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Performance analysis of channel estimation techniques in MIMO-OFDM

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Abstract

In wireless communication, multiple input multiple output-orthogonal frequency division multiplexing (MIMO–OFDM) plays a major role because of its high transmission rate. A multiple-input multiple (MIMO) communication system combined with the orthogonal frequency division multiplexing (OFDM) modulation technique can achieve reliable high data rate transmission over broadband wireless channels. The channel estimation based on comb type pilot arrangement through different algorithms for estimating channel at pilot frequencies is investigated in this paper. The estimation of channel at pilot frequencies is based on LS, MMSE and LMMSE channel estimation algorithm. The performances of channel estimation algorithm is compared in LS, MMSE and LMMSE channel estimation techniques by measuring MSE vs. SNR with QPSK modulation scheme. LMMSE estimation has been shown to perform much better than LS and MMSE.

Keywords: channel estimation, OFDM, transmitting antennas, receiving antennas, MIMO, AWGN

1. Introduction

In order to fulfill the high data speed demand in current increasing multimedia scenario, there is required to research more in this field. Many researchers focused their work in enhancing the performance rate. In this research work, literature focuses on the work performed in the field of noise estimation in wireless channel. It is done because as the noise level in channel will be estimated, there would be convenient for transceivers for successfully receive data bits correctly. Good channel estimation technique will make the system more robust and consequently performance will be enhanced.

For implementing the channel estimation technique, researchers are mainly focusing on MIMO-OFDM communicating system as its ability is to enhance the channel capacity or the more and more users can send their data bits in limited bandwidth and it also increases the diversity gain with multiple transmitter and receiver. As OFDM is used in wireless communication for high quality data transmission and enhancing the spectral efficiency. The combination of MIMO system with OFDM system increases the complexity of the system. As a consequence, the wireless channel have an issue of inter symbol interference (ISI) which degrades performance of the entire system. With increased number of users in limited bandwidth there is requirement of channel estimation technique [1].

In the whole scenario there arise a question that why there is need of channel estimation technique? The answer to this question is that the channel estimation is important because if the estimation is not performed, the receiver will not be aware about the level of interference caused in the channel. As a consequence of whole, wrong data stream will be received, error correcting code will not perform well, antenna selection will go wrong, modulation goes wrong, etc. In this literature review several non-blind channel estimation techniques, which needs a large number of received symbols to extract statistical properties, are discussed. The review gives the result analysis of several work and finally comparative analysis is also performed which leads in the direction of finding the problem statement for development.

2. Related Work

In wireless communication, more than one signals are transmitted in the channel by using the concept of Orthogonal frequency division multiplexing (OFDM) which efficiently handles the inter symbol interference and utilizes the frequency and available bandwidth efficiently. Whereas for OFDM transmission technique is integrated with MIMO channel which contains multiple transmitter and receiver antenna at both ends. By using MIMO-OFDM system, different signals can be transmitted at the same time by utilizing same frequency and get separated in the space. As the transmitting antenna transmit signal in the noisy channel so, it is required to estimate the noise in the channel. The channel estimation technique in noisy channel helps in analyzing the effect of noise on the transmitted data. Babulkar [1], a brief review is presented for channel estimation techniques for MIMO-OFDM.

Yujie Fan, Hui Li, Shuangshuang Song, Weisi Kong, Wenjie Zhang [2], (2018) proposed a structured compression sensing (SCS)-based time-frequency joint channel estimation scheme for MIMO systems, which considerably outperforms the traditional scheme in spectrum efficiency, reliability and computational complexity. First of all, the TFT-OFDM for the MIMO system scheme produces higher spectral efficiency as well as more accurate channel estimation. In addition, the proposed PA-ASSP algorithm for accurate channel estimation has better reliability and lower complexity than the classical SP algorithm and the improved ASSP algorithm.

Table 1

Channel Estimation	SNR (in db)	BER	MSE
PA-ASSP Channe Estimation	0-30 db	10^{-1} to 10^{-2}	10^{-1} to 10^{-4}

Hao Wu, Member, Yuan Liu, and Kai Wang, [3], (2018), showed the impact of extended Kalman filter channel estimation technique over massive-MIMO system. It has been observed that in low SNR scenario, the non-allocating sub carriers with Zero padding gives optimal results. The work is based on fast Fourier transform/inverse fast Fourier transform for reducing the transmission complexity.

