SVD -Low Complexity Channel Estimation in IEEE 802.16e-DL-PUSC System

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ABSTRACT

802.16e system support high data rate transfer but at the same time user has high mobility and due to this effect,the channel response may vary rapidly.Also pilot signals are usually limited in comb type arrangement to perform interpolation. So to perform channel estimation and interpolation with low complexity in high mobility scenario is the challenging problem. In this paper channel estimation of system is carried out by finding Channel Impulse Response (CIR) of pilot sub-carrier using LS, LMMSE and SVD algorithms and then finding Channel Frequency Response (CFR) at data sub-carrier is done by time and frequency Interpolation of Pilot CIR. This paper presents BER and MSE performance for 16QAM and 64QAM Coded OFDM System(C-OFDM) evaluated on standard channel ITU-A and ITU-B. Results show that by using low complexity SVD algorithm gives better performance than LS and LMMSE at lower SNR.

General Terms:

Orthogonal Frequency Division multiplexing(OFDM),Channel Estimation,Mobile WiMAX(802.16e)

Keywords:

Coded OFDM System (C-OFDM), Channel Estimation, LS (Least square Estimation), LMMSE (Linear minimum mean square error), SVD (Singular Value Decomposition), Channel Impulse Response (CIR), Channel Frequency Response (CFR), Down-link Partially Used Sub channelization (DL-PUSC)

1. INTRODUCTION

Channel estimation is one of challenging problems in IEEE 802.16e Orthogonal Frequency Division Multiplexing Access (OFDMA) down-link system.[1] In order to facilitate the correct detection of transmitted symbols, the effects of the channel must be removed from the received signal. This is the task of equalizer block which perform normalization of the signal received by each sub-carrier with its channel transfer function.[2] Channel transfer estimates are generated within the channel estimation block. The approach for OFDMA mobile WiMAX system channel estimation is pilot assisted or training symbol based channel estimation which employ pilot symbols known both to the receiver and the transmitters [3]

OFDM is key technology of standard (802.16e) Mobile WiMAX is based on orthogonality principle support to multicarrier transmission technique which is built by many orthogonal carriers that transmits simultaneously[1][3]. Idea behind OFDM is that to divide the transmitted bit stream in to many different sub-stream and send these over many sub channels, also the number of sub-stream is chosen to ensure that each sub channel has a bandwidth less than the coherence bandwidth of the channel, so that sub channels experience relatively flat fading and due to this Inter Symbol Interference (ISI) on each sub-channel is small. And the remaining ISI effect is eliminated by using cyclic prefix. [4]

The estimated Channel Frequency Response (CFR) at pilot subcarriers can be obtained by the Least Squares (LS) or the Minimum Mean Square Error (MMSE) criteria [5][6]. However, the computational complexity of MMSE is too high and requires the knowledge of channel information and operating SNR, these make MMSE difficult in practical use. Linear Minimum Mean Square Error (LMMSE) has a very low computational complexity compare to MMSE algorithm by taking some known values: one is β which depends upon different modulation; another being $R_{H_pH_p}$, which is the auto correlation matrix of the channel. A low rank approximation is applied to a LMMSE estimator which uses the frequency correlation of the channel. By using the Singular-Value Decomposition (SVD) an optimal low-rank estimator is derived, where performance is essentially preserved - even for low computational complexities[7][8].

In this paper CIR has been obtained by exploiting pilot by means channel estimation algorithms and then CFR can be obtained by exploiting pilot at symbol data with two dimension interpolation scheme called time and frequency interpolation in DL-PUSC.[9] Based on simulations over fast- and slow-fading mobile channels(ITU-R-A ,ITU-R-B), it has been observed that significant improvement in SNR with lowest computational complexity under SVD algorithm in terms of Bit Error Rate and Mean Square Error performance for 16QAM and 64QAM systems which has been simulated on MATLAB.

