Investigation on Channel Estimation techniques for MIMO- OFDM System for QAM/QPSK Modulation

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Abstract:
Multiple Input Multiple Output (MIMO) systems has provide high transmission data rate without increasing transmitting power for wireless communication systems. The performance can be further improved by properly estimating the channel at the receiver side. In this paper, investigation on various channel estimation techniques for MIMO-OFDM has been done and a new approach based on time-domain interpolation (TDI) has been presented. TDI is obtained by transforming output of estimator to time domain through Inverse Discrete Fourier Transform (IDFT), zero padding and going back to frequency domain through Discrete Fourier Transform (DFT). The comparison has been carried out between power of true channel and estimated power for the given channel using LS, LS-Spline and MMSE for QPSK/QAM modulation at SNR 30dB. It is investigated that by applying the DFT over the estimated power of channel for QPSK, the performance of the channel estimators becomes better.

Keywords: Channel estimation, Discrete Fourier transform (DFT), Least square error (LS), Minimum mean square error (MMSE), MIMO-OFDM, QAM, QPSK.

1. Introduction

MIMO-OFDM is an important part of modern wireless communication standards such as IEEE 802.11n, 4G, 3GPP LTE and WiMAX [1]. It can eliminate the effect of frequency selective fading and significantly increase both the system's capacity and spectral efficiency. The data rate can be increased by spatial multiplexing without consuming more frequency resources and without increasing the total transmit power.

The performance of the system depends generally on modulation schemes, channel estimation techniques used to estimate channel. The capacity of communication system increases linearly with the number of antennas, when perfect knowledge about the channel is available at the receiver. In practice, the channel estimation procedure is done by transmitting pilot (training) symbols that are known at the receiver. Further, channel estimation depends on the pattern of transmitting pilots. Block type and comb type patterns have been considered in this paper. LSE, MMSE algorithms have been used to estimate the channel. Simulations and comparisons are carried out for QPSK and QAM data using LSE, MMSE algorithms with and without DFT.

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 is described. Section 3 discusses Channel Estimation in MIMO-OFDM System. Section 4 describes channel estimation based on DFT. Simulation and results for the performance of LS, MMSE and DFT based techniques are given in section 5. Section 6 concludes the paper.

2. MIMO System

MIMO communication uses multiple antennas at both the transmitter and receiver to exploit the spatial domain for spatial multiplexing and/or spatial diversity. Spatial multiplexing [2]-[3] has been generally used to increase the capacity of a MIMO link by transmitting independent data streams in the same time slot and frequency band simultaneously from each transmit antenna, and differentiating multiple data streams at the receiver using channel information about each propagation path. In contrast to spatial multiplexing, the purpose of spatial diversity is to increase the diversity order of a MIMO link to mitigate fading by coding a signal across space and time so that a receiver could receive the replicas of the signal and combine those received signals constructively to achieve a diversity gain.

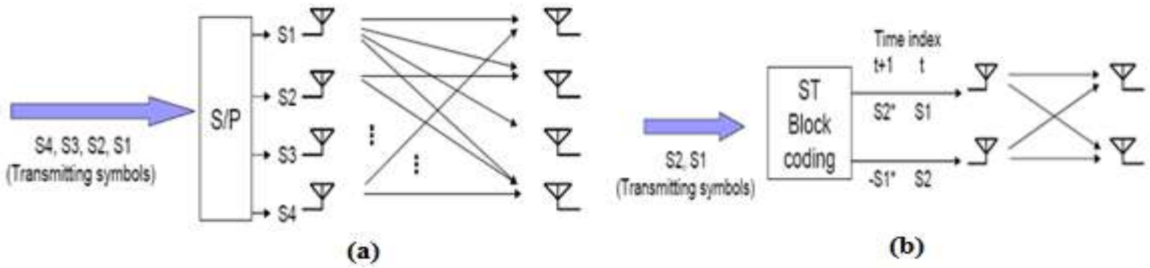


Figure 1. (a) Spatial Multiplexing (b) Spatial Diversity

Fig. 1.1 depicts a MIMO-OFDM [4] system consists of N_T transmitter antennas, N_R receiver antennas and K number of sub-carriers. Each transmitter (or receiver) antenna uses an ordinary OFDM modulator (or demodulator). $a^{(r)}(n)$ denotes OFDM symbol generated in r^{th} transmitted antenna for n^{th} time index, before transmitting the vector is processed by an

