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Performance Analysis of Adaptive Channel Estimation in MIMO-OFDM system using Modified Leaky Least Mean Square

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Abstract : *The Modified Leaky Least Mean Square (MLLMS) algorithm is used to mitigate the drifting problem of the Leaky Least Mean Square (LLMS) algorithm. Though the LLMS algorithm solves drifting problem of Least Mean Square (LMS) algorithm, its performance is similar to that of the LMS algorithm in which the result obtained for Bit Error Rate (BER) is* 10^{-3} *to* $10^{-2.5}$ *and Signal to Noise Ratio (SNR) is 16 dB. In this paper, MIMO-OFDM system are used for 2x2 and 4x4 antennas for wireless communication system and which is implemented in MATLAB. The evaluation of Bit Error Rate (BER), Signal to Noise Ratio (SNR) and Mean Square Error (MSE) performance of the MIMO-OFDM technique based on comparative analysis of modulation schemes namely QPSK, 16-QAM, 64-QAM over AWGN channel is been carried out using an improved version of the Leaky Least Mean Square (LLMS) algorithm i.e. Modified Leaky Least Means Square (MLLMS) algorithm . Compared with Least Mean Square (LMS) and Leaky Least Mean Square (LLMS), Modified Leaky Least mean Square(MLLMS) algorithm gives better performance than the LLMS and LMS algorithm with obtained results of Signal to Noise Ratio (SNR) from 15 to 5dB and Bit Error Rate (BER) from 0.96 to* 10^{-1} *and similarly solves the problem of drifting in the LMS algorithm. This better performance is achieved at a negligible increase in the computational complexity. The performance of the MLLMS algorithm is compared to that of the conventional LLMS algorithm and LMS algorithm to show the better performance of MLLMS algorithm.*

Keywords: *BER, LLMS, LMS, MSE, MLLMS,MIMO-OFDM, SNR*

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I. Introduction

The least-mean-square (LMS) algorithm [1] is the adaptive filtering algorithms because of its simplicity and ease of analysis. This has made most researchers to improve the LMS algorithm and to find solutions to some of its drawbacks.

One of the main drawbacks of the LMS algorithm is the drifting problem as analyzed in [2]. This is a situation where the LMS algorithm generates unbounded parameter estimates for a bounded input sequence. This may drive the LMS weight update to diverge because of inadequate input sequence. The drifting problem has been shown in [2]-[4] in details.

The leaky least-mean-square (LLMS) algorithm [2] is one of the improved LMS-based algorithms that use a leakage factor to control the weight update of the LMS algorithm [3]. This leakage factor solves the problem of drifting in the LMS algorithm by bounding the parameter estimate. It also improves the tracking capability of the algorithm, convergence, and stability of the LMS algorithm. One of the main drawbacks of the LLMS algorithm is its low convergence rate compared to the other improved LMS based algorithms. In this paper, we implemented a new algorithm that improves the convergence rate of the LLMS algorithm.

This is achieved by employing the sum of exponentials of the error as the cost function; this cost function is a generalized of the stochastic gradient algorithm as proposed by Boukis et al. [4]. A leakage factor is added to the sum of exponential cost function, which makes the algorithm a combination of the generalized of the mixed norm stochastic gradient algorithm with a leaky factor.

Channel estimator is described for MIMO OFDM systems. These channel estimation methods uses adaptive estimator [5], which are able to update parameters of the estimator continuously, so that knowledge of channel and noise statistics are required [6]. This Modified Leaky Least Mean Square Channel Estimation algorithm requires knowledge of the received signal only. This can be done in a digital communication system by periodically transmitting a training sequence that is known to the receiver. In addition, MLLMS algorithm mitigates the coefficient overflow problem.

This paper is organized as follows. In Section II, a review of the OFDM is introduced. In Section III, the MIMO-OFDM is introduced. In Section IV, Channel estimation using different algorithm like LMS, LLMS, and MLLMS. In Section V, experimental results are presented and discussed. Finally, In Section VI, conclusions are drawn.

II. OFDM System

OFDM is widely recognized as a robust modulation technique for wireless communication. OFDM is a promising multi carrier transmission technique for the broadband wireless communication systems, which offers an efficient way to control the multipath and frequency selective fading without complex equalization. OFDM/QAM systems are efficient for multipath channels because the cyclically prefixed guard interval is included between consequent symbols to remove inter symbol interference (ISI).

OFDM necessitates time and frequency synchronization to sustain its orthogonally between sub carriers and also it is very sensitive to frequency offset which can be caused either by Doppler shift due to relative motion between transmitter and receiver or by the difference between the frequencies of the local oscillators at the transmitter and receiver .

In OFDM, implementation [8] is performed using fast Fourier transform (FFT)/Inverse fast Fourier transform (IFFT) algorithms, and it is robustness against frequency-selective fading channels that are acquired by converting the channel into flat fading sub channels.

