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Performance Evaluation of Channel Estimation in OFDM System for Different QAM and PSK Modulations

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Abstract

To recover accurate transmitted data at the receiver end, the information regarding channel state derived from channel estimation methods play a very important role in any communication system. In this paper the performance evaluation of different types of QAM and PSK modulations with three different channel estimation methods in OFDM system for wireless communication in frequency domain for slow fading channel is compared. The results must be useful in OFDM based applications like IEEE 802.16(d) and equivalent standards.

Keywords*: OFDM, QAM, PSK, modulations*

1. Introduction

A title of An orthogonal frequency division multiplexing (OFDM) is an efficient high data-rate, having advantages of high spectrum efficiency, simple & efficient implementation by using the fast Fourier transform (FFT) & the inverse FFT (IFFT), mitigation of inter symbol Interference by inserting a cyclic prefix (CP) and robustness to frequency selective fading channels transmission technique for wireless communication[1].

Any channel estimation technique is used to evaluate the performance of the channel to know its behaviour during the transmission of data under different conditions and for different type of modulations. The channel estimation can be done either block type pattern in which the pilot tones are inserted in all subcarriers of an OFDM symbols, periodically or comb type pattern in which pilot tones are inserted in each individual OFDM data block & channel is estimated in all OFDM symbols [2], known as pilot symbol assisted (PSA) estimation. Block type pattern is suitable for slow-fading assuming channel characteristics are stationary. For comb type pilot pattern and fast fading channel the estimation can be done by interpolation methods like linear, cubic, spline and second order interpolations [1].

In this paper, a comparative study of different types of quadrature amplitude modulation (QAM) and phase shift keying (PSK) modulations with least square (LS), linear minimum mean square error (LMMSE) and modified minimum mean square error (Mod MMSE) channel estimation techniques applied to OFDM systems for the purpose of detecting the received signal, improving the throughput of orthogonal frequency- division multiple - access (OFDMA) systems. Different experts have put efforts to exploit channel estimators for OFDM systems. They are primarily categorized into two branches, depending on whether the fading and dispersive channel is treated as stationary within an OFDM symbol period or not [3-10]. First, when the OFDM symbol duration is much smaller than the channel coherence time, the fading channel is viewed as stationary within one OFDM symbol. This paper elaborates the channel estimation for such a channel situation. The technique is also be useful to provide wireless last mile broadband access in Metropolitan Area Network, delivering performance comparable to traditional cable, DSL or T1 offerings [6, 11-17]

2. System Model

The system model of simulated OFDM Trans-receiver [1] is depicted in figure 1. At transmitter end, the modulator generates Ns data symbols S_n, 0< n <N_{s-1} which are multiplexed to the N_c ($N_s \leq N_c$) subcarriers [7]. The time domain samples S_n transmitted during one OFDM symbol are generated by inverse fast Fourier transformation (IFFT) and transmitted over the channel after inserting the cyclic prefix (CP). In this research our multicarrier system employs 256 subcarriers and cyclic prefix (CP) length of 64. The result of OFDM transmitter will be sent through the multipath fading channel to the receiver.

At the receiver side, the cyclic prefix is removed from the received time-domain samples, and fast Fourier transformation (FFT) is carried out on the data samples y(n), in order to achieve the received data symbols Y_n frequency-domain. This received signal Y_n characterizing one OFDM symbol can be written in frequency domain in matrix form as

$$Y=XH+W \tag{1}$$

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where X is transmitted symbol, H is channel transfer function, W is additive white Gaussian noise.

$X=diag(X_0,\ldots,X_{Nc-1})$

$H=[H_0,\ldots,H_{Nc-1}]^T$

$W=[N_0,\ldots,N_{Nc-1}]$

N_c is the number of subcarriers in an OFDM symbol.

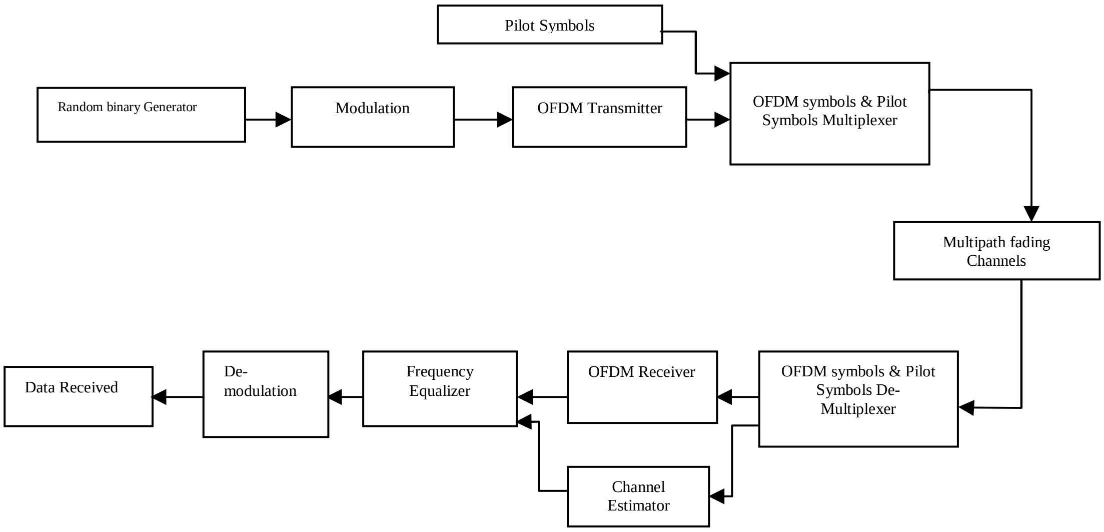

Figure. 1 OFDM system block diagram

3. Channel Estimation Techniques

We have to find the channel transfer function. The impulse response of the multipath fading channel is given by:

$$h(t,\tau) = \sum_m a_m \delta(t-\tau(m)) \quad (2)$$

Where $\tau(_{m})$ is the multipath delay spread factor. Considered that the channel is almost stationary within one symbol period, and then the frequency domain channel frequency at subcarrier k is given by:

$$H_k = \sum_m a_m e^{-j2\pi\tau(m)k / TsN} \quad (3)$$

The equivalent discrete time channel impulse response due to the time domain sampling effect can be taken as under:

$$g_n = 1/N \sum_{k=-N/2}^{\frac{N}{2}-1} H_k e^{j2\pi\tau(m)k/N} \quad (4)$$

After simplification, we get

$$g_k = \frac{1}{\sqrt{N}} \sum a_m e^{-j\pi(k+(N-1)\tau(m))/N \sin(\pi\tau m)/\sin(\pi(\tau(m)-k)/N)} \quad (5)$$

The channel transfer function can be obtained by taking the fast Fourier transformation of g_k

3.1 Least Square Based Estimation

In this estimation the weighted errors between the measurements and the model are minimized [6-7]. In block type pilot arrangement where pilots are inserted in all subcarriers of an OFDM symbol, LS estimator channel transfer function can be written as:

$$H_{LS} = X^{-1}Y = [X_0^{-1}Y_0, X_1^{-1}Y_1, X_z^{-1}Y_z \ldots.. X_{Nc-1}^{-1}Y_{Nc-1}] \quad (6)$$

Where N_c is the number of subcarriers.

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3.2 Linear Minimum Mean Square Error Estimation (LMMSE)

In general the Channel Autocorrelation matrix is expressed as:

$$R_{HpHp} = E[\, H_p H_P]^H \tag{7}$$

where

$$E\{H_m H_n\} = \begin{cases} 1 & \text{for } (m=n) \\ \dfrac{1-e^{-j2\pi (m-n)/N}}{(j2\pi (m-n)/N)} & \text{for } (m \neq n) \end{cases} \tag{8}$$

Note that for an exponentially decaying multipath power-delay profile ($\Phi(\tau) = e^{-\tau/}\tau_{(rms)}$) the correlation between K_1-th and K_2-th subcarriers $r_h(k_1, k_2)$ can be expressed as:

$$R_h(k_1,k_2) = \frac{1-e^{-L[1/\tau(rms) + (2\pi j(k1-k2))/N]}}{\tau_{(rms)}\,(1-e^{-L/\tau(rms)})(1/\tau_{(rms)}+j2\pi(k_1-k_2)/N)} \tag{9}$$

Where L is the length of cyclic prefix, $\tau_{(rms)}$ is RMS delay spread factor of the channel [1].
If $_{RHH}$ is given as

$$\begin{bmatrix} r_h(0,0) & r_h(0,1) & . \; . & r_h(0,N_c-1) \\ r_h(1,0) & r_h(1,1) & . \; . & r_h(1,N_c-1) \\ r_h(2,0) & r_h(2,1) & . \; . & r_h(2,N_c-1) \\ & & . & \\ & & . & \\ & & . & \\ r_h(N_c-1,0) & r_h(N_c-1,1) & . \; . & r_h(N_c-1,N_c-1) \end{bmatrix}$$

Based on the knowledge of the auto-correlation matrix, the channel transfer function can be written for LMMSE estimator as:

$$H_{MMSE} = R_{HH}\,(R_{HH} + I\,\beta/SNR)^{-1} H_{LS} \tag{10}$$

Where I is an Identity matrix and

$$\beta = E[|X_k|^{\,2}]\; E\;\; [|\, 1/X_k|^2],\; k= 0,1,..N_{Nc-1} \tag{11}$$

β is a constant value depending on the modulation type. In our case β=1 [6].

3.3 Modified MMSE Estimation

The equation of channel transfer function can be written as:

$$H_{MMSE} = AH_{LS} \tag{12}$$

where A is a weight matrix defined as:

$$A = R_{HH}\,(R_{HH} + I\,\beta/SNR)^{-1} \tag{13}$$

If R_{HH}^{Mod} is give as:

$$\begin{bmatrix} \mathbf{r_h(0,0)} & \mathbf{r_h(0,1)} & \mathbf{r_h(0,2)} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{r_h(1,0)} & \mathbf{r_h(1,1)} & \mathbf{r_h(1,2)} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{r_h(1,0)} & \mathbf{r_h(1,1)} & \mathbf{r_h(1,2)} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{r_h(1,0)} & \mathbf{r_h(1,1)} & \mathbf{r_h(1,2)} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{r_h(1,0)} & \mathbf{r_h(1,1)} & \mathbf{r_h(1,2)} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{r_h(1,0)} & \mathbf{r_h(1,1)} & \mathbf{r_h(1,2)} \end{bmatrix}$$

Then A can be modified as:

$$A^{Mod} = R_{HH}^{Mod} (R_{HH}^{Mod} + I\ \beta/SNR)^{-1} \quad (14)$$

To modify the autocorrelation channel matrix a significant number (Z) out of N–subcarriers is considered for computations [1] to reduce the rank of this matrix by assigning the zero values to non-significant coefficients. Therefore the Modified channel transfer function is:

$$H_{MMSE}^{Mod} = A^{Mod} H_{LS} \quad (15)$$

It can be seen from above equation that the calculation of A^{Mod} contains of two steps: i) inversing an $N_c \times N_c$ matrix. ii) Multiplying the yield matrix and $N_c \times N_c$ matrix

