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Discrete Fourier Transform based Channel Estimation Scheme for MIMO-OFDM Communication System

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ABSTRACT

A multi-input multi-output (MIMO) communication system combined with orthogonal frequency division multiplexing (OFDM) system can provide high transmission data rate, spectral efficiency and reliability for wireless communication systems. These parameters can be further improved by combating with fading, the effect of which can be reduced by properly estimating the channel at the receiver side. This paper presents a discrete Fourier transform based channel estimation scheme, which shows better performance when compared with existing channel estimation schemes like least square error (LSE) and minimum mean square error (MMSE) schemes.

Keywords - **Channel estimation, Discrete Fourier transform, Least square error, Minimum mean square error, MIMO- OFDM.**

1. Introduction

Wireless system designers are facing a number of challenges. These include the limited availability of the radio frequency spectrum and a complex space–time varying wireless environment. In addition, there is an increasing demand for higher data rates, better quality of service and higher network capacity [1]. In recent years, Multiple-Input Multiple-Output (MIMO) systems have emerged as a most promising technology in these measures. The core idea behind MIMO is that signals sampled in the spatial domain at both ends and combined in such a way that they either create effective multiple parallel spatial data pipes, and/or add diversity to improve the quality of the communication. However [2], alone use of MIMO cannot achieve zero ISI. On the other hand ISI free signal can be achieved by combining MIMO with OFDM known as MIMO-OFDM, which seems to be an attractive solution for future broadband wireless systems. Because in MIMO-OFDM, OFDM simplifies the implementation of MIMO without loss of capacity, reduces receiver complexity, avoids inter-symbol-interference by modulating narrow orthogonal carriers and each narrowband carrier is treated as a separate MIMO system with zero delay-spread. However to achieve the features like high data rate, reliability and spectral efficiency, the channel conditions must be estimated since perfect channel knowledge is never known before. Channel estimation algorithms allow the receiver to approximate the impulse response of the channel and explain the behavior of the channel. This knowledge of the channel's behavior is well-utilized in modern radio communications. Adaptive channel equalizers utilize channel estimates to overcome the effects of inter symbol interference. Diversity techniques utilize the channel estimate to implement a matched filter such that the receiver is optimally matched to the received signal instead of the transmitted one. Maximum likelihood detectors utilize channel estimates to minimize the error probability. One of the most important benefits of channel estimation is that it allows the implementation of coherent demodulation. Coherent demodulation requires the knowledge of the phase of the signal. This can be accomplished by using channel estimation techniques. In this paper channel impulse response has been estimated and compared using LS, MMSE and DFT based estimation techniques. The paper is organized as follows. In Section 2, MIMO system and channel estimation is described. Section 3 discusses training (pilot) based channel estimation. Simulation and results for the performance of LS, MMSE and DFT based techniques are given in section 4 and Section 5 concludes the paper.

2. MIMO System and Channel Estimation

In radio communications [3], MIMO means multiple antennas both on transmitter and receiver side of a specific radio link as shown in Fig.1. Typical MIMO systems consist of M transmit antennas and N receive antennas. They transmit independent data (say $x_1, x_2 \dots x_M$) on different transmit antennas simultaneously and in the same frequency band. At the receiver, a MIMO decoder uses $M \ge N$ antennas.

Assuming N receive antennas, and representing the signal received by each antenna as r_j we have:

$$r_1 = h_{11}x_1 + h_{12}x_2 + \cdots + h_{1M}x_M$$

$$r_2 = h_{21}x_1 + h_{22}x_2 + \cdots + h_{2M}x_M$$
$$\vdots$$
$$r_N = h_{N1}x_1 + h_{N2}x_2 + \cdots + h_{NM}x_M$$
(1)

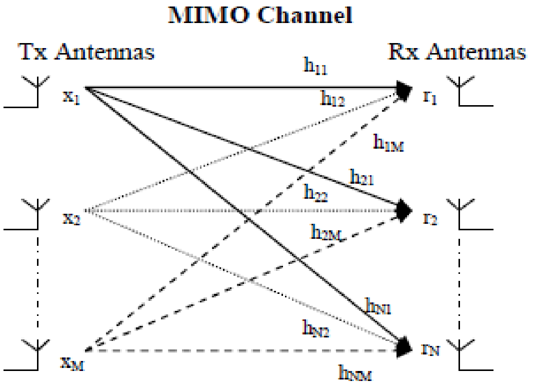

Figure 1. MIMO System

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals $\{x_1, x_2, \ldots, x_M\}$ are all combined. Traditionally this "combination" has been treated as interference. However, by treating the channel as a matrix, we can in fact recover the independent transmitted streams $\{x_i\}$. To recover the transmitted data stream $\{x_i\}$ from the $\{r_j\}$. The individual channel weights h_{ij} must be calculated to construct the Channel matrix ***H***. Having estimated ***H***, multiplication of the vector ***r*** with the inverse of ***H*** produces the estimate of the transmitted vector.

