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Blind Impulse Response Identification of frequency Radio Channels: Application to Bran A Channel

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Abstract**—** This paper describes a blind algorithm for estimating a time varying and frequency selective fading channel. In order to identify blindly the impulse response of these channels, we have used Higher Order Statistics (HOS) to build our algorithm. In this paper, we have selected two theoretical frequency selective channels as the Proakis's 'B' channel and the Macchi's channel, and one practical frequency selective fading channel called Broadband Radio Access Network (BRAN A). The simulation results in noisy environment and for different data input channel, demonstrate that the proposed method could estimate the phase and magnitude of these channels blindly and without any information about the input, except that the input excitation is i.i.d (Identically and Independent Distributed) and non-Gaussian.

Keywords**—** Frequency Response, System Identification, Higher Order Statistics, Communication Channels, Phase Estimation.

I. Introduction

IN the literature we have important results [1], [2], established that blind identification of finite impulse response (FIR) single-input single-output (SISO) communication channels is possible only from the output second-order statistics, without using any restrictive assumption on the channel zeros, color of additive noise, channel order overestimation errors, and without increasing the transmission rate of the data stream. The common feature of this class of approaches [1], [2] is that they induce cyclostationary statistics at the transmitter by means of a periodically time-varying precoder (e.g., a filterbank [2] or a simple periodic modulator [1]) and exploit the resulting second-order cyclostationary statistics of the received samples. Those algorithms have been termed transmitter-induced multinationality approaches. Some class of algorithms for blind channel identification are based on the iterative strategy [3]. In these algorithms, an initial channel estimate is used by a symbol estimator to provide tentative soft estimates of the transmitted symbol sequence. These estimates are used by a channel estimator to improve the channel parameters. The improved channel estimates are then used by the symbol estimator to improve the symbol parameters, and so on.

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In this paper, we have principally focussed in channel impulse response estimation such as: magnitude and phase. The considered channels are with non minimum phase and frequency selective. In most wireless environments, there are many obstacles in the channels, such as buildings, mountains and walls between the transmitter and the receiver. Reflections from these obstacles cause many different propagation paths. This is called multi-paths propagation or a multi-path channel. The frequency impulse response, of this channel, is not flat (ideal case) but comprising some hollows and bumps, due to the echoes and reflection between the transmitter and the receiver. Another problem encountered in communication is the synchronism between the transmitter and the receiver. To solve the problem of phase estimation we well use, in this paper, the HOC to test what's the robustness of those techniques if the channel is affected by a colored noise. Higher order cumulants (HOC) are a fairly a topic with many applications in system theory. The HOC are only applicable to non-gaussian and non linear process because the cumulants of a gaussian process are identically zero [4]. Many real world applications are truly non-gaussian [5]. Also, the Fourier transformation of HOC, which is termed higher order spectra (or polyspectra) provides an efficient tool for solving the problem of equalization technology used in communication. The major feature of HOC, from the point of view of equalization, is that the phase information of channels is present [8], and therefore they can be used to estimate the parameters of the channel model with no a priori knowledge of the phase property (minimum phase (MP) or non-minimum phase (NMP)) of channel or the transmitted data (assuming a non-Gaussian distribution) [5].

In this paper we have proposed an algorithm based only on third order cumulants. The solution, in least squares sense, gives an estimation of the frequency-selective fading channel impulse response parameters of the considered theoretical channel such as: Prokis 'B' [6], [7] and Macchi [8] channels. In order to test the efficiency of the proposed algorithm we have considered practical, i.e. measured, frequency-selective fading channel, called Broadband Radio Access Network (BRAN A), representing the transmission scenario at the interior of the office. This model channel is normalized by the European Telecommunications Standards Institute (ETSI) [9] [10].

