1. Introduction

The fundamental problem in communications is to detect the vector of messages, starting from the vector composed by the signals received by each antenna at the receiver side. The vector of received signals represents the product of the vector of messages with the channel’s matrix. The channel’s matrix depends on a lot of network features as: the signal model (including the parameters of multipath propagation, the type of modulations, the type of coding, the impulse waveform, the value of symbol duration, the sampling frequency, the distance from Gaussianity, the degree of cyclostationarity), the multiple access solution (number of mobile users, number of antennas, their geometry, their attenuation profiles, directions of arrival/departure) and the receiver architecture (diversity techniques, bandwidth, noise power, Peak to Average Power Ratio-PAPR). The vector composed by the signals received can be measured. If the channel’s matrix can be estimated and left inverted, then the message can be estimated.

Hence, the message estimation problem can be reduced to a channel estimation problem. If the channel involved is slow time variant then a non blind estimation can be used for message estimation. In mobile wireless communications (WiMAX and LTE) the channel estimation is useful for other purposes like the multiple accesses scheduling as well. The channel estimation is realized in mobile wireless communications with the aid of training sequences (using pilot subcarriers as in the case of Orthogonal Frequency Division Multiplexing (OFDM)-based WiMAX or LTE), obtaining an estimation of the channel’s matrix. These are non blind estimations. A non blind estimation procedure can be used if the estimated channel matrix obtained is left invertible. It consists of the message transmission followed by the measurement of the vector of received messages, the left inversion of the channel’s matrix and the message estimation performed using the product of the inverse of the channel’s matrix with the vector of received messages. All these operations are time consuming, especially the estimated channel matrix left inversion and the matrices multiplication, which must be implemented as fast as possible. The time required by the implementation of those operations increases with the dimensions of the matrices involved. Another disadvantage of this method is given by the concatenation of two estimators which could produce an error difficult to control. Based on these reasons, a faster blind estimation procedure would improve the performance. If the channel involved is fast time varying then a blind estimation is required.

The goal of this paper is to adapt a famous signal processing method, already used in other applications, for the blind estimation of messages in OFDM communication systems. In 1992, Professor David Donoho from Stanford University introduced the term denoising in connection with the adaptive non-linear filtering applied in the wavelets domain [1]. This paper produced a high interest in the world of science and represents a source of inspiration for a huge number of published papers. Despite its advantages, this method was not systematically exploited in communications yet. Let us suppose that the input signal $s$ is additively perturbed by the white Gaussian noise $n$. This is the well known scenario of the Additive White Gaussian Noise (AWGN) channel model. The received signal has the expression: $x = s + n$. To estimate the signal $s$, Donoho, proposed the following three steps method:

1) Computation of the Discrete Wavelet Transform (DWT) of the signal $x$ obtaining the wavelet coefficients sequence $y = s + n$ where the signal $n$ is white Gaussian noise (WGN). The approximation $y_a$ and details $y_d$ sequences are separated.

2) A non linear filtering is applied to the sequence of detail coefficients obtained.

3) The approximation coefficients sequence $y_a$ is concatenated with the new detail coefficients sequence $y_d$ obtaining the new sequence of wavelet coefficients $y_0$ and next is computed its inverse DWT (IDWT). The estimation of the signal $s$, denoted by $s_0$ is obtained.

The non linear filter applied at the second step is named soft-thresholding [1]. The success of the Donoho’s estimation procedure is assured by an appropriate choice of the soft-thresholding threshold’s value $t$. If $t$ is chosen to be equal with three times the standard deviation of the noise $n$ then the probability that $y_d$ to be affected by noise is of 0.2% (rule of three times sigma). The standard deviation already mentioned can be estimated using the same DWT with the aid of a median filter applied to the sequence of details from the first decomposition level [1]. Depending on the value of the input signal to noise ratio $\text{SNR}_i$, the optimum value of the threshold could become superior to the maximum value of the useful component of the sequence $y_d$. In this case the soft thresholding filter removes all the detail wavelet coefficients. So, in the case of low $\text{SNR}_i$, the
Donoho’s denoising method supposes only the separation of the approximation coefficients, all the detail coefficients being met to zero. The step 2, supposing filtering in the wavelet domain, is no longer necessary. The idea of this paper is the inclusion of a denoising system in the chain of a wireless receiver based on OFDM, to improve its Bit Error Rate (BER).

The structure of the paper is the following. The architecture of an OFDM communication system and the localization of the proposed blind estimation system are described in the second section. Next, it is presented the architecture of the proposed blind estimation system. In the third section, we present some simulation results. The last section is dedicated to the conclusions of the paper.