The total number of subcarriers is N. Basically the MIMO-OFDM transmitter has N_t parallel transmission paths which are very similar to the single antenna OFDM system. In OFDM system, the binary data is first grouped and mapped according to the modulation in “signal mapper”. Then the binary information data is obtained back in “signal demapper” block. Following IDFT block, guard time, which is chosen to be larger than the expected delay spread, is inserted to prevent inter symbol interference. This guard time is a copy of the last part, which is pretended to OFDM symbol. This makes the transmitted symbol periodic, which plays a key role in identifying frames correctly, to avoid ISI and inter carrier interference (ICI).

A fast Fourier transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) and its inverse is used to convert frequency domain to time domain and vice-versa. An FFT is a way to compute the same result more quickly and faster compare to other. The OFDM transmitters usually employ an inverse fast Fourier transform (IFFT) of size N for modulation. In order to limit the transmit signal to a bandwidth smaller than 1/T. where, T is the sampling time interval of the OFDM signal.

The guard band also enables us to choose an appropriate analog transmission filter to limit the periodic spectrum of the discrete time signal at the output of the IFFT or IDFT. A guard interval is also added for every OFDM symbol to avoid inter symbol interference caused by multipath fading channels.

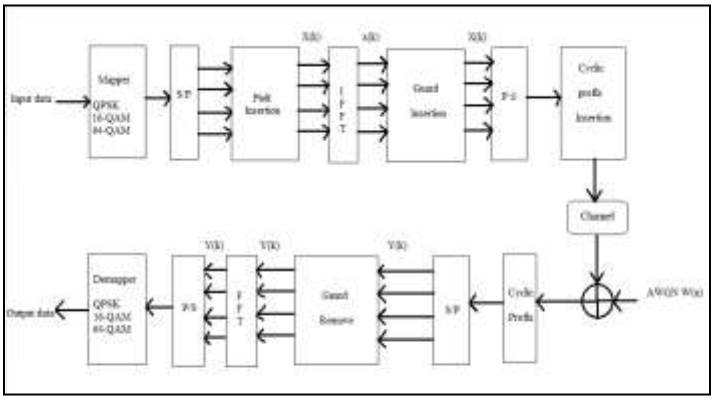

Fig. 2-1 Block Diagram of OFDM System

III. MIMO-OFDM System

MIMO-OFDM system [9] was chosen in this study because it has been widely used today due to its high data rate, channel capacity and its adequate performance in frequency selective fading channels. For this purpose a 4x4 and 2x2 system was designed and adaptive channel estimation with MLLMS algorithm, is made iterative to enhance BER performance.

In this paper consider MIMO–OFDM systems with 4x4 and 2x2 antennas. The total number of subcarriers is N (i.e N=1000000). Subsequently at the receiver, the CP is removed and N-point FFT is performed per receiver branch. Next, the transmitted symbol per TX antenna is combined and outputted for the subsequent operations like digital demodulation and decoding. Finally, all the input binary data are recovered with certain BER .

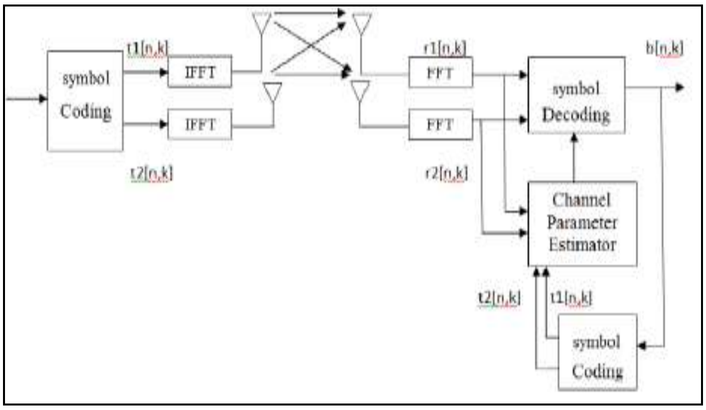

Fig. 3-1 Channel Estimation in MIMO-OFDM System

The techniques developed in this paper can be directly applied to any OFDM system with multiple transmit antennas. At time, a data block is,{b[n,k]: k=0,1,........,} transformed into two different signals, {t_i[n,k]: k=0,1,.......K-1 and i=1,2}at the transmit diversity processor, where, K, k, and i are the number of sub-channels of the OFDM systems, sub-channel index, and antenna index, and similarly for 4x4 antennas respectively.

