Reduction of Impulsive Noise in OFDM Systems Using a Hybrid Method

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***Abstract*—Impulsive noise is one of the commonly affecting noise in Orthogonal Frequency Division Multiplexing (OFDM) systems. Methods have been implemented for the reduction of this noise in literature previously. Also, in communication systems, hybrid methods have been implemented for impulsive noise removal. In this paper, an adaptive filter based technique comprised of Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS) algorithms along with clipping method is implemented as a solution for impulsive noise cancellation in OFDM system. The scheme is tested on random binary data modulated over different types of constellation schemes. The impulsive noise cancellation in OFDM system was appreciable using the hybrid technique after demodulation at the receiver for different modulation schemes namely 8-PSK, 16 QAM and 32 QAM. The convergence characteristics are demonstrated by the simulation results comparing their Bit Error Rates (BER) under same parameters which shows the effectiveness of the implemented hybrid method in OFDM.**

***Index Terms*—impulsive noise, OFDM, clipping, adaptive filter, BER**

I. Introduction

Orthogonal Frequency Division Multiplexing is a variant of signal modulation that splits the modulated high data rate stream into many slow modulated narrowband close-spaced subcarriers and is less sensitive to frequency selective fading. Therefore OFDM has attracted much attention in past decades and is successfully implemented in the cellular communication standards like LTE/LTE-A and WiMAX. Digital Audio/Video broadcasting standards have also adopted OFDM making it suitable for high data throughput [1].

OFDM is normally corrupted by the impulsive noise, which is non-Gaussian in nature and has disastrous effects in OFDM transmission [2]. The performance of OFDM system is degraded by the multiple impulsive noise existence in received OFDM signal because of its wide frequency component. Researchers are inspecting solutions for mitigating this type of noise, and therefore improving systems performance in terms of mean square error and bit error rate.

Methods have been proposed to generate impulsive noise such as in [3], [4]. For noise cancellation, clipping technique is implemented in literature which clips the received signal above a threshold [5].

In [6] the performance comparison of the adaptive filter algorithms such as the least mean square (LMS), Normalized LMS (NLMS) and Recursive least squares (RLS) were carried out to remove the noise from an audio signal. Adaptive filters have been used to remove impulsive noise along with comparison with its variants [7]. Impulsive noise has been removed using NLMS filter over different modulation schemes in [8] on the basis of step size and likelihood probabilities. A comparison of clipping method is held with adaptive filters in [9] for the removal of impulsive noise.

The impulsive noise suppressing techniques of nulling are proposed in [10]. The sample replacement [11] algorithm was proposed to cater for removing multiple impulsive noises in received OFDM signal. However the replica signal subtraction method [12] was proposed to solve the problem when impulsive noise arises between the OFDM samples in time domain. In [13], the Periodic impulsive noise from OFDM based power line communication systems was suppressed by notch and Least Mean Square algorithms. Another new technique based on Clipping and Adaptive Filters in AWGN Channel for impulsive noise reduction is proposed in [14].

In this paper, we have presented the hybrid method in [14] as a solution for IN mitigation in OFDM systems. Moreover, a comparison of this proposed method is conducted over different modulation schemes as a contrary to the practical implementation of this noise removal technique in frequency domain. The data is modulated over different types of constellations e.g., 8-PSK, 16-QAM and 32-QAM.

Following the introduction above, the paper is organized as: Section II describes the OFDM briefly. Section III gives the review of clipping method which is followed by discussion of different adaptive filters in Section IV; Section V has elaboration of the implemented method for OFDM systems, supported with the simulation results in Section VI. In the end, Section VII concludes the paper followed by the references.

II. OFDM

The Orthogonal Frequency Division Multiplexing is a multicarrier modulation in which transmission over a dispersive channel is carried out. The basic block diagram

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of OFDM system is shown in Fig. 1. In OFDM the high data rate streams are split 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. 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 clipped and passed through the adaptive filter block followed by demodulation for impulsive noise reduction in the OFDM signal.

III. Clipping

In practical applications, clipping method is usually used for impulsive noise mitigation due to its simplicity. A clipping algorithm is employed at the receiver end of the AWGN channel, where we presume that impulsive noise is being added by the channel during the communication. It is to reckon that clipping method only changes the amplitude of the data without changing the other parameters such as phase.

$$y_k = \begin{cases} r_k, & |r_k| \le T_c \\ T_c e^{j\arg(rk)}, & |r_k| > T_c \end{cases} \quad k=0,1,\ldots,N\text{-}1 \tag{1}$$

T_c is the Clipping threshold that can be set according to the maximum value of data if known. In this method the amplitude of the received data is clipped or limited by the threshold and no other change occurs to the signal/data that has been received.

