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Performance evaluation of high mobility OFDM channel estimation techniques

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Article Info	ABSTRACT
	In wireless communication, Orthogonal Frequency Division Multiplexing (OFDM) has been adopted due to its robustness to multipath fading and high data rate transmissions. At the other hand, the performance of OFDM systems severely degraded due to multi-path fading and Doppler frequency shifts in mobile systems, which causes inter-carrier-interference (ICI). Thus, Estimation of channel parameters is required at the receiver using a pre designed estimator where pilot tones are inserted in each OFDM symbol. In this paper, a random pilot data are generated and inserted in each OFDM symbol at equally spaced locations. The performance test of Least Square (LS) and Linear Minimum Mean Square (LMMSE) estimation methods are proposed with Discrete Fourier Transform (DFT) based on both LS and LMMSE, where different ITU channel models are considered in order to compare their performance for data transmission in high mobile systems with different Doppler frequencies exceeds 200 Hz and minimal number of pilots. *Copyright © 2020 Institute of Advanced Engineering and Science.* *All rights reserved.*

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1. INTRODUCTION

Recent mobile applications require high and reliable data transmissions, thus, OFDM has been deployed in several applications due to its spectral efficiency and robustness to multipath fading. High speed data transmissions severs from frequency selective fading which causes a serious Inter Symbol Interference (ISI) between the transmitted symbols. OFDM can overcome this problem with high data rates. Channel estimation is an important part of OFDM system and it is an essential process to recover the channel impulse response [1, 2]. In high mobility systems, the resulting high Doppler shifts leads to performance degradation in channel estimation accuracy [3].

Majority of communication systems adopt the coherent detection in order to pursue better transmission performance through channel estimation of Channel State Information (CSI). Several techniques are adopted for the purpose of channel estimation in OFDM systems. LS and LMMSE estimation methods are the most popular pilot based channel estimation techniques [4, 5]. A performance comparison of LS and LMMSE is proposed in [4], where the two methods are simulated and LMMSE performs better than LS with Binary Phase Shift Keying (BPSK) modulation. A pilot insertion method was proposed in [6] to test the performance of LS estimation in OFDM system, where it based on a combination of block and comb types using linear and cubic spline interpolation [7].

Discrete Fourier Transform (DFT) based pilot insertion method is one of estimation techniques introduced in several publications in order to improve estimation performance. Since DFT estimation based on noise cancellation in time domain using Fast Fourier Transform (FFT), it represents a low complex method with performance depends on tested channel environments [8-10]. An improved DFT method was

proposed in [11] in order to enhance estimation performance close to LMMSE with lower complexity, where all samples outside the cyclic prefix are considered noisy and set to zero. In [12], a conventional and improved DFT methods were proposed and only significant components within cyclic prefix length are selected while the noise components are ignored. The research based on selecting different number of iterations in each trial, where the one gives best performance is evaluated. The proposed work test the environments effects on channel estimation techniques with different Doppler frequencies not exceeding 33 Hz. In [13], OFDM estimation algorithms were tested for a time variant channel with different pilot insertion schemes. Block type, comb type, and a hybrid pilot insertion scheme was proposed. The test of all schemes shows that the comb type pilot insertion method performs better than block type and the hybrid scheme yields a good tradeoff between them.

With the revolution in communication systems, several estimation techniques are proposed in order to enhance system performance at mobility situations. The enhancement cost increased as number of pilots increased where bandwidth efficiency degraded [14]. A lower bound of pilot's number was targeted by [14-15], which stated that, in order to achieve acceptable BER performance and good throughput and if the channel length is known or estimated, the number of pilots Np must be greater or equal to the channel length assuming equally-spaced and equal power pilot tones. Thus, the target of this paper is to evaluate the performance of conventional estimation techniques with minimum number of pilots as required by [14], with high Doppler frequencies, in order to save bandwidth using a predetermined pilot locations.

The rest of the paper is organized as follows. A brief background on channel estimation and the criteria of estimation techniques was proposed in section 2. Clarifying such model together with other system parameters and specifications proposed in section 3. Performance evaluation in the form of Bit Error Rate (BER) is then presented in sections 4. Finally the main concluding remarks are given in section 5.

