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SDSELMS-A Simplified Adaptive Channel Estimation Algorithm for MIMO-OFDM System

Madhuri P. L., Anu Anna John
(Department of Electronics and Communication Engineering,
Mar Baselios College of Engineering and Technology, Trivandrum, India)

Abstract : *The demand for high speed wireless applications increased the popularity of MIMO-OFDM systems, which provides high data rates with improved link reliability and capacity. One of the key challenges faced by a MIMO-OFDM system is accurate Channel Estimation (CE). Adaptive Channel Estimation (ACE) is widely used for CE as it can track the time varying wireless channel rapidly. Among different ACE algorithms Least Mean Square (LMS) algorithm is the one with low complexity. But it suffers from high Mean Square Error. Normalized LMS algorithm overcomes this disadvantage with low MSE but the complexity is very high. Main design aim of any communication system is to minimize the complexity. In order to further reduce the complexity of LMS algorithm, several simplified algorithms are used. It includes Sign Error LMS (SELMS) algorithm, Sign Data Normalized LMS (SDNLMS) algorithm etc. In this paper, a new, low complex Sign Data Sign Error LMS (SDSELMS) algorithm is proposed which improves the convergence rate and reduces the computational complexity of the existing algorithms which is required for making channel estimation simpler.*

Keywords - *Channel estimation, MIMO-OFDM, LMS, NLMS, SDNLMS*

I. Introduction

Wireless Communication Technology has developed many folds over the past few years. This developments lead to the increasing demand for high speed wireless communication systems. In order to meet this increasing demand for various multimedia and internet related services; an efficient, high speed wireless communication technology is required. The Multiple-Input Multiple-Output (MIMO) system combined with the multicarrier modulation scheme, Orthogonal Frequency Division Multiplexing (OFDM) is such a popular and effective communication system that provides large system capacity and high data rates without any extra consumption of bandwidth and power [1].

Multiple-input multiple-output system refers to the use of multiple antennas at both the transmitter and receiver ends. It increases the system capacity by exploiting the spatial dimension. A MIMO system transmits the signal through different antennas without using any extra bandwidth or power than that required for a single-input single-output (SISO) system. It provides increased link reliability, quality of service, improved coverage and performance by mitigating the effects of fading.

Orthogonal frequency division multiplexing is a multi-carrier modulation technique, which ensures high data rate transmission in delay-dispersive environment by eliminating inter symbol interference. An OFDM system converts a frequency selective channel into several parallel frequency flat channels and thus reduces the effect of fading and makes multi channel equalization simpler. At first it converts the high speed serial data stream into a number of low speed data strings that can be transmitted in N subchannels. Then the OFDM technology modulates them using N subcarriers that are orthogonal to each other. The N modulated signals are transmitted together to the destination [2].

MIMO in combination with OFDM is widely used due to its best performance in terms of high data rates, capacity and good outcome in frequency selective fading channels. When the generated OFDM signal is transmitted over a number of antennas in order to achieve higher transmission rates or to achieve diversity then the system is referred to as a MIMO-OFDM system. Together they overcome the effects of ISI, improve the link reliability and also improve the spectral efficiency by using orthogonal subcarriers. So MIMO OFDM is a promising candidate technology for modern high speed wireless communication [3].

Channel estimation is one of the major challenges faced by a MIMO-OFDM system. It refers to the process of characterizing the effect of physical medium on the input sequence. Channel estimates or Channel State Information (CSI) are required at the receiver for the effective retrieval of transmitted signal. Various channel estimation techniques are used to judge the physical effects of the medium present for MIMO-OFDM systems [4-6]. As the wireless channel is rapidly varying with time, adaptive channel estimation (ACE) techniques that are able to update the parameters continuously, are suitable for the estimation of such a time variant channel. They are pilot based channel estimation techniques, which estimate the channel by transmitting a sequence of known signals along with the data signals. Main advantage of ACE techniques is that it doesn’t require any prior knowledge of channel and noise statistics [7]. Only parameter required is the knowledge of the received signal, which can update the channel parameters automatically. Out of various adaptive channel estimation algorithms, Least Mean Square (LMS) algorithm is the simplest one with low complexity [8]. The three important parameters that are to be considered in selecting the adaptive algorithms for channel estimation are Mean Square Error (MSE), computational complexity and convergence rate [9]. Thus the main aim of any channel estimation technique is to minimize the MSE by utilizing as little computational resources as possible allowing easier implementation with low complexity and faster convergence.

