Estimation of Bit Error Rate and Mean Square Error in 4G Wireless Networks

1 author:

Usha Kumari
Gokaraju Rangaraju Institute of Engineering & Technology

Estimation of Bit Error Rate and Mean Square Error in 4G Wireless Networks

Hinduja Annemalla[1], CH.Usha Kumari[2]

[1]M.Tech Final year student, Department of ECE, G. Narayanamma Institute of Technology and Science Hyderabad, India,

[2]Asociate Professor, Department of ECE, G. Narayanamma Institute of Technology and Science Hyderabad, India,

Abstract: **In 4G systems to improve the capacity with good Quality of Service (QoS), Orthogonal Frequency Division Multiplexing (OFDM) is used. This paper discusses the channel estimation in OFDM system using Block type- Least Square (LS) and Minimum Mean Square Error (MMSE) estimation algorithms. Improvement of channel estimation in terms of Bit Error Rate (BER) and Mean Square Error (MSE) between LS and MMSE is simulated in MATLAB. Finally it is improved by converting from frequency domain to time domain using Discrete Fourier Transform (DFT). The implementation is done for 64 subcarriers between LS, MMSE, DFT-LS and DFT-MMSE. Simulation results show that DFT-MMSE is best channel estimator than DFT-LS, MMSE and LS. The BER of DFT-MMSE is 91.32 and BER of MMSE is 353.2. The MSE of DFT-MMSE is 0.00888and LS is 0.00257. This clearly shows the BER and MSE of DFT based system is less than LS and MMSE.**

Keywords: OFDM system, Channel estimation, LS, MMSE, DFT.

Introduction

The 4G is the fourth generation of mobile telecommunications technology, succeeding 3G and preceding 5G. A 4G system, in addition to the usual voice and other services of 3G, provides mobile broadband Internet access, for example to laptops with wireless modems, to smartphones, and to other mobile devices. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, 3D television, and cloud computing. One of the 4G candidate system that commercially deployed and the first-release Long Term Evolution (LTE) standard. One of the key elements of LTE is the use of OFDM, Orthogonal Frequency Division Multiplex, as the signal bearer and the associated access schemes, OFDMA (Orthogonal Frequency Division Multiplex. OFDM is used in a number of other of systems from WLAN, WiMAX to broadcast technologies including DVB and DAB. OFDM has many advantages including its robustness to multipath fading and interference. In addition to this, even though, it may appear to be a particularly complicated form of modulation, it lends itself to digital signal processing techniques.

LTE modulation & OFDM basics

The use of OFDM is a natural choice for LTE. While the basic concepts of OFDM are used, it has naturally been tailored to meet the exact requirements for LTE. However its use of multiple carrier each carrying a low data rate remains the same. The actual implementation of the technology will be different between the downlink (i.e. from base station to mobile) and the uplink (i.e. mobile to the base station) as a result of the different requirements between the two directions and the equipment at either end. However OFDM was chosen as the signal bearer format because it is very resilient to interference. Also in recent years a considerable level of experience has been gained in its use from the various forms of broadcasting that use it along with Wi-Fi and WiMAX. OFDM is also a modulation format that is very suitable for carrying high data rates - one of the key requirements for LTE.

Bit error rate (BER) definition and basics

As the name implies, a bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. The definition of bit error rate can be translated into a simple formula:

$$\text{Bit error rate(BER)} = \frac{\text{Number of errors}}{\text{Total no or bits sent}}$$

If the medium between the transmitter and receiver is good and the signal to noise ratio is high, then the bit error rate will be very small - possibly insignificant and having no noticeable effect on the overall system However if noise can be detected, then there is chance that the bit error rate will need to be considered. The main reasons for the degradation of a data channel and the corresponding bit error rate, BER is noise and changes to the propagation path (where radio signal paths are used). Both effects have a random element to them, the noise following a Gaussian probability function while the propagation model follows a Rayleigh model. This means that analysis of the channel characteristics are normally undertaken using statistical analysis techniques. For fibre optic systems, bit errors mainly result from imperfections in the components used to make the link. These include the optical driver, receiver, connectors and the fibre itself. Bit errors may also be introduced as a result of optical dispersion and attenuation that may be present. Also noise may be introduced in the optical receiver itself. Typically these may be photodiodes and amplifiers which need to respond to very small changes and as a result there may be high noise levels present. Another contributory factor for bit errors is any phase jitter that may be present in the system as this can alter the sampling of the data.

