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Performance Evaluation of LMS and VSS-LMS Channel Estimation Techniques for LTE Uplink under Different Doppler Shifts

Mohammed H. M. Nerma[*] and Nidaa M. H. Elshaikh

[*]School of Electronic Engineering, College of Engineering, Sudan University of Science and Technology, Khartoum – Sudan

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Abstract

In 3GPP LTE, OFDMA is used as a multiple access technique in downlink while SC-FDMA is used in uplink since it has low PAPR compared with ODFMA and that will lead to saving power of transmitter (MS). In this paper SC-FDMA is modeled and LMS and VSS-LMS channel estimation techniques is applied to the model in order to estimate the channel response. The performance is analyzed under different channel environments by calculating BER and MSE for both algorithms. The results show that the performance of both algorithms degrades under high Doppler shifts however VSS-LMS has better performance compared with LMS.

Keywords: *BER, LMS, MSE, ODFMA, PAPR, SC-FDMA, VSS-LMS.*

1. Introduction

In cellular applications, a big advantage of OFDMA is its robustness in the presence of multipath signal propagation [1]. The immunity to multipath derives from the fact that an OFDMA system transmits information on M orthogonal frequency carriers, each operating at 1/M times the bit rate of the information signal. On the other hand, the OFDMA waveform exhibits very pronounced envelope fluctuations resulting in a high peak-to-average power ratio (PAPR). Signals with a high PAPR require highly linear power amplifiers to avoid excessive inter modulation distortion. To achieve this linearity, the amplifiers have to operate with a large back off from their peak power. The result is low power efficiency (measured by the ratio of transmitted power to dc power dissipated), which places a significant burden on portable wireless terminals. Another problem with OFDMA in cellular uplink transmissions derives from the inevitable offset in frequency references among the different terminals that transmit simultaneously. Frequency offset destroys the orthogonality of the transmissions, thus introducing multiple access interference. To overcome these disadvantages, 3GPP is investigating a modified form of OFDMA for uplink transmissions in the "long-term evolution (LTE)" of cellular systems [1], [2] and [3]. The modified version of OFDMA, referred to as single carrier FDMA (SC-FDMA). As in OFDMA, the transmitters in an SC-FDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols. However, they transmit the subcarriers sequentially, rather than in parallel. Relative to OFDMA, this arrangement reduces considerably the envelope fluctuations in the transmitted waveform.[4]

Since the radio channel is highly dynamic, the transmitted signal travels to the receiver by undergoing many detrimental effects that corrupt the signal and often place limitations on the performance of the system. Channel estimation (CE) techniques allow the receiver to approximate the impulse response of the channel and explain the behavior of the channel. [5], [6]. In general, CE techniques can be divided into two major categories such as the trained and blind. The former CE algorithm requires probe sequences that occupy valuable bandwidth whereas the latter uses the received data only. Due of course to their self-sufficiency in training, blind CE techniques are considered more attractive than trained based techniques [7], [8]. In this paper an adaptive LMS and VSS-LMS Channel Estimation algorithms are analyzed since they do not require prior knowledge of channel statistics or noise and simple for practical implementation.

In section two the SC-FDMA model and algorithms used in this work is discussed. Section three includes the simulation description and parameters used in this work. The results are shown in section four. In Section five, the discussion is shown and finally the conclusion and future work in sections six and seven respectively.

2. System design

2.1 SC-FDMA model

In order to model the SC-FDMA system shown in figure 1 a sequence of bits are generated, no matter if they are represent data or voice since we concern only about delivering them correctly. Using frame 1 as a frame type the data is concatenated. Then the data is modulated using types mentioned in table 1 (two types of modulation was used to obtain different data rates so as to get different cases for analysis). The symbols are then transferred to the frequency domain using Fourier transform in order to mapping them by IFDMA mapping and convert them to the time domain to add the cyclic prefix to them which is represents the final step in the transmitter. In the receiver the reverse operations are made. The cyclic prefix was removed then the mapping was restored by transforming the data to the frequency domain. In this time another operation, channel estimation, is inserted before transforming the data back to the time domain.

