Performance Analysis of Turbo-Coded Decode-and-Forward Relay Channels with Middleton Class-A Impulsive Noise

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***Abstract*—Relays are used to improve wireless network performances. In this paper, the decode-and-forward relaying technique is used to achieve spatial diversity. We considered a system with a symmetric turbo coded relay and its three channels (source-relay, source-destination and relay-destination) affected by impulsive noise. The statistic model used for noise was Middleton additive white Class-A. The performances are evaluated by investigating the system behavior when at destination the traditional iterative decoder and the heuristically modified iterative decoder proposed by Huynh are used. The simulations were made for different parameter values of the noise model and they showed that in high impulsive noise conditions, the relay system offers better performance than the direct link. However, when the source-destination channel is weak, the traditional iterative decoder assures an additional gain than the heuristically modified one. When the Gaussian component is dominant, the relay system ensures better performances, but only at high values of Signal-to-Noise Ratio. In this case, the heuristically modified decoder, with conveniently chosen value for α, is better than the traditional one in terms of bit error rate.**

***Index Terms*—decode-and-forward, impulsive noise, iterative decoder, relay channels, turbo codes.**

I. Introduction

In general, the evaluation of communication system performance is done in terms of Bit Error Rate (BER). The noise and fading that affect the channel are two of the factors that have a major contribution in communication deterioration (by increasing the BER). In order to mitigate the fading, a solution would be using multiple transmit and receive antennas [1], or alternative techniques, called cooperative diversity or cooperative communication [2]. This implies the use of a relay channel between user and base station [3]. In this relay system, the information is transmitted from source to destination using at least one node, called relay [4]. Such a network offers certain advantages, such as: mobility, easy installation, reliability, cost effectiveness, high capacity [5].

The most known relaying techniques are amplify-and-forward (AF) relaying and decode-and-forward (DF) relaying [6]. In the case of DF relaying, the relay decodes and re-encodes (using the same code as the source or a different code) the signal received from the source. Less complex, the AF relaying does no more than to amplify the signal received from the source and to transmit it further towards the destination.

By using the DF relaying technique together with a turbo encoded relay, the communication performance is improved. The turbo code offers an intercalation gain, the iterative decoder a processing gain, the system further assuring both encoding and diversity gain [7]. The model of such a system (two-hop relay network) is given in Fig. 1.

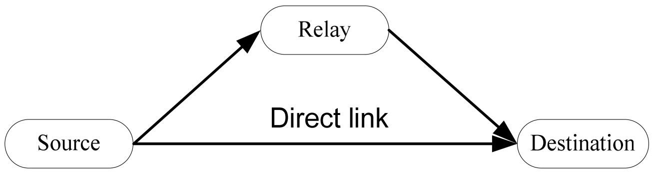

Figure 1.The model of a two-hop relay network with direct link

The source transmits the signals to relay and destination, respectively. At relay, these are decoded and interleaved, before their re-encoding. The receiver (the destination) receives both the information encoded by the source, sent directly, and also the coded interleaved information transmitted by the relay.

The three channels source-relay, relay-destination and source-destination are affected by noise. In most of the proposed schematics, the channel was considered affected by fading and additive Gaussian white noise (AWGN), ignoring the non-Gaussian one (or impulse noise).

The performance of the decode-and-forward cooperative relaying scheme operating in fading channel disturbed by impulse noise and AWGN suffers degradation for low Signal-to-Noise Ratio (SNR) [8]. The spatial diversity is still accomplished under the influence of non-Gaussian noise [9], the cooperative relaying being significantly better than direct transmission for low impulse rate and slightly worse at severally impulse noise ranges.

The Middleton Class-A model is frequently used to model the impulsive noise. This was used to investigate the performance of cooperative communications over Rayleigh fading channels, considering a multi-relay network with amplify-and-forward relaying [10]. The results showed that full spatial diversity can be obtained in high impulsive noise environment for sufficiently high SNR values. For low SNR, the performance of the system depends on the impulse nature.

To the best of our knowledge, no research results have been published for turbo-coded decode-and-forward relay channels in the presence of impulsive noise. To fill this, our paper presents the performance analysis of the decode-and-forward system with a symmetric turbo coded relay, when

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the three channels (source-relay, source-destination and relay-destination) are affected by AWGN and Middleton additive white Class-A impulse noise (MAWCAIN). For the decoding part, we used the traditional iterative decoder (TID), which has the disadvantage of neglecting decoding errors propagated by relay, and the modified one, based on the TID but with some modifications, which takes into account the decoding errors at relay, named heuristically modified iterative decoder (HMID) [11].

The paper is structured as follows. Section II describes the Middleton Class-A impulse noise model and Section III presents the system model. The simulation results are shown in Section IV and conclusions are highlighted in Section V.

II. Middleton Class-A model

In many applications, in addition to Gaussian noise the non-Gaussian noise appears. Some of its sources are: automotive ignition noise, power transmission lines, devices with electromechanical switches (photocopy machines, printers), microwave ovens etc. [10]. 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) is given by relation (1) and it is a Poisson weighted sum with Gaussian distributions [12].

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

The significance of quantities in (1) is as follows: m is the number of active interferences (or impulses), A is the impulsive 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:

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

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

An impulsive noise sample is [13]:

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

where x_g is the white Gaussian background noise sample with zero mean and variance σ_g^2, w is the white Gaussian sample with zero mean and variance σ_i^2 / A and K_m is the Poisson distributed sequence, whose PDF is characterized by the impulsive index A.

