Less Complex Channel Estimation Technique for MIMO OFDM system

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Abstract - Channel estimation of multiple input multiple output orthogonal frequency division multiplexing system for coherent system is very much crucial. In this paper we had introduced a new channel estimation technique based on artificial intelligence. It is designed and its performance of the technique is compared to the traditional technique like least square error (LS), least mean square error (LMS), minimum mean square error (MMSE) algorithms and artificial intelligence by using computer simulations.

Key Words: MIMO-OFDM, channel estimation, mobile communication system, artificial intelligence, LS, MMSE

1.INTRODUCTION

The multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) is one of the most promising techniques in the current era. It is widely used in wireless communications. Estimation of Channel has been successfully used to improve the performance of OFDM systems. For instance, differential detection would result in a 3-dB loss in signal-to-noise ratio (SNR) compared with coherent detection, where channel parameters are required. Most diversity schemes are designed with the assumption that the channel information is available.

For example, channel estimation is crucial for the receiver combining or decoding of space-time code. Therefore, channel estimation is essential in MIMO-OFDM system design.

Various OFDM channel estimation schemes have been proposed in the literature, mostly for single antenna system [14, 15]. In this paper, we consider channel estimation for transmit diversity using space time coding for OFDM systems. Assuming that the channel is quasi-stationary and the synchronization is perfect, we are interested in channel estimators based on a single block of OFDM data. The received signal is a superposition of different signals transmitted from different transmit antennas simultaneously. With the assumption of tolerable leakage, Fourier transform model based algorithms were studied in [1], [2], [16], and [17]. Later, a reduced complexity detection scheme was studied by exploiting the correlation of the adjacent subchannel responses [3]. A polynomial model based approach was developed in [12]. These typical schemes [2], [9], [10] assume a maximum delay profile and do not adapt to sparse channel conditions or higher delay profiles. Consequently, the estimation accuracy will be degraded under these conditions. Note that the channel impulse response is characterized by the delays of the paths, therefore, estimating time of arrivals (TOAs) is one way to improve channel estimation. A multidimensional maximum-likelihood (ML) search is one solution but a prohibitively complex task. A number of alternatives have been proposed to reduce the complexity. The alternating projection (AP) method [5] is interesting due to its good performance. A channel estimation scheme via near-ML TOA estimation, with its root in AP, was presented in [11] with good performances. However, the AP algorithm still suffers from high computational costs, especially when the number of paths is unknown.

2. OFDM Parameters

Table 1 lists the main parameters of the draft OFDM standard. A key parameter which largely affected the choice of the other parameters is the guard interval of 800 ns. This guard interval provides robustness to root-mean-squared delay spreads up to several hundreds of nanoseconds, depending on the coding rate and modulation used. In practice, this means that the modulation is robust enough to be used in any indoor environment, including large factory buildings. It can also be used in outdoor environments, although directional antennas may be needed in this case to reduce the delay spread to an acceptable amount and to increase the range.
<table>
<thead>
<tr>
<th>Data rate</th>
<th>6, 9, 12, 18, 24, 36, 48, 54 Mbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation</td>
<td>BPSK, QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>Coding rate</td>
<td>1/2, 2/3, 3/4</td>
</tr>
<tr>
<td>Number of subcarriers</td>
<td>52</td>
</tr>
<tr>
<td>Number of pilots</td>
<td>4</td>
</tr>
<tr>
<td>OFDM symbol duration</td>
<td>4 µs</td>
</tr>
<tr>
<td>Guard interval</td>
<td>800 ns</td>
</tr>
<tr>
<td>Subcarrier spacing</td>
<td>312.5 kHz</td>
</tr>
<tr>
<td>-3 dB Bandwidth</td>
<td>16.56 MHz</td>
</tr>
<tr>
<td>Channel spacing</td>
<td>20 MHz</td>
</tr>
</tbody>
</table>