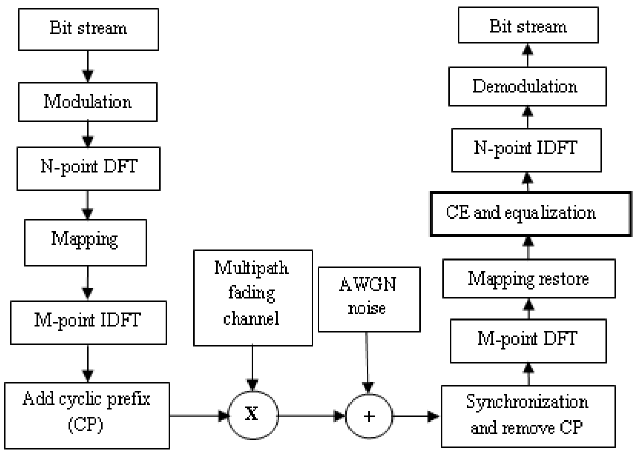

Fig.1 LTE SC-FDMA block diagram

2.2 Channel model

The realistic channel model for wireless communication is essential for the analysis, design and deployment of the communication systems. The correct knowledge of the mobile channel models are significant for testing, optimization and performance improvements signal processing algorithms. Wireless communication has the phenomenon named multi path fading. This is because of reflection from objects when the signal is transmitted in the channel. As a result signal reaches the receiver by two or more paths with some delay [9 – 12].

Multipath propagation will be modeled as

$$\mathrm{Y(n) = h_1 s(n-t_1) + h_2 s(n-t_2) + h_3 s(n-t_3) + \cdots + h_T s(n-t_T) + W(N)} \quad (1)$$

Where y(n) is the received signal, hT are the channel coefficient, hTs(n-tT) is delayed version of transmitted signal s(n) due to reflection, and w(n) is additive noise. Noise is usually measured by SNR (Signal to Noise Ratio), which is defined as the ratio of the received signal power to the power of noise within the bandwidth of the transmitted signal s(n) . To make the simulation close to reality some kind of channel model should be chosen. There are different channel models like Rayleigh fading channel and Rician. In Rayleigh fading channel, there is no line of sight between transmitter and receiver and channel taps are independent where as in Rician fading channel, the fading dips are low due to presence of line of sight [9].

2.3 Channel Estimation

2.3.1 LMS algorithm

Stochastic gradient based adaptive algorithms, such as the least mean square (LMS) one, are the most popular in adaptive filtering applications, due to its low computational complexity and very good stability characteristic. Moreover, in the LMS algorithm a previous knowledge of the process statistics is not required [13]. Such advantages make the LMS algorithm adequate for system identification, noise canceling, echo canceling, channel equalization, among other applications [14]. The standard LMS uses a fixed adaptation step size, determined by considering a tradeoff between convergence rate and misadjustment.[9]

If: s(m) is the transmitted signal, z(m) is the additive white Gaussian noise (AWGN) and W(m) is the channel coefficients. The output from the channel can be expressed as:

$$r(m) = W^T(m)s(m) + z(m) \quad (2)$$

The output of the adaptive filter is:

$$y(m) = W_{est}^T(m)s(m) \quad (3)$$

Where: W_{est} (m) is the estimated channel coefficients at time m.

The priori estimated error signal needed to update the weights of the adaptive filter is:

$$e(m) = r(m) - y(m) = W^T(m)s(m) + z(m) - W_{est}^T(m)s(m) \quad (4)$$

This error signal is used by the CE to adaptively adjust the weight vector so that the MSE is minimized. If w (m) is the tap-weight vector at the m^{th} iteration then the following recursive equation may be used to update W_{est} (m):

$$W_{est}(m+1) = W_{est}(m) + \eta s(m)e^*(m) \quad (5)$$

Where W_{est} (m+1) denotes the weight vector to be computed at iteration (m+1) and η is the LMS step size which is related to the rate of convergence. The smaller step size means that a longer reference or training sequence is needed, which would reduce the payload and hence, the bandwidth available for transmitting data. The term [ηs(m)e*(m)] represents the correction factor or adjustment that is applied to the current estimate of the tap-weight vector. The iterative procedure is started with an initial guess $W_{est}(0)$. The detail steps of this CE algorithm are shown in Figure 2. [15].

