A COMPARATIVE STUDY OF CHANNEL ESTIMATION FOR MULTICARRIER SYSTEM FOR QAM/QPSK MODULATION TECHNIQUES

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Abstract— Rapid changes and growth in mobile communication have inspired the researcher for the better performance of the high speed wireless communication systems. This paper proposes the comparative study of Channel Estimation for the Multicarrier system using various estimation techniques mainly for skirmishing fading effect; it improves the performance of the system. The problems such as Inter-Carrier Interference which is mainly due to the carrier offset effect is reduced to a considerable extent by applying different estimation algorithm. A new approach based on TDI has been presented. TDI is obtained by passing estimated channel to time domain through Inverse Discrete Fourier Transform and zero padding. The comparison between the LS, LS-Spline and MMSE for QPSK and QAM modulation techniques for different SNR and FFT values has been carried out. It is investigated that by applying the DFT over estimated power of the channel for 16-QPSK modulation technique, the performance of the channel estimators becomes better.

Index Terms— Multi Input Multi Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Discrete Fourier Transform (DFT), Least Square Error (LSE), Minimum Mean Square Error (MMSE)

I. INTRODUCTION

Multicarrier modulations attract a lot of attention both in the case of wired and wireless communication system and it is difficult to design such a system as it has several problems in multipath propagation. 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. 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 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. The 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. 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 discussed. Section 3 discusses training based channel estimation. Simulation and results for the performance of LS, MMSE and DFT based estimation techniques are given in section 4 and Section 5 concludes the paper.

![Fig.1 MIMO-OFDM System](image-url)
II. MIMO-OFDM SYSTEM AND CHANNEL ESTIMATION

The figure 1 shows the Multicarrier communication system here multiple antenna are utilized both at transmitter and receiver ends so by this spatial diversity or spatial multiplexing techniques are exploited. By sampling the signals in spatial domain at both ends and combining them they either create effective multiple parallel spatial data pipes, and/or add diversity to improve the quality of the communication.

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 NT 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 before transmitting from multiple antennas not necessarily implemented jointly over all the branches. Subsequently at the receiver, the CP is removed and N-point FFT is performed per receiver branch. It is significant to note 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 before transmitting from multiple antennas not necessarily implemented jointly over all the NT branches. Subsequently at the receiver, the CP is removed and N-point FFT is performed per receiver branch. Next, the transmitted 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, NT different signals are transmitted simultaneously over NT X NR transmission paths and each of those NR received signals is a combination of all the NT 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 for two transmitting and two received antenna with N number of subcarrier.

\[
A = \begin{bmatrix}
A_1 & A_2
\end{bmatrix}
\]

(A \[0\] \[1\] \[2\] \[3\] \[\ldots\] \[N-1\])

The vectors A1 and A2 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.

\[
A^{NT}(n) = \text{IDFT} \{ A^{NT}(k) \}
\]

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

In the above equation \[
\begin{bmatrix}
\mathbf{e}_1 \mathbf{e}_2 \ldots \mathbf{e}_{NT}
\end{bmatrix}
\] denotes Additive White Gaussian Noise (AWGN). The n\textsuperscript{th} column of H is often referred to as the spatial signature of the n\textsuperscript{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.

III. 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 Np pilot signals are uniformly inserted into A(k) according to the following equation [9]

\[ A(k) = A(M+m) \quad m=0,1, \ldots \ldots , M - 1 \]

(4)

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

Frequency response of the channel at pilot sub-carriers defines as \( H_p(k) = H[0], H[1], \ldots \ldots , H[N] \). The estimate of the channel at pilot sub-carriers based on LS estimation is given by:

\[ H_p(k) = \frac{B_p(k)}{A_p(k)} \quad k = 0,1, \ldots \ldots , N_p - 1 \]

(5)

\( B_p(k) \) and \( A_p(k) \) are output and input at the kth 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.

