A Comprehensive Review on Channel Estimation in OFDM System

Neha Dubey

M. Tech. Scholar

Department of Electronics and Communication Engineering

Rabindranath Tagore University

Bhopal M.P, India

nehadubey4693@gmail.com

Ankit Pandit

Assistant Professor

Department of Department of Electronics and

Communication Engineering

Rabindranath Tagore University

Bhopal, India

Abstract-**In wireless communication, orthogonal frequency division multiplexing (OFDM) plays a major role because of its high transmission rate. Channel estimation and tracking have many different techniques available in OFDM systems. Among them, the most important techniques are least square (LS) and minimum mean square error (MMSE). In least square channel estimation method, the process is simple but the major drawback is it has very high mean square error. Whereas, the performance of MMSE is superior to LS in low SNR, its main problem is it has high computational complexity. If the error is reduced to a very low value, then an exact signal will be received. In this paper an extensive review on different channel estimation methods used in MIMO-OFDM like pilot based, least square (LS) and minimum mean square error method (MMSE) and least minimum mean square error (LMMSE) methods and also other channel estimation methods used in MIMO-OFDM are discussed.**

Keywords: **Channel estimation, MIMO, OFDM, LS and MMSE, LMMSE.**

I. INTRODUCTION

Now-a-days, OFDM is of great interest to researchers all over the world [1]. In OFDM, the entire channel is splitted into many narrow parallel sub channels, so the duration of symbol is increased and the inter symbol interference (ISI) produced by the multi-path environments is reduced or eliminated [2,3].OFDM supports high data rate traffic because the incoming serial data stream is divided into parallel low-rate streams that are transmitted on orthogonal sub-carriers simultaneously [4]. OFDM system has the ability of extenuating a frequency-selective fading channel to a set of parallel flat fading channels, which require simple processes for channel equalization [5]. The available spectrum in an OFDM system is divided into manifold sub-carriers and all these subcarriers are orthogonal to each other [6].

OFDM has been standardized for several applications, such as digital audio broadcasting (DAB), digital television broadcasting, wireless local area networks (WLANs), and asymmetric digital subscriber lines (ADSLs) [7,8].

The capability of OFDM system is improved using MIMO technique, which spatially multiplexes data streams via multiple antennas [9]. MIMO–OFDM, the combination of both OFDM and MIMO technologies, is currently under study and is one of the most propitious candidates for future communication systems, ranging from wireless LAN to broadband access [10]. The MIMO communication systems use multiple transmit and receive antennas, increase the data rate without increasing the bandwidth, increase the diversity, and improve the performance against fading channels using space–time codes [11]. It has been found that the capability of MIMO–OFDM systems grow linearly with the number of antennas, when optimal knowledge of the wireless channel is available at the receiver.

The channel condition is not known in practical application. Thus, the channel estimation, i.e., channel identification plays a major role in MIMO–OFDM system [12]. Channel estimation is one of the most salient processes in communication system [13]. A perfect channel estimation algorithm should comprise both the time and frequency domain characteristics of the OFDM systems [14]. The performance of OFDM system can be improved by allowing for coherent demodulation using an exact channel estimation algorithm [15]. In OFDM transmission system, numerous channel estimation methods have been developed under the assumption of a slow-fading channel, wherein the channel transfer function remains stable within one OFDM data block [16]. Several channel estimation techniques have already been developed for MIMO–OFDM systems. Channel estimation involves two types of technique: blind and pilot based. Blind channel estimation uses the statistical properties of received signals without the need to resort to a preamble or pilot signal. Obviously, blind channel

estimation does not incur overhead related to training signals; however, this approach requires a large number of received symbols for the extraction of statistical properties. Furthermore, the performance of blind channel estimation rarely meets that of conventional channel estimation employing training signals [2].

Pilot channel estimation involves the insertion of a training sequence comprising known data symbols (pilots) at the beginning of transmission for the initial estimation of channel parameters [3]. Pilot channel estimation can be arranged into block-type or comb-type.

In block-type, OFDM symbols are periodically transmitted with pilots on all subcarriers to perform channel estimation. Pilot tones are inserted into all subcarriers of pilot symbols within a given period; therefore, the block-type pilot arrangement is suitable for frequency-selective and slow fading channels.

