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INFLUENCE OF EXTRINSEC INFORMATION SCALING FACTOR ON MAX-LOG-MAP DECODING ALGORITHM FOR TURBO CODES WITH TRANSMISSION ON CHANNEL AFFECTED BY MIDDLETON CLASS-A IMPULSIVE NOISE

BY

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Abstract. This paper analyzes the influence of extrinsic information scaling factor on iterative decoding algorithm for turbo codes, over a channel affected by impulsive noise and Binary Phase-Shift Keying modulation. The statistical model used for the impulsive noise is Middleton Class-A. We considered the case of Log-MAP and Max-Log-MAP decoding algorithms and two lengths for the random interleaver, 1,024 and 16,384, respectively. The simulations were done for different values of the parameters that describe the impulsive noise model. Log-MAP algorithm ensures the best performances for turbo code in the presence of impulsive noise. For Max-Log-MAP algorithm, the best results are obtained for scaling factor of 0.7, 0.75 and 0.8.

Key words: impulsive noise; MAP algorithm; scaling factor; turbo codes.

1. Introduction

In general, the evaluation of error correcting codes performances is done in terms of Bit Error Rate (BER). An improvement can be achieved by

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concatenating codes, a technique that has led to the appearance of turbo codes (Berrou *et al.*, 1993). French researchers have used for creating the aforementioned codes two recursive systematic convolutional codes parallel concatenated, with an interleaver placed in between, such that the input of the second convolutional encoder is an interleaved version of the input sequence.

The decoding algorithm used in the original work was a modified version of Maximum-A-Posteriori (MAP) algorithm proposed by Bahl and his collaborators (Bahl *et al.*, 1974). This provides the likelihood ratios (in logarithmic form) for each bit of the received coded block. Because of the increased complexity of the algorithm mentioned above, there have been proposed simplified versions: Max-Log-MAP (Kock *et al.*, 1990) and Log-MAP (Robertson *et al.*, 1995).

Turbo codes decoding is iterative, a turbo decoder being made up of two MAP decoders. Information that they exchange between them are only extrinsic information, i.e. additional information introduced by decoders at each iteration, after examining the received sequence.

If the extrinsic information is scaled with a subunit scaling factor *s*, the Max-Log-MAP algorithm leads to better performances both on channels affected by Additive White Gaussian Noise (AWGN) and by Rayleigh fading (Vogt *et al.*, 2000). The factor value for which a low BER was obtained was 0.7. For the MAP algorithm, *sf* brings improvements at a value of 0.7 for Signal-to-Noise Ratio (SNR) between 0 and 2.6 dB, and for high SNR, *sf* can be chosen to be 0.9 (Balta *et al.*, 2013).

In addition to improving performance, using this scaling is beneficial in reducing the correlation effect between extrinsic and intrinsic information, which is inevitable in iterative decoding. The best solution for choosing the scaling factor is that it has to be constant during decoding, its change, adapted to the channel conditions and to the decoding iterations, not bringing any gains (Taskaldiran *et al.*, 2007).

Most of the time, the influence of scaling factor on turbo code performances was addressed for AWGN channels, ignoring other sources of noise, like industrial noise, man-made activity such as automobile spark plugs, microwave ovens (Middleton, 1977) and network interference (Kanemoto *et al.*, 1998), noises known to be non-Gaussian (or impulse noise).

The Middleton Class-A model is frequently used to describe the impulsive noise. This was used to investigate the performances of turbo codes over channels affected by impulsive noise versus AWGN, when the encoder has two identical recursive systematic convolutional encoders with constraint length 5, rate 1/2, generator matrix G = [1, 23/25] (in octal form) and Binary Phase Shift Keying (BPSK) modulation. These are significantly weaker than the ones for Gaussian noise (Umehara *et al.*, 2004a). Most of the systems affected by non-Gaussian noise suffer performance degradation for high SNR values.

This paper presents an analysis of turbo code performances for a channel affected by Middleton additive white Class-A impulsive noise

(MAWCAIN), for various values of parameters that describe the impulsive noise model, with different values of scaling factor. We considered the cases of Log-MAP and Max-Log-MAP decoding algorithms. The interleaver used is of random type, of length 1,024 and 16,384, respectively.

The paper is structured as follows. Section **2** describes the Middleton Class-A impulse noise model and Section **3** presents the system model. The simulation results are shown in Section **4** and conclusions are highlighted in Section **5**.