OFDM Model

The basic idea underlying OFDM systems is the division of the available frequency spectrum into several subcarriers. To obtain a high spectral efficiency, the frequency responses of the subcarriers are overlapping and orthogonal, hence the name OFDM. This orthogonality can be completely maintained with a small price in a loss in SNR, even though the signal passes through a time dispersive fading channel, by introducing a cyclic prefix (CP). A block diagram of a baseband OFDM system is shown in below Figure

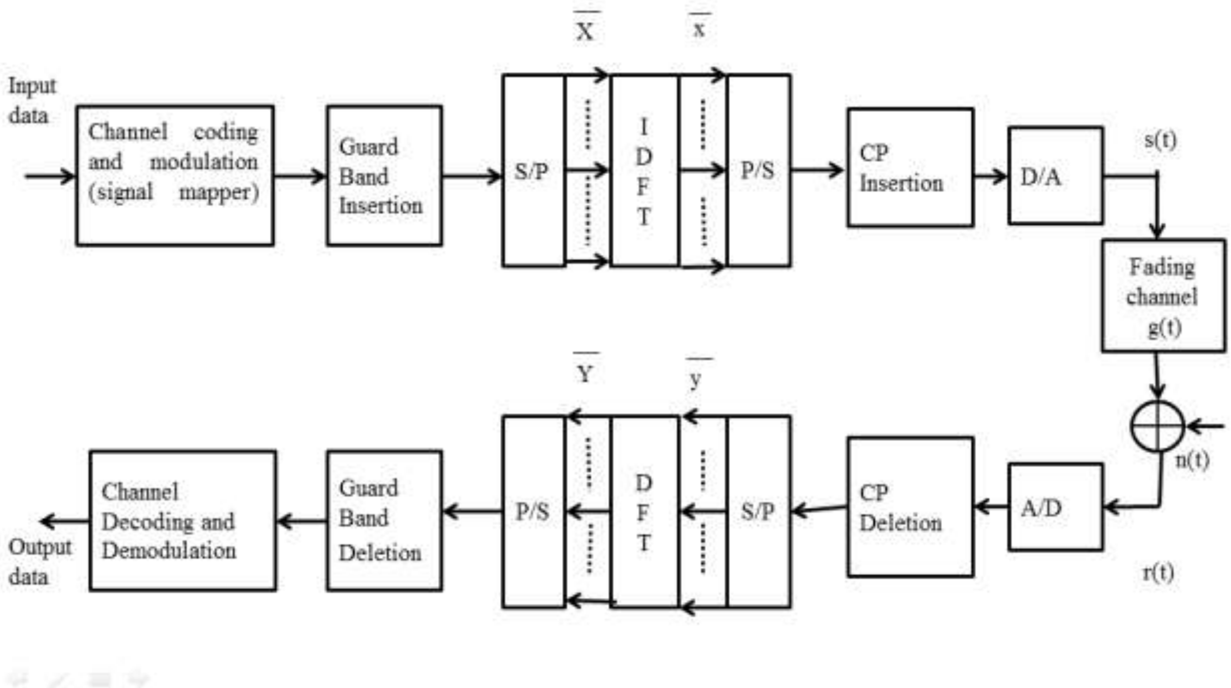

Fig.1: OFDM Block diagram

The binary information is first grouped, coded, and mapped according to the modulation in a "signal mapper." After the guard band is inserted, an N-point inverse discrete-time Fourier transform (IDFTN) block transforms the data sequence into time domain (note that N is typically 256 or larger). Following the IDFT block, a cyclic extension of time length TG, chosen to be larger than the expected delay spread, is inserted to avoid intersymbol and intercarrier interferences. The D/A converter contains low-pass filters with bandwidth $1/T_S$, where TS is the sampling interval. The channel is modeled as an impulse response g(t) followed by the complex additive white Gaussian noise (AWGN) n(t), where αm is a complex values and $0 \leq \tau m T_S \leq T_G$.