IV. Adaptive Filters

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

A. NLMS

The Normalized Least Mean Square (NLMS) is a one of the variants of Least Mean Square (LMS) algorithm whose convergence ate is faster than LMS. The drawback of LMS algorithm is its sensitivity. Also its input signal scaling is prone to errors. When input signal is large, then LMS experiences a gradient noise amplification problem. Thus NLMS algorithm is used in which the tap weight $w(n)$ at $n+1$ is normalized with the Euclidean norm of the square of the input to the filter. The weight update equation is normalized so that the convergence is stable. The filter tap weights are updated using:

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

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

B. RLS

The Recursive least squares (RLS) adaptive filter belongs to the least square family of the adaptive filters. It tends to minimize a linear least cost function related to the deterministic input signal by finding the coefficients recursively. In contrast to other filtering algorithms such as LMS or NLMS it finds the cost function whereas those tend to minimize the error signal. The convergence rate of RLS is far higher than many other adaptive algorithms. However, it costs in higher computational complexity. The weights of the filter are updated by these equations [15].

$$w(n+1) = w(n) + k(n)x(n) \tag{3}$$

$$k(n) = \frac{\lambda^{-1}\Phi^{-1}(n-1)x(n)}{1+\lambda^{-1}x^T(n)\Phi^{-1}(n-1)x(n)} \tag{4}$$

$$\Phi^{-1}(n) = \lambda^{-1}\Phi^{-1}(n-1) - \lambda^{-1}k(n)x^T(n)\Phi^{-1}(n-1) \tag{5}$$

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

V. System Model

This paper proposes a solution for impulsive noise mitigation in OFDM system, based on clipping method along with adaptive filters. Fig. 1 shows the simple model carried for the underlined method.

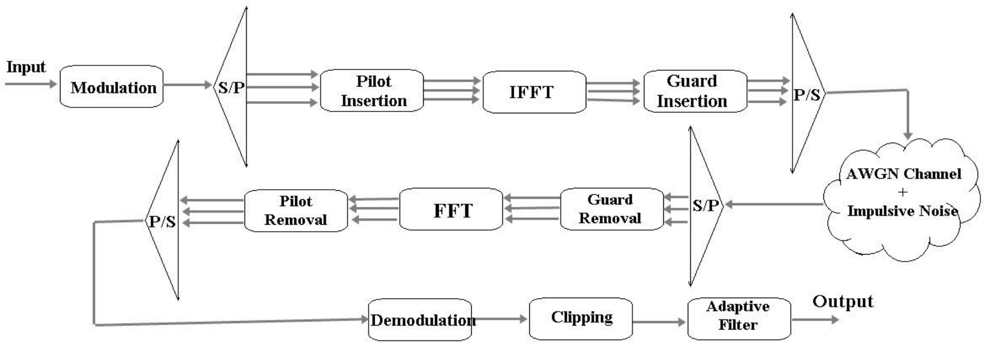

Figure 1. Block diagram of OFDM system for IN reduction

The received data is passed through the general receiver of OFDM system. The data is then demodulated and is clipped over a defined threshold, for the removal of higher peaks caused y the addition of impulsive noise in OFDM. This reduces the high peaks of the signal but cannot cater the noise that lies below the threshold value set for clipping. The clipped data is then passed through the adaptive filter for the removal of rest of the noise.

In this hybrid technique two different techniques are used in cascade or in combination to each other and are supposed to give better results for OFDM system than each individual method. In this combined method, the higher peaks added to the data while frequency multiplexing, are removed by the clipping method so the input to the adaptive filters has lower values and the data is recovered recursively with lesser convergence time.

VI. Simulation Results

The parameters for simulating the OFDM system are described below in Table I.

TABLE I. Parameters for OFDM System

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

The impulsive noise is generated by following steps mentioned in [16] and depicted in Fig. 2 and the parameters used for the impulsive noise generation are listed in Table II.

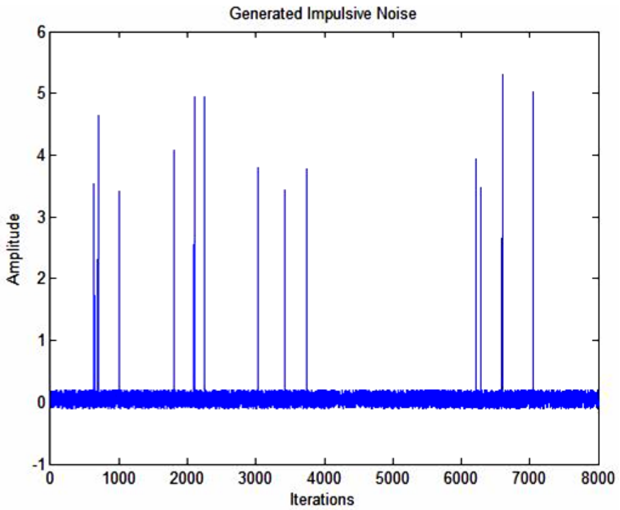

Figure 2. Generated impulsive noise

TABLE II. Parameters for Impulsive Noise Generation

Parameters	Symbol	Value
Sampling Frequency	F	10
Total time	T	8000
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
Standard deviation of Gaussian Noise	σ	0.3

