DFT based Channel Estimation Methods for MIMO-OFDM System using QPSK modulation technique

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ABSTRACT

Multiple-Output (MIMO) antenna systems provide high transmission data rate, spectral efficiency and reliability for wireless communication systems. These parameters can be further improved by combating fading, the effect of which can be reduced by properly estimating the channel at the receiver side. In this paper a new approach based on time-domain interpolation (TDI) has been presented. TDI is obtained by passing estimated channel to time domain through Inverse Discrete Fourier Transform (IDFT), zero padding and going back to frequency domain through Discrete Fourier Transform (DFT). The analysis of the channel estimators has been conducted using a MATLAB. 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 modulation at *SNR 30dB*. It is investigated that by applying the DFT over the estimated power of channel, the performance of the channel estimators becomes better.

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

I. INTRODUCTION

The design of a mobile communication channel is very challenging in these days due to severe multipath propagation, arising from multiple scattering by buildings and other structures in the vicinity of a mobile unit [1]. A wideband radio channel is normally frequency selective and time variant. Similar number of copies of a single transmitted signal reaches at the receiver at slightly different times. Various diversity techniques help to determine the transmitted signal at highly attenuated receiver side. Multiple input multiple output (MIMO) antenna systems are a form of spatial diversity. Deployment of multiple antennas both at transmitter and receiver side, achieves high data rate without increasing the total transmission power or bandwidth in the multipath rich environment. The major advantage of MIMO system is a significant increase of both the system's capacity and spectral efficiency. The capacity of a wireless link increases linearly with the minimum of the number of transmitter or the receiver antennas [2]. The capacity of communication system increases linearly with the number of antennas, when perfect knowledge about the channel is available at the receiver. Generally, MIMO detection schemes require perfect channel knowledge but it is never known before.

In practice, the channel estimation procedure is done by transmitting pilot (training) symbols that are known at the receiver. The quality of the channel estimation affects the system performance and it depends on the number of pilot symbols being transmitted. Training based channel estimation, blind channel estimation and semi blind channel estimation techniques can be used to obtain the channel state information (CSI). The CSI and some properties of the transmitted signals are used to carry out the blind channel estimation [3]. As in Blind Channel Estimation no pilot symbols are transmitted so it has advantage of no overhead loss; it is only applicable to slowly time-varying channels due to its need for a long data record. Training symbols or pilot tones that are known a priori to the receiver are multiplexed along with the data stream for training based channel estimation algorithms [4]. Semi-blind channel technique is hybrid of blind and training technique, utilizing pilots and other natural constraints to perform channel estimation.

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-OFDM SYSTEM AND CHANNEL ESTIMATION

In MIMO system signals are 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 [5].

MIMO-OFDM technology has been researched as the infrastructure for next generation wireless networks. OFDM simplifies the implementation of MIMO without loss of capacity, reduces receiver complexity, avoids ISI by modulating narrow orthogonal carriers and each narrowband carrier is treated as a separate MIMO system with zero delay-spread in MIMO-OFDM systems.

Basically, the MIMO-OFDM transmitter has N_T parallel transmission paths which are very similar to the single antenna OFDM system, each branch performing serial-to-parallel conversion, and pilot insertion, N-point IFFT and cyclic extension before the final TX signals are up-converted to RF and transmitted. It is worth noting that the channel encoder and the digital modulation, in some spatial multiplexing systems, can also be done per branch, where the modulated signals are then space-time coded using the Alamouti algorithm [6] before transmitting from multiple antennas [7] not necessarily implemented jointly over all the N_T branches. Subsequently at the receiver, the CP is removed and N-point FFT is performed per receiver branch. Next, the transmitted

$$A_1 = \left(A[0] \;\; -A^*[1] \;\; A[2] \;\; -A^*[3] \ldots\ldots\ldots\ldots -A^*[N-1]\right)$$

$$A_2 = \left(A[1] \;\; A^*[0] \;\; A[3] \;\; A^*[2] \ldots\ldots\ldots\ldots A^*[N-2]\right)$$

The vectors A_1 and A_2 are modulated using the IFFT and after adding a CP as a guard time interval, and are then transmitted by the first and second transmit antennas respectively.