$$g(t)= \sum_{m=1}^{M} \alpha m \quad \delta(t - \tau m Ts)$$

At the receiver, after passing through the analog-to-digital converter (ADC) and removing the CP, the DFT_N is used to transform the data back to frequency domain. Lastly, the binary information data is obtained back after the demodulation and channel decoding.Let $\overline{X}=[X_k]^T$ and $\overline{Y}=[Y_k]^T$, k=(0,1,….N-1) denote the input data of IDFT block at the transmitter and the output data of DFT block at the receiver, respectively.Let $\overline{g}=[g_n]^T$ and $\overline{n}=[n_n]^T$,(n=0,1,……N-1) denote the sampled channel impulse response and AWGN, respectively. The input matrix $\underline{X}$=diag($\overline{X}$) and the DFT-matrix,

$$\underline{F} = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}$$

Where $W_n^{i,k} = (\frac{1}{\sqrt{N}})^{-j2\pi(ik/N)}$. Also define $\overline{H} = DFT_N(\overline{g}) = \underline{F}\overline{g}$ and $\overline{N} = \underline{F}\overline{n}$.

Under the assumption that the interferences are completely eliminated , the following equation is derived

$$\overline{Y} = DFT_N(IDFT(\overline{X})*\overline{g}+\overline{n}) = \underline{XF}\overline{g}+\overline{N}$$

$$\overline{Y}=\underline{X}\overline{H}+\overline{N}$$

This equation demonstrates that an OFDM system is equivalent to a transmission of data over a set of parallel channels.

As a result, the fading channel of the OFDM system can be viewed as a 2D lattice in a time-frequency plane, which is sampled at pilot positions and the channel characteristics between pilots are estimated by interpolation. The art in designing channel estimators is to solve this problem with a good trade-off between complexity and performance. The two basic 1D channel estimations in OFDM systems. The first one, block-type pilot channel estimation, is developed under the assumption of slow fading channel, and it is performed by inserting pilot tones into all subcarriers of OFDM symbols within a specific period. The second one, comb-type pilot channel estimation, is introduced to satisfy the need for equalizing when the channel changes even from one OFDM block to the subsequent one. It is thus performed by inserting pilot tones into certain subcarriers of each OFDM symbol, where the interpolation is needed to estimate the conditions of data subcarriers.

In block-type pilot-based channel estimation, OFDM channel estimation symbols are transmitted periodically, and all subcarriers are used as pilots. The task here is to estimate the channel conditions (specified by $\overline{H}$ or $\overline{g}$) given the pilot signals (specified by matrix $\underline{X}$ or vector $\overline{X}$) and received signals (specified by $\overline{Y}$), with or without using certain knowledge of the channel statistics.The receiver uses the estimated channel conditions to decode the received data inside the block until the next pilot symbol arrives.The estimation can be based on least square (LS), minimum mean-square error (MMSE), and modified LS and MMSE.

LEAST SQUARE ESTIMATION (LSE) CHANNEL ESTIMATION

In this method, at the receiver side, the information about the position of the pilots in the transmitted data ($\underline{X}$) is known. With the information of received data ($\overline{Y}$) and the position of the pilots, estimated channel ($\overline{H}$) can be calculated by minimizing the least square error:
Least square estimation of channel is given by

$$\hat{H}ls = \underline{X}^{-1}\ \overline{Y} = \frac{\underline{X}}{\overline{Y}}$$

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.

MINIMUM MEAN SQUARE ERROR (MMSE) CHANNEL ESTIMATION

The MMSE estimator employs the second-order statistics of the channel conditions to minimize the mean-square error. $\underline{R}gg$, $\underline{R}HH$, and $\underline{R}yy$ are the autocovariance matrix of $\overline{g}$,$\overline{H}$ and $\overline{Y}$, respectively, and by $\underline{R}gy$ the cross covariance matrix between $\overline{g}$ and $\overline{Y}$. σ^2_N is denoted by the noise variance $E\{|\overline{N}|2\}$. Assume the channel vector and the noise are uncorrelated, it is derived that

$$\hat{H}mmse = \underline{R}HH\,[\underline{R}HH + \sigma 2N\,(\underline{X}\,\underline{X}H)^{-1}]^{-1}\hat{H}ls$$

The MMSE estimator yields much better performance than LS estimators, especially under the low SNR scenarios.A major drawback of the MMSE estimator is its high computational complexity, especially if matrix inversions are needed each time the data in $\underline{X}$ changes.

