Comparison of Adaptive Channel Estimation Techniques in 4G MIMO-OFDM Systems

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Abstract – **In a wireless communication system channel estimation is the process of extracting the properties of a wireless communication channel for the accurate recovery of the signal at the receiver. Adaptive Channel Estimation (ACE) is used to estimate the channel with minimum mean square error. Least mean square (LMS) algorithm is most commonly used for the adaptive channel estimation. Eventhough LMS is less complex it suffers from high mean square error (MSE). Meanwhile NLMS provides low MSE and low convergence rate. This paper proposes a new method, SDSENLMS for ACE and compared the performance with other methods in a 2X2 Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system.**
Key words: MIMO-OFDM, Adaptive channel estimation, Mean square error, Least mean square, Normalized LMS, SNLMS

I. INTRODUCTION

The use of wireless mobile communication is being increased day by day. People are only interested in browsing high speed data devices. For achieving a system which supports high bandwidth and high speed flexible communication the combination of Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is used [1]. It increases the quality and capacity of a communication system. High speed data transmission is possible due to the orthogonal frequency division multiplexing. The compatibility to frequency selective channel meets the requirements of the wireless services of next generations.

Multiple carriers can be modulated in OFDM. It mitigates the effect of ISI at the receiver. In normal frequency division multiplexing a guard band is necessary between each channel in order to retrieve the signal at the receiver but in OFDM since the carriers are orthogonal to each other they could be retrieved easily and bandwidth could be saved. The guard band is not required for an OFDM. In MIMO the system uses spatially separated multiple antennas both at transmitter side and receiver side. Even if larger number of transmitter and receiver

antennas is used the power requirement is the same as used for a single antenna. The combination of MIMO-OFDM improves the performance of communication system since it produces higher capacity and bandwidth efficiency [1].

Accurate estimation of the channel state information (CSI) is a major concern for the MIMO-OFDM systems. Various channel estimation techniques are available in literature and the adaptive channel estimation is the technique used to estimate the CSI from a time varying channel. In digital communication system, a receiver known training sequence is transmitted periodically for ACE process.

The literature review on various adaptive channel estimation techniques showed that each of these techniques which we have considered throughout our work differ in their complexity, convergence rate and mean square error (MSE) [2]. One of the commonly used estimation technique is the Least Mean Square (LMS) algorithm. The complexity of this algorithm is low but has high MSE value [3]. Later another algorithm has been proposed in order to reduce the mean square error by performing normalization procedure. NLMS algorithm provides low mean square value but has low convergence rate [4]-[5]. The convergence rate is dependent on the step size of the LMS algorithm. VSSNLMS provides low MSE and high convergence rate [6]. The computational complexity of the algorithm can be further reduced by the signum function and SDNLMS algorithm has better convergence rate while SENLMS algorithm has low MSE than LMS and NLMS. In this paper we proposed a new technique to improve the convergence rate and MSE that has the convergence rate and MSE close to VSSNLMS which is the combination of both SDNLMS and SENLMS known as SDSENLMS (Sign Data Sign Error Normalized Least Mean Square) algorithm.

The remaining parts of the paper are arranged as: Section II described the MIMO-OFDM system model under consideration, methodology of the

proposed method is described in section III. Section IV described various adaptive channel estimation algorithms, section V described the proposed algorithm and the simulation results discussed in section VI. Section V is conclusion of the paper.

II. MIMO-OFDM SYTEM MODEL

MIMO system combines with OFDM technology combines the advantages of both and provides high data rates, increased capacity, improved coverage, mitigation of ISI etc. Hence MIMO-OFDM systems become an essential technology for enhancing the performance of next generation high speed wireless communication.

A typical MIMO-OFDM transceiver is shown in figure 1. The figure 1.a described the MIMO-OFDM transmitter and it included a forward error correction encoder which encodes the source bit stream and the coded bit stream is mapped to a constellation by a digital modulator and it is encoded by a MIMO encoder and is given to the OFDM modulator. In the system under consideration the input bit stream is mapped by a QAM modulator. Then it is transformed from frequency domain to time domain using IFFT after a serial to parallel converter. The bit stream in the frequency domain is converted into a serial form and is fed to a DAC and the low amplitude signal is amplified by a High power amplifier. This signal is given to a time varying channel.

