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MOBILE COMMUNICATIONS WITH STBC AND TURBO CODES

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Abstract

Users are increasingly demanding about the quality and consumer batteries of their mobile terminals to gain access to services imposed by operators. In order to satisfy the customers, operators must provide a good quality, high transmission rates to allow videoconferencing communications and low power consumption in mobile terminals, so that battery last longer.

In mobile communications, data are transmitted over a channel that is affected by noise, thus affecting the quality of data received, and thus can degrade the received information. In traditional communications, SISO (Single-Input Single-Output systems) with one transmitting and one receiving antenna, are not efficient to minimize noise caused by the channel. Solutions such as increased bandwidth and increased power transmission would solve the problem, however, are not reliable. Although these solutions are valid in theory, none of them is put into practice, because increasing the transmission of mobile terminals, there would cause an increase in battery size, price and increasing the size of mobile terminals and the fact that it could be detrimental to our health. Increasing the bandwidth would be an easy way out and solve the problems of errors and low transmission rates, however there is a price to pay, the spectrum allocation is expensive, so this technique is not feasible. This paper aims to provide efficient solutions to improve the efficiency of power, namely to achieve a good quality with a low power consumption on the handset. The spectral efficiency is improved through the implementation of MIMO (Multi-Input Multi-Output) systems, i.e., multiple transmit antennas and multiple receiving antennas, using error correction codes. Through the union of these two techniques is possible to obtain a low error probability with low power consumption.

This paper presents how MIMO solution the STBC (Space Time Block Codes) encoding. The Alamouti code [1] is used in this coding, which consists of data transmission with two transmit antennas and one or more receiving antennas. Other STBC codes for multiple antennas and multiple receiving antennas are presented in the paper, these codes developed by Tarokh et al [2]. The novelty of this study, presented here, is the use of MIMO systems using error correction codes (Turbo-codes[3]). In the turbo code decoding algorithms are used with soft outputs, as the MAP (Maximum a Posteriori) algorithm, Log-MAP and max-log-MAP.

The error probability performance results, presented in this paper were obtained by Matlab Simulations with 4-QAM modulation in Rayleigh channel. The SISO systems are compared with MIMO systems with and without error correction. The simulation results show that there is a significant improvement when the MIMO systems are used compared to the SISO systems, and that with error correction lower error probability is achieved with lower energy consumption.

Keywords: Alamouti, STBC, MAP, log-MAP and max-log-MAP.

1. INTRODUCTION

In mobile communications, we need services and applications with better quality, lower error probability and faster transmission rates. Since the transmission channel is responsible for the introduction of noise, interference and fading, the received information appears degraded, we need to use techniques to improve performance. One of the simple solutions for achieving this goal is to increase the transmission power in mobile terminals or increase the bandwidth. Although these solutions are valid, none of them are implemented, because the increase of the transmission power in mobile terminals would increase battery consumption and cost, besides being detrimental to our health. Increasing the bandwidth would be an easy way to solve performance problems and low transmission rates, however there is a price to pay, because the allocation of spectrum is limited and expensive.

The traditional mobile communications use systems with a transmitting antenna and one receiving antenna, designed for SISO (Single-Input-Single-Output), are not effective to combat fading. One solution to combat fading proposed in this paper is the use of MIMO techniques using STBC coding with diversity reception, using error correction codes (turbo codes). Fortunately with the combination of these two techniques is possible to obtain a low error probability with low power consumption, without increasing the bandwidth and transmit power in mobile terminals.

2. STBC SHEMES

In 1998, Alamouti proposed a simple scheme of diversity [1], with two transmission antennas and one reception antenna (equation (2.1)). The extension of the Alamouti STBC for more than two transmit antennas was proposed later by Tarokh et al [2]. In this paper, in addition to Alamouti matrix, the matrix is presented with four antennas transmission (equation (2.2)). STBC schemes consist in encoding symbols carried in space and time, which are then transferred as a matrix (Figure 2.1).

$$X_2^c = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}^T \tag{2.1}$$

$$X_4^c = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & -x_2^* \\ x_4 & x_3 & -x_2 & x_1 & x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix}^T \tag{2.2}$$

