Efficient Channel Estimation of MIMO-OFDM System using Pilot Tones

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ABSTRACT: *An efficient method of channel estimation in MIMO-OFDM system is to use training symbols or pilots transmitted along with data sub-carriers. However these pilots cause inter-antenna interference when transmitted simultaneously from transmitting antennas. The use of null sub-carriers mitigates this but at the cost of spectral efficiency. This paper proposes an efficiency enhancing method in which the estimation of the channel at the receiver is done by adding the signals coming from different transmitters. The performance of the proposed method is evaluated using MATLAB.*

Keywords: Channel Estimation, MIMO, Orthogonal Frequency Division Multiplexing (OFDM), Pilot tones, Spectral Efficiency, Null sub-carriers

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1. Introduction

The demand for high data rate transmission has ever been increasing in mobile communication systems. Fortunately, Orthogonal Frequency division multiplexing (OFDM) with multiple-input multiple-output (MIMO) technique addresses this need. OFDM is a technique that divides an entire channel into many narrow parallel sub-channels, so that it improves data rate and avoids inter-symbol interference (ISI) caused by multi-path propagation [1, 2]. Multi-input multi-output (MIMO) system uses multiple antennas at both sides to increase capacity of wireless channel without the need of extra bandwidth and/or transmit power [3].

Channel estimation is very important to obtain channel state information at the receiver to compensate for the effect of channel. In order to detect a signal being transmitted over a multipath fading channel, accurate channel estimation is essential [4, 5]. This can be done using Pilot-symbol Added Channel Estimation (PACE) technique [6]. In this technique known pilot symbols are periodically inserted in the data stream. Channel estimation can be done with Least-Square (LS) channel estimation. Equally spaced pilot symbols help in reconstructing the channel response by means of interpolation [7].

PACE technique in MIMO-OFDM system is not an easy task as signals from multiple transmitting antenna cause inter-antenna interference [8]. To reduce inter-antenna interference, several pilot allocation schemes proposed the use of null sub-carriers [8-11]. However, these null sub-carriers decrease the spectral efficiency of OFDM system. In this paper an efficiency enhancing channel estimation method is proposed that estimates channel state information (CSI) for the given receiving antenna. This method eliminates the need of null sub-carrier by avoiding individual channel estimation. For estimation of the channel at pilot frequencies we use comb-type based channel estimation based on LS [6].

The rest of this paper is organized as follows. Section II describes the channel estimation for MIMO-OFDM system. Section III provides the additive channel estimation method for MIMO system. In Section IV, the simulation environment and results are described. Section V concludes the paper.

2. Channel Estimation in MIMO-OFDM

In order to compensate for the adverse effect of the channel proper and accurate Channel State Information (CSI) is required at the receiver. This helps us to achieve maximum diversity gain by improving coherent detection of OFDM signals $x(n)$. To determine the signal at the receiving end namely $y(n)$ we take the sum of transmitted baseband signal convolved with channel impulse response $h(n)$ and additive noise $z(n)$, i.e,

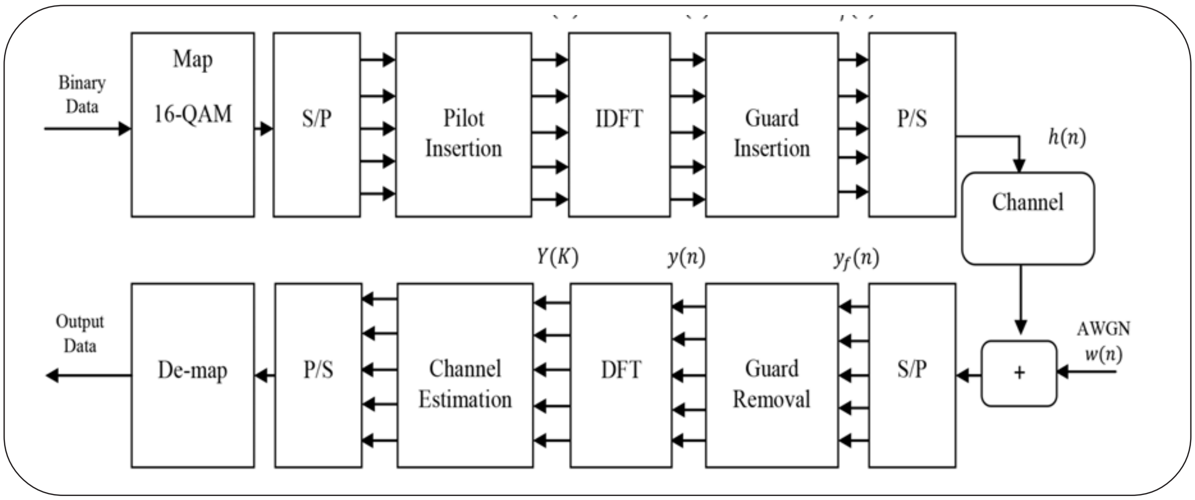

Figure 1. Baseband OFDM system [12]

$$y(n) = x(n) * h(n) + z(n) \quad (1)$$

where 'n' is the block index in time-domain. With cyclic prefix removed, $y(n)$ is sent to the FFT block to transform it into frequency domain as shown in Figure 1[2].

