Correction Impulse Method for Turbo Decoding over Middleton Class-A Impulsive Noise

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***Abstract*—The correction impulse method (CIM) is very effective to achieve low error rates in turbo decoding. It was applied for transmission over Additive White Gaussian Noise (AWGN) channels, where the correction impulse value must be a real number greater than the minimum distance of the turbo code. The original version of CIM can not be used for channels modeled as Middleton additive white Class-A impulsive noise (MAWCAIN), because of nonlinearity of channel reliability. Thus, in this paper we propose two ways to modify the method such that it improves the system performances in the case of aforementioned channels. In the first one, the value of the correction impulse is chosen to maximize the channel reliability. It depends on the signal to noise ratio (SNR) and the error rates are significantly improved compared to those obtained by using the correction impulse value applied for AWGN channels. The second version is based on the least squares method and performs an approximation of the correction impulse. The approximated value depends on the SNR and the parameter A of the MAWCAIN model. The differences between the error rates obtained by the two proposed methods are negligible.**

***Index Terms*—correction impulse method, error-correcting codes, error-floor, Middleton Class-A impulsive noise, turbo codes.**

I. INTRODUCTION

Turbo codes are a class of error-correcting codes with very good performance in the waterfall region of the error rate curve [1], but they suffer from the “error-floor” effect at high values of signal to noise ratio (SNR), wich is a flattening of the error curve.

The correction impulse method (CIM) [2], [3] is a very effective method of decreasing the error-floor, with a slight increase in the decoding complexity at high SNR. This method was applied for additive white Gaussian noise (AWGN) channels. Its core is to successively insert an impulse for the most likely erroneous bit in the received sequence and to repeat the turbo decoding. These bits are chosen those which have the smallest values of the magnitude of Logarithm Likelihood Ratios (LLRs). The inserted impulse must have suitable amplitude so that the correcting of the assumed erroneous bit is very probable. Because the AWGN channel reliability used in turbo decoding depends linearly on the received symbol, it is sufficient that the amplitude of the inserted impulse in CIM for AWGN channel to be large enough (at least the minimum distance of the used turbo code) and its sign to be inversed compared to that of the transmitted value for the assumed erroneous bit.

Impulsive noise occurs frequently in communications [4], [5] and a model often used for this type of noise is the Middleton additive white class A impulsive noise (MAWCAIN) model. In this case, the channel reliability is not a linear function of received symbol anymore and consequently, applying CIM to this channel is not straightforward. As we will see, the value of received symbol that maximizes the MAWCAIN channel reliability function is the suitable choice for the absolute value of the correction impulse, because turbo decoder considers that the bit corresponding to this value is the most likely to be transmitted. Thus, the first objective of the paper is to choose this value for the amplitude of inserted impulse in CIM for MAWCAIN channel. Because the maximum value of the MAWCAIN channel reliability depends on the SNR, a simple formula that allows obtaining the value for of the inserted impulse amplitude is very useful in practice.

The second contribution of this paper consists in the approximation of the inserted impulse amplitude as a quadratic function depending on SNR, using the least square estimation method.

The paper is structured as follows. Section II presents the MAWCAIN channel model. Section III describes the turbo encoder and decoder structure, specifying the channel reliability for AWGN and MAWCAIN channels, respectively. Section IV proposes the application of the correction impulse method in turbo decoding for MAWCAIN channels with a suitable choice for the amplitude of inserted correction impulse. Section V presents the proposed method for approximation of the value of the correction impulse for MAWCAIN channels. The simulation results shown in Section VI validate the proposed method and the last Section concludes the paper.

II. MIDDLETON CLASS-A NOISE MODEL CHANNEL

The model of Middleton Class-A noise is described with the probability density function [6]:

$$p(n) = \sum_{m=0}^{\infty} \frac{A^m e^{-A}}{\sqrt{2\pi} m! \sigma_m} \exp\left(-\frac{|n|^2}{2\sigma_m^2}\right) \tag{1}$$

where m counts the impulses that appear, A is called impulsive index and it is very useful in description of the non-Gaussian noise. Thus, if A has low values, the noise has a strongly impulsive character and conversely, if A increases, the noise tends towards AWGN [7]. σ_m^2 is given by:

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$$\sigma_m^2 = \sigma^2 \cdot \frac{\frac{m}{A} + T}{1+T}, \tag{2}$$

where $\sigma^2 = \sigma_g^2 + \sigma_i^2$ is the total noise power and

$$T = \frac{\sigma_g^2}{\sigma_i^2} \tag{3}$$

is the Gaussian-to-Impulsive noise power ratio [7]. σ_g^2 is the Gaussian noise power and σ_i^2 is the impulsive noise power [6]. The T parameter describes the Middleton Class-A noise similar to the impulsive index.

