A Stable LMS Adaptive Channel Estimation Algorithm for MIMO-OFDM Systems Based on STBC

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Abstract— Multiple input multiple output (MIMO) technology is combined with orthogonal frequency division multiplexing (OFDM) to provide robustness and high spectral efficiency. Adaptive channel estimation is the most important and difficult task in MIMO-OFDM systems where the channel is rapidly time varying. RLS and LMS are commonly used adaptive algorithm for channel estimation in wireless systems. In this paper, a stable LMS adaptive algorithm is proposed for channel estimation in MIMO-OFDM systems based on space time block coding (STBC). Recursive least square (RLS) and Least mean square (LMS) adaptive channel estimators are discussed. The stability of proposed LMS and RLS algorithms is compared in term of µ. From the simulation results, it is observed that proposed LMS is more stable than RLS for a particular range of µ with less computational complexity. Moreover, the proposed LMS provides better performance with less training sequences compare to RLS.

***Key words**:* MIMO, OFDM, STBC, Adaptive Channel Estimation, LMS, RLS

I. INTRODUCTION

OFDM: For satisfying the day by day increasing demand of multimedia services and high speed communication, significant technological achievements are required to ensure that wireless devices have appropriate architectures suitable for supporting a wide range of services . Among the existing air interface techniques, OFDM has grown to be most popular communications systems in high speed communication. OFDM is a method of encoding digital data on multicarrier frequencies. OFDM is used for transmission of signal over wireless channel. OFDM has been adopted in applications such as digital television, audio broadcasting, digital subcarrier line, 4G mobile communications, internet access and wireless networks. OFDM has been considered as a candidate standard by a number of standardization groups of the institute of electrical and electronics engineer (IEEE) such as IEEE 802.11a, IEEE 802.11g, IEEE 802.11n and IEEE 802.16

MIMO: In recent years, various smart antenna designs have emerged which have found application in wireless communication systems. MIMO is an antenna technology for wireless communication in which multiple antennas are used at both the transmitter and receiver i.e. information is transmitted over two or more antennas and received via multiple antennas as well. The capacity of MIMO systems can be improved by a factor equal to minimum number of antennas employed at the transmitter and receiver . MIMO systems are designed for achieving the maximum diversity gain i.e. robustness against transmission errors. It is developed to enhance the performance of single data signal by beam forming, spatial multiplexing and diversity .

MIMO-OFDM: MIMO-OFDM is playing an important role in current and future wireless communications. It combines MIMO which multiplies capacity by transmitting different signals over multiple antennas and OFDM which divides the radio channel into a large number of closely spaced sub-channels to provide more reliable communication at high speed. MIMO-OFDM improves quality of wireless communication by improving the transmission rate, transmission range and the transmission reliability. MIMO can potentially be combined with any modulation or multiple access technique but implementation of MIMO with OFDM is more efficient as a benefit of the straight forward matrix algebra invoked for processing the MIMO-OFDM signals.

STBC: Space-time block codes (STBC) are generalized version of Alamouti scheme. These codes are orthogonal and can achieve full transmit diversity specified by the number of transmit antennas. Space time block codes are a complex version of Alamouti space time code, where the encoding and decoding schemes are the same as there in the Alamouti space time code on the transmitter and receiver sides. The data are constructed as a matrix which has its columns equal to the number of transmit antennas and its rows equal to the number of the time slots required to transmit the data. At the receiver side, the signals are first combined and then sent to the maximum likelihood detector where the decision rules are applied.

Channel Estimation: Accurate channel estimation is required at the receiver for the sake of invoking both Coherent demodulation and interference cancellation in MIMO-OFDM systems. Channel estimation in MIMO systems becomes more challenging, since a significantly increased number of independent transmitter-receiver channel links have to be estimated simultaneously for each subcarrier. The channel response is time variant due to mobility of transmitter, receiver and other obstacles so it is hard to predict the channel. For data detection and equalization we need channel state information at the receiver side. There are three types of channel estimation techniques available: training based channel estimation, blind channel estimation and semi-blind channel estimation. Training based channel estimation uses two types of block insertion: block type and comb type. In block type, the pilots are inserted into all subcarriers of OFDM symbol within some predefined period while in comb type; the pilots are inserted into certain subcarriers of each OFDM symbol. Block type is used for slow fading channels where as comb type is used for fast fading channels. Blind channel

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estimation exploits the statistical facts of the symbols that are received at the receiver. Semi-blind channel estimation is a combination of training based channel estimation and blind channel estimation.

