International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 16 (2018) pp. 12923-12927

Channel equalization in a MIMO system using Sliced Multi Modulus Algorithm

Sakimalla Prabhakar Girija

F. A. Author is research scholar in Electronics and Communication Engineering, NERTU, UCE, Osmania University, Hyderabad, Telangana, India.
Corresponding author

Abstract

Estimation of channel plays a most important role in wireless communication. In multiple input multiple output (MIMO) systems the filter performance is degraded due to inadequate information. Multi modulus blind equalization algorithm (MMA) was proposed to improve the system performance. The improper adjustment observed in existing constant modulus algorithm (CMA) will be overcome by MMA to the maximum extent. The multi-modulus algorithm is modified as sliced multi modulus algorithm (SMMA) for equalizing the MIMO systems. This paper describes SMMA for channel estimation in an efficient manner. This method includes multi-modulus-based weight adaptation process. The proposed algorithm gives better steady-state performance. Additionally, it demonstrates that this method shows smaller steady-state error in comparison with MMA.

Keywords: Channel equalization, steady state error, statistics, MIMO, MMA

INTRODUCTION

It is known that wireless communication has significant growth in real time applications. The fast development is in the number of new subscribers with the development of different global technologies. the demand for the new, best quality, low cost services and also higher data rates are the primary inspirations for the development in the MIMO systems. However, the inter-symbol interference (ISI) caused by multipath and Doppler Effect degrades the transmission performance to great extent. In order to reduce the effect of ISI many adaptive equalization techniques are proposed in the literature. Techniques such as space-time turbo equalization algorithm, combine space-time block codes with MIMO equalizer. However, the traditional equalization fails to overcome ISI in MIMO channel equalization efficiently [1,2].

Equalizing the communication channel without using the training sequence is known as blind equalization. It utilizes bandwidth efficiently [3].The main aim of blind equalization algorithm is to match the equalizer response to the inverse impulse response of the communication channel. There are many different algorithms to update the tap values. Among all methods, the most commonly used algorithm is the CMA.

CMA is the most preferred algorithm because of its simplicity and robustness [4]. In the signal constellation where all signal points have same magnitude. The efficiency of CMA is good but this algorithm is phase-independent. At the output of the equalizer a carrier phase rotator is needed so that phase offset error can be removed and correct constellation can be produced. Performance of multi-modulus algorithm (MMA) is better than CMA. In this algorithm phase of the carrier can be recovered with better convergence [5].But the proposed SMMA gives better performance when compared to MMA giving a better BER, without compromising the convergence rate.

This paper is organized as follows. In section 2 we briefly discuss the system model with channel equalization. In section 3, MMA is reminded. Section 4 explains the proposed algorithm. Simulation Results are given in section 5 and conclusion remarks are given in section 6.

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PROBLEM FORMULATION

Basic Channel model

For a MIMO system the signals reach the receiver by means of many propagation paths. Each path may have a different phase, attenuation, delay and doppler frequency connected to it. Because of arbitrary shift in the phase connected with each signal that has been received, the signal is subjected to a phenomenon named Fading.

Depending on the type of multiple path, there are two types of multipath channels. They are discrete Multipath and diffuse multipath. Here discrete multipath channel estimation is considered for estimating signal which already exists in channel.

When there is a discrete path between transmitter and receiver the signal is subjected to different levels of attenuation and delay. The channel is said to be a discrete multipath channel.

The discrete multipath channel can be represented as:

$$y(t) = \sum_{i=1}^{N} \alpha_i s\left(t - \tau_i\left(t\right)\right) \tag{1}$$

Here N is number of received signals

$s(t)$ is band pass input

α_i is attenuation of the path

τ_i is delay of the path

A discrete multipath channel can be represented as a tapped delay line [5] with coefficients that vary with time. We express s(t) as:

$$s(t) = \hat{R}\left\{\tilde{s}(t)e^{j2\pi f_C t}\right\} \tag{2}$$

The output of the channel can be written as:

$$\tilde{y}(t) = \sum_{i=1}^{N} \tilde{\alpha}_i \tilde{s}(t - \tau_i(t)) \tag{3}$$

Here fc is the frequency of the carrier.