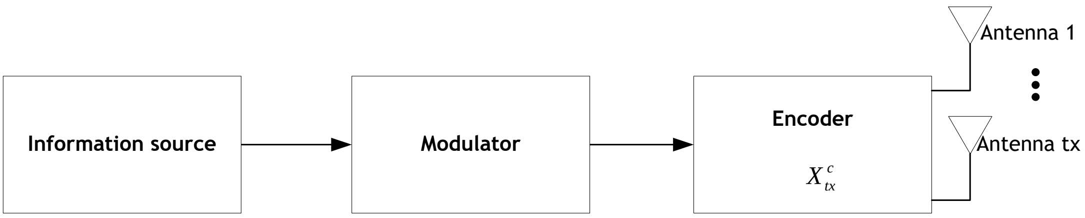


Figure 2.1 - Transmission scheme with STBC.

The rate of each matrix is obtained by dividing the number of rows (number of transmit antennas) with the number of columns (time instants) (equation (2.3)).

$$R = \frac{K}{T} \quad \text{(bit/s)} \tag{2.3}$$

Spectral efficiency is defined by [4]:

$$\varepsilon = R\log_2(M) \ \text{ bit/s/Hz} \tag{2.4}$$

where M is the number of modulation symbols used.

The received signal with the Alamouti scheme (Figure 2.2) can be defined by (equation (2.5)):

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \times \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{2.5}$$

where y_1 and y_2 correspond to the bits received at two instants of time, h_1 and h_2 correspond to the Rayleigh channel between the two antennas with one receiver.

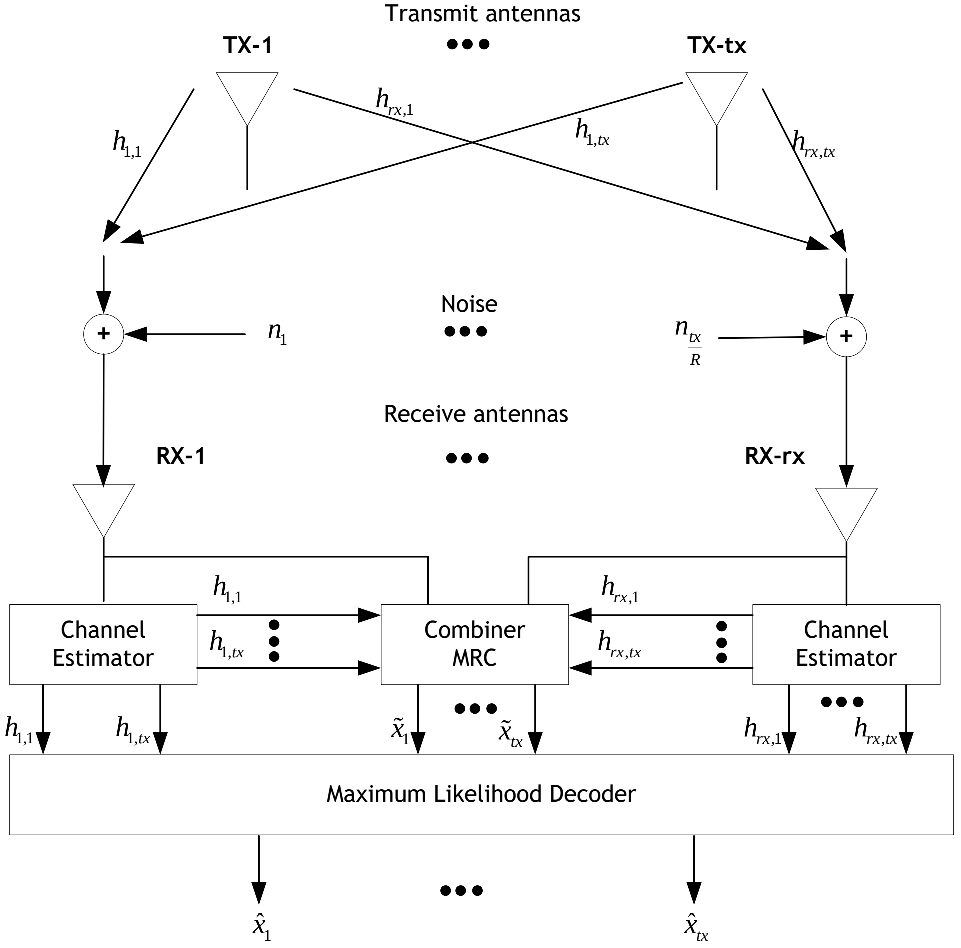


Figure 2.2 - Reception with the Alamouti scheme.

