Performance of STBC MIMO-OFDM Using Pilot-Aided Channel Estimation and Adaptive Pre-distortion


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Abstract-- In this paper, we focus on MIMO-OFDM systems that simultaneously perform channel estimation, space-time coding and adaptive pre-distortion in order to combat additive noise, multipath fading and nonlinear effect of HPA. The performance improvement is confirmed by simulations. Results show that the proposed MIMO-OFDM scheme is quite robust in simulation environments.

Key words – MIMO_OFDM, High Power Amplifier (HPA), Pre-Distorter, Pilot Embedding.

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation scheme that has gained considerable popularity over the past decade because of its ability to combat frequency-selective fading normally encountered in a multi-path wireless environment. OFDM converts the frequency selective channel into flat-fading sub-channels, thereby significantly reducing the receiver complexity by eliminating the need for using equalization at the receiver [1]. MIMO (Multiple Input Multiple Output) systems were first introduced in [2, 3]. Under certain conditions [3], the capacity of MIMO systems is shown to increase linearly with \( \min\{N_T, N_R\} \) where \( N_T \) and \( N_R \) are the number of antennas at the transmitter and the receiver, respectively.

MIMO-OFDM systems provide performance gains because they combine the diversity and multiplexing gains of MIMO with the resilience of OFDM against multi-path fading. In order to achieve these performance improvements, accurate CSI (Channel State Information) is required at the receiver which is obtained via channel estimation. A number of different pilot assisted methods have been proposed in the literature for estimating the channel, such as [4]-[6]. However, in OFDM Systems, there are two phenomena that can not be ignored: the distortion introduced by the High Power Amplifier (HPA) and the intersymbol interference (ISI) provoked by frequency selective fading channels [8-10].

This paper focuses on designing an adaptive pre-distorter to overcome the nonlinear effect of HPA and a direct inserted and extracted pilot channel estimation techniques in the MIMO-OFDM 2×2 system.

The paper is organized as follows: firstly, a brief description of the system is provided in Section II. Section III presents designing of the adaptive pre-distorter. The direct inserted and extracted pilot method is shown in section IV. Simulation results are presented in section V. Finally section VI provides a short discussion and conclusions.

II. SYSTEM DESCRIPTION

Fig. 1 shows the model of STBC MIMO-OFDM system with HPA. The input of the system is a serial of binary data, mapped onto the M-ary QAM signal constellation to give a stream of complex symbols which are assumed to be statistically independent. This complex symbol stream is come to the STBC encoder to separate into two independent signals, assume \( t_1(t) \) and \( t_2(t) \). Each \( t_i(t) \) signal is applied to OFDM modulation block. In the OFDM block, the stream is serial-to-parallel converted to produce a sequence \( c_{i,k} \) with \( i=1,2 \). \( c_{i,k} \) is transformed by a inverse fast Fourier transform (IFFT) unit. A guard interval called cyclic prefix (CP) with length \( T_g \) is added to this signal, yielding a \( T \)-spaced discrete-time representation of the transmitted signal. The \( n^{th} \) transmitted OFDM block is given by:
\[ s_{nk}(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} c_{nk} \varphi_k(t - nT) \]  

(1)

where

\[ \varphi_k(t) = \begin{cases} \exp(j \cdot 2\pi f_k t), & \forall t \in [-T_s, T_s] \\ 0 & \text{otherwise} \end{cases} \]  

(2)

where N is the number of the subcarriers, \( f_k = f_0 + \frac{k}{T_u} \) and \( f_0 = 0 \).

The non-linear distortion of a TWTA depends on the back-off. Fig. 2 shows the Saleh model (a typical HPA) written in SIMULINK and the AM/AM and AM/PM characteristics of this model are showed Fig. 3 in case of two different back-off parameters.

