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Loop Feedback Maximization for Channel Estimation in MIMO Communication

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Abstract

Background: Signal estimation and its performance have always remained a challenge for wireless communication society. To achieve noise immunity, the conventional recursive least squares estimation needs information of the noise measurements of the filtered process. A new estimation approach has been proposed that does not take knowledge of the noise statistics. **Statistical Methods:** A new min-max channel estimation approach based on state stabilization is proposed to achieve the objective of noise mitigation and higher performance in MIMO systems, using time variant interference modelling. The approach proposed has been simulated using the MATLAB environment with random input data. **Findings:** The performance of the Bit Error Rate (BER) over the specific range of Signal to Noise ratio for the existing Recursive Least Squares estimation and proposed a Min-Max estimation approach of different noise densities and fading factors. **Conclusion:** The results obtained indicate that the bit error rate of Recursive Least Squares estimation is more when compared with the Min-Max approach. Therefore, it is concluded that the proposed Min-Max estimation approach is more efficient when compared with the Recursive Least Squares estimation.

Keywords: Channel Estimation, Coding Performance, MIMO System, Recursive Filter Stabilization

1. Introduction

In high data rate wireless communication systems, impairments due to wireless channel like amplitude variations, Doppler effect and time dispersion, continuously degrade the signal transmission. The uncertainties in channel conditions degrade the estimation performance of conventional channel estimation techniques. Several schemes were suggested in the past for the enhancement of signal estimation efficiency. However, with the increase in communication approaches and offered services, the conventional models of feedback filtration are needed to be improved. To derive better performance

for such system, different methods were developed in the recent past. A frequency and time selective fading channel estimation is suggested and the issue of channel imperfection is analysed. A novel method of pilot expansion is proposed to capture the multipath signal a rise in the MIMO system. A flexible decision feedback filter is proposed for channel tracking in the communication system. A combined estimation technique of channel gain and phase noise in MIMO system is analysed. An extended decision directed feedback filtering approach for phase noise tracking is developed. The approach of the extended feedback filter is observed to be more stable in tracking phase noise estimation. A similar approach of channel estimation by using a

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min-max concept in semi-blind approach is proposed³. A recursive estimation updating in feedback based estimation logic using blocks for a MIMO system is employed. A dynamic block processing expansion model is presented to channel estimation for fast fading channel. The issue of diversity in a MIMO-OFDM system is being analysed in recent time. To achieve a faster divergence solution, a channel estimation algorithm based on feedback filter is developed4. A novel approach of estimating the channel, for high mobility MIMO-OFDM system is investigated 5.6. To execute the channel estimation for the signal received under mobility condition, a feedback filter was designed. The efficiency of a channel estimation approach rests on estimating the Channel Impulse Response (CIR) in a MIMO OFDM system. Based on the correlation of transmitter and receiver antennas a CIR estimation is investigated⁷. A channel estimation technique based on basis expansion model combined with Wiener filter that mitigates the inter carrier interference was outlined8. An Eigen value based estimation technique was analysed; but it takes a vast previous data of stochastic information and requires great computing complexity². The issue of pilot contamination was addressed by using a correlated pilot sequence based on coordinated channel estimation approach 10. Simplified approximation algorithms of first and second order for combined CFO and CIR estimated in OFDM systems were investigated11. A practical estimation approach that gives long-term characteristics by detecting invariant space time modes of the dynamically varying channel was investigated12. A unit vector based semi blind approach was developed for channel estimation and time synchronization¹³. A discrete evolutionary transform based time-variance estimation of channels was presented for high mobility MIMO OFDM communication systems¹⁴. A QR decomposition algorithm with recursive least squares approach for combined detection and channel estimation of MIMO-OFDM system was proposed¹⁵. An OFDM channel model for estimating and synchronizing the channel using a GNU radio was proposed. But this approach shows that the BER performance is less¹⁶. An ordered successive interference cancellation (OSIC) scheme was established for attaining high throughput17. An OFDM system based on weighted DHT method that decreases the bit error rate of the signal was proposed18. To achieve a better estimation, a min-max approach for channel estimation is proposed. In section 4, the proposed method of min-max approach for estimation is defined. Section 5 outlines the simulation results obtained

2. Recursive Filtration

A recursive filter utilizes a feedback control loop to estimate the signal status at a specified time instant and gets feedback as corrupted data. Projection of forward present state and estimates of error covariance to find the derivable estimates for the coming step will be completed by a set of time update equations. Another set of the measurement update equations are responsible for the feedback. The Figure 1 shows the final estimation technique that looks like a predictor-corrector algorithm.

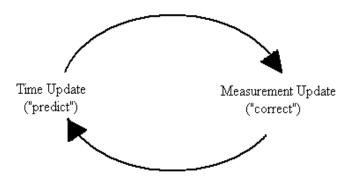


Figure 1. The recursive filtration state transition.

