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A Blind Channel Estimation Technique Based on Denoising for LTE Downlink and Uplink system

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Abstract – The main purpose of this paper is to introduce a blind channel estimation technique based on denoising for multiple access schemes in 3GPP Long Term Evolution (LTE) technology, which uses Orthogonal Frequency Division Multiple Access (OFDMA) in the Downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in the Uplink. The architecture of the proposed technique is presented and its performance is proved for both OFDMA and SCFDMA by computer simulation in term of Bite Error Rate (BER).

Keywords: OFDMA, SC-FDMA, LTE, Denoising

I. INTRODUCTION

Blind Estimation techniques have a great interest in wireless communication which has messages detection as a major problem. Taking into account the ad-hoc and time-variant nature for orthogonal communication techniques, the blind techniques are preferred for messages estimation. Starting from a 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 [1].

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.

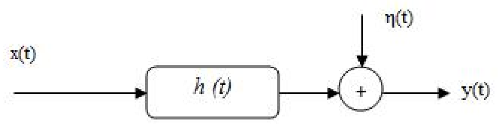

Fig. 1. Example of a Single input Single Output blind estimation: *h(t)*is to be detected using *y(t)*

In a 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 is 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 introduce a famous signal processing method; denoising in connection with the adaptive non-linear filtering applied in the wavelets domain, for the blind estimation of messages in OFDMA and SC-FDMA which are the basis of

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multiple accesses in LTE technology [2]. We have implemented our proposed blind technique in OFDMA and SC-FDMA for one user access, and it can be applicable for multiple accesses. In the rest of our paper, we give an overview of OFDMA and SC-FDMA systems in section II. The proposed blind estimator is presented in section III. We present the simulation results in section IV. The section V is dedicated to the conclusions of the paper.

II. LTE DOWLINK and UPLINK SYSTEMS

A. *OFDMA in LTE Downlink*

OFDMA allows the base station (BS) to communicate simultaneously with several mobile stations (MSs). According to [3], OFDMA is the multiple access technique for OFDM systems. The OFDMA inherits all the properties of the OFDM and exhibits some new features. Multiplexing provides packing many user packets into one frame. As a result, multiplexing scheme becomes very efficient in the sense that overheads caused by inter frame spacing is minimized.

One baseband OFDM symbol is a sum of multiple orthogonal subcarriers, modulated by the data symbols to be transmitted through the channel (X_k):

$$s(t) = \frac{1}{\sqrt{N}} \left(\sum_{k=0}^{N-1} X_k \cdot e^{j \cdot 2\pi \cdot f_k \cdot t} \right) \quad 0 < t < T, \quad (1)$$

where X_k represents the *k*-th complex data symbol, T is the length of the OFDM symbol and *N* represents the number of subcarriers. If the digital symbols to be transmitted X_k came from different users, then OFDM transforms into OFDMA.

OFDMA is used in LTE downlink when the transmitter is the eNB (also denoted by BS) and the receiver is the UE (also denoted by MS). According to the standard [4], the supported modulation schemes are QPSK, 16QAM, and 64QAM. Scrambling and interleaving are also supported. For channel coding, both Tail biting Convolutional coding and Turbo coding are used. In Fig. 2 is presented the architecture of an OFDMA system. Downlink physical channels are implemented by OFDMA for information transmission from higher protocol layers. LTE frames are 10 ms in duration and they are divided into 10 sub-frames where each sub-frame is further divided into two slots, each of 0.5 ms duration. Slots consist of either 6 or 7 OFDM symbols, depending on whether the normal or extended CP is used. Longer CP is desired to address longer fading that can be encountered in multi-cell broadcast services or very large cell deployments.

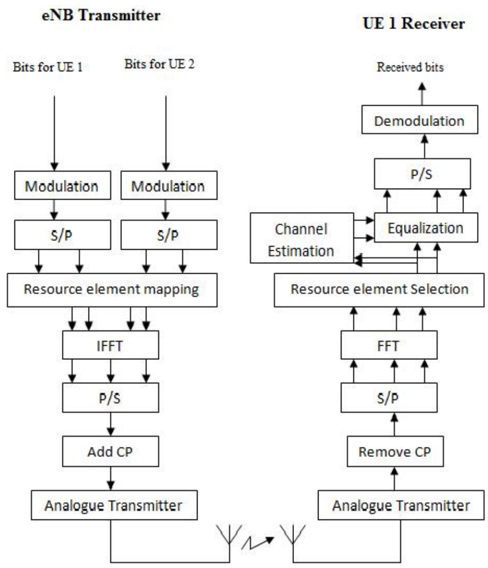

Fig 2: OFDMA system architecture.