2. Middleton Class-A Model

In many applications, non-Gaussian noise appears in addition to Gaussian noise. Some of its sources are: automotive ignition noise, power transmission lines, devices with electromechanical switches (photocopy machines, printers), microwave ovens etc. There are many statistical models for impulsive noise; in this study we assume the Middleton Class-A model. This type of noise has two components: a Gaussian one, with variance σ_g^2, and an impulsive one, with variance σ_i^2. The probability density function (PDF) of impulsive noise is a Poisson weighted sum of Gaussian distributions and it is given by (Umehara *et al*., 2004a).

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

The significance of quantities in eq. (1) is as follows: *m* is the number of active interferences (or impulses), *A* – the impulse index and it indicates the average number of impulses during interference time. This parameter describes the noise as follows: as *A* decreases, the noise gets more impulsive; conversely, as *A* increases, the noise tends towards AWGN. σ_m^2 is given by:

$$\sigma_m^2=\sigma^2\frac{m/A+T}{1+T}, \quad (2)$$

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

$$T=\frac{\sigma_g^2}{\sigma_i^2}, \quad (3)$$

is the Gaussian factor. We can observe from eq. (3) that for low *T* values, the impulsive component prevails, and that for high values, the AWGN component.

An impulsive noise sample is given by (Andreadou *et al.*, 2009):

$$n = x_g + \sqrt{K_m}\,w, \tag{4}$$

where: x_g is the white Gaussian background noise sequence with zero mean and variance σ_g^2, w – the white Gaussian sequence with zero mean and variance $A\sigma_i^2/A$ and K_m – the Poisson distributed sequence, whose PDF is characterized by the impulsive index A. If SNR_G is the value of signal-to-Gaussian noise power ratio and R_c is the coding rate, the variance σ_g^2 is obtained from:

$$\sigma_g = 1\Big/\sqrt{2R_c\text{SNR}_G} \tag{5}$$

3. System Model

3.1. The Structure of a Turbo Encoder and Decoder

The structure of the turbo code we used and the corresponding turbo decoder is given in Fig. 1. RSC1, RSC2 are the component recursive systematic convolutional codes, of memory 3 and generating matrix G = [1, 15/13] (in octal form). The global coding rate of the turbo encoder is 1/3. The interleaver π is of random type. This performs random permutation of the input sequence u, being one of the devices with a simple construction. The simulations were done for two of its lengths: 1,024 and 16,384.

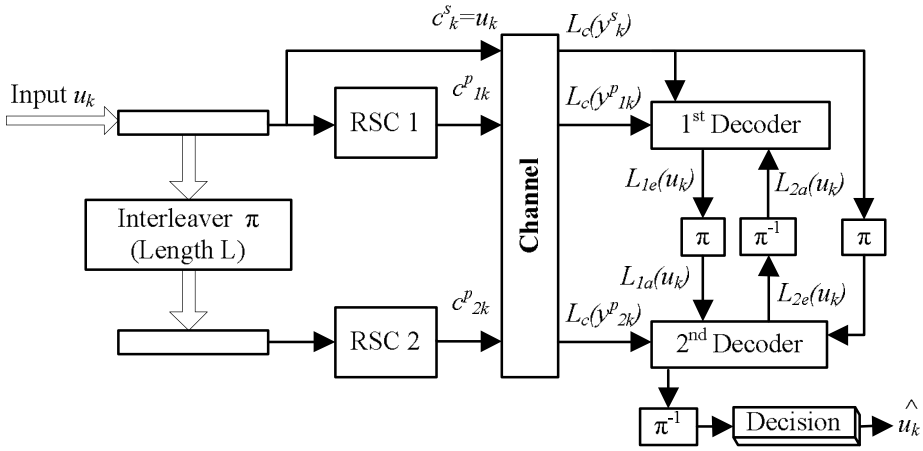


Fig. 1 – The structure of a turbo encoder and decoder.

$c_k^s = u_k$, c_{1k}^p and c_{2k}^p are outputs of the turbo encoder, having the following meaning: $c_k^s = u_k$ is the systematic bit, and c_{1k}^p, c_{2k}^p are the parity check bits from the current trellis section, corresponding to encoders RSC1 and RSC2, respectively. These bits are BPSK (Binary Phase-Shift Keying) modulated. The constellation for BPSK modulation has two real points {–1, +1}, where –1 value corresponds to bit 0 and +1 value corresponds to bit 1. Both trellises are terminated by post-interleaver method (Divsalar *et al.*, 1995). The BPSK symbols are transmitted over the MAWCAIN channel. The received version of the transmitted symbol c_k is given by:

$$y_k = c_k + n, \tag{6}$$

where n is the noise sample generated as in eq. (4).

