Analysis of LSE and MMSE Pilot Based Channel Estimation Techniques for MIMO-OFDM System

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Abstract. An Orthogonal Frequency Division Multiplexing (OFDM) has becoming a desirable modulation technique scheme for wireless systems. In recent years, with the advent of technology in Very Large-Scale Integration (VLSI), the number of higher data level is growing. Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems are used to meet these criteria due to their high performance, in terms of transmission range, data rate resistance to multi-path transmission. A MIMO OFDM framework is designed for systems such as IEEE 802.11n, 4 G and LTE in advanced communication systems. It provides secure transmission with a growing coverage area. The estimation of Channel State Information (CSI) is the biggest challenge in the implementation of MIMO-OFDM method. We evaluate and enforce the pilot-based channel analysis methods for MIMO-OFDM system such as Minimum Mean Square Errors (MMSE), Least Square (LS).

Keywords: MIMO-OFDM System, Spectral performance, Higher Data Rates, Channel State Information (CSI), Minimum Mean Square Errors (MMSE), Least Square (LS).

1. Introduction

In recent years, research on increasing the level of data transmitted through the communication network become unavoidable. Besides large files, bandwidth-intensive applications like video-on-demand and video streaming requires high data transmission rate and establish real-time connections in a reasonable amount of time. Broadband communication systems are required to support this type of service.

The speed of data transmission is increasing from one generation to other mobile system generation, which will completely support multimedia services of good quality, audios, videos, Wi-Fi connectivity, and other high-quality wired services. With these increasing demands for higher data rates coupled with efficient utilize the available spectrum; Orthogonal Frequency Divisional Multiplexing (OFDM) approaches have been introduced to meet these requirements. Since MIMO technique is one among the most preferable wireless communication technologies, it provides full improvement and data coverage without high bandwidth or those OFDM complex transmission systems. This also provides a high-performance range and stable interconnections. In current wireless technology, the most essential part is MIMO, because of its properties.

Channel State Information (CSI) offers communication channel characteristics over a wireless network. It provides an extension of the transmitter-receiver signal transmission and describes the results of scattering, fading, and other channel impairments to achieve effective communication, CSI should combine existing network conditions with the transmission data. This CSI must be provided by the transmitter and transmitted to the receiving end. Information on channel state is acquired using
various channel estimation algorithms. These connections are managed with possibly the best-known range of bit series that are unique to a particular transmitter and are repeated as each transmission explodes. Therefore, the channel estimator predicts the channel responds for different popular receive bit bursts and associated receive patterns.

2. Literature Survey

An LTE (Long Term Evolutions) system has proposed a means for more mobile users to suppress repeated channel projections and inter-carrier interference (ICI). QAM algorithm uses a radio channel in the receiver to estimate pilot signals, data signals and Doppler-borne information has been proved by W Hardjawana, B Vucetic, R Li [2]. Estimation of channels is obtained by LS (Least Square) method. The Simplified PIC (Parallel Interferences Cancellation) scheme is used along with the Decision Statistical Combination (DSC) to mitigate the ICI and improve the data mark recognition. Jain and Nandal [1] the channel estimation performance of MIMO communications networks was measured and compared using the STBC, SFBC and STFBC methods for the different OFDM systems. The output is calculated using Matlab on a variety of models.

A brief overview of channel estimation techniques for MIMO-OFDM was given by author RituBabulkar [15]. It was studied and concluded on the basis of review of the literature that the LS channel estimation method is less complicated to implement compared to other methods, but that it does not allow effective noise estimation, because with a lot of mistakes it assesses noise. This demonstrates the limitations of the LS method, which in the MMSE channel estimation method has been reduced, but due to the need to invert the matrix, the MMSE design is more complex. Furthermore, the error at this level is not greatly reduced and also requires known pilot bits. The least square method is often extended to use second order signals for statistics for block and comb pilot symbols [14]. This leads to an estimation of the minimum mean square error (MMSE), which requires much more computational effort to be more accurate.

Bhagat and Malhotra [3] were defined different categories of Channel Estimation methods Least Squares (LS), Least Minimum Mean Squares Errors (LMMSE) and Minimum Mean Squares Errors (MMSE) respectively. Those estimates were added to the mean, as well as MMSE and LS. Comparison of the output of MSE and BER for the two forms of estimators were done. W Hardjawana, B Vucetic, Y Li and R Li [4] were introduced a new pilot-assisted reproducible receiver based on soft estimates of pilot and data symbols, which combines ICI cancellation and decoding algorithms. Using discrete time scaling and Least Square (LS) methods, one can estimate channels. An effective approximation of the received signals is achieved with a measurement Maximum A-Posterior (MAP) and then enhanced with reputative procedure.