2.3.2 Variable Step Size (VSS)-LMS Algorithm

The VSS-LMS algorithm involves one additional step size update equation compared with the standard LMS algorithm. The VSS algorithm is [16], [17].

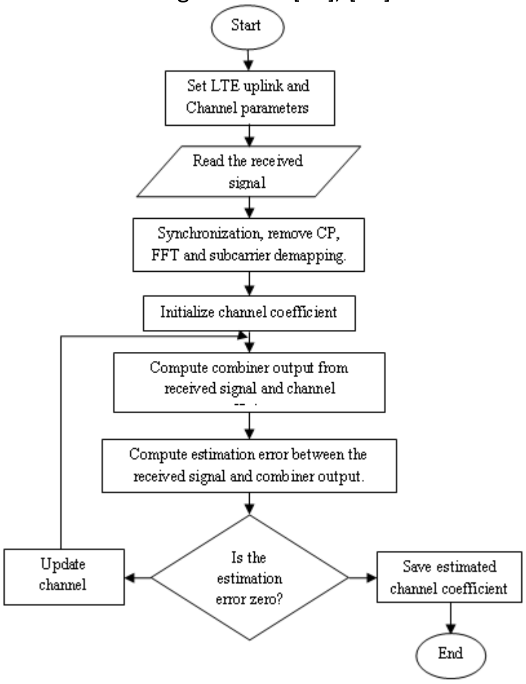

Fig.2 Flow chart of LMS Channel Estimation technique

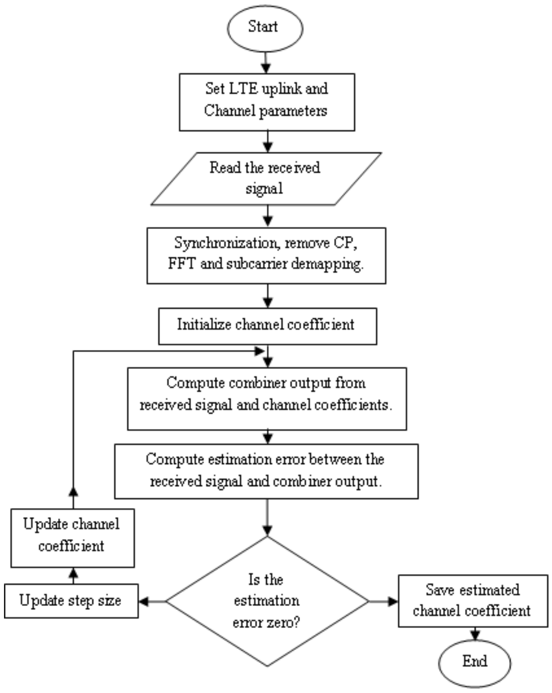

Fig.3 Flow chart of VSS-LMS Channel Estimation technique

$$\eta(m+1) = \alpha\eta(m) + \gamma P^2(m) \quad (6)$$

$$P(m) = \beta P(m) + (1-\beta)e^T(m)e(m-1) \quad (7)$$

Where 0 < α < 1, 0 < β < 1, and γ > 0. When the channel is fast time-varying then algorithm cannot accurately measure the autocorrelation between estimation errors to control step size update. Control parameters α and β need to be adjusted for a better performance [11]. The detail steps of this CE algorithm are shown in Figure 3.

3. Simulation description

Since MATLAB has an easy to use environment, it was the best choice. The SC-FDMA was modeled and LMS and VSS-LMS channel estimation algorithms was applied in order to analysis their performance under four different cases (AWGN channel without Doppler shift, Rayleigh channel with Doppler shifts 5, 50 and 500 Hz). Since BER and MSE are essential parameters for performance evaluation, they were chosen in this work. The system was tested under SNR from 0-30 dB, LMS's BER and MSE are plotted using solid line with star marker and VSS-LMS's ones are plotted with dotted line with square marker. The performance was evaluated under four different channel environments (AWGN, Rayleigh channel with Doppler shifts 5, 50 and 500 Hz). The specifications used in this simulation are tabulated in table 1 and 2.