III. System Model

The cooperative diversity scheme used in this paper is shown in Fig. 2 [11], [14].

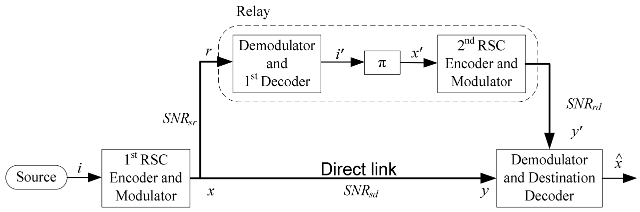


Figure 2. The cooperative diversity scheme

The significance of notations in Fig. 2 The significance of notations in Fig. 2 is as follows: SNR_{sr} is SNR for source-relay channel, *SNRsd* – SNR for source-destination channel, and SNR_{rd} represents the SNR for relay-destination channel. i is the information bit sequence, generated by the source in the first period of time. This is the entry for the 1st recursive systematic convolutional (RSC) encoder and modulator. After encoding and modulation (Binary Phase Shift Keying – BPSK), this sequence (x) is transmitted directly to destination, being the first noisy sequence y.

The x sequence affected by the source-relay channel noise forms the signal r received by relay. Here, in the second operating period of the system, the relay demodulates and decodes the received sequence, thus obtaining the sequence i'. This is interleaved, re-encoded, modulated and transmitted to destination. π represents the permutation of the interleaver at relay. The relay decoder is that of Bahl, Cocke, Jelinek and Raviv (BCJR) [15].

The destination receives two noisy sequences: y (from the source, direct link) and y' (from relay). These are decoded using the TID or HMID, resulting the output sequence $\hat{x}$.

The signals received by relay and destination are given by:

$$r = \sqrt{E_s} x + n_r, \tag{5}$$

$$y = \sqrt{E_s} x + n_d, \tag{6}$$

$$y' = \sqrt{E_r} x' + n'_d \tag{7}$$

where E_s is the energy per symbol of the signal transmitted by the source, E_r is the energy per symbol of the signal transmitted by the relay, n_r – the MAWCAIN sample at the relay, n_d, n'_d – the MAWCAIN samples at the destination. In this paper, we considered the energy values equal to 1 and the variances of Gaussian components were calculated based on the corresponding coding rates and the SNR values on the channels. The SNR value on the channel is considered to be like in [12], the ratio between the energy of the information bit and power spectral density of the Gaussian noise component. Let $\sigma_{g,sr}^2$, $\sigma_{g,sd}^2$, $\sigma_{g,rd}^2$ denote the variances corresponding to Gaussian noises on the source-relay, source-destination and relay-destination channels, respectively, $R_{c,sr}$, $R_{c,sd}$, $R_{c,rd}$ the coding rates corresponding to transmissions on the three channels and SNR_dB_{sr}, SNR_dB_{sd}, SNR_dB_{rd}, the signal-to-noise ratios in dB. The following relations can be written:

$$\sigma_{g,sr}^2 = \frac{1}{2 \cdot R_{c,sr} \cdot 10^{SNR\_dB_{sr}/10}} \tag{8}$$

$$\sigma^2_{g,sd} = \frac{1}{2 \cdot R_{c,sd} \cdot 10^{SNR\_dB_{sd}/10}} \tag{9}$$

$$\sigma^2_{g,rd} = \frac{1}{2 \cdot R_{c,rd} \cdot 10^{SNR\_dB_{rd}/10}} \tag{10}$$

The variances of impulsive components result from (3), according to the parameter T, for each channel.

The decoder used at the receiver is TID or HMID [11], based on Maximum Logarithmic Maximum A Posteriori (Max-Log-MAP) algorithm [16], with a scaling factor of extrinsic information sf=0.7, as in [17].

A. Traditional turbo code iterative decoder (TID)

The scheme for this type of decoder is shown in Fig. 3. This includes two BCJR decoders, one for each of the RSCs, a random interleaver (π) and its corresponding deinterleaver (π^{-1}).

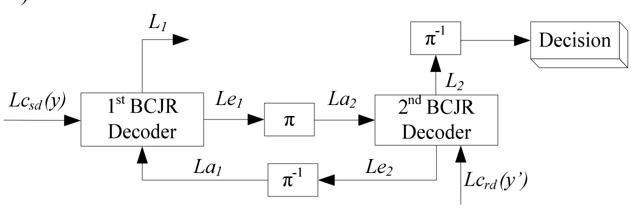


Figure 3. Traditional turbo code iterative decoder

The entries in the two decoders are: $Lc_{sd}(y)$ - the channel values for the sequence received from the source, $Lc_{rd}(y')$ - the channel values for the sequence received from the relay, and La_1, La_2 - the a priori logarithmic likelihood ratios (LLRs), respectively. Each decoder has two outputs: the extrinsic information (Le_1 - for the first decoder and Le_2 - for the second one) and the a posteriori LLR (L_1 - for the first decoder and L_2 - for the second one, respectively). After a number of iterations, L_1 and L_2 can be used for decision.

In this paper, we used L_1 for decision, because the performances are better for relay channel, at least when the relay decoding shows a significant number of errors.

For impulsive noise $Lc_{sd} \cdot y$ and $Lc_{rd} \cdot y'$ from [11] become $Lc_{sd}(y)$, $Lc_{rd}(y')$ [12], respectively. In this case, for MAWCAIN channel, the LLR is defined by [12]:

$$L_c(y_k) = \ln \frac{\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot exp\left(-\frac{(y_k-1)^2}{2\sigma_m^2}\right)}{\sum_{m=0}^{\infty} \frac{A^m}{m! \cdot \sigma_m} \cdot exp\left(-\frac{(y_k+1)^2}{2\sigma_m^2}\right)}, \tag{11}$$

where y_k is the sample received at moment k.