The turbo decoder includes two MAP decoders, one for each of the RSCs, a random interleaver (π) and its corresponding deinterleaver (π^{-1}). The entries in the two decoders are: $L_c(y_k^s)$ – the channel values for the received systematic bits, $L_c(y_{ik}^p)$ – the channel values for the received parity check bits, where i = 1 indicates the first decoder and i = 2, the second one. $L_{ie}(u_k)$ are the extrinsic information for each decoder, and $L_{ia}(u_k)$ are the a priori logarithmic likelihood ratios (LLRs), i = 1, 2. After a number of iterations, based on the calculated LLR – $\Lambda(u_k)$, the decoder will decide on the bit $\hat{u}_k$. We use for simulation in turbo decoder a genie stopper criterion to stop iterations. The maximum number of iterations was set to 5 for length 1,024, as in (Ali, 2007), and to 9 for length 16384, as in (Umehara *et al.*, 2004b).

3.2. Decoding Algorithms

We use for turbo decoding two types of algorithms. Firstly, we used Log-MAP decoding algorithm and secondly, its simplified version, namely Max-Log-MAP, with different values for scaling factor of extrinsic information, as in (Vogt *et al.*, 2000) for AWGN or Rayleigh fading channel. The Max-Log-MAP decoding algorithm was detailed described for AWGN channel in (Andrei *et al.*, 2013). The difference for MAWCAIN channel is the way how we compute reliabilities for the received symbols. We describe this in the following.

For AWGN channel, the reliability L_c is given by (Umehara *et al.*, 2004a):

$$L_c\left(y_k\right) = 4R_c\mathrm{SNR}_G y_k. \tag{7}$$

For impulsive noise, the reliability is defined by (Umehara *et al.*, 2004):

$$L_c\left(y_k\right)=\ln\frac{\sum_{m=0}^{\infty}\frac{A^m}{m!\sigma_m}\exp\left(-\frac{\left(y_k-1\right)^2}{2\sigma_m^2}\right)}{\sum_{m=0}^{\infty}\frac{A^m}{m!\sigma_m}\exp\left(-\frac{\left(y_k+1\right)^2}{2\sigma_m^2}\right)}=$$
$$=\ln\frac{\sum_{m=0}^{\infty}\frac{A^m}{m!}\sqrt{\frac{AT}{m+AT}}\exp\left(-\frac{AT}{m+AT}R_c\mathrm{SNR}_G\left(y_k-1\right)^2\right)}{\sum_{m=0}^{\infty}\frac{A^m}{m!}\sqrt{\frac{AT}{m+AT}}\exp\left(-\frac{AT}{m+AT}R_c\mathrm{SNR}_G\left(y_k+1\right)^2\right)}, \tag{8}$$

where y_k is the sample received at moment k.

As in (Umehara *et al*., 2004b), we define:

$$\delta_m(x)=-\frac{AT}{m+AT}R_c\mathrm{SNR}_G x^2+\ln\left(\frac{A^m}{m!}\sqrt{\frac{AT}{m+AT}}\right). \tag{9}$$

In this case, the reliability becomes:

$$L_c\left(y_k\right)=\ln\left(\sum_{m=0}^{\infty}e^{\delta_m(y_k-1)}\right)-\ln\left(\sum_{m=0}^{\infty}e^{\delta_m(y_k+1)}\right). \tag{10}$$

In this paper, we use, for Max-Log-MAP algorithm, the approximation (Kusao *et al.*, 1985):

$$\ln\left(\sum_{m=0}^{\infty}e^{\delta_m(x)}\right)\approx\max_{m=0,1,2}\left(e^{\delta_m(x)}\right). \tag{11}$$

Let us consider the Jacobian logarithm:

$$\ln\left(e^x+e^y\right)=\max\left(x,y\right)+\ln\left(1+\exp\left\{-\left|y-x\right|\right\}\right)=$$
$$=\max\left(x,y\right)+f_c\left(\left|y-x\right|\right), \tag{12}$$

where $\exp\{\cdot\}$ is the exponential function, $f_c\left(\cdot\right)$ is the correction function (it can be stored in a look-up table). In this paper we use a correction function approximated by eight values, as follows (Balta *et al.*, 2004). Let v be the constant:

$$v = 7/9. \tag{13}$$

Then the used correction function is:

$$f_c(x) = \begin{cases} 0.6, & \text{if } x \le v, \\ 0.3, & \text{if } v < x \le 2v, \\ 0.14, & \text{if } 2v < x \le 3v, \\ 0.065, & \text{if } 3v < x \le 4v, \\ 0.03, & \text{if } 4v < x \le 5v, \\ 0.014, & \text{if } 5v < x \le 6v, \\ 0.005, & \text{if } 6v < x \le 7v, \\ 0.002, & \text{if } 7v < x \le 8v, \\ 0, & \text{if } x > 8v. \end{cases} \tag{14}$$