The paper is organized as follows. Section 2 explains the system description; section 3 discusses channel estimation method, with pilot based channel estimation method by LS, LMMSE, and SVD with Linear Interpolation. Results have been presented in section 4, which shows the effects of lower complexity and efficient algorithms SVD for ITU-Vehicular and pedestrian channel by means of BER and MSE performance, Sections 5 conclude the paper.

2. SYSTEM DESCRIPTION.

802.16e DL-PUSC system with pilot based channel estimation is given in figure 1. The Random data input provided from the source is coded by means of $\frac{3}{4}$code rate convolution trellis code. Each parallel sub-channel which contains N_a active sub-carriers is modulated with the help of complex QAM modulator. N_p pilots subcarriers which are known at both transmitter and receiver side are added in it to perform non blind channel estimation and finally to make the FFT bin size N, other null sub-carrier $N_g$in terms of guard are added. These parallel blocks are then fed into IFFT block symbol by symbol to transform them into time domain and generate C-OFDM signal with the following equation.[1]

$$x(n) = IFFT\{X(M)\}$$

$$x(n) = \sum_{-N_{used}/2}^{N_{used}/2} X(M).e^{-j\frac{2\Pi NM}{N_{FFT}}} ...0 \leq n \leq N-1 \quad (1)$$

Where $X(n)$is the transmitted data symbol at the m^{th} subcarriers of the OFDM symbol, N-FFT is the Fast Fourier Transform (FFT)of size N and N_{used} is the number of non-suppressed subcarriers. In the frequency domain, each OFDM symbol is created by mapping the sequence of symbols on the subcarriers.[8] Mobile WiMAX has three classes of subcarriers viz., data subcarriers N_a which contain the information of data symbols, then pilot subcarriers N_p which are used to known prior at both transmitter and receiver side and finally, null subcarriers which have no power allocated to them used to adjust the total bin size$N$. After addition of cyclic prefix (CP) which is used to remove ISI , the signal is transmitted through the wireless channel mainly here AWGN and Rayleigh multipath. The channel impulse response is assumed that the entire impulse response lies in between the guard time. At the receiver, the signal which is affected by the channel noise. After synchronization and removing the CP, the simplified baseband model of the received samples is:

$$y(n) = \sum_{l=0}^{L-1} x(n-l).h(l) + w(n) \quad (2)$$

Where L is the number of sample-spaced channel taps, w(n) is the Additive White Gaussian Noise (AWGN) sample with zero mean and variance of σ_{w^2}, and the time domain CIR for the current OFDM symbol, $h(l)$, is given as a time invariant linear filter. Note that perfect time and frequency synchronization is assumed. After taking FFT of the received signal $y(n)$, the samples in frequency domain can be written as:[1]

$$Y(M) = FFT\{y(n)\} = X(m).H(m) + W(m) \quad (3)$$

Where H and W are FFTs of h and w respectively.

3. CHANNEL ESTIMATION.

3.1 Pilot aided Channel Estimation.

In this paper, channel estimation method clusters based pilot arrangement is used in order mitigate the effect of frequency selective fading; the IEEE 802.16e standard has a very unique method to allocate subcarrier including pilot is called permutation and there are a few types of permutations. In this paper it has been used a

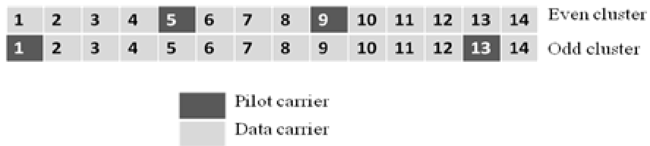

Fig. 2. Cluster structure for DL PUSC[1]

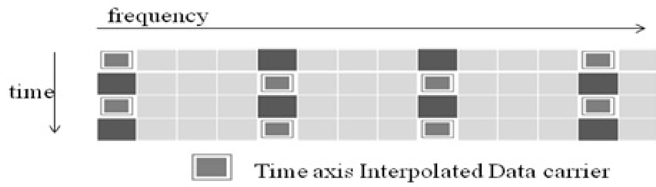

Fig. 3. Cluster structure after time interpolation[1]