This OFDM signal is modulated by using the t_i[n,k] where i=1,2. At the receiver, the discrete Fourier transform (DFT or FFT) of the received signal at each receive antenna is the superposition of two distorted transmitted signals. The received signal at the jth receive antenna can be expressed as ,

$$r_j[n,k]=\sum H_y[n,k]\ t_i[n,k]+w_j[n,k]\text{-----------------}(1)$$

Where, the channel frequency response H $_{ij}$[n k] at kth the tone of the nth OFDM block, corresponding to the ith transmit and jth receive antenna. w_j [n,k] denotes the additive complex Gaussian noise on the jth receive antenna and is assumed to be zero mean with variance σ_n^2 .The noise is uncorrelated for different n's, k's or j's.
Above equation can be expressed in matrix from as,

$$rj[n] = \sum_{i=1}^{n} Hij\,[n]tj[n] + Wj[n] - - - -(2)$$

$$r_j^{[n]}=[r_j[n,o],r_j[n,1],....r_j[n,N-1]]^T\text{--------------------}(3)$$
$$H_j^{[n]}=[H_j[n,o],H_j[n,1],....H_j[n,N-1]]^T\text{----------------}(4)$$
$$t_j^{[n]}=[t_j[n,o],t_j[n,1],....t_j[n,N-1]]^T\text{---------------------}(5)$$
$$W_j^{[n]}=[W_j[n,o],W_j[n,1],....W_j[n,N-1]]^T\text{-------------}(6)$$

IV. Channel Estimation

The use of an adaptive filter for this estimation is also difficult, since it is impossible to provide a training sequence consisting of channel parameters. That is why in this paper used Leaky LMS (LLMS) algorithm is used for channel estimation; also, it is called as adaptive beam forming algorithm [7] . Beam forming is a signal processing technique used in sensor arrays for directional signal transmission or reception. One of the main drawbacks of the LLMS algorithm is its low convergence rate compared to the other improved LMS based algorithms. In this paper, we implemented a new algorithm i.e. Modified Leaky Least Mean Square (MLLMS) algorithm that improves the convergence rate of the LLMS algorithm.

4.1. LMS algorithm:

Generally, the LMS algorithm has become one of the most popular adaptive signal processing techniques adopted in many applications including antenna array beam forming. The LMS algorithm is a popular solution used in beam forming technique. This algorithm is easy to implement with low computation. The basic LMS algorithm is expressed as below,

$$w(n+1) = w(n) + 2\ \mu x(n)e(n)\text{----------------------}(8)$$

Simply assume that the reference signal is identical to the incoming signal. The error signal is,

$$e(n)=d(n)-y(n)\text{---}(9)$$

4.2. Leaky LMS algorithm*:*

The system model has been tested for QPSK, 16-QAM, and 64-QAM modulations with an AWGN channels. In the simulation, there are 4 transmitter antennas and the number of the receiving antennas is 4.

LLMS based adaptive beam forming. The LLMS algorithm is shown in Figure 4-1,[7]. The intermediate output, LMS1 yielded from the first LMS section, LMS1, is multiplied by the image array factor (A') of the desired signal. The resultant filtered signal is further processed by the second LMS section, LMS2. For the adaptation process, the error signal of LMS2, e_2, is feedback to combine with that of LMS1, to form the overall error signal, e_{LLMS}, for updating the tap weights of LMS1. A common external reference signal is used for both the two LMS sections, i.e. d_1 and d_2 . The error signal for updating LLMS1 at the j^{th} iteration is given by,

$$e_{LLM}(j) = e_1(j)-e_2(j-1)\text{--------------------------------------}(10)$$

$$e_1(j) = d_1(j) - w_1^H(j)x_1(j)\text{----------------------------------}(11)$$

$$e_2(j) = d_2(j)-w_2^H(j)x_2(j)\text{-------------------------------------}(12)$$

The input signal of LMS_2 is derived from the LMS_1,

$$x_2(j)= A^1Y_{LMS1}(j) = w_1^H(j)\, x_i(j)\text{--------------------------}(13)$$

Where, A^1 is the image of the array factor of the desired signal. The weight vector W for the i^{th} LMS section is updated according to,

$$w_i(j+1) = w_i(j) + \mu_i e_i(j)x_i(j)\text{-------------------------------}(14)$$

Where, $0 < \mu_i < \mu_0$ and i^{th} is 1 for LMS1 and 2 for LMS2.μ_i is the step size and μ_0 is a positive number that depends on the input signal statistic.

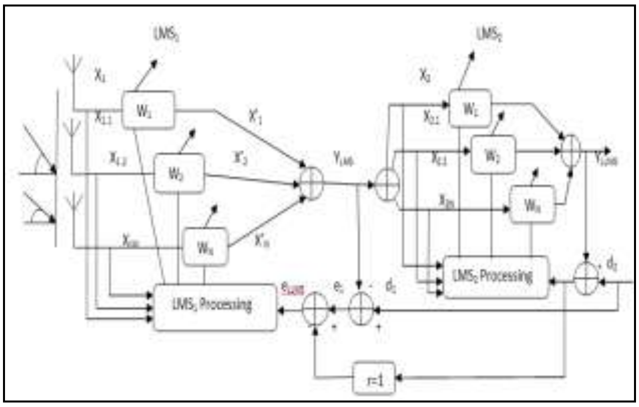

Fig. 4-1 Block diagram of LLMS algorithm

4.3. Modified Leaky Least Mean Square*:*

In order to improve the convergence rate of the LLMS algorithm [11], a new algorithm that employs a sum of exponentials into the cost function of the LLMS algorithm gives a new cost function is defined as;

$$J(k) = (\exp(e(k))+\exp(-e(k)))^2+ \gamma w^T(k)w(k),\text{-----------}(15)$$

Where e (k) is defined as in above. Deriving (15) with respect to w (k), gives;

$$\frac{J(k)}{w(k)} =2(-x(k)\exp(e(k))+x(k)\exp(-e(k)))+2\gamma w(k).\text{------}(16)$$

