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MIMO Systems using OFDM in Underwater Communications

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Abstract: *This work presents an underwater acoustic communication mechanism which has not been much explored yet. The main goal of this paper is to present academic studies in this subject and try to implement communication systems that can be used to attend modern market needs. In the beginning of this work an introduction about underwater communication is done, as well as the presentation of the equipment used and the most common techniques applied. After, the Alamouti's transmission technique [1] is presented and detailed. Finally, simulations are developed in order to obtain results for the use of MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency-Division Multiplexing) in underwater scenario and analyze the gains achieved by the system.*
Keywords: *Alamouti, hydrophone, projector, MIMO, OFDM*

I. INTRODUCTION

In the last decades there has been a great progress in the wireless communications using radio frequency. However, the underwater communications didn't grow so fast and nowadays there is a great demand in the market to improve this technology. Due to many difficulties faced in the use of undersea channels, like fast attenuation, seasonal variations and multipath propagation the transmission in this ambient using high speed connections is a big challenge. To overcome these problems and improve the wireless communications in the sea, the most recent studies are using acoustic transmission, combined with modern technologies [2, 3, 4].

The main direction of the studies is the use of OFDM modulation, due to the good results that it provides in wireless communications [5,6]. In this paper, a simulation will be done to compare the gains that can be obtained using Alamouti scheme combined with OFDM, when compared to a scheme using only OFDM. The main goal of this study is to test the efficiency of the MIMO techniques applied to underwater channels and also its combination with OFDM.

For the simulations, the underlying assumption is that the multipath propagation is according to Rayleigh model [7, 8]. The noise is considered to be white Gaussian and the Doppler tracking is fixed in 25db. The turbo codification is applied and the modulation used is 16-QAM.

This paper is organized as follows. In Section II, the system model is described. In Section III, the results of the first simulation are showed. In Section IV, the experimental results of the second simulation are presented and are compared with results of the first simulation. The conclusions are drawn in Section V.

II. PRESENTATION OF SIMULATION SCHEME

The scheme [9, 10] used for the simulations (developed in MatLab - Mathworks) is showed in the Fig. 1. The data are modulated with 16-QAM and them OFDM is applied. The transmission is done by one projector and the reception is made by one hydrophone.

Two displays are used in the scheme in order to present the status of the transmitted data. The first one shows the signal spectrum after the transmission in the channel. The other one shows the symbol distribution in the reception. These informations are used for qualitative analyses about the system and about the results that are expected. As shown, the channel is simulated with two blocks: one for AWGN (Additive White Gaussian Noise) and the other for Rayleigh fading.

At the end of the data transmission cycle, the symbol errors are registered, as well as the total amount of data transmitted. This information is used for quantitative analyses and later will be used to compare the two systems.

The next item will show the main results of the simulations.

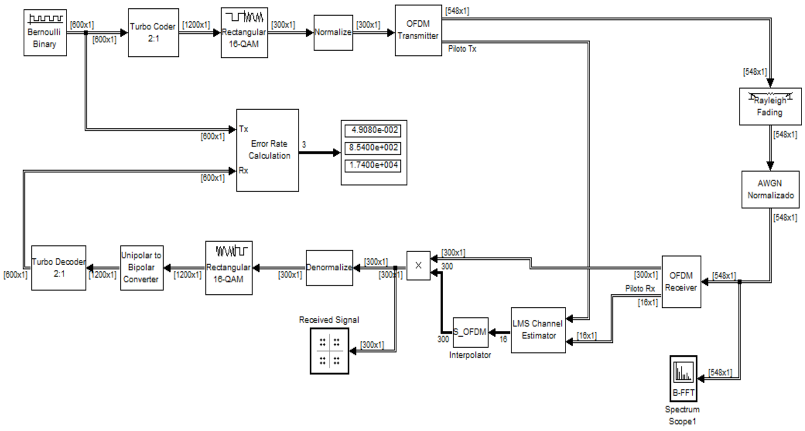

Fig. 1: Scheme used for OFDM underwater simulation.

