# Implementation and Analysis of Channel Response in Wireless OFDM System

Mehak Saini[1], Priyanshu Tripathi*[2], K K Saini[3]
[1]*Aricent Pvt. Ltd, Gurgram, Haryana, India*
[2,3]*Department of Electronics and Communication Engineering*
*Hindu College of Engineering Sonepat, INDIA*
[1]*mhk.saini1904@gmail.com*,[2]*prk.tripathi@gmail.com*,[3]*dphce2015@gmail.com*

*Abstract*— Orthogonal Frequency Division Multiplexing (OFDM) based systems are strong candidates for an air interface of future higher generation mobile wireless systems, which provide high data rates and high mobility. In this work, channel response is analyzed in presence AWGN and mean square error (MSE) of different estimators is calculated. Different estimators used in this work are LS Estimator and MMSE estimator. Performance wise MMSE estimator is better than LS estimator has but MMSE estimator has more complexity than LS estimators. Hence this works present modifications to both MMSE and LS estimators that use the assumption of a finite length impulse response. The performance is presented in terms of mean-square error (MSE)

Keywords- OFDM, LS Estimator, MMSE estimator, Channel estimation, MSE.

## I. INTRODUCTION

Recently, Orthogonal frequency-division multiplexing (OFDM) systems [1] are investigated significantly since this technique has been employed in the European digital audio broadcasting (EDAB) system [2], OFDM in fading channel environments has gained a broad interest. For instance, it is employed to digital TV broadcasting [3]. The use of differential phase-shift keying (DPSK) in OFDM systems avoids the tracking of a time varying channel. However, this limits the number of bits per symbol and results in a 3 dB loss in *signal-to-noise power ratio* (SNR) [4]. In [5] and [6], an OFDM system using 16-QAM has been investigated. In the design of wireless OFDM systems, the channel is usually assumed to have a finite-length impulse response. In order to reduce Inter block interference and preserve orthogonality of the tones, A cyclic extension, longer than its channel response, is put between consecutive blocks [7]. This paper discusses channel response and mean square error in wireless OFDM systems. Minimum mean-square error (MMSE) and least-squares (LS) channel estimators are used to find channel impulse response. Performance wise MMSE estimator is better than LS estimator has but MMSE estimator has more complexity than LS estimators. Hence this work present modifications to both MMSE and LS estimators that use the assumption of a finite length impulse response. The performance is presented in terms of mean-square error (MSE).

## II. DESCRIPTION OF THE PROBLEM

The aim of this work is to present modifications to both MMSE and LS estimators. The following are the assumptions

### A. *Assumptions*

- The assumption of a finite length impulse response system.

### B. *System operation*

For the simulations a system is considered operating with a bandwidth of 500 kHz, divided into 64 tones with a total symbol period of 138 microseconds, of which 10 microseconds is a cyclic prefix. Sampling is done with a rate of ½ MHz and also 5 out of 69 samples which are contained in the cyclic prefix (i.e. L = 5) are used. 50K channels are randomized per average SNR, each consisting of five pulses, of which four have uniformly distributed delays over the interval 0-10 microseconds, while one tap is always assumed to have a zero delay, corresponding to a perfect time synchronization of the sampling instants. The multipath intensity profile is assumed to be $\phi(\tau) \cong e^{-\tau / \tau_{rms}}$, where $\tau_{rms}$ is ¼ of the cyclic extension. Monte-Carlo simulations to generate the Rgg for this channel model are used in this. This covariance matrix together with the true noise variance $\sigma_n^2$ is used in the MMSE estimations to follow[8]-[13].

## III. INGREDIENTS REQUIRED FOR CHANNEL ESTIMATION

The ingredients required for channel estimation are presented as following.

### A. *Generation Of G Matrix*

The G matrix are given as:

$$s = s + e^{-j\,(\pi\,(1/N)*(K+\,(N-1))*\,\tau\,(m)*\,((\sin\pi\,*\,\tau\,(m))\,/\,(\sin\pi\,*\,1/N)*\,\tau\,(m-k)}$$

*Also* $g(k+1)=s/sqrt(N)$

*Finally,* $G = g'$

Where g' is the transpose of channel matrix G.

