BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

ASYMMETRIC TURBO-CODED DECODE-AND-FORWARD RELAY CHANNEL PERFORMANCE COMPARISON OF COMPONENT RECURSIVE SYSTEMATIC CONVOLUTIONAL CODES WITH GENERATOR MATRICES OF MEMORY 3 AND 4

BY

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Received: December 17, 2012
Accepted for publication: February 18, 2013

Abstract. In this paper, a component code analysis is performed for the asymmetric turbo-coded decode-and-forward relay channel by comparing the use of memory 3 and memory 4 RSC codes having generator matrices with both primitive and non primitive feedback polynomial generators for the source, respectively the relay on channels affected by fast flat Rayleigh fading. From the performed simulations results that when SNR_{rd} has a very low value the source RSC code of memory 3 code has more influence over the BER performances for all values of SNR_{sd} compared with the RSC code of memory 4. When SNR_{rd} has medium values the source RSC code of memory 3 code has more influence over BER performances for small to medium values of SNR_{sd} , and the source RSC code of memory 4 code has more influence over BER performances for high values of SNR_{sd} .

Key words: relay channel; asymmetric turbo-codes; decode-and-forward.

1. Introduction

This paper, in conjunction with Bahl *et al.*, (1974), Wang *et al.*, (2005) represents a performance comparison study for different component recursive

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systematic codes for the source and the relay in an asymmetric turbo-coded decode-and-forward relay system.

The relay system consisting of the source, the relay and the destination terminal nodes take advantage of the diversity gain, the coding gain and the interleaving gain introduced by the turbo code, also of the turbo processing gain by using an iterative decoder (Zhao & Valenti, 2003). The performance comparison was conducted for RSCs of memory 3 and memory 4 at the source and the relay with generator matrices characterized by both primitive and non-primitive feedback polynomials. The channel used for transmitting the information is a fast flat Rayleigh fading channel and the decoding method used consists of an iterative decoder which does not take into consideration the decoding errors propagated by the relay (Huynh & Aulin, 2012).

The paper is structured in five sections. In section **2** is presented the relay system model, in section **3** the simulation results of the RSC codes of memory 3 for the source and the RSC codes of memory 4 for the relay are given also, section **4** contains the simulation results of the RSC codes of memory 4 for the source and the RSC codes of memory 3 for the relay and section **5** comprises the concluding arguments of this paper.

2. System Model

The relay system model is represented in Fig. 1 (Savin & Trifina, 2013).

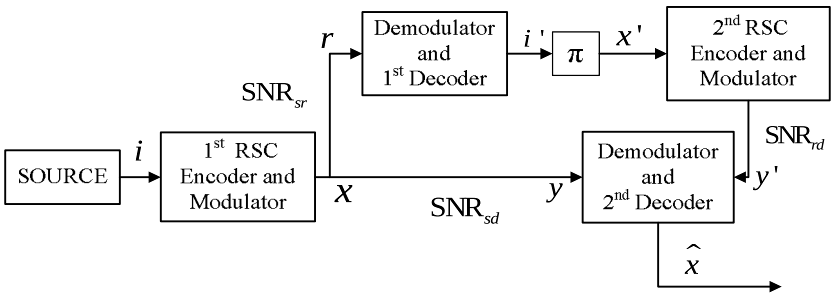


Fig. 1 – The relay system model.

In Fig. 1 the channels between the three nodes are mutually independent flat fading Rayleigh channels. In this paper, the Signal to Noise Ratio (SNR) for the source-destination channel was denoted SNR_{sd} , SNR_{sr} for the source-relay channel and SNR_{rd} for the relay-destination channel. The system operates in two periods of time: in the first time period the source generates the information bit sequence, *i*, which goes through the first RSC encoder, is Binary Phase Shift Keying (BPSK) modulated and is transmitted to the destination and the relay as the first noisy observation sequence, *y*. In the second time period the source is silent, the relay demodulates, decodes and generates the detected sequence, *i'*, from the original source sequence, *i*, which is affected by relay decoding errors. For decoding, at the relay, the Bahl, Cocke, Jelinek and Raviv (BCJR) decoder was used (Bahl *et al.*, 1974). The destination receives the re-encoded and re-modulated sequence that is represented by the second noise affected observation sequence, y'. These two noise affected sequences (y and y') which go through an iterative decoder that uses the Max-Log-MAP decoding algorithm (Robertson *et al.*, 1995), resulting at the destination in the output sequence of data, $\hat{x}$. In the relay system model, π is the permutation that describes the interleaver at relay.