An impulsive noise sample can be generated as shown in [8] and used in [7].

III. TURBO ENCODER AND TURBO DECODER FOR AWGN AND MAWCAIN CHANNELS

A. Turbo Encoder

The structure of the turbo encoder used in our study is shown in Fig. 1. It employs two identical recursive systematic convolutional (RSC) encoders with the constraint length 4 (i.e. the memory of order m=3), the global rate 1/2, and the generator matrix:

$$G = \begin{bmatrix} 1 & \frac{1+D+D^3}{1+D^2+D^3} \end{bmatrix} \tag{4}$$

where D represents the unit delay operator. In octal form, the generating matrix is $G = \begin{bmatrix} 1 & \frac{15}{13} \end{bmatrix}$.

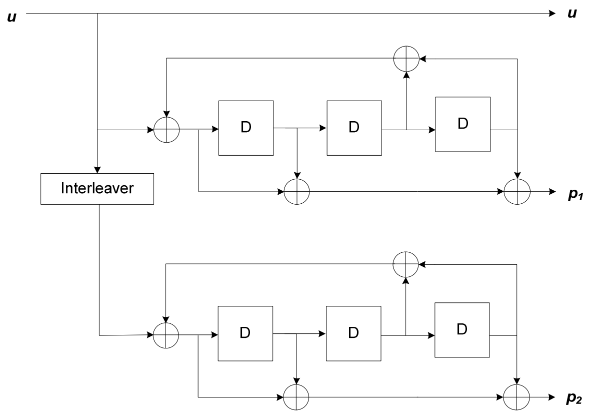

Figure 1. The structure of turbo encoder

The interleaver used in the structure of turbo code is of dithered relative prime (DRP) type [9] with length L=1024. We considered that the both encoders are terminated, by dual termination method [10]. The motivations for the choice of these encoder parameters are as follows. The Long Term Evolution (LTE) standard [11] uses the same generator matrix, a quadratic permutation polynomial interleaver and the trellis termination is post interleaver. In our study, we use a DRP interleaver and the dual termination as in [2], where CIM for AWGN channel was firstly presented. However CIM also works for other encoder parameters because it only involves a modification of the turbo decoder input.

The turbo encoder has three outputs: u - the sequence of information bits and p_1, p_2 - the sequences of parity bits. For error detections, unlike [2] where a "genie" cyclic redundancy check (CRC) was used, we used a 16-bit CRC code. The motivation is that, unlike "genie" CRC, this code is a practical error detecting code. If no errors are detected by this code, the iterative turbo decoding is stopped [2]. The cyclic generator polynomial used is: $g_{CRC16}(D) = D^{16} + D^{12} + D^5 + 1$ or 1021 in hexadecimal [11]. The turbo coding rate is $R_c = 0.3261$. This value is obtained from the relationship corresponding to the dual termination i.e. $R_c = (L - L_{CRC} - 2m)/3L$, where L_{CRC}=16.

B. Turbo decoder

The description of Maximum A Posteriori (MAP) turbo decoding for AWGN and MAWCAIN channels was very well done in [6], [10]. In this subsection we recall only the decoding principle, with different notations.

We denote the sequences of matched filter outputs by y_s, $y_{p,1}$ and $y_{p,2}$ respectively. They correspond to encoder sequences u, p_1 and p_2, respectively, from subsection III.A. Subscript s stands for systematic sequence and p for parity sequences.

The turbo decoder structure is shown in Fig. 2. It has two MAP decoders [13] corresponding to RSC encoders in the turbo encoder. The MAP decoder calculates the Logarithm Likelihood Ratio (LLR) for the estimated systematic bits (denoted by $\hat{u}_k$) and it can be split into three terms

$$L(\hat{u}_k) = L_e(u_k) + L_c(y_{s,k}) + L_a(u_k) \tag{5}$$

The terms in the right hand side in (5), $L_e(u_k)$, $L_c(y_{s,k})$ and $L_a(u_k)$ are the extrinsic value, the channel value, and *a priori* value, respectively. Given $L_c(y_{s,k})$, $L_c(y_{p,i,k})$ (where $i=1$ indicates the first decoder and $i=2$, the second one), and $L_a(u_k)$, the quantities $L(\hat{u}_k)$ or/and $L_e(u_k)$ can be calculated.