The Channel estimator infers the channel parameters from the received signal and maps the received signal and prior knowledge about the channel and pilot symbols. The channel estimation can be performed using blind channel estimation and training (pilot) based channel estimation. Blind channel estimator uses the received signal information to estimate channel. This method has the disadvantage of high computational complexity and is fixed for only particular system. In training (pilot) based channel estimation, receiver has a-prior knowledge of the information (pilots) being sent over the channel, it can utilize this knowledge to obtain an accurate estimate of the impulse response of the channel. This estimator is easy to derive and analyze because the unknown data are not part of the observation which leads to low complexity. So in the present work we have considered training (pilot) based channel estimation to estimate the channel.

3. Training (pilot) Based Channel Estimation

In this work, we have considered Block Type and Comb Type pilot arrangements. Block type pilot arrangement is mainly employed for slow fading and it is assumed that the channel behave same for whole block. OFDM channel estimation symbols are transmitted periodically, in which all sub-carriers are used as pilots [4]. The estimation can be performed by using either LSE or MMSE. The comb type arrangement is usually employed for fast fading channels. In this arrangement [5], N_P pilot signals are uniformly inserted into $X(k)$ according to equation 2:

$$X(k) = X(mL + l)$$
$$= \begin{cases} x_p(m), & l = 0 \\ \inf.data & l = 1, 2 \ldots\ldots L - 1 \end{cases}$$

(2)

where $L = N/N_P$ and N is the number of carriers , $x_P(m)$ is the m^{th} pilot carrier value and $\{H_P(k) \;\; k = 0, 1, \ldots\ldots N_P\}$ is defined as the frequency response of the channel at pilot sub-carriers. The estimation of the channel at the pilot frequencies for comb-type based channel estimation can be based on LSE, MMSE similar to block type whereas an efficient interpolation technique is necessary in order to estimate channel at data sub-carriers by using the channel information at pilot sub-carriers. The training symbols ***X(k)*** for *k={0,1,2,3…N-1}* subcarriers can be represented by diagonal matrix **X.** Given that the channel gain *H(k)* for each sub-carrier ***k***, ***z*** is the noise vector, the received training signal *Y(k)* can be represented by [4]

$$Y = XH + Z$$
(3)

$$Y \triangleq \begin{bmatrix} Y[0] \\ Y[1] \\ \vdots \\ Y[N-1] \end{bmatrix} = \begin{bmatrix} X[0] & 0 & \cdots & 0 \\ 0 & X[1] & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & X[N-1] \end{bmatrix} \begin{bmatrix} H[0] \\ H[1] \\ \vdots \\ H[N-1] \end{bmatrix} + \begin{bmatrix} Z[0] \\ Z[1] \\ \vdots \\ Z[N-1] \end{bmatrix}$$

4. Brief Description of LS, MMSE and DFT based Channel Estimation

4.1 Least square error channel estimation

The least-square (LS) channel estimation method evaluates the channel estimate $\hat{H}$ in such a way that the following error function is minimized:

Let $\hat{H}$ be the estimate of the channel matrix *H*,

$$E(\hat{H}) = \left\| Y - X\hat{H} \right\|^2 \qquad (4)$$

$$\hat{H}_{LS} = X^{-1}Y \qquad or$$

$$\hat{H}_{LS}[k] = \frac{Y[k]}{X[k]}, \quad k = 0, 1, 2, \ldots., N-1 \qquad (5)$$

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

$$MSE_{LS} = E\left\{Z^H (XX^H)^{-1} Z\right\} = \frac{\sigma_z^2}{\sigma_x^2} = \frac{1}{SNR}$$

(6)

The LS estimators are calculated with very low complexity, but obviously it suffers from a high MSE, the channel is in deep null.