The tap-update is given by:

$$w(k+1) = w(k)-\frac{\mu\, J(k)}{2w(k)}\text{--------------------------------------}(17)$$

Substituting (16) in (17) and rearranging, the update becomes

$$w(k+1) = (1-\gamma\mu)w(k) + 2\mu x(k)\sinh(e(k)).\text{----------------}(18)$$

V. Simulation Results

That is assuming to have perfect synchronization since the aim is to observe channel estimation performance. Simulations are carried out for different signal-to-noise (SNR) ratios and Bit Error Rate (BER). The digital modulation technique used is QPSK,16-QAM and 64-QAM.The following simulation parameters are taken for and MIMO-OFDM using Least Mean Square (LMS), Leaky least Mean Square (LLMS) and Modified Leaky Least Mean Square (MLLMS) algorithm as shown in table 1, 2 and 3.

Table 5.1. MIMO-OFDM Parameters for simulation using LMS, LLMS, and MLLMS algorithm for QPSK modulation

Parameters	Value
MIMO-OFDM system	2x2 and 4x4
FFT size	64
No. Of data subcarriers	52
No. Of bits per symbol	64
No. Of samples	1000000
Carrier modulation used	QPSK
Guard period type	Cyclic Extension of the symbol
SNR	0-15dB

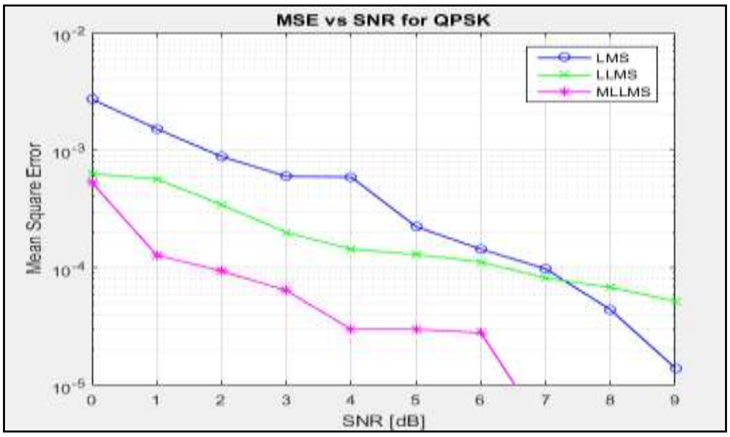

Fig. 5.1.1 (QPSK) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 2x2

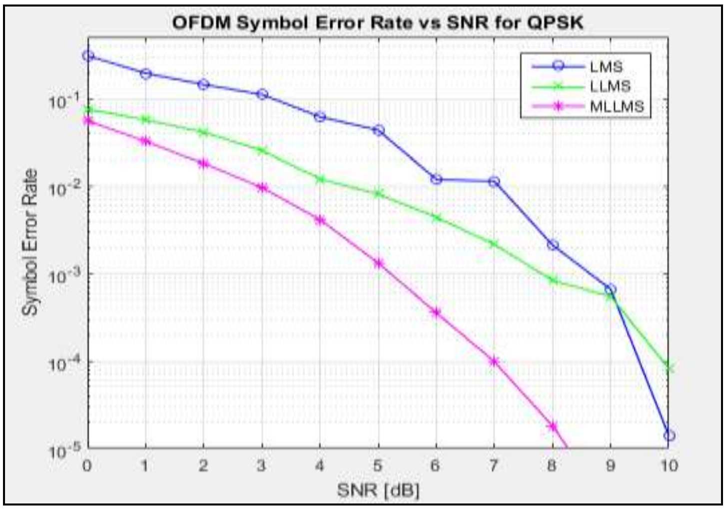

Fig. 5.1.2 (QPSK) modulation LMS, LLMS and MLLMS algorithm (BER v/s SNR) 2x2

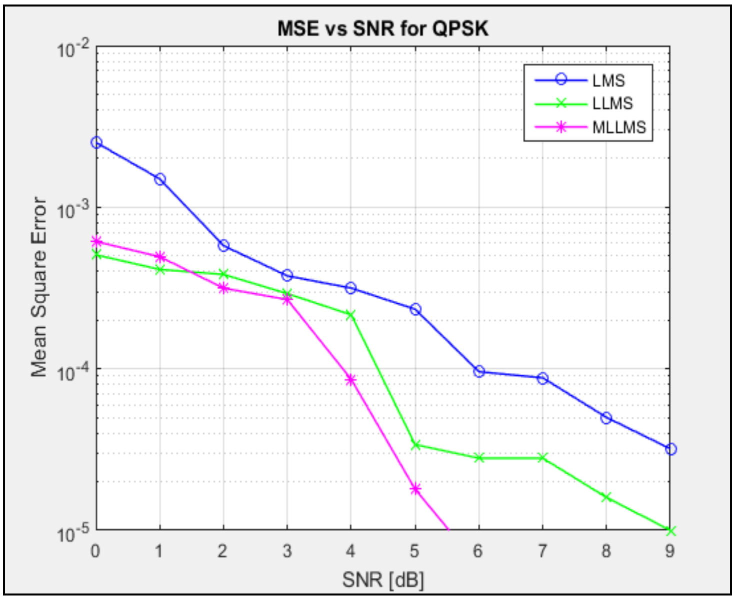

Fig. 5.1.3 (QPSK) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 4x4

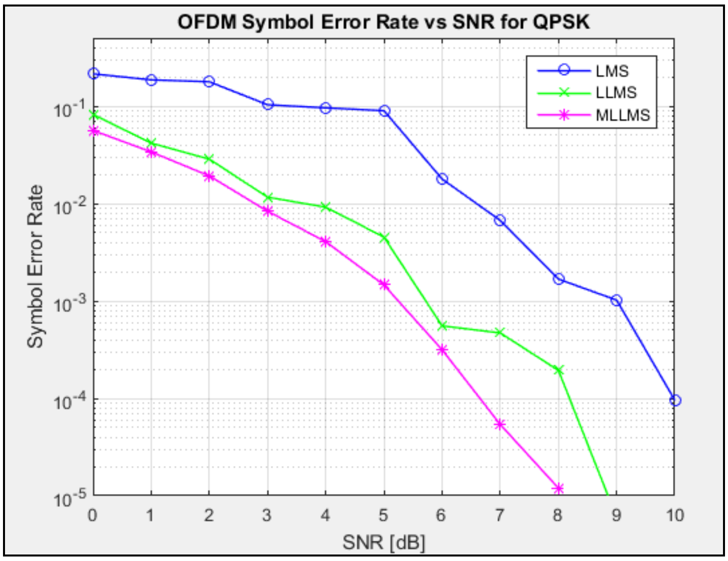

Fig. 5.1.4 (QPSK) modulation LMS, LLMS and MLLMS Algorithm (BER v/s SNR) 4x4

Table 5.2. MIMO-OFDM Parameters for simulation using LMS, LLMS and MLLMS algorithm for 16-QAM modulation

Parameters	Value
MIMO-OFDM system	2x2 and 4x4
FFT size	64
No. Of data subcarriers	52
No. Of bits per symbol	64
No. Of samples	1000000
Carrier modulation used	16-QAM
Guard period type	Cyclic Extension of the symbol
SNR	0-15dB