The eqs. for the received signals at the relay and at the destination are the following (Sneessens *et al.*, 2008):

$$r = h_{sr}\sqrt{E_s}\,x + z_r\,, \tag{1}$$

$$y = h_{sd}\sqrt{E_s}\,x + z_d\,, \tag{2}$$

where: x represents the base-band BPSK modulated signal transmitted by the source, E_s – the energy per modulated symbol, h_{sr} – the Rayleigh fading coefficient affecting the source-relay (SR) signal, h_{sd} – the fading coefficient affecting the source-destination (SD) signal, z_r – the AWGN noise sample at the relay and z_d – the AWGN noise sample at the destination. The fading coefficients, h_{sr} and h_{sd}, are Rayleigh random variables with variance 1 and the noise signals, z_r and z_d, are random variables of zero mean value and two-sided power spectral densities of $N_0/2$.

The encoded and modulated signal is decoded at the relay by the BCJR decoder and then a hard decision is taken. Even if errors occurred after interleaving the signal is re-encoded and modulated into x'. The information about the state of the source–relay channel can be transmitted by the relay to the destination (RD) as channel state information (h_{rd}). The signal received at the destination is given by relation

$$y' = h_{rd}\sqrt{E_r}\,x' + z_d'\,, \tag{3}$$

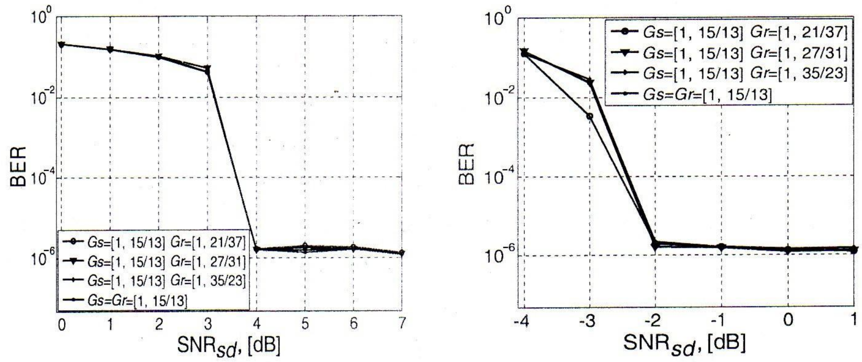
where: E_r is the average energy per modulated symbol transmitted by the relay, h_{rd} – amplitude of the fading, x' – the base-band BPSK modulated signal transmitted by the relay and z_d' – AWGN noise at the destination.

3. Simulation Results for Component RSC Codes of Memory 3 at Source and Memory 4 at Relay

This section performs an analysis based on the simulations of the bit error rate (BER) using a memory 3 RSC code with generator matrices that have both primitive (13 and 15) and non-primitive (17) feedback polynomials at the source and a memory 4 RSC with generator matrices that have both primitive

(23 and 31) and non-primitive (37) feedback polynomials at the relay. The data sequence has the length of 65,536 bits and the number of iterations used for decoding is 6. Two cases are considered: one is when SNR_{sr} = 12 dB and SNR_{rd} = –7 dB, the other is when SNR_{sr} = 12 dB and SNR_{rd} = 2 dB. For both cases the SR channel is good having high SNR_{sr} values and the RD channel is worse having low or medium SNR_{rd} values.

Fig. 2 *a* depicts the BER curves for the source code generator matrix of memory 3: *Gs* = [1,15/13] and the relay code generator matrices of memory 4: *Gr* = [1,21/37], *Gr* = [1,27/31] and *Gr* = [1,35/23].



a *b*

Fig. 2 – BER curves for the source RSC with generator matrix of memory 3, *Gs* = [1,15/13] and the relay RSCs with generator matrices of memory 4, *Gr* = [1,21/37], *Gr* = [1,27/31] and *Gr* = [1,35/23] and the memory 3 symmetric code *Gs* = *Gr* = [1,15/13] for *a* – SNR_{sr} value of 12 dB and SNR_{rd} value of –7 dB and *b* – SNR_{sr} value of 12 dB and SNR_{rd} value of 2 dB.

