FPGA Implementation of Channel Estimation Technique in MIMO-OFDM System

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***Abstract*—Supporting high mobility will be an important character of the future wireless communication systems. It challenges the channel estimaton technique a lot and there are two tough problems in front of us, they are multipath fading channel and bandwidth efficiency. Orthogonal Frequency Division Multiplexing (OFDM) technique changed the frequency selective multipath fading channels into flat fading channel in frequency domain, which effectively mitigates the effects of multipath propogation and, hence, increases data rate. We summarize and analyse the exciting channel estimation methods in mimoofdm system. In this paper, we propose a new hardware implementation of channel estimation for MIMO-OFDM. Our target is to minimize hardware resource utilization. At first, proper algorithm is chosen in consideration of hardware feature as well as communication theory for fast proto typing. Based on the algorithm, our architecture performs channel estimation by simple calculation logic without redundancy. Theoretical analysis and numerical results show that the new channel estimation scheme can offer a good performance and a high ability to track the time varying channel.**

***Index Terms*—FPGA,OFDM , mimo-ofdm, channel estimation**

I .INRODUCTION

Multiple-input multiple- output (MIMO) and orthogonal frequency division multiplexing (OFDM) are two key techniques for broadband wireless mobile communications.
Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) technology is an attractive transmission technique for wireless communication systems with multiple antennas at transmitter and receiver. The core of this technology is that it divides one data stream to many. Hence, data rate, reliability and diversity can be increased along with the stability for multi-path signals.

Future wireless communication system have to be designed to integrate features such as high data rates, high quality of service and multimedia in the existing communication framework. Increased demand in wireless communication system has led to demand for higher network capacity and performance. Higher bandwidth, optimized modulation offer practically limited potential to increase the spectral efficiency. Hence MIMO systems utilizes space multiplex by using array of antenna's for enhancing the efficiency at particular utilized bandwidth. MIMO use multiple inputs multiple outputs from single channel. These systems defined by spectral diversity and spatial multiplexing. The aim of this paper is to design and implement of channel estimation method and modulation technique for MIMO system. The design specifications are obtained using MATLAB. The RTL coding is carried for the design to be implemented on Xilinx FPGA.

Next generation broadband wireless communications systems will be based on multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) [1] in order to deliver constantly increasing multimedia contents. MIMO-OFDM is a promising technique due to its different modulation schemes, implementation flexibility and robustness against channel frequency selectivity. In order to achieve a preset quality of service in MIMO-OFDM
systems, channel estimation and detection techniquesare mandatory. In the literature, depending on the type of MIMO-OFDM system, several channel estimation and detection techniques have been proposed [2][3]. Bit error rate (BER) and implementation complexity are the main performance aspects when comparing their performances. In [2], reduced complexity single-input single-output OFDM (SISO-OFDM) channel estimation techniques have been proposed minimum mean square error (MMSE). The same procedure has been applied also to least squares (LS) type leading to an improvement in performance with a little increase in complexity. In this paper, an extension of these algorithms has been applied to MIMO-OFDM systems. Moreover, a rapid prototyping of these channel estimation techniques is proposed in order to compare hardware resources needed in case of FPGA implementations of these algorithms. The rest of the paper is organized as follows: in section 2, the SISO-OFDM and MIMO-OFDM systems are

introduced. Channel estimation techniques are presented in section 3. In section 4, simulation results is presented . Finally, the conclusion is given in section 5.

II.OFDM SYSTEM

A.SISO-OFDM Structure

In conventional SISO-OFDM, shown in Figure 1, a blockof N data symbols is fed into an inverse fast Fourier transform(IFFT) before cyclic prefix (CP) insertion in order to form anOFDM symbol. The CP, named also a guard interval, isinserted to mitigate the effects of intersymbol interference (ISI)caused by channel delay spread. The OFDM symbol isconverted from parallel to serial (P/S) in order to betransmitted. The impulse response of the multipath channel canbe represented by (1)

g(t) $= \sum_m \alpha_m \delta\,(t - \tau_m T_s)$.......................................(1)

where$\alpha_m$are complex valued multipath coefficients, τ_m theircorresponding delays, $0 \leq \tau_m T_s \leq T_G$,$T_s$the sampling periodand $T_G$the maximum channel delay.The received signal, obtained by channel convolution andwhite noise addition, is converted
from serial to parallel (S/P).Then, an FFT is applied to the received signal after CPremoval. The output of FFT block can be modeled by:

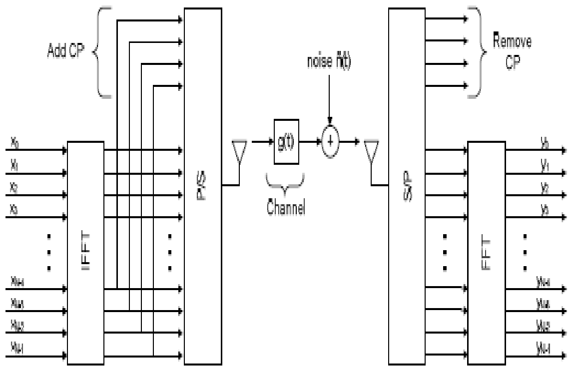

Fig1:*SISO-OFDM* System

$y = FFT_N\left(IFFT_N(x)\ \#\ \frac{g}{\sqrt{N}} + \tilde{n}\right)$..........(2)

Fig 3. Where # represents the cyclic convolution ,$x = [x_0 x_1\ \dots\dots\dots . x_{N-1}]^T$, $y = [y_0 y_1\ \dots\dots\dots . y_{N-1}]^T$,

$\tilde{n} = [\tilde{n}_0 \tilde{n}_1 \dots\dots\dots \tilde{n}_{N-1}]^T$white Gaussian noise and $g = [g_0 g_1\ \dots\dots\dots . g_{N-1}]^T$. From [1]

$$g_k = \frac{1}{\sqrt{N}} \sum_m \left(\alpha_m e^{-j\frac{\pi}{N}(k+(N-1)\tau_m)} \frac{\sin(\pi\tau_m)}{\sin(\frac{\pi}{N}(\tau_m - k))} \right)$$

A SISO-OFDM system can be described as an N independent parallel channels :

$$y_k = h_k x_k + n_k, k = 0 \dots\dots\dots N-1$$

Where h_k is the complex-valued channel fading coefficients given by $h = [h_0 h_1\ \dots\dots\dots . h_{N-1}]^T = FFT_N(g)$and $n = [n_1 n_2\ \dots\dots\dots . n_{N-1}]^T = FFT_N(\tilde{n})$.
Or in a more compact form :$y = XF_g + n$
Where X is a diagonal matrix with diagonal elements being x_k and FFT matrix:

$$F = \begin{bmatrix} W_N^{00} & \dots & W_N^{0(N-1)} \\ \dots & \dots & \dots \\ W_N^{(N-1)0} & \dots & W_N^{(N-1)(N-1)} \end{bmatrix}, W_N^{nk} = \frac{1}{\sqrt{N}} e^{-j2\pi\frac{nk}{N}}$$

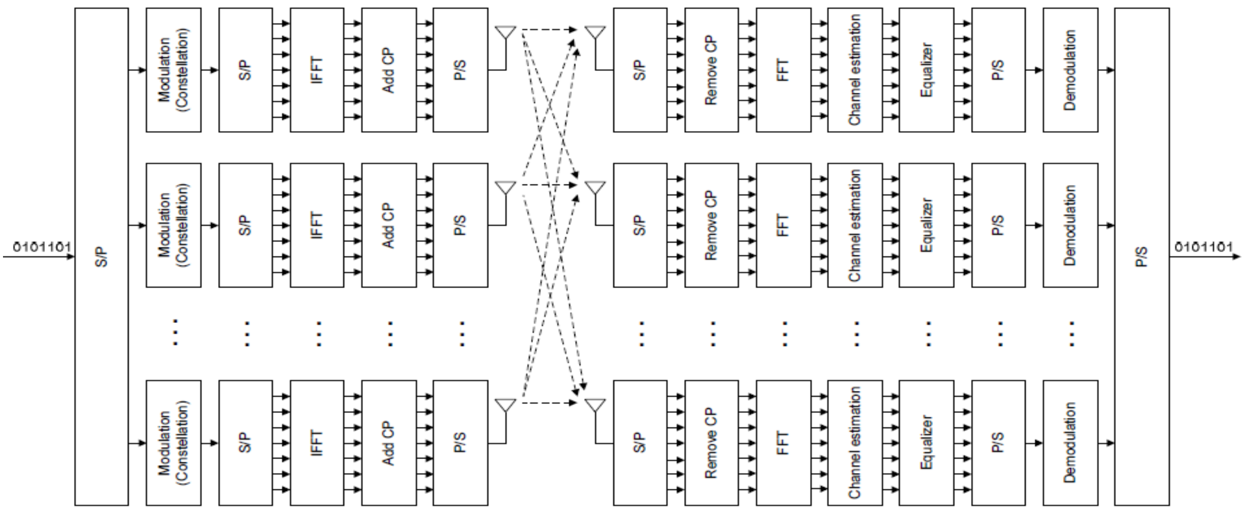

Fig 2 :MIMO-OFDM Model

B. MIMO-OFDM Structure

Recent research in information theory has shown that Multiple-Input Multiple-Output (MIMO) wireless communication systems can achieve high gains in capacity, reliability and data speed transmissions in future wireless communications [4]. This is achievable by exploiting the spatial diversity made possible by multiple antennas at the transmitter and the receiver; especially when the channel and array structures are such that the transfer functions between different transmit and receive antenna pairs are sufficiently uncorrelated [5]. A simple MIMO-OFDM scheme is shown inFigure 2. It represents a simple extension of the SISO-OFDM system. In all OFDM systems with frequency selective channels, an equalizer is mandatory. In this paper, a simple zero-forcing equalizer is considered [3]. In order to apply such equalizer, a channel estimation technique is necessary. Channel estimation techniques considered in this study are presented in the next section.