2.   BACKGROUND

Channel estimation is an effective tool to predict the behavior of the channel and it is adopted at the receiver side. Training based channel estimation and blind channel estimation are the two main methods may be used for this purpose, where, training based channel estimation is the popular and widely used according to its ability to obtain an effective CSI by fully utilizing its pilots and training sequences [13, 16-18]. A brief description for Least Square (LS), Linear Minimum Mean Square (L MMSE), and Discrete Fourier Transform (DFT) techniques are reviewed in the next subsections.

2.1. Least square (LS)

It is the simplest channel estimation method, where the transmitted signals at pilot subcarriers are used to estimate the channel impulse response. The estimated channel taps are then used to recover the transmitted data [4, 19].

$$H_{LS}[k] = \frac{Y_p[k]}{X_p[k]} \qquad 1 < k < N_p \tag{1}$$

$H_{LS}[k]$, the estimated channel response at k^{th} pilot subcarrier using LS.
$X_p[k]$, the transmitted symbol at k^{th} pilot subcarrier.
$Y_p[k]$, the received symbol at k^{th} pilot subcarrier.
N_p, the number of pilots.

2.2. Linear minimum mean square (LMMSE)

It is a more complex channel estimation method as compared to LS method. LMMSE depends on minimizing the error between the transmitted and received signals through the expression below [12, 20];

$$H_{MMSE} = H_{LS} \times W \tag{2}$$

where W is a weighted matrix and it is given by;

$$W = R_{HHLS} R_{HLSHL}^1 \tag{3}$$

and hence, the error value computed by [12];

$$e = H - H_{MMSE} \tag{4}$$

where:

H_{MMSE}, the estimated channel response using MMSE

R^1_{HLSHL}, the auto-correlation matrix of HLS

R_{HHLS}, the cross-correlation matrix of the true channel and estimated one

H, represents the true channel coefficients.

2.3. Discrete fourier transform (DFT)

The Discrete Fourier Transform (DFT) based channel estimation method is introduced to improve the performance of LS and MMSE methods. This method is used for noise reduction where it eliminate the noise outside the maximum channel delay [21].

$$IDFT(H_{LS}) = hDFT[n] = h[n] + z[n] \qquad n = 0,1\ldots,N-1 \tag{5}$$

where:

$H_{LS}[n]$, the estimated channel response at nth subcarrier using LS

h[n], the sampled impulse response of the channel

z[n], the noise component in the estimated channel

3.   SYSTEM MODLE

Orthogonal frequency division multiplexing is a promising multi carrier modulation scheme. It is a widely used technology in rich multi path wireless communications due to its ability to overcome the ISI problem [22]. It also provide a simple equalization process in frequency domain [2, 23, 24]. The proposed OFDM based channel estimation model is defined as shown in Figure 1(a). Where different number of pilots are inserted within the transmitted OFDM symbol for the purpose of retrieving the CSI with a simple frequency equalization process.

As mentioned before in section I, the number of pilots is constrained by the relationship [14, 15, 25];

$$N_p \geq L^\wedge \tag{6}$$

where $L^\wedge$ is the expected channel length

Since CP was chosen to cover the maximum channel delay, in the proposed simulations, the number of pilots are selected to be greater than or equal to the CP length in the presence of Doppler shifts.

$$N_p \geq L_{cp} \tag{7}$$

where they are assumed to have an equal power and inserted at equally spaced locations in each OFDM symbol as shown in Figure 1(b).
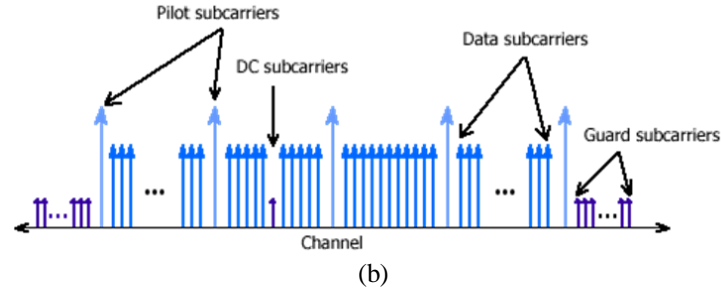

