TURBOCODING PERFORMANCES ON FADING CHANNELS

Ioana Marcu, Simona Halunga, Octavian Fratu

Telecommunications Dept. Electronics, Telecomm. & Information Theory Faculty, Bd. Iuliu Maniu 1-3, 061071, Bucharest 6, Romania, Phone: +40 21 402 4996; Fax: +40 21 410 2379; e-mail:imarcu@radio.pub.ro

This paper investigates some effects of fading channels on the turbo encoder-decode performances, evaluated in terms of Bit-Error Rate BER. Extended Monte Carlo simulations have been developed to determine the effect of Rayleigh / Rice fading, with /without Doppler shift over the performances of a turbo encoder decoder system that uses either helical or random interleaver and either MAP or SOVA decoding algorithms. The results and some interesting conclusions are presented in chapter 4.

Keywords: turbo-coding, Rayleigh/Rice fading, Doppler shift, error probability

1. INTRODUCTION

In the last five decades many structures have been developed in order to achieve better performances. The structure proposed by Berroux and Glavieux in 1993 [1] exploits the concatenation of the convolutional codes with the interleaving principle in order to obtain a BER as close as possible to the Shannon limit, while the transmission channel is affected by AWGN only.

However, in mobile communication systems, the channel is distorted by fading and multipath propagation and the BER is affected in concordance. This paper aims to investigate the fading effect on the turbo-encoded data. The system model is presented in figure 1.

This paper investigates the turbo encoder-decoder performances evaluated in terms of Bit-Error Rate BER, in the presence of flat non-frequency-selective Rayleigh / Rice fading with and without Doppler shift.

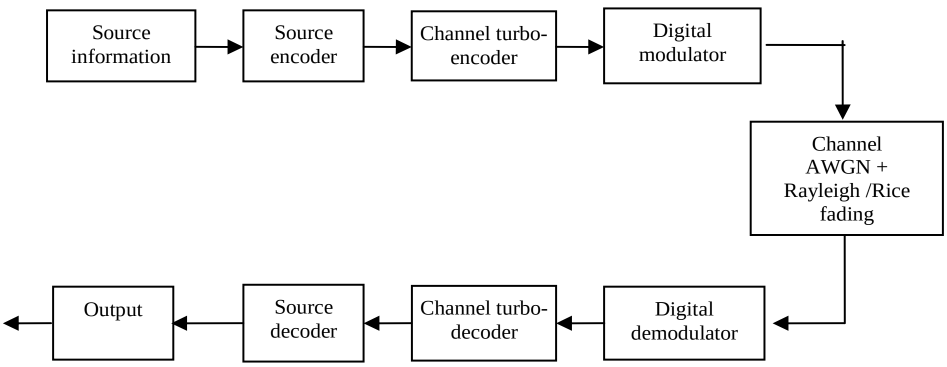

Fig. 1. A communication system model

2. THE ENCODER STRUCTURE. THE INTERLEAVER

The Turbo Encoder structure consists of two recursive Systematic Codes (RSC) that operates on the same input bits. For the second encoder the input bits order is changed by placing an interleaver in front of it; this way the overall code is better protected against burst errors that often appear in mobile communication systems. The encoder structure is shown in figure 2, where RSC1 and RSC2 are two recursive systematic codes with the same structure and with the generator polynomial of degree 2. The puncturing and multiplexing block ensures the transmission of all the systematic bits from the first encoder and half of the parity bits from each encoder alternately.

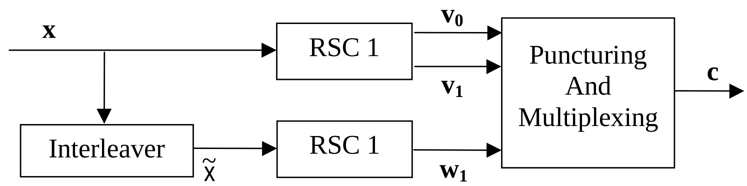

Fig.2. Encoder architecture

Two types of interleaver have been taken into consideration. The "*helical*" interleaver is a block type one, based on a matrix structure in which the data is written in row-wise and read out diagonal-wise. This structure prevents consecutive input bits to have consecutive positions in the output sequence. The "*random*" interleaver introduces an N bits input block of data into a memory and reads it out randomly, in accordance to the following N step algorithm:

Step 1: choose index i_1 from the set $A \in \{1,2, ... ,N\}$, in accordance to a uniform probability function $p(i_1) = \frac{1}{N}$; the corresponding output index is $\pi(1)$;

…

Step k: choose index i_k from the set $A_k = \{i \in A,\ i \neq i_1, i_2, ...\ i_{k-1}\}$, in accordance to a uniform probability function $p(i_k) = \frac{1}{N-k-1}$; the output index is $\pi(k)$;

2. THE CHANNEL MODEL

In a wireless mobile communication system, a signal can travel from transmitter to a receiver over multiple reflective paths, phenomenon which causes fluctuations in the received signal's amplitude, phase and angle of arrival, giving rise to the *multipath fading*. It has been taken in consideration the small-scale fading which refers to the dramatic changes in signal amplitude and phase as a result of a spatial positioning between a receiver and a transmitter. Small-scale fading is called *Rayleigh fading* if there are multiple reflective paths that are large in number and there is no line-of-sight component. When a dominant nonfading signal component is present, the small-scale fading envelope is described by a *Rician* pdf. In other words small scale fading statistics are said to be Rayleigh whenever the line-of-sight is blocked and Rician otherwise. The Rician distribution is often described in terms of a parameter K defined as the ratio of the power in the nonfading signal component to the power in multipath signal. The Rician probability density function approaches Rayleigh pdf:

$$p(w_0) = \begin{cases} \frac{w_0}{\sigma^2} \exp\left[-\frac{w_0}{2\sigma^2}\right], \text{for } w_0 \geq 0 \\ 0, otherwise \end{cases} \quad (1)$$

where w_0 is the nonfading signal component and σ^2 is the prediction mean power of the multipath signal. [7]

3. THE DECODER STRUCTURE.

The iterative decoder structure consists of two component decoders, serially concatenated via an interleaver, identical to the one used in the encoder, as shown in figure 2. The first decoder uses the received information bits r_0 and the parity bits generated by the first encoder r_1 in order to produce a soft output, which is interleaved and used to improve the estimate of the apriori probabilities for the second decoder. The other two inputs of the second decoder are the interleaved information sequence $\tilde{r}_0$ and the received parity sequence produced by the second encoder. This decoder produces a soft output also, that is de-interleaved and used by the first decoder to improve its apriori probabilities. This iterative feedback operation increases the performances of the overall structure, especially in the first decoding steps. After a number of iterations the soft outputs from the decoders will no longer affect significantly the performances, and, therefore, a hard decision is applied at the end in order to obtain the decoded data sequence. The log-likelihood ratio, used in making the decisions, can be determined using either MAP or SOVA algorithms [8]