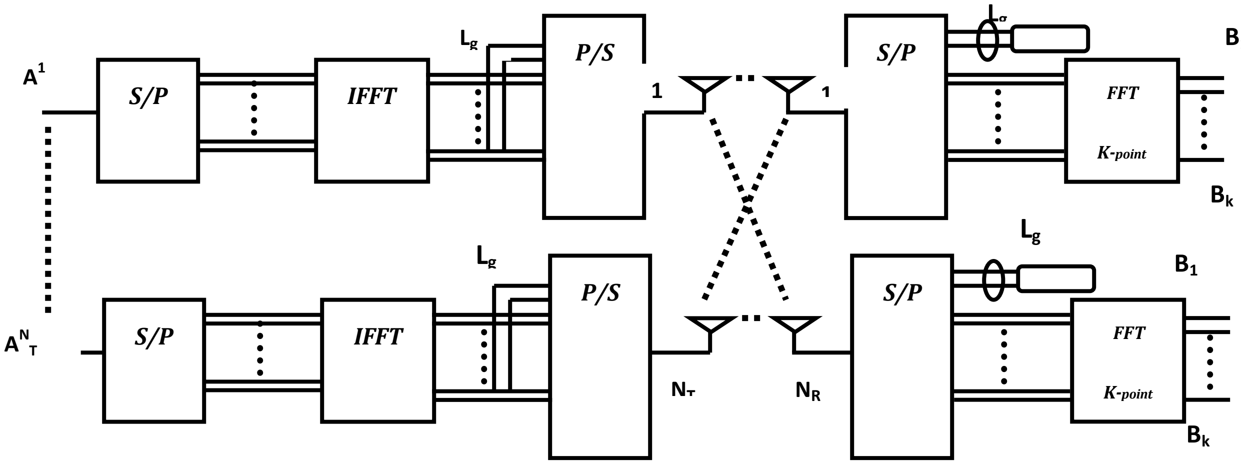


Figure 2. MIMO-OFDM

Inverse Fast Fourier Transform (IFFT) block with K points and a CP of length L_g is added to its beginning. The lengths of CP have to fulfill the inequality of $L_g \geq L - 1$ in which L is the maximum length of channel impulse response (CIR) among all sub-channels. At the receiver, after discarding the CP, OFDM symbol is received after processing Fast Fourier Transform (FFT) [5].

3. Channel Estimation in MIMO-OFDM System

An accurate estimate of the impulse response of the channel can be obtained, if the receiver has a prior knowledge of the information being sent over the channel. The pilots are transmitted on all subcarriers in periodic intervals of OFDM blocks for a slow fading channel, where the channel is constant over a few OFDM symbols and this type of pilot arrangement is known as block type pilot arrangement. The pilots are transmitted at all times but with an even spacing on the subcarriers, representing a comb type pilot placement as shown in Fig. 3 for a fast fading channel, where the channel changes between adjacent OFDM symbols. With interpolation techniques the estimation of channel at data subcarrier can be obtained using channel estimation at pilot subcarriers [6].

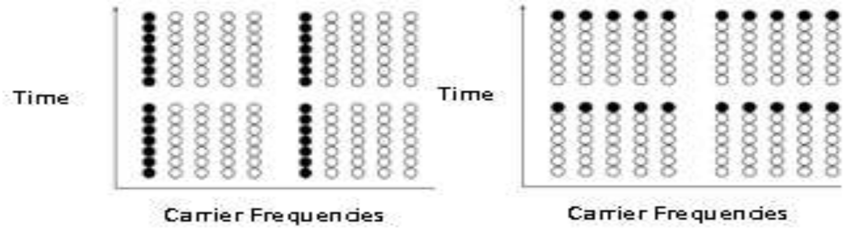


Figure 3. Block Type Pilot Arrangement and Comb Type Pilot Arrangement [6]

In this paper, whereas LS- Spline, piece-wise, second order, time domain interpolation technique has been employed for estimating channel at data subcarriers.

3.1. Channel estimation at pilot subcarriers

Various algorithms such as Least Square (LS), Minimum MMSE have been employed for estimating channel at pilot subcarriers.