Adaptive channel estimation is required if the channels are rapidly time varying. An adaptive algorithm is a process that changes its parameters as it gain more information of its possibly changing environment. RLS and LMS are commonly used adaptive algorithms for channel estimation.

In this paper, we compare the performance of LMS, RLS and proposed LMS channel estimation adaptive algorithms for MIMO-OFDM systems based on STBC. We show that proposed LMS provides better stability compare to LMS and RLS with low computational complexity.

II. STBC MIMO-OFDM SYSTEM

Space time block codes were designed to achieve the maximum diversity order for given number of transmit and receive antennas subject to the constraint of having a simple linear decoding algorithm [8]. This has made STBC very popular and most widely used scheme in MIMO-OFDM systems. The main idea of Alamouti STBC MIMO-OFDM systems is that the conjugate symbols transmitted over two antennas that have same property. MIMO-OFDM with STBC is a deserving candidate for wireless communication systems due to its ability to withstand high speed, high capacity and robustness to multipath fading.

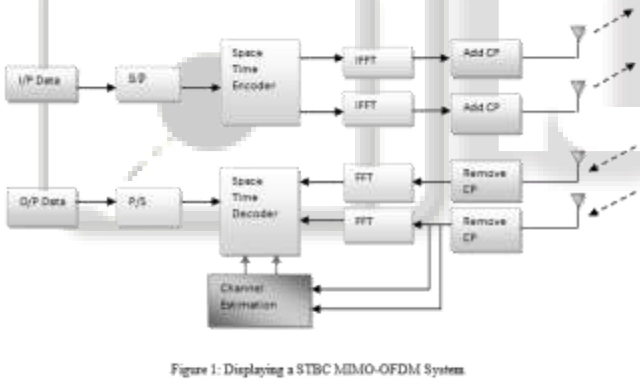


Fig. 1: Displaying a STBC MIMO-OFDM System

III. RELATED WORK

Melli et al analyzed the least mean square (LMS) and recursive least square algorithms. These two algorithms were applied to a multiple-input multiple-output (MIMO-OFDM) system based on STBC. The channel was frequency selective Rayleigh fading channel. The radio channel can be linear filter with a time varying impulse response. A STBC-MIMO-OFDM platform was build based on MATLAB, and then these two algorithms were applied to the platform respectively. It has seen that with increase of Eb/N0, the BER performance of these two algorithms will be smaller and smaller, and its performance is similar before Eb/N0=9. The MSE curve of RLS algorithm was smaller than LMS with the increase of the Eb/N0. Hence the convergence speed of RLS algorithm was faster than the LMS algorithm. The complexity of RLS was higher than LMS, the LMS was unstable.

N. daryasafar et al investigated and proposed a channel estimation method for MIMO-OFDM systems. The proposed method was based on comparison between different channel estimation methods. Optimum training courses were designed and comparative methods based on LMS algorithm were introduced. A MIMO-OFDM system with 2 transmitter antennas and 2 receiver antennas was used for the simulation. The assumed system had a QPSK modulation. It was observed from simulations that the channel estimation with LMS algorithm was closed to LS method with a careful choice of μ. The channel estimation was performed for a MIMO-OFDM system through the LMS algorithm. The LMS algorithm was extremely dependent on parameter μ. This method presented appropriate channel estimation through applying simple recurrence relations.2012.

Md. M. Rana et al described normalized least mean square (NLMS) and RLS for MIMO-OFDM systems. The NLMS and RLS adaptive channel estimator required knowledge of the received signal to update parameters of the estimator continuously. The knowledge of channel and noise statistics was not required. Multiple antennas were used at the transmitter and receiver which provide better performance as compare to single antennas. The MIMO-OFDM systems considered were 2×2, 4×4, 6×6 and 8×8. The data symbol was based on QPSK modulation. Multiple antennas provided much higher BER performance compared to fewer antennas. RLS algorithm provided faster convergence rate than NLMS algorithm. However, RLS CE had computational complexity. In order to combat the channel dynamics, the RLS CE algorithm is better to use for OFDM systems.

