

SSRLS based Enhanced Impulsive Noise OFDM Suppressor in AWGN Channel

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Abstract

Orthogonal Frequency division multiplexing is a popular method for high data rate applications and is corrupted by impulsive noise. Methods must be investigated to mitigate this noise. In this paper, a State Space Recursive Least Square (SSRLS) algorithm based adaptive impulsive noise suppressor ofdm communication is proposed. It gives the better tracking due to its state space model-dependent recursive parameters. The proposed method came out to be very effective in noise cancellation of OFDM signal without requiring reference noise source. The fastest convergence and better tracking characteristics of proposed scheme demonstrated by the simulation results in mean square error (MSE) sense proved to be the effective solution for the impulsive noise cancellation in OFDM signal.

Keywords: Impulsive Noise, OFDM, cyclic prefix, NLMS, RLS, SSRLS, MSE

Introduction

Orthogonal Frequency Division Multiplexing (OFDM), with their ability to mitigate the effects of multipath, makes them most suitable for the transmission over high data rate in wireless communications [Ghorpade et al (2013); Krishnamoorthy et al (2013)]. Therefore numeric wireless standards of audio/video broadcasting fourth generation mobile systems particularly WIMAX and LTE have been used in OFDM systems over the past decade [Zhou and Xie (2007)]. Orthogonal Frequency division multiplexing is suspected to have impulsive noise, which completely destroys the information. Practically, impulsive noise is a non-Gaussian noise generated by human activities and has more catastrophic effects in communication systems [Torio (2011)]. Nowadays active area of research is to inspect the impulsive noise behavior and suggest solutions to improve the performance of systems by suppressing it. For noise cancellation, various techniques are reported in literature which attempt to recover the original transmitted signal by [Jimaa et al (2012); Araj (2011)].

[Mathew and Murukan (2014)] carried out the comparative bit error rate analysis of adaptive notch and Least Mean Square algorithm to suppress the Periodic impulsive noise from OFDM based power line communication systems. An adaptive receiver technique based on NLMS, RLS, VSNLMS filters are used to remove impulsive noise from the MIMO-OFDM system by [Hakam et al, (2012)]. An impulsive noise canceller of sinusoidal and ECG signal based on SSRLS filter in time domain has been proposed by [Mirza et al (2015)]. In addition comparison of SSRLS with RLS and NLMS adaptive algorithm was carried out. Motivated by the results obtained by [Mirza et al (2015)] an impulsive noise suppressor for OFDM system is designed and implemented in this paper.

This paper is organized as: Section II briefly explain the basic mechanism of OFDM, Section III gives the review of different adaptive filters which is followed by comparative analysis supported with the simulation results in section-IV. In the end, section V then concludes the paper and is then followed by the references.

OFDM

Orthogonal Frequency Division Multiplexing is a multicarrier modulation in which transmission over a dispersive channel is carried out. In OFDM the high data rate streams are splitted into low data rate streams in parallel and modulated separately on different orthogonal sub-carriers. The introduction of pilot insertion and cyclic redundancy at the transmitter reduces the complexity to only Fast Fourier Transform FFT processing on the receiver side.

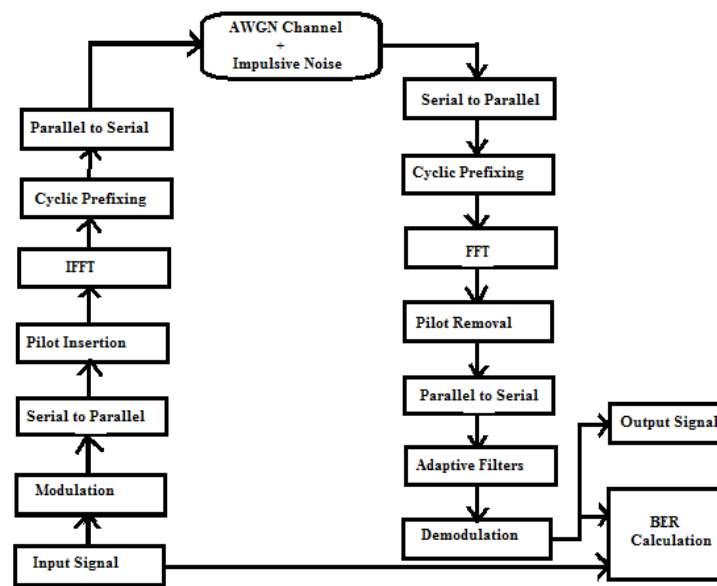


Figure 1. Block Diagram of OFDM system

These subcarriers are multiplexed and passed through the channel, which is responsible for adding impulsive noise and white Gaussian noise in the transmitted OFDM signal. At the receiver side, the signal is demodulated and passed through the adaptive filter block for impulsive noise reduction in the OFDM signal. The parameters used in simulating the OFDM system are tabularized below.