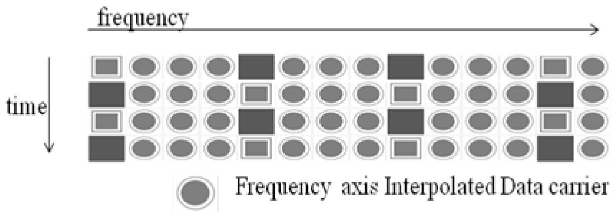

Fig. 4. Cluster structure after frequency interpolation[1]

method called Downlink Partially Used Sub channelization (DL-PUSC) [9]. In DL-PUSC, the subcarriers are divided into clusters containing 14 adjacent subcarriers each. Figure 2 shows a cluster structure and the position of pilot subcarriers in each cluster for even and odd symbols.

First is interpolation at time dimension which has 2 symbols time spacing. In this paper we use linear interpolation for time dimension interpolation because it is sufficient for small time spacing. The time dimension interpolation steps are shown in figure 3. Next is frequency dimension interpolation is done shown in figure 4 and we get complete Channel Frequency Response of the channel.

3.2 Channel Estimation Algorithms.

In this the simplest case, the channel estimates are found by straight forward multiplying the received pilot by the inverse of the known transmitted pilot.[5] This method is called least square (LS) estimator, given by $\hat{H}_{P_{LS}} = {X_P}^{-1}Y_P$. Without using any knowledge of the statistics of the channels, the LS Estimator has very low complexity, but suffers from high MSE. The MMSE channel estimator employs the second order statistics of the channel condition to minimize the MSE. The major disadvantage of the MMSE estimator is its high complexity, which grows exponentially with the observation sample. So to reduce its computational complexity, new algorithm is employed known as linear MMSE (LMMSE)[6]. The frequency domain LMMSE estimate of channel response in term of RH_pH_p and SNR are known or fixed as known values, matrix inversion of $RH_pH_p + \sigma^{2n}(X_P{X_P}^H)^{-1}$ is just needed to be calculated only once. But, because of consideration of influence of noise, the MSE of LMMSE is smaller than MMSE. [9][10] To further reduce the complexity of computation of LMMSE estima-

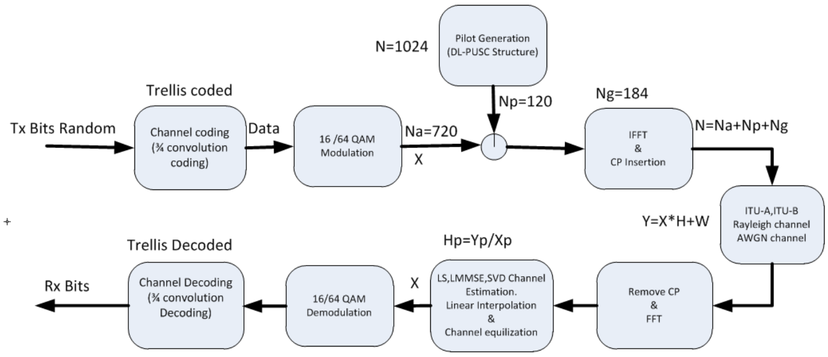

Fig. 1. Block Diagram of the Pilot Based OFDM System

tor, SVD estimator is considered. So a low rank approximation is applied to a LMMSE estimator that uses the frequency correlation of the channel. By using the singular-value decomposition (SVD) an optimal low-rank estimator is derived, where performance is essentially preserved - even for low computational complexities.[8] Because the channel energy is mainly in low frequency domain, the first P orders could be chosen to be used in estimator. Let us denote the SVD of channel correlation matrix[7]