B. Heuristically modified iterative decoder (HMID)

The HMID decoder is shown in Fig. 4. Its structure is very similar to the decoder presented at point A.

The extrinsic information Le_2' is the one through which the errors from the relay are propagated from one iteration to the other and from the second decoder to the first. For decision, L_1 is recommended to be used, not L_2, because this one carries the flawed information. In order to minimize the number of propagated errors, Huynh [11] proposed to modify Le_2', by a heuristic solution, adding a scaled version of L_1 at each iteration, with the advantage of accurate transmission of information,) to Le_2', according to relation (12).

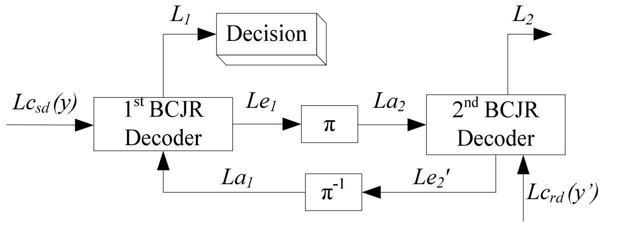


Figure 4. Heuristically modified iterative decoder

Using this trick in each iteration, when the source-destination channel is good enough, that is, the SNR large enough to lead to small BER, the erroneous information carried by Le_2' will be reduced:

$$Le_2' := Le_2' + \alpha\pi(L_1), \alpha > 0, \tag{12}$$

where α is a coefficient defining the amount of L_1 that should be added to Le_2' and $\pi(L_1)$ is the interleaved value of L_1. The value of α must not be too small, that is, not too close to zero, because then the effect of L_1 would be insignificant, and the HMID performances would be similar to those of TID. The value of α should not be neither too large because the extrinsic information, transferred from decoder 2 to 1 would be, in fact, a version of the L_1 information.

IV. Simulation Results

In this section, we present the simulation results for the turbo-coded relay system, in which all three channels of the system (source-relay, source destination and relay-destination) are affected by MAWCAIN noise with the same parameters. Four situations are considered, where the values for A and T are the following: (A=0.01, T=0.01), (A=0.01, T=0.1), (A=0.1, T=0.01) and (A=0.1, T=0.1), respectively. The direct polynomial and the feedback one are the same, for the recursive convolutional encoder from the source and also for the one at relay, that is, 21 and 37, respectively (in octal form). These are the polynomials also used in [11], where the HMID decoder is proposed for the turbo encoded system with relay on AWGN channel. At both the source and the relay, the encoders are terminated by the post-interleaver method [18].

The interleaver used at the relay is random and has the length of 1000. This length was chosen in order to allow faster decoding at destination. The analysis in this paper does not take into consideration the effect of the interleaver length on the performances of the turbo encoded relay system, but only the dependency on the channel parameters of MAWCAIN and the comparison with the direct link performance. As it was specified in section III, the relay decoder is the BCJR one for the source encoder. At the destination, both the TID decoder (described in Section III.A) and the HMID decoder (described in Section III.B) are considered, in order to observe the differences between their performances. For the TID decoder, α is obviously zero. For both TID and HMID, the decoding algorithm used is Max-Log-MAP with an extrinsic information scaling factor *sf*=0.7, as mentioned in section III, and the iteration stopping criterion is genie-stopper (GS), the maximum number of iterations being 12.

It must be noted that, since we compare the relay system performances with the direct link, for a fair comparison, the global encoding rate must be the same. In the case we considered, it is 1/3. For this, in the case of relay system, only systematic sequence from source is transmitted, because the information from the relay can be affected by errors resulting from the decoding at that point. Both the parity sequences at the source and at the relay are transmitted. It results that, at the source, the global encoding rate is $R_{c,sr} = R_{c,sd} = 1/2$ and, at the relay it is $R_{c,rd} = 1$. Therefore, the Gaussian noise variances on the source-relay, source-destination and relay-destination channels will be generated for these global encoding rates with relations (8), (9) and (10), respectively.

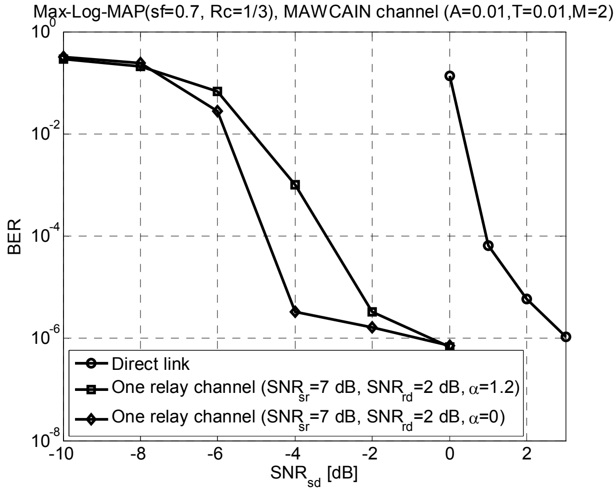
For a plausible scenario, when the distance from source to relay and that from relay to destination is smaller than the distance from source to destination, the SNR_{sr} and SNR_{rd} values must be higher than those considered from the range of SNR_{sd} values.