The logarithm of a sum of exponentials can be written as:

$$L_X = \ln\left[\sum_{k=0}^{M} \exp\{X_k\}\right] = X_{\max} + \ln\left[1 + \sum_{X_k \ne X_M} \exp\{X_k - X_{\max}\}\right], \tag{15}$$

where:

$$X_{\max} = \max_{k=0,\dots,M} X_k. \tag{16}$$

We denote

$$L_{X_0} = \ln\left[\exp\{X_0\}\right] = X_0. \tag{17}$$

From eqs. (12) and (14), (15) can be approximated with

$$L_{X_k} = \max\left(L_{X_{k-1}}, X_k\right) + f_c\left(\left|L_{X_{k-1}} - X_k\right|\right), \ (k = 1,\dots, M), \tag{18}$$

$$L_X \cong L_{X_M}. \tag{19}$$

This approximation was used in the Log-MAP turbo decoding algorithm.

In the case of Max-Log-MAP algorithm, the logarithm of the sum of exponentials is approximated with the maximum exponent, *i.e.*:

$$\ln\left[\sum_{k=0}^{M}\exp\left\{X_k\right\}\right]\approx X_{\max}. \tag{20}$$

In our simulations we have used the Log-MAP algorithm and the version of Max-Log-MAP with scaling the extrinsic information with a scaling factor *sf* between 0.55 and 1, with a step of 0.05.

The results obtained from simulations are presented in the next section.

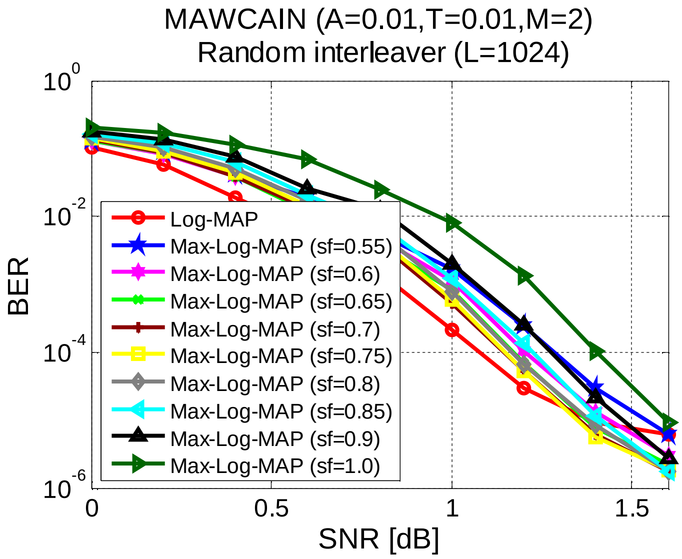
4. Simulation Results

The simulations were performed using a turbo code with the structure presented in Fig. 1, with a global coding rate of the encoder of 1/3. The generator matrix for the two component convolutional codes is G = [1, 15/13]. The interleaver used is of random type. We considered two interleaver lengths, 1,024 and 16,384, respectively. In this paragraph, we analyzed the performances of turbo code with the above features over a MAWCAIN channel, with BPSK modulation and Log-MAP and Max-Log-MAP decoding algorithms. The extrinsic information scaling factor for Max-Log-MAP decoding algorithm ranges from 0.55 to 1 with the step 0.05. The decoder performs maximum 5 iterations for interleaver length 1,024, as in (Ali, 2007), and 9 for length 16,384, as in (Umehara *et al.*, 2004b), with a genie stopper type stopping criterion. The parameters for the Middleton Class-A impulsive noise were varied as follows: (A; T)= (0.01; 0.01), corresponding to a strongly impulsive noise and (0.1; 0.1), corresponding to a weakly impulsive noise. The number of terms in the Middleton Class A PDF that was considered while generating the noise samples is M = 2, for all cases considered (Umehara *et al.*, 2004a), (Umehara *et al.*, 2004b).

