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A Review of Channel Estimation of MIMO-OFDM

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Abstract:
In the modern wireless communication, a combination of multiple-input multiple-output (MIMO) with orthogonal frequency division multiplexing (OFDM) can be used to provide robust to multipath delay, achieve high data rate and better spectral efficiency. MIMO-OFDM Systems are widely used nowadays because of their improved performance in terms of link reliability, high data rates and capacity. Channel estimation is the major issue faced in MIMO-OFDM systems. Since, Inter-symbol interference (ISI) which is caused by multipath delay spread in band limited frequency selective channels distorts the transmitted signal, causing bit error at receiver. ISI is the major obstacle to high speed data transmission over wireless channels. Channel estimation is a technique used to combat the inter-symbol interference and accomplish efficient data transmission.

Keywords: MIMO, OFDM, Channel Estimation, ISI, MSE.

1. INTRODUCTION

Broadband wireless access under high speed-mobility conditions has received much attention, and the high speed railway broadband wireless access is one of the typical scenarios. OFDM, known as an attractive technique for the transmission of the high-bit-rate data, has been investigated as a candidate for the next generation wireless communication for combating the frequency selective fading caused by the multipath channel. But OFDM is very sensitive to the ICI, which may be caused by the carrier frequency offset (CFO), phase noise, timing offset, and the Doppler spread under high-mobility condition. For the ICI induced by the first three impairments, OFDM system can completely compensate or correct it. However, in high-mobility scenarios (such as high speed railway whose velocity reaches 350 km/h – 500 km/h), the channel fluctuates during communication due to the Doppler spread induced by the mobility. In OFDM systems, a frequency selective channel is converted into a collection of flat fading channels, which can be compensated by simply using a one-tap equalizer [1]. Hence, OFDM can greatly simplify equalizer design while enabling rather high data rates. As a result, OFDM has been standardized as a key physical-layer technique in many commercial systems. Multiple-input multiple-output with Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is the latest wireless communication technology which provides robustness against multipath fading and high mobility and has capability of high rate transmission. MIMO-OFDM also has significant potential performance enhancements over existing wireless technology by concurrently exploiting the space, time and frequency domains. MIMO-OFDM is capable of satisfying the requirements of next-generation networks such as Wireless Local Area Networks (WLANs), Worldwide interoperability for Microwave Access (WiMAX), Wireless Fidelity (WiFi), Cognitive Radio, and 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE).

2. LITERATURE REVIEW

MIMO transmission greatly improves the capacity of wireless communications. Since OFDM can convert a frequency selective channel into parallel flat fading channels, it is natural to combine MIMO with OFDM to provide high rate data transmission over frequency selective channels. However, channel estimation in MIMO-OFDM systems is a challenging task due to the presence of multiple transmit antennas. There are two approaches for channel estimation data-aided approach and blind estimation approach. In a data-aided approach, the channel estimation is based on some known data, which is known both at the transmitter and at the receiver, such as training sequences or pilot data. In a blind approach, the estimation is based only on the received data, without any known transmitted sequence. The tradeoff is the accuracy versus the overhead. A data-aided approach requires more bandwidth or it has a higher overhead than a blind approach, but it can achieve a better channel estimation accuracy than a blind estimator.

2.1 System Model of MIMO-OFDM

Basically, OFDM system can easily be implemented in a digital domain by using Inverse Fast Fourier Transform (IFFT) as the demodulator at receiver. Using the ICI-SC scheme, the binary bits are first mapped onto constellation points, and then the serial symbols are converted into a block of N/2 parallel symbols, where N is the total number of subcarriers of OFDM system. Then, the parallel symbols with the width N/2 are mapped into N subcarriers by the ICI-SC scheme. The MIMO-OFDM transmitter has Nth parallel transmission path with each performing conversion, N-point inverse fast Fourier transform (IFFT) and guard interval before the final transmitted signals are up-converted to RF signal and then transmitted.

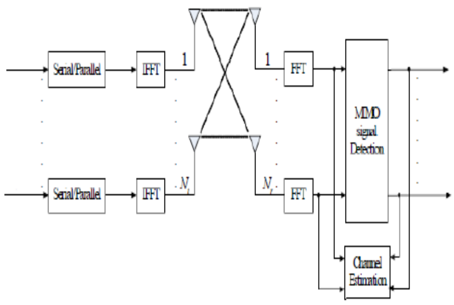

Figure.1. MIMO-OFDM system.