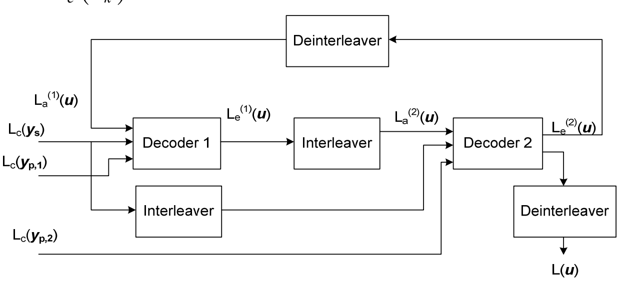

Figure 2. The structure of turbo decoder

As shown in Fig. 2, the inputs of the MAP decoder are $L_c(y_{s,k})$, $L_c(y_{p,i,k})$ and $L_a(u_k)$ and the outputs of the MAP decoder are $L(\hat{u}_k)$ or $L_e(u_k)$. In the turbo decoder, the current MAP decoder utilizes the extrinsic value $L_e(u_k)$ of the previous MAP decoder as *a priori* value $L_a(u_k)$. By alternating the process of the MAP decoder 1 and 2 in Fig. 2 the turbo decoder can enhance the reliability of the extrinsic value $L_e(u_k)$. After an appropriate number of iterations performed by the two MAP decoders, the turbo decoder gives to its output the LLRs for the estimated systematic bits

$L\left(\hat{u}_k\right)$, $k = 1,2,\ldots,L$. If the turbo decoder output is positive (or negative), the detector output is 1 (or 0).

In the following, we present only the reliabilities for the two types of channels. In the next two relations y_k can be either $y_{s,k}$ or $y_{p,i,k}$, with $i = 1$ or 2.

Thus, for AWGN channels, the reliability is given by:

$$L_c\left(y_k\right) = 4 \cdot R_c \cdot SNR \cdot y_k, \tag{6}$$

where SNR is the value of the signal-to-noise ratio, R_c is the coding rate of the turbo code and y_k is the received value corresponding to the information bit u_k.

The MAWCAIN channel, the reliability is given by:

$$L_c\left(y_k\right) = \ln \frac{\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot \exp\left(-\frac{\left(y_k - 1\right)^2}{2\sigma_m^2}\right)}{\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot \exp\left(-\frac{\left(y_k + 1\right)^2}{2\sigma_m^2}\right)}, \tag{7}$$

where y_k has the same significance as that for the AWGN channel and the other parameters were presented in Section II.

Because the sums in (7) are infinite, they cannot be calculated in practice. In [6], the upper limit of these sums is proposed to be $M = \max\left(2, \lceil 10 \cdot A \rceil\right)$, where $\lceil x \rceil$ is the smallest integer greater than or equal to x. This choice does not affect the performance of turbo decoding, because the terms over this limit are very small.

IV. Correction Impulse Method for Turbo Decoding

The correction impulse method was proposed in [2], [3]. CIM requires an error detection procedure and involves the following steps. The received codeword is firstly decoded in the normal manner. In the case of decoding failure, indicated in error detection stage, a few positions in the decoded information frame are determined to have most likely bit errors, that is the smallest values of the magnitude of LLRs. Successively, for each such position, change the bit from the first decoding to the opposite value, and decode again the obtained codeword. The repeated decoding continues until a successful decoding is declared or all candidate bit positions have been tested.

For binary phase shift keying (BPSK) modulation, each bit b is converted into the value 2b-1. To decide on the bit value b_k on position k, the correction impulse method from [2] consists in inserting the impulse $I_k = \left(1 - 2 \cdot \hat{u}_k\right) \cdot E$, in the sequence y_s, where E is a real number greater than the minimum distance of the turbo code and $\hat{u}_k$ is the most likely erroneous estimated bit.

As shown in Fig. 2, the sequence $L_c\left(y_{s,k}\right)$ appears every iteration at the entrance of the two decoders and so do the sequences $L_c\left(y_{p,i,k}\right)$, where $i = 1,2$ indicates the decoder 1 and 2, respectively. The a priori information $L_a\left(u_k\right)$ at the input of each of the two decoders comes from the extrinsic information of the other decoder. The change of the value k in sequence y_s, by inserting the impulse I_k, leads to correction of bit k, if it is erroneous. As it can be seen from (6), the AWGN channel reliability is linearly increasing with respect to y_k. Unlike the AWGN channel, the MAWCAIN channel reliability in (7) is not a linear function of y_k, anymore.

For the results in this section, the MAWCAIN channel parameters are A = 0.01 and T = 0.01. We choose these parameters because in this case the noise gets more impulsive and we want to see the capability of turbo decoder to remove the impulsive component of MAWCAIN.

In Fig. 3, we have plotted the MAWCAIN channel reliability under the above mentioned conditions, as a function of y_k, for 3 values of SNR (0, 1.6 and 4 dB).