Table 1: Parameter set for simulation of OFDM system

Parameters	Values
Modulation technique	QPSK
Number of subcarriers	52
Size of cyclic prefix	16
FFT-length	64
Number of bits generated	52000

Adaptive Algorithms

There are many adaptive algorithms used for noise removal. The brief summaries of adaptive algorithms which are used in this research are as follow.

RLS Algorithm

The Gauss Recursive least squares (RLS) adaptive filter is the one in which autocorrelation matrix estimation is used to de-correlate the current input data. It recursively finds the filter coefficients that is then used to minimize a weighted linear least squares cost function relating to the deterministic input signals. Also, The RLS exhibits extremely fast convergence over all variants of LMS but with a cost of high computational complexity. The filter weights w are updated in RLS algorithm by following equations.

$$w(n+1) = w(n) + k(n)x(n) \quad (1)$$

$$k(n) = \frac{\lambda^{-1}\Phi^{-1}(n-1)x(n)}{1 + \lambda^{-1}x^T(n)\Phi^{-1}(n-1)x(n)} \quad (2)$$

$$\Phi^{-1}(n) = \lambda^{-1}\Phi^{-1}(n-1) - \lambda^{-1}k(n)x^T(n)\Phi^{-1}(n-1) \quad (3)$$

Where λ is the forgetting factor. Φ^{-1} is the cross correlation matrix. The λ is initialized with 1 and Φ^{-1} with $\delta^{-1}I$. I is the identity matrix.

SSRLS Algorithm

State Space Recursive Least Squares or SSRLS algorithm is state space representation of an extension of RLS algorithm. It is used to remove noise and its performance can be evaluated in a non-stationary environment(impulsive noise). The steps of SSRLS form II filter along with sinusoidal model for implementation are given by [Malik (2004)].

$$\hat{x}[n] = \hat{x}[n] + K[n]\varepsilon[n] \quad (4)$$

$$\hat{x}[n] = A\hat{x}[n-1] \quad (5)$$

$$\varepsilon[n] = y[n] - \bar{y}[n] \quad (6)$$

$$\bar{y}[n] = Cx[n] \quad (7)$$

$$\Phi[n] = \lambda(A^{-T}\Phi[n-1])A^{-1} + C^TC \quad (8)$$

$$K[n] = \Phi^{-1}(n)C^T \quad (9)$$

Where $\hat{x}[n]$ is the input state, $\varepsilon[n]$ is the prediction error, $K(n)$ is observer gain, n is predicted input state, $\hat{n}$ is estimated state, $\bar{y}[n]$ is the predicted output state and $\Phi[n]$ is the correlation matrix.

NLMS Algorithm

The variant of Least Mean Square (LMS) algorithm is Normalized Least Mean Square which gives faster convergence than LMS. The limitation of the LMS algorithm is its sensitivity to its input signal scaling. The convergence is very slow and step size should be chosen carefully to guarantee algorithm stability. The whole algorithm remains same only filter tap weights are updated by following recursive formula:

$$w(n+1) = w(n) + \frac{\mu e(n)x(n)}{\epsilon + \|x(n)\|^2} \quad (10)$$

Where ϵ a small number is added for algorithm stability, μ is the step size of filter and $e(n)$ is error signal.

Simulation Results

In this section, we compare the performance of the different adaptive filters in impulsive noise cancellation of OFDM signal by computer simulation using MATLAB version 12.