At the receiver guard interval is removed and N-point fast Fourier transform (FFT) is performed per receiver branch. Then, the operations like digital demodulation and decoding are done. Finally, all the input binary data are recovered with certain bit error rate (BER) [1]. The data stream from each antenna undergoes OFDM modulation. Figure 1 depicts the MIMO-OFDM system.

3. METHODOLOGY

High mobility communications dictate an operation environment of doubly-selective (both time-selective and frequency-selective) fading, which introduces channel dispersions in both time and frequency domains. The fast time-variation along with the long time-dispersion of doubly-selective fading impose great challenges on the accurate estimation and tracking of the doubly-selective channel. The channel estimation methods are typically classified as blind, semi-blind, and pilot-aided/data-aided channel estimations. The blind channel estimations are realized by using the statistics of the received data, the cyclic prefix (CP), the virtual carriers, and receiver diversity. Due to the low convergence speed, blind estimations often require the channel to be constant for a large number of blocks, therefore they are not suitable for high mobility applications. Most communication standards such as LTE and Digital Video Broadcasting (DVB) adopt pilot assisted channel estimations. Pilot-aided channel estimations include both pilot designs and estimation algorithms. In high mobility channel estimations, each aspect has unique features and challenges due to the fast time-variation and long time dispersion of the channels[6].

3.1 Data-aided approach

Data aided estimation uses pilot sequences or training sequences sent as a preamble of each data frame and known at the receiver is simple to implement and can be applied to different types of channels although the use of pilots affects the data rate. One of the channel estimation methods is by using pilot symbols as reference signal. The pilot symbol does not carry information, but it is known by both of the transmitter and receiver. Characteristic of estimated channel that approach to the true value provides a good reference to make equalization at the receiver. In data aided channel estimation, known information to the receiver is inserted in OFDM symbols so that the current channel can be estimated. Two techniques are commonly used: sending known information over one or more OFDM symbols with no data being sent, or sending known information together with the data. The previous arrangement is usually called channel estimation with training symbols while the latter is called pilots aided channel estimation.[7]

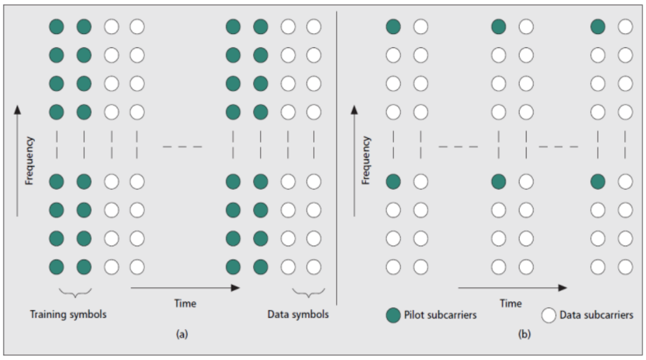

Figure.2. Typical training symbols and pilot subcarriers arrangement

3.1.1 Pilot Based Channel Estimation

In pilot based channel estimation algorithms, training symbols or pilot tones that are known to the receiver are multiplexed along with the data stream for channel estimation. The idea behind these methods is to exploit knowledge of transmitted pilot symbols at the receiver to estimate the channel. The addition of pilot symbol with the specific pilot pattern used for channel estimation often called the pilot-based channel estimation.[8] For a block fading channel, where the channel is constant over a few OFDM symbols, the pilots are transmitted on all subcarriers in periodic intervals of OFDM blocks. This type of pilot arrangement, depicted in Fig. 2.3(a), is called the block type arrangement. In block type pilot estimation, pilot tones are inserted into all frequency bins within the periodic intervals of OFDM blocks. This estimation is suitable for slow fading channels. For a fast fading channel, where the channel changes between adjacent OFDM symbols, the pilots are transmitted at all times but with an even spacing on the subcarriers, representing a comb type pilot placement, Fig. 2.3(b) The channel estimates from the pilot subcarriers are interpolated to estimate the channel at the data subcarriers.[9]