In order to further reduce the complexity of LMS algorithm, several simplified LMS algorithms can be used. It includes the Sign Error LMS (SELMS) algorithm, Sign Data Normalized LMS (SDNLMS) algorithm [10] etc. In this paper a low complexity Sign-Data Sign-Error Least Mean Square (SDSELMS) algorithm is proposed for channel estimation of MIMO OFDM System, which further reduces the complexity of other simplified algorithms.

II. MIMO-OFDM System Model

The MIMO OFDM system model based on pilot based channel estimation is depicted in Fig. 1.

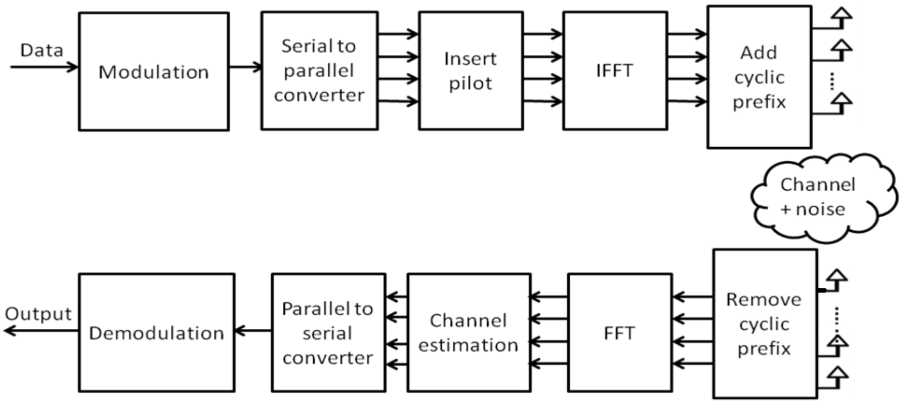

Figure 1. MIMO-OFDM system model

The input data in the form of binary sequence is first mapped into multi amplitude multi phase signals according to the type of modulation used. Here QPSK modulation is used. The modulated serial data sequence is then converted into N parallel data sequences with the help of a serial to parallel converter. Then pilot signals are inserted uniformly between the information sequences at known positions for the purpose of channel estimation at the receiver side. After inserting the pilot signals, the parallel data sequences are passed through an IFFT block which converts the complex data sequence in frequency domain into time domain. In the next stage cyclic prefix is added to each of the OFDM signal. Cyclic prefix is the copy of last part of OFDM symbol that is added at the beginning of each OFDM symbol. It is inserted mainly to prevent the effect of Inter Symbol Interference (ISI) in OFDM signals. It acts as a buffer between two OFDM symbols and thus prevents ISI. After adding cyclic prefix, the parallel sequence is converted into serial data sequences and is transmitted through a number of antennas to the receiver through a Rayleigh fading channe [11l.

At the receiver end the data is received by a number of receive antennas as it is a MIMO system. The received serial data is converted into parallel sequences with the help of a serial to parallel converter. The cyclic prefix added at the transmitter is removed and the received signal is passed through an FFT block for demultiplexing the multicarrier signals. It converts the time domain signal back into frequency domain signal. The pilot signals are then extracted from demultiplexed sample. This pilot signal is further used for the estimation of channel using various adaptive channel estimation algorithms. After estimating the channel, transmitted data signals can be recovered by dividing the received signal by the obtained channel frequency response. Further the parallel data is converted into serial data sequence and is demodulated to reconstruct the original binary data at the receiver output [12].

