Estimation and Compensation of IQ Imbalance for Both Transmitter and Receiver in WiMAX Systems

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Abstract:- WiMAX systems are very popular in wireless communication now-a-days. The main reason behind its popularity is high data rates possible in WiMAX systems. But due to in-phase quadrature imbalance (i.e. IQ imbalance) at the transmitter (Tx) and receiver (Rx), the system performance may be degraded in WiMAX systems. Therefore, it is necessary to compensate for the in-phase quadrature imbalance. In this paper, we have studied estimation and compensation of IQ imbalance in transmitter as well as receiver. We have formulated an efficient least square technique for estimating IQ imbalance parameters for WiMAX system. We have analyzed the BER performance of the WiMAX system using different methods of constellation modulation for e.g. QPSK and 16QAM using proposed method of estimation. Results clearly showed that the proposed least square technique for IQ imbalance have better performance.

Keywords—In-phase quadrature imbalance (IQI), Worldwide Interoperability for Microwave access (WiMAX), Least square estimation (LSE), Bit error rate (BER), signal to noise ratio (SNR).

I. INTRODUCTION

In present scenario, there is enormous demand of information networks which requires communication networks with very high data rates. There is lot of advancement in telecommunication industry, wide range of services like video conferencing, video calling, application with multimedia contents etc. need high data rates. WiMAX stands for “worldwide interoperability for microwave access” is basically a Broadband Wireless Access Metropolitan Area Network (BWA-MAN). WiMAX is based upon IEEE 208.16 standard [1]. This is developed by working group number 16 of IEEE 802. This group has specialization in Broadband Wireless Access. In 2004, IEEE 802.16d standard [2] for fixed wireless access (FWA) application was published by IEEE 802.16 standard for wireless metropolitan area network. In 2005, IEEE 802.16 standard publish IEEE 802.16e standard [3] for mobile wireless access (MWA) applications. This standard is now very popular in industry now-a-days.

WiMAX systems have lot of applications in wireless communication as it offers very high data rates. The physical layer of WiMAX is based on Orthogonal Frequency Division Multiplexing (OFDM). Direct conversion receivers, is also known as zero intermediate frequency (IF) receivers in which there is no intermediate-frequency (IF) stage, therefore no need of an image rejection filter. Due to this it is easier to integrate direct conversion receivers as it has low component count. OFDM systems mostly employed direct conversion receivers due to its low cost and low power dissipation. But direct conversion receivers suffers from one major drawback i.e. IQ imbalance [4]. The performance of WiMAX system is degraded due to IQ imbalance. Therefore it is necessary to estimate and compensate the IQ imbalance.

Due to non-perfections of analog front end oscillators (LO) in RF circuits, the amplitude in in-phase and quadrature oscillator is not equal and the phase shift is not exactly 90° [5]. This mismatch is known as IQ imbalance. The mismatches of amplitude and phase shift are called gain and phase imbalances, respectively. The WiMAX system performance is degraded due to IQ imbalance. This performance degradation is more prominent for high order modulations. Therefore it is necessity to estimate and compensate the IQ imbalance for direct conversion receivers.

With direct conversion receivers, the gain and phase imbalance results in mirror frequency image interference effect which degrade the system performance. Several techniques have been proposed to estimate and compensate IQ imbalance, for example, [6]-[10]. Weikun Hou et al. in [6] proposed an iterative joint channel and IQ imbalance parameter estimation scheme based on the ALS algorithm. Mohamed Marey et al. in [7] proposed a novel optimal EM-based algorithm for the problem of joint estimation of the channel impulse response and both transmitter and receiver IQ imbalances. Hiroyuki Miyashita et al in [8] proposed an algorithm to overcome the problem of DC offset in deterioration of IQ imbalance estimation. V.K. VarmaGottumukkal et al in [9] proposed a generalized system model that includes a multi-antenna system with frequency-selective IQ imbalances at both the transmitter and the receiver sides, in addition to the presence of CFO, and perform capacity analysis considering joint detection of the signal and its self-interference. Shashwat Jainwal et al. in [10] proposed a novel tracking method based on the minimum mean square error (MMSE) to update the effective channel matrix in the rest of the OFDM frame. In previous researches, high computational complexity required to estimate and compensate the algorithms for the IQ imbalance.