2. Denoising Systems as Blind Estimators in OFDM Receivers

An OFDM transmitter is composed by the following signal processing blocks: an encoding system (for example a turbo encoder) followed by a digital modulator (which implements for example a Quadrature Phase Shift Key (QPSK) modulation) and a system for the administration of the multiple access (based for example on the Orthogonal Frequency Division Multiplexing Access (OFDMA) technique). Next an Inverse Fast Fourier Transform (IFFT) computation block generates the OFDM signal, s, which is injected in the communication channel. The structure of the corresponding receiver is composed by the blocks which implement the inverse functions connected in inverse order. So, at the output of the communication channel is connected a block which computes the Fast Fourier Transform (FFT-base band demodulation) of the received signal x, followed by a system which administrate the multiple accesses (OFDMA). Next is connected a digital demodulator (QPSK) and a decoding block (turbo decoder). For AWGN channels, the received signal is expressed in the form: \( x = s + n_i \) and for flat fading Rayleigh channels the last equation becomes \( x = r s + n_i \), where r is a Rayleigh random variable. The flat fading Rayleigh channel model contains two types of perturbations, the zero mean AWGN noise \( n_i \) produced by the electronic components of the first stage of the receiver and the multiplicative noise \( r \) produced by the flat fading. The SNRi at the output of the base band demodulator could be very small. We have included the blind estimation system based on denoising in the receiver’s structure at the output of the base band demodulator as can be seen in Fig. 1.

![Fig. 1. Simulation system.](image)

The proposed denoising system implements the simplified variant of the Donoho’s denoising method, without filtering, which consists in meting all the detail coefficients to zero, because the SNRi could be very small. Generally, the OFDM wireless communication systems use spatial diversification to improve the BER performance, the transmitters and the receivers having multiple antennas systems. In some conditions, the spatial diversity is equivalent with the temporal diversity. To simplify our simulations we have considered that these conditions are satisfied in our case and we have simulated a transmission with single transmitter and receiver antennas, but we have equipped the blind estimation system with a temporal diversity scheme. It is implemented with the aid of an interpolator with an interpolation factor of 8. So, our blind estimation system is composed by the interpolator, followed by the denoising system and by a down sampling system having the down sampling ratio equal with 8. This last system selects the fourth sample from a group of 8 samples.

3. Simulation Results

We simulated the OFDM transmission chain already described including the blind estimation system at the output of the base band demodulator from the receiver for an AWGN communication channel. For the DWT computation we have used the Haar wavelets mother and we have made six iterations. We have selected the Haar mother wavelets because it has the best time localization which is more important than the frequency localization in the case of AWGN and flat fading Rayleigh communication channels. We have not solved yet the problem of the selection of the best number of iterations of the DWT. We have obtained the following results:
(SNRi=1 dB BER=0.03), (SNRi=2 dB BER=0.003), (SNRi=3 dB BER=2.75e-004), (SNRi=4 dB BER=1.07e-004), (SNRi=5 dB BER=1.52e-005), (SNRi=6 dB BER=5.72e-006) and (SNRi=7 dB BER=1.91e-006). The corresponding results obtained without the blind estimation system are the following:
(SNRi=1 dB BER=0.16), (SNRi=2 dB BER=0.08), (SNRi=3 dB BER=0.04), (SNRi=4 dB BER=0.02), (SNRi=5 dB BER=0.013), (SNRi=6 dB BER=0.003) and (SNRi=7 dB BER=0.002).
Comparing the two types of results, presented in Fig. 2, it can be observed that the contribution of the blind estimation system is important.

Fig. 2. A comparison of results obtained with and without blind estimation.

4. Conclusions

The DWT computation algorithm implemented with the Haar mother wavelets is faster than the FFT algorithm. The soft thresholding filter is also very fast. So, the blind estimation method proposed in this paper is faster than the non-blind estimation methods which are based on iterative algorithms and permits the tracking of faster time varying channels. The proposed blind estimation method is simpler than the non-blind estimation methods, because it does not require the channel estimation. It could be used for channel estimation. The simulation results presented prove the very good quality of the proposed estimation method outperforming the results obtained using other equalization methods as for example zero forcing method. Such results can be obtained on AWGN channels only with the aid of coding techniques which are redundant and require important computing resources. Future research directions are:
- the analysis of the proposed estimation method on flat and frequency selective Rayleigh channels (we have already applied it on flat Rayleigh channels in the context of wavelet modulation [2]).
- the integration of the proposed estimation methods in our WiMAX simulator and in a LTE simulator to analyze the merits of its association with turbo codes,
- the implementation of the proposed estimation method on FPGA.

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