$$R_{HH} = U \wedge U^H \quad (4)$$

Where U is a unitary matrix, and $\wedge$ is a diagonal matrix with the singular values ofR_{HH} as $\lambda_0 \geq \lambda_1 ..... \geq \lambda_{(N-1)} \geq 0$. Therefore,

$$\hat{H}_{LMMSE} = U \wedge U^H (U \wedge U^H + ((\beta)/SNR).I))^{-1}.\hat{H}_{LS}$$

$$\hat{H}_{LMMSE} = U \wedge (U \wedge U^H + ((\beta)/SNR).I))^{-1}.U^H.\hat{H}_{LS}$$

$$\hat{H}_{LMMSE} = U \Delta U^H \hat{H}_{LS} \quad (5)$$

Where $\Delta = \wedge(U \wedge U^H + ((\beta)/SNR).I))^{-1}$and it is also $= \lambda_k/(\lambda_k + \beta/SNR)$ so the value on the diagonal of Δ could be written by

$$\delta_k = \begin{cases} \lambda_k/(\lambda_k + \beta/SNR) & \text{if } k = 0, 1, ...p-1; \\ 0 & \text{if } k = p, p+1, ...N-1. \end{cases}$$

Then, the channel estimation by SVD algorithm as:[7]

$$\hat{H}_{SVD} = U \begin{bmatrix} \Delta_p & o \\ 0 & 0 \end{bmatrix} .U^H.\hat{H}_{LS} \quad (6)$$

Where theΔ_p is the left up $P * P$ corner of Δ as

$$\begin{bmatrix} \lambda_0/(\lambda_0 + \beta/SNR)) & ... & 0 \\ \vdots & \ddots & \dots \\ 0 & \cdots & \lambda_{p-1}/(\lambda_{p-1} + \beta/SNR) \end{bmatrix} \quad (7)$$

The channel estimation by SVD algorithm as [7]

$$\hat{H}_{SVD} = U \begin{bmatrix} \Delta_p & o \\ 0 & 0 \end{bmatrix} .U^H.\hat{H}_{LS}$$

Assuming the matrix U^H as the transform, the singular value λ_k is the channel energy of information received after $\hat{H}_{LS}$is transformed by U^H. It chooses the larger P points of all N points and assumes the channel energy of them is larger than noise, so the channel energy of other N-P points are smaller. Therefore the P point are used for estimation, but the N-P points are set as 0 in order to reduce the complexity of computation and influence of noise. The block diagram of SVD estimator is shown below in figure 5.[8][10]

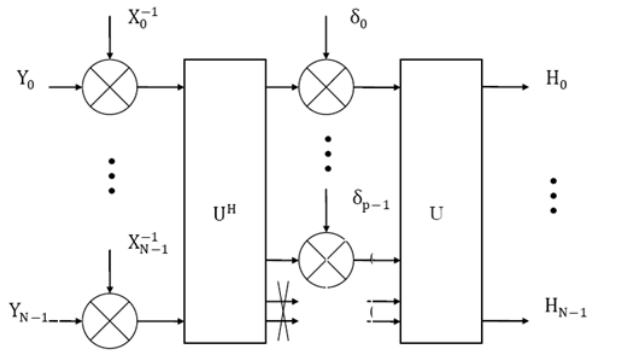

Fig. 5. Block diagram of SVD estimator[8]

Table 1. SIMULATION PARAMETERS

Parameter	Value
FFT size (N_{FFT})	1024
System Bandwidth(MH_Z)	10
Sampling Frequency(MH_Z)	11.2
Channel Coding	CC-trellis
Code rate	$3/4$
Modulation	16QAM,64QAM
Number of used Subcarrier $N_u = N_a + N_p$	840=720+120
Cyclic Prefix ratio(N_g)	$1/8 = 256$
Number Of Cluster used	24
OFDM symbol duration(micro second)	108.26
Fading Channel	Rayleigh(ITU-A, ITUB)
Carrier Frequency(GH_Z)	2.5

$$Y = \begin{bmatrix} Y_0 \\ \vdots \\ Y_{N-1} \end{bmatrix}, X = \begin{bmatrix} X_0 & ... & 0 \\ \vdots & \ddots & \dots \\ 0 & \cdots & X_{N-1} \end{bmatrix}$$

4. SIMULATION RESULTS.

In this simulation the parameters used are given in Table 1.

