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INFLUENCE OF IMPULSIVE NOISE ON IMAGE TRANSMISSION USING SPACE-TIME BLOCK CODES

BY

MIHAELA ANDREI*

“Dunarea de Jos” University of Galaţi, Romania

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Abstract. The paper proposes an application of the space–time block code with two emitting and two receiving antennas for image transmission. The channel is considered to be affected by Rayleigh fading and impulsive noise. The influence of the Middleton Class-A type of impulsive noise on the image quality is studied. The simulations were done for various parameter values that describe the noise pattern, in order to mitigate it after the image has been received, using different types of median filters.

Key words: space–time block codes; image transmission; impulsive noise; median filters.

1. Introduction

Wireless communication systems are currently in the spotlight, due to their high usage in human activities. The safety of data transmitted by such systems, on channels affected by fading, is considerably improved by using of space–time codes. These ensure protection, especially at high speeds (Tarokh *et al.*, 1998), and furthermore, they accomplish transmission diversity (Vucetic *et al.*, 2003). The simplest scheme is that proposed by Alamouti, (1998), with two emitting antennas, being an important accomplishment in the field of

* *e-mail*: mihaela.andrei@ugal.ro

communications, because it achieves a full diversity gain with a simple maximum-likelihood decoding algorithm.

The noise that could affect the data transmission on multiple-input multiple-output (MIMO) channels can be Additive White Gaussian Noise (AWGN) or non-Gaussian. There are various sources that can produce non-Gaussian noise: industrial noise, man-made activity such as automobile spark plugs (Middleton, 1977), microwave ovens (Kanemoto *et al.*, 1998) and network interference (Win *et al.*, 2009).

There are many statistical models for impulsive noise; in this paper we use the Middleton Class-A model. Most of the Space–Time Block Code (STBC) receptors were designed for the AWGN case. That's why, in the presence of impulsive noise, their performance drop significantly, compared to the AWGN case, especially for high values of Signal-to-Noise Ratio (SNR) (Madi *et al.*, 2011; Andrei *et al*., 2013). The performances of orthogonal space–time codes (OSTBC), in the presence of Middleton Class-A impulsive noise, were investigated for various modulations, on channels affected by Rayleigh fading (Gong *et al.*, 2010). The conclusion was that for low SNR values, the Symbol Error Rate (SER) drops with at most 6 dB from the AWGN, and that for high values increases along with SNR.

Images can be affected by impulsive noise on transmission channels in the same way as any digital data. Some filters, with very good results, were proposed to mitigate the noise. Progressive switching median filter (PSMF) proposed by Wang *et al.*, (1999), implements an impulse–noise detector before filtering. The comparison of results for the aforementioned filter and standard median filter 3 × 3, switching median filter, iterative median filter and center weighted median (CWM) filter, sustains the feasibility of the farmer. It performs very well, even when images are heavily affected by noise.

This paper proposes an application of Alamouti's code in image transmission for two emitting and two receiving antennas. We consider a MIMO channel affected by Rayleigh fading, BPSK modulation and Middleton Class-A type of impulsive noise. The influence of the parameters that describe the non-Gaussian noise pattern on the quality of images is investigated, by comparing it with the AWGN noise. To filter the received images, various choices of the median filter are used.

This paper is organized as follows: Section **2** describes the pattern of Middleton Class-A type of impulsive noise, the model of the system being used, and also the filters applied to the received images. Simulation results are shown in Section **3**, and the conclusions are drawn in Section **4**.

2. System Description

This section presents the model for the system being used in the simulations, the adopted noise pattern, and various choices of median filters.

2.1. Mathematical Model of MIMO System

The relation that describes the transmission on a MIMO type channel is

$$r = Hx + n\,, \tag{1}$$

where: r is the received signals array; H – the channel's matrix that contains the fading coefficients between the emitting antenna, i, and the receiving one, j. These are complex random Gaussian variables, with identical distribution and zero mean value; n is the noise array (Gaussian or impulsive).