In the first two situations, that is, A=0.01 and T=0.01 or T=0.1, the following fixed values were considered: SNR_{sr} =7 dB and SNR_{rd}=2 dB and the performances of BER/FER were evaluated at destination, depending on the value of SNR_{sd}. In the last two situations, meaning A=0.1 and T=0.01 or T=0.1, we considered two values for SNR_{sr} (20 dB and 28 dB) and one value for SNR_{rd} (10 dB). The BER/FER performances were also evaluated depending on the value of SNR_{sd}. The reason why we also considered the value SNR_{sr} =28 dB is that, when A=0.1 and T=0.01, for SNR_{sr}=20 dB, when SNR_{sd} is high, the direct link offers better performances than the relay system and we are interested in the value of SNR_{sr} that leads to superior performances throughout the whole range of SNR_{sd} values.

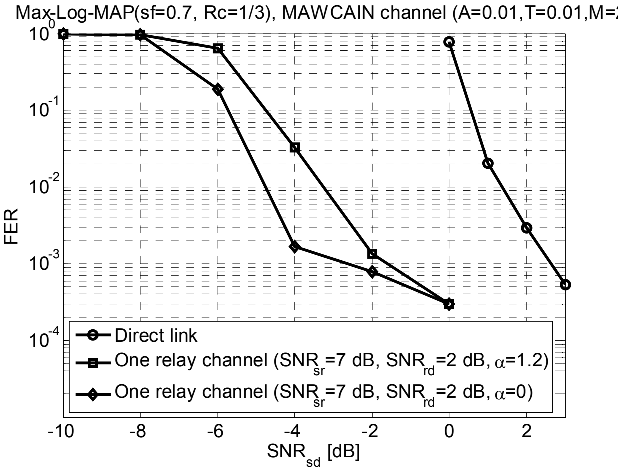
The value of α in case of the HMID decoder for the first two situations is chosen to be 1.2, which was found to give performances similar or better than TID for the entire domain of SNR_{sd} values, when A=0.1. This case requires more special attention, because, as we will see, very high SNR values are required for the three channels to get low BER. Comments on other values of α will be made for each case.

BER and FER curves for relay turbo coded system (with HMID when α=1.2 or TID when α=0, SNR_{sr} =7 dB, SNR_{rd} =2 dB) and for direct link, when MAWCAIN channels parameters are A=0.01 and T=0.01 are given in Figs. 5 a) and b), respectively. From these figures we can observe that the relay system, be it with TID, or with HMID at destination, leads to better performances than the direct link. For example, for BER=10^{-5}, when using HMID with α=1.2, the additional encoding gain, as opposed to the direct link, is 4.17 dB, and TID brings an additional gain of 1.85 dB, as opposed to HMID. In the FER domain, for example for FER=$2\text{x}10^{-3}$, the additional encoding gain brought by the relay system with HMID with α=1.2, as opposed to the direct link, is 4.48 dB, and TID brings an additional gain of 1.82 dB, compared to HMID.

This behavior, different from the cases analyzed in [11], is because the SNR_{sd} on the source-destination channel is small. Thus, the quantity from L_1 added to $Le_2{}'$ degrades the performance of relay system.



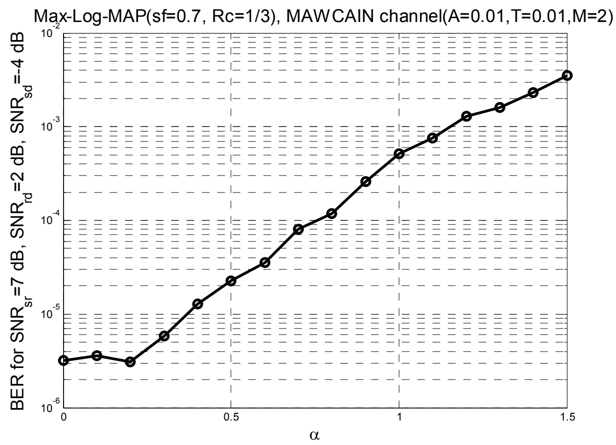
a)



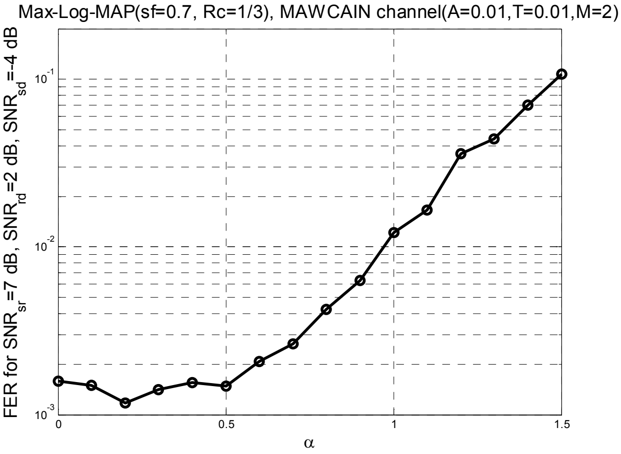
b)

Figure 5. a) BER and b) FER curves for relay turbo coded system (with HMID when α=1.2 or TID when α=0, *SNRsr*=7 dB, *SNRrd*=2 dB) and for direct link, when MAWCAIN channels parameters are A=0.01 and T=0.01 (global coding rate for both cases is 1/3).