The Traveling Wave Tube Amplifiers (TWTA) model given in [2, 8] is used for a nonlinear HPA.

\[ z(t) = A(y_\rho) \exp[j \cdot (y_\rho + B(y_\rho))] \]  

(3)

where \( y_\rho \) and \( y_\theta \) are the amplitude and phase of the complex transmitted signal.

The functions \( A(.) \) and \( B(.) \) denote AM/AM conversion (non-linear amplitude) and AM/PM conversion (non-linear phase) respectively, and are given by:

\[ A(y_\rho) = \frac{2 \cdot y_\rho}{1 + y_\rho^2} \]  

(4)

\[ B(y_\rho) = \frac{2 \cdot y_\rho^2 \cdot \pi}{1 + y_\rho^2} \]  

(5)

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If the signal \( x(t) = A_0 \cos 2\pi f_c t \) is transmitted over a multipath fading channel, the output is given by:

\[ y(t) = A_0 \sum_{i=1}^{N} a_i \cos(2\pi f_c t + \theta_i) + d(t) \]  

(6)

where \( a_i \) and \( \theta_i \) are random variables. \( d(t) \) is complex additive white Gaussian noise with two-sided spectral density \( N_0 / 2 \).

If \( N \) is large, the received signal can be rewritten as:

\[ y(t) = A_0 R(t) \cos(2\pi f_c t + \Theta(t)) \]  

(7)

where \( R(t) \) has a Rayleigh distribution.

The amplitude distortion \( R(t) \) can severely degrade performance of wireless systems operating in a fading channel.

At the receiver, the received signal is passed through a receiver filter and then sampled. The data samples are serial to parallel converted, and applied to the remove guard + FFT processor. The guard interval is removed.
and only the data in the time interval \([0, T]\) is employed and the output signal is converted back to a serial data sequence and demodulated.

III. ADAPTIVE PREDISTORTION SCHEME

The predistorsion technique is a solution to combat the nonlinear effect of HPA [5]. It consists of inverting the HPA nonlinearity characteristic. In this paper, an adaptive PD is considered to linearize the operation of a nonlinear HPA. The principle of this technique is shown in Fig. 4.

![Baseband model of the predistortor](image)

Figure 4. Baseband model of the predistorter

If we add predistorter before the HPA, the output of the predistorter is expressed as:

\[
z_d = F(y_p(t)) \exp(j(\gamma_\theta + \psi(y_p(t))))
\]  

(8)

Ideally, the predistorter output would be:

\[
A(F(y_p(t))) = \alpha y_p(t)
\]

\[
\psi(y_p(t)) + B(F(y_p(t))) = 0
\]  

(9)

The inverse function can be approximated by a polynomial.

\[
F(y_p) = f_1y_p + f_2y_p^2 + \ldots + f_Ly_p^L = V^TR_f
\]

\[
\psi(y_p) = \psi_0 + \psi_1y_p + \psi_2y_p^2 + \ldots + \psi_My_p^M = P^TR_{\psi}
\]  

(10)

where

\[
R_f = [y_p, y_p^2, \ldots, y_p^L]^T
\]

\[
R_{\psi} = [\psi_0, \psi_1, \ldots, \psi_M]^T
\]

\[
V = [f_1, f_2, \ldots, f_L]^T
\]

\[
P = [\psi_0, \psi_1, \ldots, \psi_M]^T
\]

The optimal coefficients \(V\) and \(P\) are determined by using Least Mean Square algorithm:

\[
J_I(V) = E((\alpha y_p - A(V^TR_f))^2)
\]  

(11)

And the values of \(V\) and \(P\) are updated as following:

\[
y_{k+1} = y_k + \mu_y R_{f,k} A(V_{k}^TR_{f,k})(\alpha y_p - A(V^TR_f))
\]

\[
P_{k+1} = P_k + \mu_{\psi} R_{\psi,k} B(V_{k}^TR_{f,k}k - B(F(y_p)) - P^TR_{\psi,k})
\]  

(12)

\(A'(.)\) and \(B'(.)\) are the derivatives of \(A(.)\) and \(B(.)\) respectively.