The recursive filters are used for noise mitigation in linear systems. It predicts the present state of the signal by using the knowledge of initial conditions of the system variables. All the random vectors observed from a subset are taken at once to estimate a random vector \mathbf{Y} and then update the estimator with newly observed random vectors. This estimation process is completed recursively with observed random vectors X_0, X_1, X_2, \dots A primary estimation will be done for the random vector Y by using X_{\bullet} ; this primary estimating process is catered in combination with X_1 to get the optimum prediction established on X_0 and X_1 . Such a process is employed recursively to attain linear predictions for Y based on $X_0, X_1, X_1, ...$ for $j = 1, 2, \dots, \infty$. The RLS estimator linearly transforms the measurement Z to obtain the solution X. A result recognized from the first (k + 1) quantities were represented as a linear transform of the result built on k measurements and an updated term as per (k+1)thstatistics only.

3. Recursive Filter Estimation

The Recursive filter predicts the status x of a discretetime controlled process governed by the linear difference equation

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1} \tag{1}$$

with a measurement Z that is

$$z_k = Hx_k + v_k \tag{2}$$

As shown in the Figure 2, equations (1) and (2) can be represented pictorially. The letter T in the feedback block indicates time delay.

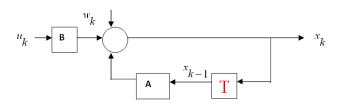


Figure 2. The state space equation of a recursive filter.

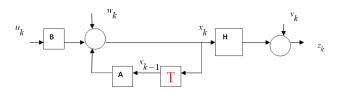


Figure 3. The measurement equation of a recursive filter.

The term W_k indicates the process noise and Q is its covariance matrix. The term v_k denotes the measurement noise and R is its covariance matrix. In the absence of noise an $n \times m$ matrix A in the difference equation denote the relation between k th and (k-1)th states. An $n \times l$ matrix B relates the input applied to the system u to the state x. An $m \times n$ matrix H in the measurement equation relates the state to the measurement Z_k . The Recursive filter takes up that the noise properties are known. If the system is unknown, the recursive filter fails to predict the effect. The recursive filter is preferred for minimizing the mean prediction inaccuracy. It does not work for minimizing the worst-case estimation error. A min-max estimation approach giving open range estimation is proposed to solve these issues.

4. Proposed Min-max Estimator

With the aforementioned restrictions, a novel estimation algorithm based on min-max approach is investigated. The proposed approach of min-max filtering minimizes the "worst-case" prediction error. Min max estimation approach does not necessitate the information of the noise statistics. The recursively estimated states * of a linear system that is ruled by the equation (1) are given as,

$$x_{k+1} = Ax_k + Bu_k + W_k$$

$$y_k = C_{x_k} + z_k$$
(3)

where, x – the state of the system

u – input applied to the system

y – output obtained from the system

k – time variable

W, Z – noise statistics

A, B, C – known matrices

Since the time index k of the aforementioned system is well-defined only at discrete values (0,1,2,....) the two equations represent a discrete time system. The state χ of the above system cannot be measured directly; but only y could be measured directly. By using a recursive filter to estimate the state referring estimate as x filter equations are represented as:

$$K_k = AP_k C^T \left(CP_k C^T + S_z \right)^1 \tag{4}$$

$$\hat{x}_{k+1} = \left(\hat{Ax_k} + Bu_k\right) + K_k \left(y_{k+1} \hat{Cx_k}\right) \tag{5}$$

$$P_{k+1} = AP_{k}A^{T} + S_{w} AP_{k}C^{T}S_{z}^{1}CP_{k}A^{T}$$
 (6)

where.

 S_w – covariance matrix of W

 S_z – covariance matrix of z

k - recursive gain

P – estimation error variance

When the expectation value of covariance matrices w and z at each time instant is equal to zero, the recursive estimation approach works acceptably. To obtain the standard deviation of the noise as design parameters the recursive filtration process employs the covariance matrices S_w and S_z . For the min-max estimation logic, a vector norm is given by,

$$||x|| = \sqrt{x^T x} \tag{7}$$

This is also defined as,

$$\|x\|^2 = x^T x \tag{8}$$

A weighted vector norm is defined as,

$$\left\| x \right\|_{Q}^{2} = x^{T} Q x \tag{9}$$

where, Q is any diagonal matrix with attuned dimensions. The diagonal matrix Q aids to weight the elements of x when the norm is calculated. In general, Q could be a non-diagonal matrix, assuming that Q is diagonal and the estimate try to resolve the following problem as,

$$\min_{\hat{x}} \max_{w,v} J \tag{10}$$

where, J is the cost function that defines the estimation performance. The noise terms w and v are the worst possible values that try to worsen the estimation. The min-max filter tries to solve the problem of obtaining an estimated state that minimizes the worst probable consequence that w and v have on estimation error. The min-max filter attempts to minimize the maximum estimation error by employing the cost function J that is defined as:

$$J = \frac{ave \left\| x_k - \hat{x}_k \right\|_{\mathcal{Q}}}{ave \left\| w_k \right\|_{\mathcal{W}} + ave \left\| v_k \right\|_{\mathcal{V}}}$$

$$\tag{11}$$

where, the averages are taken over all time samples k. The term \hat{x} has to be found that is as close to x as possible.

5. Simulation Results

A MIMO model coding using an OFDM communication is used. The developed approach of Min-Max modelling is used for estimation and compared with the conventional RLS based recursive estimation logic.