4.2 Minimum Mean Square Error Estimation

If the channel and AWGN are not correlated the MMSE estimate of H becomes

$$\hat{H}_{MMSE} = R_{HY} R_{YY}^{-1} Y$$

(7)

where $R_{HY} = E\left\{HY^H\right\} = R_{HH} X^H$

(8)

$$R_{YY} = E\left\{YY^H\right\} = XR_{HH} X^H + \sigma_N^2 I_N$$

(9)

are the cross covariance matrix between ***H*** and ***Y*** and the auto-covariance matrix of ***Y*** respectively [6]. Further, R_{HH} is the auto covariance matrix of H and σ_N^2 denotes the noise variance $E\left\{|n_k|^2\right\}$.

If R_{HH} and σ_N^2 are known to the receiver, channel impulse response could be calculated by MMSE estimator as below: $\hat{H}_{MMSE} = R_{HY} R_{YY}^{-1} Y$

$$= R_{HH} (R_{HH} + \sigma_N^2 (X^H X)^{-1})^{-1} \hat{H}_{LS}$$

(10)

The performance of MMSE estimator is much better than LS estimator, especially under the lower E_b/N_o. However, because of the required matrix inversions, the computation is very complex when the number of subcarriers of OFDM system increases.

4.3 DFT Based Channel Estimation

To improve the LS or MMSE channel estimation performance, the DFT-based method has been proposed as it can advantageously target both noise reduction and interpolation purposes. Let $\hat{H}[k]$ denote the estimate of channel gain at the k^th^ subcarrier, obtained by either LS or MMSE channel estimation method. Taking the IDFT of the channel estimate $\left\{\hat{H}[k]\right\}_{k=0}^{N-1}$,

$$IDFT\left\{\hat{H}[k]\right\} = h[n] + z[n] \square \hat{h}[n], \quad n = 0,1,\ldots,N-1$$

(11)

where $z[n]$ denotes the noise component in the time domain. Reduction of the noise components owing to operations in the transform domain, and thus achieve higher estimation accuracy, define the coefficients for the maximum channel delay L as:

$$\hat{h}_{DFT}[n] = \begin{cases} h[n] + z[n], & n = 0,1,2,\ldots,L-1 \\ 0, & otherwise \end{cases}$$

(12)

Taking the DFT remaining L elements to transform in frequency domain [8-11] :

$$\hat{H}_{DFT}[k] = DFT\left\{\hat{h}_{DFT}(n)\right\} \tag{13}$$

DFT can be used simultaneously as an accurate interpolation method in the frequency domain when the orthogonality between training sequences is based on the transmission of scattered pilots. Figures 4(a) and (b) show the received signal constellation before and after channel compensation for the OFDM system with 16-QAM, illustrating the effect of channel estimation and compensation. Figure 5 illustrates the channel estimates obtained by using LS- linear, LS-spline and MMSE channel estimation methods with and without DFT technique and reveals that the DFT-based channel estimation method improves the performance of channel estimation. OFDM system parameters used in the simulation are indicated in the TABLE 1.

TABLE 1 SIMULATION PARAMETERS

Parameters	**Specifications**
FFT size	32
Number of symbol (M)	16
Guard interval	4
OFDM symbol length	36
Symbol duration	100
Pilot spacing	4
Number of pilot	8
Data per OFDM(modulated) symbol	24
Number of bits per symbol	4
Signal Constellation	16 QAM

Simulations are carried out for channel estimation using LS-Linear, LS-spline, MMSE methods. The Simulation results show that the performance of DFT based channel estimator is much better over the LS, MMSE estimator. Fig. 2 represents the improvement in estimated power with DFT operation.