III. Simulation of Acoustic Underwater Communication Using OFDM

In the simulation with the OFDM system, three samples were collected in different moments of the transmission, in order to observe the error rates. For all these samples, graphic information were collected for analysis and qualitative information, as explained before in the scheme presentation. In Fig. 2 are shown the graphs related to the sample number 2.

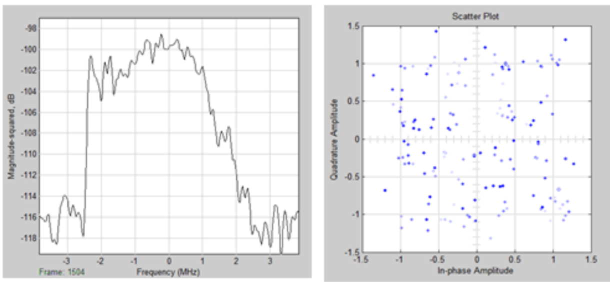

Fig. 2: Graphic information from sample number 2 in OFDM system simulation.

By the analysis of the graphs in Fig. 2 we can conclude that the symbol detection are not very accurate because the signal spectrum is very scattered. This can induce to the conclusion that the error rate may be high for this system.

To give quantitative values about the system, the symbol errors are registered and showed in the Fig.3.

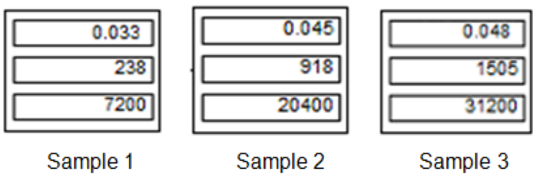

Fig. 3: Error information from three samples

The first value of each sample is the accumulated error rate in the moment that the sample is collected. The second value is the total amount of symbols detected wrongly by the system. The last value is the total amount of symbols transmitted by the system.

As mentioned in the analyses of the graph information, the error rate in this system is very high, reaching 4.8% in the third sample. These errors are caused because the system cannot recover many of the symbols affected by noise and channel attenuation, which are very strong factors in undersea channel.

IV. SIMULATION OF ACOUSTIC UNDERWATER COMMUNICATION USING OFDM COMBINED WITH ALAMOUTI SCHEME

In this second simulation, the scheme presented in section II is adapted to use the Alamouti technique. The transmission is now made by two projectors instead of one, and the Alamouti code is applied in the symbols. The new scheme is shown in Fig.4.

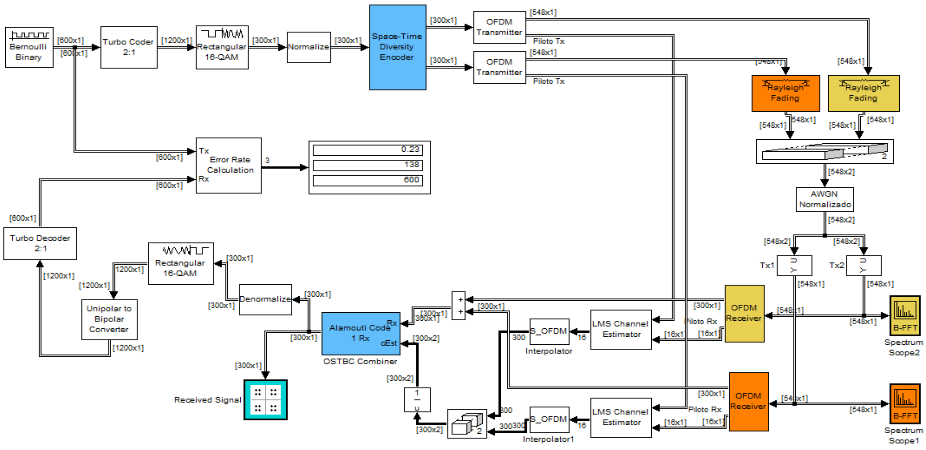

Fig. 4: Scheme used for underwater simulation combining OFDM and Alamouti. .

Alamouti coding is exploited to improve the data detection, and thus provide the channel estimator with improved symbol decisions [11, 12, and 13]. The simulation is performed and the results are shown below.