Fig. 2 *b* depicts the BER curves for the same source code of memory 3 and the relay code generator matrices of memory 4 presented in Fig. 2 *a*. The SNR_{sr} value is 12 dB, the SNR_{rd} value is –7 dB and SNR_{sd} takes values between 0 dB and 7 dB for the plot in Fig. 2 *a*, and the SNR_{rd} value is 2 dB and SNR_{sd} takes values between –4 dB and 1 dB for the plot in Fig. 2 *b*.

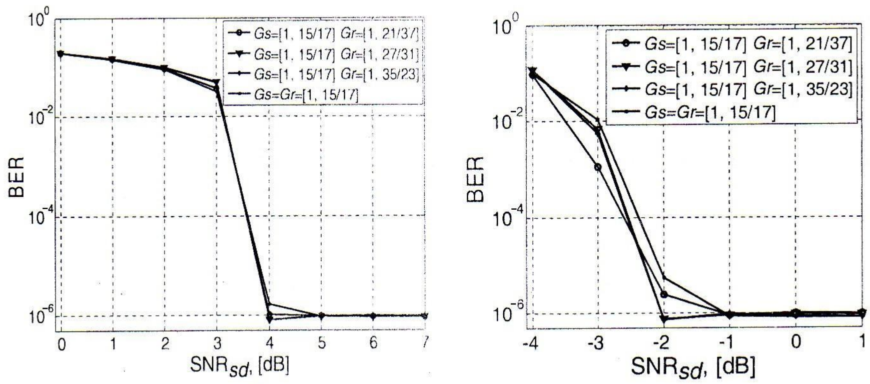
The simulation results in Fig. 2 *a* show that at low (0…3 dB) SNR_{sd} values the RSC with primitive feedback polynomial at the source 13 and non-primitive feedback polynomial 37 at the relay offers better performances than the codes with primitive feedback polynomials at the relay. In the “waterfall” and “error-floor” region all codes have similar BER performances.

From Fig. 2 *b* it can be observed that at low SNR_{sd} values the source and relay RSC with the primitive feedback polynomial, 13, and the non-primitive feedback polynomial, 37, offers better performances, a coding gain of up to 0.5 dB at BER = 2×10^{-2} compared with the RSCs with primitive feedback polynomials at the relay. In the “waterfall” region the previous mentioned code offers a 0.3 dB coding gain for BER = 10^{-4} over the other RSC codes. At high SNR_{sd} values the performances for all codes are similar.

Figs. 3 *a* and 3 *b* plot the BER curves for the source memory 3 code with the generator matrix *Gs* = [1,15/17] and the same memory 4 relay codes with generator matrices that were used in Fig. 2. The values of SNR_{sr}, SNR_{rd}, and also the range of SNR_{sd} were maintained.

From Fig. 3 *a* it can be observed that at low SNR_{sd} values the source generator matrix with the non-primitive feedback polynomial, *Gs* = [1,15/17], and the relay generator matrix with the non-primitive feedback polynomial, *Gr* = [1,21/37], offer a coding gain of 0.2 dB at BER = 4×10^{-2} compared with the relay generator matrices with primitive feedback polynomials. In the "waterfall" region the same source RSC with non-primitive feedback polynomial, 17, and relay primitive feedback polynomial, 23, offers better BER performances (a coding gain of up to 0.6 dB at BER = 1.2×10^{-6}) compared with the memory 3 symmetric code.

In Fig. 3 *b* for low SNR_{sd} values the code with the source generator matrix *Gs* = [1,15/17] and the relay generator matrix *Gr* = [1,21/37], both having non-primitive feedback polynomials offer better performances (a supplementary coding gain of 0.4 dB at BER = 10^{-2}) than the RSC codes with generator matrices having the non-primitive feedback polynomial, 17, at source and primitive feedback polynomials at relay. For high SNR_{sd} values all codes have similar performances.