By use of these equations channel matrix G is evaluated, the simulation graph of which is given below.

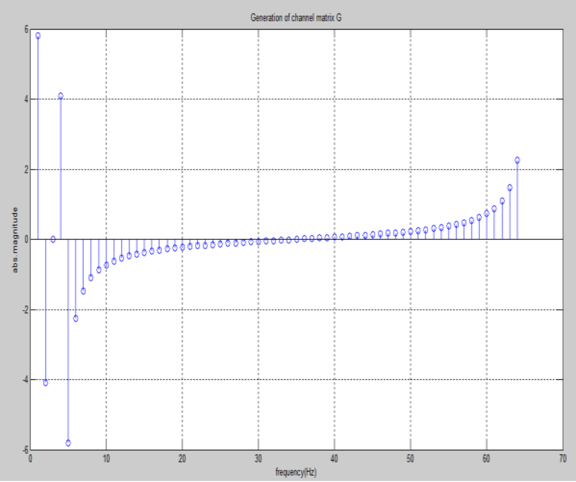

Fig.1- Generation of channel matrix G

### B. *Generation Of H Matrix*

Now the next ingredient for channel estimation is H matrix which is derived by the given formula as G is to be used in this therefore H is given as

H matrix is basically a channel impulse matrix and given as $H=Y_{out}/X_{in}$ where $Y_{out}$ and $X_{in}$ are the output and input channel responses respectively[14].

By simulation taking the discrete points at different frequencies at x axis, the result is given below in Fig.2.

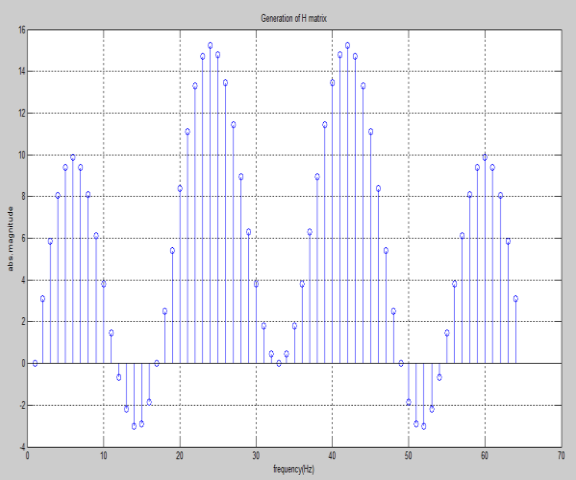

Fig.2- Generation of H matrix

Now XFG is an another matrix to be used in the channel estimation which is given as

$$XFG=X*H$$

Where X is the channel input matrix and H channel impulse matrix. The XFG matrix is also plotted in Fig.3

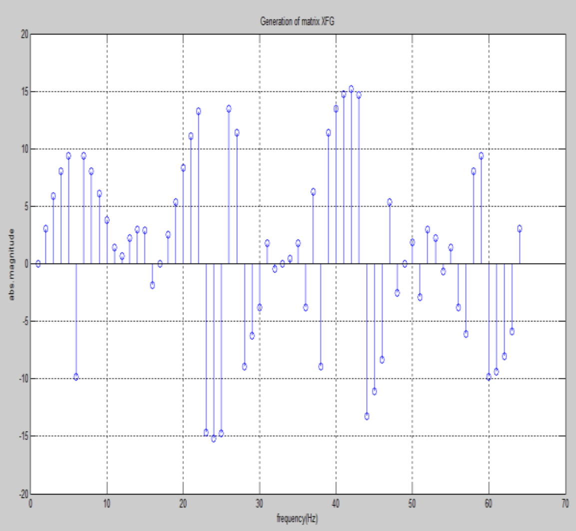

Fig.3- Generation of matrix XFG

### C. *Noise*

The noise is also to be considered in the channel estimation as AWGN i.e. Additive White Gaussian Noise which adds complex Gaussian noise to the channel. If the simulation is performed then the following plot between absolute magnitude v/s frequencies in hertz of noise is seen in Fig.4.