As made in the first simulation, Fig. 5. Shows the graphic results for the second sample collected in this scheme. The main difference is that each sample now has two signals being transmitted and so two spectrums are showed. It is important to notice that the samples were collected at the same moment in both transmissions, that means, for the same amount of symbols transmitted.

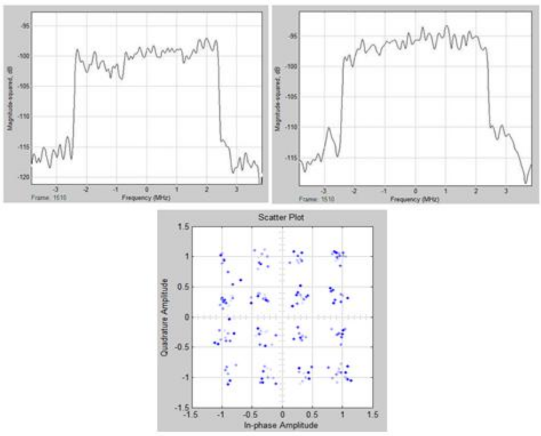

Fig. 5: Graphic information from sample number 2 in Alamouti-OFDM system simulation.

After the signals are combined in the reception, the symbol's decision is optimized because the system has more information about the signal transmitted. This can be noticed comparing the symbols distribution in Fig. 4 and Fig. 5 and observing that the symbols in Fig. 5 are closer to the expected signal level.

In order to have quantitative information about the system, the symbol errors are registered and analyzed in Fig. 6.

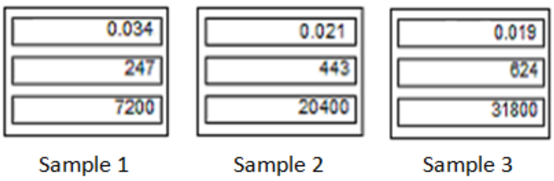

Fig. 6: Scheme 2 error information from 3 samples

Comparing the error rates of both systems, it can be noticed that for the second scheme there is a decrease of the errors for the same amount of transmitted symbols, as expected. In the moment of the third sample, the symbol error amount was reduced by more than half, reducing the error rate from 4.8% to 1.9%.

Another result obtained in the simulations is that the second scheme has a better response for the moments where the channel is affected by a strong attenuation. In the first scheme the error rate reached 6% in a moment of strong selective fading. In the scheme 2 the maximum error rate in the same conditions was 4.9%. This improvement is achieved due to the existing diversity in the transmission.

To summarize the analyses, Fig 7 shows the response of both systems for different values of SNR values and confirms that the scheme 2 has always the best performance.

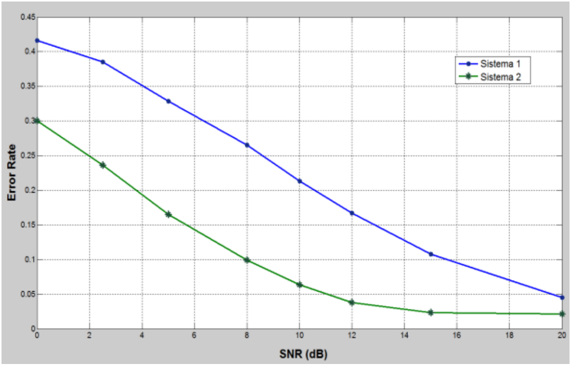

Fig. 7: System response for different SNR values.

V. Conclusion

Considering that all the parameters in the systems remained the same, the two systems were compared and an expected performance improvement was observed in the scheme 2. The improvements in the symbols decodification and error rate can be attributed to the use of the Alamouti scheme, combined with OFDM technique.

Despite the gain that was obtained with the implementation of Alamouti system combined with OFDM in the samples collected in this experiment, the graphic in the Fig. 7 shows that the system can offer even better gains for lower values of SNR. For an error rate of 0.025 for example, the gain is approximately 10 dB.

However, for a reliable and efficient communication system it is necessary to achieve lower error rates. The implementation of next level MIMO systems, like a 2 x 2 configuration (two projectors and two hydrophones) and so on, can be the next step to try to improve the system presented in this work in order to achieve very low error rates for a high speed and a reliable data transmission.

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