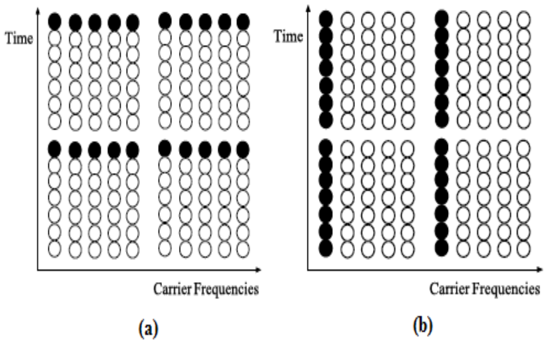

Figure.3. Type of Pilot-based Channel Estimation (a) Block type (b) Comb type

3.1.2 Training Based Channel Estimation

Training symbols can be used for channel estimation, usually providing a good performance. However, their transmission efficiencies are reduced due to the required overhead of training symbols such as preamble or pilot tones that are transmitted in addition to data symbols. The least-square (LS) and minimum-mean-square-error (MMSE) techniques are widely used for channel estimation when training symbols are available. We assume that all subcarriers are orthogonal (i.e., ICI-free). Then, the training symbols for N subcarriers can be represented by the following diagonal matrix:

$$\begin{bmatrix} X(0) & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & X(N-1) \end{bmatrix} \qquad (1)$$

Where *X[k]* denotes a pilot tone at the kth subcarrier, with $E\{X[k]\} = 0$ and $Var\{X[k]\} = \sigma^2{}_x$, k= 1, 2, 3,…,N-1. Note that X is given diagonal matrix as we assume all subcarriers are orthogonal. Given that the channel gain is *H[k]* for each subcarrier k, the received training signal *Y[k]* can be represented as,

$$Y \triangleq \begin{bmatrix} Y(0) \\ \vdots \\ Y(N-1) \end{bmatrix} = \begin{bmatrix} X(0) & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & X(N-1) \end{bmatrix} \begin{bmatrix} H(0) \\ \vdots \\ H(N-1) \end{bmatrix} + \begin{bmatrix} Z(0) \\ \vdots \\ Z(N-1) \end{bmatrix} \qquad (2)$$

$$= XH+Z$$

where H is a channel vector given as $H = [H(0); H(1); \ldots\ldots; H(N-1)]^T$ and Z is a noise vector given as $Z = [Z(0); Z(1); \ldots\ldots; Z(N-1)]^T$ with $E\{X[k]\} = 0$ and $Var\{X[k]\} = \sigma^2{}_x$, k= 1, 2, 3,…, N-1. In the following discussion, let $\hat{H}$ denote the estimate of channel H.

3.1.2.1 LS Estimation

The Least-Square (LS) estimation can be used as it requires no statistical information about the CFRs. In the case of white Gaussian noise, it is easy to show that LS estimation is equivalent to maximum-likelihood (ML) estimation. For the classical estimation problem, ML estimation is the optimal approach and it can achieve the Cramer-Rao bound (CRB). Since LS (or ML) estimation requires no knowledge about the channel statistics, the estimation performance is generally not good enough. In addition, LS estimation may suffer from noise enhancement when the channel matrix has a large condition number. The channel estimate $\hat{H}$ for LS estimator is given by,

$$\hat{H}_{LS}[k] = \frac{Y[k]}{X[k]} \qquad (3)$$

The mean-square error (MSE) of this LS channel estimate is given as,

$$MSE_{LS} = \frac{\sigma^2{}_z}{\sigma^2{}_x} \qquad (4)$$

Note that the MSE in Equation (4) is inversely proportional to the $SNR = \sigma^2{}_x/\sigma^2{}_z$, which implies that it may be subject to noise enhancement, especially when the channel is in a deep null. Due to its simplicity, however, the LS method has been widely used for channel estimation.

3.1.2.2 MMSE Estimation

Consider the LS solution in Equation (3), $\hat{H}_{LS}[k] = Y[k]/X[k]$. Using the weight matrix W, define $\hat{H} = W\tilde{H}$, which corresponds to the MMSE estimate. MMSE channel estimate $\hat{H}$ is given as,

$$\hat{H} = W\tilde{H} = R_{H\tilde{H}}R^{-1}_{\tilde{H}\tilde{H}}\tilde{H} \qquad (5)$$

Where $R_{H\tilde{H}}$ is the cross-correlation matrix between the true channel vector and temporary channel estimate vector in the frequency domain.