DISCRETE FOURIER TRANSFORM (DFT) BASED CHANNEL ESTIMATION

DFT based channel estimation is a time domain channel estimation technique. It is used to suppress the noise in time domain because energy is concentrated in time domain. The main asset of this method is that it has less complexity than LSE estimation because of the use of fast algorithms i.e. FFT and IFFT. Performance of DFT based estimation is better than both LSE and MMSE estimation .In this method, first the frequency domain channel estimation is done using LSE channel estimation**.** Now estimated output is converted to time domain using the M-point IDFT. In the time domain, energy is concentrated to only a small number of samples. Due to multipath fading, a lot of samples in the channel which have lesser energy. So only L samples are considered which have a considerable amount of energy than noise [9], so after IDFT, zero padding is applied to increase the number of samples. Since the channel response beyond L samples have only noise so this part can be cast aside. Only first L samples are considered in DFT based channel estimation.

$\tilde{H}LS$= $DFT[\tilde{H}ZP, LS]\ 0 \leq m \leq M-1$

So DFT based channel estimation gives better performance because noise is removed in time domain and has less complexity with the use of FFT and IFFT

RESULTS

The combination of OFDM with Multiple Input and Multiple Output has fulfilled the future needs of high transmission rate and reliability. The quality of transmission can be further improved by reducing the effect of fading, which can be reduced by properly estimating the channel at the receiver side. For high SNRs the LSE estimator is both simple and adequate. The MMSE estimator has good performance but high complexity. To further improve the performance of LSE and MMSE, DFT based channel estimation is applied.