Fig.1. MIMO-OFDM System Model

At the receiver in figure 1.b the reverse process is taking place to recover the base band signal. The received signal is transformed to frequency domain by using FFT. This signal in frequency domain is converted to a serial form and signal is demodulated using a QAM demodulator. The MIMO decoder combines the signal for detection with the help of a channel estimator. The channel estimator gives the CSI and channel estimation, especially adaptive channel estimation is one of the main challenges of MIMO-OFDM system and this paper focusing on that.

III. METHODOLOGY

The signal was transmitted to the receiver through a $N_r \; X \; N_t$ MIMO wireless channel. The signal received at the receiver end can be written as:

$$\mathbf{Y = HX + n}$$
(1)

where n is the additive white Gaussian noise vector with zero mean and H is the MIMO channel matrix and can be expressed as:

$$\overline{H} = \begin{bmatrix} h_{11}^T & h_{12}^T & \dots & h_{1N_t}^T \\ h_{21}^T & h_{22}^T & \dots & h_{2N_t}^T \\ M & M & O & M \\ h_{N_r1}^T & h_{N_r2}^T & \dots & h_{N_rN_t}^T \end{bmatrix}^T$$
(2)

Now the received signal at nr-th receiver antenna is:

$$\hat{y}_{n_r}(n) = \hat{h}_{n_r:}^T(n)x(n) + n_{n_r}$$
(3)

where $\vec{h}_{n_rn_t}$ is the wireless channel vector from receiver antenna n_r to transmitter antenna n_t.

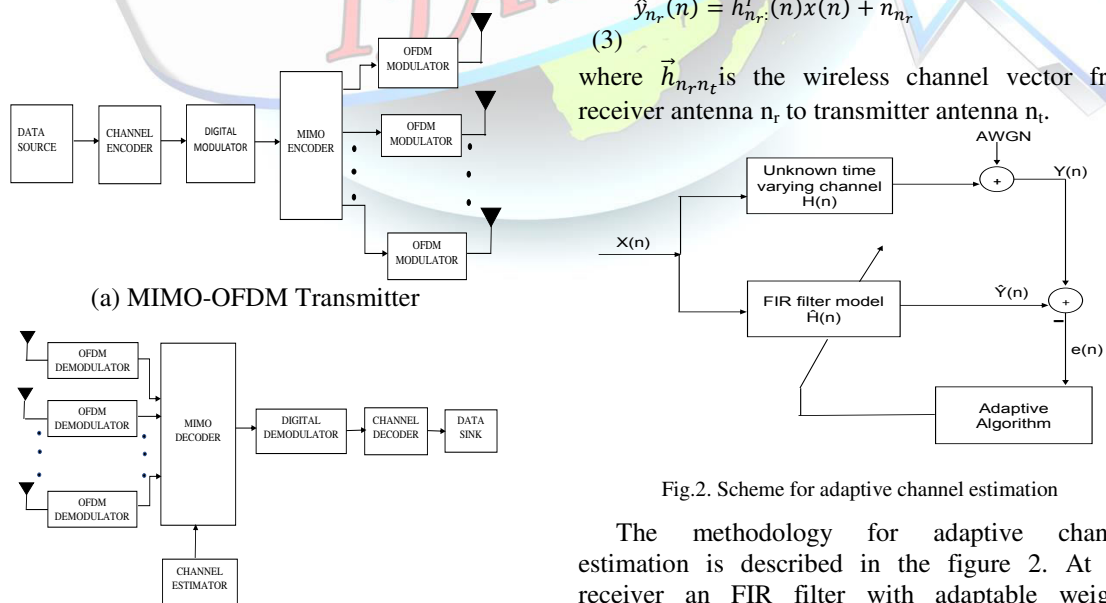(a) MIMO-OFDM Transmitter

(b) MIMO-OFDM Receiver

Fig.2. Scheme for adaptive channel estimation

The methodology for adaptive channel estimation is described in the figure 2. At the receiver an FIR filter with adaptable weights equivalent to the channel coefficients, h(n) was considered and it was convolved with the pilot

sequence that was used at the transmitter. With the updated weight vectors the FIR filter imitate the unknown time varying sparse channel **H**.