**Table 1: Main Parameters of the OFDM standard.**

In order to limit the relative amount of power and time spent on the guard time to 1 dB, the symbol duration was chosen to be 4 µs. This also determined the subcarrier spacing to be 312.5 kHz, which is the inverse of the symbol duration minus the guard time. By using 48 data subcarriers, uncoded data rates of 12 to 72 Mbps can be achieved by using variable modulation types from BPSK to 64-QAM. In order to correct for subcarriers in deep fades, forward error correction across the subcarriers is used with variable coding rates, giving coded data rates from 6 up to 54 Mbps. Convolutional coding is used with the industry standard rate 1/2, constraint length 7 code with generator polynomials (133, 171). Higher coding rates of 2/3 and 3/4 are obtained by puncturing the rate 1/2 code.

### 3. System Description

I. The block diagram of an OFDM system. The binary information data are grouped and mapped into multi-amplitude-multi-phase signals. In this paper, we consider the 16-QAM modulation. After pilot insertion, the modulated data X(k) are sent to an IDFT and are transformed and multiplexed into x(n) as

II. \[ x(n) = \text{IFFT}\{X(k)\} = \sum_{k=0}^{N-1} X(k) e^{-j2\pi kn/N} \]

III. For \( n = 0, 1, 2, ..., N-1 \)

IV. where \( N \) is the number of subcarriers. The guard interval \( N_g \) is inserted to prevent possible inter-symbol interference in OFDM systems, and the resultant samples \( x_g(n) \) are

V. \[ x_g = \begin{cases} x(n + n) & n = N_g, N_g + 1, ..., N \\ x(n) & n = 0, 1, ..., N-1 \end{cases} \]

VI. where \( N_g \) is the number of samples in the guard interval. The transmitted signal is then sent to a frequency selective multipath fading channel. The received signal can be represented by

VII. \[ y_g(n) = x_g(n) \otimes h(n) + w(n) \]

VIII. \[ h(n) = \sum_{i=0}^{r-1} h_i e^{j2\pi f_i n T_s} N^i \]

IX. Where \( h(n) \) is the channel impulse response (CIR) and \( w(n) \) is the Additive White Gaussian Noise (AWGN) and \( \otimes \) is the circular convolution. The channel impulse response \( h(n) \) can be expressed as [17]

X. \[ Y(k) = \text{FFT}\{y(n)\} = \frac{1}{N} \sum_{n=0}^{N-1} y(n) e^{-j2\pi kn/N} \]

XI. Where \( r \) is the total number of propagation paths, \( h_i \) is the complex impulse response of the ith path, \( f_i \) is the ith path’s Doppler frequency shift which causes Inter channel Interference (ICI) of the received signals, \( \tau_i \) is the delay spread index, and \( i \) is the ith path delay time normalized by the sampling time. After removing the guard interval from \( y_g(n) \), the received samples \( y(n) \) are sent to a Fast Fourier Transform (FFT) block to demultiplex the multi-carrier signals.

XII. \[ Y(k) = X(k) N \]

XIII. If we assume that the guard interval is longer than the length of channel impulse response there is no inter-symbol interference between OFDM symbols-the demultiplexed samples \( Y(k) \) can be represented by

XIV. \[ Y(k) = X(k) H(k) W(k), \quad k = 0, 1, ..., N-1 \]

XV. Where \( H(k) = h_i e^{j2\pi f_i n T_s} N^i \) and \( W(k) \) is

XVI. \[ \hat{x}(k) = \frac{y(k)}{H(k)} \]

XVII. After that, the received pilot signals \( \hat{f}_p(k)g \) are extracted from \( \hat{Y}(k)g \), the channel transfer function \( \hat{H}(k)g \) can be obtained from the information carried by \( \hat{f}_p(k)g \). With the knowledge of the channel responses \( \hat{H}(k)g \), the transmitted data samples \( \hat{X}(k)g \) can be recovered by simply dividing the received signal by the channel response:

XVIII. \[ \hat{x}(k) = \frac{y(k)}{H(k)} \]
XIX. where \( \hat{H} (k) \) is an estimate of \( H(k) \). After signal
demapping, the source binary information data are
reconstructed at the receiver output.