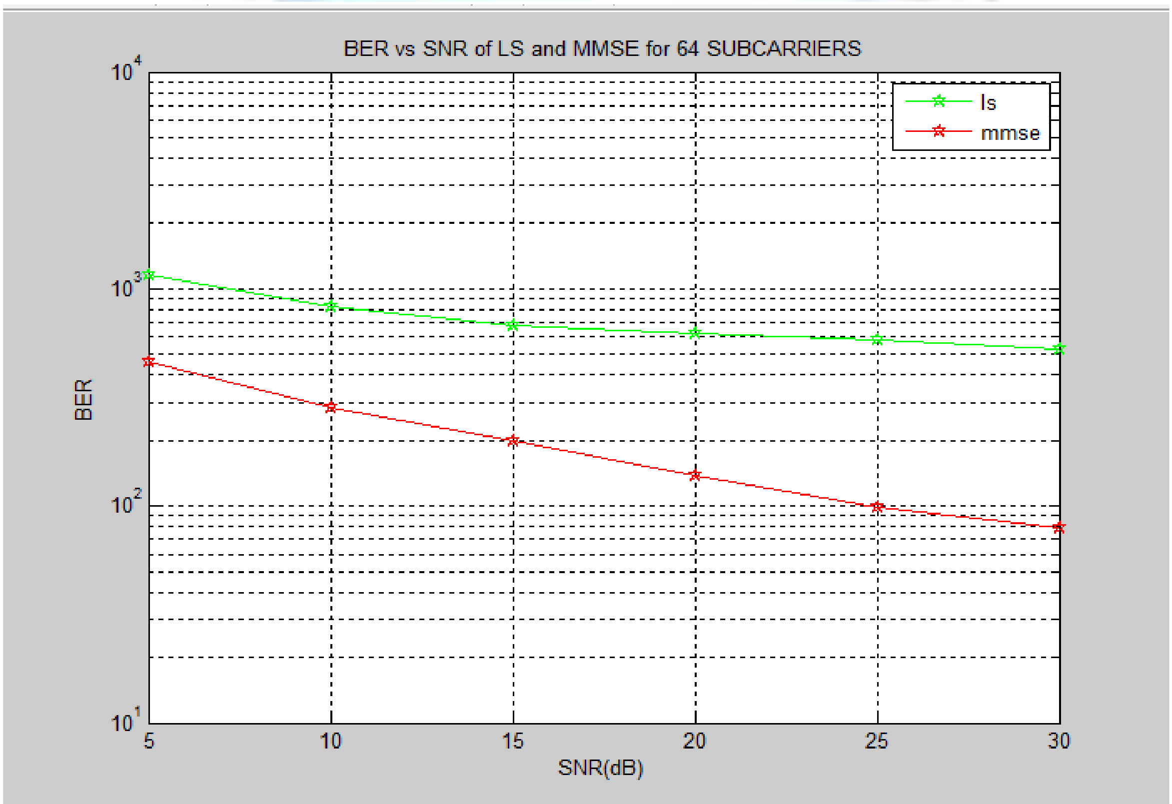

Fig.2: BER vs SNR of LS & MMSE for 64 subcarriers

The Fig.2 shows the BER Vs SNR of LS and MMSE estimators. As the SNR increases BER decreases, MMSE estimator has the better performance compared to the LS estimator.

Table.1: BER vs SNR of LS & MMSE for 64 subcarriers

BER vs SNR of LS & MMSE for 64 subcarriers			
S.No	SNR(dB)	LS	MMSE
1.	5	1113.5	503.3
2.	10	805	353.2
3.	15	633.7	258.12
4.	20	588.5	225.125
5.	25	581.5	201.6
6.	30	571.2	172.5

The Table.1 shows the values of BER Vs SNR of LS and MMSE estimators for 64 carriers. For 10dB SNR the average value BER of LS is 805 and for MMSE is353.2. This shows MMSE has better performance as the errors are reduced.

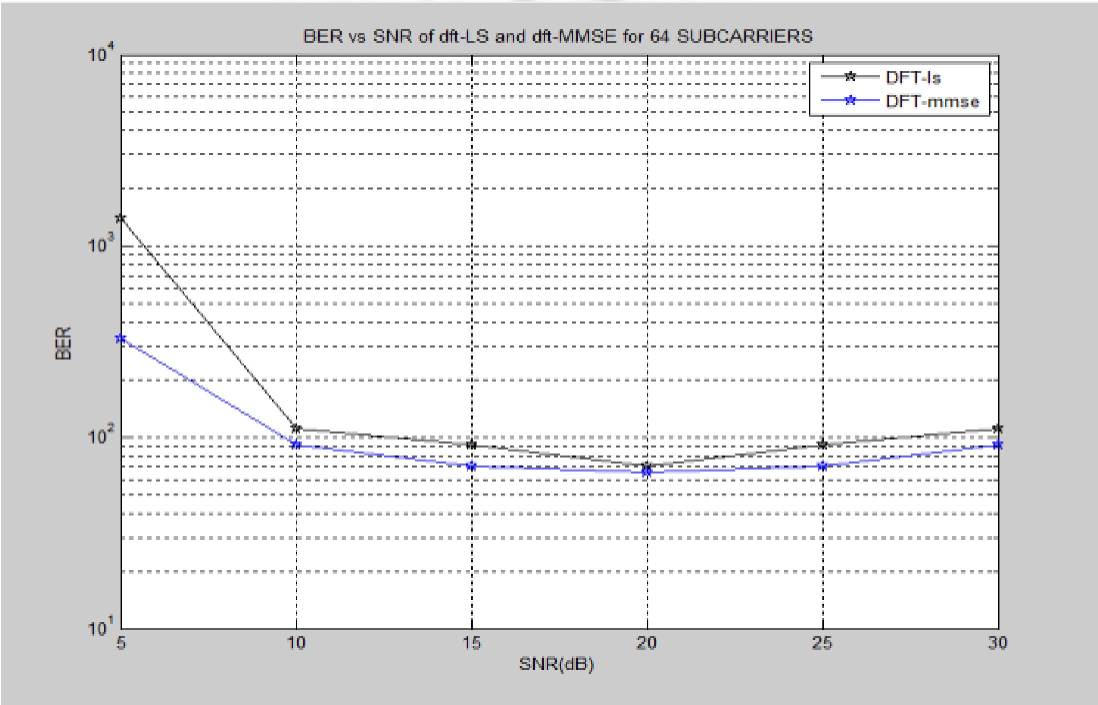

Fig.3: BER vs SNR of DFTLS & DFTMMSE 8.for 64 subcarriers

The Fig.3 shows the BER Vs SNR of DFTLS and DFTMMSE estimators. As the SNR increases BER decreases, DFTMMSE estimator has the better performance compared to the DFTLS estimator.