Impulsive noise from Fig. 2 and AWGN are added to the data from channel and OFDM system. For noise removal the received OFDM signal is first clipped over a threshold after demodulation. In this way the data is clipped or limited at the threshold but it makes no changes to the noise or data that lie below the threshold.

In the next part, the clipped signal is then filtered using the adaptive filters i.e., NLMS & RLS. The basic scenario is that the output of the filter is compared with the desired signal. Their difference produces the error signal and the filter updates its weights recursively using the adaptive weight update (2) & (3), such that the error is minimized.

For these simulations the length of the two adaptive filters is fixed to 32. The range of the step size parameter μ for NLMS Algorithm is 0 to 1 and the value is chosen to be 0.01 and forgetting factor λ for RLS is taken to be 0.98 from the range 0.98 to 1.

Fig. 3 represents the bit error rate (BER) plot of the OFDM signal after the removal of AWGN and IN using clipping; NLMS algorithm and NLMS based hybrid method.

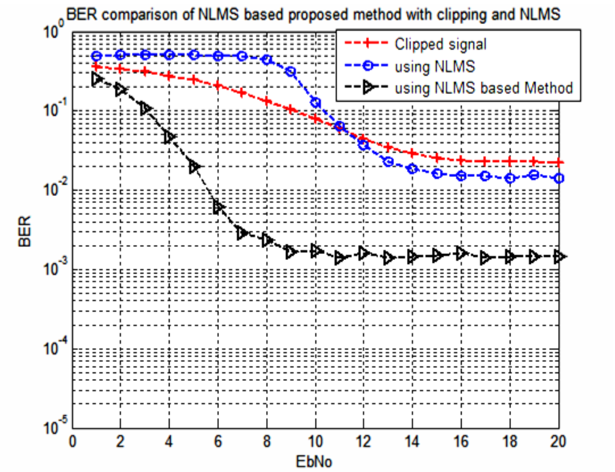

Figure 3. BER comparison of NLMS based hybrid method for IN reduction in OFDM signal

The performance of NLMS based hybrid technique is more than 1dB better than clipping and NLMS filtering methods. Among the three methods, the performance of the hybrid method is quite better than the rest of the methods for an SNR of up to 20dB.

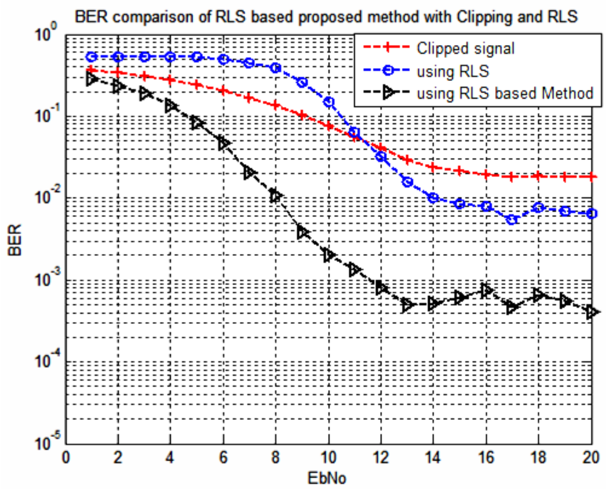

Figure 4. BER comparison of RLS based hybrid method for IN reduction in OFDM signal

The IN reduction performance of RLS based hybrid method is compared with clipping and RLS conventional receivers IN Fig. 4. The performance of RLS based hybrid method is better than other methods. The performance of RLS algorithm is degraded by more than

1dB as compared to that of RLS based hybrid method. The modulation scheme used for both the results in Fig. 4 and Fig. 5 is 16-QAM.

Furthermore, for IN reduction in OFDM signal, the performance of both NLMS based and RLS based hybrid methods are compared for different modulation schemes. Fig. 5 shows the BER comparison of both the hybrid methods while the OFDM signal is modulated over 8-PSK. The performance of NLMS based hybrid method is 1dB better than the clipping method. And the RLS based hybrid method performance is 3dB better than the clipping method for this research work.