A discrete multipath channel which varies with time can be described by a complex impulse response that varies with time:

$$\tilde{h}(\tau;t) = \sum_{i=1}^{N} \tilde{\alpha}_i \tilde{s}(t - \tau_i(t)) \tag{4}$$

Where $\tilde{\alpha}_i$ is the complex attenuation of each path which varies with time. If N is the fixed number of paths and τ_i is the path delay of the ith path. If the properties of the complex attenuation α_i can be specified then the characteristics of the time varying channel can also be specified.

Channel equalization

In a MIMO system one of the most critical difficulties is not only to separate the signals, but also concurrently equalize the MIMO channel so as to achieve the high quality communication. Blind MIMO channel identification & equalization method is being used on multiple access signal detection, as any information on MIMO channels is not required & retrieves all the inputs simultaneously. Current procedures for equalizing the channels do not select the channel but directly design an equalizer for the channel.

The parameters like convergence rate, bit error rate, residual ISI and symbol rate are used to rate the efficiency of the equalizer. Convergence rate is considered to be most important among other performance measures as it is connected to the amount of time taken for the process to be initialized. SER gives information about the performance of the equalizer. Therefore, adaptive equalizer should give the best possible convergence-time with minimum possible SER[6].

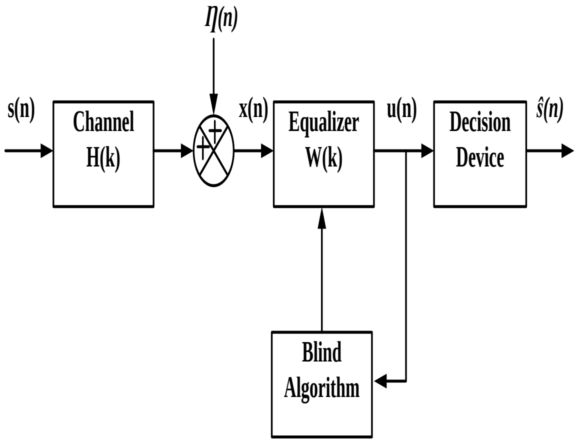

Figure 1. Block Diagram of Blind Equalization

One of the main considerations when implementing the equalizer is the complexity of blind adaptation algorithm. There are many different algorithms for updating the values of equalizer. CMA is one of those algorithms that could achieve desired convergence requirements. Multi-modulus algorithm (MMA) was proposed to improve the performance of CMA. Though MMA provides better convergence for higher MIMO constellation compared to CMA, it suffers from high mis-adjustment in the steady state. Hence SMMA algorithm is used [7-8].

Impulse response of the channel is estimated using various channel estimation algorithms. It describes the behavior of the channel. To eliminate ISI, channel estimates are used in adaptive channel equalizers. Channel estimates are used in Maximum likelihood detectors to decrease mean squared error. The channel impulse response H is estimated in the presence of noise & model mismatch, by observing the channel output X(n). Reducing mean square error (MSE) with minimum computation is the objective of channel estimation algorithms. Using the channel estimation techniques coherent demodulation can be formulated which requires information about phase of the signal.

Without using training sequence, equalizing a communication channel is blind equalization. This ensures efficient use of bandwidth. The main aim of blind equalization algorithm is to match the equalizer response to the inverse impulse response of the communication channel. There are many different algorithms to update the tap values. Among all methods, the most commonly used algorithm is the constant modulus algorithm (CMA).

After acknowledging the model, as the channel changes continuous updation of the parameter is done to minimize the error.ISI can be eliminated by channel equalization. To calculate and modify equalizer coefficients adaptive algorithms are used when a channel is unknown & time-varying. The equalizer coefficients are to match the impulse response of the communication channel. This is the main objective of blind equalization.