Vaishali B. Niranjane et al have investigated performance analysis of channel through adaptive channel estimation algorithms for estimating channel using different modulation scheme. RLS and LMS CE algorithms were used for estimating the channel at the pilot frequencies. The RLS algorithm had better performance but high complexity whereas LMS algorithm had low complexity but its performance was not good as that RLS at low SNR. The RLS algorithm was more resistant to the noise in terms of channel estimation.

An LMS and RLS based adaptive channel estimation for orthogonal STBC-OFDM systems with three transmit antennas was proposed by Berna Ozbek et al. The BER results that are obtained using the proposed RLS algorithm approach have shown that the channel coefficients are perfectly recognized at three-transmitter side with a reasonable degree. QPSK modulation has been chosen without channel coding for simulation. The channel transfer function changes between subcarriers in single OFDM frame while the whole function changes very slowly from frame to frame due to the fact that a low Doppler frequency has been chosen. The BER results that were obtained using proposed RLS algorithm approach assuming the channel coefficients were perfectly known at the transmitter side with a reasonable degree.

Hardeep Singh et al analysed enhanced adaptive channel estimation for MIMO-OFDM systems using RLMS technique. It was a combination of LMS and RLS algorithm which provided better performance. Further it was compared with simple LMS and LLMS which was the combination of two LMS algorithms. The error signal of one LMS algorithm was fed back to the other RLS algorithm. The weight vectors were updated twice by feeding the error signal i.e. first by the RLS and then by the LMS. The error signal was combined thus made it the efficient estimator increasing the convergence speed and provided lower error floor than single LMS and single RLS being used in the system. RLMS is complex but the MSE value was less than the LLMS algorithm. Mean convergence speed was more than LLMS. It had also low error value. BER performance of RLMS was better than LLMS. The BER performance becomes better with the increase in SNR value in both cases. Hence RLMS algorithm was better than LLMS algorithm for CE in MIMO-OFDM wireless systems.

IV. PROPOSED SYSTEM MODEL

The input message is a binary stream which is modulated first. BPSK modulation is applied on the binary message. The OFDM modulation transforms a broadband channel into multiplicity of parallel narrow band single channels [7]. The modulated binary message is passed through STBC encoder. The space time encoder consists of two transmit antennas as part of the multiple input multiple output technology. The information is transmitted through two separate antennas. STBC reduces the error and passed the data to the OFDM encoder. The data is encoded before transmitting through multiple antennas.

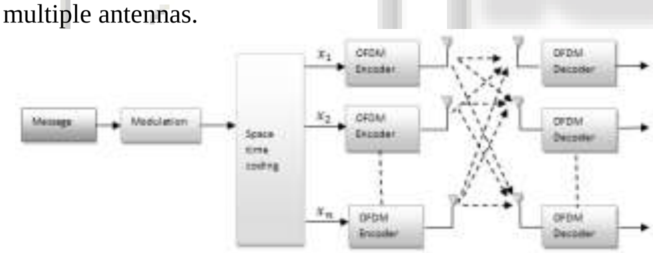
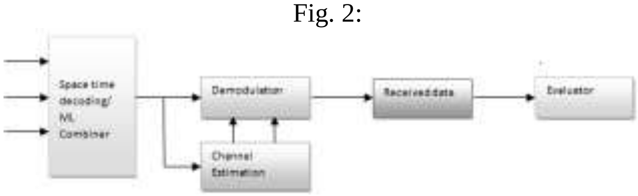


Fig. 2:



The idea behind the multiple antennas is that the signals on the transmit antennas at one side and the receiver antennas at the other side are combined in such a way that the quality of bit error rate and date rate of the communication for each MIMO user will be improved. Such an advantage can be used to increase both the network's quality of service and the operator's revenues significantly. MIMO systems are also bandwidth efficient i.e. each antenna element on a MIMO system operates on the same frequency and therefore does not require extra bandwidth. At the receiver, the signals are received by multiple antennas and combined. The receiver performs the reverse function of the transmitter. The received date is decoded by OFDM decoder to get the data into its original form. After decoding, the data is sent to the maximum likelihood combiner which acts as a space time decoder. In the decoder the received signal is fed to the channel estimator. The estimated coefficients of the channel together with the combiner are given as the input to the maximum likelihood detector.

Channel estimation is performed after space time decoding. Space time decoder reduces the BER errors which makes it easy to estimate the channel response. In our proposed system, adaptive algorithms LMS and RLS are used to evaluate the channel response. The LMS and RLS channel estimation algorithms requires knowledge of received signal only. This can be done by transmitting a training sequence that is known to the receiver. In this paper, block type training sequences are used. The detected signal is then fed to the demodulator. The demodulator gives the original information which is transmitted.