3.1.1. Least Square (LS) Algorithm

Let A is the diagonal matrix of pilots as $A = diag\{A_0, A_1, \cdots, A_{N-1}\}$, N is the number of pilots in one OFDM symbol, $\hat{h}$ is the impulse response of the pilots of one OFDM symbol, and Z is the AWGN channel noise.
If there is no ISI, the signal received is written as [10]

$$B = AF\hat{h} + Z \tag{1}$$

where B the vector of output signal is after OFDM demodulation as $B = [B_0, B_1, \cdots, B_{N-1}]^T$,

$$\hat{H}_{LS} = A^{-1}B \tag{2}$$

Because of no consideration of noise and ICI, LS algorithm is simple, but obviously it suffers from a high MSE.

3.1.2. Minimum Mean Square Error

If the channel and AWGN are not correlated, MMSE estimate of H is given by [11]

$$\hat{H}_{MMSE} = S_{HB}S_{BB}^{-1}B \tag{3}$$

where $S_{HB} = E\{HB^H\} = S_{HH}A^H$

$S_{BB} = E\{BB^H\} = AS_{HH}A^H + \sigma_Z^2 I_N$

are the cross covariance matrix between H and B, and auto-covariance matrix of B respectively. S_{HH} is auto-covariance matrix of H. σ_Z^2 is the noise-variance. If S_{HH} and σ_Z^2 are known to the receiver, CIR could be calculated by MMSE estimator as below

$$\hat{H}_{MMSE} = S_{HB}S_{BB}^{-1}B = S_{HH}A^H\left(AS_{HH}A^H + \sigma_Z^2 I_N\right)^{-1}A\hat{H}_{LS} = S_{HH}\left(S_{HH} + \sigma_Z^2\left(A^H A\right)^{-1}\right)^{-1}\hat{H}_{LS} \tag{4}$$

At lower value of E_b/N_0 the performance of MMSE estimator is much better than LS estimator. MMSE estimator could gain 10-15 dB more of performance than LS.

3.2. Channel estimation at data subcarriers

In order to estimate channel at data sub-carriers by using the channel information at pilot sub-carriers, an efficient interpolation technique is necessary in comb-type pilot based channel estimation.

3.2.1. Piecewise Constant Interpolation

Channel is estimated by previous pilot in Piecewise constant interpolation. And the channel estimation is given by,

$$\hat{H}(k) = \hat{H}(lM + m) = \hat{H}_p(l), \qquad 0 \le m \le M, \qquad l = 0, 1, \cdots, N_p - 1 \tag{5}$$

where M = No. of subcarriers (N)/ No. of pilot (Np)
l = pilot carrier index.

3.2.2. Cubic Spline Interpolation

The cubic spline interpolation is given by [52],

$$\begin{aligned} \hat{H}(k) &= \hat{H}(lM+m) \\ &= c_1\hat{H}_p(l+1)+c_0\hat{H}_p(l)+Mc_1\hat{H}'_p(l+1)-Mc_0\hat{H}'_p(l) \\ &\qquad l=0,1,\cdots,N_p-1 \qquad 0\le m\le M, \end{aligned} \tag{6}$$

where M = No. of subcarriers (*N*)/ No. of pilot (N_p)
l = pilot carrier index.
$\hat{H}'_p(l)$ is the first order derivative of $\hat{H}_p(l)$, and

$$\begin{aligned} c_1 &= \frac{3(M-m)^2}{M^2}-\frac{2(M-m)^3}{M^3} \\ c_0 &= \frac{3m^2}{M^2}-\frac{2m^3}{M^3} \end{aligned} \tag{7}$$

Cubic spline interpolation with higher order interpolation can be used for better interpolation accuracy.

4. Channel Estimation Based On DFT

Application of DFT on LS, MMSE channel estimation can improve the performance of estimators by eliminating the effect of noise.