III. Adaptive Channel Estimation Algorithms

As the wireless channel is rapidly varying with time, a channel estimation algorithm that can automatically adapt according to time is required for effective channel estimation. An adaptive algorithm is such a process that can update its parameters automatically as it gain information about the changing environment [11]. An Adaptive estimator is able to update the parameters without any prior knowledge about the channel and noise statistics. The only requirement is the knowledge of the received signal.

Adaptive CE algorithms use an adaptive filter to estimate the MIMO OFDM channel. Fig. 2 shows an adaptive channel estimation scheme.

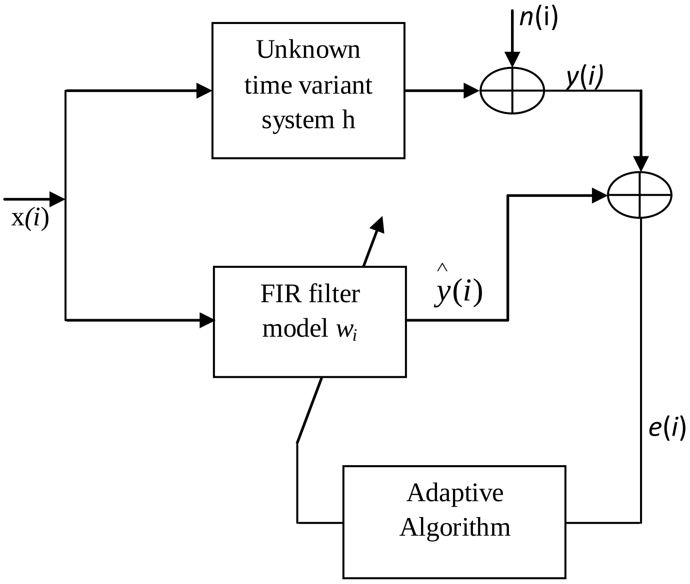

Figure 2. Adaptive Channel Estimation Scheme

In Fig. 2, $\{x(i)\}$ represents the transmitted random sequence and $\{y(i)\}$ represents the random sequence received at any time instant i after passing through the channel. The sequence $\{x(i)\}$ is passed through a Rayleigh channel which is represented by the unknown time variant system with channel impulse response sequence h . The output sequence at the receiver can be described by:

$$y(i) = x_i h + n(i) \qquad (1)$$

where, $n(i)$ represents the Additive White Gaussian Noise (AWGN) with mean zero. Thus the received signal $y(i)$ includes the effect of channel h and the AWGN noise $n(i)$.

At the receiver side consider an FIR filter with adjustable weights $w(i)$ which is excited by the same pilot sequence used at the transmitter. This FIR filter can mimic the unknown channel by updating the weight vectors. FIR filter output can be represented as:

$$\hat{y}(i) = x_i w_i \qquad (2)$$

where, w_i denotes the filter weight vector at i^{th} instant of time. The error between the desired output and filter output is given by:

$$e(i) = y(i) - x_i w_i \qquad (3)$$

The FIR filter coefficients are adjusted from w_i to w_{i+1} with the help of this error signal. The error signal is minimized through a number of iterations. After a number of iterations the output of the adaptive filter $\hat{y}(i)$ will assume values close to the output through the actual channel $y(i)$. Thus the adaptive filter will behave similar to the unknown channel [10]. Therefore, we can recover the channel impulse response sequence, h by determining the optimum value of weight vectors w_{i+1} .

There are a number of adaptive CE algorithms available with varying performance. Among them, the algorithm which is most popular and with lowest complexity is the Least Mean Square (LMS) algorithm.