V. ADAPTIVE CHANNEL ESTIMATION ALGORITHMS

A. LMS Algorithm*:*

The LMS algorithm is widely used for simultaneous estimation of the all subcarriers. It is an adaptive channel estimation technique that changes its parameters as it gain more information of its possibly changing environment [10]. It minimizes the mean square error between the received signal and its estimate.

$Y(n)= X(n)H(n)+W(n)$ (1.1)

The adaptive filter response:

$P(n) = W_{est}(n)X(n)$ (1.2)

$W_{est}(n)$ is the estimated channel coefficient

$e(n) = Y(n)-P(n)$ (1.3)

$= X(n)H(n) + W(n) - W_{est}(n)X(n)$ (1.4)

e(n) is minimized mean square error

The cost function of LMS algorithm is defined as:

$J(n) = e^T e$ (1.5)

By using steepest descent method we have:

$\hat{w}(n) = \hat{w}(n-1) + \mu u(n)e^*(n)$ (1.6)

Adjustments of system parameters depend on u(n). When u(n) is too large, the LMS algorithm is unstable [1].

B. RLS Algorithm:

The RLS channel estimation algorithm requires all the past samples of the input. It will get the estimation of the current subcarrier value by use of the previous subcarrier value in a recursive manner. For example: we will get h(k) by the kth input, output and h(k-1).

The received single subcarrier can be represented as:

$Y(k) = W(k)h + v(k)$ (1.7)

Where,

Y(k) is the received signal in frequency domain, W(k) is the pilot signal and h is the channel impulse response (CIR).

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$$Y(k) = [Y^1(k), Y^2(k), \dots \dots \dots \dots \dots \dots Y^M(k)] \qquad (1.8)$$

$$W(k)= [W_1^1(k), W_2^1(k) \dots \dots W_L^1(k) \dots \dots W_1^M(k), W_2^M(k), \dots \dots W_L^M(k)] \qquad (1.9)$$

C. Proposed Stable LMS Algorithm:

The main drawback of the LMS algorithm is that it is sensitive to the scaling of its x(n). This makes it very hard to choose the learning rate μ on which stability of LMS algorithm depends. The proposed LMS algorithm is based on the normalised LMS because NLMS solves this problem by normalising with the power of the input. The value of μ is chosen so that so that it makes the LMS algorithm stable. For stability the value of μ should be:

$$0 < \mu < \frac{2}{\lambda_{max}}$$

The proposed LMS algorithm is as follows:
Parameters: M is the length of the filter
μ is the step size
Initialization:

1) Select the initial weight vector $\hat{w}(0)$,
2) $[u(n) = u(n), u(n-1), \dots \dots u(n-M+1)]^T$ is the input vector at time n,
3) d(n) is the expected value of receiving at time n,

Computation: For n = 0, 1, 2...

$e(n) = d(n) - \hat{w}^H(n)u(n)$, Where e(n) is the error of the estimation,

$$\hat{w}(n+1) = \hat{w}(n) + \frac{\mu u(n) e^*(n)}{u^H(n)u(n)},$$ is the adaptive weighting,

end.

The value of μ should be small for better stability and is independent of input x(n) and the unknown impulse response h(n). If there is no interference the value of μ is 1. In simulation, we vary the value of μ and check the stability.

VI. SIMULATION RESULTS

A STBC MIMO-OFDM system platform is built on MATLAB. In simulations, a 2×1 and 2×2 MIMO-OFDM system is used in this paper. The channel is a frequency selective Rayleigh fading channel. The simulations parameters are shown in table 1.

Parameter	Specification
Code Length	64
Pilot Length	8
IFFT	8
Tx and Rx antenna	2×2 and 2×1
Guard Time	1
Subcarrier Number	64
Maximum Time Delay	1

A. Simulation Graphs:

The digital modulation used is BPSK. In this paper, the STBC MIMO-OFDM system without LMS, with LMS, with RLS and with proposed LMS algorithm is compared on the basis of simulation results in terms of μ. Figure 3 shows the comparison results. It is concluded from graph that proposed LMS system is more stable compare to RLS algorithm with low BER rate.