4. Simulation Results

The symbol error rate is calculated in LS, LMMSE and Modified MMSE methods in frequency domain for 500 iterations. The performance comparison of channel in terms of symbol error rate and signal to noise ratio for different QAM and PSK modulations has been obtained. In modified MMSE method, a number significant (Z) has considered for calculating the channel transfer function (H) at reduced rank of autocorrelation matrix by assigning zero values to non-significant elements. So, the final computation takes place only for the significant elements near to main subcarrier. Hence the computational complexity of LMMSE algorithm is reduced without loss of MSE performance. We consider two paths with non integer sampling interval of 0.5 and 3.5 micro seconds. The impulse response of the multipath fading channel is given by:

$$h(\tau,t) = \sum h_{m\,(t)}\, \delta\,(t-\tau m) \quad (15)$$

Where, $h_m(t)$ and τ_m are the gain and delay of the multipath. In Simulation, we considered

$$h(\tau, t) = \delta(t\text{-}0.5Ts) + \delta(t\text{-}3.5Ts) \quad (16)$$

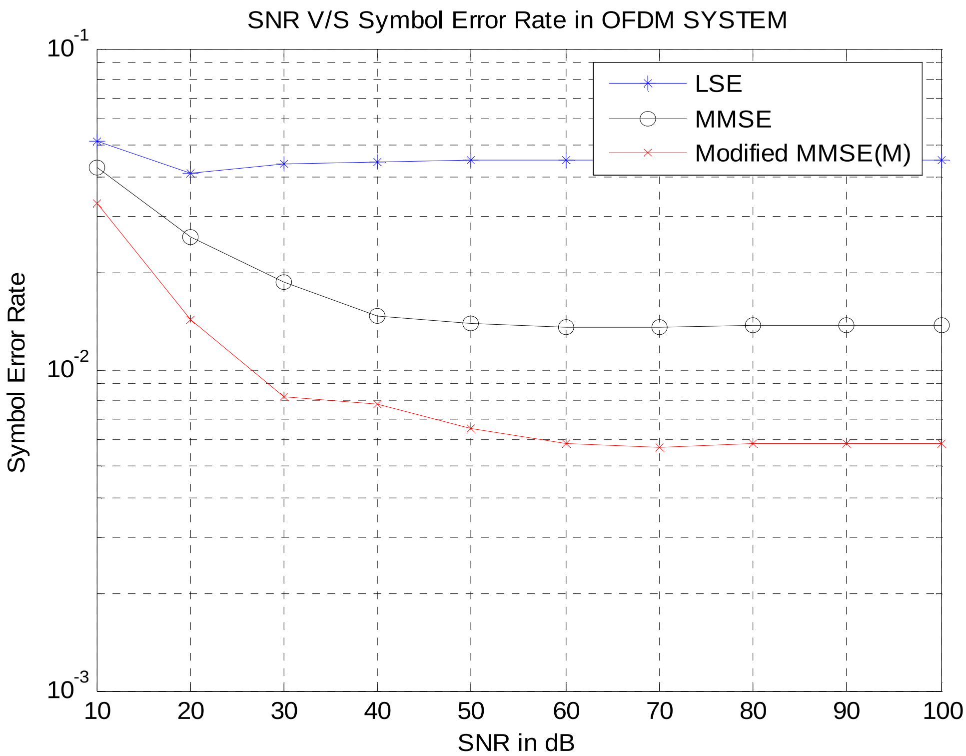

Figure 2. Performance comparison of QAM symbol error rate.

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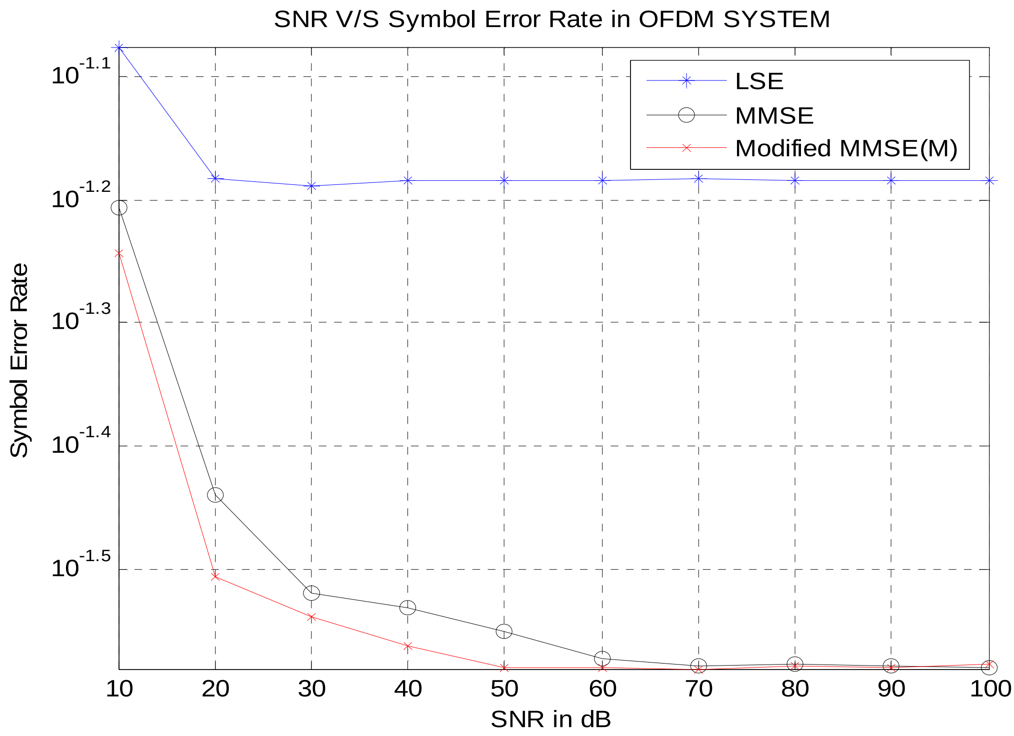

Figure 3. Performance comparison of 4QAM symbol error rate.