Now the estimation error, e_{n_r} at time n and for n_r-th receiving antenna can be written as:

$$e_{n_r}(n) = y_{n_r}(n) - \hat{y}_{n_r}(n)$$
$$= y_{n_r}(n) - \hat{h}_{n_r:}^T(n)x(n)$$

(4)

The principle behind the proposed method is to minimize the errors by updating the weights of an adaptive filter. A time varying channel is used for this estimation technique. It's represented by a matrix **h**. Here we are considering a 2X2 MIMO system having 2 antennas at the transmitter and 2 at the receiver.

IV. ADAPTIVE CHANNEL ESTIMATION ALGORITHMS

There are various channel estimation algorithms are available in literature for the adaptive channel estimation. Least mean square algorithm is the most commonly used technique due to its simplicity and its variants are also used generally. The techniques considered for this study is described below:

A. *LMS Algorithm*

Least Mean Square algorithms (LMS) are class of adaptive filter algorithms used to find the filter coefficients that relate to produce the least mean squares of the error signal. It is a gradient descent method in which the filter is only based on the error at the current time [3]. When the training sequences are sent, the weights of the adaptive filter change by the following iterative formula:

$$w'(n + 1) = w'(n) + \mu . e(n). x(n) \qquad (5)$$

where, w'(n+1) is the estimation of weighting vector of the filter, μ is the step factor,e(n) is the estimation error and x(n) is the input vector at time n.

The LMS algorithm process is as follows:
    i.   Select initial weight vector w' (0).
    ii. Calculate error e(n) by using $e(n) = Y(n) - \hat{Y}(n)$
    iii. Update filter coefficient using the formula:
$$w'(n + 1) = w'(n) + \mu . e(n). x(n)$$

From the above equation, it is observed that the adjustment of system parameters only depend on x(n).Thus, when x(n) is too large, this algorithm is not stable. The LMS algorithm is convergent in the mean square if and only if the step-size parameter satisfy, $0 < \mu < \frac{2}{l_{max}}$, l_{max} represents the largest eigen value of the covariance matrix, $E\{XX^H\}$. Thus the step size parameter is selected such that it satisfies this condition.

B. *NLMS Algorithm*

The main limitation of "pure" LMS algorithm is that it is very sensitive to the input x(n). Hence it makes it very difficult to choose the value of μ that gives the stability for the algorithm. The *Normalized Least Mean Square* algorithm [5] is a modified form of LMS algorithm which rectifies the drawback of LMS algorithm by normalizing the input power. The weight update equation of NLMS algorithm is

$$w'(n + 1) = w'(n) + \mu . e(n). \frac{x(n)}{||x(n)||^2} \qquad (6)$$

where $||$x(n)$||^2$ is the norm of the input.

Good MSE performance, high complexity and low convergence rate are the key features of NLMS algorithm whereas LMS algorithm is low complex but provides poor MSE performance. A trade-off exists between the MSE and convergence rate. For achieving better MSE and high convergence variable step size is used. This is employed in VSS-NLMS algorithm.

C. *VSS-NLMS Algorithm*

The main purpose of a VSS algorithm is to develop a method to vary the step size so that the value of μ is larger during the initial iterations and decreases gradually. *Variable Step-Size Normalized Least Mean Square* [6] solves the dilemma of fast convergence rate and low excess MSE. It uses a variable step factor μ(n). It has good convergence and tracking properties. The step size can be varied according to the expression [6]:

$$\mu(n + 1) = \alpha\mu(n) + \gamma e^2(n)$$

(7)

where, and $0 < \alpha < 1$and $\gamma > 0$.

Now the update equation for VSS-NLMS algorithm is:

$$w'(n + 1) = w'(n) + \frac{\mu(n+1)}{\varepsilon + ||x(n)||^2} x(n)e(n)$$

(8)

ε is a stabilization parameter to avoid the situation of division by zero and it is a small non-negative value.

D. *SNLMS ALGORITHM*

The *Sign Normalized Least Mean Square* [8] Algorithm is a variant of NLMS algorithm. The Signum function is defined as:

$$sign(a) = \begin{cases} +1, & a > 0 \\ -1, & a < 0 \\ 0, & a = 0 \end{cases}$$

(9)

Applying sign function to the standard NLMS algorithm gives different simplified ACE algorithms.

(a) Sign Error Normalized LMS Algorithm (SENLMS):

In this algorithm, sign function is applied to the error signal e(n).The coefficients of adaptive filter are updated by the equation:

$$w'(n + 1) = w'(n) + \mu.\frac{(sgn\ e(n)).x(n)}{\varepsilon + ||x(n)||^2}$$

(10)

When e(n) = 0, this algorithm does not involve multiplication operation. In this situation the algorithm has only shift and addition operations.