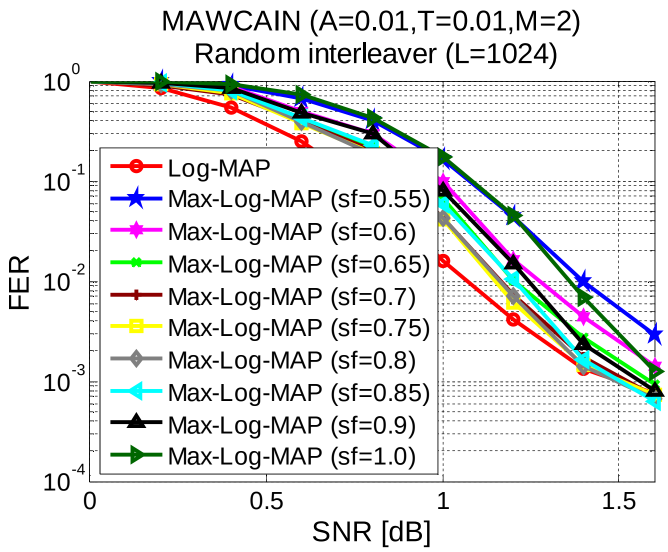
The purpose was to find the optimal value of the scaling factor so that the turbo codes performance on a channel affected by this type of noise to be high, *i.e.* BER and FER to be minimal possible.

Case A: (A; T)=(0.01; 0.01), L=1,024

For the interleaver length of L=1024 and parameters A = 0.01 (highly impulsive noise), T = 0.01, the BER and FER curves function of SNR were represented in Figs. 2 *a* and 2 *b*. In the BER domain, until SNR = 1.3 dB, the Log-MAP algorithm has the best results, slightly better than for Max-Log-MAP algorithm with the best scaling factors, bringing an additional coding gain of about 0.1 dB, at a BER roughly between 10^{-4} and 10^{-2}. For Max-Log-MAP algorithm, similar performances are obtained in the waterfall region, for scaling factor values of 0.7, 0.75 and 0.8, and after SNR = 1.3 dB, the best results are obtained for *sf* 0.7 and 0.75. In the FER domain, the situation is similar regarding the superiority of the Log-MAP algorithm, up until SNR = 1.3 dB, bringing an additional coding gain of about 0.12 dB at a FER roughly between 10^{-2} and 2×10^{-1}. In this case, the values from the middle of the interval, from which *sf* was considered, bring the best results, which are 0.7, 0.75 and 0.8. For the extreme values of *sf*, the performances are lower.



a

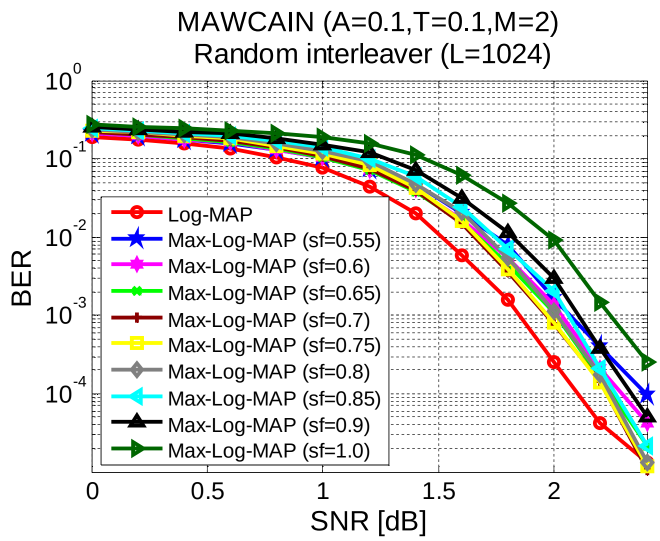


b

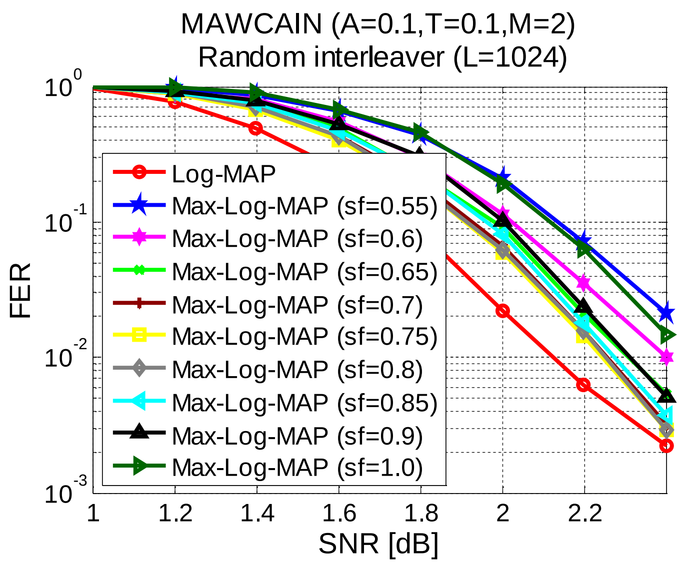
Fig. 2 – *a* – BER and *b* – FER curves for turbo code over MAWCAIN channel with $A = 0.01$ and $T = 0.01$, $L = 1{,}024$.