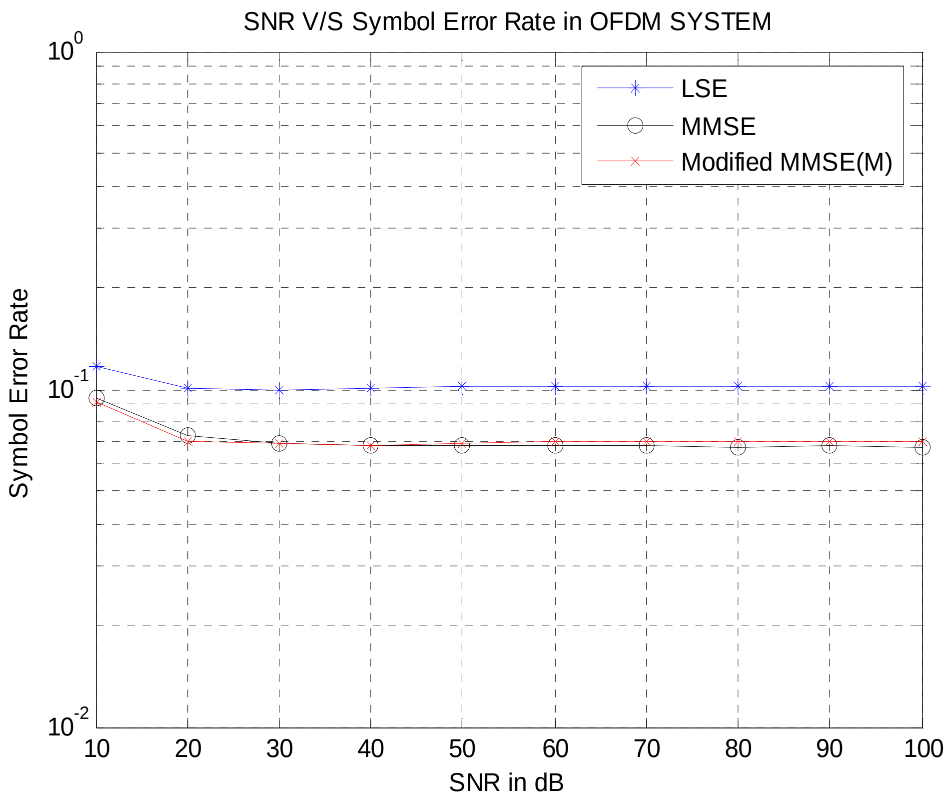

Figure 4. Performance comparison of 8QAM symbol error rate.

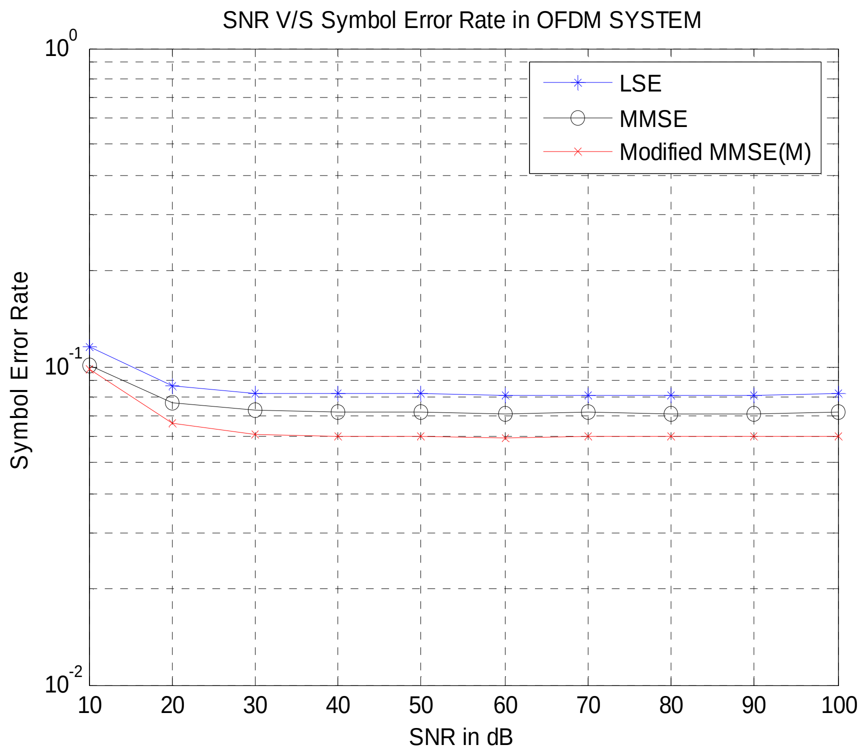

Figure 5. Performance comparison of 16QAM symbol error rate.