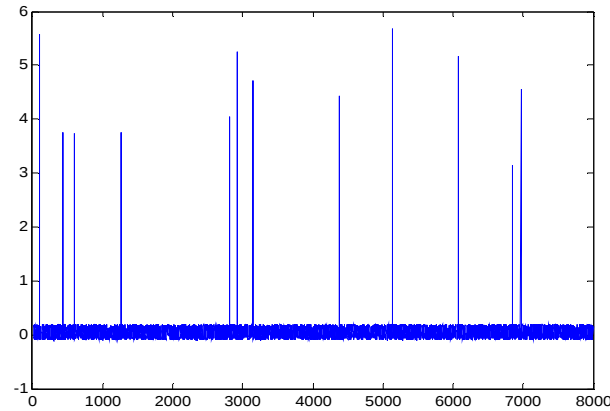


Figure 2. Impulsive Noise Signal

Table 2. Parameter set for simulation of Impulsive Noise

Parameters	Symbol	Value
Sampling Frequency	F	10
Total time	T	100
Average Time between samples	β	1s
Mean of log amplitude	A	10dB
Standard deviation of log amplitude	B	5dB
Mean of Additive Gaussian Noise	m	0.1
Standard deviation of Gaussian Noise	σ	0.4

The generated binary data is passed through the channel responsible for adding impulsive noise and white Gaussian noise are depicted in Fig. 3.

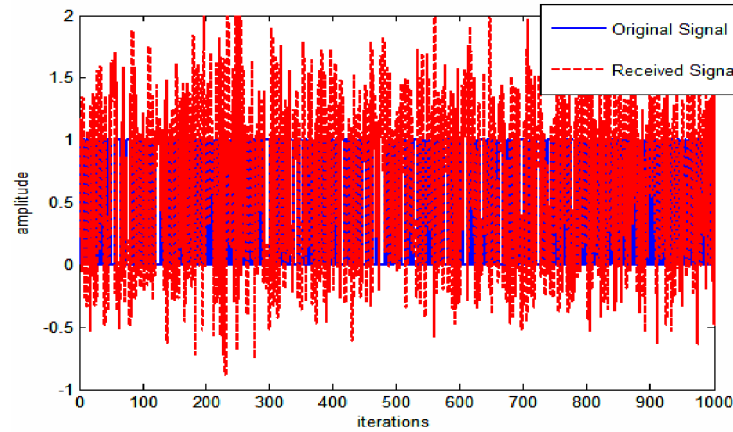


Figure 3. Original and received signal

The system output error signal should contain the original signal in an optimum sense. The length of all the three adaptive filters is fixed to 10. The step size parameter for NLMS Algorithm is chosen to be equal to 0.005 and forgetting factor for RLS is 1 and for SSRLS is 0.99. The error signals obtained by above mentioned adaptive filters are compared with one another in Fig. 4-6.

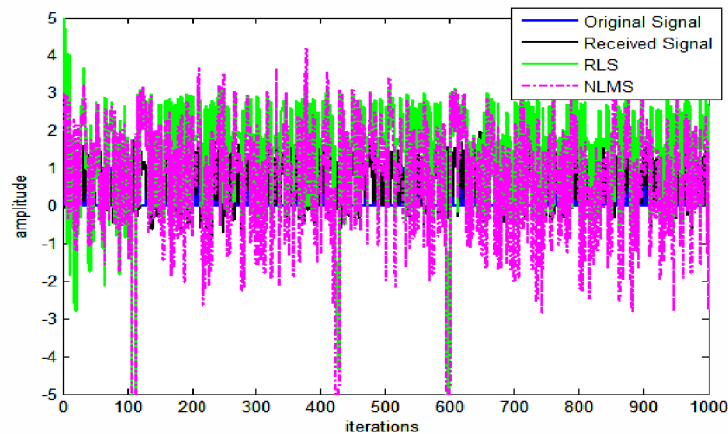


Figure 4. Comparison of original data, received data and recovered data using NLMS and RLS Filters

Fig.4 represents that the largest peaks of impulsive noise from the noisy binary signal are not properly removed by the RLS and NLMS algorithm. The RLS filter is removing impulsive noise better than NLMS. The error plots of above mentioned algorithms are also compared with the original signal and received signal.

