

Joint Channel and Phase Noise Estimation in MIMO-OFDM Systems

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Abstract. The combination of multiple-input multiple-output (MIMO) techniques with orthogonal frequency division multiplexing (OFDM), MIMO-OFDM, is a promising way of achieving high spectral efficiency in wireless communication systems. However, the performance of MIMO-OFDM systems is highly degraded by radio frequency (RF) impairments such as phase noise. Similar to the single-input single-output (SISO) case, phase noise in MIMO-OFDM systems results in a common phase error (CPE) and inter carrier interference (ICI). In this paper the problem of joint channel and phase noise estimation in a system with multiple transmit and receive antennas where each antenna is equipped with its own independent oscillator is tackled. The technique employed makes use of a novel placement of pilot carriers in the preamble and data portion of the MIMO-OFDM frame. Numerical results using a 16 and 64 quadrature amplitude modulation QAM schemes are provided to illustrate the effectiveness of the proposed scheme for MIMO-OFDM systems.

1. Introduction

Multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) systems are currently been deployed in the latest forth generation (4G) wireless systems. Similar to the OFDM case, phase noise in MIMO-OFDM systems leads to common phase error as well as inter-carrier interference due to loss of orthogonality among the subcarriers. CPE estimation schemes for MIMO-OFDM were derived in [1] and [2] by assuming that the channel state information (CSI) is perfectly known at the receiver and only for a case where the receiver antennas are affected by the phase noise. Together with CSI estimation the problem of phase noise estimation especially for multiple antennas is only rarely discussed [3]. To the best of the author's knowledge, no publication exists in the up to date literature about the joint channel and phase noise estimation and compensation in MIMO-OFDM systems where both the transmit and receive antennas are equipped with an independent oscillator.

2. MIMO-OFDM with Phase Noise

Fig. 1(a) and Fig. 1(b) show the block-diagrams of the MIMO-OFDM transmitter and receiver, respectively. In general, a MIMO-OFDM transceiver has N_t transmit antennas and N_r receive antennas, where each antenna is equipped with its own independent oscillator. The received



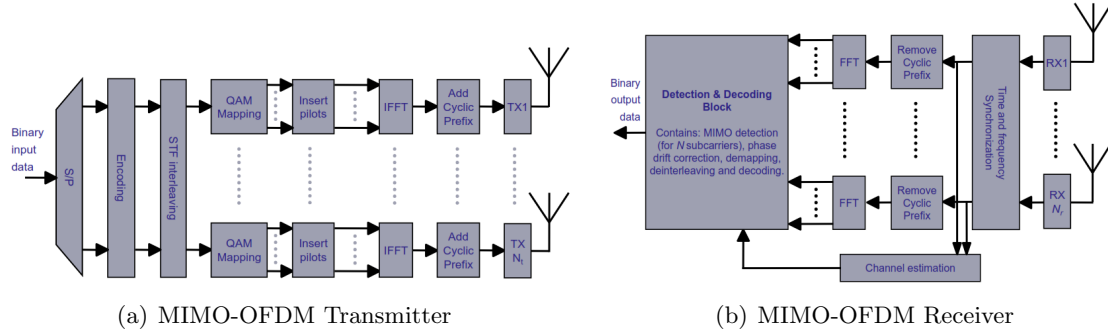


Figure 1: MIMO-OFDM Tranceiver

time domain signal at the q -th receive antenna in the presence of phase noise can be expressed as

$$y_q(n) = e^{j\theta_q^{[r]}(n)} \sum_{m=1}^{N_t} h_{q,m}(n) \star e^{j\theta_m^{[t]}(n)} x_m(n) + w_q(n) \quad (1)$$

where $x_m(n)$ is the signal transmitted by the m -th transmit antenna, $h_{q,m}$ describes the time domain channel impulse response between the m th transmit antenna and the q th receive antenna, $\theta_q^{[r]}(n)$ and $\theta_m^{[t]}(n)$ are the phase noise processes experienced at the q -th and m -th receive and transmit antennas, respectively. $w_q(n)$ is the additive white Gaussian noise and is assumed to be circularly symmetric complex Gaussian ($w_q(n) \sim \mathcal{N}(0, \sigma^2)$). The operator \star represents the convolution operation. Assuming that the cyclic prefix (CP) has been perfectly removed and after performing the discrete Fourier transform (DFT) demodulation at the receiver, the signal received at the q -th receive antenna at the k -th sub-carrier is given by

$$\begin{aligned} Y_q(k) &= \sum_{j=0}^{N_c-1} P_q^{[r]}(k-j) \sum_{m=1}^{N_t} H_{q,m}(j) \sum_{i=0}^{N_c-1} P_m^{[t]}(j-i) X_m(i) + W_q(k) \\ &= \sum_{m=1}^{N_t} H_{q,m}(k) \underbrace{P_q^{[r]}(0) P_m^{[t]}(0)}_{CPE_{q,m}} X_m(k) + \sum_{m=1}^{N_t} \underbrace{\left[\sum_{\substack{j=0 \\ j \neq k}}^{N_c-1} P_q^{[r]}(k-j) H_{q,m}(j) \sum_{\substack{i=0 \\ i \neq j}}^{N_c-1} P_m^{[t]}(j-i) X_m(i) \right]}_{ICI_{q,m}} \\ &\quad + W_q(k) \end{aligned} \quad (2)$$