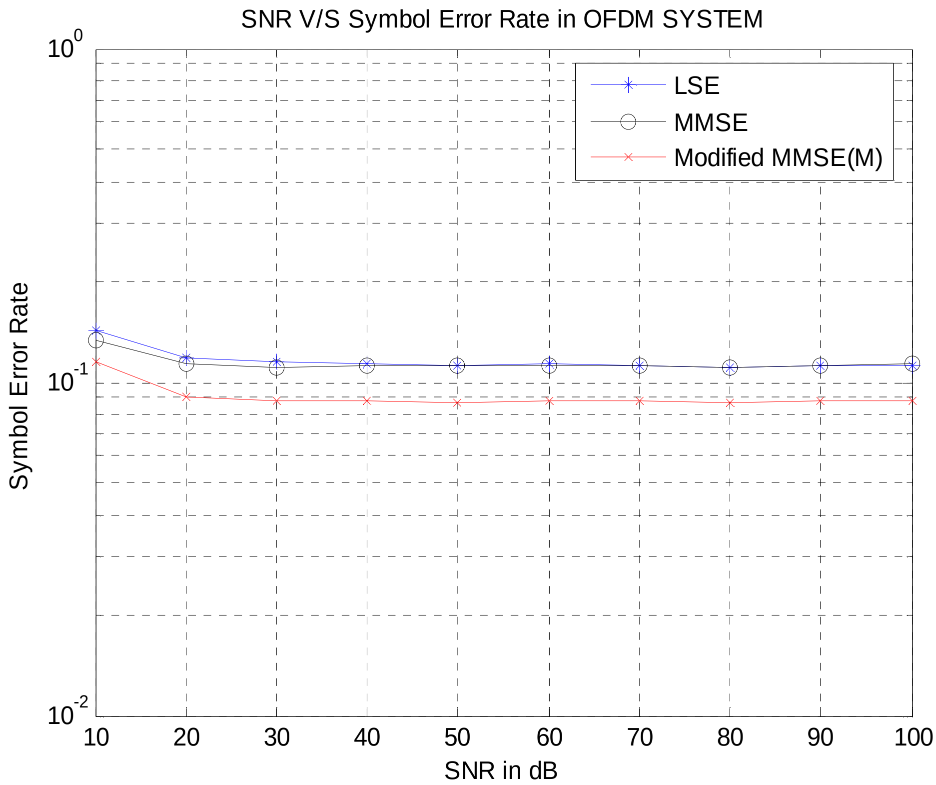

Figure 6. Performance comparison of 32QAM symbol error rate.

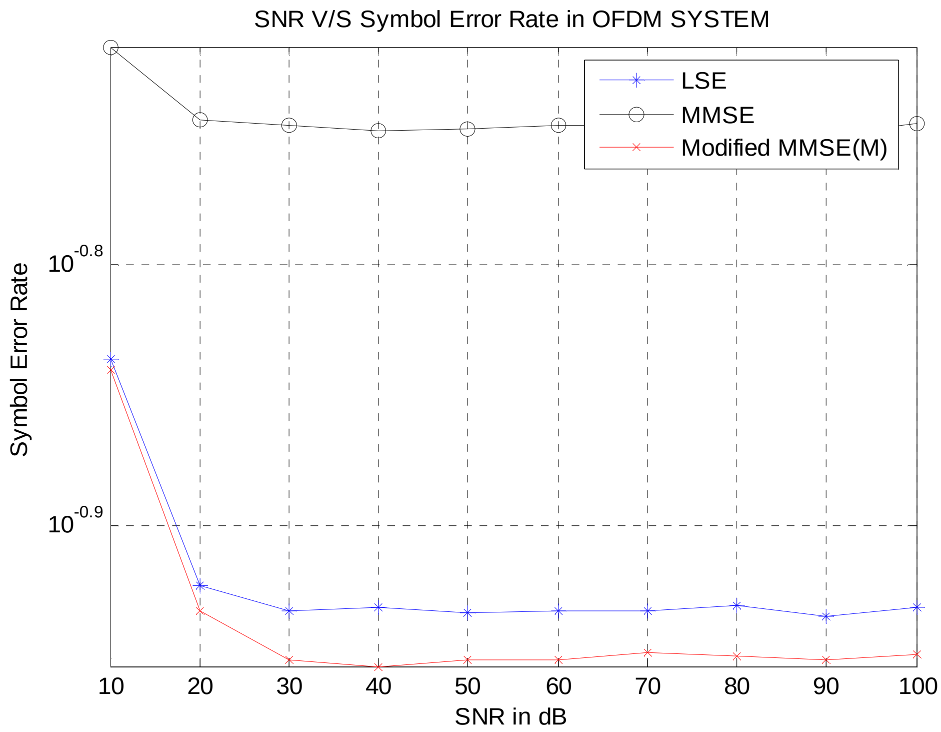

Figure 7. Performance comparison of 64QAM symbol error rate.

The simulations are carried through for channel estimation methods with the aid of pilot symbols insertion. The model parameters are given as under

Table 1. Parameter /Specifications for OFDM system for QAM & PSK modulations

Parameter	Specifications
No. of Subcarriers	N = 256
FFT size	256
Length of Guard Interval	64 samples
Modulation type	QAM,4QAM,8QAM,16QAM,32 QAM & 64 QAM, BPSK,QPSK,8PSK,16PSK, 32 PSK & 64 PSK
Pilot Type	Block type (256 subcarriers)
Significant Number (Z) for Modified MMSE Method.	105 out of 256 for QAM & 90 out of 256 for PSK modulations
Channel Model	Rayleigh fading
Number of Iterations	500

5. Results Discussions

In Figures 2 to 13, shows the symbol error rates of different types of quadrature amplitude modulation (QAM) and phase shift keying (PSK) as per conditions in Table 1 parameters for 256 subcarriers with three methods of channel estimation along with insertion of pilot tones block type assuming the channel characteristics are stationary. The channel correlation matrix R_{HH} for LMMSE method consists of 256 coefficients & the modified MMSE method considered 105/90 coefficients by assigning zero values to the non-significant coefficients of the $R_{HH}^{modified}$ matrix.