XX. The OFDM transmission scheme makes it easy to
assign pilots in both time and frequency domain. two major
types of pilot arrangement. The first kind of pilot
arrangement shown it is denoted as block-type pilot
arrangement. The pilot signal is assigned to a particular
OFDM block, which is sent periodically in time domain. This
type of pilot arrangement is especially suitable for slow-
fading radio channels. The estimation of channel response is
usually obtained by either LS or MMSE estimates of training
pilots [5].

XXI. The second kind of pilot arrangement, is denoted as
comb-type pilot arrangement. The pilots signals are uniformly
distributed within each OFDM block. Assuming that the
payloads of pilot signals of the two arrangements are the
same, the comb-type pilot assignment has a higher
retransmission rate. Thus, the comb-type pilot arrangement
system is provides better resistance to fast-fading channels.
Since only some sub-carriers contain the pilot signal, the
channel response of nonpilot subcarriers will be estimated by
interpolating neighboring pilot sub-channels. Thus, the
combtype pilot arrangement is sensitive to frequency
selectivity when comparing to the block-type pilot
arrangement system. That is, the pilot spacing \( f_p \), must be
much smaller than the coherence bandwidth of the channel
\( f_c \) [3].

4. Channel Estimation

For comb-type pilot sub-carrier arrangement, the \( N_p \) pilot
signals \( X_p(m) \); \( m = 0; 1; \ldots; N_p - 1 \), are uniformly inserted into
\( X(k) \). That is, the total \( N \) sub-carriers are divided into \( N_p \)
groups, each with \( L = N/N_p \) adjacent sub-carriers. In each
group, the first sub-carrier is used to transmit pilot signal.
The OFDM signal modulated on the \( k \)th sub-carrier can be expressed as

\[
X(k) = X(mL + l) = \begin{cases} 
X_p(m) & l = 0 \\
n & l = 1, 2, \ldots, L - 1 
\end{cases}
\]

Let

\[
H_p = [H_p(0) H_p(1) \ldots H_p(N_p - 1)]^T
= [H(0) H(L - 1) \ldots H((N_p - 1)(L - 1))]^T
\]
be the channel response of pilot carriers, and

\[
Y_p = [Y_p(0) Y_p(1) \ldots Y_p(N_p - 1)]
\]
be a vector of received pilot signals. The received pilot
signal vector \( Y_p \) can be expressed as

\[
Y_p = X_p H_p + W_p
\]

where \( W_p \) is the vector of Gaussian noise in pilot sub-
carriers.

A. LS Estimation

In conventional comb-type pilot based channel estimation
methods, the estimation of pilot signals, is based on the LS
method is given by

\[
\hat{H}_{p,i} = [H_{p,i}(0) H_{p,i}(1) \ldots H_{p,i}(N_p - 1)] \\
= X_p^T Y_p \\
= \begin{bmatrix} 
Y_p(0) & Y_p(1) & \ldots & Y_p(N_p - 1) \\
X_p(0) & X_p(1) & \ldots & X_p(N_p - 1)
\end{bmatrix}
\]

The LS estimate of \( H_p \) is susceptible to AWGN and Inter-
Carrier Interference (ICI). Because the channel responses of
data subcarriers are obtained by interpolating the channel
characteristics of pilot subcarriers, the performance of OFDM
systems which are based on comb-type pilot arrangement is
highly dependent on the rigorousness of estimate of pilot
signals. Thus, a estimate better than the LS estimate is
required. The MMSE estimate has been shown to be better
than the LS estimate for channel estimation in OFDM systems
based on block-type pilot arrangement. The Mean Square
Error (MSE) estimation, given in [17], shows that MMSE
estimate has about 10-15 dB gain in SNR over the LSEstimte
for the same MSE values. The major drawback of the MMSE
estimate is its high complexity, which grows exponentially
with the observation samples.