When α becomes higher, the performance is weaker, because the extrinsic information is further deteriorated, and when α is smaller, the performance becomes better, nearing to that of the TID decoder, when α is closer to zero. To exemplify this, BER and FER curves were represented in Fig. 6, depending on α, when SNR_{sd}=-4 dB.



a)



b)

Figure 6. a) BER and b) FER for relay turbo coded system with HMID, when *SNRsr*=7 dB, *SNRrd*=2 dB, *SNRsd*=-4 dB and when MAWCAIN channels parameters are *A*=0.01 and *T*=0.01.

BER and FER curves for relay turbo coded system (with HMID, when α=1.2 or TID, when α=0, SNR_{sr} =7 dB, SNR_{rd} =2 dB) and for direct link, when MAWCAIN channel parameters are A=0.01 and T=0.1 are given in Figs. 7 a) and b) respectively.

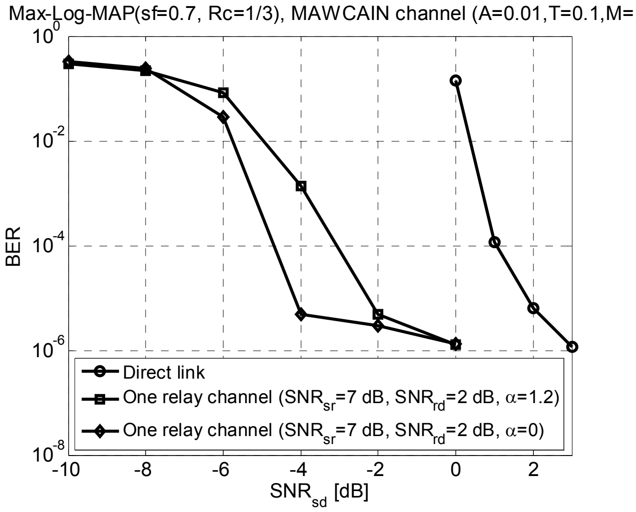
For example, for BER=10^{-5}, when using HMID with α=1.2, the additional encoding gain, as opposed to the direct link, is 4.09 dB, and the TID decoder brings an additional gain of 1.91 dB, as opposed to TID. In the FER domain, for example FER=3×10^{-3}, the additional encoding gain brought by the relay system with HMID with α=1.2, as opposed to the direct link, is 4.31 dB, and TID brings an additional gain of 1.79 dB, as opposed to TID. We mention that, in this case (T=0.1), the SNR_{sd} values needed to obtain the same BER or FER are slightly larger than the previous case (when T=0.01).

This can be explained by the fact that, for the same value of A, when T is smaller, the impulsive noise prevails, and the destination decoder is adapted for this kind of noise and therefore leads to better performances than those when T is larger and so, the Gaussian noise has higher power [12]. As the SNR_{sd} values are the same as those for simulations shown in Fig. 5, the same observations regarding the changing value of α for HMID are maintained.

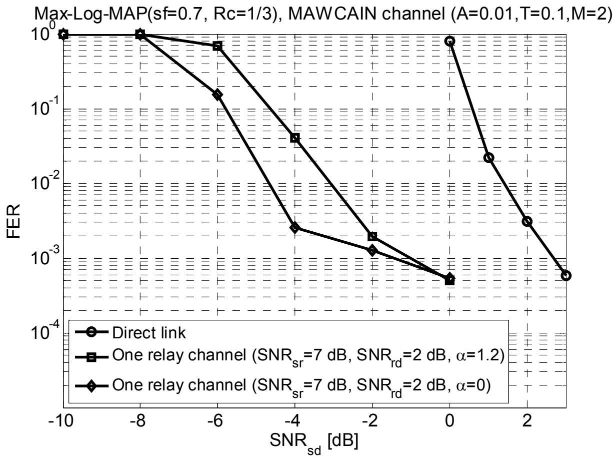
This can be observed from Fig. 8, where BER and FER, respectively, are represented, depending on α, when SNR_{sd} =-4 dB. For α>0.3, the performance gradually decreases (BER/FER increase).

BER and FER curves for the relay turbo coded system (with HMID when α>0 or TID when α=0, SNR_{sr} =20 dB or 28 dB, SNR_{rd} =10 dB) and for direct link, when MAWCAIN channels parameters are A=0.1 and T=0.01 are given in Figs. 9 a) and b), respectively.

It can be observed that, because the value of A is increased and, therefore, the Gaussian component of the noise is dominant, higher SNR_{sd} values are needed in order to obtain low BER/FER. Furthermore, in the case of the relay system, the SNR_{sr} and SNR_{rd} values must be high enough, so that BER/FER are smaller than in the case of direct link throughout the entire range of considered SNR_{sd} values.



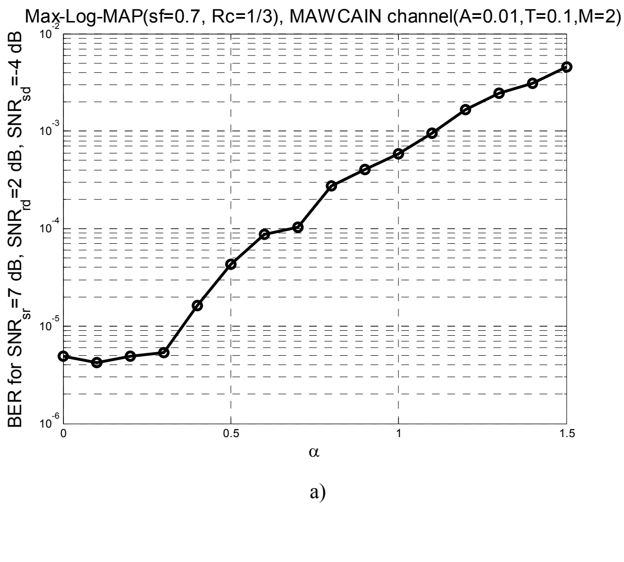
a)



