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Abstract
In this paper, we propose a new approach to compensate the residual frequency offset (RFO) in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel working in the burst mode. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then a new decision aided approach is employed to achieve the RFO compensation on the nonlinearity-free symbols. The effectiveness of the proposed approach has been verified by computer simulations.

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DECISION AIDED COMPENSATION OF RESIDUAL FREQUENCY OFFSET FOR MIMO-OFDM SYSTEMS WITH NONLINEAR CHANNEL

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ABSTRACT

In this paper, we propose a new approach to compensate the residual frequency offset (RFO) in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel working in the burst mode. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then a new decision aided approach is employed to achieve the RFO compensation on the nonlinearity-free symbols. The effectiveness of the proposed approach has been verified by computer simulations.

1. INTRODUCTION

Multi-input multi-output orthogonal frequency division multiplexing is a promising technology to increase the capacity of wireless communications over frequency selective fading channels. By using space-time coding, MIMO-OFDM can achieve transmit diversity and power gain over spatially un-coded systems without sacrificing the bandwidth [1]. However, when the MIMO-OFDM is operated in the burst mode, even very small residual frequency offset (RFO) with the estimation of carrier frequency offset (CFO) would cause significant degradation of the bit error rate (BER) performance, especially at the latter part of data symbols in a burst frame. Some compensation techniques have been proposed to remedy the problem and a recently proposed one is the so called decision-directed compensation algorithm which uses the decision (output) of the MIMO-OFDM system to estimate and compensate the RFO [2]. It is shown that the approach works well for the cases when the transmitter has a linear characteristic. However, in practice nonlinearity exists due to the use of the high power transmit amplifier (HPA), and in this case the RFO compensation in [2] will not be effective when the HPA working in the strongly nonlinear region [3].

In this paper we propose a new scheme to achieve nonlinear elimination and RFO compensation. With the scheme, a decision aided algorithm is firstly employed to cancel the nonlinearity in the received symbols and then a decision-based RFO compensation is applied to the nonlinear-free output of the first stage. The rest of the paper is organized as follows. Section 2 gives a brief description of the problem and the approach proposed in [2]. Then Section 3 presents the new method for both nonlinear elimination and RFO compensation. Numerical results are presented in Section 4. Finally, Section 5 concludes the paper.

2. PROBLEM STATEMENT

Figure 1 shows the block diagram of MIMO-OFDM transmitter with HPA. Let us assume that an M-ary modulation scheme is used. The Alamouti space-time block coding STBC encoder takes a block of two modulated symbols $x_1$ and $x_2$ in each encoding operation according to a code matrix given by

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$

(1)

where $x_t = \begin{bmatrix} x_{t,1} & x_{t,2} & \cdots & x_{t,N} \end{bmatrix}^T$, $t=1,2$ is the data symbol ($N$ sub-carriers) at time $t$. The symbols are transformed to time domain by IFFT and amplified by the HPA and then transmitted by antennas.

![Transmit Block Diagram of STBC-OFDM](image)

The receiver with RFO compensation is shown in Figure 2. Signals from antennas firstly pass matching filters, and then are sampled and the cyclic prefix is removed from each frame. Then FFT is applied followed by STBC decoder.
In burst mode MIMO-OFDM system, even very small RFO will cause significant degradation of the BER performance especially at the latter part of data symbols in the burst frame [4]. A decision-directed technique for compensation of phase noise and RFO is proposed in [2] which models the system by

\[ Y_{m,k}^i = U_{m,0} \sum_i X_{m,k}^i H_{m,k}^{i,j} + n_{ICL,k}^i + w_k^i \]  

(2)

where \( Y_{m,k}^i \) is the \( k \)-th sub-carrier received signal of symbol \( m \) at antenna \( i \), \( H_{m,k}^{i,j} \) is the \( k \)-th tap of the DFT of the corresponding CIR from Tx antenna \( i \) to Rx antenna \( i \), \( X_{m,k}^i \) denotes the corresponding transmitted symbols by antenna \( i \), \( n_{ICL,k}^i \) is the inter-carrier-interference (ICI), and \( U_{m,0} \) term is resulted from the RFO. The \( U_{m,0} \) term can be evaluated by

\[ U_{m,0} = \frac{1}{N} \sum_{k} \sum_{i} \left( Y_{m,k}^i - \sum_{j} (H_{m,k}^{i,j}) \hat{X}_{m,k}^i \right) \nonumber \]

\[ \sum_{i} \sum_{k} \left| \sum_{j} \hat{X}_{m,k}^i H_{m,k}^{i,j} \right|^2 \]  

(3)

where \( \hat{X}_{m,k}^i \) is the decision observation, \( \Omega \) is a carrier subset. Then, the RFO is compensated by dividing \( Y_{m,k}^i \) by \( U_{m,0} \).