Results showed that in frequency domain estimation the use of LMMSE estimator performs significantly better than the LS estimator and modified MMSE gives better or equivalent performance with suitable significant number for channel weight matrix. The modified MMSE has a significant advantage of reduced computational complexity. Further, the results showed that symbol error rate increases with the higher order of modulations.

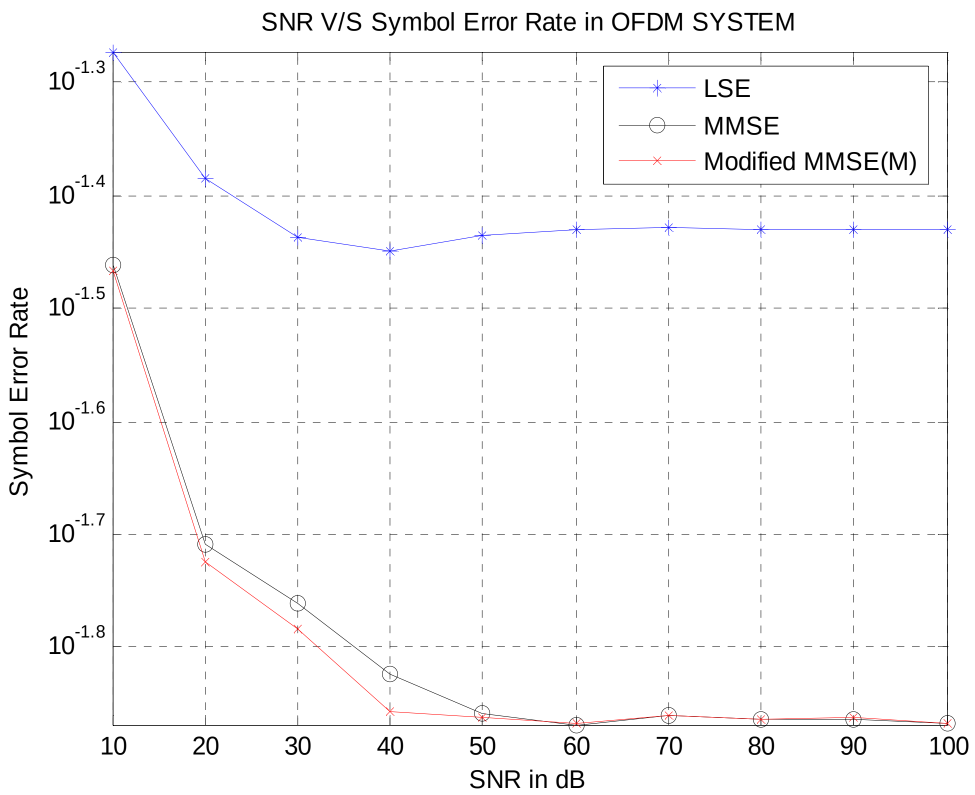

Figure 8. Performance comparison of BPSK symbol error rate.

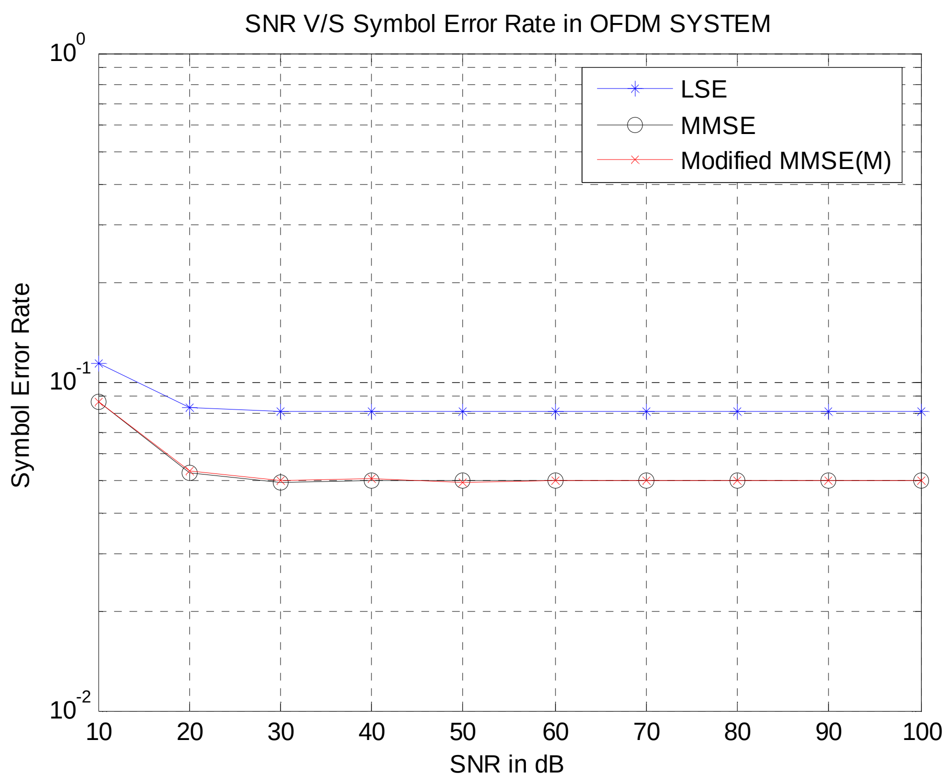

Figure 9. Performance comparison of QPSK symbol error rate.