A. Problem Statement

The channel output of a FIR channel, excited by an unobservable input sequences, i.i.d zero-mean symbols with unit energy, belonging to some alphabet A, across a selective channel with memory p and additive colored Gaussian noise. The output time series is described by the following equation

$$r(k) = h_p x_k + n(k) \tag{1}$$

where $h_p = (h(1), h(2), ..., h(p))$ represents the channel impulse response, $x_k = (x(k-1), x(k-2), ..., x(k-p))$ and n_k is the additive colored Gaussian noise with energy $E\{n^2(k)\} = \ {}^2$.
The completely blind channel identification problem is to estimate h_p based only on the received signal r and without any knowledge of the energy of the transmitted data x nor the energy of noise.

B. Basic relationships

The output of the channel is characterized by its impulse response $h(n)$, which we identify "blindly" its parameters is given in the following equation (2).

$$y(k) = \sum_{i=0}^{P} x(i)h(k-i); \quad r(k) = y(k) + n(k) \tag{2}$$

Let us suppose that: The additive noise $n(k)$ is Gaussian, colored or with symmetric distribution, zero mean, with variance $\ {}^2$, i.i.d with the m^{th} order cumulants vanishes for $m > 2$. In addition we suppose that the noise $n(k)$ is independent to $x(k)$ and $y(k)$. The channel order p is supposed to be known and $h(0) = 1$.

Then the m^{th} order cumulant of the output signal is given by the following equation [4]

$$C_{my}(t_1, ..., t_{m-1}) = \ _{mx} \sum_{i=-\infty}^{+\infty} h(i)h(i+t_1)..h(i+t_{m-1}) \tag{3}$$

with $\ _{mx}$ represent the m^{th} order cumulants of the excitation signal $(x(k))$ at origin.
If $m = 3$ the equation (3) becomes:

$$C_{3y}(t_1, t_2) = \ _{3x} \sum_{i=0}^{P} h(i)h(i+t_1)h(i+t_2) \tag{4}$$

the same, if $m = 2$ the equation (3) becomes

$$C_{2y}(t_1) = \ ^2 \sum_{i=0}^{P} h(i)h(i+t_1) \tag{5}$$

the Fourier transformation of the equations (4) and (5) give us the spectre and bispectra respectively

$$S_{3y}(\ _1, \ _2) = \ _{3x} H(\ _1)H(\ _2)H(-\ _1 - \ _2) \tag{6}$$

$$S_{2y}(\ ) = \ ^2 H(\ )H(-\ ) \tag{7}$$

if we suppose that $\ = (\ _1 + \ _2)$, the equation (7) becomes

$$S_{2y}(\ _1 + \ _2) = \ ^2 H(\ _1 + \ _2)H(-\ _1 - \ _2) \tag{8}$$

then, from the equations (6) and (8) we obtain the following equation

$$H(\ _1 + \ _2)S_{3y}(\ _1 + \ _2) = \ H(\ _1)H(\ _2)S_{2y}(\ _1 + \ _2) \tag{9}$$

with $\ = (\frac{3x}{2})$. The inverse Fourier transformation of the equation (9) demonstrates that the 3^{rd} order cumulants, the Auto-Correlation Function (ACF) and the impulse response channel parameters are combined by the following equation

$$\sum_{i=0}^{P} h(i)C_{3y}(t_1 - i, t_2 - i) = \ \sum_{i=0}^{P} h(i)h(i+t_2-t_1)C_{2y}(t_1 - i) \tag{10}$$

if we use the property of the ACF of the stationary process, such as $C_{2y}(t) \neq 0$ only for $(-p \leq t \leq p)$ and vanish elsewhere. In addition if we take $t_1 = -p$, the equation (10) takes the form

$$\sum_{i=0}^{P} h(i)C_{3y}(-p-i, t_2-i) = \ h(0)h(t_2+p)C_{2y}(-p) \tag{11}$$

else if we suppose that $t_2 = -p$, the equation (11) becomes

$$C_{3y}(-p, -p) = \ h(0)C_{2y}(-p) \tag{12}$$

using the equation (11) and (12) we obtain the following relation

$$\sum_{i=0}^{P} h(i)C_{3y}(-p-i, t_2-i) = h(t_2+p) \tag{13}$$

else if we suppose that the system is causal, i.e. that $h(i) = 0$ if $i < 0$. So, for $t_2 = -p, ..., 0$, the system of equations (13) can be written in matrix form as