Table 1: Parameters for the downlink transmission scheme for OFDMA [4]

Bandwidth (MHz)	1.25	2.5	5	10	15	20
Sub-frame Duration (ms)	0.5	0.5	0.5	0.5	0.5	0.5
Subcarrier spacinf (kHz)	15	15	15	15	15	15
Sampling Freqency (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Occupied subcarriers /FFT size	76/ 128	151/ 256	301/ 512	601/ 1024	901/ 1536	1200/ 2048
Short /Long CP	7/6	7/6	7/6	7/6	7/6	7/6
Long CP (s/samples)	16.67/ 32	16.67/64	16.67/ 128	16.67/ 256	16.67/ 384	16.67/ 512
Short CP	4.69 /9	4.69 /18	4.69 /36	4.69 /72	4.69/ 108	4.69/ 144
Resource block Bandwidth (kHz)	180	180	180	180	180	180
No of available RBs	6	12	25	50	75	100
Sampling frequency (kHz)	1.92	3.84	7.68	15.36	23.04	30.72

Parameters for OFDMA downlink are shown in Table 1 for system bandwidth ranging from 1.25 MHz to 20 MHz. The number of available subcarriers changes depending on the transmission bandwidth;

however, OFDM downlink transmission scheme uses fixed subcarrier spacing regardless of transmission bandwidth. Pilot symbols are used to estimate the channel impulse response and for time and frequency synchronization. The orthogonal pilots sequence or a pseudo-random numerical sequence is used in order to avoid interference; a specific element of a set of 510 unique orthogonal sequences is assigned to each cell in order to distinguish it from others.

B. *SC-FDMA in LTE Uplink*

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a multiple access technique used in LTE Uplink. SC-FDMA is an extension of Single Carrier modulation with Frequency Domain Equalization (SC-FDE) to accommodate multiple-user access [5]. The Peak-to-Average-Power Ratio (PAPR) in SC-FDMA, whose high value is a typical problem in multiple access techniques, has a lower value than in OFDMA [10].

In Fig. 3 is presented the architecture of a SC-FDMA transceiver.

The input of the transmitter and the output of the receiver are complex modulation symbols. Practical systems dynamically adapt the modulation technique to the channel quality, using QPSK in weak quality channels and up to 64-level QAM in good quality channels. The data block consists of M complex modulation symbols. The M-points Discrete Fourier transform (DFT) produces M frequency domain symbols that modulate M out of N orthogonal subcarriers which are distributed over a bandwidth. Then, the SC-FDMA system can handle up to Q (N/M) source signals (transmitted by different users) with each source occupying a different set of M orthogonal subcarriers. Hence, each source signal is transmitted using a set of M orthogonal subcarriers.

The subcarriers mapping in SC-FDMA can be performed by two methods: Localized subcarrier mapping (LFDMA) and Distributed subcarrier mapping (DFDMA). In the LFDMA mode, DFT outputs data are allocated over consecutive subcarriers, whereas in DFDMA, the DFT outputs are spread over the entire bandwidth, the unused subcarriers being met to zero. In both modes, the IDFT in the transmitter assign zero amplitude to the N-M unoccupied subcarriers. The case of $N= Q\times M$ is referred to as Interleaved FDMA (IFDMA) [6], [7] for the distributed mode with equidistance between occupied subcarriers.

IFDMA is a special case of subcarriers mapping in SC-FDMA and it is very efficient in that the transmitter can modulate the signal strictly in the time domain without the use of DFT and IDFT. Fig. 4 shows three examples of SC-FDMA transmit symbols in the frequency domain for M=4 symbols per block, N=12 subcarriers, and Q= N/M=3 terminals.

Table 2: Parameters for UL SC-FDMA transmission scheme in 3GPP LTE [4]

Band-width (MHz)	Sub-frame Duration (ms)	LB size (μ/# of occupied subcarrier s/FFT size)	SB size (μ/# of occupied subcarrier s/FFT size)	CP duration (μ/# of subcarriers)
20	0.5	66.67/1200/2048	33.33/600/1024	(4,13/127) or (4.39/135)
15	0.5	66.67/900/1536	33.33/450/768	(4.12/95) or (4.47/103)
10	0.5	66.67/600	33.33/300	(4.1/63) or (4.62/71)
5	0.5	66.67/300	33.33/150	(4.04/31) or (5.08/39)
2.5	0.5	66.67/150	33.33/75	(3.91/15) or (5.99/23)
1.25	0.5	66.67/128	33.33/38	(3.65/7) or (7.81/15)

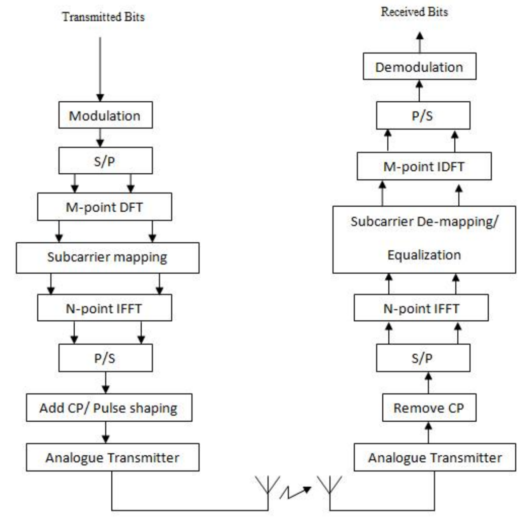

Fig 3. SC-FDMA transceiver structure [4].

