Signal Processing 137 (2017) 109–123

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

A *p*th order moment based spectrum sensing for cognitive radio in the presence of independent or weakly correlated Laplace noise

Xiaomei Zhu[a,*], Yingdong Zhu[a], Yaping Bao[a], Weiping Zhu[b]

[a] College of Electronics and Information Engineering, Nanjing Tech University, Nanjing, 211816, China
[b] Department of Electrical and Computer Engineering, Concordia University, Montreal, Quebec, H3G1M8, Canada

ARTICLE INFO

Article history:
Received 5 September 2016
Revised 19 December 2016
Accepted 25 January 2017
Available online 27 January 2017

Keywords:
Cognitive radio
Spectrum sensing
POM
Non-Gaussian noise

ABSTRACT

In cognitive radio systems, noise samples are often assumed to be independent Gaussian in order to simplify the spectrum sensing problem. However, due to the high frequency of sampling, a certain level of correlation exists among the noise samples. Furthermore, non-Gaussian noise often has a negative effect on the signals which the secondary users finally receive. Spectrum sensing methods based on the independent Gaussian noise assumption may not achieve satisfying detection performance when noise samples are correlated and non-Gaussian distributed. A novel signal detection method based on *p*th order moments (POM) in a multi-user cooperative scheme is proposed to address spectrum sensing issue for both independent and weakly correlated Laplace noise. Different from other detectors, our detector does not require a priori knowledge of PU, noise and communication channels. Theoretical performance measures are derived and verified for both independent and weakly correlated Laplace noise. Moreover, the detection performances versus signal-to-noise ratio *SNR*, order p, scale parameter b and correlation coefficient τ of the background noise are investigated by computer simulation. It is shown that, for both independent and weakly correlated Laplace noises, the POM-based detector outperforms energy detector (ED) and polarity-coincidence-array (PCA) detector when $p < 2$.

1. Introduction

An efficient use of spectrum resource is essential in broad-band wireless communications. With the rapid development of wireless communication systems, the demand for wireless spectrum has been increasingly growing ever the past decades. However, the wireless spectrum resources have not been utilized efficiently in the traditional fixed allocation mode [1]. Therefore, cognitive radio (CR) has been proposed to alleviate the shortage of radio spectrum resources and improve the utilization rate of spectrum [2,3].

By sensing and learning from the surrounding wireless communication environment, CR technology can adjust transmission parameters (such as power, frequency, modulation and encoding, etc.) intelligently, with an aim to access the temporarily unused wireless spectrum for communication. One of the most fundamental technologies in cognitive radio is spectrum sensing [4], which is proposed to deal with two kinds of users in CR: primary users (PUs) and secondary users (SUs). The purpose of spectrum sensing is to determine whether there are primary users in the communication channels. According to this, spectrum sensing can be divided into two situation :H_0 (PU is absent) and H_1 (PU is present). When the primary users are absent, the secondary users can enter the channel to communicate. However, once the secondary users have detected the existence of a primary user, they must quit the channel within a specified period of time to avoid interfering the communication of PUs. According to IEEE 802.22 standard, the disengaging time is limited to two seconds [5].

Non-Gaussian noises often exist in a realistic wireless communication system, which have adverse effects on the signals that SUs have received. Furthermore, it is very difficult for SUs to make an accurate decision in complex environments that are characterized by weakly correlated non-Gaussian noises and fading effects.

A non-Gaussian noise can be the man-made impulsive noise, mutual interference among cognitive users, spectrum leakage and interference of the ultra-bandwidth system, etc [6]. At present, several probability models are commonly used to fit the non-Gaussian distributions, including the generalized Gaussian distribution (GGD), mixed Gaussian distribution (MGD), τ-distribution and alpha stable distribution, etc [7]. It is known that Laplace model, as a special case of GGD model [8], is widely used to simulate real-world noises with heavy tail in signal processing area [9,10]. Furthermore, this distribution only needs location and scale

* Corresponding author.
E-mail addresses: njiczxm@njtech.edu.cn, njiczxm@njut.edu.cn (X. Zhu).

http://dx.doi.org/10.1016/j.sigpro.2017.01.030
0165-1684/

parameters. Different degrees of tailing can be achieved through a scale parameter. In this paper, we focus on a class of noise that has Laplace distribution.

In most of prior works, noise samples are assumed to be statistically independent, which is not true in realistic sampling processes, especially when the sampling frequency is high, which leads to a weak correlation among noise samples. Under this circumstance, to ensure the sensing performance of a CR system, it is essential to take correlation among the noise samples into consideration. Correlated noise can often be modeled as ϕ-mixed noise [11], m-correlated noise [12] or transformed noise [13]. When the noise components are weakly correlated, on the other hand, an independent random process corresponding to first order moving average (First-Order Moving Average, FOMA) is often exploited to simulate the weak correlation noise model [14,15]. In this paper, we investigate sensing performance in the background of independent as well as weakly correlated Laplace noise.