(a)

(b)
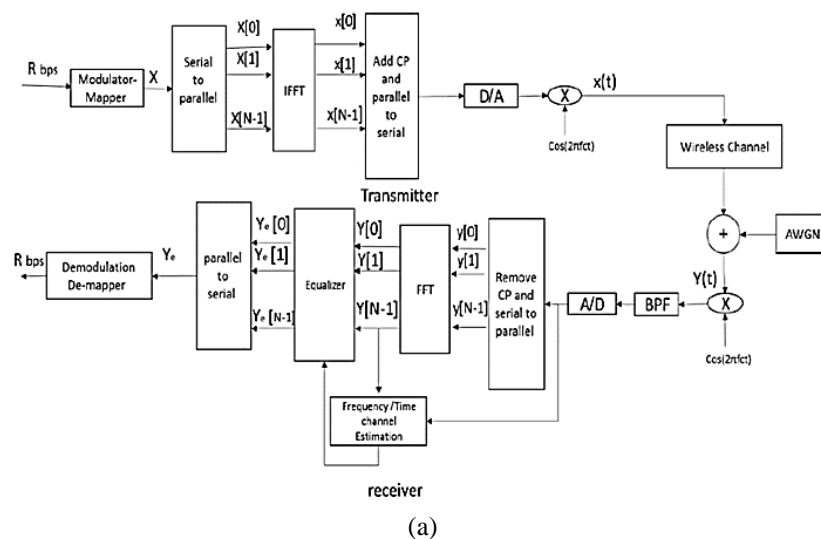
Figure 1. (a) OFDM Communication System [6], (b) Pilot and data subcarriers locations

A set of commonly used channels in mobile communication systems was specified in ITU-R recommendation M.1225. Three channel environments are proposed in this specification; Indoor, Pedestrian, and Outdoor. For each of these specified environments, a multipath tap delay profile is specified as shown in Table 1 [26].

Table 1. ITU channel models [26]

Tap No.	Indoor Environment (A)		Pedestrian Environment (B)		Outdoor Environment (A)	
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)	Delay (ns)	Power dB)
1	0	0	0	0	0	0
2	50	-3	200	-0.9	310	-1.5
3	110	-10	800	-4.9	710	-9.0
4	170	-18	1200	-8.0	1090	-10.0
5	290	-26	2300	-7.8	1730	-15.0
6	310	-32	3700	-23.9	2510	-20.0

4.   SIMULATION TESTS AND RESULTS

The OFDM system of Figure 1(a) was tested with different estimation techniques which were described briefly in the previous section. In addition to AWGN, the test considers a Rayleigh fading channel with delay and power vectors standardized by ITU channel models of Table 1. For each pilot aided estimation method tested, the pilot insertion method consider an equally spaced locations with spline interpolation. The results are plotted in the form of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR), where SNR is determined by the corresponding $(^{E_b}/_{N_o})$ in dB. The required system parameters of OFDM system, Doppler shift (F_d), and data rate (R_s) are shown in Table 2. Where, when $F_d = 0, N_p = 8 < L_{cp}$, while when $F_d > 0, N_p = 16$ which is the considered length of L_{cp}.

Table 2. System parameters

Parameter	Value
Number of transmitted bits	64000
Modulation	BPSK
Rate b/sec.	Variable
OFDM Subcarriers	64
Number of pilots (N_p)	8, 16
Cyclic prefix length (L_{cp})	16
Carrier Frequency (fc)	2.4 GHz
Maximum Doppler shift (F_d) Hz	0, 5, 250