At moment t, the signal received by the antenna j will be given by

$$r_j^t = \sum_{i=1}^{N_T} h_{ji}^t x_i^t + \eta_j^t\,. \tag{2}$$

The diagram proposed by Alamouti uses two emitting antennas and N_R receiving ones. In this paper we will consider two emitting antennas and two receiving ones. The encoding operation consists in transmitting two signals, as follows: at moment t, the first antenna transmits the x_1 signal, and the second one, the x_2 signal; the following moment, the signals emitted by the two antennas will be $-x_2^*$ and x_1^*, respectively. The receiving antennas will get the signals given by the relations

$$\begin{cases} r_{j,1} = h_{j,1}x_1 + h_{j,2}x_2 + \eta_{j,1}, \\ r_{j,2} = -h_{j,1}x_2^* + h_{j,2}x_1^* + \eta_{j,2}. \end{cases} \tag{3}$$

The decoding is based on the Maximum Plausibility Algorithm (ML), by selecting the most probable received symbols, $\hat{x}_1$ or $\hat{x}_2$; it is given by

$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = \begin{bmatrix} \arg\min\limits_{\hat{x}_1 \in S} \left(\sum\limits_{j=1}^{N_R} \left| \tilde{r}_{j,1} - \left(\left|h_{j,1}\right|^2 + \left|h_{j,2}\right|^2 \hat{x}_1 \right) \right|^2 \right) \\ \arg\min\limits_{\hat{x}_2 \in S} \left(\sum\limits_{j=1}^{N_R} \left| \tilde{r}_{j,2} - \left(\left|h_{j,1}\right|^2 + \left|h_{j,2}\right|^2 \hat{x}_2 \right) \right|^2 \right) \end{bmatrix}. \tag{4}$$

2.2 Middleton Class-A Noise Model

Noise is an undesired signal that affects the signal being emitted. Its sources are various and can deteriorate an image's quality more or less, depending on its strength. There are many statistical models for noise; in this study we assume the Middleton Class-A model. This has two components: a Gaussian one, with variance σ_g^2, and an impulsive one, with variance σ_i^2. The probability density function is given by relation

$$p(n) = \sum_{m=0}^{\infty} \frac{A^m e^{-A}}{\pi m!\sigma_m^2} \exp\left(-\frac{|n|^2}{\sigma_m^2} \right). \tag{5}$$

and it is a Poisson weighted sum with Gaussian distributions.

The significance of variables in (5) is as follows: *m* is the number of active interferences (or impulses), *A* is the impulse index and it indicates the average number of impulses during interference time. This parameter describes the noise as follows: as *A* decreases, the noise gets more impulsive; conversely, as *A* increases, the noise tends towards AWGN. σ_m^2 represents the noise's total variance and it is given by:

$$\sigma_m^2 = \frac{m/A + T}{1 + T}, \tag{6}$$

where

$$T = \frac{\sigma_g^2}{\sigma_i^2} \tag{7}$$

is called *the Gaussian factor*. We can observe from (7) that for low *T* values, the impulsive component prevails, and that for high values, the AWGN component.

2.3. Median Filters

By applying the Middleton Class-A type of impulsive noise on an image transmitted through MIMO channels, using Alamouti's block code, the received image presents a salt & pepper noise. To eliminate it, we used different types of median filters, such as: standard median filters 3 × 3, 5 × 5, 7 × 7 and progressive switching median filters.

The most popular filter for cancelling salt & paper noise is the median one (Pitas *et al.*, 1992). This is an order filter and consists of a filtering window that contains an odd number of pixels, where the central pixel is replaced by the median window's pixel. The filtering windows' dimensions used are 3 × 3, 5 × 5 or 7 × 7. Because this type of filter has poor performance when the image is strongly affected by noise (Kukarni *et al.*, 2013), various forms of standard median filter were introduced.

Progressive switching median filter (PSMF) proposed by Wang *et al.*, (1999), implements an impulse-noise detector before filtering, both operations – detection and filtering, respectively – being accomplished progressively in an iterative manner. Thus, only the pixels that were considered affected by noise will be filtered, the disadvantage being that details and edges of images may not be totally recovered.