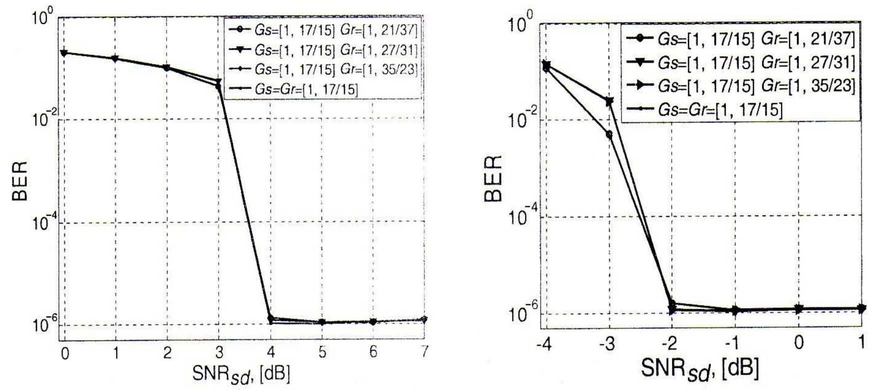
a *b*

Fig. 3 – BER curves for the source RSC with generator matrix of memory 3, *Gs* = [1,15/17], the relay RSCs with generator matrices of memory 4, *Gr* = [1,21/37], *Gr* = [1,27/31] and *Gr* = [1,35/23] and the memory 3 symmetric code *Gs* = *Gr* = [1,15/17] when: *a* – SNR_{sr} = 12 dB and SNR_{rd} = –7 dB and *b* – SNR_{sr} = 12 dB and SNR_{rd} = 2 dB.

Fig. 4 *a* represents the BER curves for the source code of memory 3 with the generator matrix *Gs* = [1,17/15] and the same relay codes of memory 4 used in Fig. 3, for the SNR_{sr} value of 12 dB and the SNR_{rd} value of –7 dB. Fig. 4 *b* represents the BER curves for the same generator matrices at the source and relay as in Fig. 4 *a*, but for the SNR_{sr} value of 12 dB and the SNR_{rd} value of 2 dB.

From Fig. 4 *a* it can be observed that all codes have similar BER performances, only the code with the primitive feedback polynomial, 15, at the source and the non-primitive feedback polynomial, 37, at the relay, is slightly better at BER = 4×10^{-2}, compared with the other asymmetric codes.

In Fig. 4 *b*, at low SNR_{sd} values, the code with the source generator matrix having primitive feedback polynomials and the relay generator matrix with the non-primitive feedback polynomial, 37, offers a coding gain of 0.4 dB at BER = 2×10^{-2} and in the “waterfall” region a coding gain of 0.1 dB at BER = 10^{-3} compared with the other asymmetric codes and the symmetric code of memory 3. For high SNR_{sd} values, in the “error-floor” region, all codes have similar BER performances.



a *b*

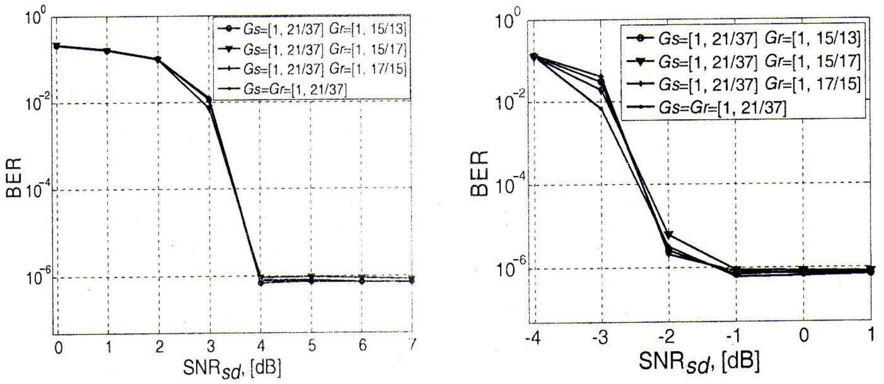
Fig. 4 – BER curves for the source RSC with generator matrix of memory 3, *Gs* = [1,17/15], the relay RSCs with generator matrices of memory 4, *Gr* = [1,21/37], *Gr* = [1,27/31] and *Gr* = [1,35/23] and the memory 3 symmetric code with *Gs* = *Gr* = [1,17/15] when: *a* – SNR_{sr} = 12 dB and SNR_{rd} = –7 dB and *b* – SNR_{sr} = 12 dB and SNR_{rd} = 2 dB.