MMA

Considering the MIMO system with NT antennas, the relation between the transmitted and received signal is expressed as

$$x(n) = \sum_{i=0}^{N-1} h(i)s(n-i) + \eta(n) \quad (5)$$

Where h(i) denotes baseband impulse, N is the length of the equalizer tap weights, x(n) is complex received signal, s(n) is source signal and η(i) is additive white Gaussian noise. The equalizer complex tap weight-vector & input-vector are respectively described as W(n)=[w0(n), w1(n), w2(n)….. wL-1(n)]T , X(n)=[x0(n),x1(n), x2(n)….. xL-1(n)]T where T represents transpose of vector. The output of the equalizer α(n)=W(n)T X(n). Outcome of the decision device is given by s̃(n) which is computed as the closest constellation symbol to α(n). The main purpose is to achieve an estimate of the actual transmitted signal s(n) without employing training signal, such that s̃(n)= s(n-Δ) [8]. Here the equalizer perfectly evaluates the symbol that was transmitted Δ baud times earlier.

Multi-modulus algorithm is a popular algorithm in the field of blind equalization as it permits both joint blind equalization and carrier phase recovery. In this adaptive phase rotator is not needed to carry out separate constellation phase recovery. The dispersion of real part uR and imaginary part uI, of u(n) are penalized separately in MMA. Unlike CMA the cross term uR uI between the in-phase and quadrature components are ignored in MMA. Hence, the cost function is not a two-dimensional but it is pseudo two-dimensional as it contains only uR(n) and uI(n). The cost function of MMA is as follows

$$J = E\left[\left(u_R^2(n) - \gamma_R\right)^2 + \left(u_I^2(n) - \gamma_I\right)^2\right] \quad (6)$$

here $E[\cdot]$ represents the statistical expectation. uR(n), uI(n) are real and imaginary parts of u(n) respectively. γ_R is the dispersion constant for real parts and γ_I is the dispersion constant for imaginary parts of the transmitted signal, which is given by

$$\gamma_R = \frac{E\left[s_R^4(n)\right]}{E\left[s_R^2(n)\right]} \quad (7)$$

$$\gamma_I = \frac{E\left[s_I^4(n)\right]}{E\left[s_I^2(n)\right]} \quad (8)$$

here sR(n) & sI(n) are real and imaginary parts of the transmitted signal s(n), respectively.

The MMA tap updation can be done as

$$W(n+1) = W(n) + \mu \cdot e_{MMA}(n) \cdot X^*(n) \quad (9)$$

The error function eMMA(n) is as follows

$$e_{MMA}(n) = u_R(n)\left(\gamma_R - u_R^2(n)\right) + j \cdot u_I(n)\left(\gamma_I - u_I^2(n)\right) \quad (10)$$

The cost function of MMA is not truly two-dimensional. It can be taken as the sum of two one-dimensional cost functions, that reduce dispersion of uR & uI around second contours. Hence MMA takes advantage of the symbol statistics of few signal constellations, like non-square and very dense constellations [9-11].

Though CMA provides accurate convergence and helps in reducing ISI to a considerable low level. It suffers from phase error when the signal constellations become very large. Hence, the complexity increases with the receiver. MMA also has some difficulties with very dense constellations. Therefore,S-MMA has been used to better the performance of MMA by reducing the mismatch values. Since the algorithm is devised by embedding the sliced symbols in the dispersion constants, it is known as sliced multi-modulus algorithm (S-MMA).

PROPOSED SMMA

Sliced multi-modulus algorithm (S-MMA) has been proposed for application to MIMO systems. In the S-MMA, the dispersion constant & the slicer output are embedded in the cost function. A number of desirable features like multiple-modulus, symmetry & uniformity are taken care of by the cost function. The S-MMA cost function shows a much lower mis-adjustment when compared to other adaptive algorithms.

The S-MMA cost function is given by

$$J_{S-MMA} = E\left[\left(u_R^2(n) - \left|\hat{a}_R(n)\right|^c \gamma_R\right)^2 + \left(u_I^2(n) - \left|\hat{a}_I(n)\right|^c \gamma_I\right)^2\right] \quad (11)$$

The corresponding S-MMA tap updation algorithm is

$$W(n+1) = W(n) + \mu \cdot e_{MMA}(n) \cdot X^*(n) \quad (12)$$

Where μ a step-size parameter and asterisk is represents complex conjunction. The error eMMA(n) function is given by

$$e_{MMA}(n) = u_R(n)\left(\left|\hat{s}_R(n)\right|^c \gamma_R - u_R^2(n)\right) + j \cdot u_I(n)\left(\left|\hat{s}_I(n)\right|^c \gamma_I - u_I^2(n)\right) \quad (13)$$