3. Simulation Results

The simulations were done for a space-time block code with two emitting antennas and two receiving ones, BPSK modulation, on a channel affected by Rayleigh fading and impulsive noise described by Middleton Class-A model. The images transmitted on the channel are shown in Figs. 1 *a* and 3 *a*, grayscale images, of size 512 × 512 pixels with 8 bits per pixel – lena.bmp and peppers.bmp. The simulations were done for two SNR values: 5 dB and 10 dB, by varying the parameters of the impulsive noise. The impulsive noise of type Middleton Class-A was generated by the toolbox (Gulati *et al.*, 2011). The A and T parameters, that describe the pattern of the considered impulsive noise, were varied in these intervals: $A \in [10^{-2}, 1]$, $T \in [10^{-2}, 1]$. The results are compared to AWGN case. Lena was transmitted on a MIMO channel, affected by Rayleigh fading and AWGN, using Alamouti code 2 × 2 and BPSK modulation (Andrei *et al*., 2012).

The comparisons are realized in terms of the mean square error (MSE), given in (9) and the peak signal–noise ratio (PSNR), given in (10). The two parameters' values that "measure" the image quality were calculated before and after applying the median filters. The windows for the standard median filter were considered to be 3 × 3, 5 × 5 and 7 × 7. For PSMF the parameters proposed by Wang *et al.*, (1999), were considered: the filtering window, $W_F = 3$; the impulse detection iteration $N_D = 3$; the threshold, $T = 40$; $a = 65$; $b = -50$. T is used to make a decision if the pixel x_i is affected by noise or not. So, if the difference between the median pixel of the samples in 3 × 3 window and the current pixel x_i is less than or equal to T, the impulse is detected. The parameters a and b are used for establishing the threshold detection, T_D, given by

$$T_D = a + b\frac{N_I}{N}, \tag{8}$$

where N_I is the number of impulses that have been detected and N – the total number of pixels.

The image quality is assessed in terms of mean squared error (MSE) and peak signal to noise ratio (PSNR) defined as:

$$\mathrm{MSE} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - \hat{I}(i,j)]^2, \tag{9}$$

where: M, N represent the image's horizontal and vertical number of pixels, respectively; I – the original image and $\hat{I}$ – the received image, and

$$\mathrm{PSNR} = 10\,\log_{10}\left(\frac{255^2}{\mathrm{MSE}}\right). \tag{10}$$

We have used two test images, Lena and peppers. The values of MSE are collected in Tables 1 and 3, respectively, for the two images. The values for PSNR are given in Tables 2 and 4, respectively, for the two images.

Table 1

Image Quality Metric, MSE – Lena

SNR dB	Type of noise			Before filter	Type of median filter			
					MF 3 × 3	MF 5 × 5	MF 7 × 7	PSMF
5	AWGN			81.22	19.48	49.42	81.98	8.37
	Middleton Class-A	A=0.01	T = 1	135.36	19.93	49.94	81.94	9.89
			T = 0.1	157.48	20.22	50.10	82.11	10.91
			T = 0.01	162.79	20.16	49.94	82.31	10.95
		T = 0.01	A = 1	123.08	19.77	49.78	82.18	10.16
			A = 0.1	267.30	21.83	51.23	83.05	16.33
10	AWGN			42.20	18.59	48.91	81.41	5.06
	Middleton Class-A	A = 0.01	T = 1	46.04	19.06	49.26	81.64	6.90
			T = 0.1	81.48	19.28	49.51	81.75	8.00
			T = 0.01	83.17	19.35	49.51	81.92	8.29
		T = 0.01	A = 1	46.67	18.61	48.95	81.42	5.19
			A = 0.1	49.25	19.00	48.82	81.66	6.71