$$\begin{pmatrix} C_{3y}(-p-1, -p-1) & . & C_{3y}(-2p, -2p) \\ C_{3y}(-p-1, -p) - & . & . \\ . & . & . \\ . & . & . \\ C_{3y}(-p-1, 1) & . & C_{3y}(-2p, -p) - \end{pmatrix} \times \begin{pmatrix} h(1) \\ . \\ h(i) \\ . \\ h(p) \end{pmatrix} = \begin{pmatrix} 0 \\ -C_{3y}(-p, -p+1) \\ . \\ . \\ -C_{3y}(-p, 0) \end{pmatrix} \tag{14}$$

where $\ = C_{3y}(-p, -p)$
the above equation (14) can be written in compact form as

$$M\ h_p = d \tag{15}$$

with M the matrix of size $(p+1) \times (p)$ element, h_p a column vector constitute by the unknown impulse response parameters $h(n) : n = 1, ..., p$ and d is a column vector of size $(p+1) \times (1)$ as indicated in the equation (14). The Least Squares solution (LS) of the system of equation (15), permit an identification of the parameters $h(n)$ blindly and without any 'information'

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of the input selective channel. So, the solution will be written under the following form

$$h_p = (M^T M)^{-1} M^T d \tag{16}$$

II. Simulation Results

A. Proakis 'B' channel

The Proakis 'B' channel is more frequency selective, the parameters of their impulse response is given by:
$h_p = (0.407, 0.815, 0.407)$.
The characteristics of this channel are illustrated in the following figure (Fig. 1). One of their zeros is outside of the unit circle (i.e. non minimum phase channel). The magnitude of the impulse response of this channel represent more frequency selective.

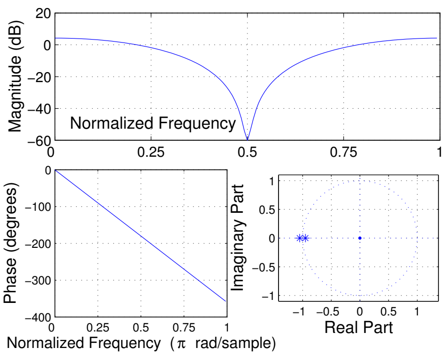

Fig. 1. Proakis 'B' channel characteristics.

1) Impulse response parameters estimation:

In the following Table I, we represent the estimated parameters for different data length and for different SNR (Signal to Noise Ratio) defined by:

$$SNR = 10\log(\frac{{}^2_x}{{}^2}) \tag{17}$$

The qualities of the estimated parameters are evaluated by the quadratic criteria (Mean Squares Error (MSE)) given by the following equation

$$MSE = \frac{1}{p}\sum_{i=1}^{P}(h(i) - \hat{h}(i))^2 \tag{18}$$

TABLE I
Estimated parameters of Proakis 'B' channel model excited by different sample sizes and for $SNR = 16dB$

$\hat{h(i)} \pm \sigma$	$N = 512$	$N = 2048$
$\hat{h}(1) \pm \sigma$	0.150 ± 0.514	0.334 ± 0.254
$\hat{h}(2) \pm \sigma$	0.722 ± 0.458	0.764 ± 0.237
$\hat{h}(3) \pm \sigma$	0.325 ± 0.691	0.297 ± 0.364
MSE	0.0271	0.0067

from the Table I we can conclude the following remark: 1) The smallest values of the MSE imply that the parameters estimation are very close to the true ones. 2) The difference between the parameters estimation values obtained using the data length $N = 512$ and $N = 2048$ (for an important $SNR = 16$) is due principally to the bias estimation of the HOC using the data length $N = 512$.