Where c represents a positive constant (c ≤ 1). Here we can observe that S-MMA update is very similar to the MMA. When c=0, the S-MMA reduces to MMA. Since we use equalizer and the slicer output, the S-MMA forces uR(n) and uI(n) to lie on the point contours. The value of this point contours is given by sign $[u_R(n)]\sqrt{\left|\hat{s}_R(n)\right|^c \gamma_R}$ and sign $[u_I(n)]\sqrt{\left|\hat{s}_I(n)\right|^c \gamma_I}$. The S-MMA yields faster convergence and offers the potential of multiple tap equalizer implementations [12-14].

SIMULATION RESULTS

Results show detailed analysis of the MIMO system with S-MMA algorithm. It makes use of Bit Error Rate (BER) curves to prove the validity and study the system in a detailed manner. Simulations are done for Multi-modulus algorithm (MMA) and Sliced multi-modulus algorithm (S-MMA) for different cases.

The Bit Error occurs when the bits that are received over a channel differs from the bits that are transmitted. This occurs because of alteration of the signal which may occur due to the interference of unwanted signals, noise effects, distortions or bit synchronization errors, multipath fading, attenuation. The bit error rate or bit error ratio (BER) is the ratio of bit errors to the total transferred bits during the specified time interval. BER is performance measure used for evaluating the performance or the functionality of various methods & systems. BER Vs. Eb/N0 graphs from which, the performance of the system can be inferred. Eb/N0 is the energy per bit Eb to noise power spectral density (N0) ratio of the received signal. Eb/N0 is basically a normalized signal-to-noise ratio (SNR) measure of the signal. The system considered Rayleigh noise channel for BER comparison. Rayleigh fading model agrees that magnitude of a signal that passes through channel will vary randomly or fade, based on Rayleigh distribution.

In this section, the length of the user input data N has been varied, in order to assess the performance of the system. The Rayleigh channel has been considered and in all cases, BER curves for both the MMA and S-MMA have been plotted.