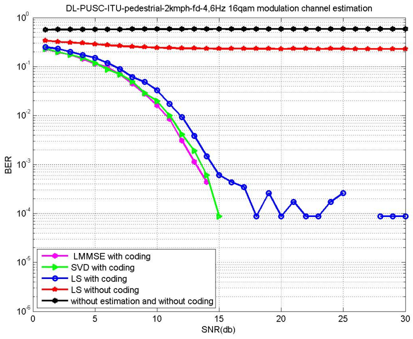

Fig. 6. BER performance of Pilot-aided 16QAM for Rayleigh Channel

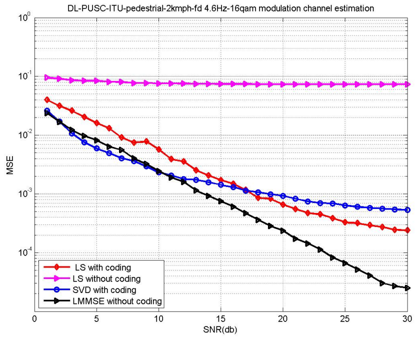

Fig. 8. MSE performance of Pilot-aided 16QAM for Rayleigh Channel

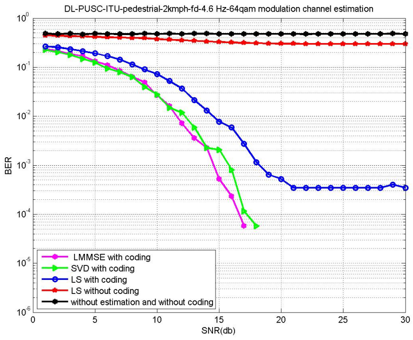

Fig. 7. BER performance of Pilot-aided 64QAM for Rayleigh Channel

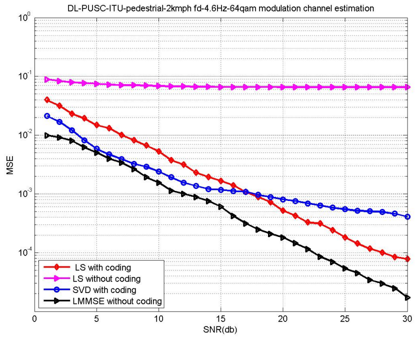

Fig. 9. MSE performance of Pilot-aided 64QAM for Rayleigh Channel

The effect of frequency selective slow fading mitigated by using channel estimation and channel coding for 16QAM and 64QAM are shown in figure 6-7. In that the doppler frequency is set to be 4.6 Hz which is related to 2 kmph user mobility and it shows that BER performance is improved by using estimation and channel coding compared to without estimation without coding.

BER comparison of 16QAM and 64QAM are shown in figure 6-7, and it is observed that BER performance is improved by LMMSE algorithm compared to the LS algorithm but the same time the computational complexity is also increase so by minimizing the complexity of LMMSE using SVD algorithm, we obtained same BER performance that has been achieved by LMMSE algorithm at Lower SNR.

MSE comparison of 16QAM and 64QAM are shown in figure 8-9 for ITU-Pedestrian user. It is observed that MSE performance is improved by LS, LMMSE and SVD algorithms respectively compared to without estimation.

The effect of frequency selective fast fading mitigated by using channel estimation and channel coding for 16QAM and 64QAM are shown in figure 10-1. In that the doppler frequency is set to be 104.6 Hz which is related to 45 kmph user mobility and it shown that BER performance is improved by using estimation and channel coding compared to without estimation without coding.