B. MMSE Estimation

The MMSE estimator employs the second order statistics
of the channel conditions in order to minimizes Mean Square
Error (MSE). Let \( R_{hh} \), \( R_{hk} \), and \( R_{hk} \) be the autocovariance
matrix of \( h \), \( H \), and \( Y \), respectively and \( R_{yy} \) be the cross
covariance matrix between \( h \) and \( Y \). Also \( \sigma^2 \), denotes the
AWGN variance \( E[|w|^2] \). Assume the channel vector \( h \), and the
AWGN \( w \) are uncorrelated, it can be derived that [18]

\[
R_{hh} = E\{HH^H\} = E\{(Fh)(Fh)^H\} = FR_{hh}F^H
\]

Where
\[
TW_N^{00} \ldots \ldots \ldots TW_N^{0(N-1)} \\
\vdots \\
\vdots \\
\vdots \\
TW_N^{(N-1)0} \ldots \ldots \ldots TW_N^{(N-1)(N-1)}
\]

And

\[
_TW_{ij}^k = \frac{1}{\sqrt{N}} e^{-j2\pi \frac{i}{N}}
\]

is called as the twiddle factor matrix. Assuming \(R_{hh}\) (thus \(R_{HH}\)) and \(\sigma_w^2\) are known at the receiver in advance, the MMSE estimator of the \(h\) is given

\[
\hat{h}_{\text{MMSE}} = R_{yy} R_{yr} Y^H.
\]

At last it can be estimated that

\[
H_{\text{mmse}} = \text{dshgfd}
\]

MMSE employs the second order statistics of the channel for estimation. Sometimes the channel statistics are not available, so it is difficult to estimate the channel in this situation. However, in OFDM systems the signal can be available at the receiver by means of pilot carriers.

Our Proposed Algorithm: 1. The Algorithm is as follows:

1) Initialize the observation weights \(w_i = 1/n; i = 1, 2, \ldots, n\).
2) For \(m = 1\) to \(M\).
   a) Fit a classifier \(T(m)(x)\) to the training data using weights \(w_i\).
   b) Compute
   \[
   \text{err}^{(m)} = \sum_{i=1}^{n} w_i \left\| (C_i \neq T^{(m)}(x)) \right\| / \sum_{i=1}^{n} w_i
   \]
   c) Compute
   \[
   \alpha^{(m)} = \log \frac{1 - \text{err}^{(m)}}{\text{err}^{(m)}} + \log(K - 1)
   \]
   d) Set
   \[
   w_i \leftarrow w_i \exp(\alpha^{(m)} I(C_i \neq T^{(m)}(x)))
   \]
   e) Re-normalize \(w_i\).

IV. SIMULATION RESULTS

The OFDM system channel estimation was simulated with LS, MMSE, BLUE and AdaBoost methods. In all simulations we have used QAM16 as the modulation scheme for the individual carriers. Other parameters of the simulation are given in the Table.I. Figure.3 shows comparison of Bit Error Rate (BER) for LS, MMSE, BLUE and AdaBoost. Figure.3 shows that the AdaBoost algorithm improves the performance specially in low SNR values. However, at high SNR both MMSE and AdaBoost show a similar performance. Furthermore, AdaBoost gives better performance when compared to LS and BLUE. Nevertheless, BLUE and LS are performing same or we can tell BLUE gives very marginal improvement to LS. The reason for this performance increase is because of the covariance matrix used in the BLUE. As our noise is AWGN and it has variance of 1 so the BLUE’s performance is all most that of LS algorithm.

V. CONCLUSION

The computational complexity of the MMSE increases exponentially as the number of carrier increases, whereas the computational complexity is not exponential in the case of Our algorithm. Hence, Our proposed algorithm can be employed when a high number of carriers is required. Furthermore, as it is a classification algorithm so in the receiver side we will require a separate demapper (or decoder) to get the desired data bits. AdaBoost not only increases the performance of the OFDM systems it also
renders the QAM mapping obsolete and thereby reducing the complexity of receiver designs.

REFERENCES