The variables n_1 and n_2 correspond to the noise sample in the respective moments of time. Equation (2.6) can be rewritten as follows:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \underbrace{\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}}_{H_2^c} \times \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (2.6)$$

Generalizing equation (2.6) for more transmission antennas, equation (2.7) is obtained:

$$\begin{bmatrix} y_1 \\ \vdots \\ y^*_{x+\frac{tx}{R}} \\ \vdots \\ y^*_{\frac{tx}{R}} \end{bmatrix} = H_M^c \times \begin{bmatrix} x_1 \\ \vdots \\ x_{tx} \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_{\frac{tx}{R}} \end{bmatrix} \quad (2.7)$$

where M is the number of antennas. The variable $x=0$ with two transmit antennas (Alamouti) and $x=1$ for more than two antennas. At the reception, we have perfect knowledge of the channel so we use MRC (Maximum Ratio Combining) and the maximum likelihood detection [4]. The MRC is shown in equation (2.8), which shows the symbols from the received signals and the estimation of channel. After the combination of two signals, these are then sent to a maximum likelihood decoder and, simultaneously, we can estimate the transmitted symbols (equation (2.9)).

$$\begin{bmatrix} \tilde{x}_1 \\ \vdots \\ \tilde{x}_{tx} \end{bmatrix} = \left(H_{tx}^{c}\right)^{*T} \times \begin{bmatrix} y_1 \\ \vdots \\ y^{*}_{x+\frac{tx}{R}} \\ \vdots \\ y^{*}_{\frac{tx}{R}} \end{bmatrix} \tag{2.8}$$

$$\begin{bmatrix} \hat{x}_1 \\ \vdots \\ \hat{x}_{tx} \end{bmatrix} = \begin{bmatrix} \tilde{x}_1 \\ \vdots \\ \tilde{x}_{tx} \end{bmatrix} \times \frac{1}{\left|H_{tx}^{c}\right|^2} \tag{2.9}$$

3. TURBO CODES

This paper refers to the TC (Turbo codes) [3] (Figure 3.1) with two RSCC (Recursive and Systematic Convolutional Coders), eight states, concatenated in parallel and separated by pseudo-random interleavers. The matrix is given by equation (3.1):

$$G(D) = \begin{bmatrix} 1 & \dfrac{1+D+D^3}{1+D^2+D^3} \end{bmatrix} \tag{3.1}$$

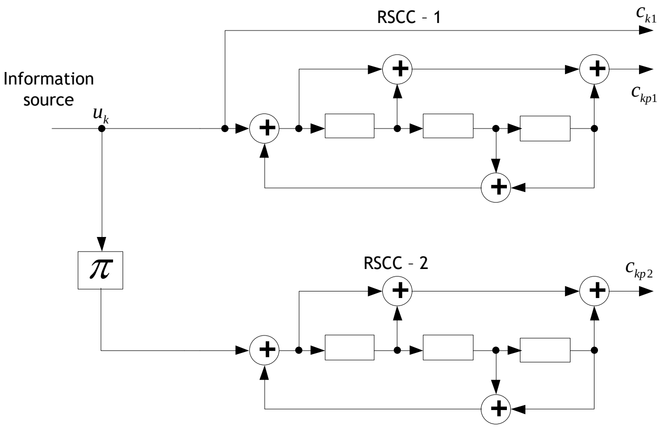


Figure 3.1 - Schematic block TC.

3.1 Iterative Decoding

Consider the diagram of Figure 3.2, which consists of two decoders RSCC concatenated and separated by a interleaver. The first decoder uses the received systematic bit sequence y_{k1} and received parity sequence y_{kp1} generated by the first encoder with the extrinsic information produced by the second decoder $E_1^{P'}(u_k)$ after deinterleaving. In the first iteration, the extrinsic information $E_1^{P'}(u_k)$ is zero. The output of MAP, log-MAP and max-log-MAP decoding, of the first decoder is a soft output, known as $L_1(u_k|y)$. The second decoder takes as input $y_{k1}^{(P)}$, which is obtained by the permutation of the sequence of bits y_{k1} and received parity sequence y_{kp2} generated by the second encoder with the extrinsic information produced by the second decoder $E_1^P(u_k)$. The $E_1^P(u_k)$ extrinsic information is obtained through the equation (3.2), with interleaver:

$$E_1(u_k) = L_1(u_k \mid y) - E_1^{P'}(u_k) - y_{kp1} \tag{3.2}$$

When we no longer need any more iterations, then the output of the second decoder $L_2(u_k|y)$ is subjected to the deinterleaver, resulting in $L(u_k|y)$ and by a decision maker is the sequence obtained $\hat{u}_k$ estimated. If we need more iterations, then the extrinsic information is calculated $E_2(u_k)$, through the equation (3.3) which is subject to extrinsic information that originates the deinterleaved $E_1^{P'}(u_k)$, thus returning to the beginning of turbo decoding.

$$E_2(u_k) = L_2(u_k \mid y) - E_1^P(u_k) - y_{k1}^P \tag{3.3}$$

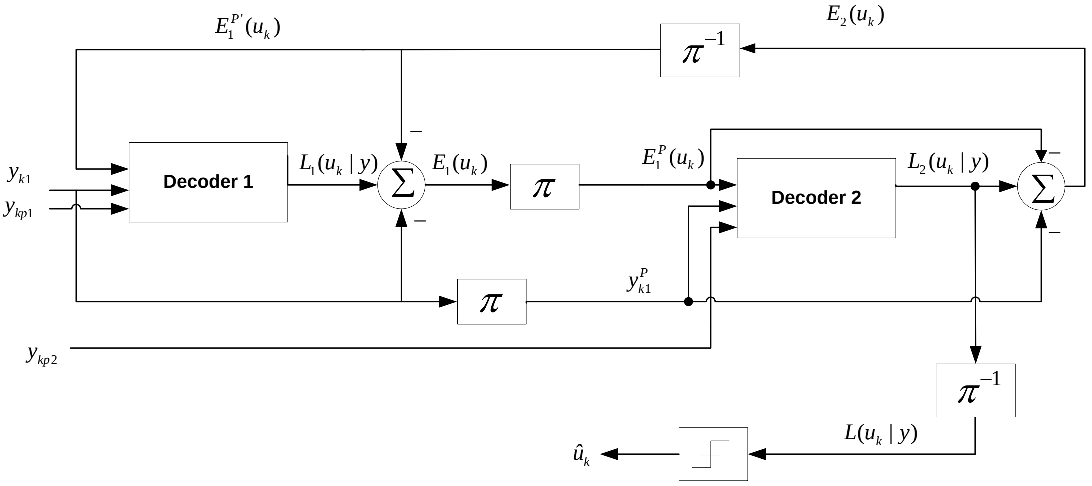


Figure 3.2 - Block diagram of a decoder for TC.

3.1.1 Iterative decoding based on the MAP, log-MAP and max-log-MAP algorithm

In [5], the probability "a posteriori" $L(u_k \mid y)$, for the three algorithms is defined by equation (3.4) and (3.5):

$$L(u_k \mid y) = \ln \frac{\sum_{R_1} \alpha_{k-1}(s')\gamma_k(s',s)\beta_k(s)}{\sum_{R_0} \alpha_{k-1}(s')\gamma_k(s',s)\beta_k(s)} \tag{3.4}$$

$$L(u_k \mid y) = \max_{R_1}{}^* \left[A_{k-1}(s') + \Gamma_k(s',s) + B_k(s)\right] - \max_{R_0}{}^* \left[A_{k-1}(s') + \Gamma_k(s',s) + B_k(s)\right] \tag{3.5}$$

where the equation (3.4) corresponds to the MAP algorithm and the equation (3.5) corresponds to the general equation log-MAP algorithm and max-log-MAP.

4. ANALYSIS OF RESULTS

In this work we simulated two types of scenarios: schemas Alamouti and STBC (with four transmit antennas) with diversity without error correction (Figure 4.1 and Figure 4.2), which can be obtained by equation (4.1) and with error correction (Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6).

$$P_b = \frac{1}{2}\left(1-\sqrt{\frac{1}{1+\frac{M}{E_b/N_0}}}\right)\times\sum_{q=0}^{Q-1}\left\{\frac{\prod_{i=0}^{q}|2i-1|}{q!2^q}\left(1+\frac{E_b}{N_0}\right)^{-q}\right\} \qquad (4.1)$$

where $Q = M \times N$, M is the number of transmit antennas and N the number of receiving antennas.