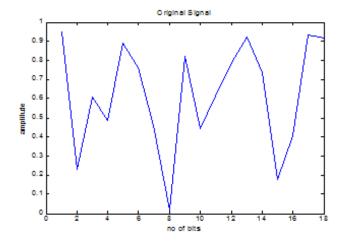


Figure 4. The original message signal.

Figure 4 indicates the plot between the number of bits and amplitude which give the original signal. The basic theme of this work is some desired random signal is generated and that signal has to be modified and modulated at the transmitter part. Then that signal is sent through a channel and received at the receiver. The signal may be corrupted during transmission through the channel. How the signal affects in the channel and how it is rectified is shown in the following figures.

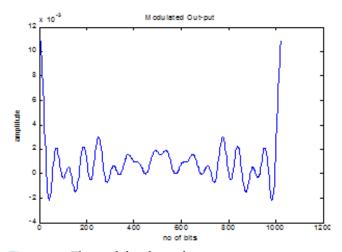


Figure 5. The modulated signal output.

After the original random signal is generated the signal has to be modulated and sent through the channel. The above graph gives the modulated output. It is a graph between the number of bits transmitted and the amplitude of the corresponding part. This modulated signal, then passes through the channel.

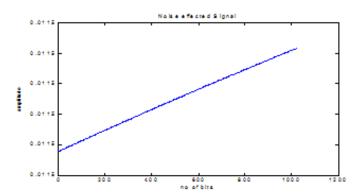


Figure 6. The noise effected signal.

The Figure 6 indicates the noise affected signal. When the modulated signal enters into channel there is a chance of signal distortion due to some channel effects and interference noises. This is a plot between the amplitude and number of bits.

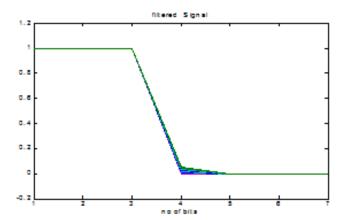


Figure 7. The filter output signal.

In order to filter the noise affected signal the signal is passed through a linear filter and a channel estimation block. The filtered signal has to be estimated in the channel estimation block by using normalized constant modulus algorithm. Since the constant modulus algorithm has more number of cost functions the work has moved to normalized RLS to minimize the number of cost functions.

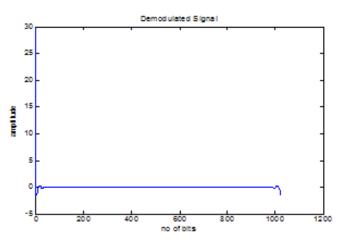


Figure 8. Demodulated signal output.

The Figure 8 gives the plot between number of bits transmitted and corresponding amplitude. The filtered signal is estimated in the channel estimation block by using normalized constant modulus algorithm. The signal is demodulated and the original random signal is got back. By this it is concluded that without any training sequence the original signal is estimated by using the proposed Min-Max estimation approach.

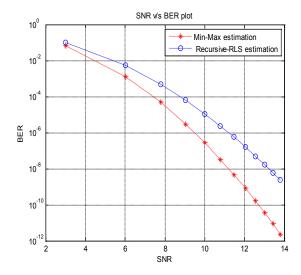


Figure 9. The comparison plot for RLS and Min-Max technique

Figure 9 gives the clear picture of SNR Versus BER of both the methods of RLS and Min-Max estimation. This is evidently indicates that the bit error rate of Min-Max approach is less compared to Recursive Least Squares estimation.

pp 11 -	ON TID /	DID	
Table 1.	SNR v/s	SBER	comparison.

SNR (dB)	BER (RLS)	BER (Min-Max)
3	3.6742e-011	1.6969e-008
6	1.6468e-010	5.0291e-008
7	8.2895e-010	1.6224e-007
8	4.7935e-009	5.7924e-007
9	3.2819e-008	2.3407e-006
10	2.7741e-007	1.1045e-005
11	3.0752e-006	6.3686e-005
12	4.8964e-005	0.00048099
13	0.0012887	0.0053197
14	0.065899	0.10077

A similar test is carried out for a simulation parameter of the noise density of 14 dB, and the fading factor of 15 KHz, is simulated. The observed result is shown in Figure 10.

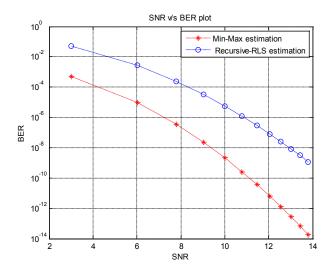


Figure 10. Simulation result of the developed approach under the noise density of 14dB and the fading factor of 15 KHz.

6. Conclusion

The error performance is observed to be minimized under the different channel conditions using the conventional recursive least squares and proposed min-max estimation approach in a MIMO-OFDM environment. The bit error rate measured for various values of signal to noise ratio indicates that the proposed Min-Max estimation approach works well when compared with the Recursive Least Squares estimation. The overall performance was proved to be optimal under channel diversity condition. The error performance validates the usage of proposed min-max approach as compared to conventional recursive filtration.

7. References

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