Table 2

Image Quality Metric, PSNR – Lena

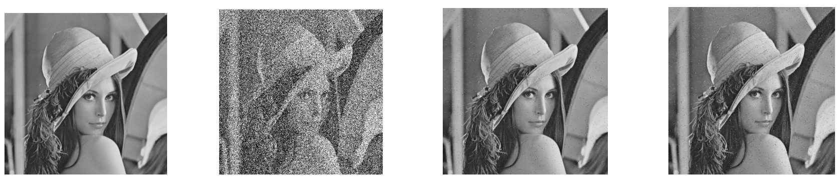
SNR dB	Type of noise			Before filter	Type of median filter			
					MF 3 × 3	MF 5 × 5	MF 7 × 7	PSMF
5	AWGN			29.03	35.23	31.19	28.99	38.89
	Middleton Class-A	A = 0.01	T = 1	26.81	35.13	31.14	28.99	38.17
			T = 0.1	26.15	35.07	31.13	28.98	37.74
			T = 0.01	26.01	35.08	31.14	28.97	37.73
		T = 0.01	A = 1	27.22	35.16	32.15	28.98	38.06
			A = 0.1	23.86	34.73	31.03	28.93	35.99
10	AWGN			31.87	35.43	31.23	29.02	41.08
	Middleton Class-A	A = 0.01	T = 1	31.49	35.20	31.20	29.01	39.73
			T = 0.1	29.02	35.27	31.18	29.00	39.09
			T = 0.01	28.93	35.26	31.18	28.99	38.94
		T = 0.01	A = 1	31.44	35.43	31.23	29.02	40.97
			A = 0.1	31.20	35.24	31.24	29.01	39.86

Without filtering, the MSE values calculated for the AWGN case, are significantly lower than in the case of impulsive noise. It can be observed that MSE increases with the impulsive component weight, so that for the case of $A = T = 0.01$, situation which characterizes a strong impulsive noise, the image quality is very low – MSE is approximately 4 times larger than in the case of Gaussian noise. If SNR increases, the noise affects less the image, MSE having significantly lower values. After filtering, the MSE values plummet, for every filter. Comparing MSE for the different filters we used, the lowest values are for PSMF. The worst results were obtained for MF 7 × 7, so these type of filter is not suitable for mitigate the Middleton Class-A Noise, especially for high SNR.

In the PSNR case, for the situation when the received image is not filtered, this has higher values for AWGN, comparable with the impulsive noise for SNR = 10 dB. At SNR = 5 dB, the differences are only approximately 1% as against Middleton Class-A. For $A = 1$ and $T = 0.01$, the PSNR values are close to the AWGN case. After filtering, PSNR increases significantly, but remains almost constant for the rest of the cases. As in the case of MSE, the best performances are given by PSMF, and the worst are for MF 7 × 7.

Fig. 1 shows three images affected by noise and Fig. 2 presents the results of filtering the image in Fig. 1 *a* corrupted by impulsive noise at SNR = = 5 dB, for $A = T = 0.01$, by using standard median filters and PSMF filter.

Fig. 1 shows that Alamouti space–time block code has better results in image transmission. The image at the receiver looks much better than the image transmitted over an uncoded channel.



a *b* *c* *d*

Fig. 1 – *a* – original image; corrupted images: *b* – uncoded, with AWGN; *c* – coded, with AWGN; *d* – coded, with Middleton Class-A Noise – $A = T = 0.01$.

a *b* *c* *d*

Fig. 2 – Filtered images: *a* – MF 3x3; *b* – MF 5 × 5; *c* – MF 7 × 7; *d* – PSMF.

The results obtained for the test image peppers are similar to those obtained for Lena. The same conclusions can be drawn: image quality is strongly affected by the impulse noise, comparatively with AWGN. The best filter used for mitigate de noise is PSMF. MF 3 × 3 has good results and MF 7 × × 7 is not suitable for high SNR. The values for MSE (Table 3) and PSNR (Table 4) are comparable with those for Lena, under the same conditions.

