

S α S noise suppression for OFDM wireless communication in rayleigh channel

Heyem Hamlili, Samir Kameche, Abdelhafid Abdelmalek

STIC Laboratory, Department of Telecommunication, Abou Bakr Belkaid University, Algeria

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a form of multi-carrier transmission technique widely used in the modern wireless network to achieve high-speed data transmission with good spectral efficiency. However, in impulsive noise environment BER performances of these systems, originally designed for a Gaussian noise model, are much degraded. In this paper, a new symmetric-alpha-stable (S α S) noise suppression technique based conjointly on adaptive modulation, convolutional coding (AMC) and Recursive Least Square (RLS) filtering is presented. The proposed scheme is applied on OFDM system in Rayleigh fading channel. The transmissions are analyzed under different combinations of digital modulation schemes (BPSK, QPSK, 16-QAM, 64-QAM) and convolutional code rates (1/2, 2/3, 3/4). Simulation results show that our proposed hybrid technique provides effective impulsive noise cancellation in OFDM system and exhibits better BER performance.

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Corresponding Author:

Heyem Hamlili,
STIC Laboratory, Department of Telecommunication,
Abou Baker Belkaid University,
Tlemcen, 13000, Algeria.
Email: heyem.hamlili@student.univ-tlemcen.dz

1. INTRODUCTION

In the communication system, we can not avoid the existence of disturbances that may occur during the communication. Traditional methods treat noise as Gaussian white noise AWGN in which its statistical and spectral characteristics are predefined. However, this is not the case practically the noise is non-Gaussian impulsive in nature, which is generally nonstationary with a very complex frequency behavior. We find this kind of noise in underwater communications [1], highfrequency communications, LPC broadband communications [2] and telemedicine [3] etc. In the literature, several models have been proposed to simulate impulsive noise Middleton class A [4], Bernoulli Gaussian [5] distribution or symmetric alpha-stable distribution (S α S) [6]. We consider the α -stable noise model for our study.

Improvements in the Orthogonal Frequency Division Multiplexing OFDM communication system have become a major focus of research, as it is increasingly being adopted as a physical-layer modulation scheme in latest and emerging wireless standards. OFDM has been chosen for Wi-Fi arena [7] where the standards like 802.11a, 802.11n, 802.11ac and more. It has also been adopted for the cellular telecommunications standard LTE / LTE-A, WiMAX [8] and many more. Many approaches confirm that an OFDM family is the right candidate for 5G like W-OFDM [9], G-DFT-s-OFDM [10], WR-OFDM [11] and F-OFDM [12].

OFDM systems are usually corrupted by an impulsive noise which has more harmful effects. The performance of the OFDM system is degraded and the efficiency of the transmission is reduced due to impulsive noise's broad frequency component. Nowadays, the main concern of this research area is to investigate a new method to mitigate this type of noise, therefore improving systems performance in terms of

bit error rate. Various techniques are described in the literature to eliminate the impulsive noise of the transmitted original signal. The conventional method of suppressing this type of noise is the median filter with some signal degradation [13]. Wavelet transform based logarithmic shrinkage technique is used in [14] to eliminate the impulsive noise of corrupted images. Adaptive filters have been used successfully for the same purpose. A technique based on trained Least Mean Square algorithm (LMS) adaptive filtering is proposed by Khedkar [15] to mitigate the effect of inter-carrier interference. LMS is also used in [16] to reduce the effect of periodic impulsive noise in the Power Line Communication channel. Alina Mirza et al. in [17] used the State Space Recursive Least Square (SSRLS) algorithm to reduce the impulsive noise in the OFDM system. Srinu Pyla et al. [18] analyse the performance of adaptive filter channel estimated MIMO OFDM communication system. However, the proposed solutions are still suboptimal and further improvements are required. Thus, the goal of this research is to improve the performance of OFDM systems by minimizing (SaS) impulse noise in Rayleigh Fading Channel, using a new hybrid approach based on adaptive RLS filters and adaptive modulation and convolutional coding (AMC) technique applied to OFDM sub-channels.