Case B: (A; T) = (0.1; 0.1), L = 1,024

For parameters A = 0.1, T = 0.1 (weakly impulsive noise), in both the FER and BER domains, the best performances are obtained by the Log-MAP algorithm, for the entire SNR chosen range of values. This can be observed in Figs. 3 *a* and 3*b*.



a



b

Fig. 3 – *a* – BER and *b* – FER curves for turbo code over MAWCAIN channel with A = 0.1 and T = 0.1, L = 1,024.

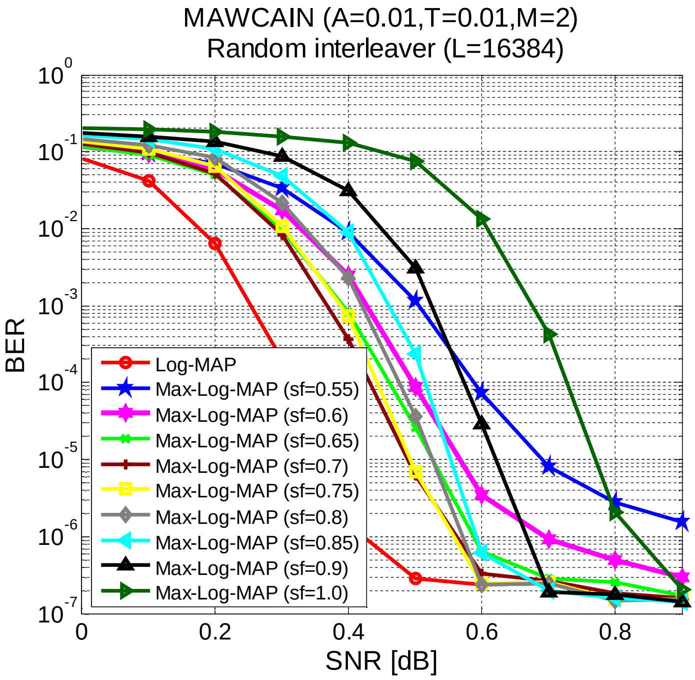
The *sf* values for which Max-Log-MAP has good results are 0.7, 0.75 and 0.8, both for BER and FER. The additional coding gain for the Log-MAP algorithm compared with Max-Log-MAP with the best scaling factor is about 0.12…0.14 dB, at a BER roughly between 10^{-4} and 10^{-2} and about 0.13…0.14 dB, at a FER roughly between 10^{-2} and 2×10^{-1}. The extreme range values for *sf*: 0.55, 0.6, 0.9 and 1 do not enhance the performances, as opposed to the middle ones, which ensure better performances.

Case C: (A; T) = (0.01; 0.01), L =16,384

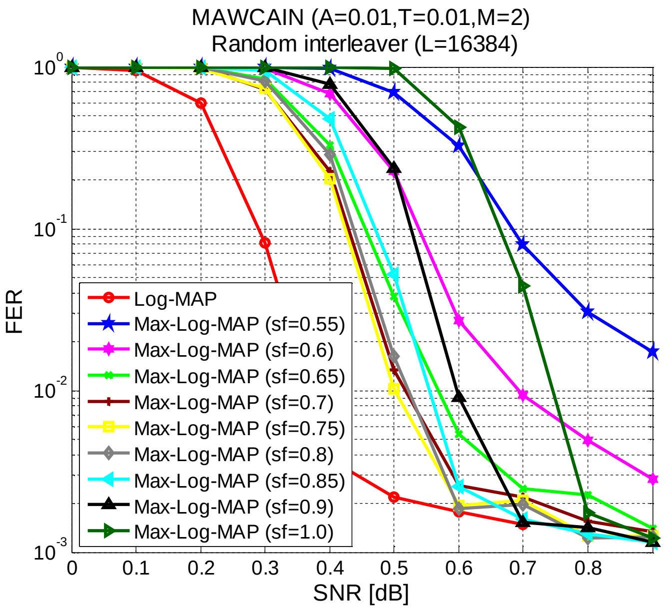
Figs. 4 *a* and 4 *b* show the simulation results for the interleaver length of L = 16,384 and impulsive noise model parameters A = 0.01 and T = 0.01. In both BER and FER domains, Log-MAP ensures significantly better performances for turbo codes, compared to Max-Log-MAP, for waterfall region, on a channel affected by non-Gaussian noise, bringing a coding gain of approximately 0.15 dB compared to the best scaling factors for Max-Log-MAP, at a BER roughly between 10^{-6} and 10^{-2} and a FER roughly between 3×10^{-3} and 8×10^{-1}. In the waterfall region, up until SNR = 0.6 dB, for BER domain, the best results are obtained for sf = 0.7, and for 0.75 for FER domain. For error-floor region, the performances are the same for Log-MAP algorithms and for Max-Log-MAP with scaling factors 0.7, 0.75 and 0.8. For the scaling factors close to 1, the performance of Max-Log-MAP algorithm is approached to the same value of error-floor, but for higher SNR values. When the scaling factor nears 1 (that is the case without scaling), the performance of the Max-Log-MAP algorithm in the "error-floor" region is similar to that of the Log-MAP algorithm, but for SNR increasingly higher. When the scaling factor nears 0.55 (the case when the extrinsic information transferred between the component decoders of the turbo decoder is strongly attenuated), the performance of the Max-Log-MAP algorithm in the "error-floor" region is increasingly weaker compared to that of the Log-MAP algorithm, that is the "error-floor" phenomenon manifests for an increasing BER/FER.