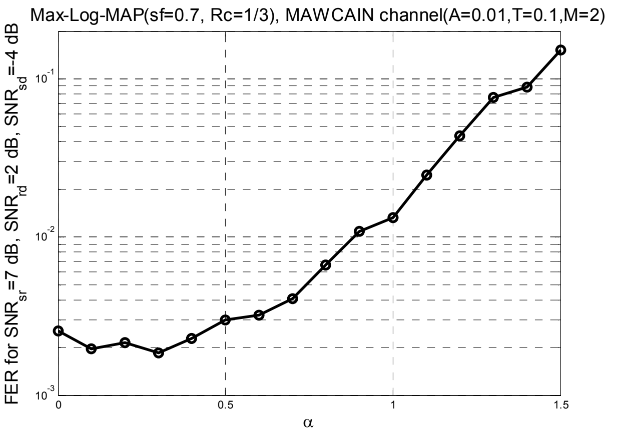
b)

Figure 7. a) BER and b) FER curves for relay turbo coded system (with HMID when α=1.2 or TID when α=0, *SNRsr*=7 dB, *SNRrd*=2 dB) and for direct link, when MAWCAIN channels parameters are *A*=0.01 and *T*=0.1 (global coding rate for both cases is 1/3).

In this case we have also represented BER and FER depending on α values, when SNR_{sr} =20 dB, SNR_{rd} =10 dB, SNR_{sd} =4 dB (Fig. 10). It can be observed that the behavior when changing the value of α in HMID decoder is different from the case A=0.01. Thus, the performance is the best when α=2.5, and for values of α smaller or larger, the performance becomes weaker. A similar representation shows that α close to 2 leads to the best performances when SNR_{sr} =28 dB, SNR_{rd} =10 dB, SNR_{sd} =4 dB.

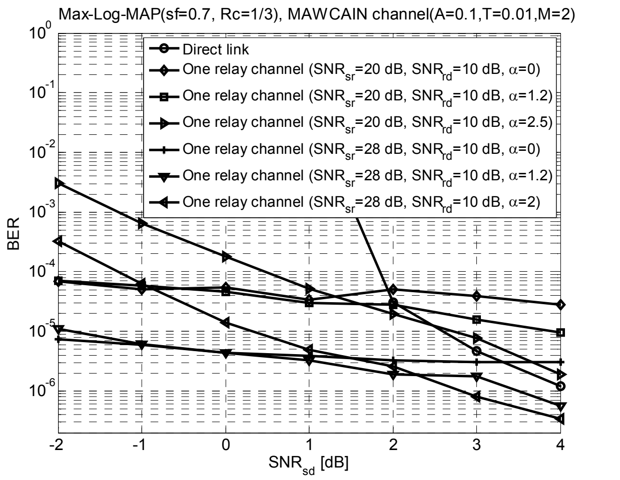


a)

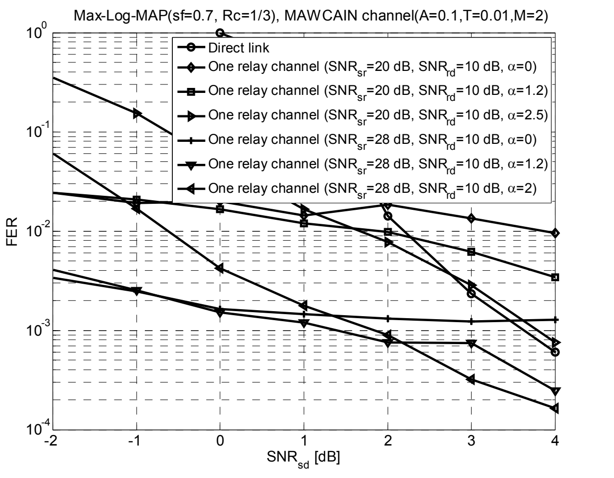


b)

Figure 8. a) BER and b) FER for relay turbo coded system with HMID, when *SNRsr*=7 dB, *SNRrd*=2 dB, *SNRsd*=-4 dB and when MAWCAIN channels parameters are *A*=0.01 and *T*=0.1.



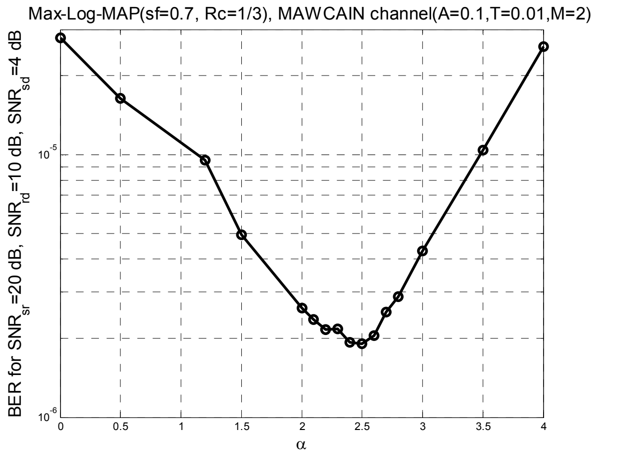
a)