However, this scheme does not consider the nonlinearity introduced by HPA, which can be significant if the HPA works in the strong nonlinear region due to the high peak to average power ratio (PAPR). As can be seen by the numerical computation in Section 4, the performance of the RFO compensation technique proposed in [2] will degrade a lot when the nonlinearity exists.

3. THE PROPOSED APPROACH

In order to solve the problem mentioned above, we propose a scheme depicted in Figure 3.

We use decision-based algorithms for both nonlinearity elimination and RFO compensation. Assume that signal at the output of transmitter HPA are:

\[ \psi_B^i = \frac{1}{N} \sum_{n=0}^{N-1} \left\{ Arg \left[ \hat{y}_{rec,m,n}^i \right] \right\} \]  

(8)

where \( \hat{y}_{rec,m,n}^i \) are the two previous symbol observations after and before RFO compensation respectively, and \( Arg \left[ x \right] \) is the argument of \( x \). Using (8), the phase rotation of symbol \( m \) due to the RFO can be compensated by [4]

\[ \hat{y}_{rec,m}^i = y_{rec,m}^i e^{-j(m-\frac{3}{2})\psi_B} \]  

(9)

Then the residual one is further compensated by using the scheme proposed in [2]. Note that the nonlinearity and
RFO compensation processing can be repeated if necessary.

4. NUMERICAL RESULTS

Computer simulations are performed to test the performance of the proposed approach. The parameters used in our simulations are as follows: the system has two transmitting and receiving antennas and has 128 OFDM sub-carriers. The channels are of Rayleigh fading. The high power amplifier at the transmitter RF stage has been modeled as a non-linear circuit with the amplitude characteristic:

\[ A_{\text{out}} = \frac{A_{\text{in}}}{\left(1 + \left(\frac{A_{\text{in}}}{A_0}\right)^2 p \right)^{1/2p}} \]  

(10)

where \(A_{\text{in}}\) and \(A_{\text{out}}\) are the amplitudes at the input and at the output of an amplifier, respectively, \(A_0\) is the maximum (saturation) amplitude at its output, while \(p\) is the so-called Rapp’s parameter. A good approximation of the AM/AM characteristics of existing amplifiers is obtained with the parameter \(p\) in the range of 2 to 3 [6]. For large values of \(p\) the model converges to an amplifier that is perfectly linear until it reaches its saturation level. For our simulations we have chosen \(p=2\). The saturation level is described by the \(IBO\) (Input Backoff) parameter, which is defined as:

\[ IBO = 10 \log \frac{A_0^2}{A_{\text{av}}} \]  

(11)

where \(A_{\text{av}}\) is the signal amplitude having the power equal to the average OFDM signal power.

Figure 4 BER performances versus SNR for 16QAM when IBO=2dB

Figure 5 presents the BER performances versus IBO for 16QAM when SNR=20dB. It can be observed that the IBO performance of the compensated signals can be improved about 3.5dB at BER=10^-5.

Figure 6 BER performances versus SNR for 64QAM when IBO=4dB

Figure 6 and figure 7 show the BER performance versus SNR when IBO=4dB and BER performances versus IBO

Figure 7 BER performances versus IBO for 64QAM when SNR=25dB
when SNR=25dB, respectively, for 64QAM. From these figures, we can draw almost the same conclusions with 16QAM cases.

5. CONCLUSIONS

In this paper, we propose a RFO compensation scheme in the burst mode MIMO-OFDM systems when severe nonlinearity exists in the HPAs. With the proposed technique, the nonlinearity is eliminated by a decision aided method, and then the RFO is compensated by a modified decision aided approach. It is shown that the BER performance can be significantly improved by proposed technique. One problem associated with the approach is that the nonlinearity model is assumed to be known which may not be true in practice, and deviation of the model will result in degrade of the performance. In fact more work should be done regarding the modeling of the HPA nonlinearity, which may be an issue for further research.

6. REFERENCES