The paper is organized as follows: section 2 discusses impulsive noise model, where precisely (SaS) distribution and geometric signal-to-noise-ratio (GSNR) are presented. Section 3 briefly explain the adopted OFDM system. Section 4 describes our proposed solution for impulsive noise cancellation, based conjointly on adaptative RLS filter and AMC technique. Simulation results and discussion are presented in section 5. Section 6 concludes the paper.

2. IMPULSIVE NOISE MODEL

2.1. SaS Distribution

In this work, as pointed before we consider α -stable distribution model [19, 20]. A real random variable X follows a law α -stable if and only if its characteristic function is described as follows:

$$\Psi_{\alpha}(t) = \exp\{-\gamma^{\alpha}|t|^{\alpha}[1 + i \beta \text{sign}(t) \omega(t, \alpha)] + i \delta t\} \tag{1}$$

Where

$$\omega(t, \alpha) = \begin{cases} -\tan\left(\frac{\pi\alpha}{2}\right) & \text{si } \alpha \neq 1 \\ \frac{2}{\pi} \ln|t| & \text{si } \alpha = 1 \end{cases} \tag{2}$$

$$\text{And sign}(t) = \begin{cases} 1 & \text{si } t > 0 \\ 0 & \text{si } t = 0 \\ -1 & \text{si } t < 0 \end{cases} \tag{3}$$

An α -stable distribution is completely defined by four parameters summarized in Table 1 and it can be denoted $X \sim S_{\alpha}(\beta, \gamma, \delta)$.

Table 1. Parameter descriptions for stable distributions

Parameters	Symbol	Values
Characteristic exponent	α	$\alpha \in]0,2]$
Scale parameter	γ	$\gamma > 0$
Location parameter	δ	$\delta \in]-\infty, +\infty[$
The symmetry parameter	β	$\beta \in [-1,1]$

A random variable is symmetric α -stable (SaS) if β and γ are equal to zero [21], subsequently the distribution of such a variable reduces to $X \sim S_{\alpha}(0,0, \delta)$ if:

- $\alpha = 2$ the distribution reduces to a Gaussian distribution described by the following Probability Density Function (PDF):

$$f(x) = \frac{1}{\sqrt{4\pi\gamma^2}} \exp\left(-\frac{x^2}{2\gamma^2}\right) \tag{4}$$

- $\alpha = 1$ we have a Cauchy distribution where the PDF is defined as follows:

$$f(x) = \frac{\gamma}{\pi(\gamma^2 + x^2)} \tag{5}$$

- $\alpha = 1/2$ The distribution follow the Low of Lévy and the PDF is presented as follows:

$$f(x) = \sqrt{\frac{\gamma}{2\pi}} \frac{1}{(x-\delta)^{3/2}} \exp\left(-\frac{\gamma}{2(x-\delta)}\right), \delta < x < \infty \tag{6}$$

For the other cases we can approach PDF of a stable law by the inverse transform of the characteristic function. The integral is written as follows:

$$f_X(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-i t x} \Psi_{\alpha}(t) dt \tag{7}$$

Figure 1 shows PDFs of the SaS model for different values of α while the other parameters are kept fixed at 0.

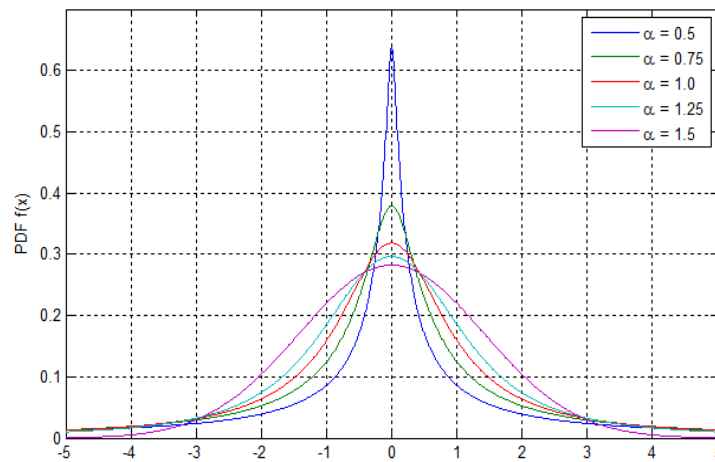


Figure 1. SaS distributions for different values of α

2.2. GSNR

For digital communication systems in impulse noise environments the BER curve is conventionally represented as a function of the GSNR geometric signal-to-noise ratio which was first proposed by Gonzalez in [22]. The GSNR is defined as:

$$GSNR = \frac{1}{2 C_g} \cdot \left(\frac{A}{S_0}\right)^2 \tag{8}$$

Where:

- S_0 is the geometric power of a symmetric α -stable given by :

$$S_0 = S_0(X) = e^{2 E(\ln|x|)} \tag{9}$$

- C_g is the exponential of the Euler constant $C_g = e^{C_e} = 1.7811$
- A is the peak amplitude of the transmitted signal

3. OFDM SYSTEM

Orthogonal frequency division multiplexing is a multi-carrier modulation technique in which high-rate streams are divided into low-throughput streams in parallel and modulated separately on many closely spaced sub-carriers. The adopted system consists of a tail biting convolutional codes (CC) whose constraint length is 7 in the transmitter side and an RLS adaptive filter in the receiver side. Figure 2 illustrates the system diagram used in our study and the parameters used during the simulation are summarized in Table 2.

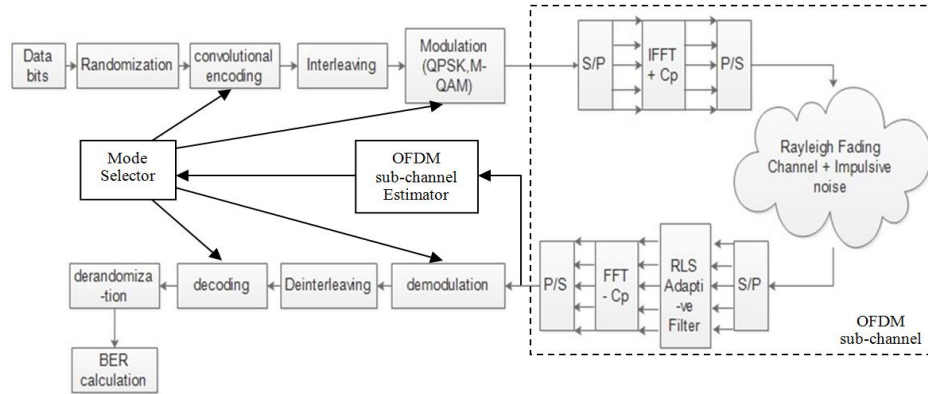


Figure 2. Block diagram of proposed scheme for OFDM system

Table 2. Parameter set of OFDM system simulation

Parameters	Values
Modulation technique	QPSK, M-QAM
Number of subcarriers	16
Size of cyclic prefix	128
FFT-length	512
BW	2 GHZ
Channel model	Rayleigh Fading Channel

4. PROPOSED HYBRID TECHNIQUE FOR SaS NOISE SUPPRESSION

Our solution is to equalize the Rayleigh SaS channel by RLS adaptive filtering and eliminate residual noise in OFDM sub-channels by AMC.

4.1. RLS Adaptive Filter

Adaptive filters are self-design systems that can adapt to different environments so they are used in various applications such as biomedical engineering, active noise control, interference cancellation and so on [23]. Figure 3 represents the concept of interference cancellation. The steps of the RLS filter used in this research are given in [24] and it's summarized as follow:

$$y(n) = W^T(n)x(n) \tag{10}$$

So, the expression of prediction error $e(n)$ is defined as:

$$e(n) = d(n) - y(n) \tag{11}$$

$x(n)$ and $d(n)$ are the primary input and the reference input respectively. $W(n)$ denotes the coefficient vector (or the weighting vector), where:

$$W(n + 1) = W(n) + k(n)x(n) \tag{12}$$

$$k(n) = \frac{\lambda^{-1}\phi^{-1}(n-1)x(n)}{1+\lambda^{-1}x^T(n)\phi^{-1}(n-1)x(n)} \tag{13}$$

$$\phi^{-1}(n) = \lambda^{-1}\phi^{-1}(n-1) - \lambda^{-1}k(n)x^T(n)\phi^{-1}(n-1) \tag{14}$$