$$Y[k] = FFT[y(n)]$$
$$= FFT[\{x(n) * h(n)\} + z(n)] \quad (2)$$
$$So,\ Y[k] = X[k] + Z[k]$$

where $k = 1, 2, 3... N-1$ is the number of sub-carriers and $Z[k]$ is the frequency domain representation of noise in k^{th} sub-channel and $H[k]$ is the channel response of k^{th} sub-carrier. In vector domain,

$$Y = X.H + Z \quad (3)$$

where Y is the response vector, X is the input signal vector, H is the channel vector and Z is the noise vector. Let $\hat{H}$ be the estimate of channel H. The Least-square (LS) estimation finds the estimate in such a way that the cost function is minimized:

$$J(\hat{H}) = \|Y - X\hat{H}\|^2$$

Hence,

$$\hat{H} = X^{-1}Y$$

And estimate k^{th} of sub-carrier is given by

$$\hat{H}[k] = \frac{Y[k]}{X[k]} \quad (4)$$

The mean square-error (MSE) of the estimate is

$$MSE = \frac{\sigma^2_z}{\sigma^2_x}$$

Where, σ^2_z and σ^2_x are the variance of noise vector and signal vector respectively. The channel estimation method given in (4) can be achieved by Pilot Added Channel Estimation (PACE) technique. Among the various pilot structures available, comb-type pilot insertion is suitable for channel estimation [6].

In comb-type pilot insertion, the pilots are inserted in periodically spaced sub-carriers which are used for frequency domain interpolation to estimate the channel along frequency axis. Pilot insertion for a MIMO system having multiple transmitting antennas is more difficult as it leads to superposition of signals from multiple transmitting antennas causing inter-antenna interference. This interference can be reduced by the use of null sub-carriers shown in figure 2. For instance, when transmitting antenna ‘*A*’ sends a pilot signal at time *t*, then transmitting antenna ‘*B*’ has to send a null sub carrier to avoid interference. However, null subcarriers decrease the spectral efficiency of OFDM system. To mitigate this, additive CSI of the channels between multiple transmitting antennas to the receiving antenna is estimated. Due to elimination of null sub-carriers this proposed method aims at improving spectral efficiency.

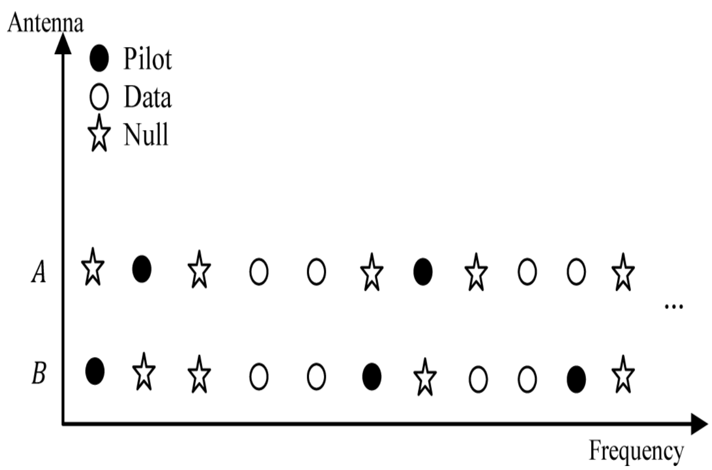

Figure 2. Pilot Allocation of null carrier 2×2-OFDM system [8]

For system with multiple transmitting antennas, this work proposes to estimate the additive response at the receiver instead of estimating each channel separately. So MISO and MIMO systems are ensured enhancement of spectral efficiency. When transmitted pilot from each transmitting antenna reaches the receiving antenna it undergoes various path gains [4]. The received signal at each receiving antenna is then combined using Equal Gain Combining (EGC). For estimation of additive CSI, the transmitted signal from i^{th} transmitting antenna $x_i(n)$ is taken as $x(n)$ for all *i*. The signal received at the receiving antenna for $(N_T X N_R)$system where N_T is the number of transmitting antennas is;

$$Y_j(n) = x(n) * \sum_{i=1}^{N_T} h_i(n) + \sum_{i=1}^{N_T} z_i(n) \quad (5)$$
$$for\ i = 1,2.....N_T$$
$$for\ j = 1,2.....N_R$$