Table.2: BER vs SNR of DFTLS & DFTMMSE 8.for 64 subcarriers

BER vs SNR of DFTLS & DFTMMSE 8.for 64 subcarriers			
S.No	SNR	DFT-LS	DFT-MMSE
1.	5	1397.81	327.4
2.	10	111.59	91.32
3.	15	91.4	70.2
4.	20	70.4	65.21
5.	25	91.4	70.20
6.	30	111.59	91.32

The Table.2 shows the values of BER Vs SNR of LS and MMSE estimators for 64 carriers. For 10dB SNR the average value BER of DFTLS is 111.59 and for DFTMMSE is 91.32. This shows DFTMMSE has better performance as the errors are reduced.

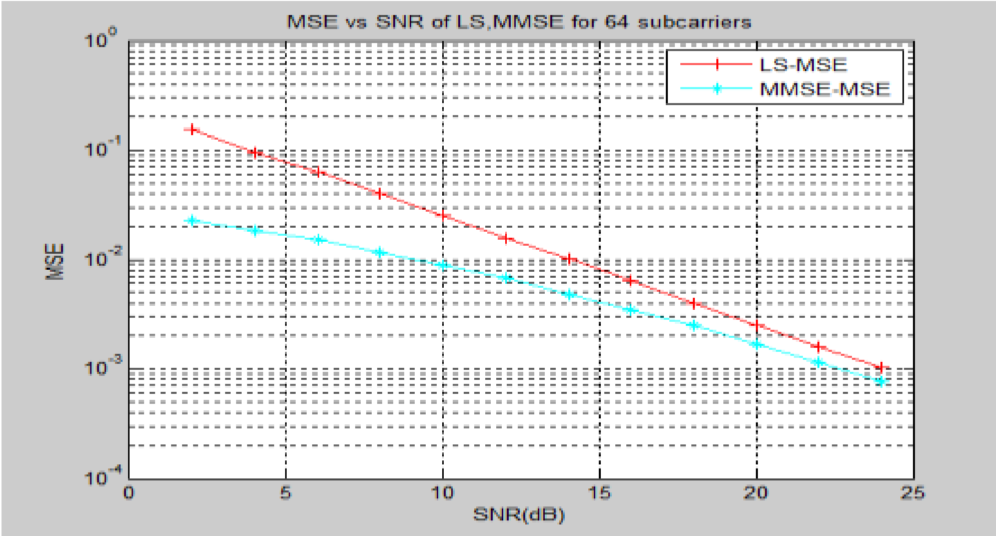

Fig.4: MSE vs SNR of LS & MMSE for 64 subcarriers

The Fig.4 shows the MSE Vs SNR of LS and MMSE estimators. As the SNR increases MSE decreases, MMSE estimator has the better performance compared to the LS estimator.

Table.3: MSE vs SNR of LS & MMSE for 64 subcarriers

MSE vs SNR of LS & MMSE for 64 subcarriers			
S.No	SNR(Db)	LS	MMSE
1.	2	0.152	0.022
2.	4	0.0954	0.0182
3.	6	0.0633	0.0149
4.	8	0.0403	0.0116
5.	10	0.0257	0.00899
6.	12	0.0159	0.0068
7.	14	0.0100	0.00471
8.	16	0.00633	0.00342
9.	18	0.00398	0.00247
10.	20	0.00249	0.00164
11.	22	0.00158	0.00113
12.	24	0.00104	0.00073

The Table.3 shows the values of MSE Vs SNR of LS and MMSE estimators for 64 carriers. For 10dB SNR the average value MSE of LS is 0.0257and for MMSE is 0.00899. This shows MMSE has better performance as the errors are reduced.