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

$$\left\{\hat{H}[k]\right\}_{k=0}^{N-1}, \quad IDFT\left\{\hat{H}[k]\right\} = h[n]+z[n] \square \hat{h}[n], \quad n=0,1,...,N-1 \tag{8}$$

where *z[n]* denotes the noise component in the time domain. Eliminate the impact of noise in time domain, and thus achieve higher estimation accuracy.

$$\hat{h}_{DFT}[n] = \begin{cases} h[n]+z[n], & n=0,1,2,...,L-1 \\ 0, & otherwise \end{cases} \tag{9}$$

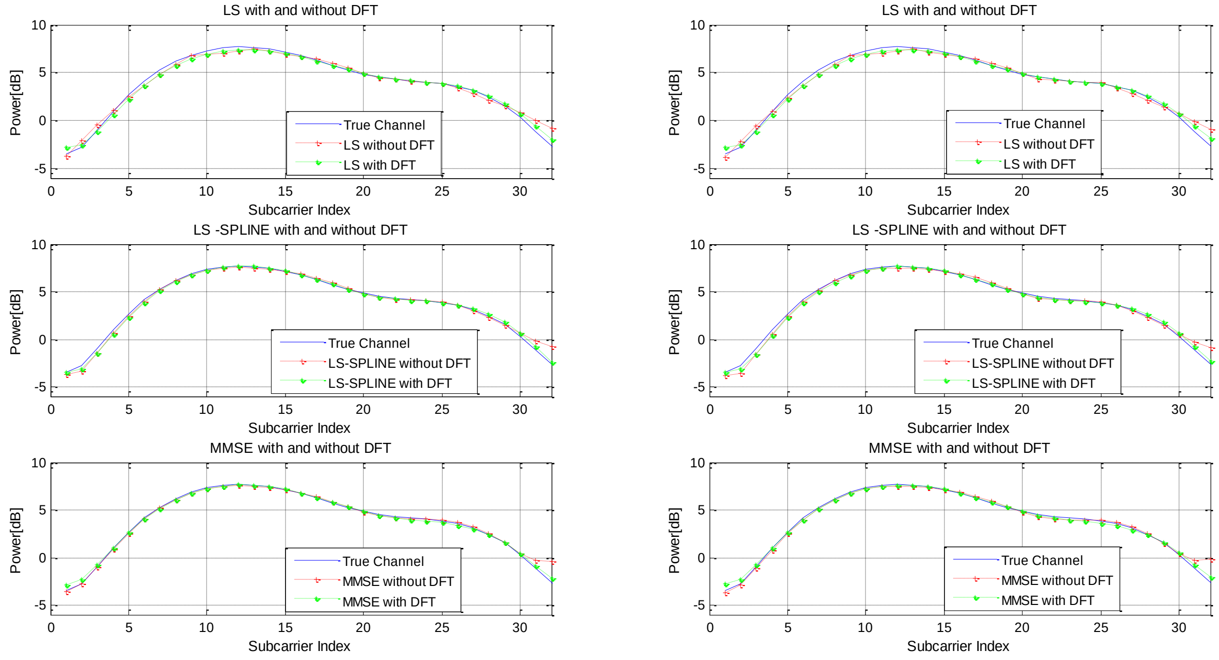
Taking the DFT remaining *L* elements to transform in frequency domain [12-14]

$$\hat{H}_{DFT}[k] = DFT\left\{\hat{h}_{DFT}(n)\right\} \tag{10}$$

Simulations are carried out for channel estimation using LS-Linear, LS-spline, MMSE methods for QPSK and QAM modulation schemes. The Simulation results show that the performance of DFT based channel estimator is much better over the LS, MMSE estimator in case of QPSK, but the symbol rate decreases. Fig. 2, 3 and 4 represents the performance of above mentioned channel estimator with and without DFT.

5. Simulations and Results

In this simulation work, first the random pilot sequence of length 8, where $X_p \in \{-1,1\}$ and data sequence of length 24, $a \in \{0,15\}$ are generated. Sequence ‘a’ is modulated using 16-QAM at SNR = 20dB, 30dB, 40dB. The pilot symbols are inserted in the modulated data sequence using pilot duration of 4 symbols and forms a new data sequence *A*. After pilot insertion data sequence *A* is converted into time domain sequence using 32-point IFFT and 4 symbol CP is added, the resultant sequence is denoted as ‘a_t’. The guard interval or the length of the CP is longer than the maximum delay spread of the channel. The sequence ‘a_t’ is then transmitted over a randomly generated 3-tap channel. AWGN is added to the received signal. The CP is removed from the noise corrupted received signal which is then subject to FFT. Now, since the transmitted pilots and received pilots are known, the CSI is estimated using LS Linear, LS-Spline Interpolation and MMSE.