III. CHANNEL ESTIMATION

When the channel is not available at the receiver, it can be estimated through the transmission of an N × 1 training sequence x_{train}. We recall that an OFDM transmission involves multiple time-serial OFDM sequence transmissions, where the training data corresponds to a predetermined number of known OFDM sequences at the beginning of each transmission. In such a case the OFDM receiver incorporates the training sequence and the transmitter HPA transfer function to perform ML estimation of the baseband channel as follows.

The ML estimate of the channel vector c takes the form$\widehat{c_{ML}} = \operatorname{argmax}_{\hat{c}}\ f_{y|c=\hat{c}}\ (\bar{y})$

Where $\bar{y}$ denotes the corresponding observation data vector.Since **n**is considered AWGN, the maximization in (19) becomes

$$\begin{aligned} \hat{c}^{ML} &= \arg\min_{\hat{c}} \|\bar{y} - \hat{c} \otimes t^{g}\|^2 \\ &= \operatorname{argmin}_{\hat{c}} \left\|\bar{y} - W^{H}\, diag\left(W\widehat{c_{zp}}\right) W t^{g}\right\|^2 \\ &= \operatorname{argmin}_{\hat{c}} \left\|\bar{y} - W^{H}\, diag(\,W t^{g})\, W\widehat{c_{zp}}\right\|^2 \\ &= \operatorname{argmin}_{\hat{c}} \left\|\bar{y} - W^{H}\, diag(\,W t^{g}) W_{1:N,1:L}\hat{c}\right\|^2 \end{aligned}$$

Where $\hat{c} \in C^{L}$, $t^{g} = g(W^{H} x_{train})$ is the nonlinearly amplified inverse DFT of the training sequence,diag(v) denotes the diagonal matrix whose diagonal is the vector v,and $\widehat{c_{zp}}$ is the zero padded channel impulse response.The above problem results in

$$\hat{c}^{ML} = (A^{H}A)^{-1}A^{H}y$$

Observe that the ML estimate takes into account the PA nonlinear characteristics.

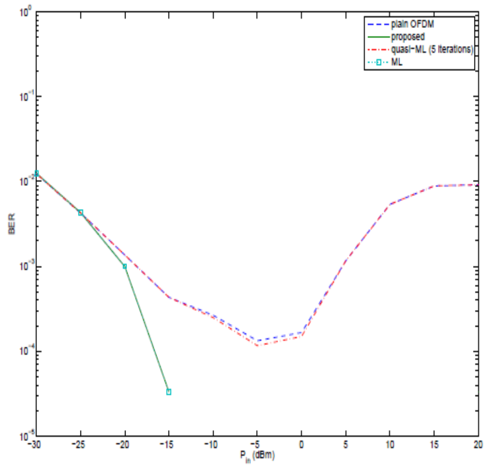

Fig3 :BER versus Pin for plain OFDM, ML & Quasi-ML

	# of subcarriers
N	64
CP	16
Payload data	48
Non used at OFDM symbol edges	10
Non used around 0 frequency	2
Pilot synchronization	4
Spacing between pilot synchronization	16

Fig4 : Main OFDM Simulation Plateform Characteristics

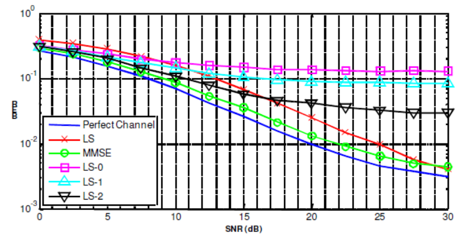

Fig5 :BER performance of ML Channel Estimation Technique for MIMO-OFDM system with 2 transmit and 2 receive antennas

IV. SIMULATION RESULTS

To analyze the impact of reducing the complexity on channel estimation techniques in a MIMO-OFDM system, we have realized a Matlab simulation platform based on [6]. The main OFDM characteristics are summarized in table 1. To reduce the implementation complexity, several modified versions have been simulated in order to quantify the performance loss while reducing the complexity. Performance of channel estimation techniques cannot be solely compared in basis of their BER but also in their hardware implementation. In this study, FPGA platform is thetarget and the algorithms are compared in terms of space required within an FPGA. AccelDSPallows us to rapidly synthesis a part of Matlab code of interest.

V.CONCLUSION

Channel estimation techniques for MIMO-OFDM havebeen compared in terms of their BER performance and implementation complexity using rapid prototyping. This will allow us toincorporate different equalizers and analyze the impact in performance and complexity.

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VI . ACKNOWLEDGEMENT

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