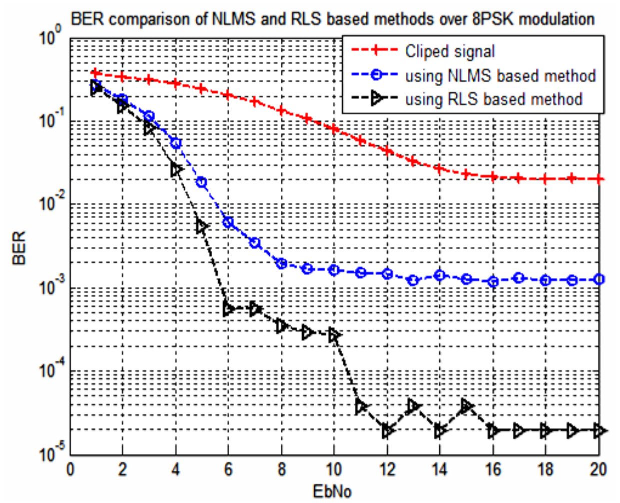

Figure 5. BER comparison of NLMS and RLS based hybrid methods over 8-PSK in OFDM signal

In Fig. 6, the performance of RLS based hybrid method is better than NLMS based hybrid method as following the adaptive filter laws and the performance of RLS based hybrid method is nearly 3 dB better than clipped signal while that of NLMS based hybrid method is around 1 dB better than the clipping method.

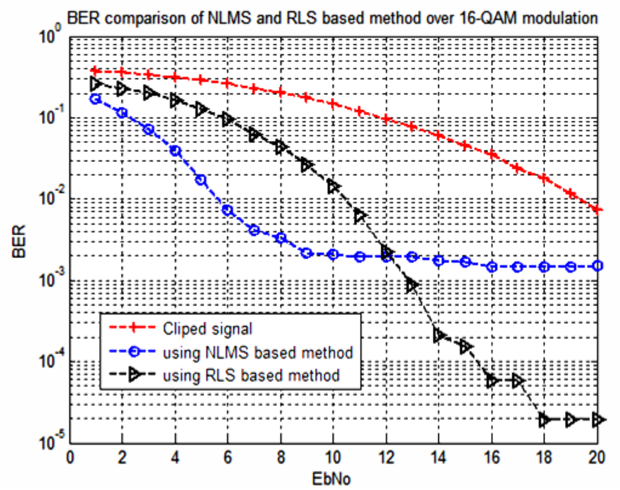

Figure 6. BER comparison of NLMS and RLS based hybrid methods over 16-QAM in OFDM signal

For the 32-QAM modulation of OFDM signal, the performance of NLMS based method is 1 dB better than clipped OFDM signal and the RLS based hybrid method performed 2.5dB better than the clipping method as depicted in Fig. 7. The aim of this investigation is to find the modulation scheme for which the implemented hybrid technique performs better.

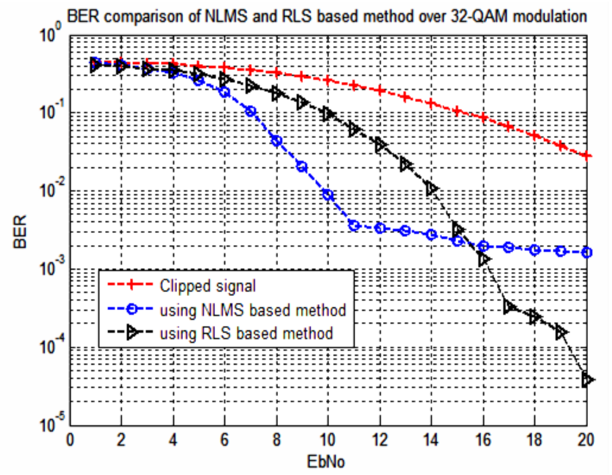

Figure 7. BER comparison of NLMS and RLS based Hybrid methods Over 32-QAM in OFDM Signal

The performance metric bit error rate in decibel indicates that these hybrid methods can be effectively used for IN reduction in OFDM systems as well. The RLS based hybrid method performance is better in terms of BERs under same conditions and scenario.

VII. Conclusion

In this paper, a solution for impulsive noise cancellation is introduced for OFDM signals. The technique consists of adaptive filters i.e., Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS) in cascade with clipping. Due to recursive parameters, the presented scheme exhibits better impulsive noise cancellation when compared with the individual performances of those techniques. Furthermore, the comparison is carried out over different modulation schemes such as 8-PSK, 16-QAM and 32-QAM. The results ensured the better performance of the hybrid method in terms of convergence speed and lower BER.

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