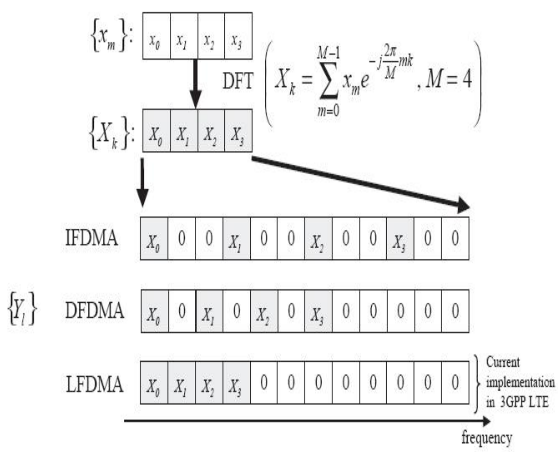

Fig 4. An example of different subcarrier mapping schemes for M = 4, Q = 3 and N = 12[5].

In the uplink, the data are mapped onto signal constellations as QPSK, 16QAM, or 64QAM. Turbo code based on 3GPP UTRA Release 6 is used for Forward Error Correcting (FEC). The transmission is organized as a sequence of frames.

The sub-frame has duration of 0.5 ms and consists of six blocks (LB) and two short blocks (SB). CP is added in front of each block. Long blocks are used for control and/or data transmission and short blocks are used for reference (pilot) signals for coherent demodulation and/or control/data transmission. Both localized and distributed subcarrier mapping methods use the same sub-frame structure. Table 2 shows the UL parameters for SC-FDMA transmission scheme in 3GPP LTE.

III. BLIND ESTIMATION SYSTEM

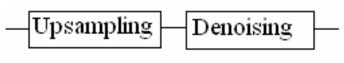

Fig 5. The architecture of the proposed blind estimation system.

Let us suppose that the signal $x[k]$ is additively perturbed by the white Gaussian noise $n_i[k]$. This is the well known scenario of the AWGN channel. The received signal has the expression:

$$y[k] = x[k] + n_i[k] . \quad (2)$$

To estimate the signal $x[k]$, Donoho, [2], proposed the following three steps method:

1) Computation of the Discrete Wavelet Transform (DWT) of the signal $y[k]$ obtaining the wavelet coefficients sequence:

$$y_i[k] = x[k] + n_y[k] \ . \quad (3)$$

where the noise $n_y[k]$ is white and Gaussian noise (WGN) [3]. The approximation y_{ia} and details y_{id} sequences are separated.

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

$$y_{0d}[k] = \begin{cases} \operatorname{sgn}\{y_{id}[k]\}\left(|y_{id}[k]| - t\right), & |y_{id}[k]| > t \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where t is a threshold.

3) The approximation coefficients sequence y_{ia} is concatenated with the new detail coefficients sequence y_{0d} obtaining the new sequence of wavelet coefficients y_0 and is computed its inverse DWT (IDWT). The estimation of the signal $x[k]$, denoted by $x[k]$ is obtained.

The non linear filter applied at the second step is named soft-thresholding. The success of the Donoho's estimation procedure is assured by an appropriate choice of the threshold's value t. If $t=3\sigma_n$, where σ_n represents the standard deviation of the noise n_{yd}, then the probability that y_{0d} to be affected by noise is of 0.2% (rule of three sigma). The standard deviation σ_n can be estimated using the same DWT:

$$\sigma_n = \frac{median\{|y_{id}[k]|\}}{0.6745} \quad (5)$$

where y_{id1} represents the sequence of details from the first decomposition level. In [8] is proposed a blind threshold selection method which maximizes the output signal to noise ratio, SNR_0. Starting from a small value of t, in [8] is proved that SNR_0 increases with the increasing of t till an optimal value t_{opt}. Depending on the value of the input signal to noise ratio SNR_i, the value of t_{opt} could become superior to the maximum value of the useful component of the sequence y_{id}. In this case the soft thresholding filter removes all the detail wavelet coefficients. So, in the case of low SNRi 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. We will show in the following that the case of fading channels corresponds to very low SNR*i*.