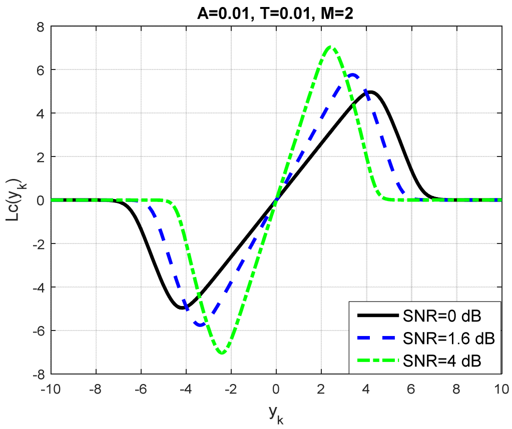

Figure 3. MAWCAIN channel reliability for A=0.01, T=0.01, M=2

It can be seen that the reliability has a maximum that depends on the SNR. For high y_k, the reliability tends asymptotically to a constant value which also depends on the SNR and it is less than the maximum specified above. That is why, imposing a very high value for E for MAWCAIN channels, it does not lead to the best decoding performances in terms of frame error rate (FER), compared with AWGN case. For this reason, we propose to choose the value of E (the absolute value of the correction impulse) equal to the value of y_k that maximizes $L_c\left(y_k\right)$ for that SNR. In the following, this value will be named optimal. It is an extreme for $L_c\left(y_k\right)$ given in (7), therefore it is obtained by setting to 0 its first derivative with respect to y_k.

$$\begin{aligned}
&\left(y_k - 1\right) \cdot \left[\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot \exp\left(-\frac{\left(y_k + 1\right)^2}{2\sigma_m^2}\right)\right] \cdot \\
&\left[\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m^3} \cdot \exp\left(-\frac{\left(y_k - 1\right)^2}{2\sigma_m^2}\right)\right] - \\
&-\left(y_k + 1\right) \cdot \left[\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot \exp\left(-\frac{\left(y_k - 1\right)^2}{2\sigma_m^2}\right)\right] \cdot \\
&\left[\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m^3} \cdot \exp\left(-\frac{\left(y_k + 1\right)^2}{2\sigma_m^2}\right)\right] = 0
\end{aligned} \tag{8}$$

Equation (8) has two solutions greater than 0. Finding its closed-form solutions is difficult, if not impossible, but they can be still determined using the computer. We denote the left hand side of (8) by $f(y_k)$. The function $f(y_k)$ is plotted in Fig. 4 for the same three values of SNR considered in Fig. 3.

The two positive solutions of (8), denoted by $y1_k$ and $y2_k$ are highlighted for each case. However, only the solution $y1_k$ corresponds to the maximum and is the suitable choice for the absolute value E of the correction impulse. The second solution corresponds to a minimum, as shown in Fig. 4.

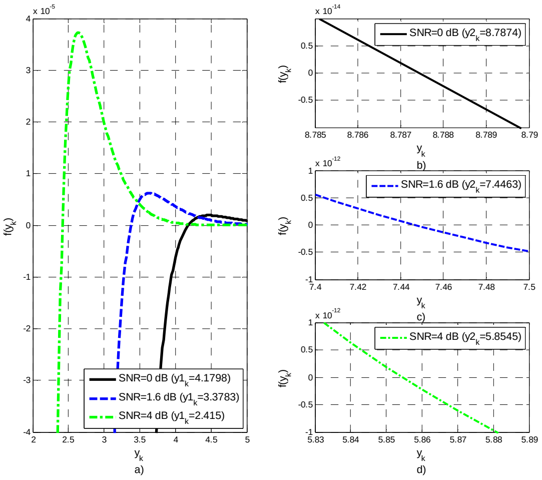

Figure 4. a) The function $f(y_k)$ for SNR=0 dB, SNR=1.6 dB and SNR=4 dB, respectively (A=0.01, T=0.01 and M=2). The second solution of equation (9) is shown in the right figures for b) SNR=0 dB, c) SNR=1.6 dB and d) SNR=4 dB.

Finally we mention that the most likely erroneous bits for which we apply CIM for MAWCAIN channel are still those corresponding to the lowest absolute values of LRRs, because also in this case the decision is taken by comparing LLR with the threshold 0.

V. Approximation of Correction Impulse for CIM Used in Turbo Decoding over MAWCAIN Channel

We observed that for a set of parameters A and T of the MAWCAIN channel, for the SNR values of interest (for the interleaver length of 1024 and memory of order 3, the SNR values are less than 4 dB), the optimal correction impulse can be approximated by a parabola depending on the SNR, i.e.:

$$E1_{approximated} = E_0 + E_1 \cdot SNR + E_2 \cdot SNR^2 \qquad (9)$$

The parabola coefficients can be determined by the least squares method, similar to the approximation of the LLR thresholds in stopping criterion based on LLR absolute value from [14]. The validity of the approximation is shown in Fig. 5 for A = 0.01 and T = 0.01. The approximation is valid for values of optimal E greater than one. As the SNR increases, E is getting closer to 1.