In equation (2) above $P_q^{[r]}(k)$ and $P_q^{[t]}(k)$ are the receiver and transmitter phase noise Fourier coefficients given by $P_q^{[r]}(k) = \frac{1}{N_c} DFT\{e^{j\theta_q^{[r]}(n)}\}$, $P_m^{[t]}(k) = \frac{1}{N_c} DFT\{e^{j\theta_m^{[t]}(n)}\}$, respectively. $H_{q,m}$ is the frequency domain channel impulse response between the q -th receive and m -th transmit antennas.

2.1. Channel Estimation

Fig. 2 shows the arrangements of pilots and data symbols in a MIMO-OFDM frame that can be used for effective channel and phase noise estimation. In the preamble section of the MIMO-OFDM frame, a transmitter transmits known pilots in two consecutive time slots while the rest of the transmit antennas do not transmit. In the first instant, half of the sub-carriers transmit nulls and the other pilots. In the second time instant the roles of pilot and null

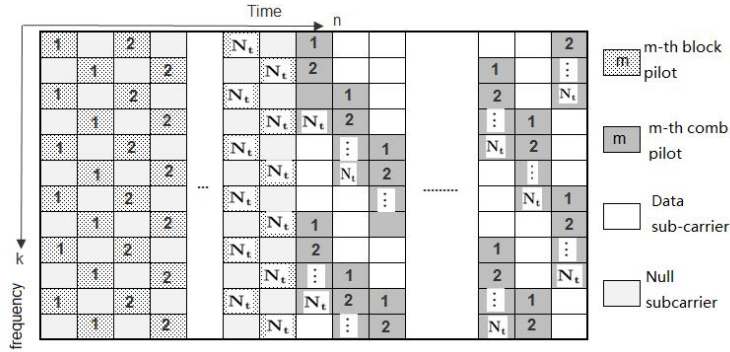


Figure 2: Pilot structure

sub-carriers are interchanged so that the channel estimates can be obtained at all sub-carriers via the use of the least squares (LS) method. The data section of the MIMO-OFDM frame employs a comb structure such that each sub-carrier carries data from a different antenna thus effectively implementing a frequency division multiplexing (FDM) scheme. To begin the initial channel estimation, let $S_{m,1}^p$ denote the set of pilot indices in transmit antenna m during the first time instant whilst $S_{m,2}^p$ denotes the set of indices during the second transmission instant. We note that $|S_{m,1}^p \cup S_{m,2}^p| = N_c$, where N_c is the number of sub-carriers. Similarly $S_{m,1}^z$ and $S_{m,2}^z$ denotes the set of null sub-carriers of the m -th transmit antenna in the first and second transmissions, respectively. Let the received signal at the q -th receive antenna when transmit antenna m transmits be given by $Y_{q,m}^b(k)$ whilst the transmitted pilot sub-carrier is given by $X_m^b(k)$. The estimated channel coefficient if we apply the LS method is then given by $\hat{H}_{q,m}^b(k) = \frac{Y_{q,m}^b(k)}{X_m^b(k)}$, $k \in S_{m,1}^p \cup S_{m,2}^p$. Since we do not know the variance of the sum of the ICI and AWGN, we assume it to be uncorrelated and Gaussian.¹ We estimate the variance by calculating the average energy of the null sub-carriers as follows $\sigma_{q,m}^2 = \frac{1}{N_z} \sum_{k \in S_{m,1}^z \cup S_{m,2}^z} |Y_{q,m}^b(k)|^2$, where N_z denotes the cardinality of the set $S_{m,1}^z \cup S_{m,2}^z$.

2.2. CPE Estimation

A relative $CPE_{q,m}$ for the data portion can be calculated from the channel estimates that would have been obtained from the preamble by applying the least squares to the comb structure of pilot arrangements in the data portion. This relative $CPE_{q,m}$ is given by

$$CPE_{q,m} = \frac{\sum_{k \in S_m^c} Y^c(k) \hat{H}_{q,m}^*(k) X_m^*(k)}{\sum_{k \in S_m^c} |\hat{H}_{q,m} X_m(k)|^2} \quad (3)$$

The channel estimate as seen by the data portion of the frame is relative to the preamble section and is given by $\hat{H}_{q,m} = \frac{\hat{H}_{q,m}}{CPE_{q,m}}$. Applying MIMO to sub-carrier index k , the signal received at all the antennas can be given by $\mathbf{Y}(k) = \hat{\mathbf{H}}(k) \mathbf{X}(k) + \mathbf{V}(k)$, where $\mathbf{Y}(k) = [Y_1(k) \ Y_2(k) \ \dots \ Y_{N_r}(k)]^T$ and $\mathbf{X}(k) = [X_1(k) \ X_2(k) \ \dots \ X_{N_t}(k)]^T$.