IV. CHANNEL ESTIMATION

As mentioned in section 2, the system equation can be written as:

\[
Y(n) = H(n)X(n) + W(n)
\]  

(13)

where \(H\) is the channel matrix, \(Y(n)\) is the \(2\times2\) receive vector, \(X(n)\) is the \(2\times2\) transmit vector and, \(W(n)\) is the \(2\times2\) white Gaussian noise vector. This pilot pattern using on Pilot Adder block is on-off pilot pattern with on pilot is the high frequency data signal from OFDM modulator. Assume the pilot matrix is \(P\), we have:

\[
P = \begin{bmatrix} 0 & p_1 \\ p_2 & 0 \end{bmatrix}
\]  

(14)

where \(p_1\) is a constant.

By using the pilot and the corresponding receiver signal \(Y_p\), the channel state information (CSI) can be estimated as:

\[
P^{-1}Y_p = P^{-1}PH + P^{-1}W
\]  

(15)

With assumed that \(P^{-1}W=0\), we have obtained the CSI used in STBC encoder.

V. SIMULATION RESULTS

The BER in term of SNR, varying between 0 and 20 dB of this model is shown in Fig. 5 within 4 cases as shown in Table 1. The BER performance of the proposed system is evaluated using the Monte-Carlo method. The simulations are carried out for a OFDM system with 144 subscribers and 16-ary QAM constellation on each subcarrier. The fading channel is characterized by the maximum Doppler shift of 113 Hz, five paths with the delay vector \([0 \ 1e-9 \ 2e-9 \ 1.2e-9 \ 4e-9]\) (in seconds) and with the vector gain \([0 \ -5 \ -3 \ -2 \ -3.5]\) (in dB).
TABLE 1. FOUR SCHEMES IN THE PROPOSED OFDM SYSTEM

<table>
<thead>
<tr>
<th>Scheme No.</th>
<th>Impairments</th>
<th>Compensation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HPA &amp; Rayleigh + AWGN noise</td>
<td>No-PD &amp; EQ in SISO system</td>
</tr>
<tr>
<td>2</td>
<td>HPA &amp; Rayleigh + AWGN noise</td>
<td>PD &amp; EQ in SISO system</td>
</tr>
<tr>
<td>3</td>
<td>HPA &amp; Rayleigh + AWGN noise</td>
<td>PD &amp; EQ in MIMO system</td>
</tr>
<tr>
<td>4</td>
<td>HPA &amp; Rayleigh + AWGN noise</td>
<td>No-PD &amp; EQ in MIMO system</td>
</tr>
</tbody>
</table>

There are four curves in this figure that correspond to four scenarios. Comparing the results of the 3rd scenario versus the 4th, the serious influence of the HPA is evidenced. By using the adaptive PD, the proposed scheme (3) had over 3 dB higher SNR gain at the BER of $10^{-5}$ than the existing schemes (4).

Comparing the results between the SISO and MIMO systems, it is evidenced that MIMO-OFDM systems can significantly improve the BER performance in both cases: with PD or without PD.

![Figure 5. The plot of BER vs SNR for: SISO without PD (1), SISO with PD (2), MIMO-OFDM 2×2 with PD (3), and MIMO-OFDM 2×2 without PD (4)](image)

VI. CONCLUSIONS

In this paper, two compensation methods are combined: adaptive predistorter to combat HPA and pilots to estimate CSI over multipath fading channel. Results show that this simple technique tremendously enhances the performance of the compensated system. Due to large envelope variations, the distortion introduced by a nonlinear HPA is more obvious in MIMO-OFDM systems. The PD can reduce most of the out-band noise caused by HPA, while the use of pilots is the simplest method to estimate channels in MIMO STBC system.

The combined scheme proposed in this paper is shown to enjoy these two positive effects.

REFERENCES