the deadzone width to the regular bin width is equal to 2. Assuming the embedding distortions to be exactly the same as in case of the classical DM, one needs to solve the following equation to obtain the regular bin width of the UDQ:

$$\Delta^2 - \Delta_1^2(4 - 3e^{-2\lambda\Delta_1}) = 0, \quad (10)$$

where Δ, Δ_1 are the bin width of the uniform quantizer and regular bin width of the UDQ, respectively; λ is the parameter of the Laplacian distribution. The parameter λ can be determined for the given Watermark-to-Image ratio, WIR, ($WIR = 10\log_{10}\left(\frac{\sigma_W^2}{\sigma_X^2}\right)$). Thus, in case of the DDM one has:

$$\lambda = \frac{1}{\Delta}\sqrt{6 \cdot 10^{-0.1WIR}} \quad (11)$$

and in case of the DDC-DM:

$$\lambda = \frac{1}{\Delta\nu}\sqrt{6 \cdot 10^{-0.1WIR}}. \tag{12}$$

3.2. DM: Uniform Noise attack

Under the uniform noise attack due to the absense of the "self noise" one has $\phi = z$ that is uniformly distributed with the following pdf:

$$f_\Phi(\phi) = \begin{cases} \frac{1}{2\eta}, & \text{if } \phi \in (Q_b(x) - \eta, Q_b(x) + \eta], \\ 0, & \text{otherwise}, \end{cases} \tag{13}$$

where η is within the interval $\eta \in [\Delta\sqrt{10^{-0.1WNR_{max}}}, \Delta\sqrt{10^{-0.1WNR_{min}}}]$, $WNR_{min} = -5$ dB, WNR_{max}=10 dB were defined in the beginning of this section.

Thus, assuming the MSE distortion measure, attacking distortions are equal to the noise variance, $D_Z = \eta^2/3$. Taking into account that different bins have different robustness to the noise, one can obtain based on (9):

$$P_e^d = \begin{cases} 0, & \text{if } \eta \leq \Delta_1, \\ (1 - e^{-2\lambda\Delta_1})(1 - \frac{\Delta_1}{\eta}), & \text{if } \Delta_1 < \eta \leq 2\Delta_1, \\ 0.5(1 - e^{-2\lambda\Delta_1}), & \text{if } 2\Delta_1 < \eta \leq \eta_{max}; \end{cases} \tag{14}$$

$$P_e^1 = \begin{cases} 0, & \text{if } \eta \leq \frac{\Delta_1}{2}, \\ (e^{-2\lambda\Delta_1} - e^{-3\lambda\Delta_1})(1 - \frac{\Delta_1}{2\eta}), & \text{if } \frac{\Delta_1}{2} < \eta \leq \frac{3\Delta_1}{2}, \\ (e^{-2\lambda\Delta_1} - e^{-3\lambda\Delta_1})\frac{2+\Delta 1}{4\eta}, & \text{if } \frac{3\Delta_1}{2} < \eta \leq \eta_{max}; \end{cases} \tag{15}$$

$$P_e^2 = \begin{cases} 0, & \text{if } \eta \leq \frac{\Delta_1}{2}, \\ e^{-3\lambda\Delta_1}(1 - \frac{\Delta_1}{2\eta}), & \text{if } \frac{\Delta_1}{2} < \eta \leq \frac{3\Delta_1}{2}, \\ e^{-3\lambda\Delta_1}\frac{\Delta 1}{\eta}, & \text{if } \frac{3\Delta_1}{2} < \eta \leq \eta_{max}, \end{cases} \tag{16}$$

where P_e^d, P_e^1 and P_e^2 are bit error rate probabilities for the cases when x is located within the intervals (-2Δ_1, 2Δ_1], (-3Δ_1, -2Δ_1]$\cup$(2Δ_1, 3Δ_1] and ($-\infty$, -3Δ_1]$\cup$(3Δ_1, $+\infty$), respectively, η_{max}, $\eta_{max} = \Delta\sqrt{10^{-0.1WNR_{min}}}$, is the maximal value of the attacking noise, $WNR_{min} = -5$ dB is the minimal WNR for the targeting range.

Finally, a total bit error rate probability is given by the sum of its components:

$$P_e = P_e^d + P_e^1 + P_e^2. \tag{17}$$

Like in case of the classical DM, one can claim about "provable robustness" of the DDM[3] due to zero bit error rate probability if the noise is concentrated within the interval (-$\frac{\Delta_1}{2}$, $\frac{\Delta_1}{2}$].