$$a^{NT}(n) = IDFT\{A^{NT}(k)\} \quad (2)$$

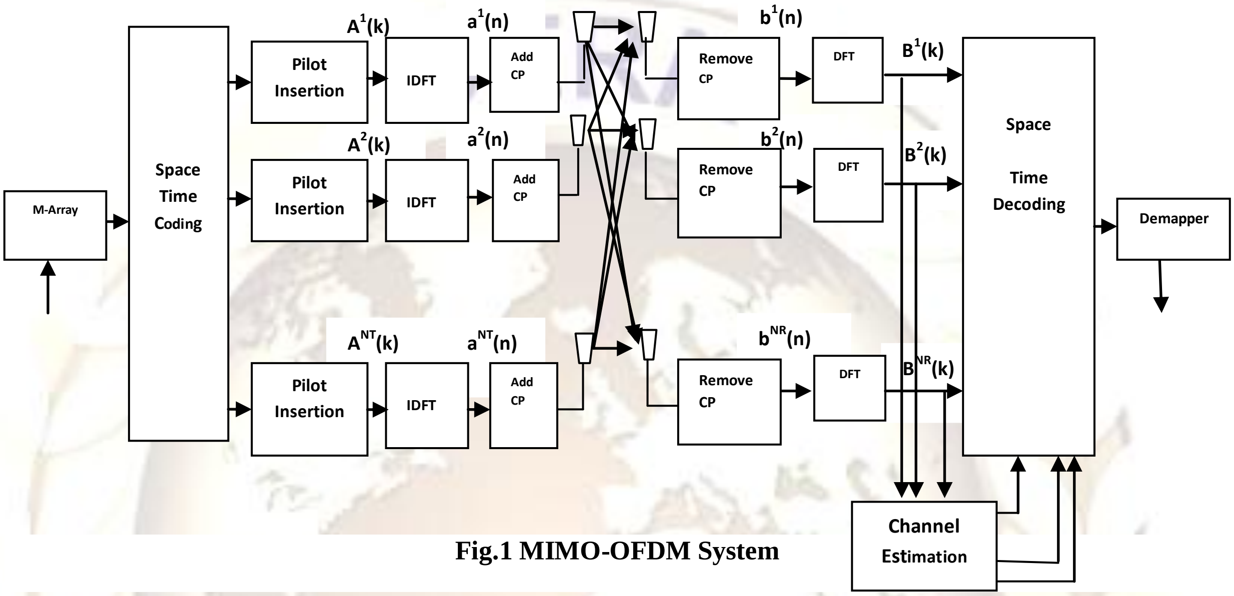

Fig.1 MIMO-OFDM System

symbol per TX antenna is combined and outputted for the subsequent operations like digital demodulation and decoding. Finally all the input binary data are recovered with certain BER.

As a MIMO signaling technique, N_T different signals are transmitted simultaneously over $N_T \times N_R$ transmission paths and each of those N_R received signals is a combination of all the N_T transmitted signals and the distorting noise. It brings in the diversity gain for enhanced system capacity as we desire. Meanwhile compared to the SISO system, it complicates the system design regarding to channel estimation and symbol detection due to the hugely increased number of channel coefficients. The data stream from each antenna undergoes OFDM Modulation. The Alamouti Space Time Block Coding (STBC) scheme has full transmit diversity gain and low complexity decoder, with the encoding matrix represented as referred in [8] for two transmitting and two received antenna with N number of subcarrier

$$A = \begin{bmatrix} A_1 & -A_2^* \\ A_2 & A_1^* \end{bmatrix} \quad (1)$$

Assuming that guard time interval is more than the expected largest delay spread of a multipath channel. The received signal will be the convolution of the channel and the transmitted signal. Assuming that the channel is static during an OFDM block, at the receiver side after removing the CP, the FFT output as the demodulated received signal can be expressed as

$$\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_{N_R} \end{bmatrix} = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,N_T} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots \\ H_{N_g,1} & H_{N_g,2} & \cdots & H_{N_R,N_T} \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_{N_T} \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_{N_T} \end{bmatrix} \quad (3)$$