However, in practice, it is desirable a formula for E valid for any A and T. The parabola coefficients E_0, E_1 and E_2 were determined by the least squares method that approximates the optimal E according to SNR for ten values of interest of A and T, namely 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1. In this way, 100 combinations of parameters A and T result. Afterwards, the coefficients E_0, E_1 and E_2 are also approximated by parabolas for each T, according to A, also using the least squares method. These coefficients are plotted in Fig. 6. For the 10 values of T, the coefficients were averaged and the resulting average coefficients are given in Table I.

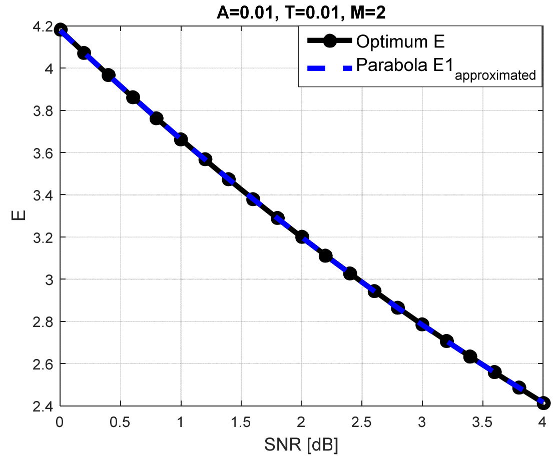

Figure 5. Optimum E and parabola $E1_{approximated}$ for MAWCAIN with A=0.01 and T=0.01.

TABLE I. AVERAGED E_{0_est}, E_{1_est} AND E_{2_est} COEFFICIENTS OF PARABOLA

i	E_{0_est}	E_{1_est}	E_{2_est}
0	4.5752	-0.5877	0.0268
1	-39.7822	5.0279	-0.2217
2	247.5123	-30.8342	1.3999

The parabolas corresponding to these average coefficients are plotted in Fig. 6 with solid lines. The coefficients E_{i_est}, $i = 0,1,2$, are determined by:

$$E_{i\_est} = E_{i0\_est} + E_{i1\_est} \cdot A + E_{i2\_est} \cdot A^2 \qquad (10)$$

Finally, the approximated value of E is determined by:

$$E2_{approximated} = E_{0\_est} + E_{1\_est} \cdot SNR + E_{2\_est} \cdot SNR^2 \qquad (11)$$

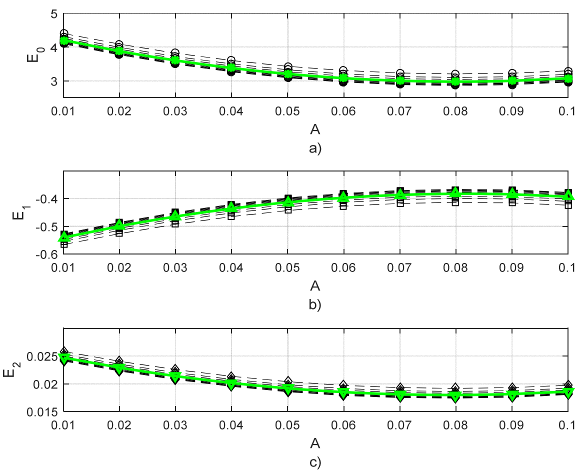

Figure 6. Parabola approximated coefficients a) E_0, b) E_1 and c) E_2. The solid line represents the parabola with average coefficients.

VI. Simulation Results

In this section we present simulation results for the AWGN channel and for MAWCAIN channel with parameters A=0.01 and T=0.01. The used turbo code for both channels is that in subsection III.A, with G = [1 15/13], a DRP interleaver with length L=1024, dual termination and a 16-bit CRC error detecting code.

The decoding algorithm used for AWGN channel is Max-Log-MAP with an extrinsic information scaling factor s=0.7 [14]. The iteration stopping criteria in this case was based on LLR absolute value from [14]. The approximation of the LLR thresholds was made using the least squares method.

For MAWCAIN channel, the decoding algorithm is Log-MAP [6], [7], with approximation from [16]. The used iteration stopping criterion is based on the magnitude of LLR [17] corresponding to a transmitted bit frame and the chosen LLR threshold is LLRThresh = 15.