Table 1 System assumptions

Systems parameter	Assumption
System bandwidth	5 MHz
Sampling frequency	7.68 MHz
Subcarrier spacing	9.765 kHz (5 MHz/512)
Modulation data type	BPSK
FFT size	16
Subcarrier mapping scheme	IFDMA
IFFT size	512
Cyclic Prefix	normal
Frame Type	Type 1
Antenna Configuration	SISO
Pilot Spacing	6
Channel model	AWGN, Extended Pedestrian-A
Maximum Doppler shift	5, 50, 500 Hz
Pilot	Zadoff Chu
Equalization	Zero Force
Channel Estimation	LMS, VSS-LMS

Table 2 Channel Estimation Algorithms' assumptions

Channel Estimation Algorithm parameter	Assumption	Channel Estimation Algorithm
η	$6.0000e^{-004}$	LMS
η_0	η_{max}	VSS-LMS
α	0.97	VSS-LMS
β	0.99	VSS-LMS
γ	$7e^{-8}$	VSS-LMS
η_{min}	0	VSS-LMS
η_{max}	$7e^{-004}$	VSS-LMS
Number of iterations	300	LMS/VSS-LMS

3. Results and discussion

The figures from 4- 7 shows BER as a function of SNR for both algorithms for AWGN channel Rayleigh channel with Doppler shift equal (5, 50, 500 Hz) respectively. In figure 4 at low SNR(less than 6 dB) the BER for both of the algorithms are almost the same. For higher SNR (greater than 6 dB) the BER for VSS-LMS is better than LMS algorithm. At SNR greater than 14 dB both of algorithms has BER equal to zero.

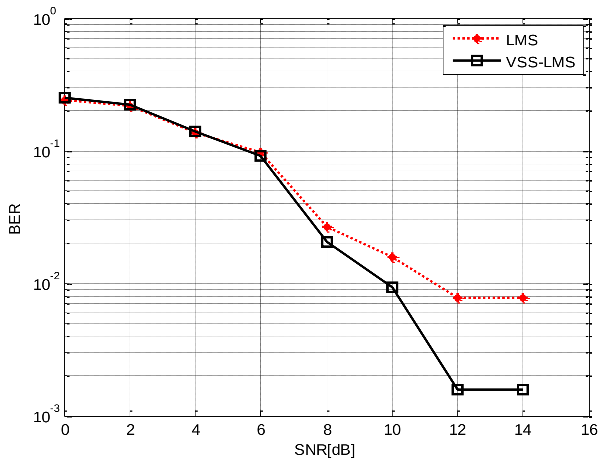

Fig.4 BER of LMS and VSS-LMS algorithms as a function of SNR (AWGN)

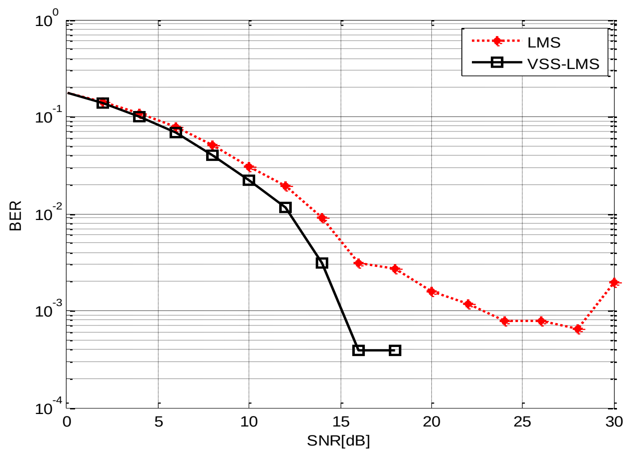

Fig.5 BER of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 5 Hz).

In figure 5, at low SNR(less than 6 dB) the BER for both of the algorithms are almost the same. For higher SNR (greater than 6 dB) the BER for VSS-LMS is better than LMS algorithm. In SNR greater than 12 dB VSS-LMS has BER equal to zero, while the BER of LMS equal to zero for SNR greater than 16 dB. As it is clear in figure 6, VSS-LMS is better than LMS algorithm for SNR greater than 4 dB. In SNR greater than 16 dB both of algorithms has BER equal to zero. In figure 7, the BER is greater for both algorithms if it is compared to the previous ones; however, the difference between the performances of VSS-LMS and LMS is more obvious especially at SNR greater than 10 dB. At SNR greater than 24 dB the BER of VSS-LMS is equal to zero while BER of LMS doesn't reach 0.01 till the end of simulation(SNR = 30 dB).