In the above equation $\left[Z_1, Z_2 \cdots, Z_{N_T}\right]$ denotes Additive White Gaussian Noise (AWGN). The n^{th} column of H is often referred to as the spatial signature of the n^{th} transmit antenna across the receive antenna array. The purpose of channel estimation is to estimate channel parameters from the received signal. The function that maps the received signal and prior knowledge about the channel and pilot symbols is called the estimator. The effect of the physical channel on the input sequence can be characterized using channel estimation process. The channel estimate is simply the estimate of the impulse response of the system if the channel is assumed to be linear. A "good" channel estimate is one where some sort of error minimization criteria is satisfied. If *e(n)* denotes estimation error (difference between actual received signal and estimated signal), channel estimation algorithms are used to minimize the mean squared error (MSE), $E[e^2(n)]$ while utilizing as little computational resources as possible in the estimation process.

3. TRAINING BASED CHANNEL ESTIMATION USING LS AND MMSE ESTIMATOR

In this work we have considered Block Type and Comb Type pilot arrangements. 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 called the block type arrangement. The pilots are transmitted at all times but with an even spacing on the subcarriers, called comb type pilot arrangement 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. For comb-type pilot based channel estimation, the N_p pilot signals are uniformly inserted into *A(k)* according to the following equation [9]

$$A(k) = A(lM+m) \qquad m = 0,1,....,M-1$$
$$= \begin{cases} A_p(k) & m = 0 \\ \inf.Data & m = 1,2,......,M-1 \end{cases} \qquad (4)$$

where M = No. of subcarriers (N)/ No. of pilot (N_p)
l = pilot carrier index.
Frequency response of the channel at pilot sub-carriers defines as $\{H_p(k)\, k = 0,1,....N_p\}$. The estimate of the channel at pilot sub-carriers based on LS estimation is given by:

$$H_p(k) = \frac{B_p(k)}{A_p(k)} \qquad k = 0,1,.........,N_p-1 \qquad (5)$$

$B_p(k)$ and $A_p(k)$ are output and input at the k^{th} pilot sub-carrier respectively. LSE and MMSE algorithms are used for estimation of channel at pilot frequencies for both block type and comb type pilot arrangement. An interpolation technique is necessary in order to estimate the channel impulse response at data frequencies using channel information at pilot subcarriers.

3.1 LSE

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]
$B = AF\hat{h} + Z$

Where B the vector of output signal is after OFDM demodulation as $B = [B_0, B_1, \cdots, B_{N-1}]^T$,
^{T} is transpose, F is the Fourier transfer matrix. The purpose of LS algorithm is to minimize the cost function K without noise.

$$K = \left|B - AF\hat{h}\right|^2 \qquad (6)$$

Let $\hat{H}$ is the estimate impulse response of the channel

$$\hat{H}_{LS} = A^{-1}B \qquad (7)$$

or

$$\hat{H}_{LS} = \left[\frac{B_0}{A_0}\frac{B_1}{A_1}\frac{B_2}{A_2}\cdots\frac{B_{N-1}}{A_{N-1}}\right]^T$$

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

3.2 MINIMUM MEAN SQUARE ERROR

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

$$\hat{H}_{MMSE} = S_{HB}S_{BB}^{-1}B \qquad (8)$$

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

$$\begin{aligned}\hat{H}_{MMSE} &= S_{HB}S_{BB}^{-1}B \\ &= S_{HH}A^H\left(AS_{HH}A^H + \sigma_Z^2 I_N\right)^{-1}A\hat{H}_{LS} \\ &= S_{HH}\left(S_{HH} + \sigma_Z^2\left(A^H A\right)^{-1}\right)^{-1}\hat{H}_{LS}\end{aligned} \qquad (9)$$

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.

4. DFT BASED CHANNEL ESTIMATION

Application of DFT on LS, MMSE channel estimation can improve the performance of estimators by eliminating the effect of noise. In OFDM system, the length of the channel impulse response is usually less than the length of the cyclic prefix L. DFT-based algorithm uses this feature to increase the performance of the LS and MMSE algorithms. It transforms the frequency channel estimation into time channel estimation using IDFT, considers the part which is larger than L as noise, and then treats that part as zero in order to eliminate the impact of the 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

$$\left\{\hat{H}[k]\right\}_{k=0}^{N-1},$$

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

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.

$$\hat{h}_{DFT}[n] = \begin{cases} h[n]+z[n], & n = 0,1,2,...,L-1 \\ 0, & otherwise \end{cases} \qquad (10)$$

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

$$\hat{H}_{DFT}[k] = DFT\left\{\hat{h}_{DFT}(n)\right\} \qquad (11)$$

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, 3 and 4 represents the performance of above mentioned channel estimator with and without DFT.
OFDM system parameters used in the simulation are indicated in the TABLE 1.

