Performance Analysis of MIMO-OFDM under imperfect channel state information

C. Padmaja*, Dr. B. L. Malleswari†

*Research Scholar, JNTUH, Hyderabad, †Principal, SWEC, Hyderabad

Keywords: MIMO, OFDM, STBC, DDCE-EM, SNR.

Abstract

The demand for high data rates in fourth generation wireless communication systems (4G) is to provide low complexity and high reliable system. Orthogonal Frequency Division Multiplexing (OFDM) technique with multiple inputs and multiple outputs (MIMO) system are used to support 4G requirements under unstable fading channels. We propose a combined decision directed channel estimation with an expectation maximization algorithm (DDCE-EM) scheme under the dispersive Rayleigh fading channel. The simulation results are compared with the single iteration channel estimation schemes and demonstrated that the proposed scheme exhibits better performance under different practical conditions.

1 Introduction

The wireless channel suffers from multipath fading and the received signal may be distorted. To achieve the performance improvements, accurate CSI (Channel State Information) is required at the receiver via channel estimation. To recover the transmitted symbols, the affected channel needs to be estimated using the known approaches using pilot assisted, decision directed and blind channel estimation methods.

There is several pilot assisted channel estimation methods, investigated by Li [1], Morelli and Mengali [2], Yang et al. [3] as well as Chang and Su [4], differentiated by its performance requirement, computational complexity and speed of the time varying channel. Since the pilot symbols do not carry the useful information data, as a result reduction in the overall system throughput.

On the other hand, there are several Decision Directed Channel Estimation DDCE techniques uses both pilot and information bearing signal, was investigated by van de Beek et al. [5], Mignone and Morello [6], Edfors et al. [7], Li et al. [8], Li and Sollenberg [9] as well as Münster and Hanzo [10-12]. Though the requirement of pilot symbols is reduced, but if any error in the detected symbol is prone to degrade its performance.

The blind estimation methods eliminate the use of all redundant pilot or training symbols. However, these methods depend on the decision feedback and the redundancy, demonstrated by Ant´on-Haro et. al.[13], Boss et.al.[14], Endres et. al.[15], Giannakis and Halford [16], Zhou and Giannakis [17] as well as by Necker and Stuber [18].

The Blind channel estimation methods have higher spectral efficiency. But, they often suffer from high computation complexity and low convergence speed and are not suitable for applications with fast varying fading channels.

The class of iterative channel estimation schemes such as Expectation Maximization (EM), joint iterative DDCE for turbo coded MIMO OFDM systems was proposed by Qiao [19], Sandell et. al. [20], Valenti [21], Yeap et. al. [22], Song et. al.[23], as well as by Otnes and Tückler [24].

The goal of this paper is to propose a concatenated iterative technique by combining the advantages of both decision directed channel estimation with Expectation Maximization algorithm (DDCE-EM), where the channel estimation is carried out through a series of iterations.

The paper is organized as follows. Section II describes system model of space time coded MIMO-OFDM system. Section III describes the EM algorithm using decision feedback for estimating unknown channel parameters. Section IV describes the decoding scheme for iterative receiver. In section V simulation results are included. Finally concludes the paper in section VI.

2 System model

A space time coded MIMO-OFDM system with Nt transmit antennas and Nr receiving antennas is shown in figure 1. Initially, the incoming bit stream is mapped into data symbols using m-QAM modulation technique. Then the block of data symbols is encoded into codeword matrix C, which is then sent through Nr transmitting antennas in T OFDM blocks. Each OFDM block consists of Nc subcarriers. Such that each bit stream is converted into OFDM symbols denote the data Sl and pilot signals Pl respectively. Once the initial estimation is done, the channel coefficients can be updated using Decision Directed channel estimation (DDCE). The rth received space time data matrix is given as

\[ Y_r = H_r \cdot X_r + N_r = H_r \left( S_r + P_r \right) + N_r \]  \hspace{1cm} (1)

Where the received signal \( Y = [y_1, y_2, \ldots, y_{N_c}]^T \). The transmitted signal \( X = [x_1, x_2, \ldots, x_{N_c}]^T \)
The AWGN noise $N = [n_1, n_2, \ldots, n_{N_r}]^T$
And the channel matrix $H = N_r \times N_t$ square matrix.

![Figure 1: STBC-MIMO OFDM system model](image)

Given a block of received data $[Y_1, \ldots, Y_L]$, the pilot space-time code words $[X_1, \ldots, X_L]$, and the prior probabilities of the space-time code words $X_1, \ldots, X_L$, maximize the expected data log-likelihood function with respect to the conditional distribution of the unobserved data.