For the first scenario, one can conclude that for both schemes (Alamouti and STBC (with four transmit antennas)) with the introduction of the receiving antenna gain between them tends to be zero and the gain obtained from two to four antennas transmission tends to decrease as they enter the reception antennas, so that the SNR required for these two schemes tend to it (Figure 4.7).

In the second scenario, as in the first, one can conclude that the technique using TC for both schemes (Alamouti and STBC (with four transmit antennas)) with the introduction of the receiving antenna gain between them tends to be null and unlike the first scenario, where there is a significant gain between the schemes Alamouti and STBC with four transmit antennas, using the TC this gain is relatively smaller. You can also see in Figure 4.8, the MAP algorithm has the same performance than the algorithm log-MAP and a better performance than the algorithm max-log-MAP, with a difference of about 0.3 dB, where as receiving antennas are introduced in this difference tends to zero.

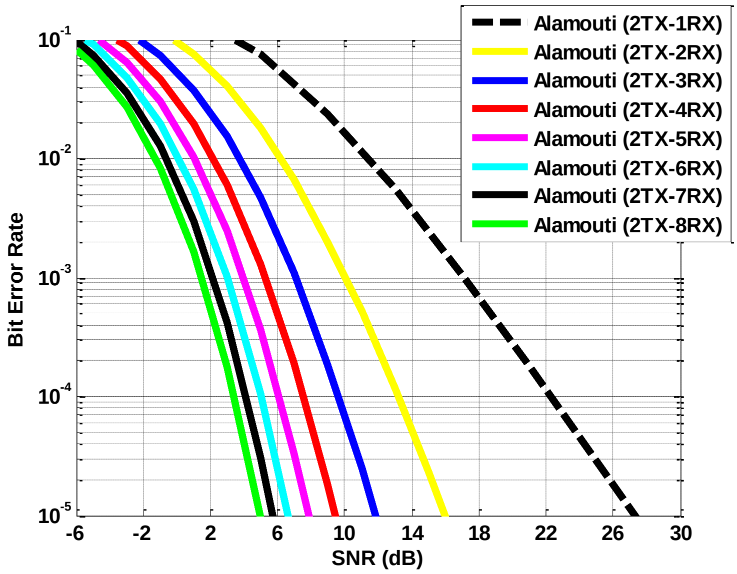


Figure 4.1 - Simulation Alamouti scheme with diversity reception.

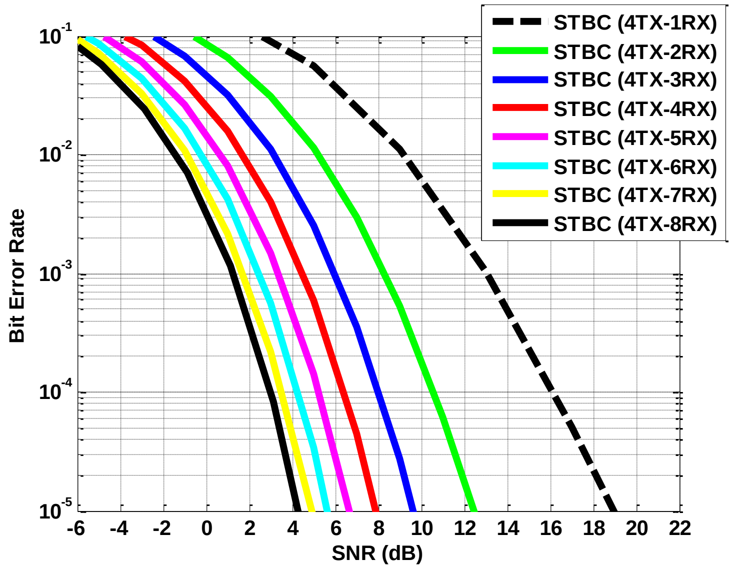


Figure 4.2 - Simulation STBC scheme with diversity reception.