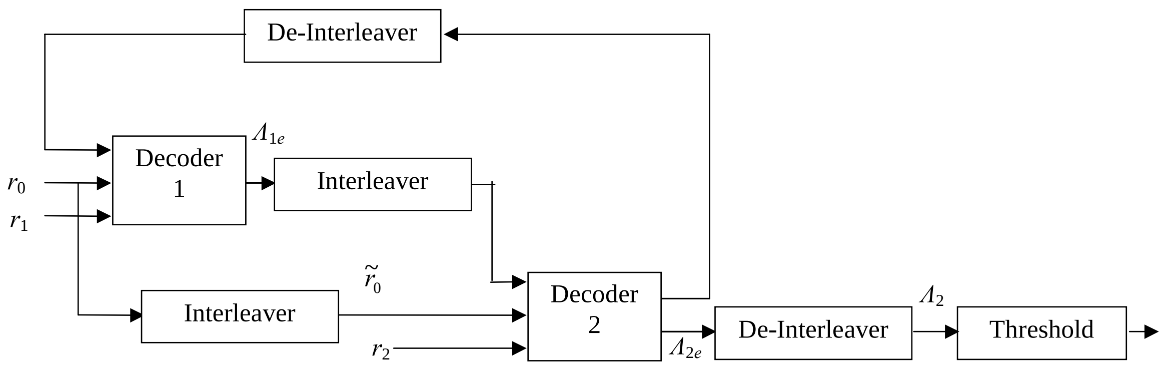

Fig.3. Iterative Decoder Architecture

4. SIMULATION RESULTS AND CONCLUSIONS.

In order to analyze the performances obtained by different turbo-codes structures, an interactive Matlab program has been developed. User data is randomly generated and encoded using two component RSC codes. The encoded data is transmitted through an AWGN channel (the signal –to-noise ratio at channel level is also defined by the user), affected by Rice / Rayleigh fading and with/without Doppler shift and demodulated at receiver level using either MAP or SOVA algorithms. The user can also define the number of iterations for each frame and the number of frame errors the decoder terminates. The receiver counts and displays the bit error rate and the frame error rate at each decoding algorithm iteration. The simulation parameters are:

- frame size: 200 bits
- number of iterations: 5
- no puncturing
- code rate: ½
- both RSCs use generator polynomial of degree 2
- Doppler shift: 10Hz

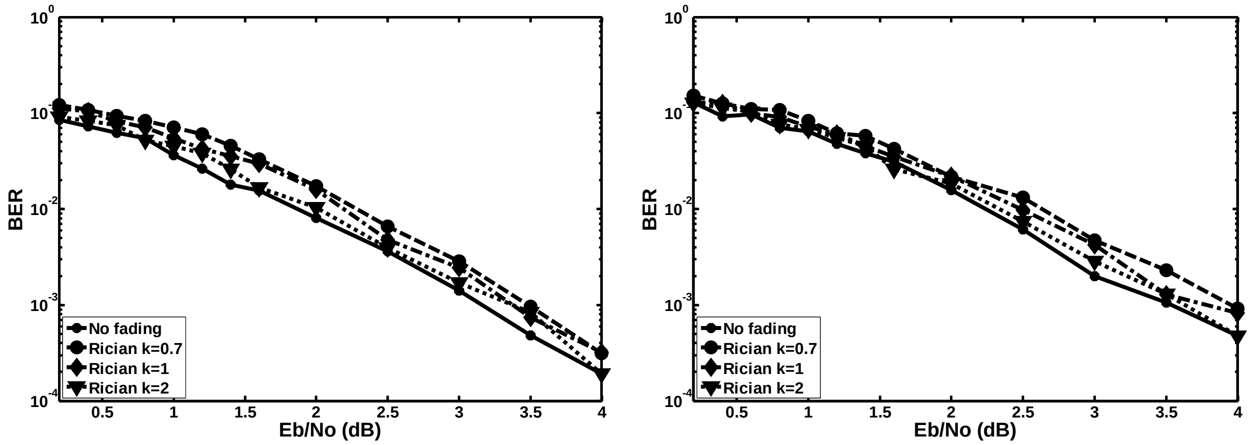

Fig.4. BER performances on Rice fading channel using MAP and SOVA decoding algorithms and helical interleaver