We proposed a new algorithm for least square estimation technique to overcome the disadvantages in previous subsection. In this work, the efficient estimation and compensation of IQ imbalance at both transmitter and receivers is formulated. The BER performances have been evaluated for the proposed least square estimation technique with different constellation modulation techniques.

This paper is organized as follows. In section II, we introduce the proposed model for IQ imbalance. The algorithm is introduced for estimation of IQ imbalance parameters in Section III. Simulations and results are provided in Section IV. Section V concludes the paper.

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II. SYSTEM MODEL

Let us consider a cyclic prefixed WiMAX system. A cyclic prefix of length D is appended to the beginning of the signal vector ‘y’ to eliminate the ICI in multipath fading channels.

The transmitted signal vector is referred as . It is assumed that there is in-phase quadrature imbalance (IQI) at both the Tx and Rx. As the IQ imbalances firstly occurs at the Tx, the distorted signal can be modeled as [11]

\[ y' = y \cos(\theta_y) - jy \sin(\theta_y) \]

(1)

Where the variables \( \mu \) and \( \nu \) are the IQ imbalance parameters at the Tx obtained by [11]. They are modeled as

\[ \mu = \cos(\phi_\mu), \quad \nu = \sin(\phi_\nu) \]

(2)

Where \( \phi \) and \( \phi_\nu \) are the phase and amplitude imbalance in the I and the Q branch at the Tx, respectively.

WiMAX system transmits a block of data symbols over a channel with delay L. This results in a received vector having length \( D + L - 1 \). The received signal can be written by

\[ y = \begin{bmatrix} y_1 & y_2 & \cdots & y_D \end{bmatrix}^T \]

(4)

Where \( Y \) refers the linear convolution operation, Propagation path loss is referred by \( P, h = [h_0, h_1, \cdots, h_{D-1}]^T \) is the CIR vector with L-taps, \( m \in \mathbb{C}^{D-L} \) is the vector at the receiver with white Gaussian noise samples.

If guard interval is discarded and select \( D \) entries from the received vector \( s_t \) to form a new vector \( s \), then the equation (4) can be rewritten as

\[ y = \begin{bmatrix} y_1 & y_2 & \cdots & y_D \end{bmatrix}^T \]

(5)

Where \( Y \) whose entries are chosen from \( \{0,h_0,\ldots,h_{D-1}\} \) according to how \( s \) is selected.

\[ Z = \begin{bmatrix} [y_1, y_2, \ldots, y_D, 0,0,\ldots,0] & \text{if } 0 < D < M \\ [0, y_1, y_2, \ldots, y_D, 0,0,\ldots,0] & \text{if } M < D < N \end{bmatrix} \]

(6)

\[ Y = \begin{bmatrix} y_1 & y_2 & \cdots & y_D \end{bmatrix} \]

(7)

The received signal vector at the receiver is distorted by IQ imbalance as

\[ y' = y \cos(\theta_y) - jy \sin(\theta_y) \]

(8)

Where \( \theta_y \) and \( \theta_\nu \) are the IQ imbalance parameters at the receiver. These are modeled as

\[ \mu = \cos(\phi_\mu), \quad \nu = \sin(\phi_\nu) \]

(9)

here \( \mu \) and \( \nu \) are the phase and amplitude imbalance at the receiver, respectively.

By expanding (8), we can write

\[ y = R[y_1, y_2, \ldots, y_D] + w \]

(10)

Where \( w = \mu \alpha + \nu \beta \) is the matrix formed by similarly to \( H \).