$h_i(n)$is the impulse response of the channel from $i = 1,2.....N_T$ transmitting antennas to j^{th} receiving antenna and $Z_i(n)$ is the noise at i^{th} path with variance $\sigma_{z\,i}^{\;2}$. Assuming that the channel is Linear Time-Invariant (LTI) for one OFDM block duration, the received signal is

$$Y_j(n)=\{x(n)*h_{COMP_J}(n)\} + z_{COMP_J}(n) \quad (6)$$

$h_{COMP_J}(n)$ and $z_{COMP_J}(n)$ are the additive impulse response and the additive noise of the channels for receiving j^{th}antenna. after FFT block of receiver,

$$Y_j[k] = FFT[y(n)]$$

$$= \text{FFT}[\{x(n)*h_{COMP_J}(n)\} + z_{COMP_J}(n)]$$

$$= X[k].\, H_{COMP_J}[k] + Z_{COMP_J}[k]$$

where $H_{COMP_J}[k]$ and $Z_{COMP_J}[k]$ are the *CSI* and noise respectively of the additive channel in frequency domain. Using *LS* estimator, the CSI of additive channel at j^{th} receiving antenna is given by

$$H_{COMP_J}[k] = \frac{Y_j[k]}{X[k]}$$

where, $Y_j[k]$ is the frequency domain signal received at receiving antenna.

4. Simulation Results and Analysis

The simulation of our proposed channel estimation method is performed using Stanford University Interim SUI-1 model as channel for IEEE802.16. MIMO-OFDM system parameters used in the simulation are indicated in Table I and Table II.

Parameters	Specifications
FFT size	32
Number of Active Carriers(N)	32
Pilot Ratio	1/4
Guard Interval	4
Signal Constellation	16-QAM
Number of Frames	100
Pilot Type	Comb

Table 1. Simulation Parameters

In our simulation we use an OFDM system with 32 sub-carriers per block. A cyclic prefix guard interval of 4 i.e. 1/8th of block size is used in order to diminish the effect of multipath. We use 16-QAM modulator to modulate the base band signal. To estimate the channel along frequency axis for frequency domain interpolation we use comb type pilot insertion structure.

Parameters	Specifications
Channel Model	Rician
Path Delays	[0 0.5 1.0]
Average Path Gain	[0 -10 -20]dB
Max. Doppler Shift	0.5Hz
K-Factor on first path	4

Table 2. Channel Specifications

For channel specifications we use Rician channel model with path delays and average path gain specified in Table II. Simulations are carried out for different signal-to noise (SNR) ratios. Performance analysis of OFDM system with and without diversity at both ends using proposed method is shown. The performance of system without diversity is simulated just for comparison. TheBER performance is measured by averaging over 100 OFDM blocks. The CSI between transmitting antennas to j^{th} receiving antenna is done using (7). At the receiver the signals are equalized using CSI of respective channels and combined using equal gain combining (EGC) [13]. The following simulation results indicate the increase in performance of the system with increase in diversity.

4.1 System without Diversity and Receiver Diversity

Figure 3 shows the performance of system without diversity (SISO) and receiver diversity. This result is shown for the purpose of comparison. The BER performance for the single-input multiple-output (SIMO) increases with increase in diversity at the receiver side as shown.