(b) Sign Data Normalized LMS Algorithm (SDNLMS):

In SDNLMS algorithm, sign function is applied to the input data signal x(n). This algorithm updates the weights of the adaptive filter by [7]:

$$w'(n + 1) = w'(n) + \mu.\frac{e(n).(sgn(x(n))}{\varepsilon + ||x(n)||^2}$$

(11)

When e(n) ≠ 0, this algorithm involves only one multiplication operation. The MSE performance of the SDNLMS is better than the SENLMS.

V. PROPOSED ALGORITHM

In the proposed method combine the features of both SNLMS algorithms ie. SDNLMS algorithm and SENLMS algorithm are combined together to reduce the complexity and to improve the performance. Hence the proposed method is termed as *Sign Data Sign Error Normalized Least Mean Square (SDSENLMS) Algorithm*. In this algorithm, the signum function is applied to both input signal x(n) and error signal e(n). Now the update equation for the weight vector of the LMS algorithm can be formulated as:

$$w'(n + 1) = w'(n) + \mu.\frac{(sgn\ e(n)).(sgn\ x(n))}{\varepsilon + ||x(n)||^2}$$

(12)

From the equation it is clear that multiplication process is involved only if both the input signal and the error signal is non zero. Thus the computational complexity is reduced by minimizing the number of complex multiplications required per iteration.

VI. SIMULATION RESULTS

This section described the evaluation of proposed adaptive channel estimation algorithm *SDSENLMS* for a 2x2 MIMO-OFDM system and compares its results with existing methods in literature. Monte Carlo simulation with 1000

iterations was carried out for the evaluation. The simulation parameters used for evaluation is described in table 1. The performance of the proposed algorithm was evaluated with the average MSE and it is defined as:

$$Average\ MSE\left\{\hat{H}(n)\right\} = E\left\{\left\|H - \hat{H}(n)\right\|_2^2\right\},$$

where **H** is the actual MIMO channel vector and $\hat{H}(n)$ is its estimate at the nth update. Initial channel estimator was considered as zero for computer simulation. The step size used for NLMS was $\mu_{NLMS} = 0.5$ and that of VSS-NLMS is variable according to the corresponding expression (7).

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Transmit antennas, N_t	2
Receive antennas, N_r	2
IFFT size	256
Active subcarriers	200
Length of cyclic prefix	16
Mapping Scheme	16 QAM
Length of channel, N	272
Noise	Random AWGN
Step size for NLMS	0.5
α, γ (vssnlms)	0.99, $5*10^{-5}$
SNR	15 dB

The performance curves are showed in figure 3 and it was evident that the proposed SDSENLMS system achieves better performance in terms of MSE. But the convergence rate is better for the VSS-NLMS algorithm Performance of the proposed method was evaluated at an SNR of 15 dB.
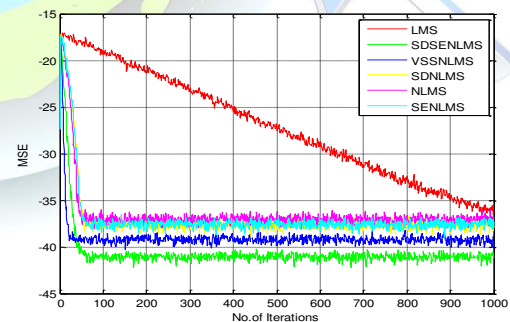

Fig.3. MSE Performance Curves

VII. CONCLUSION

Channel estimation is the most significant issue in next generation wireless communication which utilizes MIMO-OFDM system. The comparison of different adaptive channel estimation techniques gave us an idea about the convergence rate and

error performance. In this paper, study of various algorithms such as LMS, NLMS, VSS-NLMS, SDNLMS, SENLMS and the proposed *SDSENLMS algorithm* has undergone. The highest convergence rate has seen in VSS-NLMS. The proposed method SDSENLMS algorithm provides better MSE performance at a cost of convergence rate. In order to improve the convergence rate and MSE the proposed SDSENLMS algorithm can be modified with a variable step size and the modified algorithm is kept as the future work of this paper. This work can be further extended to next generation ie, 5G MIMO-OFDM and also for MU-MIMO-OFDM.

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