An estimate of the transmitted symbols $X(k)$ can be obtained by using MMSE equalization as $\hat{\mathbf{X}}(k) = \mathbf{C}^H(k) \mathbf{Y}(k)$. The MMSE equalizing matrix $\mathbf{C}(k)$ is given by

$$\mathbf{C}(k) = \left(\hat{\mathbf{H}}(k) \hat{\mathbf{H}}^H(k) + \mathbf{\Sigma}(k) \right)^{-1} \hat{\mathbf{H}}(k) \quad (4)$$

¹ In reality the ICI in MIMO-OFDM systems exhibits spatial correlation and is not Gaussian.

The matrix Σ denotes the combined AWGN and ICI noise covariance matrix.

3. Simulation Results

To evaluate the performance of our technique, it was assumed that between every transmit antenna m and every receive antenna q , there is a complex SISO channel impulse response $h_{q,m}(k)$ of length $L + 1$ where $L = 7$. That is $\mathbf{h}_{q,m} = [h_{q,m}(0), \dots, h_{q,m}(L)]^T$. All channels have the same channel order L and the channel energy is normalized so that $\sum_{k=0}^L E|h_{q,m}(k)|^2 = 1 \quad \forall q, m$. The number of subcarriers used is equal to $N = 512$, and the modulation schemes used are 16-QAM and 64-QAM. The simulation makes use of 2 transmit and 2 receive antennas. The number of pilot tones per transmitter is equal to 4.

3.1. Results and Discussion

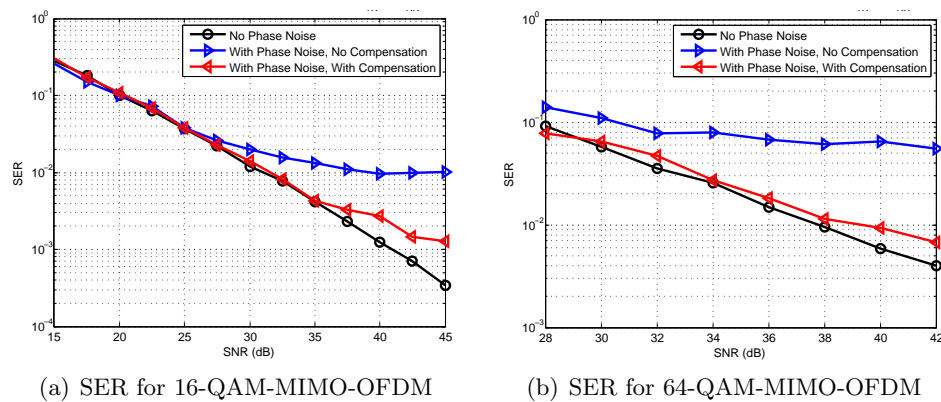


Figure 3: SER Graphs for 16-QAM and 64-QAM Modulations for transmitter and receiver phase noise standard deviations of 1°

Fig. 3(a) and 3(b) show the symbol error rate (SER) results for 16-QAM and 64-QAM modulation schemes, respectively. The results show that the proposed scheme is very effective in estimating and compensating for phase noise. Results for 64-QAM shows that the higher the modulation scheme the more sensitive it is to the phase noise impairment. However, the results show that the proposed scheme is also effective for higher modulation orders.

4. Conclusion

In this paper the problem of joint estimation of channel and phase noise in a MIMO-OFDM system where both the receive and transmit antennas are equipped with independent oscillators was tackled through the use of a novel placement of pilots and nulls in the preamble and data portions of the MIMO-OFDM frame. Simulation results show that the proposed scheme is quite effective in jointly estimating the channel and the phase noise impairment. Furthermore, the effects of phase noise become much more severe as the modulation order is increased.

5. References

- [1] T. C. W. Schenk, X.-J. Tao, P. F. M. Smulders, and E. Fledderus, "On the influence of phase noise induced ici in mimo ofdm systems," *IEEE Communications Letters*, vol. 9, no. 8, pp. 682–684, Aug 2005.
- [2] K. Nikitopoulos and A. Polydoros, "Decision-directed compensation of phase noise and residual frequency offset in a space-time ofdm receiver," *IEEE Communications Letters*, vol. 8, no. 9, pp. 573–575, Sept 2004.
- [3] H. Minn, N. Al-Dhahir, and Y. Li, "Optimal training signals for mimo ofdm channel estimation in the presence of frequency offset and phase noise," *IEEE Transactions on Communications*, vol. 54, no. 10, pp. 1754–1759, Oct 2006.