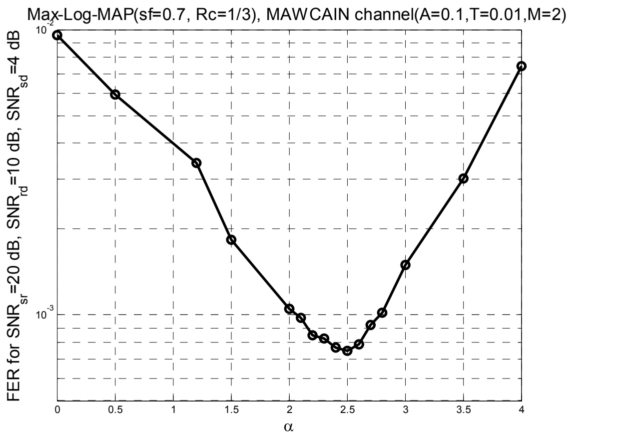
b)

Figure 9. a) BER and b) FER curves for relay turbo coded system (with HMID when α>0 or TID when α=0, *SNRsr*=20 dB or 28 dB, *SNRrd*=10 dB) and for direct link, when MAWCAIN channels parameters are *A*=0.1 and *T*=0.01 (global coding rate for both cases is 1/3).

Therefore, in Fig. 9, we considered only the results for α=1.2 and α =2.5, when SNR_{sr} =20 dB, and for α=1.2 and α =2 when SNR_{sr}=28 dB. For SNR_{sr} =20 dB, when the value of α is increased from 1.2 to 2.5, the relay system performance is better only for high SNR_{sd} (in Fig. 9 for SNR_{sd} values greater than about 1.5 dB), while for lower and higher values, the performance is weaker. At higher values of α (over 2.5) and low SNR_{sd} the performance worsens even more than the TID decoder or even than for α=2.5.



a)

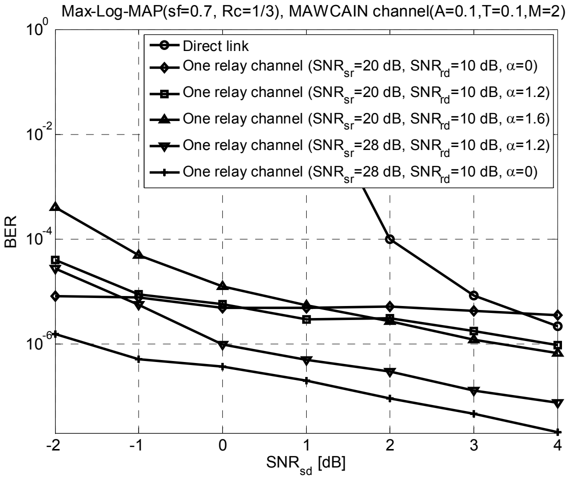


b)

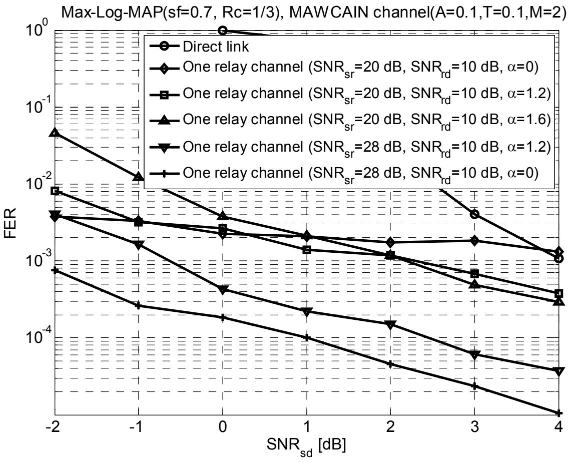
Figure 10. a) BER and b) FER for relay turbo coded system with HMID, when *SNRsr*=20 dB, *SNRrd*=10 dB, *SNRsd*=4 dB and when MAWCAIN channels parameters are *A*=0.1 and *T*=0.01.

For α lower than 2.5, the performance is closer to that of TID decoder as α approaches zero. This behavior is explained below. In this case, the source-relay and the relay-destination channels are very good (they have SNR high enough). The source-destination channel has SNR_{sd} values that we could fit into three areas: one for low values, where HMID decoder performs worse than TID (similar cases from Figs. 5 and 7, a second one with intermediate values, where HMID and TID have similar performances and a third one with higher values, where HMID decoder becomes more efficient when α is conveniently chosen, that is neither too high nor too low, as it was specified in Section III.B (for the values we analyzed, the performances are the best for α=2.5). For SNR_{sr} =28 dB, the behavior is similar to that for SNR_{sr} =20 dB (in our case, HMID decoder with α=2 leads the best results for SNR_{sd} greater than about 2 dB). As it can be seen in Figs. 9 a) and b), only the HMID decoder, with α=1.2 or α=2, in the case of SNR_{sr} =28 dB, is superior to the direct link for BER<2×10^{-6} or FER<10^{-3}. The increase of SNR_{sr} from 20 to 28 dB leads to a drop, by approximately an order of magnitude, for the values of BER or FER in the case of the relay system. The direct link is superior to it (with HMID or TID), when SNR_{sr} =20 dB, for BER<10^{-5} or FER<4×10^{-3}, meaning SNR_{sd} values higher than approximately 2.5 dB.