In comb-type OFDM, every symbol has pilot tones on the periodically located subcarriers. Compared to the block-type pilot arrangement, comb-type is suitable for flat-fading and fast-fading channels. Least square (LS), minimum mean and square error (MMSE) algorithms can be used with pilot-based channel estimation. MMSE algorithms generally outperform LS algorithms; however, they are far more complex.

A wide range of research methodologies is employed for channel estimation in MIMO-OFDM is presented here. The reviewed works are classified different channel estimation methods such as pilot based, blind channel, RLS and LMS, LS & MMSE and other channel estimation methods.

II. RELATED WORK

Pilot Based Channel Estimation Methods

A low complexity, bandwidth efficient, pilot symbol assisted (PSA) channel estimator for multiple transmitter OFDM systems was proposed by [4].

In order to allow simultaneous sounding of the multiple channels, the pilot symbols are constructed to be non-overlapping in frequency. A set of estimates acquired through periodically transmitted pilot symbols have been interpolated to find the time varying channel responses. The efficacy of the proposed estimator has been verified and its limitations have been analyzed by using the simulation results. Moreover, it has shown that the PSA channel estimator has a less computational complexity and enhanced performance when compared to existing decision directed minimum mean square error MMSE channel estimator for OFDM transmitter diversity systems. A pilot-aided channel estimation algorithm for estimating OFDM wireless channels in the presence of synchronous noise was presented by [5].

They have confirmed that the use of a priori available information regarding the interference structure can considerably reduce the number of covariance parameters in the synchronous case. They have modelled the user and interference channel responses using basis functions for further minimizing the number of unknown parameters. Consequently for the above approximations, a structured covariance model with smaller number of parameters has been obtained without any significant loss in detection

efficiency. Then these parameters have been estimated by deriving the MLE and asymptotic MLE algorithms. The unknown interference parameters have been estimated by asymptotic MLE using a residual method of moments (RMM) estimator which is invariant to the user channel parameters resulting in a computationally competent non-iterative algorithm. Also, the performance of three algorithms such as, ordinary least squares, asymptotic MLE, and unstructured MLE has been compared. A robust semi-blind technique for jointly estimating the CFOs and channels of an uplink multiuser MIMO–OFDM system was proposed by [6].

The CFOs and channels have been found simultaneously based on the SOS of the received signal and one specially designed pilot OFDM block. Also, the signals corrupted by the CFOs have been recovered by using a fast equalization technique. The MMSE pilot-aided channel estimation for broadband OFDM systems was discussed by [7].

Blind Channel Estimation Methods

Two semi blind methods for multiuser MIMO channel estimation were proposed by [8].

These methods are useful when OSTBCs are used for data transmission. The proposed methods are based on the extension of the concepts of the popular Capon and MUSIC methods to the problem of multiuser MIMO channel estimation. An intrinsic structure of OSTBCs has been developed to blindly calculate the subspace which contains the user channel matrices, and then only a few training blocks have been used to extract the user channels from this subspace. The proposed methods require only less training blocks as compared to the standard non blind LS-based channel estimator, and so, the bandwidth efficiency has been improved. A subspace-based blind channel estimation method for MIMO OFDM systems using the second order statistical analysis was developed by [9].

One advantage of the proposed method is that it is competent to apply channel estimation, even though the number of the transmit antennas is greater than or equal to the number of the receive antennas, where the conventional subspace-based algorithms could not be applied. They have considered the channel estimations with matrix ambiguity as well as with scalar ambiguity. Simulation results have clearly shown the efficiency of the proposed algorithm under different scenarios. A robust subspace (SS) based blind channel estimation for MIMO OFDM systems were proposed by [10].

LMS and RLS Channel Estimation Methods

An LMS and RLS based adaptive channel estimation for orthogonal STBC-OFDM systems with three transmit antennas was proposed by [11].

The BER results that are obtained using the proposed RLS algorithm approach have shown that the channel coefficients are perfectly recognized at threetransmitter side with a reasonable degree. An adaptive channel estimation techniques such as normalized least mean (NLMS) square and RLS for the MIMO-OFDM systems was proposed by [12].

An adaptive estimator has been used by these CE techniques, and it has the ability to update the parameters

of the estimator constantly and thereby the knowledge of channel and noise statistics are not needed. The proposed NLMS/RLS CE algorithm necessitate only the knowledge of the received signal. Their simulation results have proved that the RLS CE technique has superior performance than the NLMS CE technique for MIMO OFDM systems. Moreover, a higher performance has been achieved through the utilization of more multiple antennas at the transmitter and/or receiver than with fewer antennas.