3. Overview of OFDM

The main requirements for any communication system are large data rates and moderate error rate in bit. Orthogonal Frequency Division Multiplexing (OFDM) enables significantly faster data rates over frequency selective channels. An OFDM is a kind of a Frequency Division Multiplexing(FDM) this is used as multicarrier modulations. This is a special multicarrier transmitting case when an individual data flow is transmitted across multiple slow sub-carriers. Every channel will have the transmission rate which is lower than the usual data rates that of single-carrier transmitter. An OFDM is the idea of dividing the total bandwidth into several orthogonal subcarriers and use these subcarriers for parallel symbol transmission.

The OFDM's unique property is orthogonality among subcarriers, which is obtained through the division of carriers into closely spaced orthogonal channels or subcarriers. This property guarantees a significant reduction in Inter Carrier Interferences (ICI). Therefore, the transmitter and receiver design become easier compared to the FDM method. It is much easier to insert guard intervals between DDM symbols if the symbol duration is longer. Therefore, Inter Symbol Interferences (ISI) is effectively eliminated without use of a pulse shaping filter. OFDM was the basis
of many telecommunication standards, including most of the world's wireless Local Area Network (LAN), Digital Terrestrial Televisions (DTT) and Digital Transmission.

![Figure 1: Basic block diagram of OFDM](image)

4. Estimation of Channel

Channel State Information (CSI) provides knowledge of the channel properties of link resources for wireless connections. CSI must be evaluated at the receiver and normally must be returned to the sender. The transmitters and the receivers may have different CSI that are either instant or statistical. The current state of the transmitter is known and verified by realizing the reaction to the impulse of a transmissible pattern. Statistical CSI also contains statistical properties such as propagation of attenuation, channel gains, and high variations.

![Figure 2: Channel Estimation Algorithm](image)

The acquisition of CSI is practically limited by the speed at which the behavior of the channel changes. Statistical CSI is appropriate in fast fading models where the channel varies within a shorter duration than the symbol time. However, the instantaneous CSI can be estimated with reasonable precision in slow fading systems. Therefore, the technique of channel signaling is implemented to increase the reliability of the received data. Radio stations are usually multipath fading signals in wireless communication networks which cause inter-symbol interferences (ISI) in the receiver end. In the receiver side, the different detection algorithm is used for removing the ISI from signals. Such detectors should be aware of Channel Impulse Responses (CIR) with separate channel estimation method.
5. MIMO-OFDM System

![Diagram of MIMO-OFDM System](image)

Figure 3: MIMO-OFDM System

Considering the MIMO OFDM system with the N_Tx Transmitter (Tx) and N_Rx Receiver (Rx) antenna. Typically, the entering bit streams are initially coded with single-dimension encoders, and then the bits encoded on the available parameters were mapped using Space Time Frequencies (STF) Mapping. Through Tx branch has nearly one complete OFDM transmitter, after STF Mapping.

![Diagram of MIMO-OFDM Tx System](image)

Figure 4: MIMO – OFDM Tx System

The CP is extracted on the receiver side, and FFT is carried out for each branch of the receiver. In the context of a uniform representation, it is necessary at this point to carry out a general recognition and decode of STF to capture the binary digital signal. Since the MIMO algorithm is a Single Carrier Algorithm and the MIMO identification functions are normally done for each sub-carrier of OFDM. Signals obtained from sub-carriers i are sent to the i-th MIMO detectors for this purpose, to restore the transmission N_t-QAM symbol on these sub-carriers. For every Tx stream, the symbol is then normalized and finally, STF de mapping and decoding for the related N_t flows and the resulting information are merged to produce a signal at output.
Finally, focus on the benefit of OFDM that introduce some similarities through the \( N_c \) subcarriers. This fact can be used in MIMO-OFDM. In other words, on a subcarrier, when MIMO detections are performed, a particular detector calculates similar \( N_c \) with the equivalent data rate in a carrier system that is slower than the equivalent MIMO detector.

6. Pilot Based Channel Estimation

Pilot Based Channel Estimations are also called as a Training Based Channel Estimation. The channels are assessed based on the training sequences which are also known to the receivers and transmitters. Using training bits and samples received from them in the receiver could even assess the channels. The proposed techniques used in estimation methods of pilot channels are Least Squares (LS) and Minimum Mean Squares Errors (MMSE).