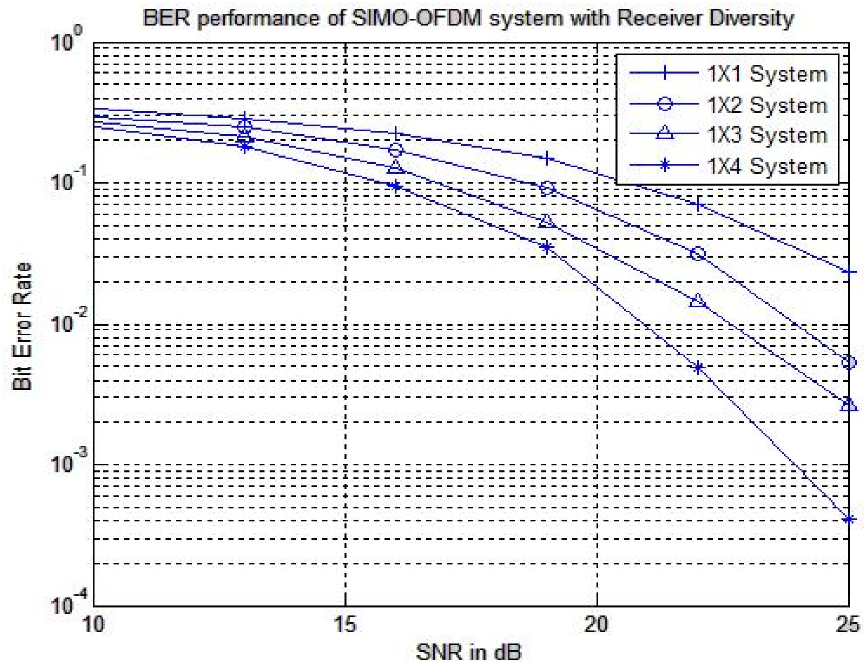

Figure 3. BER comparison for system without Diversity and Receiver Diversity

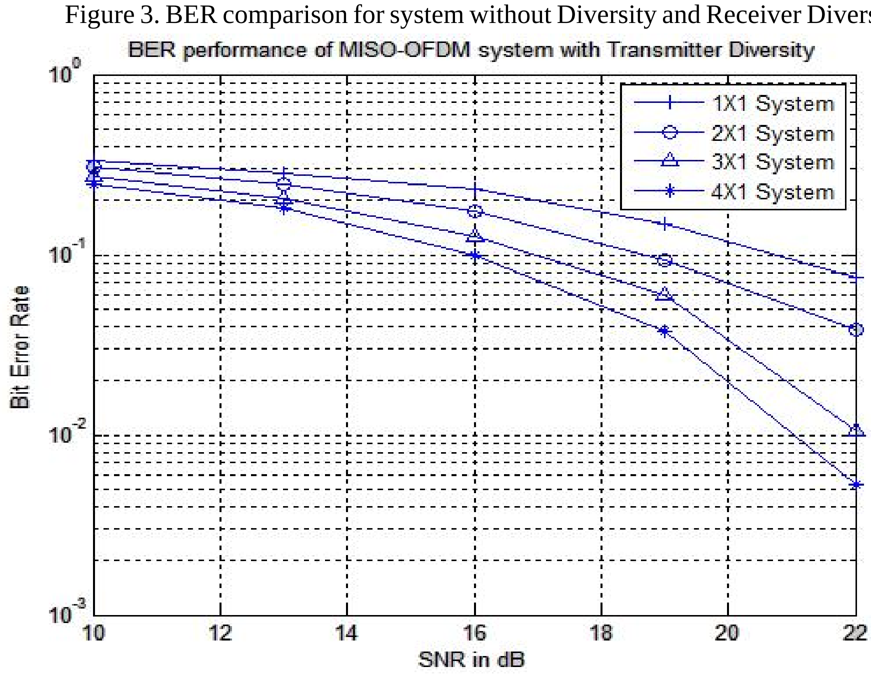

Figure 4. BER performance for system with Transmitter Diversity

4.2 Transmitter Diversity

Figure 4 shows the performance of transmitter diversity only. The signal is equalized at receiving end by estimating the additive channel effect between all transmitting antennas to receiving antenna. It is observed that the BER performance improves in high signal to noise ratio (SNR) values.

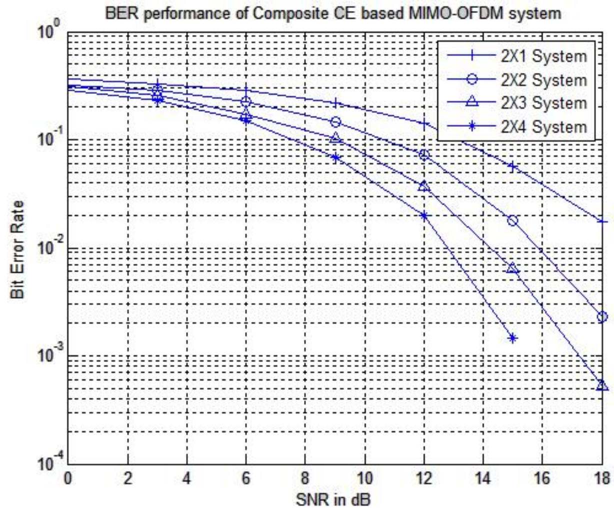

Figure 5. BER performance of MIMO system

4.3 MIMO

Figure 5 shows the performance of Multiple Input Multiple Output (MIMO) system. After estimating additive channels at each receiving antenna using (7), received signals at each receiving antenna are combined using equal gain combining (EGC). MIMO system with 2X4 shows the BER of at SNR level of 16dB which is the best in comparison to other lower diversity combinations.

5. Conclusion

In this paper we proposed an additive channel estimation method that additively combines the received signals at each receiving antenna in a MIMO-OFDM system. This method eliminates the need of null sub-carrier by avoiding individual channel estimation at the receiver. The spectral efficiency of MIMO-OFDM system is enhanced. Performance of OFDM system with varying diversity at both transmitting and receiving end using the additive method is simulated. The BER performance of the system increases dramatically with increase in diversity.

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