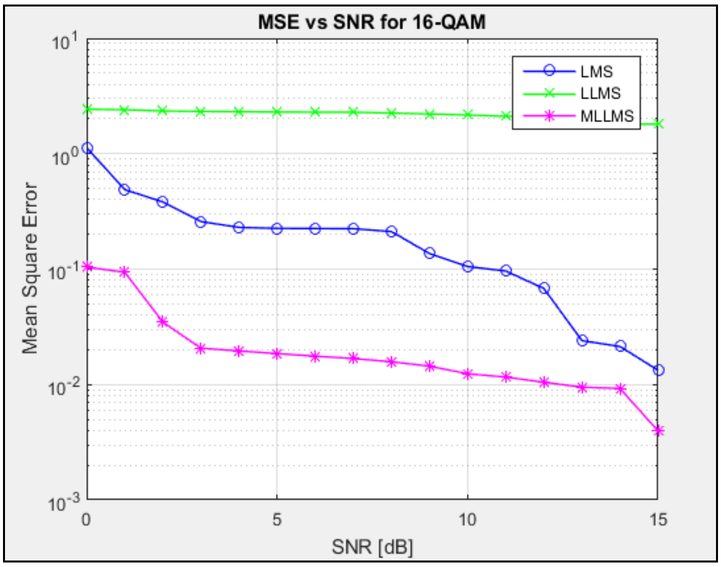

Fig. 5.2.1 (16-QAM) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 2x2

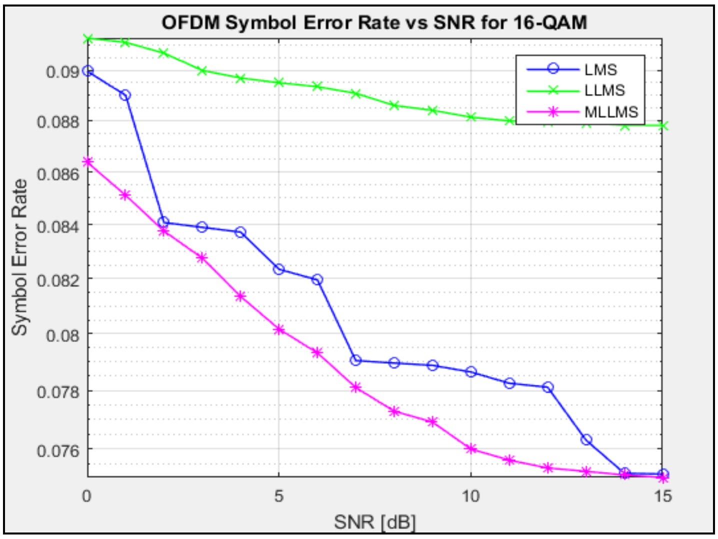

Fig. 5.2.2 (16-QAM) modulation LMS, LLMS and MLLMS Algorithm (BER v/s SNR) 2x2

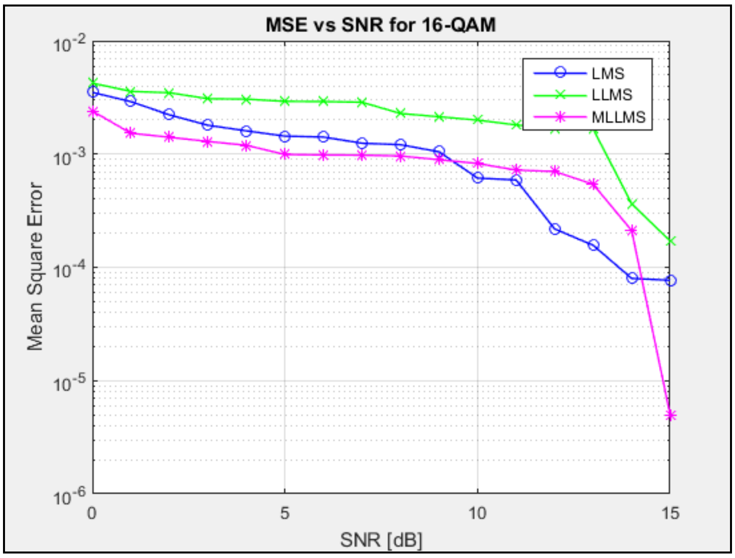

Fig. 5.2.3 (16-QAM) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 4x4

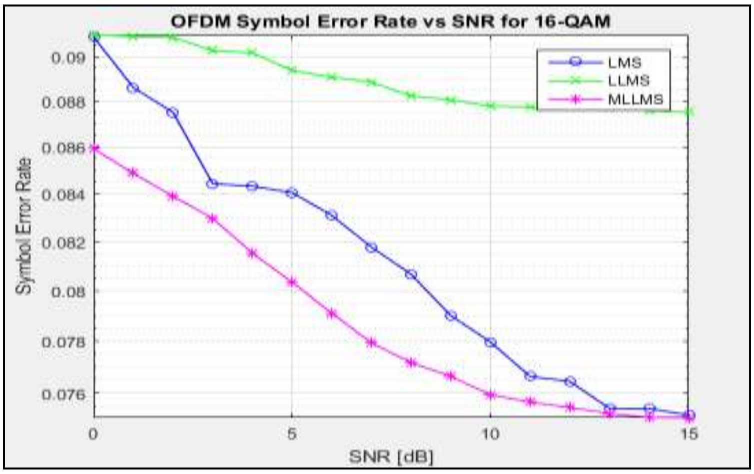

Fig. 5.2.4 (16-QAM) modulation LMS, LLMS and MLLMS Algorithm (BER v/s SNR) 4x4

Table 5.3. MIMO-OFDM Parameters for simulation using LMS, LLMS and MLLMS algorithm for 64-QAM

Parameters	Value
MIMO-OFDM system	2x2 and 4x4
FFT size	64
No. Of data subcarriers	52
No. Of bits per symbol	64
No. Of samples	1000000
Carrier modulation used	64-QAM
Guard period type	Cyclic Extension of the symbol
SNR	0-15dB