The conditional probability density function PDF of $Y$ given $H$ and $X$ can be expressed as

$$f(Y|H, X) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2} |Y - H \cdot X|^2\right)$$  \hspace{1cm} (2)

Assuming that $\{X_i\}_{i=1}^C$ are transmitted with the probability of $1/C$, the conditional probability density function PDF of $Y$ given $H$ is

$$f(Y|H, X) = \frac{1}{C} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2} |Y - H \cdot X|^2\right)$$  \hspace{1cm} (3)

The log-likelihood function can be expressed as,

$$\ln(f(Y|H, X)) = \ln\left(\frac{1}{C} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2} |Y - H \cdot X|^2\right)\right)$$  \hspace{1cm} (4)

### 3 DDCE-EM Channel Estimation Algorithm

The EM algorithm is an iterative method for computing max likelihood function for the observed data of ML estimates. EM algorithm consists of maximizing the expected complete data log-likelihood function. The expectation is computed with respect to the conditional distribution of the unobserved data using equation (4) given the observed data. The probability density function PDF of “complete” data can be rewritten by using the log-likelihood function as

$$\ln(f(Y|H, X)) = \left\{\frac{D}{d=1} \left(\frac{1}{C} f(Y^d|H, X^d)\right)\right\}$$  \hspace{1cm} (5)

Here, channel matrix $H$ is estimated by iteratively increasing the likelihood function in Equation (2) using the following two steps:

**Step 1:** Compute the expected value of the log-likelihood function of $H$ by taking expectation over $X$, conditioned on $Y$ and using the latest estimate of $H$ denoted as $H^{(p)}$, as follows

$$Q(H|H^{(p)}) = E_X\{f(Y|X,H) \cdot f(H|X\},$$

$$= \sum_{i=1}^{C} \sum_{d=1}^{D} \log\left\{\frac{1}{C} f(Y^d|H^{(p)}, X_i)\right\} f(Y^d|H^{(p)}, X_i)$$  \hspace{1cm} (6)

**Step 2:**

$H^{(p+1)}$ is determined by maximizing Equation (6) over all possible values of $H$ as follows

$$H^{(p+1)} = \arg\max_H Q(H|H^{(p)})$$  \hspace{1cm} (7)

The EM algorithm can convert a MIMO channel estimation problem into a number of single-input channel estimation problems. The EM algorithm plays an important role for channel estimation when a mobile station (MS) is located at its cell boundary.

### 4 MIMO Signal Detection

MIMO demodulator block includes both channel estimator and MIMO detector.

![Figure 2: MIMO OFDM detector model](image)

Existing MIMO detection algorithms include zero-forcing (ZF), minimum mean-square error (MMSE), nulling/cancelling, successive or parallel interference cancellation (SIC/PIC) and sphere decoding (SD) algorithms. However these sub-optimal algorithms have high complexity with low performance. Our goal is to design a low-complexity MIMO detection algorithm with near optimal performance.

ZF detection is simple and quite effective technique for decoding multiple transmitted data streams at the receiver. The detection requires knowledge of the channel state information (CSI).
The estimated CSI from DDCE-EM method can be used to decode the received data. It gives relatively better performance at high SNR. The Mathematical model for ZF was described by the following equation:

\[ \hat{X} = (H^H H)^{-1} H^H Y = H^+ Y \]  

(8)

where \( H \) is the Hermitian conjugate and \( H^+ \) is the left pseudo inverse respectively.

Though the ZF receiver enhances noise, but eliminates interference at its significant low SNR with simple structure [25]. Table 1 represents nomenclature used in the paper.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>(.)^T</td>
<td>Transpose</td>
</tr>
<tr>
<td>(.)^H</td>
<td>Hermitian conjugate</td>
</tr>
<tr>
<td>E(.)</td>
<td>Expectation operator</td>
</tr>
<tr>
<td>(.)^+</td>
<td>Left Pseudo Inverse</td>
</tr>
<tr>
<td>(.)^</td>
<td>Estimated parameter</td>
</tr>
<tr>
<td>f(.)</td>
<td>Probability Density Function</td>
</tr>
</tbody>
</table>

Table 1: Notations and meaning

**5 Simulation Results**

By considering the simulation parameters listed in Table 2, the BER performance of the proposed DDCE-EM channel estimation for MIMO OFDM can be characterized against single-iteration channel estimation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency ( f_c )</td>
<td>2.5 GHz</td>
</tr>
<tr>
<td>Channel bandwidth ( B )</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Number of carriers ( K )</td>
<td>128</td>
</tr>
<tr>
<td>FFT frame duration ( T_s )</td>
<td>16 s</td>
</tr>
<tr>
<td>OFDM symbol duration ( T )</td>
<td>20 s</td>
</tr>
<tr>
<td>cyclic prefix</td>
<td>4 s</td>
</tr>
<tr>
<td>Max. delay spread ( \tau_{max} )</td>
<td>4 s</td>
</tr>
<tr>
<td>Norm. Max. Doppler spread ( fD )</td>
<td>0.003</td>
</tr>
<tr>
<td>Number of channel</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Number of ZF detector</td>
<td>2, 4</td>
</tr>
<tr>
<td>iterations</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Simulation Parameters

Figure 3 depicts the BER performance of ZF based detection at the receiver side outperforms under 2X2 MIMO Rayleigh channel.

More specifically, Figure 4 depicts the \( E_b/N_0 \) gain of about 2dB, by comparing number of iterations with a single iteration of the channel estimator. Moreover, high \( E_b/N_0 \) gain may be achieved upon invoking a higher number of channel estimation iterations.

**6 Conclusion**

The paper presents DDCE-EM channel estimator for MIMO OFDM system, which leads to a significant gain 2dB at SNR of 7.5dB and in the performance as compared to the data-only estimator. BER performance improves rapidly upon increasing number of iterations and the equal number of transmit and receive antennas. Performance can be further improved by using adaptive channel estimation techniques like LMS, RLS and Kalman Filtering.
References