4. Simulation Results for Component RSC Codes of Memory 4 at Source and Memory 3 at Relay

This section refers to an analysis based on the simulations of the BER curves using memory 4 RSC codes at the source and memory 3 RSC codes at the relay with generator matrices that have both primitive and non-primitive feedback polynomials. The data sequence has the length of 65,536 bits and the simulation stops after 6 iterations. The same SNR_{sr} and SNR_{rd} values were used as in Section **3**.

In Fig. 5 *a* the BER curves for the source code of memory 4 with the generator matrix *Gs* = [1,21/37] and the relay codes of memory 3 with generator matrices *Gr* = [1,15/13], *Gr* = [1,15/17] and *Gr* = [1,17/15], for the SNR_{sr} value of 12 dB and the SNR_{rd} value of –7 dB are presented. Fig. 5 *b* represents the BER curves for the same memory 4 and 3 codes as in Fig. 5 *a* but for the SNR_{sr} value of 12 dB and the SNR_{rd} value of 2dB.

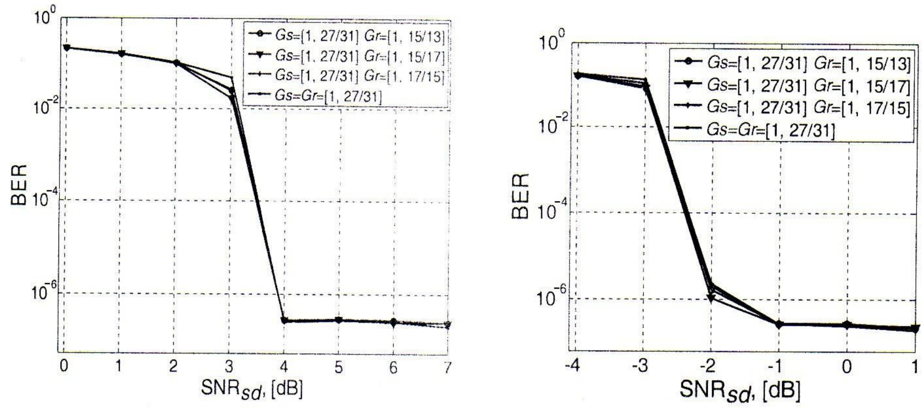
From Fig. 5 *a* it can be observed that in the "waterfall" region the source generator matrix *Gs* = [1,21/37] with the non-primitive feedback polynomial, 37, and the relay generator matrix *Gr* = [1,15/17] with the non-primitive feedback polynomial, 17, offers a coding gain of up to 0.1 dB at BER = 10^{-2} compared with the codes with primitive feedback polynomials at the relay. At high SNR_{sd} values all codes have similar BER performances, only the source generator matrix with the non-primitive feedback polynomial, 37 and the relay generator matrix with non-primitive feedback polynomial, 17, offers slightly worse performances compared to the other codes. From Fig. 5 *b* it can be observed that at low SNR_{sd} values the asymmetric code with *Gs* = [1,21/37] and *Gr* = [1,15/17] offers a coding gain of up to 0.2 dB at BER = 3×10^{-2} over the asymmetric code with the same source generator matrix but with the relay generator matrix *Gr* = [1,15/13], also the symmetric memory 4 code offers a coding gain of up to 0.4 dB at BER = 10^{-2} compared to the asymmetric code with *Gs* = [1,21/37] and *Gr* = [1,15/17]. In the "waterfall" region the code with the source generator matrix with non-primitive feedback polynomial, 37, and the relay generator matrix with primitive feedback polynomial, 15 obtains a coding gain of up to 0.6 dB at BER = 2×10^{-6} compared to the code with the same source generator matrix and the relay generator matrix with non-primitive feedback polynomial, 17. At high SNR_{sd} values all codes have similar BER performances.



a *b*

Fig. 5 – BER curves for the source RSC with generator matrix of memory 4, *Gs* = [1,21/37], the relay RSCs with generator matrices of memory 3, *Gr* = [1,15/13], *Gr* = [1,15/17] and *Gr* = [1,17/15] and the memory 4, symmetric code *Gs* = *Gr* = [1,21/37], when: *a* – SNR_{sr} = 12 dB and SNR_{rd} = –7 dB and *b* – SNR_{sr} = 12 dB and SNR_{rd} = 2 dB.