3.1 LMS ACE Algorithm

The LMS algorithm is an adaptive algorithm which incorporates an iterative procedure that makes successive corrections in the weight vector in the direction of the negative gradient vector which eventually leads to the minimum mean square error (MSE) compared to other algorithms [11]. LMS algorithm is relatively simple with the lowest complexity. In LMS algorithm the weight vector is updated by using the equation:

$$w_{i+1} = w_i + \mu \times x_i^* \times \left[y(i) - x_i w_i \right] \qquad (4)$$

where, μ is the step size parameter.

3.2 NLMS ACE Algorithm

The main drawback of the standard LMS algorithm is its sensitivity to the scaling of inputs. This makes it hard to select a step size μ that guarantees the stability of the algorithm. Normalized LMS (NLMS) algorithm is a variant of LMS algorithm that solves this problem by normalizing the update factor with the power of the input signal [12]. It is similar to the LMS algorithm except the weight update calculation which is given by:

$$w_{i+1} = w_i + \frac{\mu}{\varepsilon + \left\| x_i^2 \right\|} \times x_i^* \times \left[y(i) - x_i w_i \right] \qquad (5)$$

where, ε is a small positive constant to avoid division by zero.

IV. Simplified ACE Algorithms

Some of the adaptive filter applications require us to implement the adaptive filter algorithms on hardware targets like DSP devices, application specified integrated circuits and FPGA targets. A simplified version of standard LMS algorithm is required for such targets. The LMS algorithms can be simplified with the help of signum function. Signum function is defined as,

$$\text{sign(x)} = \begin{cases} +1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \qquad (6)$$

Applying sign function to the standard LMS algorithm returns the following simplified sign LMS algorithms:

4.1 SELMS ACE Algorithm

Sign Error Least Mean Square (SELMS) algorithm applies the signum function to the error signal. When the error signal is zero, this algorithm does not involve any multiplication operation. When the error signal is non zero, this algorithm involves only one multiplication operation. SELMS algorithm updates the weight vector of the adaptive filter using the equation,

$$w_{i+1} = w_i + \mu \times x_i^* \times sign\left[y(i) - x_i w_i \right] \qquad (7)$$

4.2 SDNLMS ACE Algorithm

Sign Data Normalized Least Mean Square (SDNLMS) algorithm applies the signum function to the input data signal [10]. When the input signal is zero, this algorithm does not involve any multiplication. When the input signal is non zero, this algorithm involves only one multiplication operation. SDLMS algorithm updates the weight vector of the adaptive filter using the equation:

$$w_{i+1} = w_i + \frac{\mu}{\varepsilon + \left\| x_i^2 \right\|} \times sign\left(x_i^* \right) \times \left[y(i) - x_i w_i \right] \qquad (8)$$

4.3 Proposed Algorithm: SDSELMS Algorithm

Sign Data Sign Error Least Mean Square (SDSELMS) algorithm applies signum function to both the input data signal and the error signal. It is a combination of SDLMS and SELMS algorithms. If either the input signal or the error signal is zero, this algorithm does not involve any multiplication. The algorithm involves a multiplication only if both the input signal and the error signal is non zero. Thus it reduces the number complex multiplications required. SDSELMS algorithm updates the weight vector of the adaptive filter using the equation:

$$w_{i+1} = w_i + \mu \times sign\left(x_i^* \right) \times sign\left[y(i) - x_i w_i \right] \qquad (9)$$

Thus by applying signum function to both the data signal and the error signal, the SDSELMS algorithm further simplifies the complexity of the low complex SDNLMS algorithm.

V. Experimental Results

The main performance parameters for a channel estimation algorithm are Mean Square Error (MSE), Convergence rate and Computational complexity. This section compares the MSE performance and computational complexity for LMS, NLMS, SELMS, SDNLMS, SDSELMS algorithms for MIMO OFDM systems. Simulation is done in MATLAB 2013. A 2*2 MIMO-OFDM system is considered in these simulations. Modulation scheme used is QPSK. Noise used in the simulation is AWGN noise and the channel under consideration is Rayleigh fading channel.