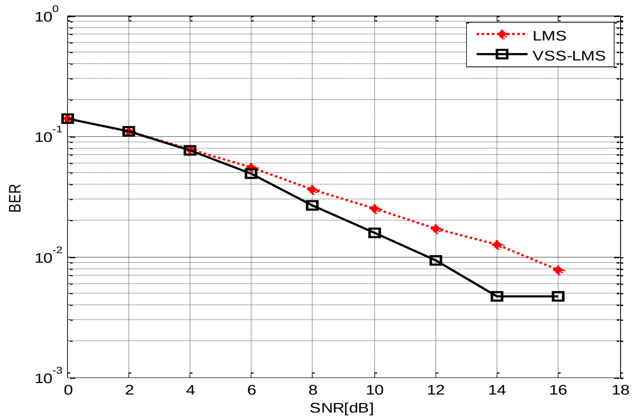

Fig.6 BER of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 50 Hz).

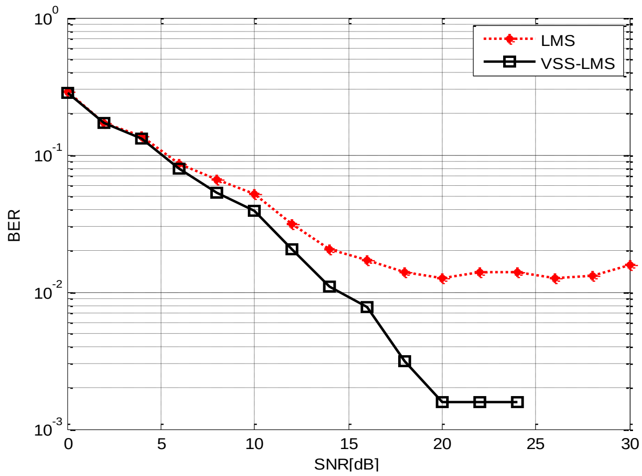

Fig.7 BER of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 500 Hz).

The figures from 8- 11 shows MSE as a function of SNR for both algorithms for AWGN channel Rayleigh channel with Doppler shift equal (5, 50, 500 Hz) respectively. In figure 8, at low SNR(less than 6 dB) the BER for both of the algorithms are almost the same. For higher SNR (greater than 6 dB) the MSE for VSS-LMS is better than LMS algorithm, the higher the SNR the better MSE for the VSS-LMS as compared to LMS one. In addition to that at SNR greater than 14 dB both of algorithms has MSE equal to zero. In figure 9, at low SNR(less than 6 dB) the MSE for both of the algorithms are almost the same. For higher SNR (greater than 6 dB) the MSE for VSS-LMS is better than LMS algorithm. In SNR greater than 12 dB VSS-LMS has MSE equal to zero, while the MSE of LMS equal to zero for SNR greater than 16 dB.

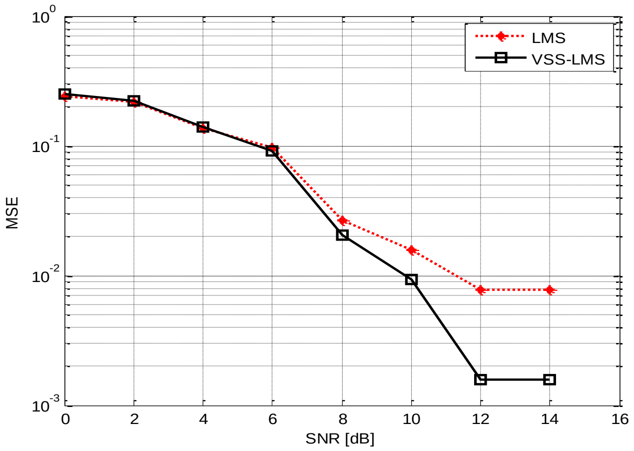

Fig.8 MSE of LMS and VSS-LMS algorithms as a function of SNR (AWGN)