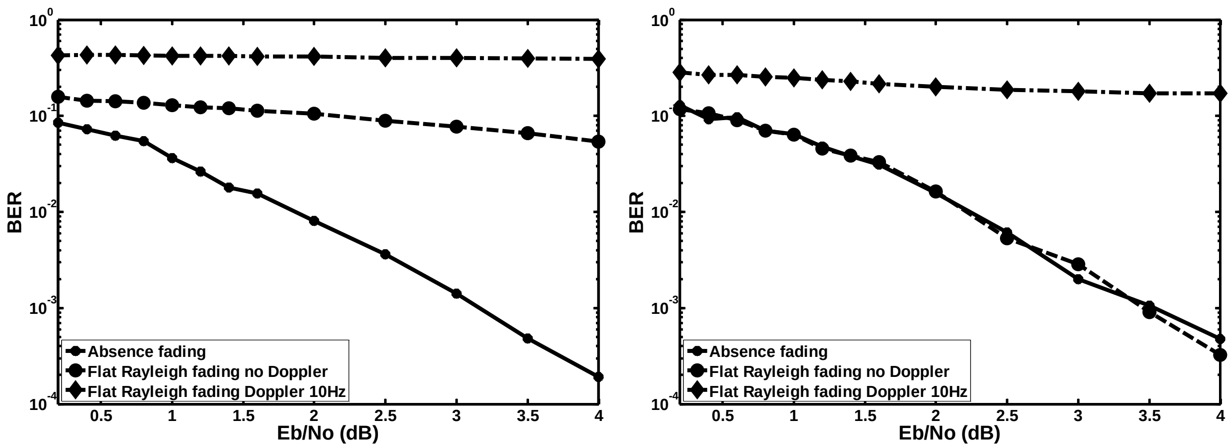

Fig.5. BER performances on Rayleigh fading channel using MAP and SOVA decoding algorithms and helical interleaver

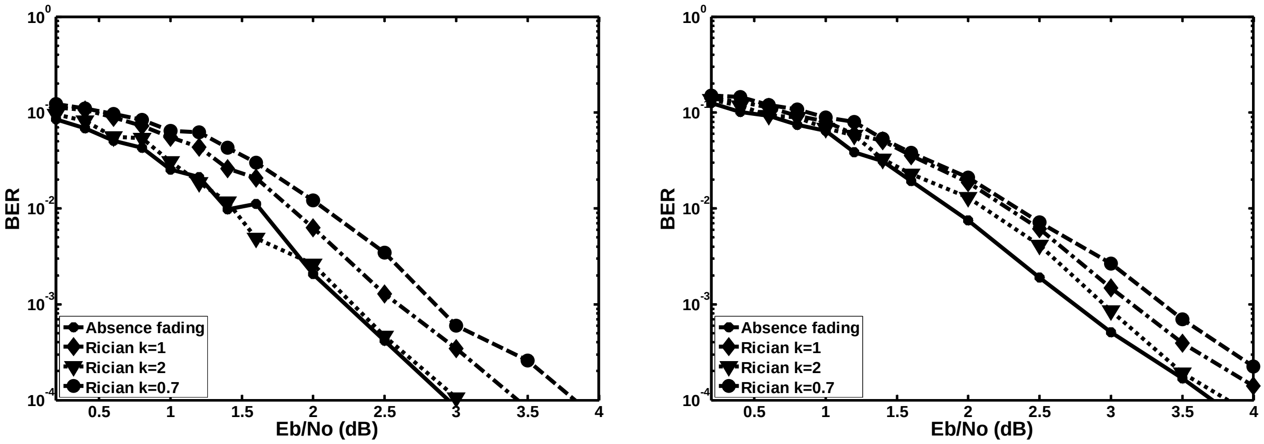

Fig.6. BER performances on Rice fading channel using MAP and SOVA decoding algorithms and random interleaver