Case D: (A; T) = (0.1; 0.1), L = 16,384

In the case of interleaver length L = 16,384 and noise model parameters A = 0.1, T = 0.1, the results are shown in Figs. 5 *a* and 5 *b*. As in previous case, in waterfall region, Log-MAP algorithm assures a supplementary coding gain of approximately 0.15 dB compared to Max-Log-MAP algorithm with the best scaling factors, at a BER roughly between 10^{-6} and 10^{-2} and a FER roughly between 3×10^{-3} and 8×10^{-1}. The performances of Max-Log-MAP algorithm are improved in both the BER and FER domains, in the waterfall region, for scaling factors values from the middle of the interval from where *sf* was chosen: 0.65, 0.7, 0.75 and 0.8. The more *sf* is lower than 0.65 and the more it's closer to 1, the more the performances drop. In this case, the *sf* value which ensures the best results for turbo codes on MAWCAIN channel is 0.75. The same observation as in previous case is valid for error-floor region.

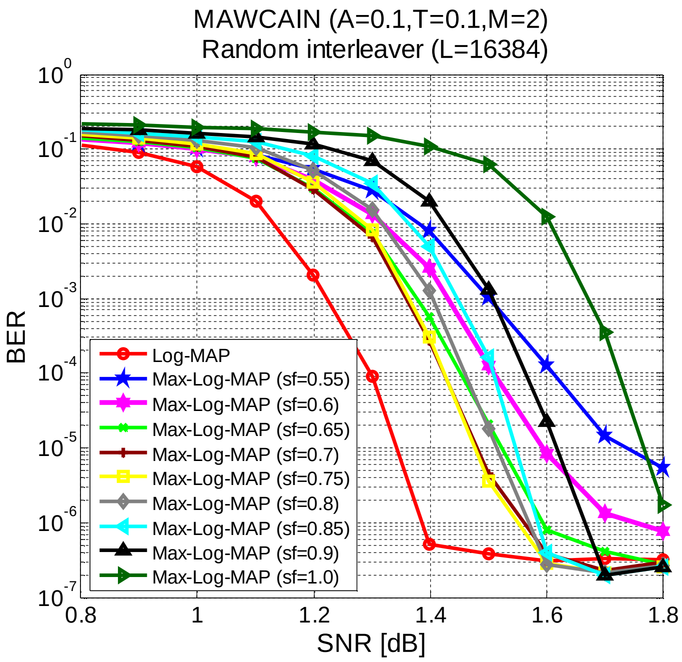


a

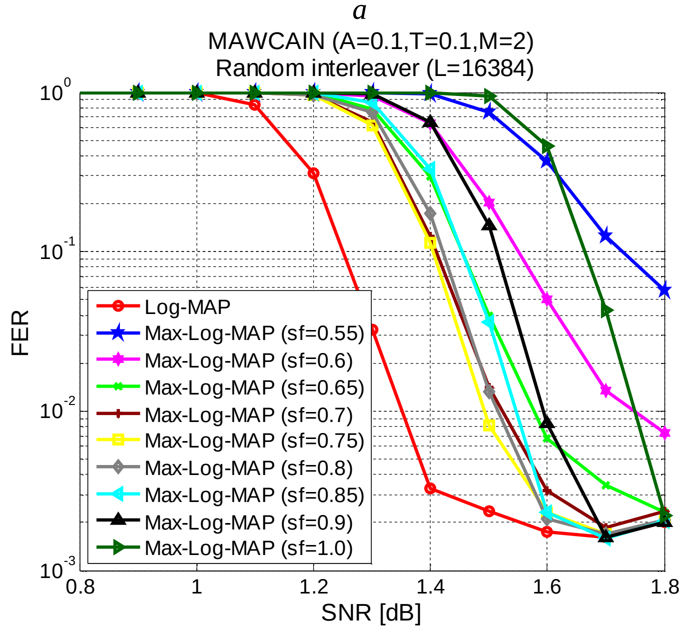


b

Fig. 4 – *a* – BER and *b* – FER curves for turbo code over MAWCAIN channel with A = 0.01 and T = 0.01, L = 16,384.



a



b

Fig. 5 – *a* – BER and *b* – FER curves for turbo code over MAWCAIN channel with $A = 0.1$ and $T = 0.1$, $L = 16{,}384$.