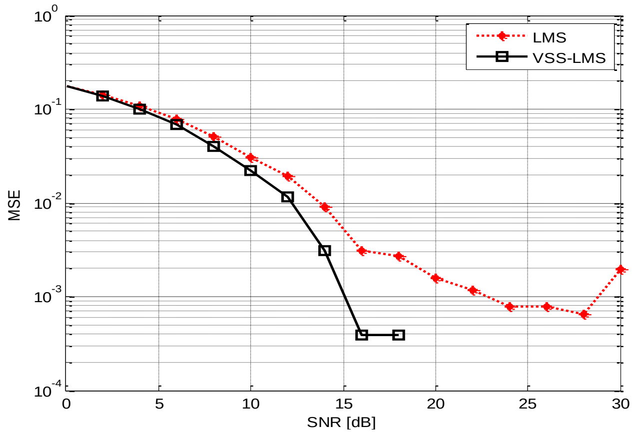

Fig.9 MSE of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 5 Hz).

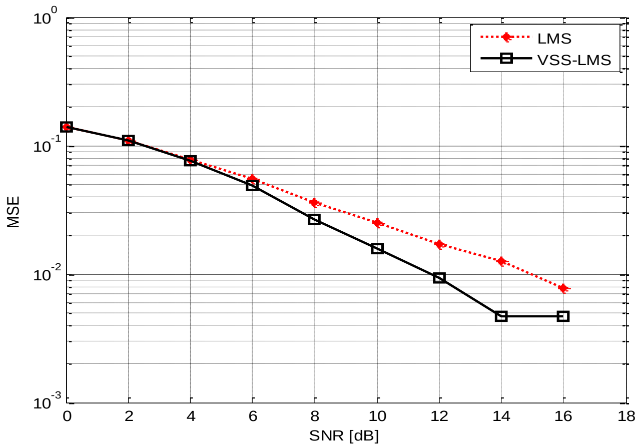

Fig.10 MSE of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 50 Hz).

As it is clear in figure 10, VSS-LMS is better than LMS algorithm for SNR greater than 6 dB. In SNR greater than 16 dB both of algorithms has BER equal to zero. In the last figure the MSE is greater for both algorithms if it is compared to the previous ones; however, the difference between the performances of VSS-LMS and LMS is more obvious especially at SNR greater than 10 dB. At SNR greater than 24 dB the MSE of VSS-LMS is equal to zero while MSE of LMS doesn't reach 0.01 till the end of simulation(SNR = 30 dB).

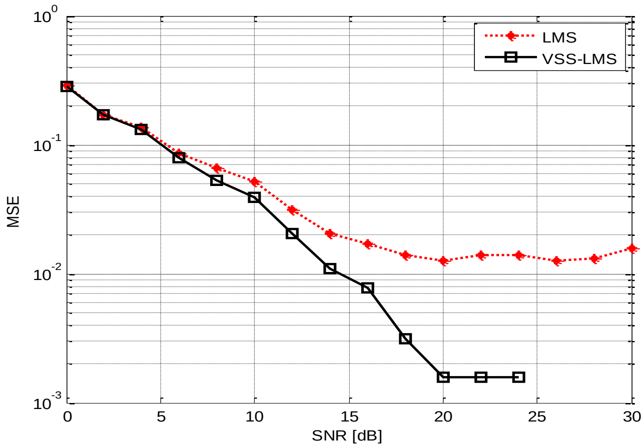

Fig.3 MSE of LMS and VSS-LMS algorithms as a function of SNR (Rayleigh channel with Doppler shift = 500 Hz).

4. Conclusion

Channel estimation of SC-FDMA under LTE umbrella is analyzed for different modulation techniques and channel environments by modeling the system and then applying LMS and VSS-LMS channel estimation techniques using MATLAB. According to results shown, channel environment affects obviously the performance of channel estimation techniques. The performance degraded clearly under high Doppler shift. The higher the Doppler shift the worse performance of both algorithms, however VSS-LMS is less affected by Doppler shift compared to LMS.

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