2) Magnitude and phase estimation:

In this section we well estimate the magnitude and phase of the Proakis 'B' channel impulse response for different data length and for different SNR. In the Figure 2 ($SNR = 16dB$) we observe that the small data have not the influence to the phase response, but, had an influence on the magnitude response of the Proakis 'B' channel. This is due to bias when we have estimated the cumulants. Therefore, the cumulants are sensitive to the phase channel (good results for small data input). When the input data increases, we remark that the magnitude response follows the original ones.

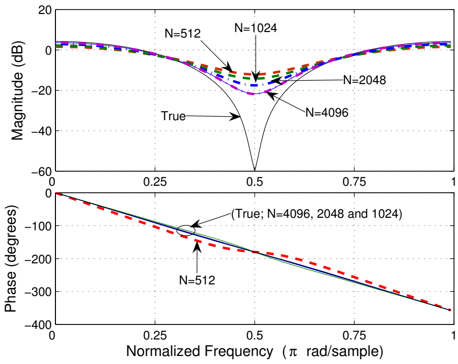

Fig. 2. Estimated magnitude and phase of the Proakis channel impulse response, for different data length, $SNR = 16dB$

Finally, if we increase the data input -for different SNR- we well obtain a good estimation of magnitude and phase response of the Proakis 'B' channel. This is very clear in Fig. 3.

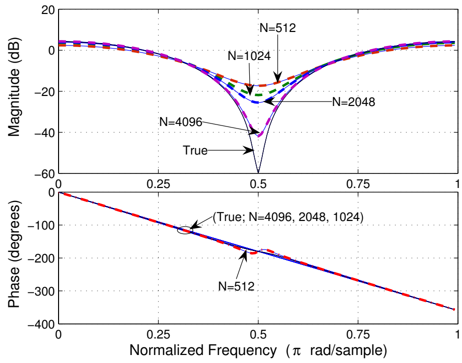

Fig. 3. Estimated magnitude and phase of the Proakis channel impulse response, for different data length, $SNR = 40dB$

B. Macchi channel

The Macchi channel has five parameters of its impulse response given by:

$h_p = (0.8264, -0.1653, 0.8512, 0.1636, 0.8100)$. The channel characteristics are illustrated in the following figure (Fig. 4). The impulse response of this channel present some fading hollow and their phase response is not linear. Two of its zeros are outside of the unit circle (i.e. non minimum phase channel). The magnitude of the impulse response of this channel represent more frequency selective in every hollow.

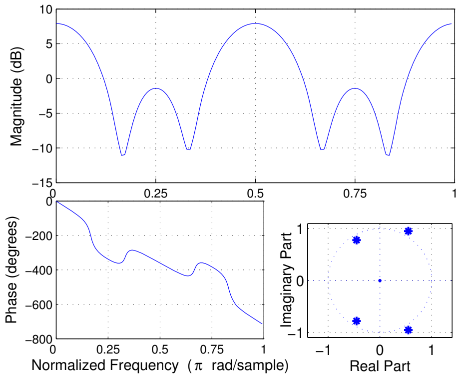

Fig. 4. Macchi channel characteristics.

1) Impulse response parameters estimation: In this sub-section we well present the impulse response parameters estimation of the Macchi's channel for different input data length and for various SNR. In the following Table (Table II) we are summarized the obtained results.

TABLE II
ESTIMATED PARAMETERS OF PROAKIS 'B' CHANNEL MODEL EXCITED BY DIFFERENT SAMPLE SIZES AND FOR $SNR = 16dB$

$\hat{h(i)} \pm \sigma$	$N = 512$	$N = 2048$
$\hat{h}(1) \pm \sigma$	0.517 ± 0.522	0.802 ± 0.378
$\hat{h}(2) \pm \sigma$	-0.801 ± 0.974	-0.216 ± 0.438
$\hat{h}(3) \pm \sigma$	0.776 ± 0.859	0.796 ± 0.311
$\hat{h}(4) \pm \sigma$	-0.138 ± 0.483	0.122 ± 0.428
$\hat{h}(5) \pm \sigma$	0.455 ± 0.649	0.806 ± 0.259
MSE	0.1446	0.0020