6.1 Least Square Algorithm

An evaluation technique Least Square (LS) is used for measuring the function \( h[m] \) by reducing the standard errors between measurement and analysis.

This can be written in matrix form as

\[
j = Xh
\]

(1)

And the error ‘e’ is determined as

\[
e = j^\circ - j
\]

(2)

Where, \( j^\circ \) is a predicted result and the square errors (S) is defined as

\[
S = |e|^2
\]

(3)

\[
S = (j^\circ - j)^2
\]

(4)

\[
S = (j^\circ - j)^*(j^\circ - j)
\]

(5)

Whereas superscript ‘\( t \)’ denotes the complex transpose of the matrix.

\[
S = (j^\circ - Xh)^*(j^\circ - Xh)
\]

(6)

The expression can be reduced by considering the derivatives ‘\( h \)’ and equating it with zero. We get the overall expression as

\[
h^\circ = (X^t X)^{-1}X^t j
\]

(7)

This is written as

\[
h^\circ = X^{-1} j
\]

(8)

\[
hls = X^{-1} j
\]

(9)
On MIMO systems this equation is implemented.

6.2 Minimum Mean Square Error

This type of estimator helps to reduce the errors in the mean squares. When 'X' is transmission across a channel response 'h', then

\[ j = X h \]  

(10)

Error is expressed as

\[ e = j^* - j \]  

(11)

Which \( j^* \) is predicted result

\[ \text{Mean Square Errors} = \text{mean} \left( \left( j^* - j \right)^2 \right) = E \left( \left( j^* - j \right)^2 \right) \]  

(12)

In which 'E' is an operator for the expected values and definition of both the expected value and correlations are used to obtain channel response.

An approximate channels \( H_{\text{mmse}} \) are calculated from equation

\[ H_{\text{mmse}} = F * \left( R_{gJ} * R_{JJ}^{-1} * J \right) \]  

(13)

Where, \( F \) represents the noise matrix

\[ R_{gJ} = R_{gg} * F^*X' \]  

(14)

\[ R_{JJ} = X^*F^*R_{gg}F^*X' + \text{Noise Variances} * \text{Identity Matrix} \]  

(15)

Where

- \( R_{gg} \) = auto co-variance matrices of 'g'
- \( R_{JJ} \) = auto co-variance matrices of 'J'
- \( R_{gJ} \) = cross co-variance matrices of 'g' and 'J'

For a MIMO system these equations can be used.

7. Simulation Result

In these sections, simulation of frequency response for Least Square channel estimate, equalization, actual channel scatter plot, estimated channel scatter plot were carried out. Once approximation of the channels is recognized, equalization becomes simpler.

7.1 Least Square Outputs

Frequency response of input and output is shown in figure 6. The normalized frequency is taken in x axis for both input and output and Magnitudes in dB is taken in y axis for the input graph, Phase in degrees is taken in y axis for the output graph. In the figure 7, the estimated channel scattered plot is shown for Least Square (LS) Estimation.
7.2 Minimum Mean Square Error Estimation

In figure 8, this graph shows the Bit Error Rates Vs Signal to Noise Ratio for an OFDM receiver system with the Minimum Mean Squares Errors (MMSE) estimators. In the above graph, it is shown that when SNR reaches 10 dB, BER becomes zero. The efficiency of MMSE is calculated using BER.
In the figure 9 and 10 the actual and estimated channel scatter plot is shown for Minimum Mean Squares Errors (MMSE) estimation technique.

8. Conclusion
The combination of OFDM with multiple inputs and multiple outputs meet the future requirements of high transmission rates and reliability. In performances, the channel estimation plays significant role such as wireless communication system. Therefore, the deployment of efficient channel estimation algorithms is important which will minimize the effect of channel variations and allow detection and retrieval of synchronized signals on the receiver. Transmission quality can be further improved by reducing the fading effect, which can be done by accurate estimation of the channels by receivers. In this paper, pilot-based channel estimate algorithm specifically Minimum Mean Squares Errors and Least Squares is explained and analyzed using MATLAB software. Estimation by the LS for high SNR is easy and reasonable, whereas MMSE estimation performance is good, but the increase in the number of carriers, will eventually increase the computing efficiency of the MMSE rapidly. Due to the simplicity of the LS method, this approach was commonly used for estimating the channels; even MMSE is far more efficient than LS estimates. Therefore, estimation technique then a tradeoff between efficiency and computation complexity.

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