Table 3

Image Quality Metric, MSE – Peppers

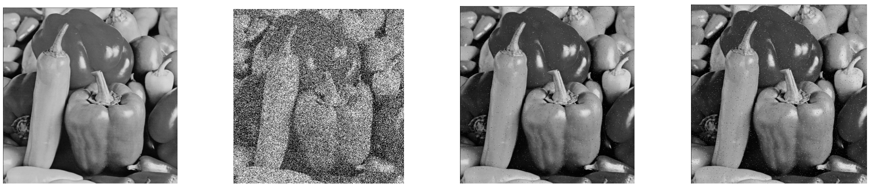
SNR dB	Type of noise			Before filter	Type of median filter MF 3 × 3	MF 5 × 5	MF 7 × 7	PSMF
5	AWGN			82.14	21.34	40.11	62.62	7.74
	Middleton Class-A	A = 0.01	T = 1	139.56	21.69	40.50	63.17	9.22
			T = 0.1	165.51	21.92	40.61	62.79	9.88
			T = 0.01	166.40	22.07	40.99	63.34	9.89
		T = 0.01	A = 1	126.12	21.66	40.64	63.08	9.16
			A = 0.1	275.87	23.58	42.27	64.86	14.14
10	AWGN			42.44	20.31	39.38	61.83	5.04
	Middleton Class-A	A = 0.01	T = 1	47.73	20.69	39.90	62.39	6.52
			T = 0.1	77.17	21.03	40.06	62.61	7.40
			T = 0.01	88.29	21.22	40.27	62.82	7.69
		T = 0.01	A = 1	46.32	20.35	39.40	61.91	5.19
			A = 0.1	44.16	20.74	39.82	62.28	6.47

Fig. 3 shows three peppers images affected by noise and Fig. 4 presents the results of filtering the image in Fig. 1 *b* corrupted by impulsive noise at SNR = 5 dB, for $A = T = 0.01$, by using standard median filters and PSMF.

Table 4

Image Quality Metric, PSNR – Peppers

SNR dB	Type of noise			Before filter	Type of median filter MF 3 × 3	MF 5 × 5	MF 7 × 7	PSMF
5	AWGN			28.98	34.83	32.09	30.16	39.22
	Middleton Class-A	A = 0.01	T = 1	26.68	34.76	32.05	30.12	38.48
			T = 0.1	25.94	34.72	32.04	30.15	38.18
			T = 0.01	25.91	34.69	32.00	30.11	38.17
		T = 0.01	A = 1	27.12	34.77	32.04	30.13	38.51
			A = 0.1	23.72	34.40	31.86	30.01	36.62
10	AWGN			31.85	35.05	32.17	30.21	41.10
	Middleton Class-A	A = 0.01	T = 1	31.34	34.97	32.12	30.17	39.98
			T = 0.1	29.25	34.90	32.10	30.16	39.43
			T = 0.01	28.67	34.86	32.08	30.14	39.26
		T = 0.01	A = 1	31.47	35.04	32.17	30.21	40.97
			A = 0.1	31.68	34.96	32.12	30.18	40.01



a *b* *c* *d*

Fig. 3 – *a* – original image; corrupted images: *b* – uncoded, with AWGN; *c* – coded, with AWGN; *d* – coded, with Middleton Class-A Noise – $A = T = 0.01$.

a *b* *c* *d*

Fig. 4 – Filtered images: *a* – MF 3 × 3; *b* – MF 5 × 5; *c* – MF 7 × 7; *d* – PSMF.

4. Conclusions

The image quality is strongly affected by the impulsive noise, compared to AWGN, when transmitting it on a MIMO channel with two emitting and two receiving antennas, affected by Rayleigh fading and impulsive noise and using a space–time block code. The simulations have shown that as the noise gets more impulsive (the impulsive component are predominant), the images get more distorted (the case of $A = 0.01$, $T = 0.01$). In order to mitigate the noise and restore the images, various median filters have been used, taking into account to modify the receiver in the future for such a noise. The best performances turned out to be given by the progressive switching median filter.

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INFLUENȚA ZGOMOTULUI IMPULSIV ÎN TRANSMITEREA IMAGINILOR FOLOSIND CODURI BLOC SPAȚIU–TIMP

(Rezumat)

Se propune o aplicație a codului bloc spațiu–timp cu două antene de emisie şi două de recepție în transmiterea imaginilor. Canalul este considerat afectat de fading Rayleigh şi zgomot impulsiv. Este investigată influența zgomotului impulsiv de tip Middleton Class-A asupra calității imaginii. Simulările au fost realizate pentru diverse valori ale parametrilor ce descriu modelul zgomotului, pentru eliminarea acestuia fiind utilizate după recepția imaginii variante ale filtrului median.