5.1 MSE performance

Fig. 3 shows the MSE performance for the various ACE algorithms described in the above section. Among the algorithms, NLMS algorithm provides the best MSE performance. SDNLMS algorithm provides almost same MSE performance as that of NLMS algorithm. MSE performance of SDSELMS algorithm is less than SDNLMS. SELMS algorithm has the least MSE performance. LMS algorithm also has less MSE performance.

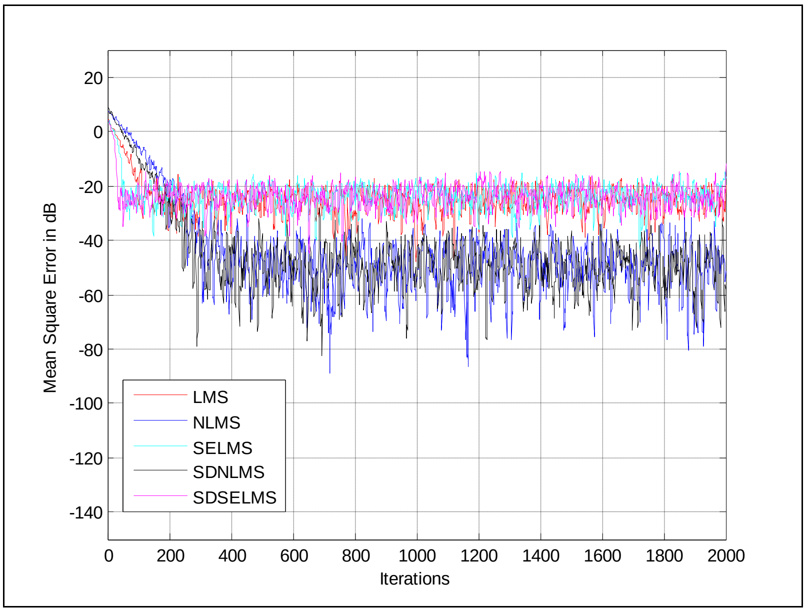

Figure 3. MSE Performance of different ACE algorithms

5.2 Convergence Rate

From the simulation results it is seen that Sign Data Sign Error LMS CE algorithm provides the fastest convergence among all the CE algorithms. SELMS CE also provides faster convergence. The LMS algorithm comes next. NLMS algorithm has the least convergence rate. SDNLMS algorithm has better convergence when compared with NLMS algorithm. Thus SDSELMS algorithm provides good performance in terms of convergence.

The convergence performance of the new SDSELMS algorithm is shown in Fig. 4. Fig. 5 shows the comparison of convergence performance for the various existing ACE algorithms with the new SDSELMS algorithm.