ϕ is the cross correlation matrix for $x(n)$, ϕ^{-1} is its inverse and λ is the forgetting factor.

RLS Adaptive filter coefficients adapt recursively so that the error signal $e(n)$ becomes minimal. Subsequently output signal $y(n)$ approaches the desired signal. So, the most important part of the impulsive noise is suppressed from the received signal. But, on the other hand, as the minimum error doesn't reach zero, a residual part of noise at the output of the filter still exists. The AMC technique will be used here to mitigate the effect of this residual noise and improve BER performance.

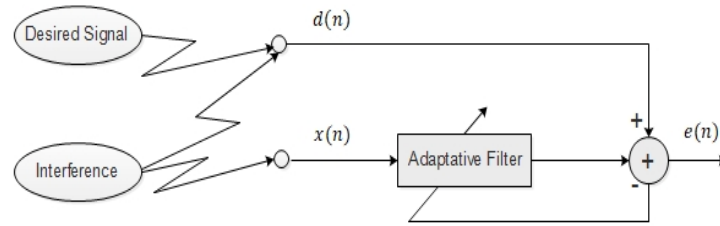


Figure 3. Block diagram of RLS noise cancellation

4.2. Adaptive Modulation and Convolutional Coding

In order to improve the performance of the system Adaptive Modulation and Convolutional Coding (AMC) is utilized. AMC technique allows controlling each OFDM sub-channels’ constellation size depending on the channel conditions. Data rate, instantaneous BER, channel code/scheme, and constellation size can be controlled using OFDM sub-Channel Quality Information (CQI). This latter is estimated at the receiver side just at the output of the RLS filter. The modulation scheme (BPSK, QPSK, 16-QAM, 64-QAM) and convolutional code rates (1/2, 2/3, 3/4) are adjusted according CQI.

5. SIMULATION RESULTS

In this section, we discuss the performance of the proposed technique according to the results of the simulation. The impulsive noise was generated from the PDF [25]. Figure 4 depict the noise generated. The results of the first experiment are given in Figure 5. where we set the length of the adaptive filter $L=32$ and take different values for the forgetting factor λ . We can notice that when the value of the forgetting factor increases, the BER decreases. In the second experiment, we used a fixed forgetting factor for different values of the adaptive filter length. From the results presented in Figure 6. It can be seen that the length of the adaptive filter has no significant influence on the BER, contrarily more it increases more the calculation becomes slow. For the rest of the simulations we took $\lambda = 0,99999$ and $L=32$.

Figure 7 presents the BER comparison of uncoded, coded and our proposed hybrid technique. The simulation is done for different α values and according to the results obtained, we notice that the algorithm gives us good results for values of α higher than 1. Thus, the BER decreases from $1.9 \cdot 10^{-2}$ to $1.8 \cdot 10^{-4}$ for $\alpha = 2$ at GSNR of -10 , and from $1.8 \cdot 10^{-3}$ to $1.88 \cdot 10^{-5}$ for $\alpha = 1.5$ at GSNR of -4 . Figure 8 shows BER performances of coded and CC-RLS systems for different modulation schemes and convolutional coding (CC) rates. It can be easily deduced that the RLS filter succeeds in reducing impulse noise and improving BER performance for all pairs of modulation patterns. For a very impulsive environment $\alpha = 1.2$, the QPSK modulation scheme with $\frac{1}{2}$ CC rate is best suited. However, for $\alpha = 1.8$, the most appropriate modulation scheme is BPSK with $\frac{1}{2}$ CC rate, in which case the RLS filter yields a gain of about 8 dB to BER of $2.6 \cdot 10^{-3}$.