Table 1 Simulation Parameters

Parameters	**Specifications**
FFT size	32
SNR	30 dB
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	2
Signal Constellation	QPSK

It is observed that simulation results become better if the estimated output from various estimators is subject to DFT. Simulation results show that MMSE with DFT performs better than other estimations at the cost of computational complexity.

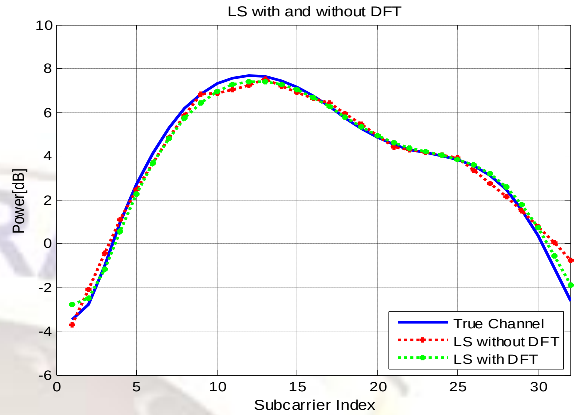

Fig. 2 Performance of MIMO-OFDM System Using LS-Linear Channel Estimation with and without DFT for QPSK at SNR 30 dB

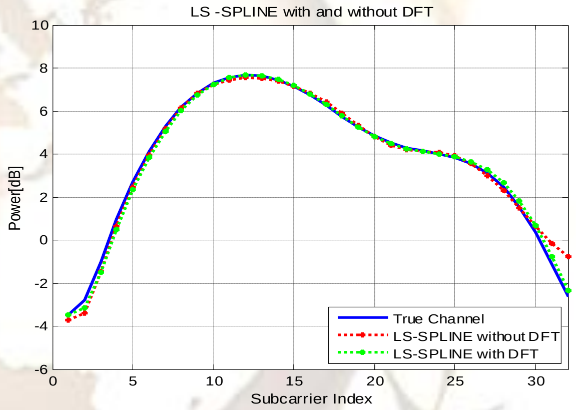

Fig. 3 Performance of MIMO-OFDM System Using LS-Spline Channel Estimation with and without DFT for QPSK at SNR 30 dB

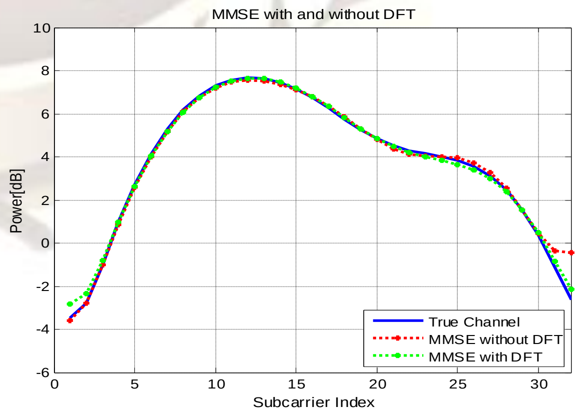

Fig. 4 Performance of MIMO-OFDM System Using MMSE Channel Estimation with and without DFT for QPSK at SNR 30 dB.

5. CONCLUSION

The combination of OFDM with Multiple Input and Multiple Output has fulfilled the future needs of high transmission rate and reliability. The quality of transmission can be further improved by reducing the effect of fading, which can be reduced by properly estimating the channel at the receiver side. For high SNRs the LSE estimator is both simple and adequate. The MMSE estimator has good performance but high complexity. To further improve the performance of LSE and MMSE, DFT based channel estimation is applied. For subcarrier index 10, true channel power comes out to be 7.294dB. Estimated power is calculated using LS linear, LS spline and MMSE as 6.879dB, 7.225dB and 7.205 dB and performance is improved by 0.57 dB, 0.003 dB and 0.0.021 dB respectively with application of DFT technique.

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