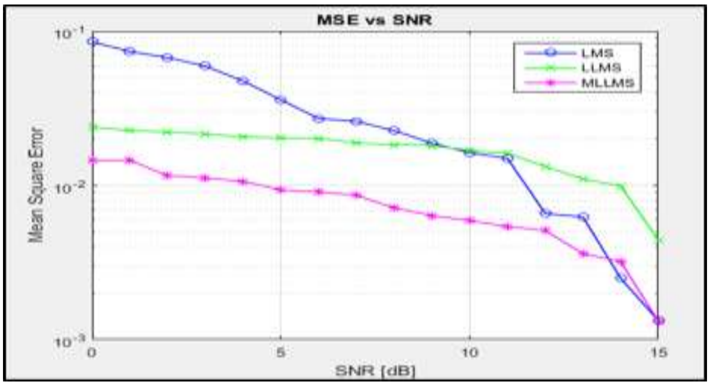

Fig. 5.3.1 (64-QAM) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 2x2

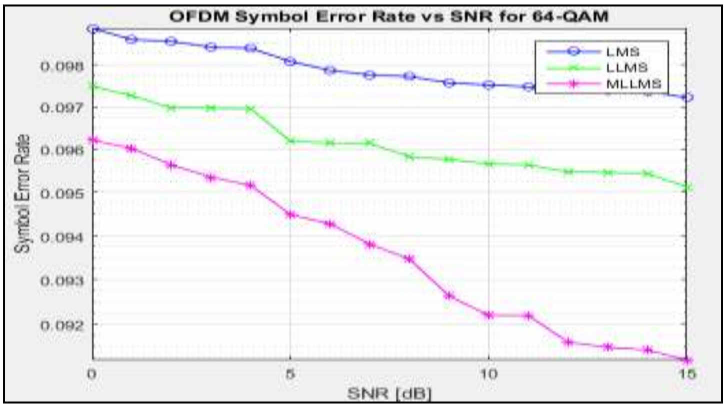

Fig. 5.3.2 (64-QAM) modulation LMS, LLMS and MLLMS Algorithm (BER v/s SNR) 2x2

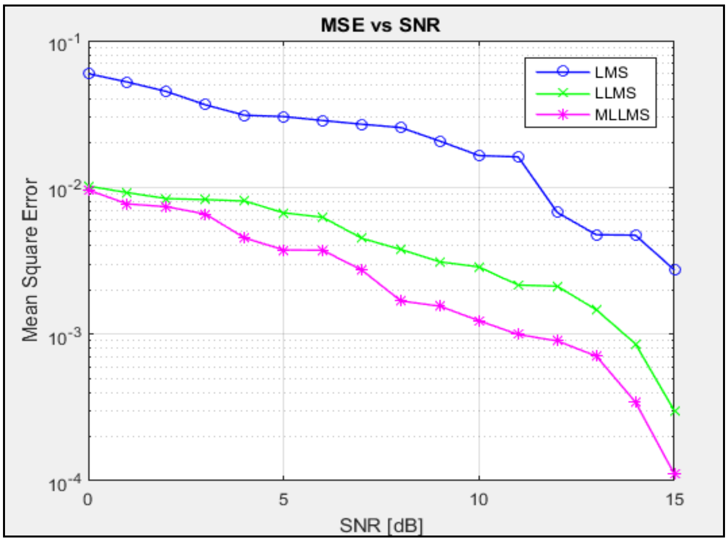

Figure 5.3.3 (64-QAM) modulation LMS, LLMS and MLLMS Algorithm (MSE v/s SNR) 4x4

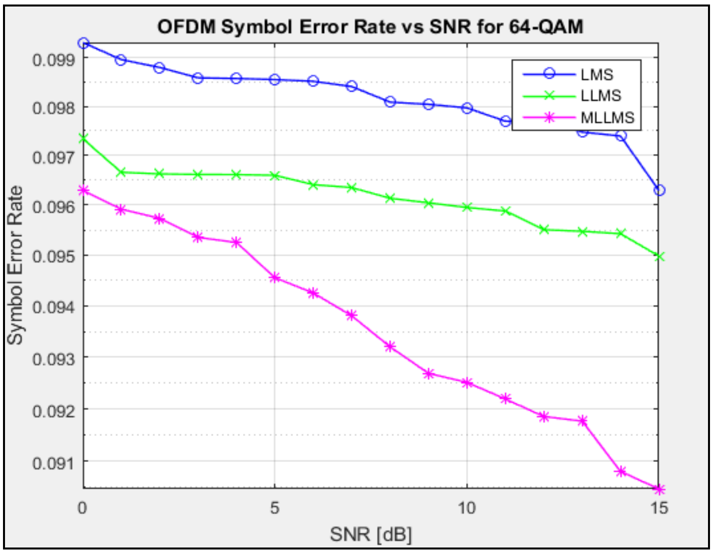

Fig. 5.3.4 (64-QAM) modulation LMS, LLMS and MLLMS Algorithm (BER v/s SNR) 4x4

From Tables 5.4 to 5.10 observed that some of the results are not showing positive values because of random values we choose. However, some of them shows better results by which we can observe that Modified Leaky Least Mean Square algorithm are having better performance than Leaky Least Mean Square and Least Mean Square algorithm. Tables below it shows comparison between different algorithm for 2x2 and 4x4 antennas and comparison between 2x2 and 4x4 antennas with different algorithm along with different modulation techniques. From all these we found better performance for 4x4 antennas from 2x2 antennas and highest percentile improvement of Modified Leaky Least Mean Square algorithm than Leaky Least Mean Square and Least Mean Square algorithm.

Table 5.4 Performance comparison between 2x2 and 4x4 antennas for QPSK with SNR=5dB

Algorithm	**BER**	**BER**	**Percentage improved**	**MSE (dB)**	**MSE (dB)**	**Percentage improved**
	2X2	**4X4**	**2x2 v/s 4x4**	**2X2**	**4X4**	**2x2 v/s 4x4**
LMS	$10^{-1.6}$	10^{-1}	-3%	$10^{-3.8}$	$10^{-3.8}$	0%
LLMS	$10^{-2.1}$	$10^{-2.8}$	80%	$10^{-3.9}$	$10^{-4.7}$	84%
MLLMS	$10^{-2.9}$	10^{-3}	20%	$10^{-4.5}$	$10^{-4.9}$	60%

Due to some random values it shows negative value which indicates reverse performance which means 2x2 has better performance than 4x4.