Table 2

Channel Estimation	NMSE Evaluation	
	RMSE	SNR
Extended H∞ Filter (EHF)	10^0-10^3	-30-30 db
Extended Kalman Filter (EKF)	10^0-10^4	-20-20 db

In this research work, DFT based channel estimation is also discussed for uplink massive MIMO system. The simulation result shows the limitation of the proposed methodology in low SNR AWGN channel. The optimal result is shown with extended Kalman filter with FFT system that reduces the computational complexity of the system significantly.

From this research work it is concluded that mismatch in carrier frequency can result in inter-carrier interference (ICI). So, from this paper, researcher got the idea of FFT and DFT based channel estimation for MIMO system.

Aqiel Almamori, Seshadri Mohan [4], (2018), proposed the Channel state information (CSI) estimation for detection of input signal data with Kalman Filter and prior knowledge of the channel or known pilot bits. The researcher designed the system with QPSK modulation based OFDM. The received signal is processed by modified Kalman filter to produce channel state information (CSI) and to estimate the channel noise. The result analysis of modified Kalman filter is less dependent on the statistics of the channel and gives minimum MSE.

Table 3

Algorithm	BER	SNR
Kalman Filter	10^{-2}-10^{-5}	0-40 db

The result shows that the proposed algorithm can estimate the CSI with low MSE and comparable sum rate to a MMSE method which needs perfect prior channel statistics. From this research, researcher got the idea of channel estimation for OFDM system from the transmission of known pilot symbols.

Pham Hong Lien, Nguyen Due Quang and Luu Thanh Tra, (2017) [5] proposed an modified algorithm for channel estimation by combining CFO technique with mobile OFDM system. Some of the existing channel estimation techniques are such as LS (Least Square), Minimum Mean Square Error (MMSE), Kalman Filter and Extended Kalman Filter based channel estimation. The result analysis is performed with modified algorithm and compared with other existing algorithms. For research performance enhancement, the extended Kalman filter algorithm is modified with CFO which jointly estimates the channel frequency from the transmission of known pilot symbols. The proposed algorithm gives best result in fading environments for high speed vehicular mobile network with OFDM system.

Table 3

Algorithm	Complexity
Kalman	$O(N/4)^3$
Extended Kalman Filter (EKF)	$O(N/2)^3$
Extended Kalman Filter-CFO	$O(N+1)^3$

Table 4

Algorithm	BER	SNR
Kalman	10^{-1}-10^{-2}	0-40 db
Extended Kalman Filter (EKF)	10^{-1}-10^{-2}	0-40 db
Extended Kalman Filter-CFO	10^{-1}-10^{-3}	0-40 db

From this research, researcher got the idea of channel estimation for OFDM system from the transmission of known pilot symbols.

M. Raju and K. Ashoka Reddy [6], (2016), analyzed the impact of Least Squares (LS), Minimum Mean Square Error (MMSE) channel estimation techniques for MIMO-OFDM System. For result analysis MSE (Mean Square Error) is considered as a performance parameter for channel noise estimation for BPSK, M-ary QAM modulation schemes over the AWGN and Rayleigh fading channel.

Table 5

Channel Estimation	BPSK		8-QAM	
	MSE	SNR	MSE	SNR
MMSE	Between 10^{-2} and 10^{-3}	0-30 db	Between 10^{-2} and 10^{-5}	0-30 db
LS	Between 10^{-4} and 10^{-7}	0-30 db	Between 10^{-4} and 10^{-7}	0-30 db

As a result, the transmitting signal with pilot symbols is constructed. From result it is observed that LS channel estimation technique gives higher MSE as compared with MMSE channel estimation technique for low SNR value for conventional OFDM systems with single transmit/receive antenna. The use of multiple transmitter and receiver antennas delivers more enhanced performance.

From this research, researcher got the idea of channel estimation for OFDM system from the transmission of known pilot symbols.

Kalpesh Hiray, K. Vinoth Babu [7], (2016) designed a multi layered perceptron (MLP) neural network based channel estimation technique for estimating the channel efficiently. For result analysis, Monte –Carlo simulations are performed and compared with LS channel estimation technique. The performance parameter used is SER and simulation is performed for low SNR values. The channel is considered as noisy with AWGN. For the SNR value of 6db, SER evaluated is 10^{-2} for LS channel estimation technique whereas for MLPNN channel estimation technique the SER value is achieved at 5 dB, thereby a 1 dB of overall gain is achieved.

Table 6

Algorithm	SER	SNR
MLP channel estimation	10^{-1}-10^{-2}	0-8 db
LMS channel estimation	10^{-1}-10^{-4}	0-8 db

From this research, researcher got the idea of neural network channel estimation for MIMO-OFDM system from the transmission of known pilot symbols and the work may be extended towards MIMO system.