From the Table II we can conclude that: The parameters estimation of the Macchi channel impulse response are not different to the true ones, in the case, when the data length are $N \geq 1024$. The MSE values are small for all data length and for all SNR, this imply, that the estimated parameters are very close to the original ones. All parameters are estimated (with acceptable variance), without more difference to the true ones for all SNR and for all data length; with the exception the parameters $\hat{h}(4)$ principally for small data length ($N \leq 1024$), in witch we have a small difference.

2) Magnitude and phase estimation: In the following figure (Fig. 5) we have presented the estimation of the magnitude and the phase of the impulse response using the proposed algorithm. For an $SNR = 16dB$; we remark that the phase estimation for all data length have the same appearance (Fig. 5). The magnitude estimations corresponding to the data length $N = 2048$ and 4096, have the same allure comparatively to the true ones; but those representing the data length $N = 512$ and 1024 represent some fluctuations.

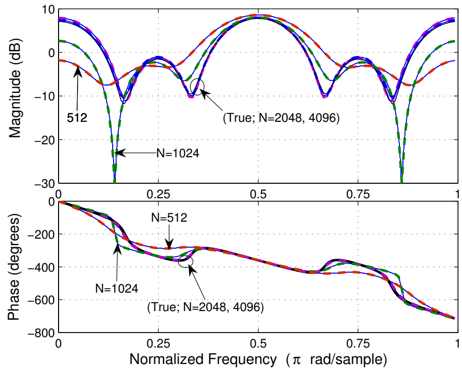

Fig. 5. Estimated magnitude and phase of the Macchi channel impulse response, for different data length, $SNR = 16dB$

So, if the $SNR \geq 16dB$, for example for a $SNR = 40dB$ (Fig. 7), we can conclude that the noise is without influence. the corresponding estimation of magnitude and phase have the same mining to the true ones. In conclusion the proposed algorithm is able to estimate the magnitude and phase of these channel characterized by the frequency selective. Seeing that the proposed algorithm is based only on third order cumulants, so, the phase estimation was estimated without more difference, in presence of colored noise and with different data length.

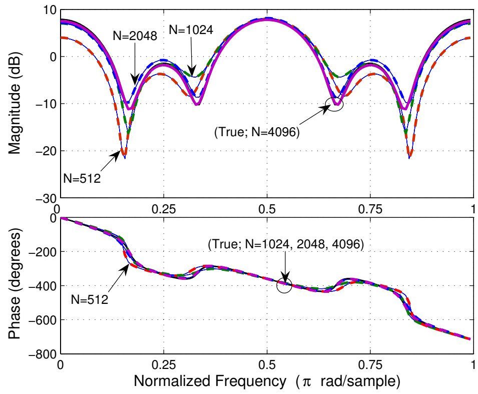

Fig. 6. Estimated magnitude and phase of the Macchi channel impulse response, for different data length, $SNR = 40dB$.

C. BRAN A channel

In this paragraph we consider the BRAN A model representing the fading radio channels, the data corresponding to this model are measured in a scenario of transmission in local office. The following equation (19) describes the impulse response of BRAN A channel.

$$h(n) = \sum_{i=0}^{N_T} C_i \, \delta(n - \tau_i) \qquad (19)$$

where $\delta(n)$ is Dirac function, C_i the magnitude of the target i, $N_T = 18$ the number of target and τ_i is the delay of target i.

In the Table III we have summarized the values corresponding the BRAN A channel impulse response.