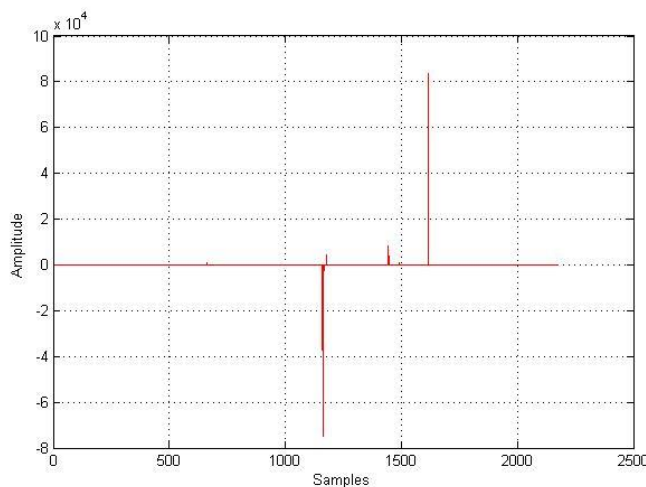


Figure 4. SaS impulsive noise signal

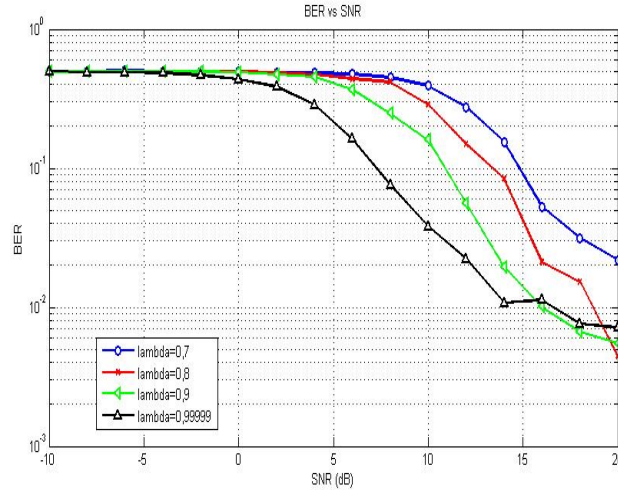


Figure 5. BER vs GSNR with $L= 16$ and differents values of λ

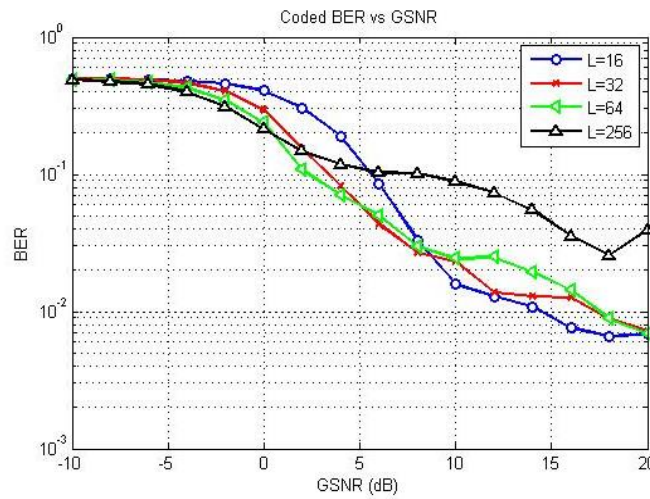


Figure 6. BER vs GSNR with $\lambda = 0.99$ and differents values of L

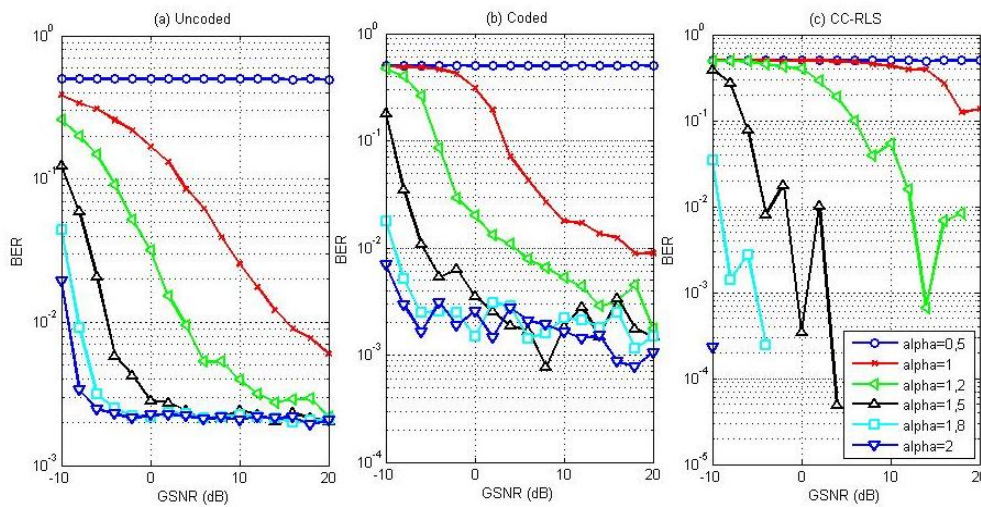


Figure 7. BER comparison of uncoded, coded and the proposed technique for different values of α

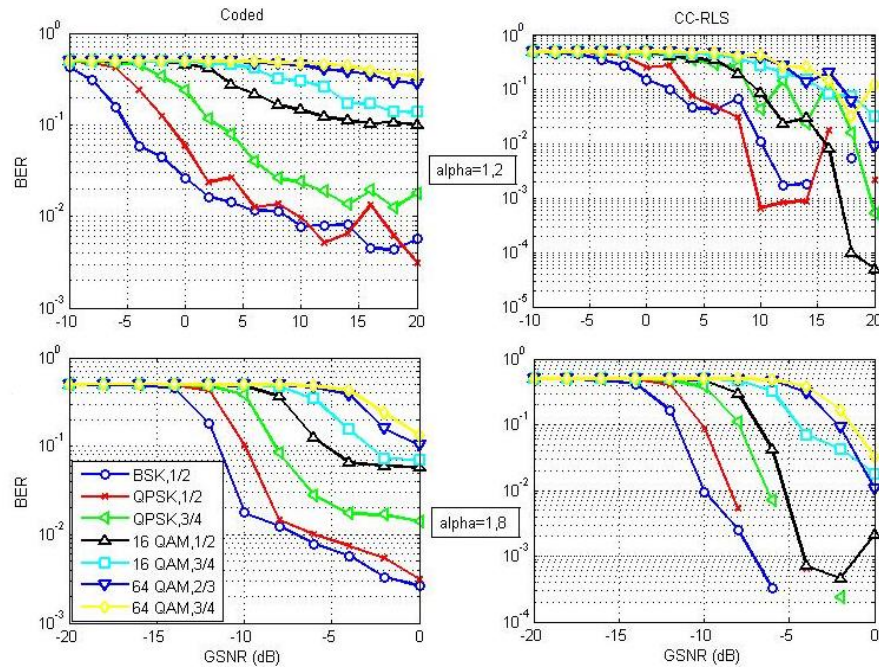


Figure 8. BER performances of coded and CC-RLS systems over different modulation schemes and convolutional coding (CC) rates for $\alpha = 1.2$ and $\alpha = 1.8$

6. CONCLUSION

In this paper, we propose a novel approach for symmetric-alpha-stable (S α S) noise suppression and BER improvement in OFDM communication systems. We explore the combination of RLS adaptive filters and the AMC technique in an impulsive noise multipath channel environment. The proposed solution equalizes the Rayleigh S α S channel by RLS adaptive filtering and eliminates residual noise in OFDM sub-channels by AMC. Simulation results show the effectiveness of our solution for noise cancelation and BER performance improvement even in the case of strong impulsive noise.

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