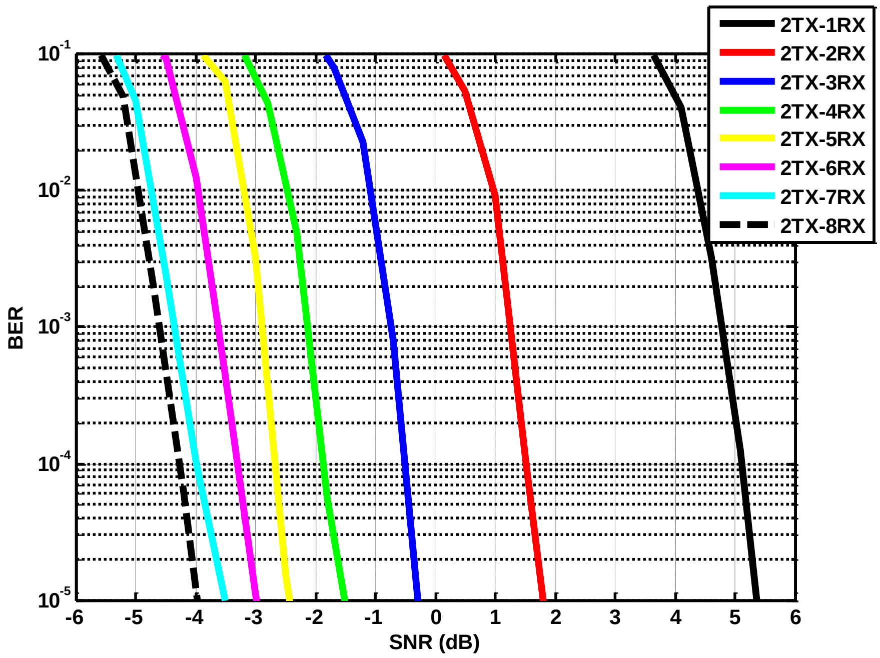


Figure 4.3 - Simulation with diversity Alamouti scheme with TC (MAP, log-MAP), 10th iteration (rate = 1/3, K = 4).

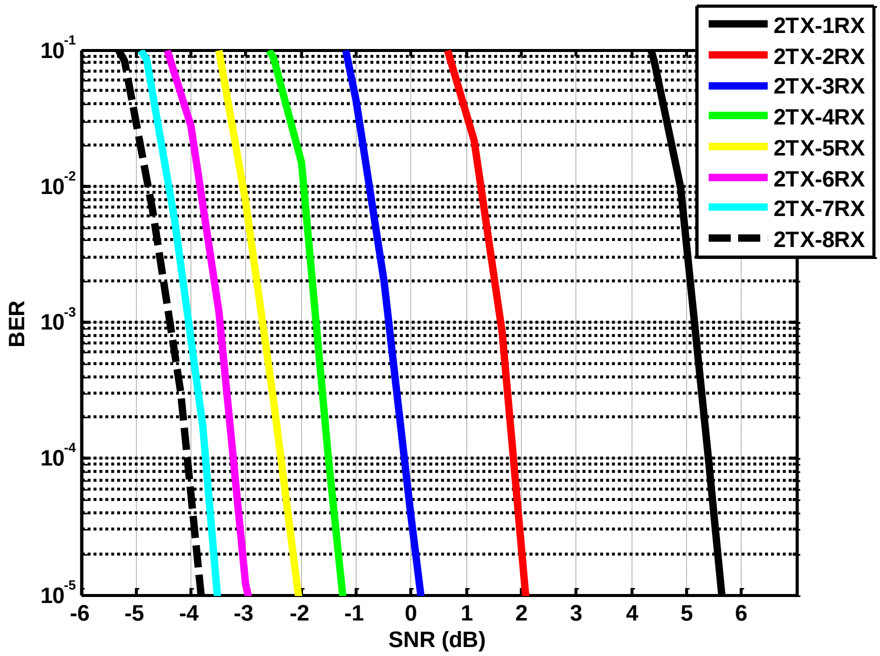


Figure 4.4 - Simulation with diversity Alamouti schemes with TC (max-log-MAP), 10th iteration (rate = 1/3, K = 4).