Fig. 6 *a* represents the BER curves for the source code generator matrix of memory 4, *Gs* = [1,27/31] and the relay code generator matrices of memory 3, *Gr* = [1,15/13], *Gr* = [1,15/17] and *Gr* = [1,17/15] for the SNR_{sr} value of 12 dB and the SNR_{rd} value of –7 dB. Fig. 6 *b* shows the BER curves for the same source and relay generator matrices but for the SNR_{sr} value of 12 dB and the SNR_{rd} value of 2 dB.



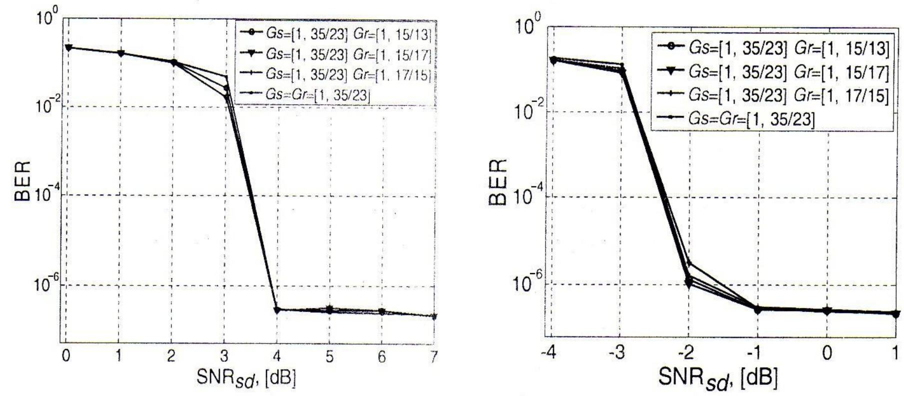
a *b*

Fig. 6 – BER curves for the source RSC with generator matrix of memory 4, *Gs* = [1,27/31], the relay RSCs with generator matrices of memory 3, *Gr* = [1,15/13], *Gr* = [1,15/17] and *Gr* = [1,17/15] and the memory 4 symmetric code *Gs* = *Gr* = [1,27/31] when: *a* – SNR_{sr} = 12 dB and SNR_{rd} = –7 dB and *b* – SNR_{sr} = 12 dB and SNR_{rd} = 2 dB.

From Fig. 6 *a* it can be observed that for low SNR_{sd} values the source generator matrix *Gs* = [1,27/31] with the primitive feedback polynomial, 31, and the relay generator matrix *Gr* = [1,15/17] with the non-primitive feedback polynomial, 17, offers a supplementary coding gain of 0.1dB at BER = 3×10^{-2} compared with the other asymmetric codes and a coding gain of 0.7 dB at BER = 4×10^{-2} when compared with the memory 4 symmetric code. In the “waterfall” region and at high SNR_{sd} values all codes have similar BER performances. From Fig. 6 *b* it can be observed that for low SNR_{sd} values the source generator matrix, *Gs* = [1,27/31] with the primitive feedback polynomial, 31, and the relay generator matrix *Gr* = [1,15/17], with the non-primitive feedback polynomial, 17, offers better performances compared with the other asymmetric codes (a coding gain of 0.4 dB at BER = 10^{-1}) and the symmetric code (a coding gain of 0.5 dB at BER = 10^{-1}) and in the “waterfall” region a coding gain of 0.3 dB at BER = 10^{-6} when compared with the symmetric code. At high SNR_{sd} values all codes have similar performances.