MMSE and LS Channel Estimation Methods

A channel estimation algorithm based on a time frequency polynomial model of the fading multipath channels was proposed by [13].

The correlation of the channel responses in both time and frequency domain has been used by this algorithm and so it minimizes more noise than the methods using only time or frequency polynomial model. Also, the estimator is more efficient than the existing methods based on Fourier transform. The simulation has shown that it has more than 5 dB enhancement in terms of mean squared estimation error under some practical channel conditions. The algorithm requires some previous knowledge regarding the delay and fading properties of the channel. The algorithm can be implemented recursively and can change itself to follow the variation of the channel statistics. An iterative receiver algorithm for MIMO systems in frequency-selective fading channels was proposed by [14].

The proposed algorithm performs iterative channel estimation, soft interference cancellation with MMSE post filtering and soft-in softout (SISO) MAP decoding. An extrinsic and aposteriori log-likelihood ratio of coded symbols in each iteration has been calculated by the decoder. LMMSE channel estimator that uses soft estimates of all the data symbols has been derived. The estimator has been initiated by using the pilot symbols, and updated in each iteration using the a-posteriori based soft data decisions obtained from the decoders' output. They have presented two approximate channel estimators, based on LMMSE and LS solution and their performance has been compared by simulations. The performance of MIMO channel estimation techniques using the training sequences was analyzed by [15].

They have considered the well-known linear LS and MMSE approaches and proposed a scaled LS (SLS) and relaxed MMSE methods. These methods require only less knowledge of the channel second order statistics and/or have enhanced performance than the conventional LS and MMSE channel estimators. The optimal choice of training signals has been examined for the aforesaid techniques. In the case of multiple LS channel estimates, the best linear unbiased estimation (BLUE) scheme for their linear combining has been introduced and studied.

III. OFDM System

OFDM is a wideband wireless digital communication technique that is based on block modulation. With the wireless multimedia applications becoming more and more popular, the required bit rates are achieved due to OFDM multicarrier transmissions. Multicarrier modulation is commonly employed to combat channel distortion and improve the spectral efficiency. Multicarrier Modulation schemes divide the input data into bands upon which modulation is performed and multiplexed into the channel at different carrier frequencies so that information is transmitted on each of the sub carriers, such that the sub channels are nearly distortion less [16].

At the OFDM transmitter end, the N-point IFFT is taken for transmitted symbols. Taking the N-point FFT of the received samples, the noisy version of the transmitted symbols can be obtained in the receiver. N point FFT is used to convert the signal from time to frequency domain [17]. The input data is first mapped into a modulation scheme. The complex plane data is transformed to parallel format and IFFT transform is obtained to produce OFDM signal. The output data is converted to serial format and cyclic prefix is added. Reverse operations are carried out at the receiver end. Cyclic prefix is removed and N-point FFT is taken to retrieve the transmitted data. Following equation can be used for computing FFT and IFFT:

$$FFTX(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N} \qquad (i)$$

Where (k=0,1,……,N-1)

IFFT

$$X(n) = 1/N \sum_{n=0}^{N-1} X(k)e^{j2\pi nk/N} \qquad (ii)$$

Where (n = 0,1,……,N-1)

IV. 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 [18].

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:

$$J(\widehat{H}) = ||Y - X\widehat{H}||^2 \qquad (iii)$$

Where, $\widehat{H}$ is channel estimate.

X = Sent Data

Y= Received Data

$J(\widehat{H})$= 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 :

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

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:

$$J(LMMSE) = E\{||H_n - DY_n||^2 \qquad (v)$$

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

$$H_n^{LMMSE} = D_{opt} Y_n \qquad (vi)$$

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

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

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

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

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

V. CONCLUSION

In this review paper, different methods for computing the channel estimation in OFDM system are presented. Analysis has been done based on pilot based, LS & MMSE methods and other methods for channel estimation. Among the other methods, LS and MMSE methods are utilized mostly in which the error value is relatively lesser than the other methods. Hence in future, the scope of channel estimation methods would be more positively in enhancing the present LS and MMSE channel estimation method, so that estimation error can be made even further.

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