BER and FER curves for relay turbo coded system (with HMID when α>0 or TID when α=0, SNR_{sr} =20 dB or 28 dB, SNR_{rd} =10 dB) and for direct link, when MAWCAIN channels parameters are A=0.1 and T=0.1 are given in Figs. 11 a) and b), respectively.



a)

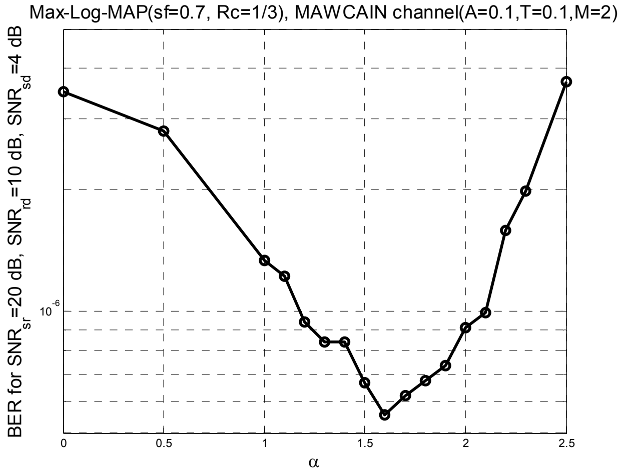


b)

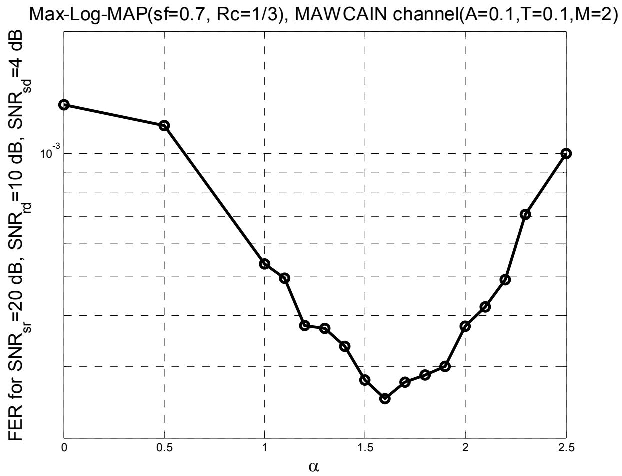
Figure 11. a) BER and b) FER curves for relay turbo coded system (with HMID when α>0 or TID when α=0, $SNRsr$=20 dB or 28 dB, $SNRrd$=10 dB) and for direct link, when MAWCAIN channels parameters are A=0.1 and T=0.1 (global coding rate for both cases is 1/3).

In this case, because both A and T are high, the Gaussian component of the noise is more important than in the previous cases. It can be observed that the direct link leads to poorer performances, according to [12]. On the other hand, the relay system leads to significantly better performances than in the previous case and also compared to direct link, except when using TID for SNR_{sr} =20 dB, when the performance is slightly lower at high SNR_{sd} (nearing 4 dB).

In Fig. 12, we represented BER and FER, respectively, depending on α, when SNR_{sr} =20 dB, SNR_{rd} =10 dB and SNR_{sd} =4 dB. For SNR_{sr} =20 dB, the behavior is similar to that for the previous case, when A=0.1 and T=0.01, but, because the value of T is higher, the Gaussian component is dominant, the value of α for which the HMID decoder leads to better performances is lower (in our case, for SNR_{sd} greater than 2dB, the HMID decoder with α=1.6 leads the best performances). Instead, for low SNR_{sd} the performance becomes weaker than for α=1.2. When the value of α decreases, the system performance is better for lower SNR_{sd}, being almost the same as the TID decoder, when α approaches 0 and when SNR_{sd} decreases. When α increases, the performance becomes weaker for high SNR_{sd} and even more for low SNR_{sd} .



a)



b)

Figure 12. a) BER and b) FER for relay turbo coded system with HMID, when $SNRsr$=20 dB, $SNRrd$=10 dB, $SNRsd$=4 dB and when MAWCAIN channels parameters are A=0.1 and T=0.1.

It is interesting to note that, when SNRsr =28dB, the relay system using TID is better for the entire SNRsr range of analyzed values, than HMID with α>0. The HMID performance becomes weaker as α is greater. This is due to the fact that SNRsr is very large and Gaussian component is dominant (T being higher). The decoded sequence at the relay is probably the correct one, such that the parity sequence originated at the relay is more viable than the one that came from the source. Therefore, positive values of α make the extrinsic information given by the second decoder (corresponding to the encoder at the relay), modified according to (12), to be altered by the output of the first decoder (corresponding to the encoder at the source).

In conclusion, when A=0.1, if we do not have source-relay and relay-destination channels with SNR high enough, in order to obtain low BER or FER values, it is more efficient to we use the direct link.

V. CONCLUSIONS

We have analyzed the performances of a decode-and-forward system with a symmetric turbo coded relay, when the three channels (source-relay, source-destination and relay-destination) are affected by Middleton Class-A impulse noise. We considered a plausible scenario, when the distance from source to relay and that from relay to destination is smaller than the distance from source to destination, so that the SNR_{sr} and SNR_{rd} values must be higher than those considered from the SNR_{sd} range of values.

The simulations have shown that for a highly impulsive noise (A=0.01), the relay system at destination, be it with TID, or with HMID (when α=1.2), offers better performances than the direct link. HMID with α=1.2 offers an additional gain of over 4 dB, as opposed to the direct link, while TID assures an additional gain on HMID of over 1.7 dB. When α increases, the HMID performance becomes weaker.

When the Gaussian component is dominant (A=0.1), the relay system leads to low BER/FER values for source-relay and relay-destination channels with SNR values high enough. In this case it has better performances only when SNR_{sd} is high. If there is not a high enough SNR on the source-relay and relay-destination channels, then it is more efficient to use the direct link.

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