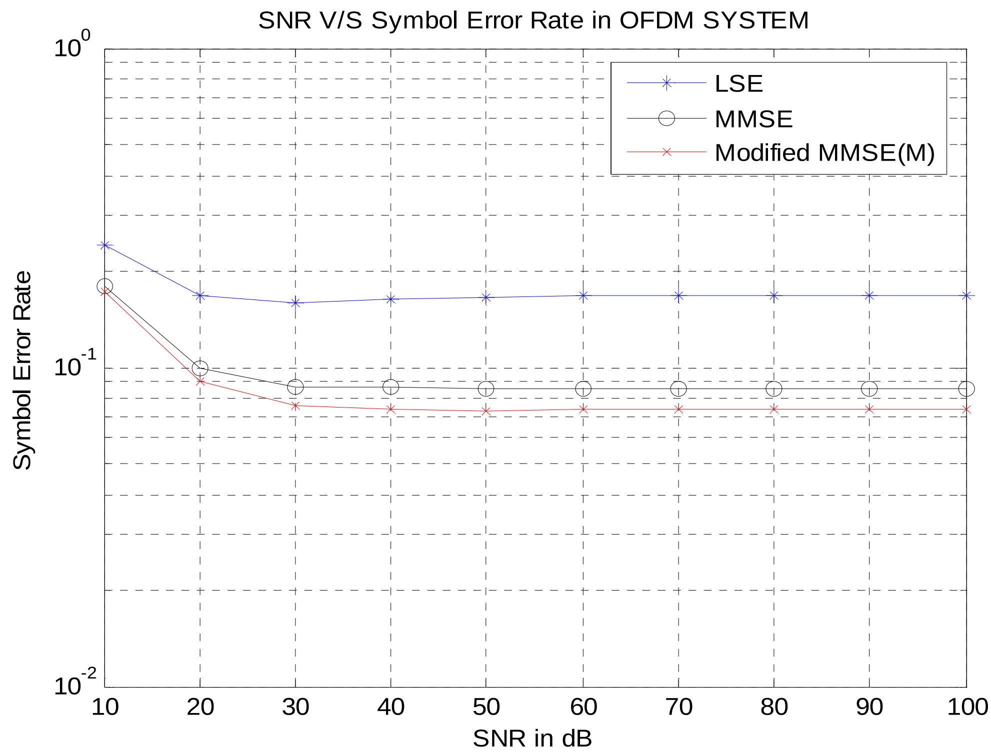

Figure 10. Performance comparison of 8PSK symbol error rate.

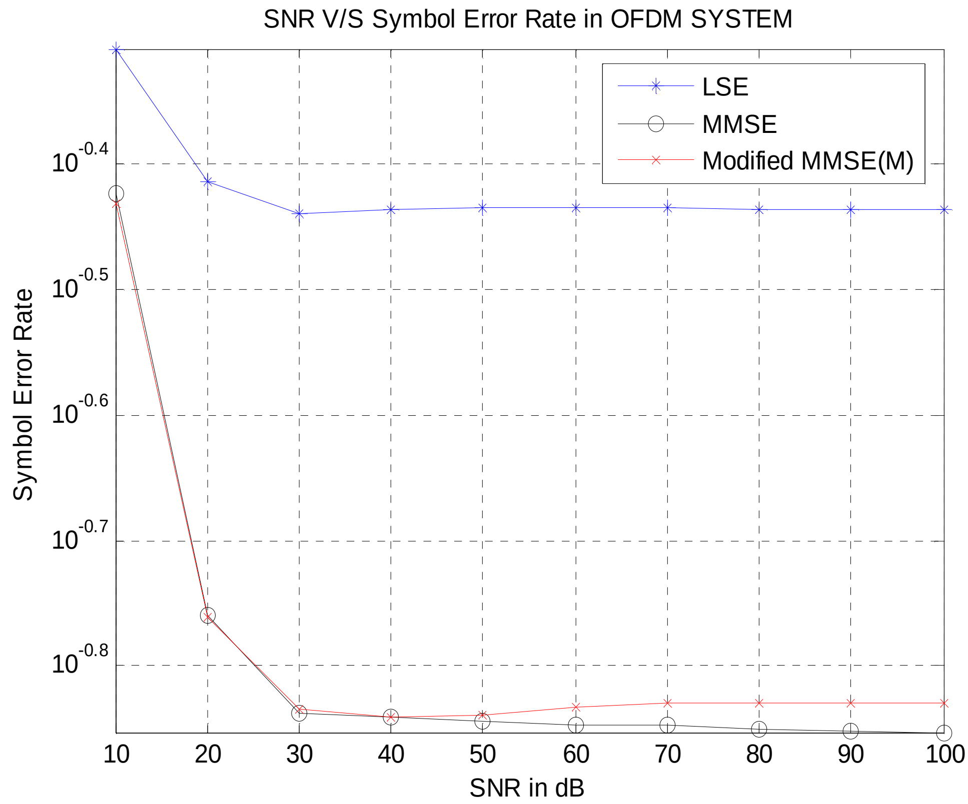

Figure 11. Performance comparison of 16PSK symbol error rate.