QPSK QAM

Figure 4. Performance of MIMO-OFDM System using various Channel Estimations with and without DFT for QPSK and QAM at SNR 30 dB

In the simulations, the power of true channel and power obtained by using this estimation have been considered. The detectors at the receiver utilize this estimated channel to obtain the information out of the received signal which is then demodulated to get random bits. It is observed that simulation results become better if the estimated output from various estimators is subject to DFT. For subcarrier index 10, true channel power comes out to be 7.294dB. The simulations have been also calculated using LS linear for 10^{th} subcarrier index for QPSK at SNR=30dB and the estimated power is calculated as 6.879dB and result improved by 0.57 dB with application of DFT technique. For LS-spline without DFT, the estimated power is calculated to be 7.225dB, whereas on applying DFT performance of this estimation technique is improved by 0.003 dB. For MMSE the estimated power is calculated as 7.205 dB and performance improved by 0.0.021 dB on applying MMSE with DFT. For LS-spline without DFT for 10th subcarrier index at SNR=30dB for QAM the estimated power is calculated to be 7.207dB. Whereas on applying DFT over this estimation technique gives 7.204 dB of power. For MMSE the estimated power for 10th subcarrier index at SNR=20dB for QAM is calculated as 7.173 dB and performance improved by 0.29 dB on applying MMSE with DFT. At higher SNR=40dB, Estimated power using LS linear, for 10th subcarrier index for QAM is calculated as 6.902dB whereas on applying DFT over this estimation technique, the simulation results improved by 0.65 dB. Simulation results show that MMSE with DFT performs better than other estimations at the cost of computational complexity. The number of symbol errors in case of QPSK is 2 whereas in case of QAM value become 22.

6. Conclusion

MIMO-OFDM has the capability of transmitting information at high data rate without increasing the transmitting power. The performance of the system can be improved by estimating the channel parameters effectively. From the simulations it is concluded MMSE algorithm estimates the channel much better than LS at the cost of increasing complexity. The results improve when the output of estimator is subject to DFT. Moreover it is observed the QPSK data symbols results in less number of errors as compared to QAM at cost of decrease in symbol rate. A trade off has made for the performance of MIMO-OFDM system among complexity, symbol rate and symbol errors.

References

[1] Andrea Goldsmith,Wireless Communication, Cambridge University Press, 2005.

[2] H. Jiang and P. A. Wilford, A hierarchical modulation for upgrading digital broadcasting systems, IEEE Transaction on Broadcasting, vol. 51, 222-229, June 2005.

[3] Siavash M. Alamouti, A Simple Transmit diversity Technique for Wireless Communications, IEEE Journal on Select Areas in Communications, Vol. 16, No. 8, October 1998.

[4] PAN Pei-sheng, ZHENG Bao-yu, Channel estimation in space and frequency domain for MIMO-OFDM systems, ELSEVIER journal of China Universities of Posts and Telecommunications, Vol. 16, No. 3, Pages 40- 44, June 2009.

[5] Mohammad Torabi, Antenna selection for MIMO-OFDM Systems, ELSEVIER journal on Signal Processing, Vol. 88, Pages 2431-2441, 2008.

[6] Meng-Han Hsieh, Channel Estimation for OFDM Systems based on Comb-Type Pilot arrangement in frequency selective fading channels, IEEE Transaction on Wireless Communication,vol.2, no. 1, pp 217-225, May 2009..

[7] M. R. McKay and I. B. Collings, Capacity and performance of MIMO-BICM with zero-forcing receivers, IEEE Trans. Commun., vol. 53, no. 1, pp. 74–83, Jan. 2005.

[8] Minn, H. and Bhargava, V.K., An investigation into time-domain approach for OFDM channel estimation, IEEE Trans. on Broadcasting, 45(4), 400–409, 1999.

[9] Van de Beek, J.J., Edfors, O., Sandell, M. et al. Analysis of DFT-based channel estimators for OFDM, Personal Wireless Commun., 12(1), 55–70, 2000.

[10] Fernandez-Getino Garcia, M.J., Paez-Borrallo, J.M., and Zazo, S. DFT-based channel estimation in 2D-pilot-symbol-aided OFDM wireless systems, IEEE VTC'01, vol. 2, pp. 810–814, May 2001.