It can be seen in (10) that the transmitted signal is distorted as a result of IQ imbalance. Compensation at both Tx and the Rx easily carried out if IQ imbalance parameters are estimated accurately, as [12]

\[ \theta = \frac{\mu \alpha + \nu \beta}{\mu \alpha - \nu \beta} \]

(11)

As it can be seen from (2), (3) and (9) that \( \mu \approx 1 \) because \( \nu = 0 \) and have a very small dynamic range for most practical scenarios, i.e., \( \mu < 1, \nu < 0 \). Therefore we can ignore them in (11). Thus only \( \mu \) and \( \nu \) are required for IQ imbalance compensation.

III. IQI PARAMETERS ESTIMATION

For estimation of the transmitter and receiver IQ imbalance parameters, consider equation (11) and the following received signal can be written as

\[ y = R[y_1, y_2, \ldots, y_D] + w \]

(12)

Where \( R_2 \) and \( c_2 \) are the extended signal matrix which contains pilots & the extended channel vector, respectively; \( c_1 \) and \( c_2 \) are given by

\[ c_1 = [x_1, \ldots, x_M], \quad c_2 = [x_M, \ldots, x_{D-1}] \]

(13)

The estimates of \( c_1 \) and \( c_2 \) can be observed using the least squares (LS) method as in [13] and given by

\[ \hat{c} = \arg \min ||c - \hat{c}||_F \]

(14)

Now, \( \hat{x} \) and can be estimated form \( \hat{c} \) and .

In this paper, estimation scheme based on optimization which estimates \( x = \) and \( \hat{c} \) assuming the other parameter known is proposed.

1) Estimation of \( x \): Suppose that \( \hat{x} \) and \( \hat{c} \) are known: From (13),

\[ \hat{c}_1 = \hat{c}_1, \quad \hat{c}_2 = \hat{c}_2 \]

(15)

Denote \( \hat{d} = [\hat{d}_1, \ldots, \hat{d}_N] \), \( \hat{c}_1 - \hat{c}_2 = \hat{d} \)

(16)
When \( \varphi \) and \( \varphi' \) are known, then \( x \) can be estimated according to the LS criterion as
\[
\hat{x} = \arg\min_{x} \| c_{1} - x - \Psi_{x}x \|^{2} + \| c_{2} - \Psi_{x}x \|^{2}.
\] (16)

2) Estimation of \( x \) supposing \( \varphi' \) is known: When \( \varphi' \) is known, and \( x \) can be estimated by solving the following LS optimization problem
\[
\begin{bmatrix} \hat{x} \end{bmatrix} = \arg\min_{x} \| c_{1} - x - \Psi_{x}x \|^{2} + \| c_{2} - \Psi_{x}x \|^{2}.
\] (17)
where \( \varphi' \) is the estimated IQ imbalance.

This is not a convex optimization problem in general. To find a local optimal solution of (17), we alternatively fix one parameter and calculate another until convergence. Therefore the original problem is divided into the following two sub problems in each iteration.

\[
\begin{aligned}
\hat{\varphi}' &= \arg\min_{\varphi'} \| c_{1} - x - \Psi_{x}\varphi' \|^{2} + \| c_{2} - \Psi_{x}\varphi' \|^{2}, \\
\hat{x} &= \arg\min_{x} \| c_{1} - x - \Psi_{x}\varphi' \|^{2} + \| c_{2} - \Psi_{x}\varphi' \|^{2}.
\end{aligned}
\] (18)
The optimal and of (17) satisfy and \( \varphi = \varphi' \), i.e
\[
\begin{bmatrix} \hat{x} \hat{\varphi}' \end{bmatrix} = \left[ \begin{bmatrix} 2x - c_{2} \end{bmatrix} x' \Psi_{x} + \Psi_{x}x \Psi_{x} + x'^{*} \Psi_{x}x' \Psi_{x} - x'^{*} \Psi_{x}c_{2} + x'^{*} \Psi_{x}c_{2} \right]
\] (19)