In Figure 2, Practical examination approved theoretical results of OFDM simulation over AWGN channel. LS, LMMSE, DFT based LS, and DFT based LMMSE estimation algorithms are tested over ITU-Indoor channel model as shown in Figure 3 with zero Doppler shift and 10 Kbps data rate, where 8 pilots are inserted at equally spaced locations along the OFDM symbol. For a BER of 10^{-3}, the LMMSE test shows an improvement in SNR by about 0.5 dB over LS method, while the DFT-LS gives a 2 dB improvement in SNR over the LS tests. At the same channel environments, 1.8 dB improvement in SNR achieved for DFT-LMMSE over traditional LMMSE tests. For the case where DFT-LS compared to DFT-LMMSE, the tests shows that DFT-LMMSE performs better than DFT-LS by about 0.25 dB.
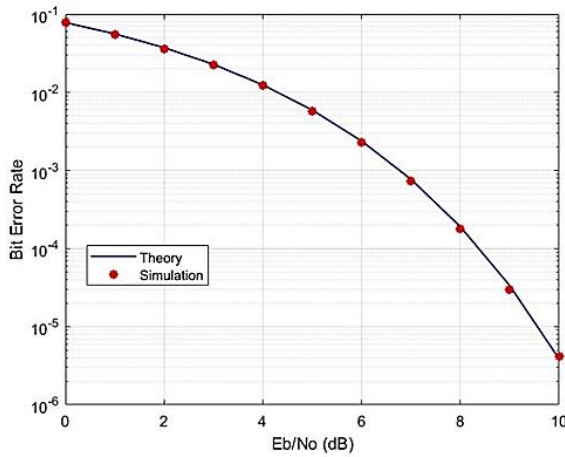
Figure 2. Performance evaluation of OFDM system in AWGN channel
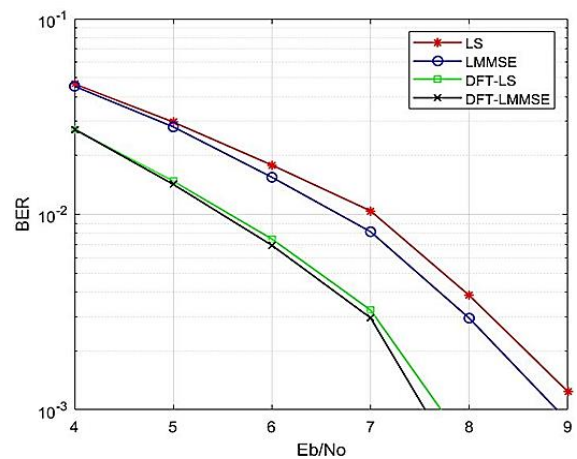

Figure 3. Performance evaluation of OFDM estimation in ITU-indoor channel

In Figure 4, the performance of the same methods are tested over ITU- Pedestrian channel with 16 pilots, data rate of 2.5 Kbps, and a Doppler shift of 5 Hz. At BER of 10^{-2}, the LMMSE gives an improvement in SNR by about 5.1 dB over LS method. At the other hand, a DFT-LS improve the performance of the traditional LS method by about 7.4 dB. However, DFT-LMMSE improves the traditional LMMSE performance by about 3.3 dB. As a consequences, DFT-LMMSE outperforms DFT-LS performance by about 1 dB at the same error rate value.
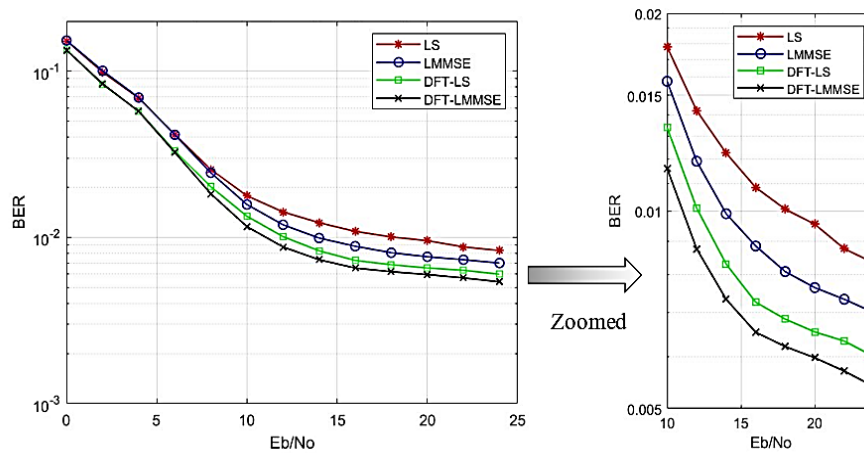