Table 5.5 Performance comparison between 2x2 and 4x4 antennas for 16-QAM with SNR=15dB

Algorithm	BER	BER	Percentage improved	MSE (dB)	MSE (dB)	Percentage improved
	2X2	**4X4**	**2x2 v/s 4x4**	**2X2**	**4X4**	**2x2 v/s 4x4**
LMS	0.088	0.076	14%	10^{-1}	$10^{-4.1}$	99%
LLMS	0.077	0.087	-12%	$10^{-1.8}$	$10^{-3.9}$	98%
MLLMS	0.076	0.075	1.3%	$10^{-2.5}$	$10^{-5.5}$	99%

Due to some random values, it shows negative value, which indicates reverse performance, which means 2x2 has better performance than 4x4.

Table 5.6 Performance comparison between 2x2 and 4x4 antennas for 64-QAM with SNR=15dB

Algorithm	BER	BER	Percentage improved	MSE (dB)	MSE (dB)	Percentage improved
	2X2	**4X4**	**2x2 v/s 4x4**	**2X2**	**4X4**	**2x2 v/s 4x4**
LMS	0.0976	0.0970	0.1%	$10^{-2.4}$	$10^{-2.5}$	20%
LLMS	0.0954	0.0950	0.4%	$10^{-2.9}$	$10^{-3.7}$	84%
MLLMS	0.0900	0.0900	0%	$10^{-2.9}$	$10^{-3.9}$	90%

Table 5.7 Percentage Improved by comparing performance between different algorithms for BER with SNR = 5dB for 2x2 antenna

Modulation	LMS	LLMS	MLLMS	LMS v/s LLMS	LLMS v/s MLLMS
QPSK	$10^{-1.6}$	$10^{-2.1}$	$10^{-2.9}$	68%	84%
16-QAM	0.0849	0.092	0.080	-0.8%	13%
64-QAM	0.098	0.0979	0.0942	0.1%	3%

Due to some random values, it shows negative value, which indicates reverse performance, which means LMS has better performance than LLMS algorithm.

Table 5.8 Percentage Improved by comparing performance between different algorithms for BER with SNR=5dB for 4x4 antenna

Modulation	LMS	LLMS	MLLMS	LMS v/s LLMS	LLMS v/s MLLMS
QPSK	10^{-1}	$10^{-2.8}$	10^{-3}	98%	36%
16-QAM	0.0840	0.090	0.079	7%	12%
64-QAM	0.0992	0.0975	0.0952	1%	2%

Table 5.9 Percentage Improved by comparing performance between different algorithms for MSE with SNR=5dB for 2x2 antenna

Modulation	LMS	LLMS	MLLMS	LMS v/s LLMS	LLMS v/s MLLMS
QPSK	$10^{-3.8}$	$10^{-3.9}$	$10^{-4.5}$	20%	74%
16-QAM	$10^{-0.9}$	$10^{0.5}$	$10^{-1.9}$	-96%	99%
64-QAM	$10^{-1.5}$	$10^{-1.7}$	10^{-2}	36%	50%

Due to some random values, it shows negative value, which indicates reverse performance, which means LMS has better performance than LLMS algorithm.

Table 5.10 Percentage Improved by comparing performance between different algorithms for MSE with SNR=5dB for 4x4 antenna

Modulation	LMS	LLMS	MLLMS	LMS v/s LLMS	LLMS v/s MLLMS
QPSK	$10^{-3.8}$	$10^{-4.7}$	$10^{-4.9}$	87%	36%
16-QAM	$10^{-2.9}$	$10^{-2.5}$	10^{-3}	-60%	68%
64-QAM	$10^{-1.2}$	$10^{-2.3}$	$10^{-2.6}$	92%	50%

Due to some random values, it shows negative value, which indicates reverse performance, which means LMS has better performance than LLMS algorithm.

VI. Conclusion

In this paper, the channel estimation based on Least Mean Squared (LMS), Leaky Least Mean Squared (LLMS) algorithms and Modified Leaky Least Mean Square (MLLMS) algorithm for different modulation techniques likes QPSK, 16-QAM and 64-QAM in MIMO-OFDM System is been observed. The main purpose is to reduced bit error rate (BER) and improve signal to noise ratio (SNR) by varying step size. After observing above all the results, smaller the step size (μ=0.0025) gives better the steady state error up to the range from 0.96 to 10^{-1} and improve SNR value up to the range from 15 to 5 dB also Comparative study suggests that result generated by using Modified Leaky Least Mean Square in combination of MIMO and OFDM system gives better than Leaky Least Mean Square and Least Mean Square algorithm in combination of MIMO and OFDM system.

As per the percentage improved among various algorithms, we observed MLLMS algorithm has highest improvement percentile. Therefore, we can conclude that Modified Leaky Least Mean Square algorithm is having highest capacity of channel to transfer the data by having minimum BER and SNR than others. Modified Leaky LMS (MLLMS) algorithm improves the capacity of channel by having minimum bit error rate (BER) and signal to noise ratio (SNR) and Mean Square Error (MSE).

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