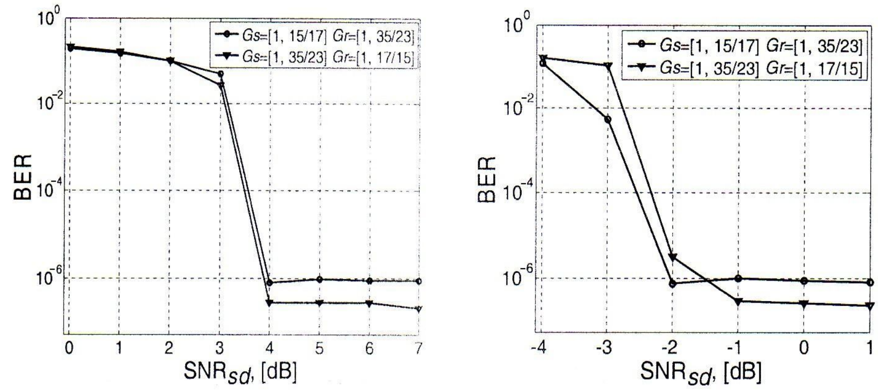
Fig. 7 *a* represents the BER curves for the source code of memory 4 with the generator matrix *Gs* = [1,35/23] and the relay code of memory 3 with the generator matrices *Gr* = [1,15/13], *Gr* = [1,15/17] and *Gr* = [1,17/15] for the SNR_{sr} value of 12 dB and the SNR_{rd} value of –7 dB. Fig. 7 *b* represents the BER curves for the same source and relay generator matrices but for the SNR_{sr} value of 12 dB and the SNR_{rd} value of 2 dB.

From Fig. 7 *a* it can be observed that for low SNR_{sd} values the source generator matrix *Gs* = [1,35/23] with the primitive feedback polynomial, 23, and the relay generator matrix Gr = [1,15/17] with the non-primitive feedback polynomial, 17, offers a supplementary coding gain of 0.3dB at BER = 2×10^{-2} compared with the other asymmetric codes and a coding gain of 0.6 dB at BER = 4×10^{-2} when compared with the symmetric code. In the "waterfall" region and for high SNR_{sd} values all codes have similar performances.



a *b*

Fig. 7 – BER curves for the source RSC with generator matrix of memory 4, Gs = [1,35/23], the relay RSCs with generator matrices of memory 3, Gr = [1,15/13], Gr = [1,15/17] and Gr = [1,17/15] and the memory 4 symmetric code $Gs = Gr$ = [1,35/23], when: *a* – SNR_{sr} = 12 dB and SNR_{rd} = –7 dB and *b* – SNR_{sr} = 12 dB and SNR_{rd} = 2 dB.



a *b*

Fig. 8 – BER curves for best memory 3 and memory 4 RSC codes in the "error-floor" region for: *a* – SNR_{sr} value of 12 dB and SNR_{rd} value of –7 dB and *b* – SNR_{sr} value of 12 dB and SNR_{rd} value of 2 dB.

From Fig. 7 *b* it can be observed that for low SNR_{sd} values the source generator matrix Gs = [1,35/23] with the primitive feedback polynomial, 23, and the relay generator matrix Gr = [1,15/17] with the non-primitive feedback polynomial, 17, offers a coding gain of up to 0.5 dB at BER = 10^{-1} compared with the symmetric code and in the “waterfall” region a supplementary coding gain of 0.5 dB at BER = 10^{-6} compared with the asymmetric code with source generator matrix, *Gs* = [1,35/23] and relay generator matrix *Gr* = [1,17/15]. At high SNR_{sd} values all codes have similar BER performances.

In Figs. 8 *a* and 8 *b* a comparison is presented, for both cases of SNR_{sr} and SNR_{rd} used in section **3** and in this section, between the source generator matrix of memory 3 and 4 and the relay generator matrix of memory 4 and 3 with the best proven performances in the “error-floor” region.

From Fig. 8 *a* it can be seen that for low SNR_{sd} values the asymmetric code with generator matrices, *Gs* = [1,35/23] and *Gr* = [1,17/15], offers a supplementary coding gain of 0.5 dB at BER = 4×10^{-2}, in the “waterfall” region it offers a coding gain of up to 0.1dB for BER = 10^{-6} and at high SNR_{sd} values offers better BER performance compared to the asymmetric code with generator matrices, *Gs* = [1,15/17] and *Gr* = [1,35/23] (in the “error-floor” region BER is 2×10^{-7} compared to 10^{-6}). Thus it can be concluded that for a good SR channel and a bad RD channel, the source and relay generator matrices with primitive feedback polynomials offer better performances in the “error-floor” region than the generator matrix with non-primitive feedback polynomials at the source and primitive feedback polynomials at the relay.