5. Conclusions

In this article, we have investigated the influence of the extrinsic information-scaling factor on the BER/FER performances of turbo codes with transmission on channels affected by impulsive noise of Middleton type class *A*. The modulation used was of BPSK type. We considered two interleaver lengths: one for small to medium lengths (1,024) and one for large lengths (16,384). For the MAWCAIN type noise, we considered two parameter sets: (A = 0.01; T = 0.01), meaning a highly impulsive noise and (A = 0.1; T = 0.1), meaning a low impulsive noise.

The decoding algorithms used are Log-MAP, like in (Umehara *et al*., 2004a), (Umehara *et al*., 2004b) and Max-Log-MAP with the extrinsic information-scaling factor having values between 0.55 and 1.0, with step 0.5.

According to simulation results from section 4, in all cases in the "waterfall" region of the BER/FER curves, the Log-MAP algorithm provides the best performances. In this region, for an interleaver length of 1,024, the Max-Log-MAP algorithm provides the best performances for scaling factors equal to 0.65, 0.7, 0.75 and 0.8 in the BER domain, and for scaling factors equal to 0.7, 0.75 and 0.8 in the FER domain. The additional coding gain for the Log-MAP algorithm compared to the Max-Log-MAP algorithm with the best scaling factor, for a length of 1024, is around 0.1 dB for highly impulsive noise and slightly higher (0.12…0.14 dB) for low impulsive noise, at a BER roughly between 10^{-4} and 10^{-2} and around 0.12 dB for highly impulsive noise and slightly higher (0.13…0.14 dB) for low impulsive noise, at a FER roughly between 10^{-2} and 2×10^{-1}.

For the interleaver length of 16384, in the "waterfall" region, the Max-Log-MAP algorithm provides the best performances for scaling factors equal to 0.7 and 0.75 in the BER domain and equal to 0.7, 0.75 and 0.8 in the FER domain. The additional encoding gain for Log-MAP algorithm compared to the Max-Log-MAP algorithm with the best scaling factor is around 0.15 dB, for both the high and low impulsive noises, for a length of 16,384 at a BER roughly between 10^{-6} and 10^{-2} and a FER roughly between 3×10^{-3} and 8×10^{-1}.

In the "error-floor" region, the performances of the Log-MAP and Max-Log-MAP algorithms, with the best scaling factors, are similar in all cases. When the scaling factor nears 1 (that is, when it nears the case without scaling) the performances of the Max-Log-MAP algorithm in the "error-floor" region is similar to that of the Log-MAP algorithm, but at an increasing SNR. When the scaling factor nears 0.55 (that is, when it nears the case when the extrinsic information transferred between the component decoders of the turbo decoder is strongly attenuated) the performances of the Max-Log-MAP algorithm in the "error-floor" region is increasingly weaker compared to that of the Log-MAP algorithm, that is the "error-floor" phenomenon occurs for an increasing BER/FER.

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INFLUENȚA FACTORULUI DE SCALARE A INFORMATIEI EXTRINSECI ÎN ALGORITMUL DE DECODARE MAX-LOG-MAP A CODURILOR TURBO CU TRANSMISIE PE CANAL CU ZGOMOT IMPULSIV DE TIP MIDDLETON DE CLASA-A

(Rezumat)

Se prezintă analiza influenței factorului de scalare a informației extrinseci în algoritmul iterativ de decodare turbo, pe un canal afectat de zgomot impulsiv, cu modulație Binary Phase-Shift Keying. Modelul statistic folosit pentru zgomotul impulsiv este Middleton Class-A. Am considerat cazul algoritmilor Log-MAP şi Max-Log-MAP şi două lungimi ale interleaver-ului aleator: 1 024 şi 16 384. Simulările au fost realizate pentru diferite valori ale parametrilor ce descriu modelul Middleton Class-A. Algoritmul Log-MAP asigură cele mai bune performanțe pentru codurile turbo în prezența zgomotului impulsiv. Pentru Max-Log-MAP, cele mai bune rezultate sunt obținute pentru un factor de scalare cu valorile 0,7, 0,75 sau 0,8.