3.1.2.3 DFT-Based Channel Estimator

The DFT-based channel estimation technique has been derived to improve the performance of LS or MMSE channel estimation by eliminating the effect of noise outside the maximum channel delay. The DFT-based channel estimation algorithm reduces the noise and pilot contamination components in the transfer domain by exploiting the property of OFDM systems, since the channel impulse response (CIR) is much less than the symbol duration. So after IDFT is turned into time domain, DFT-based channel estimation algorithm remains as in the samples in cyclic prefix (CP). This will reduce the noise power that exists only outside of the CIR part [6].

Let $\hat{H}[k]$ denote the estimate of channel gain at the kth subcarrier, obtained by either LS or MMSE channel estimation method. Taking the IDFT of the channel estimate $\{\hat{H}[k]\}_{k=0}^{N-1}$

$$IDFT\{\hat{H}[k]\} = h[n] + z[n] \triangleq \hat{h}[n], \quad n = 0,1,\ldots\ldots,N-1$$
(6)

where $z[n]$ denotes the noise component in the time domain. Ignoring the coefficients $\{\hat{h}[n]\}$ that contain the noise only, define the coefficients for the maximum channel delay L as

$$\hat{h}_{DFT}[n] = \begin{cases} h[n] + z[n], & n = 0,1,\ldots\ldots,L-1 \\ 0, & otherwise \end{cases} \qquad (7)$$

And transform the remaining L elements back to the frequency domain as follows

$$\hat{H}_{DFT}[k] = DFT\{\hat{h}_{DFT}[n]\} \qquad (8)$$

Figure 2.4 shows a block diagram of DFT-based channel estimation, given the LS channel estimation. Note that the maximum channel delay L must be known in advance.

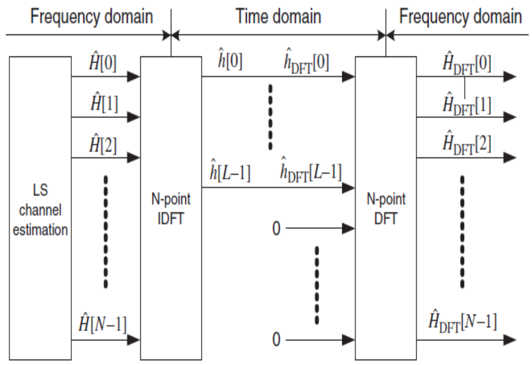

Figure.4. DFT-based Channel Estimation.[7]

The figure 2.4 uses LS estimation along with DFT based channel estimation in similar way we can implement MMSE estimation with DFT. The performance parameters for the comparison between channel estimations schemes are mean square error, bit error rate and computational complexity.

3.2 Blind Channel Estimation

Blind channel estimation which relies on the exploitation of the statistical information of the received symbols, has the bandwidth-saving advantage. However, the blind technique is limited to slow time varying channels and has higher complexity at the receiver. The training sequence is not used in blind channel estimation. Blind channel estimation techniques are divided into two categories: statistical and deterministic. Statistical estimation uses the orthogonality between the channel sub-space vector and noise sub-space vector, which also is called sub-space method. Therefore, in order to obtain the noise sub-space matrix, we need to eigen values decomposition of autocorrelation matrix of received signal. On the other hand the deterministic approach uses the property of limit alphabet of symbols and usually converges faster than statistical methods, but causes much more complexity in the transceiver.[10]

3.3 Semi-Blind Channel Estimation

Semi blind channel estimation is hybrid combination of blind and data-aided technique, utilizing pilots and other natural constraints to perform channel estimation. As number of antennas at receiver and transmitter increases the complexity of blind method increases, so in order to reduce the complexity in channel estimation semi-blind or pilot methods are used. Pilot based methods are useful only for slow varying channels. To overcome the disadvantages of blind and pilot based method many researches proposed semi blind method. It achieves the better performance compared to both methods, in fast varying channels and accuracy increased in semi blind method.

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