Because of the non-Gaussianity of background noise, sensing performance of traditional signal detectors (such as energy detector, which is based on second order statistics) will be degraded or become inaccessible. Thus, it is very important to investigate how the primary users can be efficiently detected without suffering from communication interference due to the non-Gaussian noise. There have been some literatures about spectrum sensing in non-Gaussian or weakly correlated noises. In [16], a non-parametric detection device called Polarity-Coincidence-Array (PCA) is applied to sense PU signal in non-Gaussian noise. However, if the shaping parameter is larger than 2, a PCA detector does not show a better performance than an energy detector. The optimal detector based on generalized likelihood ratio test (GLRT) was proposed in [17] and [18] to detect the PU signal in non-Gaussian noise. However, this detector needs to make maximum likelihood estimation in both H_0 and H_1 hypotheses which requires a great deal of complex calculation. Compared to the GLRT detector, the Rao test based detector in [19–21] only needs to estimate unknown parameters in H_0 hypothesis which means a less computational load. Fractional lower order moment (FLOM) based detector is put forward to detect spectrum holes in non-Gaussian noise in [29]. It is a blind sensing detector and easy to perform. The literature [22] proposes a detection method based on Kerenlized Energy Detector (KED) in the scenario of non-Gaussian noise. This detector can sense holes accurately with moderate computational complexity. It is to be noted that, the aforementioned five detectors have assumed independent noise. The authors of [23] exploit statistical covariance matrix based detector to perform spectrum sensing under the assumption of correlated noise. But its performance is restricted when the correlation is low (e.g. correlation coefficient $\tau = 0.2$). A Semi-Constant False Alarm Rate (S-CFAR) based detector is introduced in [24] under the assumption of correlated noise, too. The noise and source covariance matrices are acquired by taking the advantage of low-rank & sparse matrix decomposition. Nevertheless, the noise in both [23] and [24] is subjected to Gaussian distribution. In [25] and [26], a locally optimal detector in the time domain and a locally-optimal Neyman-Pearson detector in the frequency domain are investigated in the context of weakly correlated noise, respectively, in which the former is based on the assumption of AWGN while the latter is under non-Gaussian noise. But both of them require access to noise distribution which is usually unavailable before hand.

Cooperative spectrum sensing (CSS) is considered as a valid technique to improve sensing robustness by overcoming fading, shadowing and hidden terminals [27,28]. Recently, there have been many literatures applying CSS to improve sensing performance in correlated Gaussian noise. More attention should be concerned on utilizing cooperation in a scenario of correlated Non-Gaussian noise.

In this paper, a cooperative method based on pth order moments (POM) is proposed to address the spectrum sensing issue for both independent and weakly correlated Laplace noise. We investigate the sensing performance of POM detector under non-fading and Rayleigh fading channels separately. Besides, we analyze the relationship between the detection probability and the deflection coefficient. One of the significant advantages of the POM detector is that there is no need to obtain a priori knowledge of PU signals, noise and communication channels. Meanwhile, POM detector shows a better performance than ED and PCA detectors with the same computational complexity for CSS. According to numerous simulations, we find the POM detector can also achieve competitive detection performance under other uncorrelated or weakly correlated non-Gaussian noises.

Our principal contributions in this paper include: (1) We investigate sensing performance of the proposed POM detector versus signal-to-noise ratio *SNR*, scale parameter b, order p and correlation coefficient τ for independent and weakly correlated Laplace noises under non-fading as well as Rayleigh fading channels. (2) We derive detection probability P_d (the probability of detecting PU under H_1) of the POM detector in the regime of deflection coefficient d_p under non-fading channel for both independent and weakly correlated Laplace noises. (3) We derive a numerical relationship between detection probability P_d and false alarm probability P_{fa} (the probability of detecting PU under H_0) of the POM detector under non-fading and Rayleigh fading channels for independent as well as weakly correlated Laplace noises. (4) We calculate the detection probabilities and prove the validity of theoretical equations. (5) Numerical and simulation results are given to demonstrate that the POM detector is applicable for both independent and weakly correlated Laplace noises. Furthermore, it is shown that comparing to energy detector and the PCA detector, the proposed POM detector has a better detection performance when $p < 2$.

The reminder of this paper is organized as follows: in Section II, the system model, noise model and a test statistic based on pth-order moments are introduced. In Section III, sensing performance of the POM detector under non-fading and Rayleigh fading channels in the presence of independent Laplace noise is investigated. The numerical relation between detection probability P_d and deflection coefficient d_p is derived. In Section IV, sensing performance of the POM detector is investigated for weakly correlated Laplace noise. Simulation results along with some discussions are shown in Section V. Section VI draws the conclusion about the proposed POM detector.

2. Problem formulation

2.1. System model

Here we assume that a cognitive radio network is composed of a primary user, I secondary users and a fusion center. Each cognitive user detects the primary user over the wireless channel within a specified time interval. In this paper, we use soft fusion. Hence, CRs don't need to decide whether PU exists or not. The detection results are directly sent to the fusion center which makes the final decision. Thus, the spectrum sensing problem can be formulated with a two-hypotheses test model: H_0 and H_1. Suppose the number of observed samples is J under the two hypotheses, the spectrum sensing model, at discrete-time $j \in \{1, 2, \ldots, J\}$, being written as

$$\begin{cases} H_0: & z_i(j) = w_i(j) \\ H_1: & z_i(j) = h_i s(j) + w_i(j) \end{cases} \tag{1}$$

where $z_i(j)$ is the observed value of the i-th secondary user $i \in \{1, 2, \ldots, I\}$ at time j, $s(j)$ is the PU signal at time j with $E[s(j)] = 0$