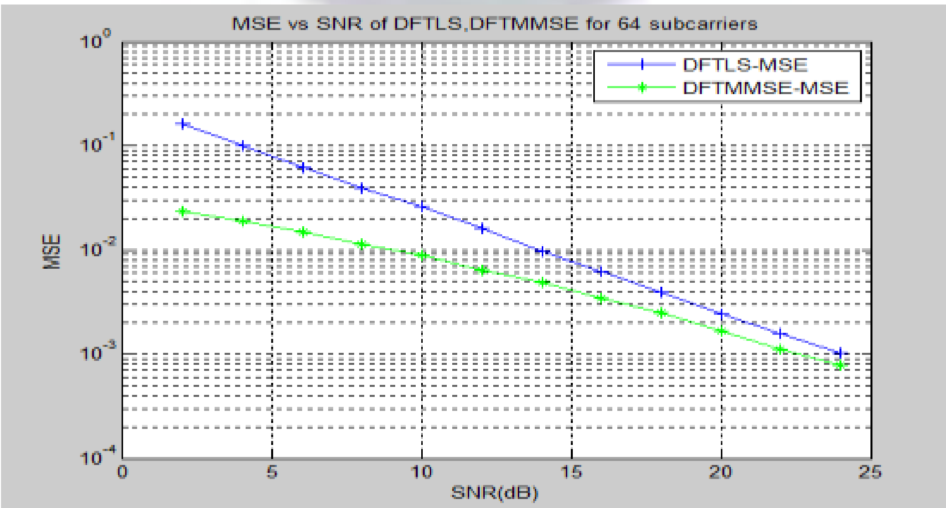

Fig. 5: MSE vs SNR of DFTLS & DFTMMSE for 64 subcarriers

The Fig.3 shows the MSE Vs SNR of DFTLS and DFTMMSE estimators. As the SNR increases MSE decreases, DFTMMSE estimator has the better performance compared to the DFTLS estimator.

Table.4: MSE vs SNR of DFTLS & DFTMMSE for 64 subcarriers

MSE vs SNR of DFTLS & DFTMMSE for 64 subcarriers			
S.No	SNR	DFTLS	DFTMMSE
1.	2	0.150	0.0219
2.	4	0.0890	0.0187
3.	6	0.062	0.01483
4.	8	0.03912	0.01122
5.	10	0.0251	0.00888
6.	12	0.0156	0.00642
7.	14	0.00966	0.00469
8.	16	0.00625	0.00330
9.	18	0.00392	0.00237
10.	20	0.002424	0.00167
11.	22	0.001575	0.00110
12.	24	0.001036	0.00079

The Table.4 shows the values of MSE Vs SNR of DFTLS and DFTMMSE estimators for 64 carriers. For 10dB SNR the average value MSE of DFTLS is 0.0251 and for DFTMMSE is 0.00888. This shows DFTMMSE has better performance as the errors are reduced.

Conclusions

In this paper, improvement in channel estimation in OFDM system using frequency and time domain techniques for Additive white Gaussian channel is modeled. The analysis is carried out for 64 carriers in terms of BER vs SNR and MSE vs SNR. In first case BER vs SNR is evaluated in two steps; in first step BER is estimated for LS and MMSE, the result shows that for 10dB SNR the average value BER of LS is 805 and for MMSE is 353.2 which shows LS has poor performance. In second step BER is estimated for DFTLS and DFTMMSE it observed that for 10dB SNR the average value BER of DFT-LS is 111.59 and for DFT-MMSE is 91.32. From this first case it shows DFTMMSE has better performance than remaining three estimators.

In second case MSE vs SNR is evaluated in two steps; in first step MSE is estimated for LS and MMSE, the result shows that for 10dB SNR the average value MSE for LS is 0.0257 and for MMSE is 0.00899 which shows LS has poor performance. In second step MSE is estimated for DFTLS and DFTMMSE the results show that for 10dB SNR the average value BER of DFTLS is 0.0251 and for DFTMMSE is 0.00888. From the second case also it shows DFTMMSE has better performance than remaining three estimators. This clearly shows the BER and MSE of DFT based system is less than LS and MMSE.

References

[1]. XinXiong, Bin Jiang, Member, IEEE, Xiqi Gao, Senior Member, IEEE, and XiaohuYou.,"DFT-based channel estimatior for OFDM sysems with Leakage estimtion", IEEE COMMUNICATIONS LETTERS,VOL.17,NO.8,AUGUST 213.

[2]. " Improving Channel Estimation in OFDM System Using Time Domain Channel Estimation for Time Correlated Rayleigh Fading Channel Model"International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 www.ijesi.org Volume 2 Issue 8 ǁ August 2013 ǁ PP.45-51.