The reliabilities are calculated by means of (7) as in [6], with M=2. CIM(L_{CIM}) denotes the error performance obtained by testing the least reliable L_{CIM} bits in the decoded frame. CIM is applied for L_{CIM} equal to 1, 4, 8, 16, 32, 64, 128, 256. For MAWCAIN channel, the simulations were performed for E approximated by (9) and E fixed to 100. This value is covering, because the known largest minimum distance of the turbo codes, does not exceed 100. The curves for standard decoding, without CIM, are also given for both channels.

The simulation results for AWGN channel are given in Fig. 7. The FER curves decrease along with increasing L_{CIM} compared to standard decoding. Thus, for SNR = 1.5 dB, from standard decoding to CIM(256), FER decreases from $2 \cdot 10^{-6}$ to $8 \cdot 10^{-9}$. CIM(64), CIM(128) and CIM(256) lead to almost the same performances. In Fig. 8 the FER curves are represented for each L_{CIM} considered in CIM compared with standard decoding. It can be observed that the best results are obtained for CIM(64), CIM (128) and CIM(256).

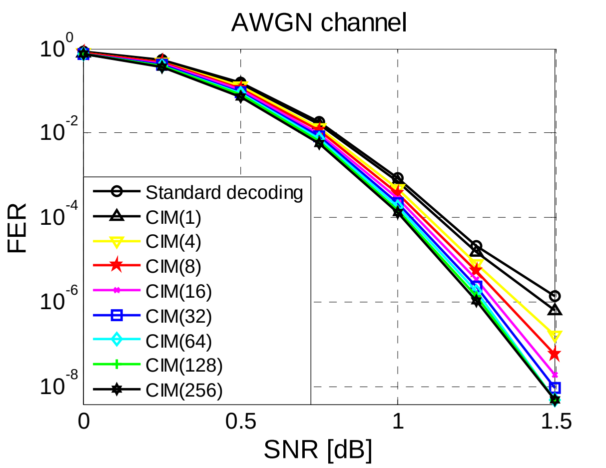

Figure 7. FER (plots) for AWGN channel.

The simulation results for MAWCAIN channel with parameters A = 0.01 and T = 0.01 are given in Fig. 9. The performances are evaluated in terms of FER, as for AWGN channel. The simulations were performed for the same system except the decoding algorithm: in this case it was used Log-MAP, as we have specified above. In FER domain, the curves are plotted in Fig. 10 for each L_{CIM} considered in CIM, for E approximated by (9) and E fixed to 100, compared with standard decoding, as was done for AWGN channel. From all the figures it can be observed that E approximated by equation (9) leads to much better FER performance compared to E = 100, for $L_{CIM} \geq 4$.

The FER decreases with increasing L_{CIM} as compared to standard decoding, as in the case of AWGN channel. Thus, for SNR = 1.6 dB from standard decoding to CIM(256) obtained for E approximated by (9), FER decreases from $1.2 \cdot 10^{-6}$ to $1.4 \cdot 10^{-8}$. The best performances are obtained for CIM(64), CIM(128) and CIM(256) with E approximated by (9).CIM(64), CIM(128) and CIM(256) lead to similar improvements. In Fig. 10, the FER curves for the aforementioned CIM(L_{CIM}) with E =100 decrease by almost an order of magnitude compared with standard decoding. FER curves for the aforementioned CIM(L_{CIM}) for E approximated by (9) decrease by almost two orders of magnitude compared with standard decoding and therefore, by almost an order of magnitude compared with CIM(L_{CIM}) with E = 100. These results validate the proposed method.

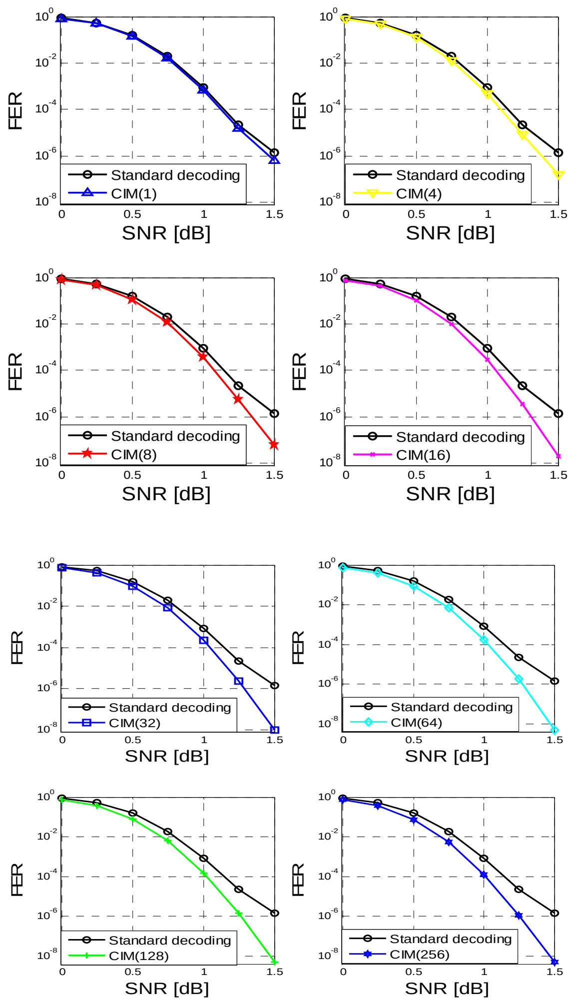

Figure 8. FER curves for AWGN channel for each L_{CIM} considered in CIM compared with standard decoding.