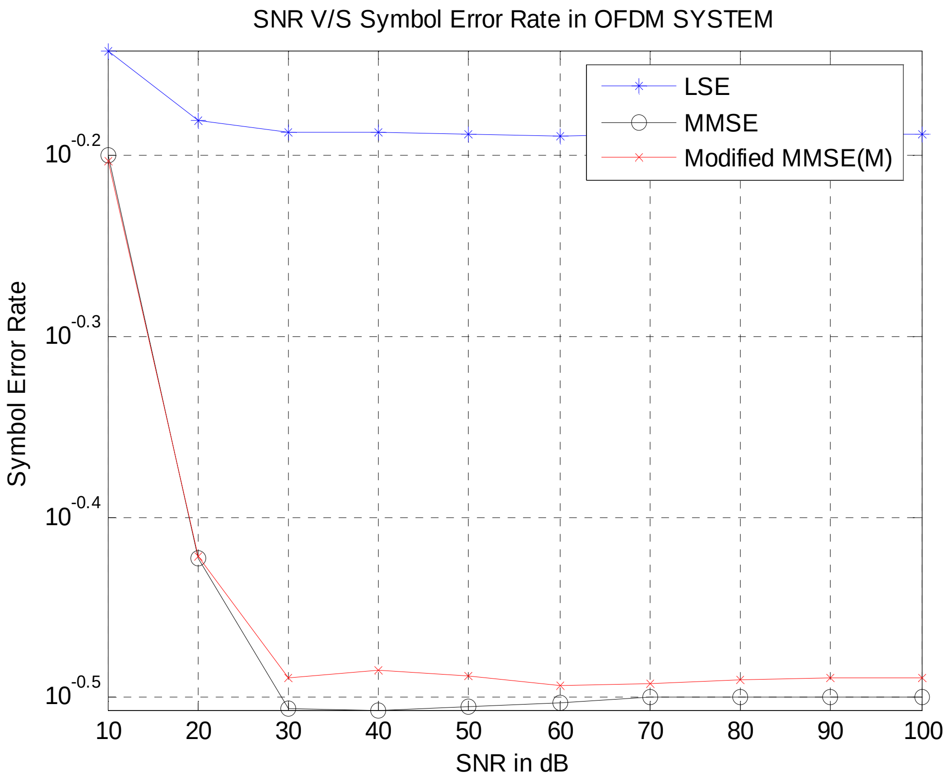

Figure 12. Performance comparison of 32PSK symbol error rate.

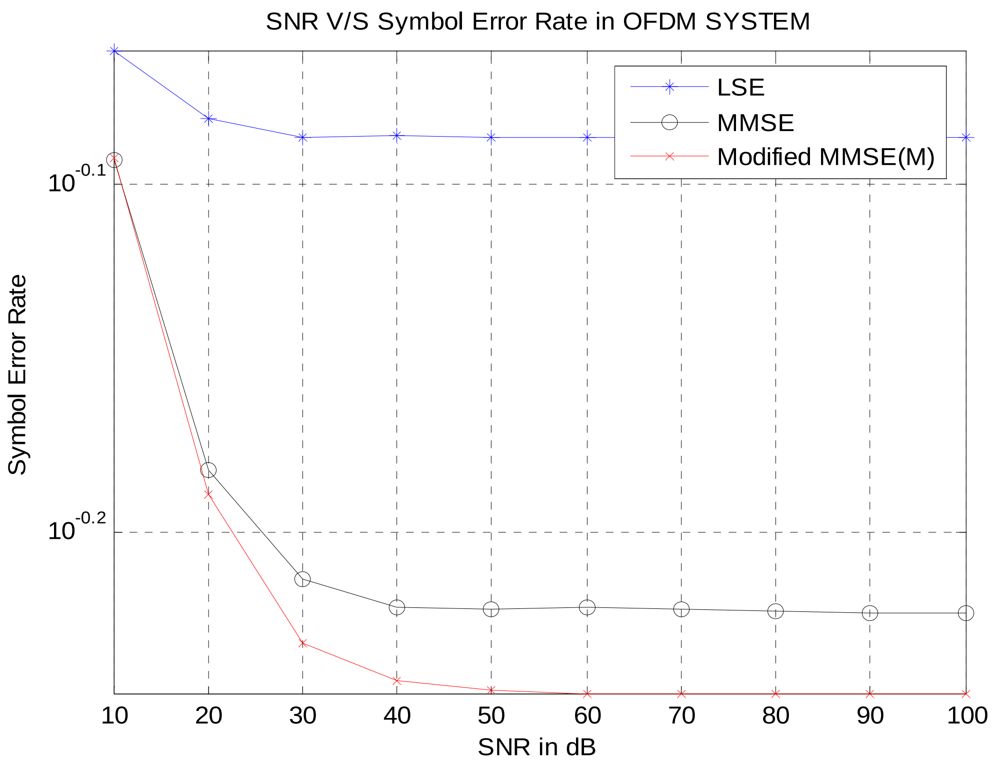

Figure 13. Performance comparison of 64PSK symbol error rate

6. Conclusion

In this paper different QAM and PSK modulations with LS, LMMSE and Modified MMSE channel estimation approaches in frequency domain have come under investigation. Results showed that in frequency domain estimation the use of LMMSE estimator performs significantly better than the LS estimator and modified MMSE gives better or equivalent performance with suitable significant number to the LMMSE. Further, the results showed that symbol error rate increases with the higher order of modulations and PSK modulations involved lesser computations than QAM modulations.

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