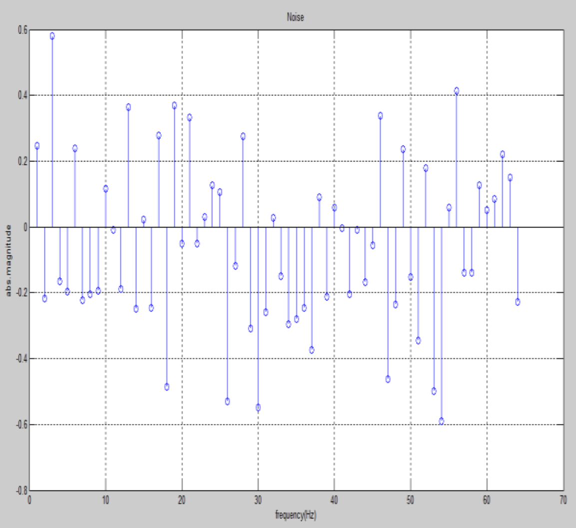

Fig.4- Plot of Noise

### D. *N Sequence*

If the FFT of the noise is to be taken, N sequence is derived as

$$N=fft\ (noise)$$

Now the plot of N is given as shown in Fig.5

Now at different frequencies the value of N is taken in absolute magnitude.

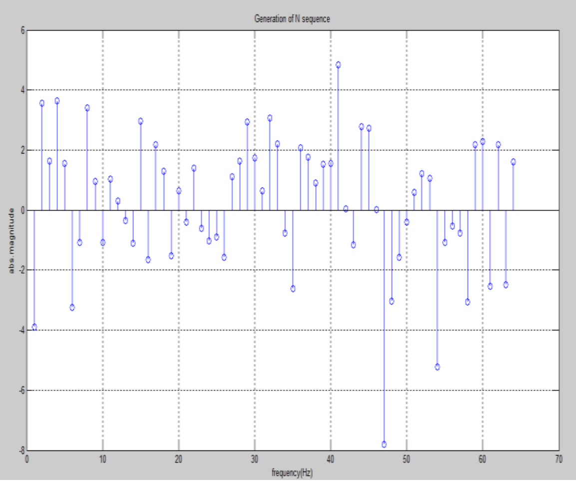

Fig.5- Generation of N sequence

### E. *OUTPUT RESPONSE OF CHANNEL Y*

Output response of the channel is given by the following equation

$$Y=XFG + N$$

XFG and N are calculated above so we get Y as the sum of these in the plot given below in Fig.6 where Y is the output channel response[15]-[20].

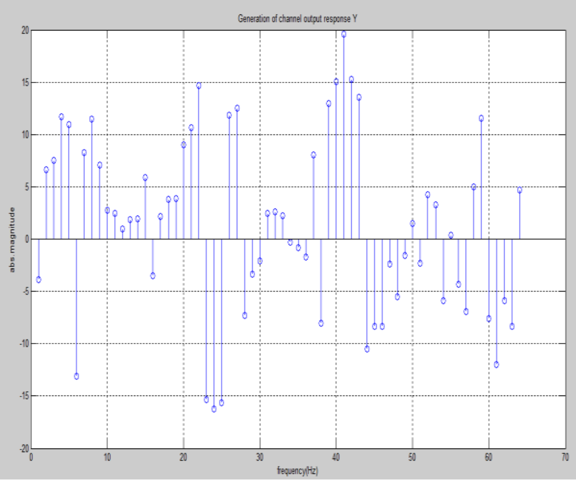

Fig.6- Generation of channel output response Y

### F. *AUTOCOVARIANCE MATRIX*

$R_{gg}$ is covariance matrix can be estimated by using the following simulation as from the calculation of Rgg i.e. auto covariance matrix.