BER comparison of 16QAM and 64QAM are shown in figure 10-11, and it is observed that BER performance is improved by LMMSE algorithm compared to the LS algorithm but at the same time the computational complexity is also increase so by minimizing the complexity of LMMSE using SVD algorithm we obtained same BER performance that has been achieved by LMMSE algorithm at Lower SNR.

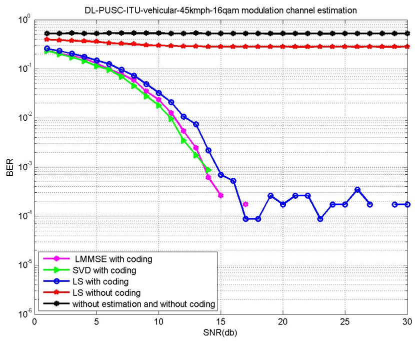

Fig. 10. BER performance of Pilot-aided 16QAM for Rayleigh Channel

MSE comparison of 16QAM and 64QAM are shown in figure 12-13 for ITU-Vehicular mobility user, and it is observed that MSE performance is improved by means of LS, LMMSE and SVD algorithms respectively compared to without estimation.

5. CONCLUSION

In this paper, Mobile WiMAX system based on IEEE 802.16e standard has been discussed with main focus to downlink chan-

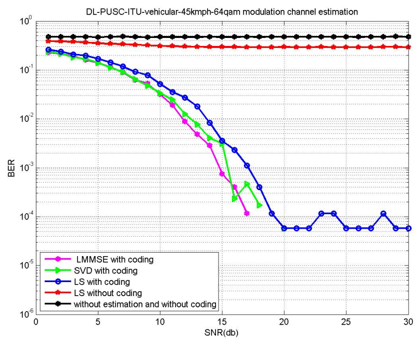

Fig. 11. BER performance of Pilot-aided 64QAM for Rayleigh Channel

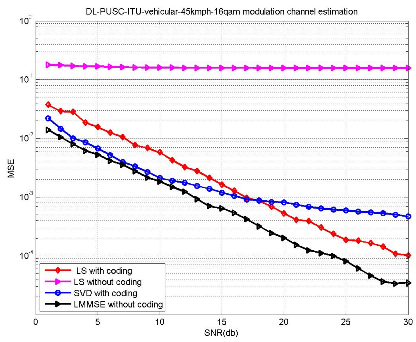

Fig. 12. MSE performance of Pilot-aided 16QAM for Rayleigh Channel

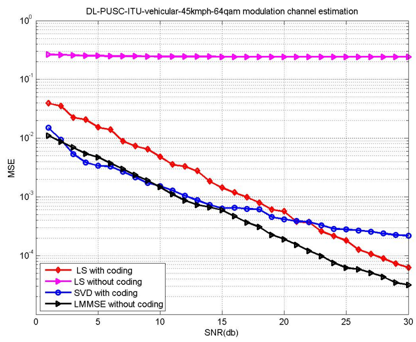

Fig. 13. MSE performance of Pilot-aided 64QAM for Rayleigh Channel

nel estimation at receiver with higher doppler frequency is carried out under multipath Rayleigh Channel with ITU-R-A and ITU-R B channel specification. The channel estimation methods based on pilot source position and two interpolation methods with LS, LMMSE and SVD have been analysed and compared. It can be conclude from this results that the data pilot based channel estimation with linear interpolate LMMSE estimator has a prior knowledge of channel statistics in the form of β and $R_{H_pH_p}$ auto correlation of the channel,the BER performance is improved by it up to 3db compared to without estimation but its Complexity is large compared to the LS estimator. So to reduce the complexity of LMMSE the new algorithm SVD is applied and it has been observed that at lower SNR it gives same BER and MSE performance that has been achieved by LMMSE with less complexity. So SVD estimator is better choice at lower SNR.

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