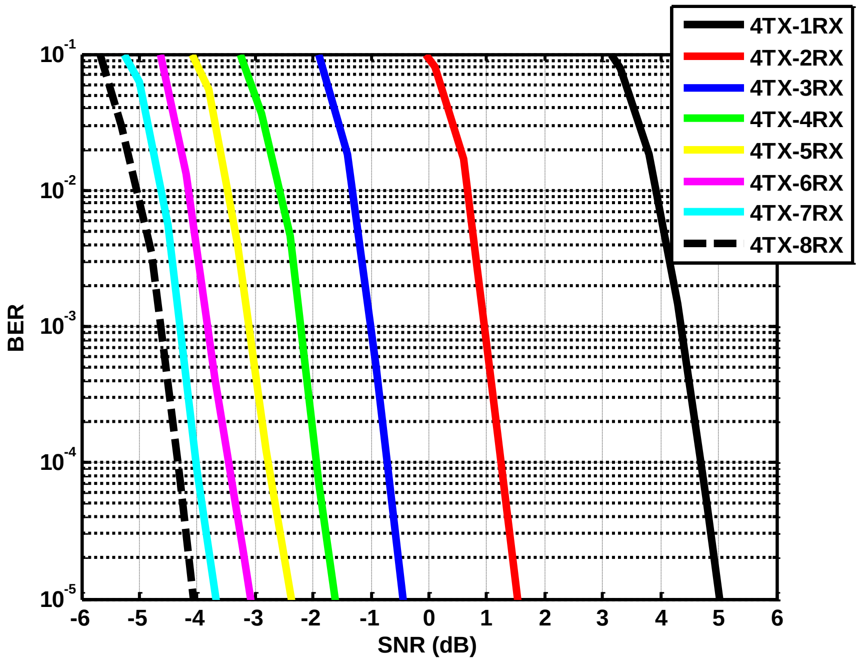


Figure 4.5 - Simulation with diversity STBC schemes with TC (MAP, log-MAP), 10th iteration (rate = 1/3, K = 4).

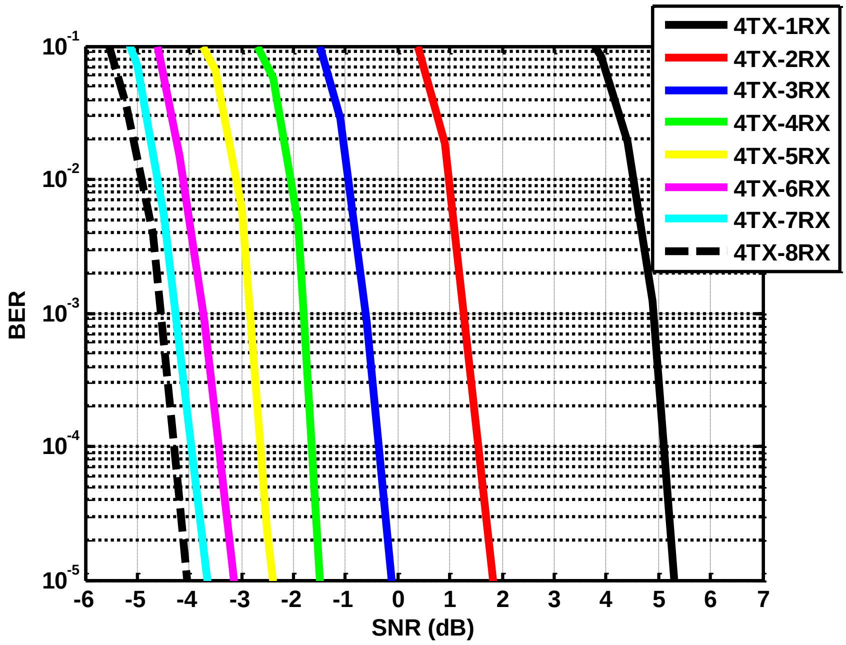


Figure 4.6 - Simulation with diversity STBC schemes with TC (max-log-MAP), 10th iteration (rate = 1/3, K = 4).