Yihua Yu and Yuan Liang [8], (2012), discussed about the limitations of the joint carrier frequency offset (CFO) and channel estimation for MIMO-OFDM systems under time-varying channels. Different CFO values are considered for different pairs of transmitting and receiving antenna. The channel estimation is performed by extended H∞ filter (EHF). The result analysis compares the performance of the conventional extended Kalman filter (EKF) and EHF. The technique does not require the information about the noise in the channel and shows that the system is robust under different conditions.

Table 7

Channel Estimation	**RMSE Evaluation**		**RMSE Evaluation**	
	RMSE	**SNR**	**RMSE**	**Noise variance error**
Extended H∞ Filter (EHF)	$10^{-0.8}$ - 10^{-1}	0-18 db	$10^{-0.8}$ - $10^{-0.9}$	0-10
Extended Kalman Filter (EKF)	$10^{-0.8}$ - 10^{-1}	0-18 db	$10^{-0.8}$ - $10^{-0.9}$	0-10

The performance parameter taken for the proposed system is RMSE and it is observed that the value of EHF method is near about EKF method, even though the EHF does not have any prior information about noise in the channel whereas the EKF have the prior knowledge of the noise in the channel.

From this research work it is concluded that mismatch in carrier frequency can result in inter-carrier interference (ICI). So, from this paper, researcher got the idea of channel estimation for MIMO-OFDM system without knowledge of noise distributions.

Jun-Han Oh and Jong-Tae Lim [9], (2010), proposed a channel estimation technique that work in two steps. The proposed model consists of equalization technique based on threshold value and time varying LS channel estimation techniques. For error reduction of the proposed technique, researcher gives the concept of adaptable threshold values by using noise variance values for different sub-carriers. Further the detected symbols are propagated and determined by the threshold values. As result comparison with pilot based channel estimation technique, the proposed channel estimation technique is better and generates low BER.

Table 8

Algorithm	**BER**	**SNR**
Two-step channel estimation (8-pilot)	10^{0}-10^{-3}	0-30 db
LS estimation (8 pilot)	10^{0}-10^{-1}	0-30 db
LS estimation (16-pilot)	10^{0}-10^{-2}	0-30 db

From this research, researcher got the idea of channel estimation for OFDM system from the transmission of known pilot symbols.

3. Channel Estimation Techniques

Channel Estimation is the method of characterizing the effect of the physical medium on the input sequence. It is an essential function for wireless systems. Even with a limited knowledge of the wireless channel properties, a receiver can achieve insight into the data sent over by the transmitter. The main goal of Channel Estimation is to measure the property of the channel on known or partially known set of transmissions [10].

i. Least Square (LS) Channel Estimation

The Least Squares Error (LSE) estimation technique can be used to estimate the system by minimizing the squared error between estimation and detection. The least square (LS) channel estimation method finds the channel estimate ^H in such a way that the following cost function is minimized:

$$J(\hat{H}) = ||Y - X\hat{H}||^2 \tag{1}$$

Where, $\hat{H}$ is channel estimate?
X = Sent Data
Y= Received Data
$J(\hat{H})$= Cost function for channel estimation

Without using any knowledge of the statistics of the channels, the LS Estimators are calculated with very low complexity, but they suffer from a high mean square error.

ii. Minimum Mean Square Error (MMSE) Channel Estimation

The MMSE estimator employs the second-order statistics of the channel conditions to reduce the mean-square error. Channel Estimation is required to determine the characteristics of a channel based on the sequence data transmitted by the transmitter. In general, channel estimation method with minimum mean square error (MMSE) is designed as:

$$J(\hat{H}) = E\{||e||^2 = E\{||H - H^2||\} \tag{2}$$

Where, $J(\hat{H})$= Cost function for channel estimation
e= error
$\hat{H}$ Is channel estimate

The aim of the MMSE estimation is to get a better estimation, in this case is the selection of proper load (W). Thus, the above equation must be minimized.

So, this we said this is the MSE of the maximum likelihood estimate and this is the prior variance. This is the MSE of the maximum likelihood estimate and the prior variance. And we said this also valued by the way we said this is also expression also valid for a complex parameter; that is when the channel coefficient h is the complex quantity. So, this is also valid for MMSE of a complex channel coefficient.

iii. Linear Minimum Mean Square Error (LMMSE) Channel Estimation

Linear minimum mean square error (LMMSE) is by definition the optimal channel estimator in the sense of mean square error criterion, but its practical application is limited by its high complexity. LMMSE is used to track time and frequency domain. Furthermore, the LMMSE estimation method requires the knowledge of both the channel and the noise statistics, which are a priori unknown at the receiver.