3.3. DC-DM: Uniform Noise attack

For the analysis of the DDC-DM we assume the following conditions[3]: $\nu = 0.53$ and $\eta \geq (1-\nu)\Delta_1$. Taking into account different bin width and due to the "self-noise" one can find:

$$f_\Phi^d(\phi) = \begin{cases} \frac{1}{2\eta}, & \text{if } |\phi| \leq \eta - (1-\nu)2\Delta_1, \\ \frac{\eta+(1-\nu)2\Delta_1-|\phi|}{8\Delta_1\eta(1-\nu)}, & \text{if } \eta - (1-\nu)2\Delta_1 < |\phi| \leq \eta + (1-\nu)2\Delta_1; \end{cases} \tag{18}$$

$$f_\Phi^{\overline{d}}(\phi) = \begin{cases} \frac{1}{2\eta}, & \text{if } |\phi| \leq \eta - (1-\nu)\Delta_1, \\ \frac{\eta+(1-\nu)\Delta_1-|\phi|}{4\Delta_1\eta(1-\nu)}, & \text{if } \eta - (1-\nu)\Delta_1 < |\phi| \leq \eta + (1-\nu)\Delta_1, \end{cases} \tag{19}$$

where $f_\Phi^d(\phi)$ and $f_\Phi^{\overline{\phi}}(\phi)$ are equivalent noise pdf in the deadzones and the rest of the bins, respectively.

Using an approach similar to the case of the DDM, one obtains:

$$P_e^d = \begin{cases} 0, & \text{if } \eta \le 2\Delta_1(\nu - 0.5); \\ (1 - e^{-2\lambda\Delta_1})\frac{(\eta - 2\Delta_1(\nu-0.5))^2}{8\Delta_1\eta(1-\nu)}, & \text{if } 2\Delta_1(\nu - 0.5) < \eta \le \eta_{max}, \end{cases} \tag{20}$$

$$P_e^1 = \begin{cases} 0, & \text{if } \eta \le \Delta_1(\nu - 0.5); \\ (e^{-2\lambda\Delta_1} - e^{-3\lambda\Delta_1})\frac{(\eta - \Delta_1(\nu-0.5))^2}{4\Delta_1\eta(1-\nu)}, & \text{if } \Delta_1(\nu - 0.5) < \eta \le \Delta_1(1.5 - \nu); \\ (e^{-2\lambda\Delta_1} - e^{-3\lambda\Delta_1})(1 - \frac{\Delta_1}{2\eta}), & \text{if } \Delta_1(1.5 - \nu) < \eta \le \Delta_1(0.5 + \nu); \\ (e^{-2\lambda\Delta_1} - e^{-3\lambda\Delta_1})(\frac{2\eta-(2-\nu)\Delta_1}{2\eta} + & \\ + \frac{(2\Delta_1(1-\nu))^2 - (\eta-(0.5+\nu)\Delta_1)^2}{8\Delta_1\eta(1-\nu)}), & \text{if } \Delta_1(0.5 + \nu) < \eta \le \eta_{max}, \end{cases} \tag{21}$$

$$P_e^2 = \begin{cases} 0, & \text{if } \eta \le \Delta_1(\nu - 0.5); \\ e^{-3\lambda\Delta_1}\frac{(\eta - \Delta_1(\nu-0.5))^2}{4\Delta_1\eta(1-\nu)}, & \text{if } \Delta_1(\nu - 0.5) < \eta \le \Delta_1(1.5 - \nu); \\ e^{-3\lambda\Delta_1}(1 - \frac{\Delta_1}{2\eta}), & \text{if } \Delta_1(1.5 - \nu) < \eta \le \Delta_1(0.5 + \nu); \\ e^{-3\lambda\Delta_1}(\frac{\eta-(1.5-\nu)\Delta_1}{\eta} + & \\ + \frac{(2\Delta_1(1-\nu))^2 - (\eta-(0.5+\nu)\Delta_1)^2}{4\Delta_1\eta(1-\nu)}), & \text{if } \Delta_1(0.5 + \nu) < \eta \le \eta_{max}. \end{cases} \tag{22}$$

As in case of the DDM, bit error rate probability is determined by summation of (20)-(22):

$$P_e = P_e^d + P_e^1 + P_e^2. \tag{23}$$

Again one can observe "provable robustness" of the DDC-DM for the case when $\eta \le \Delta_1(\nu - 0.5)$.