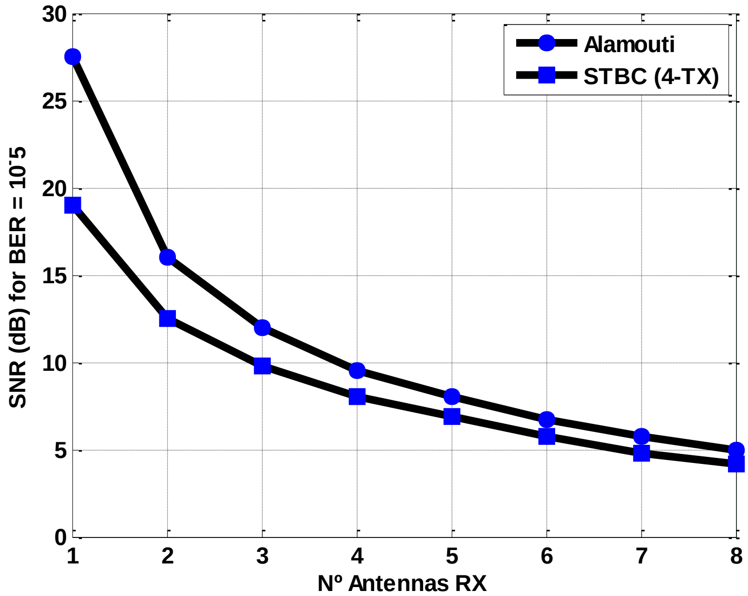
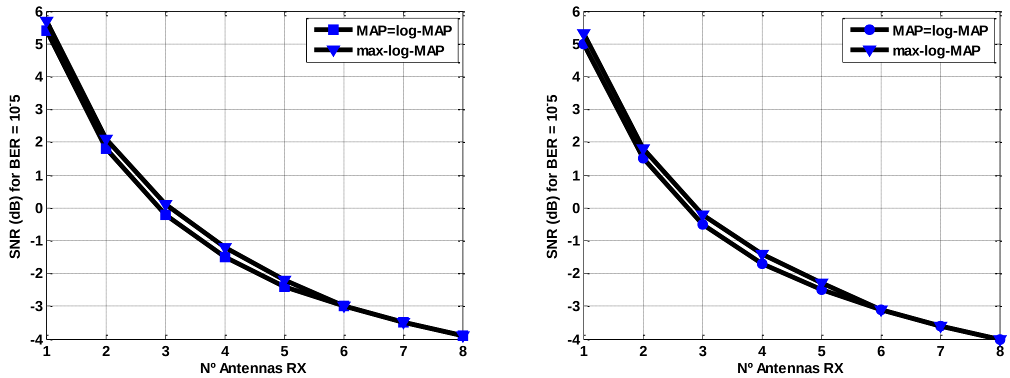


Figure 4.7- Comparison of the SNR required to obtain a BER of 10^{-5} for Alamouti and STBC schemes without TC.

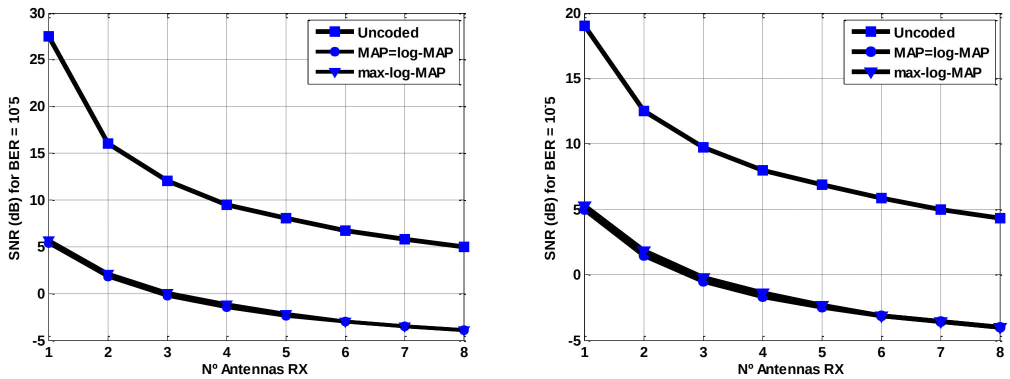


(a) (b)

Figure 4.8- Comparison of the SNR required to obtain a BER of 10^{-5} for (a) Alamouti schemes (b) STBC schemes, with TC.

5. CONCLUSIONS

The analysis of Figure 5.1 can be concluded that using TC technique, one can reduce the SNR required to achieve a low probability of error. For the TC technique, we used the MAP algorithm, Log-MAP and max-log-MAP where one can conclude that the MAP algorithm has the same performance than the log-MAP algorithm and a worse performance than the algorithm max-log -MAP, whose difference is about 0.3 dB and that the measure is introduced at the reception antennas, the difference between the three algorithms tends to be zero.



(a) (b)

Figure 5.1- Comparison of the SNR required to obtain a BER of 10^{-5} for (a) Alamouti schemes (b) STBC schemes, with and without TC.

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