From Fig. 8 *b* it can be seen that for low SNR_{sd} values the asymmetric code with generator matrices, *Gs* = [1,15/17] and *Gr* = [1,35/23], offers a supplementary coding gain of up to 1 dB for BER = 10^{-1} and in the “waterfall” region a coding gain of up to 0.3 dB for BER = 10^{-3} compared with the asymmetric code with generator matrices *Gs* = [1,35/23] and *Gr* = [1,17/15]. For high SNR_{sd} values the asymmetric code with generator matrices *Gs* = [1,35/23] and *Gr* = [1,17/15] offers better BER performance compared with the code with generator matrices *Gs* = [1,15/17] and *Gr* = [1,35/23] (in the “error-floor” region BER is 2×10^{-7} compared to 9×10^{-7}). It can be concluded that when the generator matrices are selected based on the BER performances in the “error-floor” region, for good SR channel and a medium RD channel better performances are obtained, at low SNR_{sd} values and in the “waterfall” region, by the source RSC of memory 3 with non-primitive feedback polynomials and the relay RSC of memory 4 with primitive feedback polynomials and at high SNR_{sd} values by the source RSC of memory 4 and the relay RSC of memory 3 with primitive feedback polynomials.

5. Conclusions

This paper presents the impact on BER performance for an asymmetric turbo-coded DF relay channel that uses RSC codes of memory 3 and memory 4 with generator matrices composed of specific primitive and non-primitive feedback polynomials.

BER performances depend on a suitable choice of generator matrices, on the memory of the encoders, on the type of polynomials used for the source and the relay and on the SNR values used for the three channels of the relay system.

Through the simulations performed in this paper it can be concluded that at high SNR_{sd} and for a fixed high SNR_{sr} value and a low SNR_{rd} value, the performances are better using memory 4 RSCs at the source and memory 3 RSCs at the relay with primitive feedback polynomials. At low SNR_{sd} and for a fixed high SNR_{sr} value and a medium SNR_{rd} value, the performances are better using memory 3 RSCs at the source with non-primitive feedback polynomials and memory 4 RSCs at the relay with primitive feedback polynomials. It can be summarized that for the chosen SNR_{sr} values, when SNR_{rd} is very low the source RSC code of memory 3 has an important influence over BER performances for all the values of the SNR_{sd} domain. When SNR_{rd} has medium values the source RSC code of memory 3 code has more influence over BER performances for low and medium values of SNR_{sd}, and the source RSC code of memory 4 code has more influence over BER performances for high values of SNR_{sd}.

Acknowledgment. This paper was realized with the support of POSDRU CUANTUMDOC "Doctoral Studies for European Performances in Research and Innovation" ID79407 project funded by the European Social Fund and Romanian Government.

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COMPARAȚIA CODURILOR CONVOLUȚIONALE RECURSIVE SISTEMATICE COMPONENTE AVÂND MATRICELE GENERATOARE DE MEMORIE 3 ŞI 4 ÎNTR-UN SISTEM ASIMETRIC CODAT TURBO DE TIP DECODARE ŞI TRANSMISIE PE UN CANAL CU RELEU

(Rezumat)

Este efectuată o analiză a codurilor componente pentru un sistem asimetric de tip „decodare şi transmisie" cu releu codat turbo comparând utilizarea codurilor convoluționale recursiv sistematice de memorie 3 şi 4 având matricele generatoare constituite din polinoame generatoare primitive şi neprimitive pentru sursă, respectiv releu, pe canale afectate de zgomot alb aditiv gaussian (AWGN) şi fading Rayleigh. Din simulări rezultă că atunci când SNR_{rd} are o valoare scăzută, codul RSC de memorie 3 de la sursă are o mai mare influență asupra performanțelor BER pentru toate valorile SNR_{sd} față de codul RSC de memorie 4. Pentru valori medii ale SNR_{rd} codul RSC de memorie 3 de la sursă are o mai mare influență asupra performanțelor BER pentru valori mici şi medii ale SNR_{sd} , iar codul RSC de memorie 4 de la sursă are o mai mare influență asupra performanțelor BER la valori mari ale SNR_{sd} .