TABLE III
DELAY AND MAGNITUDES OF 18 TARGETS OF BRAN A CHANNEL

delay $\tau_i(ns)$	mag. $C_i(dB)$	delay $\tau_i(ns)$	mag. $C_i(dB)$
0	0	90	-7.8
10	-0.9	110	-4.7
20	-1.7	140	-7.3
30	-2.6	170	-9.9
40	-3.5	200	-12.5
50	-4.3	240	-13.7
60	-5.2	290	-18
70	-6.1	340	-17.4
80	-6.9	390	-20.9

1) Estimated BRAN A channel using only 6 first target: The proposed algorithm is used to estimate the BRAN A channel for different data length and for different SNR. In this part, of modeling and identification, we have estimated only the sixth first target in order to know if we can reduce the number of parameters consisting the BRAN A channel impulse response. In the following figure (Fig. 7) we represent the estimated magnitude of BRAN A and using only the 6 first target for an $SNR = 32\mathrm{dB}$ and $N = 2048$.

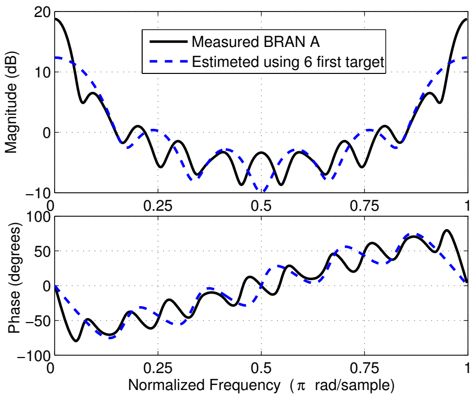

Fig. 7. Estimated magnitude and phase of BRAN A, $SNR = 16dB$.

From the figure (Fig. 7) we have approximately the same allure of the estimated (magnitude and phase) and the true ones, this is because the 6^{th} first targets have the maximum magnitude comparing to the following 12^{th} targets. The same remark can be done to the phase impulse response. So, in some context of study we can limit our modeling of channel BRAN A in the sixth first targets.

2) Estimated BRAN A channel using all target: Although, the BRAN A channel is constituted by $N_T = 18$ parameters and seeing that the latest parameters are very small. So, in order to estimates the parameters -constituting the BRAN A channel impulse response- with maximum information obtained by calculating the cumulants function, we have taking the following procedure:

1) We decompose the BRAN A channel impulse response into four sub-channel as follow:

$$\mathrm{h}(\mathrm{n}) = \sum_{j=1}^{4} \mathrm{h}_j(\mathrm{n}); \tag{20}$$

$$\left(\mathrm{h}_j(\mathrm{n}) = \sum_{i=j}^{P_j} \mathrm{C}_j \ (\mathrm{n} - \ _j); \quad \sum_{j=1}^{4} \mathrm{P}_j = \mathrm{N}_T \right)$$

2) We estimate the parameters of each sub-channel independently, using the proposed algorithm.
3) We add all sub channel parameters, to construct the full BRAN A channel impulse response.

This procedure give us a good estimation of the impulse response channel. In the case of an $SNR = 16\mathrm{dB}$ and for the data length varying from $N = 2048$ to $N = 6144$. In the following figure (Fig. 8) we have represented the estimated magnitude and phase of the impulse response BRAN A.

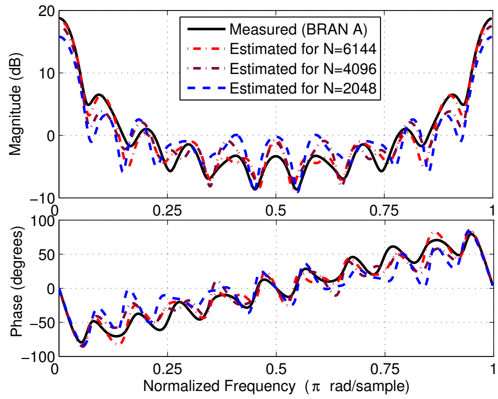

Fig. 8. Estimated magnitude and phase of BRAN A channel for different data length and for an $SNR = 16dB$.