3.4. DM: AWGN attack

Having determined parameters of the UDQ and assuming that the stego image is attacked by the AWGN with variance equal to σ_Z^2, one can find:

$$\begin{aligned} P_e = {} & (1 - e^{-2\lambda\Delta_1})\left\{2Q\left(\frac{\Delta_1}{\sigma_N}\right) - Q\left(\frac{2\Delta_1}{\sigma_N}\right)\right\} + 2e^{-2\lambda\Delta_1}\sum_{i=1}^{\infty} Q\left(\frac{(4i-3)\Delta_1}{2\sigma_N}\right) + Q\left(\frac{(4i-1)\Delta_1}{2\sigma_N}\right) + \\ & + 2\sum_{i=1}^{\infty} P_{2i-1}Q\left(\frac{(4i-1)\Delta_1}{2\sigma_N}\right) - (2P_{2i-1} + P_{2i})Q\left(\frac{(4i+1)\Delta_1}{2\sigma_N}\right) + \\ & + (P_{2i-1} + 2P_{2i})Q\left(\frac{(4i+3)\Delta_1}{2\sigma_N}\right) - P_{2i}Q\left(\frac{(4i+5)\Delta_1}{2\sigma_N}\right), \end{aligned} \tag{24}$$

where P_i is a probability of i-th bin, $Q(x)$ is a Q-function.

3.5. DC-DM: AWGN attack

In case of the MDC-DM we have the convolution of the uniformly distributed self-noise with Gaussian attack noise. Thus, the equivalent noise pdf is given by:

$$f_\Phi^d(\phi) = \frac{1}{4\Delta_1(1-\nu)}\left\{Q\left(\frac{\phi - 2\Delta_1(1-\nu)}{\sigma_N}\right) - Q\left(\frac{\phi + 2\Delta_1(1-\nu)}{\sigma_N}\right)\right\}; \tag{25}$$

$$f_\Phi^{\overline{d}}(\phi) = \frac{1}{2\Delta_1(1-\nu)}\left\{Q\left(\frac{\phi - \Delta_1(1-\nu)}{\sigma_N}\right) - Q\left(\frac{\phi + \Delta_1(1-\nu)}{\sigma_N}\right)\right\}, \tag{26}$$

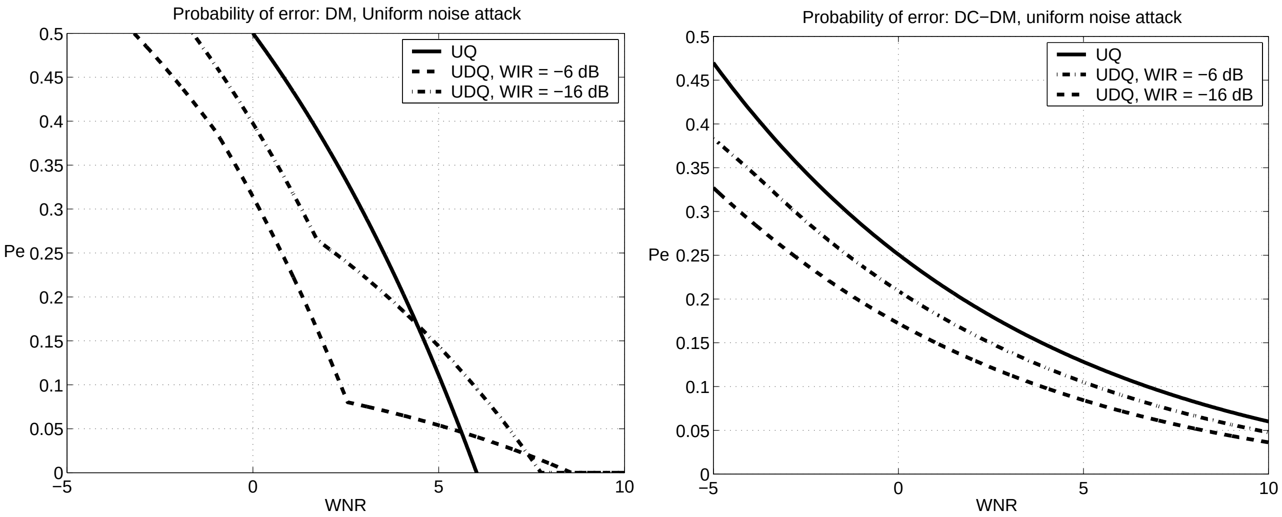
where $f_\Phi^d(\phi)$ and $f_\Phi^{\overline{d}}(\phi)$ have the same meanings as in the case of (18) and (19).