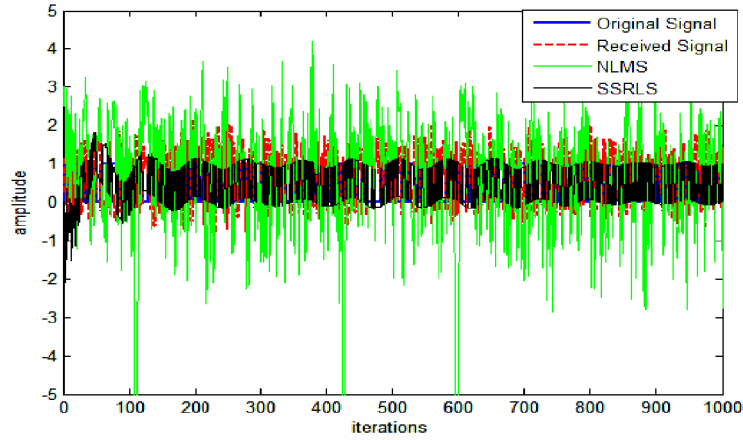


Figure 5. Comparison of original data, received data and recovered data using NLMS and SSRLS Filters

The results of Fig. 5 illustrate that superior performance of SSRLS in suppressing impulsive noise from the noisy OFDM signal as compared to the NLMS adaptive algorithm. The error plots of above mentioned algorithms are also compared with the original signal and received signal.

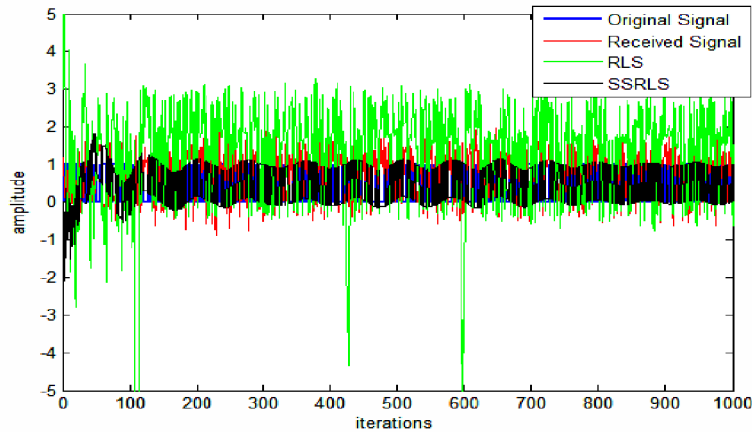


Figure 6. Comparison of original data, received data and recovered data using RLS and SSRLS Filters

Similarly the comparison of SSRLS and RLS filter error plots while cancelling impulsive noise from the OFDM signal are shown in Fig.6. It is clear from the above Figures that the SSRLS exhibit better performance in cancelling the largest peaks of impulsive noise from the OFDM signal, while other two investigated algorithms fail to remove the noise with large amplitudes.

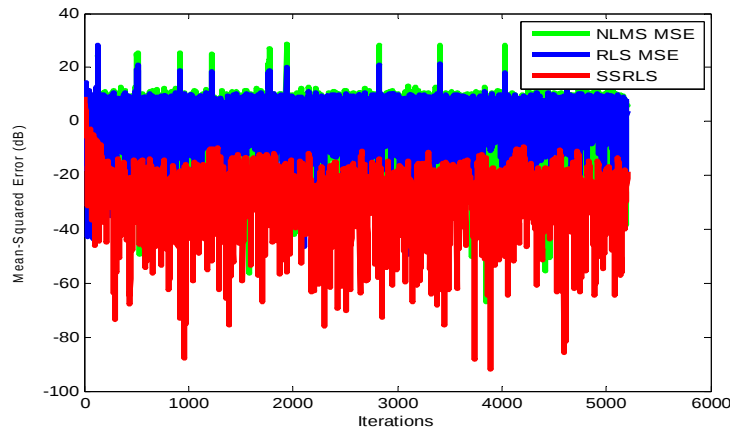


Figure 7. Comparison of MSE (dB) of adaptive filters

The mean square error in terms of decibel simulation results also confirms that SSRLS give lowest MSE and fastest convergence while cancelling impulsive noise as depicted in Fig. 7. The conclusion drawn from Fig. 4-7 is that SSRLS filter outperforms both NLMS filter and RLS in Impulsive noise cancellation of OFDM signal.

Conclusion

In this paper, an adaptive impulsive noise suppressor for OFDM system has been proposed that is based on state space recursive least square (SSRLS) algorithm. Due to the state space dependent model, the proposed technique exhibit better impulsive noise cancellation in OFDM signal when compared to normalized Least Square (NLMS) and Recursive Least Square (RLS). The simulation results obtained by proposed enhanced impulsive noise suppressor guarantees the superior performance of SSRLS in terms of convergence speed and lowest MSE.

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