VII. CONCLUSIONS

In this paper we have approached the use of the correction impulse method in turbo decoding for MAWCAIN channels. We have shown that the optimal choice of correction impulse depends on the channel SNR and the parameters of the MAWCAIN model. For the SNR values of interest, the optimal value of the correction impulse E can be very well approximated by a parabola as a function of SNR. The parabola coefficients for different values of parameters A and T were also approximated by parabolas, depending on A for a fixed T.

The coefficients of these parabolas were averaged for different values of T, resulting in a formula for E that depends only on A and SNR, given in (10) and (11).

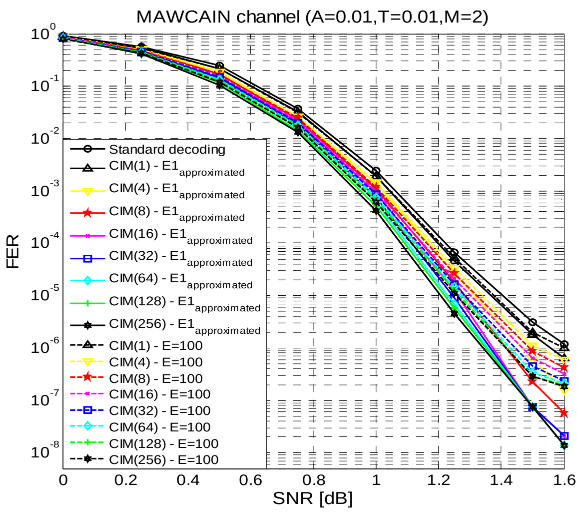

Figure 9. FER curves for MAWCAIN channel ($A = T$ =0.01).

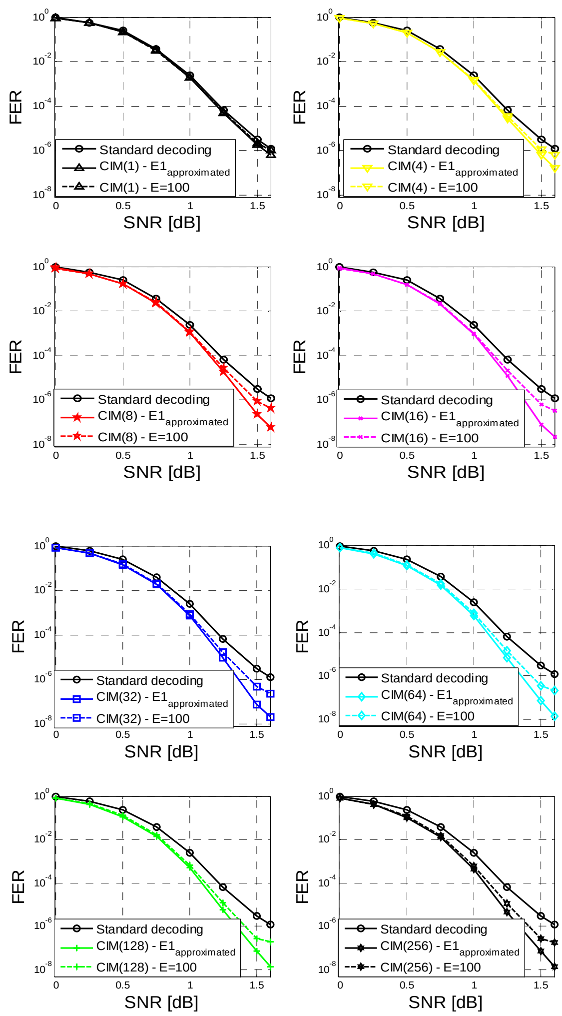

Figure 10. FER curves for MAWCAIN (A=T=0.01) channel for each L_{CIM} considered in CIM compared with standard decoding.

This approximation is proved to be effective in terms of error rates in turbo decoding. The simulation results in Section VI show the effectiveness of the determined values of E. The method was also applied for AWGN channel. In both cases, CIM(L_{CIM}) leads to better performances compared with standard decoding, the FER curve decreasing with increasing of L_{CIM}.