Therefore the local optimal solutions in each iteration are obtained from (19) as
\[
\begin{bmatrix} \hat{x} \hat{\varphi}' \end{bmatrix} = \frac{1}{2x' \Psi_{x}x + x'^{*} \Psi_{x}x'} \left[ \begin{bmatrix} 2x - c_{2} \end{bmatrix} x' \Psi_{x} + \Psi_{x}x \Psi_{x} + x'^{*} \Psi_{x}x' \Psi_{x} - x'^{*} \Psi_{x}c_{2} + x'^{*} \Psi_{x}c_{2} \right].
\] (20)
The initial values of \( \varphi \) and \( \varphi' \) are needed for implementation of the optimization method.

It can be observed in the expressions, \( \Psi_{x}, \Psi_{x}x, \Psi_{x}x' \Psi_{x} \) were for practical scenarios. Then, an approximation of (19) can be described as
\[
\begin{bmatrix} \hat{x} \hat{\varphi}' \end{bmatrix} = \frac{1}{2x' \Psi_{x}x + x'^{*} \Psi_{x}x'} \left[ \begin{bmatrix} 2x - c_{2} \end{bmatrix} x' \Psi_{x} + \Psi_{x}x \Psi_{x} + x'^{*} \Psi_{x}x' \Psi_{x} - x'^{*} \Psi_{x}c_{2} + x'^{*} \Psi_{x}c_{2} \right].
\] (21)
Solving the equation (21) results in
\[
\begin{bmatrix} \hat{x} \hat{\varphi}' \end{bmatrix} = \left( \begin{bmatrix} 2x - c_{2} \end{bmatrix} x' \Psi_{x} + \Psi_{x}x \Psi_{x} + x'^{*} \Psi_{x}x' \Psi_{x} - x'^{*} \Psi_{x}c_{2} + x'^{*} \Psi_{x}c_{2} \right)^{-1} \left( \begin{bmatrix} 0 \end{bmatrix} \right).
\] (22)
These results in equation (22) are to be used as the initial values for the solution of equation (18). The results in (22) can also be used as estimates of \( \varphi \) and \( \varphi' \).

IV. SIMULATION RESULTS

In this section, the bit error rate (BER) performance of the proposed algorithm for IQI parameter estimation and compensation is evaluated through simulations. The proposed estimation method is compared with existing method in [6] for IQ imbalance.

A WiMAX system with 256 subcarriers per symbol and a cyclic prefix length of 32 is considered. The 3GPP EVA channel model [14] containing 9 channel taps and a maximum delay of 25 samples was tested. The simulation results are shown in terms of bit error rate (BER) for QPSK and 16 QAM constellation modulation techniques.

![Fig. 1: BER vs. SNR for 256 subcarriers QPSK with and without proposed IQI imbalance.](image-url)

The bit error rate (BER) performance of QPSK modulation scheme (N=256) with consideration of IQ imbalance is illustrated in Fig. 1. According to (10), the IQ imbalance is compensated at transmitter and receiver. The BER performance of the proposed scheme outperforms the existing methods in [6] in case of QPSK modulation. Similarly, BER performance of 16 QAM modulation scheme is illustrated in Fig. 2 with consideration of IQ imbalance. Here, also the proposed methods have better BER performance as compared to existing method in [6]. The results demonstrate the robustness of the proposed method for different modulation techniques under the condition of severe IQ imbalances.
V CONCLUSION
In this paper, an efficient least square based algorithm is proposed for the estimation of IQ imbalance at both transmitter and receiver. We used this algorithm by using two different modulation techniques, QPSK and 16QAM. This algorithm can easily be applied to many different scenarios. In comparison with existing methods, the performance of the proposed method is much better. Simulation results have confirmed that performance of the system under high IQ imbalances is improved by using proposed method.

REFERENCES