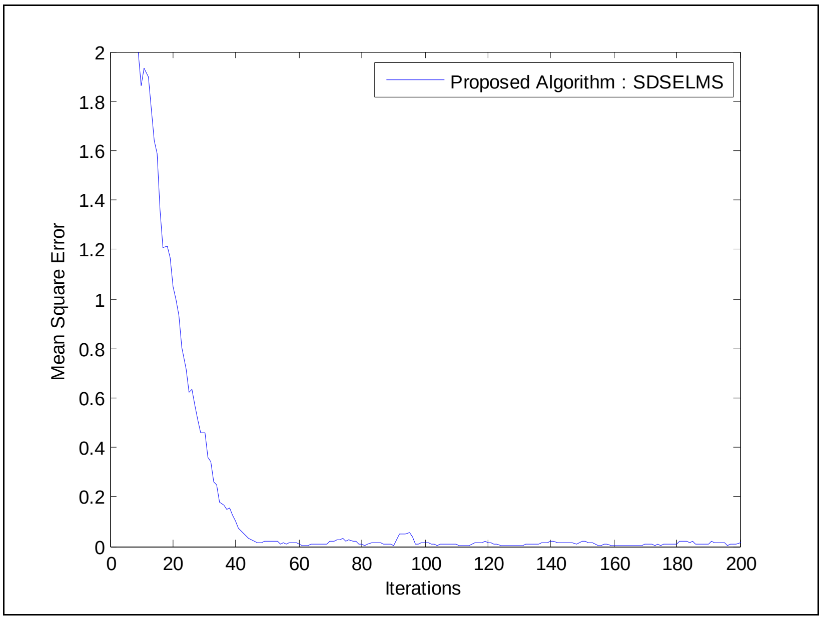

Figure 4. Convergence Performance of new SDSELMS algorithm

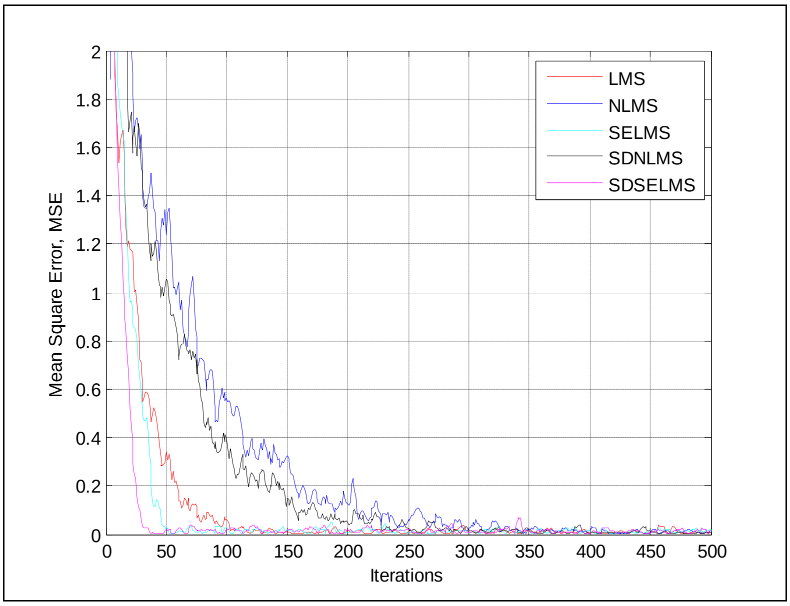

Figure 5. Comparison of Convergence Performance for different ACE algorithms

5.3 Computational Complexity

Computational complexity is one of the key parameter that is to be considered while designing a channel estimation algorithm. The complexity of the CE algorithm should be as low as possible for reducing the complexity of the whole system. The computational complexity in terms of the number of complex multiplications, divisions, additions and sign operations required during each iteration for an L length complex-valued data, is shown in Table I.

Table I

Computational complexity for different ACE algorithms

Method	Addition	Multiplication	Division	Sign
LMS	2L	2L+1	-	-
SELMS	2L	2L	-	1
NLMS	3L	3L+1	1	-
SDNLMS	3L	2L+1	1	1
SDSELMS	2L	2L	-	2

From the calculations it can be seen that SDSELMS algorithm has the least complexity as it requires less number of complex multiplications. It is due to the use of two signum functions. SELMS and LMS algorithms also have low complexity but greater than SDSELMS algorithm. NLMS algorithm has the highest complexity as it involves more number of complex multiplications and a division operation. SDNLMS has comparatively less complexity than NLMS algorithm as it requires less number of complex multiplications than NLMS algorithm.

VI. Conclusion

MIMO-OFDM technology has became a vital part in modern wireless communication systems which provides significant increase in data rates, capacity and link reliability without any additional bandwidth or power consumption. Channel estimation is one of the key challenges faced by MIMO OFDM systems. In this paper a new SDSELMS ACE algorithm is proposed for the channel estimation in MIMO-OFDM Systems. Its performance is compared with some low complexity adaptive channel estimation algorithms like LMS, NLMS, SELMS, SDNLMS. From the experimental results and analysis, it can be seen that the proposed SDSELMS algorithm provides the lowest complexity and faster convergence than the other ACE algorithms. So for those applications which require low complexity and faster convergence SDSELMS algorithm is an effective choice.

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