A Least Square Estimation:

Let \( A \) is the diagonal matrix of pilots as \( A = \text{diag} \{ A_0, A_1, \ldots \ldots , A_{N-1} \} \). N is the number of pilots in one OFDM symbol, \( \hat{f}_l \) 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].

\[ B = A \hat{f}_l + Z \]

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

\[ K = [B - A \hat{f}_l]^2 \]

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

\[ \hat{H}_{LS} = A^{-1}B \]

(7)

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

B. Minimum Mean Square Error

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

\[ \hat{H}_{MMSE} = S_{HB}^{-1} B \]

Where \( S_{HB} = E\{BB^H\} = S_{BB}A^H \)

\( S_{HH} = E\{BB^H\} = S_{BB}A^H + \sigma^2 I_N \)

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

\[ \hat{H}_{MMSE} = S_{HB}^{-1} B \]

\[ = S_{HH}^{-1} (S_{BB}A^H + \sigma^2 I_N)^{-1} A \hat{H}_{LS} \]

(8)

At lower value of Eb/N0, the performance of MMSE estimator is much better than LS estimator. MMSE estimator could gain 10-15 dB more of performance than LS.

IV. 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 \( \hat{H}_L[k] \) 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

\[ \hat{H}(n) = \text{IDFT}[\hat{H}(k)] \]

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

\[
\hat{h}^{\text{DFT}}[n] = \hat{h}^{\text{DFT}}[n] 
\]

V. SIMULATION AND RESULTS

In the simulations, the power of true channel and power obtained by using this estimation have been considered. Table 1 gives the details of simulation parameters that are used. 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. There is an improvisation in the simulation results if estimated output values from various estimators undergoes DFT .

Table 1 gives the information about the simulation parameters. Here different subcarrier index values are considered which has been put-up in the Table 2. The simulation has been carried out for both QAM and QPSK modulation techniques for different constellation values and SNR values.

The simulations have been also calculated using LS linear with and without DFT and for LS-spline. It has been also carried out for MMSE with and without DFT. By the observation it is quite clear that DFT based estimation gives better results. For the subcarrier index 15th there is a improvement of 0.090dB improvement in LS liner with DFT over the without DFT one and similarly 0.060dB improvement in LS-spline with DFT.

For MMSE the estimated power for 20th subcarrier index at SNR=30dB for QAM is calculated as 6.298 dB for the true channel value and by the observation there is a improvement of 0.410 dB in the case of MMSE with DFT over without and similarly there is the improvement by 0.756dB seen even in the QPSK case for the MMSE with and without DFT.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
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<tr>
<td>FFT Size</td>
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<td>20 and 30</td>
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<td>Guard Interval</td>
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<td>Number of Pilot</td>
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<td>Modulation Techniques</td>
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<td>Constellation</td>
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</table>

Table 1: Simulation Parameter

Fig 2: Performance of MIMO-OFDM system for SNR=20 for 16-QAM

Fig 4: Performance of MIMO-OFDM system for SNR=20 for 16-QPSK

Fig 5: Performance of MIMO-OFDM system for SNR=30 and FFT=64 for 16-QAM

Fig 5: Performance of MIMO-OFDM system for SNR=30 and FFT=64 for 16-QPSK
In this paper various channel estimation techniques has been studied and compared. The major challenge is to reduce the effect of fading here it has been proved for all the channel estimation techniques when deployed with the FFT gives a much better result. For different values of subcarriers, the FFT size and different modulation techniques MMSE with DFT shows better result than others. The performance of the MMSE channel estimation with DFT gives a better result than other techniques with QAM technique for any values of SNR and FFT.

**REFERENCES**


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**Table 2**: Simulation Results for various SNR and FFT for QAM/QPSK modulation techniques

<table>
<thead>
<tr>
<th>SNR/NFFT/Modulation</th>
<th>Sub-carryr values</th>
<th>True Channel (power in dB)</th>
<th>LS-Linear without DFT (power in dB)</th>
<th>LS-Spline without DFT (power in dB)</th>
<th>LS-Spline with DFT (power in dB)</th>
<th>MMSE without DFT (power in dB)</th>
<th>MMSE with DFT (power in dB)</th>
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**CONCLUSIONS**

In this paper various channel estimation techniques has been studied and compared. The major challenge is to reduce the effect of fading here it has been proved for all the channel estimation techniques when deployed with the FFT gives a much better result. For different values of subcarriers, the FFT size and different modulation techniques MMSE with DFT shows better result than others. The performance of the MMSE channel estimation with DFT gives a better result than other techniques with QAM technique for any values of SNR and FFT.