Therefore, it is possible to demonstrate that the bit error rate probability of the MDC-DM undergo AWGN attack is determined by:

$$
\begin{aligned}
P_e &= (1-e^{-2\lambda\Delta_1})\left(\int_{\Delta_1}^{2\Delta_1} f_\Phi^d(\phi)d\phi + \int_{\Delta_1}^{\infty} f_\Phi^d(\phi)d\phi\right) + 2e^{-2\lambda\Delta_1}\sum_{i=1}^{\infty}\int_{\frac{(4i-3)\Delta_1}{2}}^{\frac{(4i-1)\Delta_1}{2}} f_\Phi^{\overline{d}}(\phi)d\phi + \\
&+ 2\sum_{i=1}^{\infty} P_{2i-1}\int_{\frac{(4i-1)\Delta_1}{2}}^{\frac{(4i+1)\Delta_1}{2}} f_\Phi^{\overline{d}}(\phi)dt + (P_{2i-1}+P_{2i})\int_{\frac{(4i+1)\Delta_1}{2}}^{\frac{(4i+3)\Delta_1}{2}} f_\Phi^{\overline{d}}(\phi)d\phi + 2P_{2i}\int_{\frac{(4i+3)\Delta_1}{2}}^{\frac{(4i+5)\Delta_1}{2}} f_\Phi^{\overline{d}}(\phi)d\phi. \quad (27)
\end{aligned}
$$

4. EXPERIMENTAL RESULTS

In this Section we present the results of benchmarking DDM and DDC-DM watermarking methods versus classical DM and DC-DM in terms of the bit error rate probability. As it was already mentioned in the previous Sections, the analysis is performed for two different WIR, WIR_1=-6 dB and WIR_2 =-16 dB for the $WNR \in$[-5; 10] dB. The compensation parameter of the MDC-DM is equal to ν=0.53 for the case of uniform noise attack and ν=0.5 for the case of AWGN attack.[3]



(a) (b)

Figure 3. Bit error rate probabilities of the DDM and the DDC-DM versus the DM and the DC-DM in case of the uniform noise attack: (a) WIR=-6 dB and WIR=-16 dB.

The results of benchmarking are presented in Figure 3 and Figure 4. These results allow to claim that developing known-host-state watermarking methods by taking into account the statistics of the host data leads to their significant performance improvement in terms of bit error rate probability for both DM and DC-DM in the case when $WNR \leq 3$ dB (the highest WNR corresponding to the crossing point of bit error probability curves in the classical and modified cases) for both uniform noise and AWGN attacks. As the performance enhancement measure we selected the value of the bit error probability function for WNR=0 dB. For the uniform noise attack we have: P_e^{DM}=0.5 and P_e^{DDM}=0.4 when WIR=-16 dB, P_e^{DM}=0.5 and P_e^{DDM}=0.32 when WIR=-6 dB; P_e^{DC-DM}=0.25 and P_e^{DDC-DM} = 0.21 when WIR=-16 dB, P_e^{DC-DM} = 0.25 and P_e^{DDC-DM} = 0.17 when WIR =-6 dB.

In case of the AWGN attack one has: P_e^{DM} = 0.38 and P_e^{DDM} = 0.31 (WIR =-16 dB), P_e^{DM}=0.38 and P_e^{DDM} = 0.24 (WIR =-6 dB); P_e^{DC-DM} = 0.23 and P_e^{DDC-DM} = 0.2 (WIR=-16 dB), P_e^{DC-DM}=0.23 and $P_e^{DDC-DM} = 0.16$ ($WIR = -6dB$).