Various strategies can be adopted to use the frequency correlation. The optimal linear minimum mean-squared error that is called LMMSE estimate of h for all possible linear estimators h' becomes

$$h'_{M\,MSE}=A\,h'_{LS}$$

where, $A=R'_{gg'}R^{-1}_{gg'} = R_{gg}\,(R_{gg}+\sigma_n^2\,(XX^H)^{-1})^{-1}$

and $R_{gg}$ is the channel autocorrelation matrix, i.e. it is a matrix that correlates channel attenuations of the sub carriers.

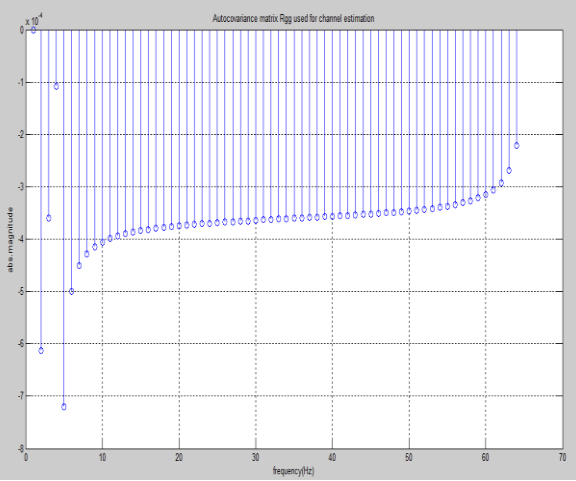

Fig.7- Autocovariance matrix $R_{gg}$

Similarly auto covariance matrix $R_{yy}$ is used in the estimation and can be calculated same as $R_{gg}$ being done and the plot of this is given below in Fig.8.

The equations for the auto covariance matrix $R_{yy}$ are nearly same as presented for the auto covariance matrix $R_{gg}$ above.

$$h'_{M\,MSE}=A\,h'_{LS}$$

where, $A=R'_{yy'}R^{-1}_{yy'} = R_{yy}\,(R_{yy}+\sigma_n^2\,XX^H)^{-1})^{-1}$

Therefore above equations are used for the auto covariance matrix $R_{yy.}$ The MMSE estimator $h'_{M\,MSE}$ is, for complexity reasons, of little practical value. Not only does Equation assume knowledge of the channel correlation and the SNR, it also requires N multiplications per estimated attenuation, and the dependency on the pilots or decisions X may require frequent recalculation of the matrix A

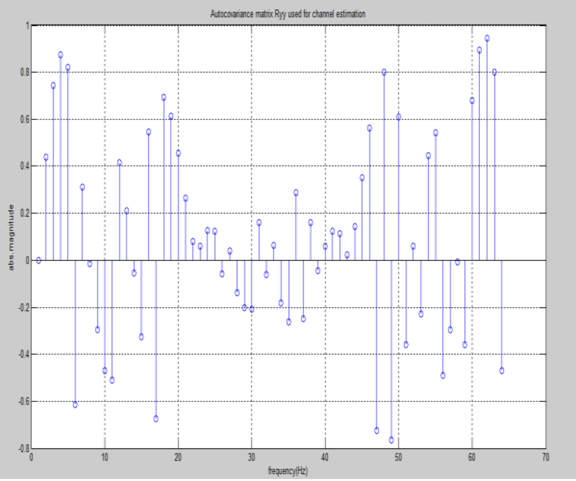

Fig.8- Autocovariance matrix $R_{yy}$

### G. *EVALUATION OF H_MMSE*

Now ingredients for channel estimation are ready and now the estimated channel response is calculated by the use of MMSE estimator that is given as H_MMSE and plot is shown as below. For calculation of this, the formulas given in [21]-[29] are to be used.