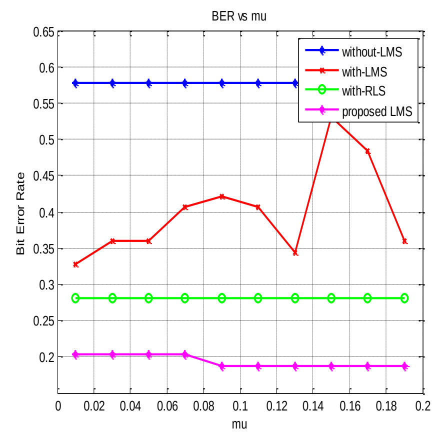

Fig. 3: BER vs. Mu performance graph for STBC MIMO-OFDM System

Different values of BER and SNR are taken and performance is checked. The proposed LMS algorithm has less computational complexity as compare to RLS algorithm. Figure 4 shows the performance of proposed LMS is better BER performance than RLS.

The BER performance of STBC MIMO-OFDM for BPSK modulation is shown in figure 5. The LMS algorithm requires less training data for estimating the symbols. Figure 6 shows the BER versus training percentage curve for STBC MIMO-OFDM system. We can see from the graph that proposed algorithm has better performance at less training sequences

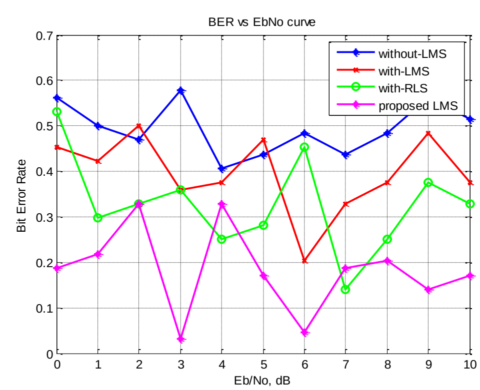

Fig. 4: BER vs. Mu performance graph for STBC MIMO-OFDM System

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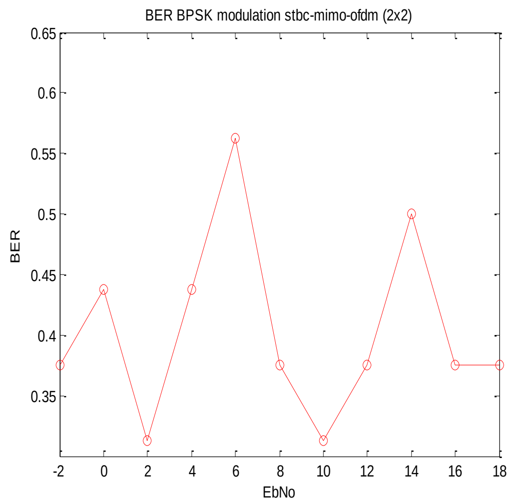

Fig. 5 : BER performance of STBC MIMO-OFDM system for BPSK modulation

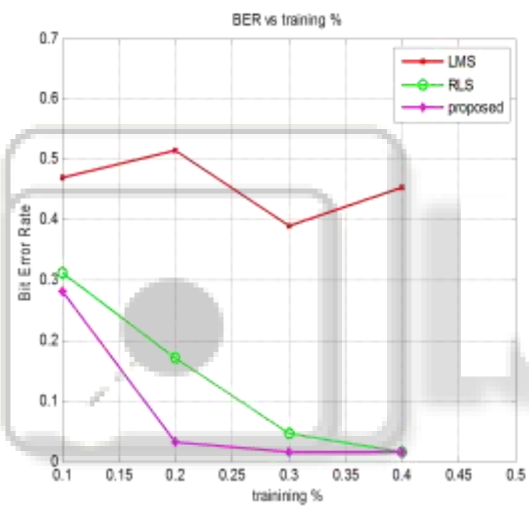

Fig. 6: BER vs. Training percentage graph for STBC MIMO-OFDM system

VII. CONCLUSION

In this paper, a stable LMS technique for channel estimation in STBC MIMO-OFDM has been presented. We have analyses a comparison of adaptive channel estimation techniques in STBC MIMO-OFDM system by using different parameters. The value of μ is adjusted to get a stable LMS system. A stable LMS algorithm is proposed which has better performance than RLS and LMS algorithms. The computational complexity is also decreased with the estimation accuracy in proposed system. The BER performance and stability of existing LMS algorithm is improved in the proposed LMS algorithm.

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