In [2], [3] and in this paper CIM was applied only for systematic sequence. Further work will consider CIM applied also to parity sequences. In this case we have to determine the weakest parity bits for which CIM should be applied.

REFERENCES

[1] C. Berrou, A. Glavieux, P. Thitimajshima, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes", Proceedings of IEEE International Conference on Communications ICC'93, Geneva, pp. 1064-1070, 1993. doi:10.1109/ICC.1993.397441

[2] Y. Ould-Cheikh-Mouhamedou, S. Crozier, K. Gracie, P. Guinand, P. Kabal, "A Method for Lowering Turbo Code Error Flare using Correction Impulses and Repeated Decoding", Proceedings of 4th International Symposium on Turbo Codes & Related Topics, Munich, Germany, 6 pages, 2006.

[3] Y. Ould-Cheikh-Mouhamedou, S. Crozier, "Improving the Error Rate Performance of Turbo Codes using the Forced Symbol Method", IEEE Communications Letters, vol. 11, no. 7, pp. 616-618, 2007. doi:10.1109/LCOMM.2007.070171

[4] D. Middleton, "Statistical-Physical Model of Electromagnetic Interference", IEEE Transactions on Electromagnetic Compatibility, vol. EMC-19, no. 3, Part I, pp. 106-126, 1977. doi:10.1109/TEMC.1977.303527

[5] D. Middleton, "Procedures for Determining the Parameters of the First-Order Canonical Models of Class A and Class B Electromagnetic Interference", IEEE Transactions on Electromagnetic Compatibility, vol. EMC-21, no. 3, pp. 190-208, 1979. doi:10.1109/TEMC.1979.303731

[6] D. Umehara, H. Yamaguchi, Y. Morihiro, "Turbo Decoding over Impulse Noise Channel", Proceedings of the International Symposium on Power Line Communications ISPLC 2004, Zaragosa, Spain, pp. 51-56, 2004.

[7] M. Andrei, L. Trifina, D. Tarniceriu, "Performance Analysis of Turbo-Coded Decode-and-Forward Relay Channels with Middleton Class-A Impulsive Noise", Advances in Electrical and Computer Engineering, vol. 14, nr. 4, pp. 35-42, 2014. doi:10.4316/AECE.2014.04006

[8] N. Andreadou, F.-N. Pavlidou, "PLC Channel: Impulsive Noise Modeling and Its Performance Evaluation Under Different Array Coding Schemes", IEEE Transactions on Power Delivery, vol. 24, no. 2, pp. 585-595, 2009. doi:10.1109/TPWRD.2008.2002958

[9] S. Crozier, P. Guinand, "High-performance low-memory interleaver banks for turbo-codes", Proceedings of 54th IEEE Vehicular Technology Conference, Atlantic City, NJ, vol. 4, pp. 2394-2398, 2001. doi:10.1109/VTC.2001.957178

[10] P. Guinand, J. Lodge, "Trellis Termination for Turbo Encoders", Proceedings of the 17th Biennial Symposium On Communications, Queen's University, Kingston, Canada, pp. 389-392, 1994.

[11] 3GPP Technical Specification TS 36.212. LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding, version 10.0.0 Release 10, 2011.

[12] D. Umehara, H. Yamaguchi, Y. Morihiro, "Turbo Decoding in Impulsive Noise Environment", Proceedings of the IEEE Global Telecommunications Conference GOBECOM'04, Dallas, Texas, USA, pp. 194-198, 2004. doi:10.1109/GLOCOM.2004.1377938

[13] L.R. Bahl, J. Cocke, F. Jelinek, J. Raviv, "Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate", IEEE Transactions on Information Theory, vol. 20, nr. 2, pp. 284-287, 1974. doi:10.1109/TIT.1974.1055186

[14] J. Vogt, A. Finger, "Improving the max-log-MAP turbo decoder", Electronics Letters, vol. 36, no. 23, pp. 1937-1939, 2000. doi:10.1049/el:20001357

[15] L. Trifina, D. Tărniceriu, H. Baltă, "Threshold Determining for MinabsLLR Stopping Criterion for Turbo Codes", Frequenz, vol. 67, no. 9-10, pp. 321-326, 2013. doi:10.1515/freq-2012-0159

[16] H. Baltă, M. Kovaci, "A Study on Turbo Decoding Iterative Algorithms", Scientific Bulletin of Politehnica University Timisoara – Transactions on Electronics and Communications, vol. 49(63), no. 2, pp. 33-37, 2004.

[17] A. Matache, S. Dolinar and F Pollara, "Stopping Rules for Turbo Decoders", Jet Propulsion Laboratory, Pasadena, California, TMO Progress Report 42-142, 2000.