[3]. Edfors, O., Sandell, M., Van de Beek, J.-J., Landström, D., and Sjöberg, F., An Introduction to Orthogonal Frequency Division Multiplexing, Luleå, Sweden: Luleå Tekniska Universitet, 1996, pp. 1–58.

[4]. Van de Beek, J.-J., Edfors, O. S., Sandell, M., Wilson, S. K., and Börjesson, O. P., "On channel estimation in OFDM systems," 45th IEEE Vehicular Technology Conference, Chicago, Il., vol. 2, pp. 815-819, July 1995.

[5]. Edfors, O., Sandell, M., Van de Beek, J.-J., and Wilson, S. K., "OFDM Channel Estimation by Singular Value Decomposition," IEEE Transactions on Communications, vol. 46, pp. 931–939, July 1998.

[6]. Strobach, P., "Low-Rank Adaptive Filters," IEEE Transactions on Signal Processing, vol. 44, pp. 2932–2947. Dec. 1996.

[7]. Coleri, S., Ergen, M., Puri, A., and Bahai, A., "Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems," IEEE Transactions on Broadcasting, vol. 48, pp. 223–229, Sept. 2002.

[8]. Wu, J., and Wu, W., "A Comparative Study of Robust Channel Estimators for OFDM Systems," Proceedings of ICCT, pp. 1932–1935, 2003.

[9]. Yang, B., Letaief, K. B., Cheng, R. S., and Cao, Z., "Channel Estimation for OFDM Transmission in Multipath Fading channels Based on Parametric Channel Modeling," IEEE Transactions on Communications, vol. 49, pp. 467–479, March 2001.

[10]. Ottersten, B., Viberg, M., and Kailath, T., "Performance Analysis of the Total Least Squares ESPRIT Algorithm," IEEE Transactions on Signal Processing, vol. 39, pp. 1122–1135, May 1991.

[11]. Hou, X., Li, S., Liu, D., Yin, C., and Yue, G., "On Two-dimensional Adaptive Channel Estimation in OFDM Systems," 60th IEEE Vehicular Technology Conference, Los Angeles, Ca., vol. 1, pp. 498–502, Sept. 2004.

[12]. Sanzi, F., Sven, J., and Speidel, J., "A Comparative Study of Iterative Channel Estimators for Mobile OFDM Systems," IEEE Transactions on Wireless Communications, vol.2, pp. 849–859, Sept. 2003.

[13]. S. Rosati, G. E. Corazza, and A. Vanelli-Coralli, "OFDM channel estimation based on impulse response decimation: analysis and novel algotithms," IEEE Trans. Commun., vol. 60, no. 7, pp. 1996–2008, Jul. 2012.

[14]. M. Jiang, G. Yue, N. Prasad, and S. Rangarajan, "Enhanced DFT-based channel estimation for LTE uplink," in Proc. 2012 IEEE VTC – Spring, pp. 1–5.

[15]. B. Yang, Z. Cao, and K. B. Letaief, "Analysis of low-complexity windowed DFT-based MMSE channel estimator for OFDM systems," IEEE Trans. Commun., vol. 49, no. 4, pp. 1207–1215, Jul. 2000.

[16]. Y. H. Yeh and S. G. Chen, "Efficient channel estimation based on discrete cosine transform," in Proc. 2003 IEEE ICASSP, pp. 676–679.

[17]. J. Seo, S. Jang, J. Yang, W. Jeon, and D. K. Kim, "Analysis of pilotaided channel estimation with optimal leakage suppression for OFDM systems," IEEE Commun. Lett., vol. 14, no. 9, pp. 809–811, Sep. 2010.

[18]. J. J. van de Beek, O. Edfors, M. Sandell, S. K. Wilson, and P. O. Borjesson, "On channel estimation in OFDM systems," in Proc. 1995IEEE VTC, pp. 815–819.

[19]. O. Edfors, M. Sandell, J. J. van de Beek, S. K. Wilson, and P. O. Borjesson, "OFDM channel estimation by singular value decomposition," IEEE Trans. Commun., vol. 46, no. 7, pp. 931–939, Jul. 1998.

[20]. S. Kay, Fundamentals of Statistical Signal Processing: Estimation Theory.Prentice Hall, 1987.