We have find only two references dealing with applications of the Donoho's denoising method in communications [8] and [9]. The channel estimation is realized in mobile wireless communications with the aid of pilot subcarriers. A sample of the frequency response of the channel is measured with the aid of the harmonic method for each pilot subcarrier. Next, these samples are interpolated, to obtain an estimation of the channel's frequency response. In [8] is proposed to perform a denoising operation before the interpolation, to improve the precision of the estimation of the frequency response of the channel. In [9] is proposed a blind estimation method for the detection of images in mobile wireless networks based on the association of the interleaved convolutional coding with a denoising method.

The idea of the present paper is the inclusion o a denoising system in the chain of wireless receiver based on OFDMA and SC-FDMA, to improve their Bit Error Rate (BER).

The architecture of the proposed blind estimator is presented in Fig 5. The blind estimation is performed after IDFT computation in OFDMA and DFT computation in SC-FDMA at the receiver of each scheme. The proposed denoising system implements the simplified variant of the Donoho's denoising method, without filtering, which consists in meeting all the DWT detail coefficients to zero.

The Blind estimator is implemented with the aid of an interpolator (Upsampling system) with an interpolation factor of 8. So, our blind estimation system is composed by the interpolator, followed by the denoising system and by down sampling system having the down sampling factor of 8. This last system selects each of the fourth samples from a group of 8 consecutive samples of its input signal.

IV. SIMULATION RESULTS

To simplify our simulations, we have considered the case when one user equipment with single transmitter and single receiver antenna. We simulated the OFDMA and SC-FDMA transmission chain already described including the blind Estimation (BE) and without BE, we used QPSK modulation and Rayleigh channel was considered. For subcarrier mapping in Sc-FDMA, we simulated the IFDMA scheme. The denoising was performed using DWT and especially the Haar mother wavelets for six iterations. We have selected Haar mother wavelets because it has the best time localization which is more important than the frequency localization.

We performed the simulations in Matlab, in order to evaluate the performance of the proposed blind estimation technique.

Fig. 6 shows a comparison of BER performance of an OFDMA system with and without the proposed blind estimation. At SNR= 20dB, the BER decreases below 0.01 when the blind estimation is implemented. At this value of BER, the gain of OFDMA with the proposed technique and the conventional OFDMA is about 5.2 dB. This value is high enough to recommend the used of the proposed blind estimation technique. Such BER gains can be attained normally only with the aid of powerful channel coding techniques as for example the Turbo-codes.

Fig. 7 shows a comparison of BER performance in, SC-FDMA when IFDMA subcarrier mapping is used with and without blind estimation technique. At SNR=3, the BER is approximately 0.0002 when the blind estimation technique is used and about 0.005 without the proposed technique. At BER equal to 0.0001 the gain of SC-FDMA with the blind estimation based on denoising is about 6 dB. These results prove also the good performance of the proposed technique.

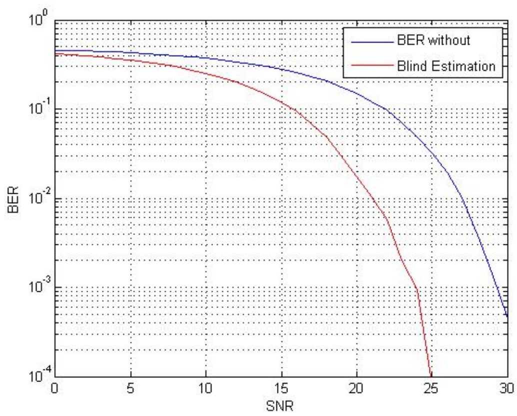

Fig 6. A comparison of the performance BER (SNR) obtained with and without blind estimation in OFDMA system.

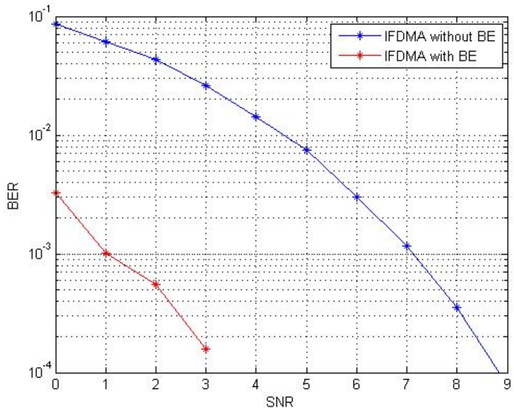

Fig 7. A comparison of the performance BER (SNR) obtained with and without blind estimation in SC-FDMA (IFDMA) system.

V. CONCLUSIONS

Comparing the experimental results, it can be observed that the blind estimation improves substantially the performance of both types of communication systems, so the contribution of this technique is very important. 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 as well for both OFDMA and SC-FDMA which are used in LTE technology. 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 simulation results presented highlight the very good quality of the proposed estimation method outperforming the results obtained using other equalization methods as for example the 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 [1]),
- the analysis of the effects of interferences on the proposed blind estimation method,
- the integration of the proposed estimation methods in our WiMAX simulator [7] 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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