MMSE response is to be taken at different frequencies across the channel. In the plot at X axis frequency is taken in hertz and across Y axis absolute magnitude is taken. MMSE estimator is, for complexity reasons, of little practical value. Their performances can be made very close to that of the optimal MMSE estimator. They are generic in the sense that they use assumed (fixed) channel correlation and SNR for the design of ‘A’ matrix which is given in section 4.1.6. They are low-complexity in the sense that they require significantly fewer than N multiplications per estimated attenuation. H_MMSE is used for the channel estimator that is minimum mean square channel estimator [30]-[44].

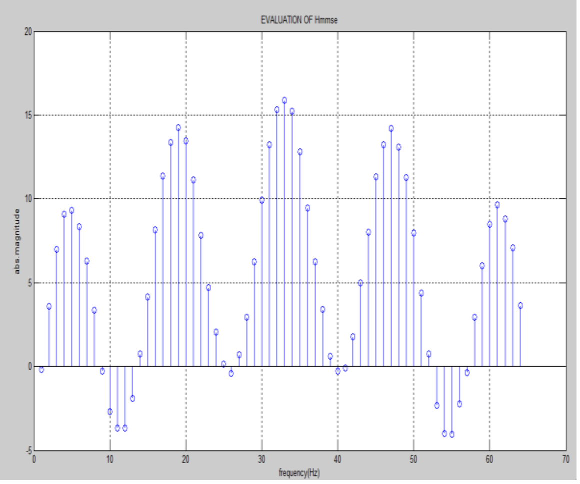

Fig.9- Plot for H_MMSE

### H. MEAN SQUARE ERROR

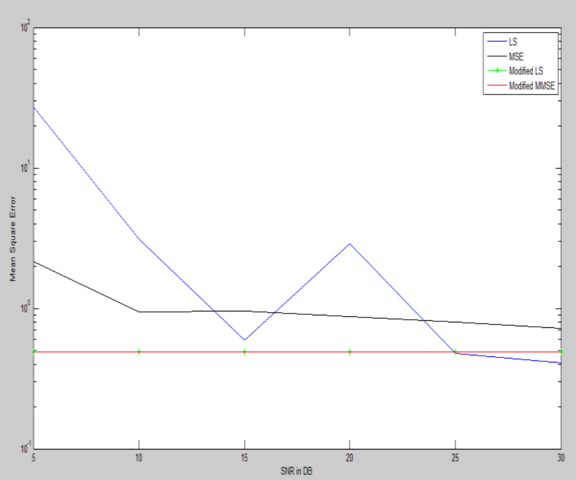

Fig.10- SNR v/s MSE for an OFDM system

Table-4.2: Comparison of the MSE of different estimators

| SNo. | ESTIMATORS | MSE | | | | |
|---|---|---|---|---|---|---|
| 1 | LS | 27.1017 | 3.1384 | 0.5962 | 2.8910 | 0.4784 |
| 2 | MLS | 0.4866 | 0.4868 | 0.4869 | 0.4869 | 0.4869 |
| 3 | MMSE | 2.1417 | 0.9464 | 0.9598 | 0.8729 | 0.7956 |
| 4 | MMMSE | 0.4867 | 0.4869 | 0.4870 | 0.4869 | 0.4869 |

## IV. CONCLUSION

Channel estimation can be performed by many ways: either inserting pilot tones into all of the sub carriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol. Study of channel estimation based on block type pilot arrangement is presented, and it is observed that this type of arrangement performs better when the channel is changing slowly[45]-[48]. The MMSE estimator has good performance but high complexity. The LS estimator has low complexity, but its performance is not as good as that of the MMSE estimator. Modifications to both MMSE and LS estimators are done and it makes use of the assumption of a finite length impulse response. Now these modified estimators are implemented and compared with the unmodified estimators, it is seen that MMSE estimators have good performance but high complexity. Therefore, to minimize the circuit complexity modified MMSE estimator is used.

## V. FUTERE SCOPE

For future research the method to determine the channel taps and improved efficiency of the system may be considered. Also the channel can be estimated by using different modulation schemes and their performance can be compared. We can also go for different methods suitable for estimating channel during fast fading by determining the number of pilots and their positions.

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