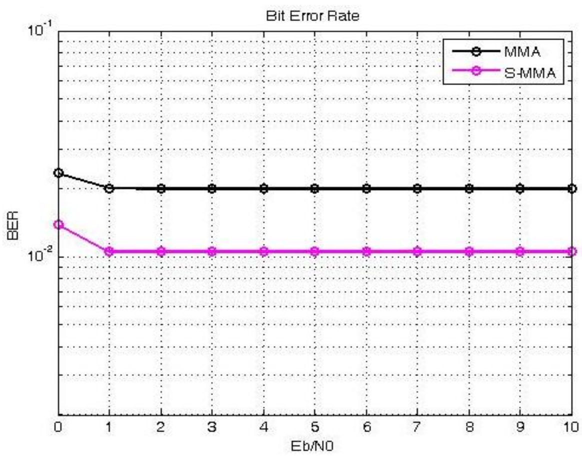

Figure 2. Bit Error Rate Vs Eb/N_0 Rayleigh channel for MC=100

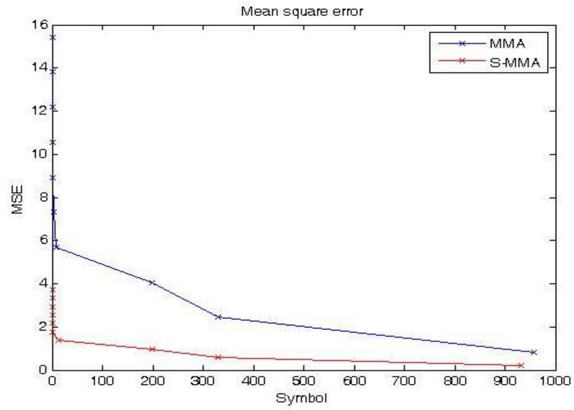

Figure 3. MSE Vs Symbol for Rayleigh channel for MC=1000

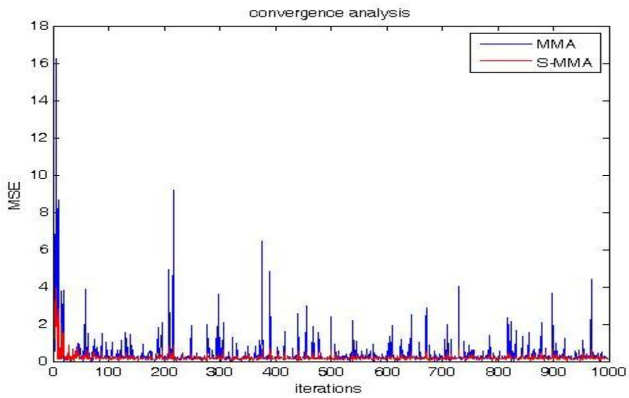

Figure 4. Convergence analysis for MC=1000

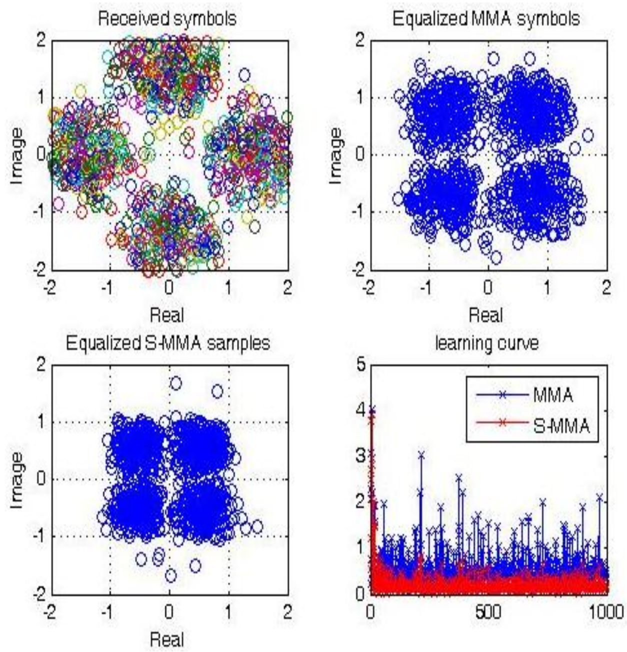

Figure 5. Learning curve for MC=1000

Inferences form the BER graphs from Fig.2 to Fig.5 (varying length of input user signal):

- Fig.2. represents BER curves for Rayleigh channel when user input is at 1000. The signal is varied between 1dB to 40 dB.
- Fig.3. demonstrates MSE curves for Rayleigh channel when user input is at 1000. The signal is varied between 1dB to 40 dB.
- Fig.4. represents the convergence analysis of Rayleigh channel. It can be clearly observed that SMMA outscores over MMA.
- Fig.5. gives the constellation diagrams of transmitted, received and equalized symbols of MMA and SMMA algorithms.

MIMO system using S-MMA performs better in terms of ISI and Symbol Error Rate (SER). This algorithm also exhibits lesser steady state maladjustment compared to MMA.

The problem with higher constellations is that MMA algorithm cannot remove the jitter properly. By decreasing the step size jitter can be reduced. If the step size is decreased beyond a limit it takes longer to converge. Hence instead of decreasing the step size, cost function of MMA is modified to obtain Sliced MMA. In this paper it is proposed to use Sliced MMA algorithm to equalize MIMO system. The performance of this algorithm when applied to a MIMO system is compared with MMA algorithm using different performance metrics like BER, SER and convergence rate.

CONCLUSION

In this paper blind equalization of MIMO system is performed. Sliced MMA cost function consists of equalized and sliced symbols. In the proposed technique the sliced symbols have been incorporated in the multi-modulus type weight adaptation procedure. To compare existing and proposed technique the steady-state mis-adjustment analysis was carried out. The outcomes of the analysis and simulations show the benefit of using the proposed method over the traditional multi modulus method. The experiment based on simulation showed that the S-MMA shows a better performance when compared to MMA giving a better BER, without compromising the convergence rate.

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