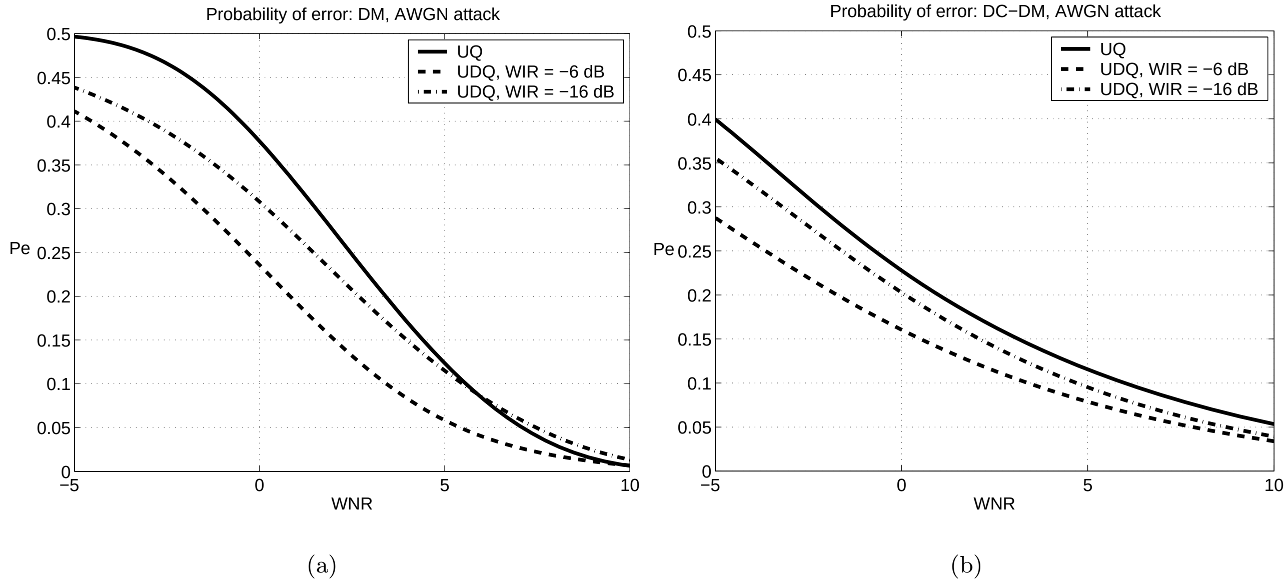


Figure 4. Bit error rate probabilities of the DDM and the DDC-DM versus the DM and the DC-DM in case of the AWGN attack: (a) WIR=-6 dB and WIR=-16 dB.

Another comparison of classical and modified quantization methods can be performed using the distance in dB between the equal bit error rate points. If $P_e = 0.3$ is selected as a reference point, the gains of the modified methods over the classical methods are:

- DM, uniform noise attack, WIR=-16 dB: ≈2 dB,
- DM, uniform noise attack, WIR=-6 dB: ≈3 dB;

- DC-DM, uniform noise attack, WIR=-16 dB: ≈1.4 dB,
- DC-DM, uniform noise attack, WIR=-16 dB: ≈2.8 dB;

- DM, AWGN attack, WIR=-16 dB: ≈1.3 dB,
- DM, AWGN attack, WIR=-6 dB: ≈3 dB;

- DC-DM, AWGN attack, WIR=-16 dB: ≈1.4 dB,
- DC-DM, AWGN attack, WIR=-16 dB: ≈1 dB.

5. CONCLUSIONS

In this paper we have considered the problem of quantization-based watermarking performance improvement using proper stochastic modeling of the host image. In particular, we have been targeting at the improvement of performance of DM and DC-DM methods under uniform noise and AWGN attacks in terms of bit error rate probability. We have adjusted existing design rules of DM and DC-DM by replacing the usually applied uniform quantizer by a uniform deadzone quantizer elaborated for the global i.i.d. Laplacian model of the host data. We have obtained close form analytical expressions for bit error rate probability calculations of deadzone-based DM and deadzone-based DC-DM for the case of above mentioned attacks taking into account actual host pdf. The obtained experimental results demonstrates performance superiority of DDM and DDC-DM over classical DM and DC-DM.

It should be pointed out that at high-WNR a performance loss of the modified techniques is observed when the uniform noise attack is applied. The reason for this is smaller regular bin width of the UDQ contrary to the uniform quantizer, when embedding distortion equality is used as one of design criteria. But these drawbacks are not so crucial in practice due to the operational WNR range of robust watermarking systems that mostly includes negative values.

A future possible research line consists in the generalization of the results obtained in the scope of this paper to the multidimensional case and in the optimization of scheme parameters.

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