From the Fig. 8 we observe that the estimated magnitude and phase are the same allure and we have not more difference between the estimated and the true ones. In conclusion, if increase the data length, i.e. $N \geq 4096$, the estimated magnitude and phase will be more closed to the true ones. In time domain we have represented the BRAN A channel impulse response parameters (Fig. 9)

Now we have estimated the magnitude and phase of BRAN A channel impulse response for different data length and for an $SNR = 32\mathrm{dB}$ (Fig. 10). We remak an apparent progress of the magnitude and phase estimation, more closed to the true ones, this is due to the influence of the colored noise on the estimation. The following Fig. 11 represent the estimated BRAN A channel impulse response for different data input and for an $SNR = 32\mathrm{dB}$. From the figure (Fig. 11) we ca can conclude that the estimated BRAN A channel impulse response are very closed to the true ones, principally for high data length ($N = 4096$ and $N = 6144$), for an $SNR = 32\mathrm{dB}$. Concerning the BRAN A channel impulse response for the data length $N = 2048$ we have a minor difference to the measured ones. This results is very interest such as the estimation of channel frequency selective impulse response in noisy environment.

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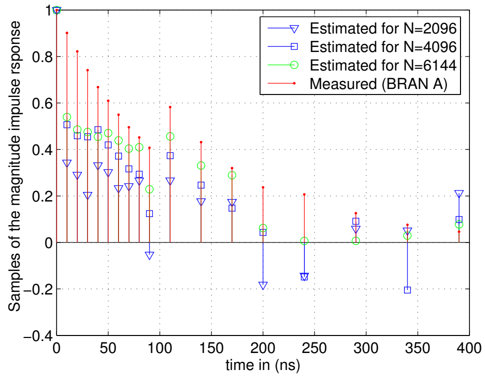

Fig. 9. Estimation of the BRAN A channel impulse response for different data length and for $SNR = 16dB$.

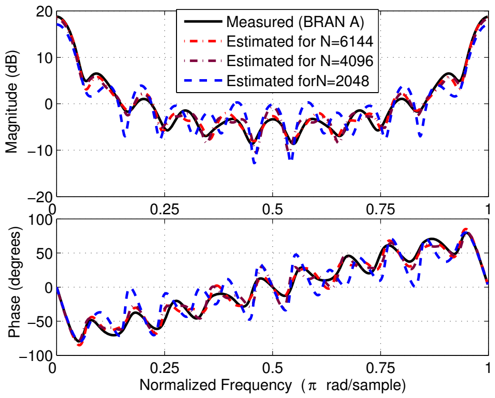

Fig. 10. Estimated magnitude and phase of BRAN A for different data and for $SNR = 32dB$.

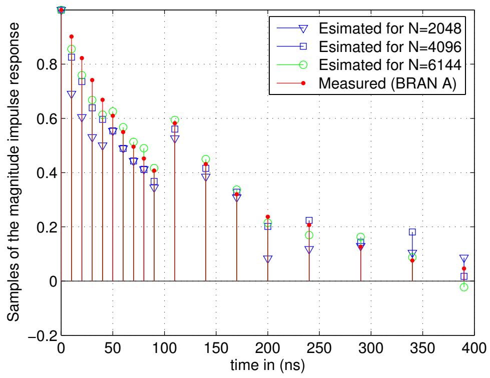

Fig. 11. Estimation of the BRAN A channel impulse response for different data length and for $SNR = 32dB$.

III. Conclusion

In this paper we have presented an algorithm based on third order cumulants. The proposed algorithm is used to identify the parameters of the impulse response of the frequency selective channel such as the Proakis 'B' and Macchi channel's. The simulation results are very important to show the efficiency of our algorithm. The phase estimation of the channel impulse response is estimated with higher precision, this is because the HOC constitute the best element to estimate the system phases. Also the magnitude of the impulse response is estimated with an acceptable precision in noisy environment in the case of small data. In the future we will test the efficiency of the proposed algorithm for the identification of the mobile channel, especially MC-CDMA (Multi-Carrier Codes Division Multiple Access) systems.

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