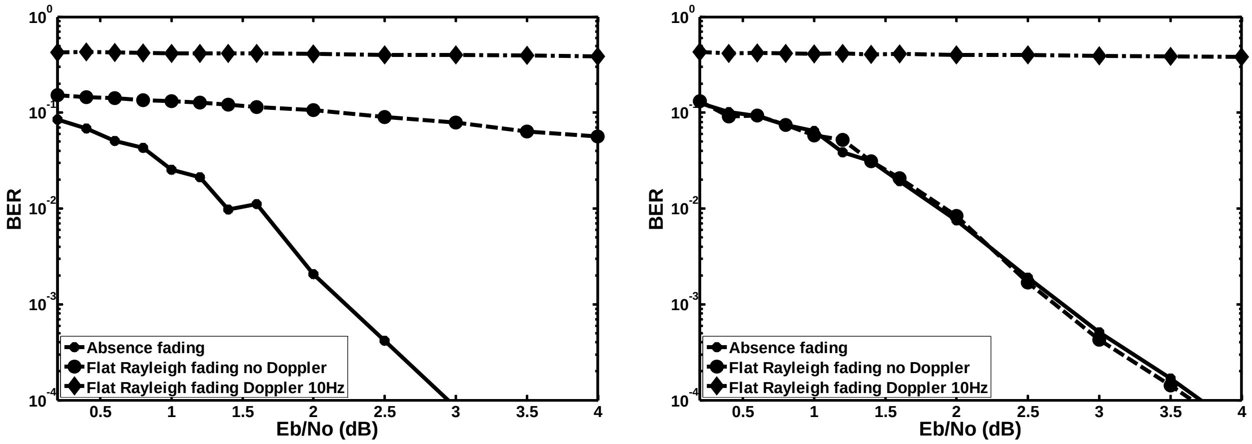

Fig.7. BER performances on Rayleigh fading channel using MAP and SOVA decoding algorithms and random interleaver

From these results some interesting conclusions may be enumerated:

- when flat, nonfrequency-selectiv fading is present, the BER performances degrades with respect to the non-fading case; the degradation is more severe in the Rayleigh fading case then in the Rician one;
- in the presence of Rician fading, we obtain good results with the helical interleaver with both MAP and SOVA algorithms; as expected the MAP algorithm has slightly higher BER results then SOVA (2 – 4 dB), but this is compensated by the simpler implementation of the decoder; The BER decreases slowly as the *k* factor increases, but the degradation is not very dramatic;
- in the presence of Rayleigh fading, no Doppler, the SOVA algorithm achieves significantly better results then MAP (when BER remains at around 0.1,

decreasing very slowly with E_b/N_0); we can conclude that MAP algorithm is inapplicable in Rayleigh fading environment;

- in the case of the Doppler shift, superimposed on the Rayleigh/ Rice, both decoding algorithms have poor results; in this case other techniques have to be applied to encounter the fading effects (diversity / RAKE receivers);
- the random interleaver leads to better performances for MAP algorithm in case of Rician fading especially for SNR between 2-4 dB;
- similar behavior can be achieved for both MAP and SOVA with random interleaver at small SNRs in presence or absence of fading on the channel;
- in absence of Doppler shift for Rayleigh fading, SOVA is less sensitive to its effect for random interleaver; still in presence of Doppler shift the effect of Rician fading increases as k decreases;
- MAP algorithm is not reliable in presence of Rayleigh fading due to its poor results;
- random interleaver provides better results, for all studied cases, than the helical one; moreover, the same tendency, corresponding to both decoding algorithms used, is noticed for Rayleigh fading channel for both interleavers;
- turbocodes are not very efficient in case of Doppler shift for all values of SNR studied.

REFERENCES

[1] C. Berrou, A. Glavieux and P. Thitimajshima, “*Near Shannon limit error-correcting coding and decoding: turbocodes*" ICC-1993, Geneva, Switzerland, pp. 1064-1070.

[2] C. E. Shannon “*A mathematical Theory of Communications*”, Bell Syst. Techn. Journal Vol. 27, pp. 379-423 (part I) & 623-656 (part II), Oct 1948.

[3] S. A. Barbulescu, W. Farrell, P. Gray, and M. Rice, “*Bandwidth Efficient Turbo Coding for High Speed Mobile Satellite Communications*", Proc. Int’l Symposium on Turbo Codes and Related Topics, Best, France, pp.119-123.

[4] H. Feldman, D.V. Ramana , “*An introduction to Inmarsat’s New mobile Multimedia services*”- the 6th Int’l Mobile Sattelite Conference, Ottawa, pp. 1-4, June 1999

[5] S. Benedetto, G. Montrosi, et.other: “*serial Concatenation of interleaved codes: performance analysis, design and iterative decoding* ”, JPL TDA Progr. repport, 42-126, Aug. 1996

[6] J.G. Proakis, *“Digital Communications”*, New York: McGraw-Hill, 1983

[7] R.L. Bogush, *“Digital Communications in Fading Channels: Modulation and Coding”*, Mission Reasearch Corp. Report no MRC-R-1043, March 11, 1987, Santa Barbara, California

[8] B Vuctic, “*Iterative Decoding Algorithms*”, PIMRC’97, Sept 1997, Finland, pp. 99-120.