The LMMSE estimation is performed along the frequency axis with a pilot preamble (Xn) and is derived from the minimization of the cost function as:

$$J(LMMSE) = E\{||H_n - DY_n||^2 \quad (3)$$

Where D is a matrix whose coefficients have to be optimized. The estimated channel frequency response vector is H_n^{LMMSE}

$$H_n^{LMMSE} = D_{opt} Y_n \quad (4)$$

Where D_{opt} is the channel covariance matrix along the frequency axis and it is denoted as in equation (viii):

$$D_{opt} = R_H X_n^H (X_n R_H X_n^H + \sigma^2 I)^{-1} \quad (5)$$

Where, I= M*M identity matrix

R_H = M*M channel covariance matrix along the frequency axis

And $(.)^H$ is the Hermitian transpose

σ^2=noise variance

$$H_n^{LMMSE} = R_H X_n^H (X_n R_H X_n^H + \sigma^2 I)^{-1} H_n^{LS} \quad (6)$$

H_n^{LS} = Vector containing the LS estimated samples of the channel frequency response.

4. Comparative Analysis

The impact of Doppler Effect in high mobility wireless channel, an effective channel estimation technique is required which helps in equalization of the received data through such noisy channel. For example, data transmission through high speed railways, the fluctuation of the data transmission among base station and transmitting high speed train is quite high. So, it is required to design such an effective system that can gives quick response with minimum MSE and BER which ensures high quality-of-service (QoS). So, such wireless communication system requires high transmission rate transmission with high mobility and minimum MSE.

Table I: MSE vs. SNR for QPSK Modulation

SNR	LS Estimator	MMSE Estimator	LMMS Estimator
5	0.240925	0.364029	0.004116
10	0.310313	0.305191	0.00408
15	0.337785	0.314933	0.004048
20	0.312972	0.305685	0.004015
25	0.305383	0.287768	0.004001
30	0.302466	0.291898	0.003979

Table I and Figure 1 represents the MSE performance of LS, MMSE and LMMSE for QPSK modulation. From the graph it is observed that when increasing SNR at 5 db for AWGN channel, LMMSE give low MSE compare to LS and MMSE.

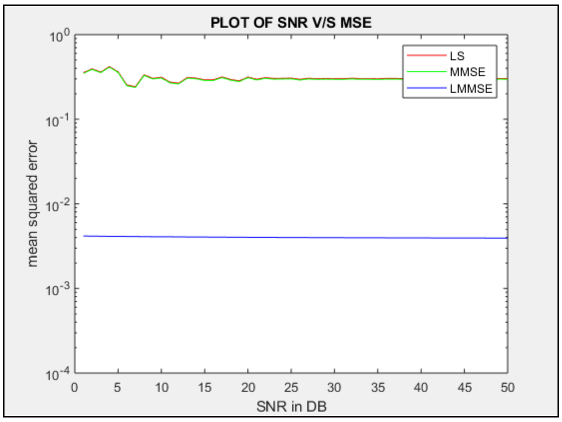

Fig 1: MSE vs SNR for QPSK Modulation

5. Conclusion

After detailed literature survey it has been observed that most of researchers have worked in the field of Orthogonal Frequency Division Multiplexing (OFDM) by using many modulation technique and algorithms for improving the MSE and BER performance. In the proposed dissertation, neural network channel estimation has considered to improving the MSE and BER performance as compare to other conventional methods.

In different channel estimation techniques there is requirement of channel state for receiver in order to estimate the noise level in the channel. Several techniques are existing in OFDM scenario. The basic concept of non-blind channel estimation technique is the existence of pilot symbol bits in the input data bits. While transmitting the pilot embedded input data stream over the noisy channel, it is seen that the pilots bits are useful in estimating the noise of the channel at the receiver end. These pilots symbols and their position are known to the receiver as they are distributed in time or frequency domain. As from literature review it is studied and concluded that LS channel estimation technique is less complex in implementation as compared to other techniques but does not estimate noise efficiently. As it estimates noise with more error rate. This shows the limitation of LS technique which was reduced in MMSE channel estimation technique but the design of the MMSE is more complex due to the need for matrix inversion. The performances of channel estimation algorithm is compared in LS, MMSE and LMMSE channel estimation techniques by measuring MSE vs. SNR with QPSK modulation scheme. LMMSE estimation has been shown to perform much better than LS and MMSE.

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