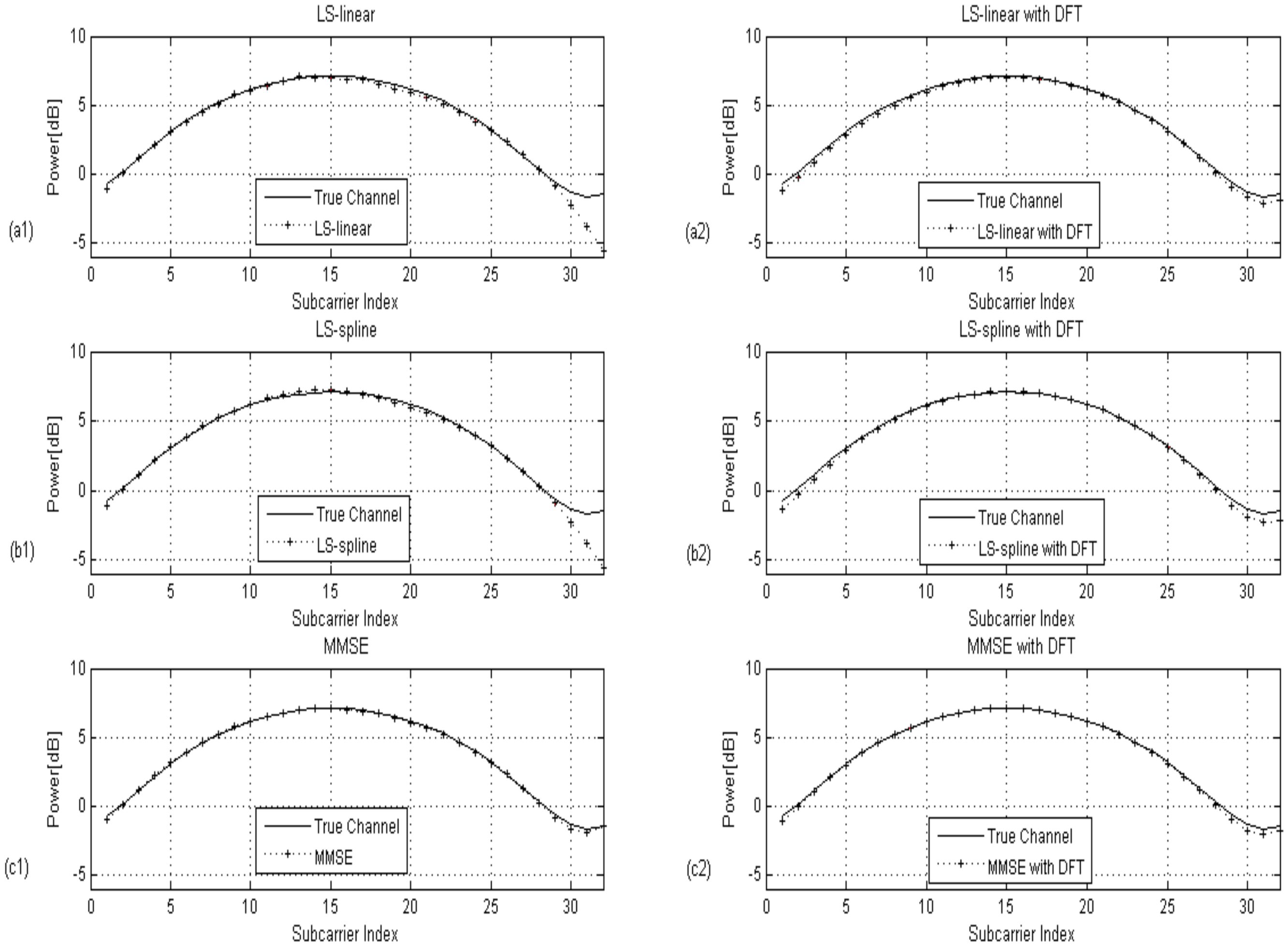

Figure. 2 Performance improvement of LS and MMSE with DFT-based channel estimation.

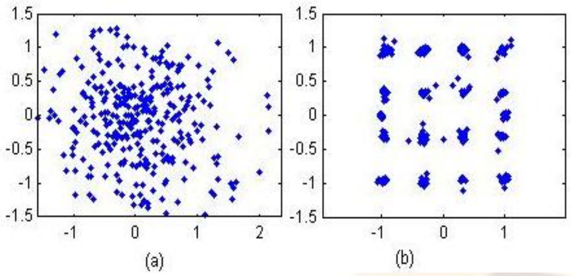

Figure.3 Received signal constellation diagrams (a) before and (b) after channel compensation.

Comparing the figures 2(a1) and 2(b1) with figure 2(c1), it is clear that the MMSE estimation shows better performance than the LS estimation does at the cost of requiring the additional computation and information on the channel characteristics.

5. Conclusions

Higher transmission rate and reliable communication over the wireless channel can be achieved through MIMO-OFDM system. Block-type pilot channel estimation is more suitable for the slow fading channel conditions, while the comb-type pilot channel estimation usually out performs for the middle and fast fading channels. This paper describes training (pilot) based channel estimation based on least square (LS), minimum mean-square error (MMSE) and DFT. For high SNRs the LS estimator is both simple and adequate. However, for low SNRs, MMSE will allow a compromise between estimator complexity and performance. The performance is observed to become better with the application of DFT technique.

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