Figure 4. Performance evaluation of OFDM estimation in ITU- pedestrian channel

The same methods are tested over ITU-Outdoor channel to characterize their performance with high Doppler shift. In Figure 5, all presented estimation methods are tested with Doppler shift of 250 Hz, 16 pilots, and 250 Mbps data rate. For a BER of 10^{-2}, LMMSE outperforms LS estimation method by about 9 dB and DFT-LS improves the performance of the traditional LS by about 11.2 dB. Also, the performance of LMMSE is improved with DFT-LMMSE by about 6 dB, where a 3.8 dB improvement achieved with DFT-LMMSE over DFT-LS method.

It is clear that in the presence of high Doppler shift, the estimation performance will degraded. This performance can be enhanced through increasing the number of pilots in each OFDM symbol which will decrease the bandwidth efficiency of the system. At the other hand, the proposed tests shows that even the Doppler frequency increased, an almost acceptable performance can be achieved with lower number of pilots equals to the channel length, and hence improve bandwidth utilization for bandwidth efficient applications.

As a final assessment of results, a little compromising between SNR gain and implementation complexity, LS channel estimation method characterized by a low complexity implementation as compared to LMMSE and DFT-LMMSE. While the performance of DFT-LMMSE better than LS with SNR gain by about; 2.25 dB for 10^{-3} error rate with zero Doppler shift in ITU-Indoor channel, 8.4 dB for 10^{-2} error rate with 5 Hz Doppler shift in ITU- Pedestrian channel, and 15 dB for 10^{-2} error rate with 250 Hz Doppler shift in ITU- Outdoor channel.
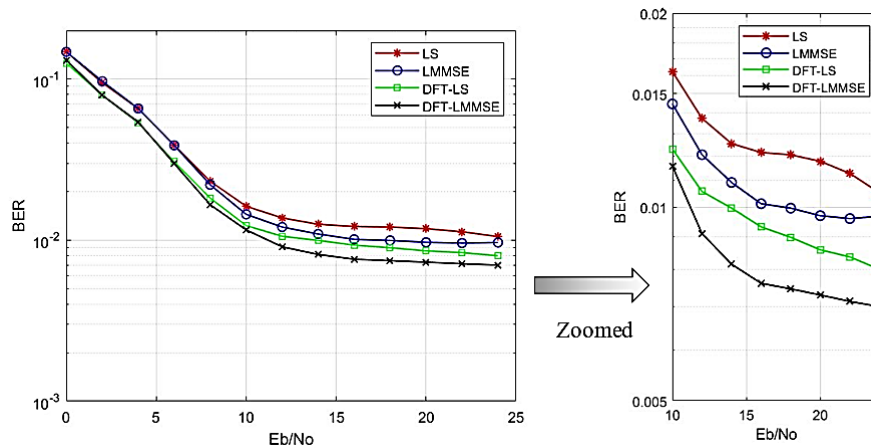

Figure 5. Performance evaluation of OFDM estimation in ITU-outdoor channel

5. CONCLUSION

Channel estimation process is an effective part of OFDM system especially in fading environment where channel statistics changes over time, and in the presence of Doppler shift the data transmission is hardly affected. In the proposed work, ITU channel models are considered to examine the suitability of different channel estimation techniques for high mobility environment in the presence of deep fading and high Doppler shifts, where minimal number of random pilots are inserted in each OFDM symbol at equally spaced locations. In such environment, the tests shows an improvement in the performance of estimation techniques when DFT adopted, where this improvement exceeds 11 dB and 15 dB for DFT-LS and DFT-LMMSE over conventional LS method respectively with 250 Hz Doppler shift where the mobility reaches 112 km/h, a BER of 10^{-2}, and 16 pilots. As a future work, a trading off between estimation complexity and BER improvement will be considered with high Doppler frequencies and reduced number of pilots.

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