Computers and Electrical Engineering 52 (2016) 226–239

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

# Adaptive energy detector for spectrum sensing in cognitive radio networks

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ARTICLE INFO

*Article history:*
Received 27 January 2014
Revised 23 August 2015
Accepted 27 August 2015
Available online 12 September 2015

*Keywords:*
Spectrum sensing
Energy detection
Noise variance estimation
Noise uncertainty

ABSTRACT

The traditional approach for energy detection (ED) consists in the comparison of the energy received against a fixed detection threshold, estimated according to an expected noise level. However, the noise power is not a static parameter since it varies as a function of the random sources of noise and interference present in the network. This random nature of the noise power originates the so-called noise uncertainty problem which adversely affects the performance of the ED. In this paper, we propose and evaluate by means of computer simulation an adaptive energy detector that incorporates a noise power estimation strategy for adjusting the detection threshold according to the noise power present at each sensing epoch. As it can be proved by simulation results, our strategy helps in reducing the sensing errors and to improve the ED's sensitivity by alleviating the negative effects of the noise uncertainty.



## 1. Introduction

The recent advances in spectrum accessing policies result in a more flexible and efficient use of the radio spectrum [1,2]. This in turn could open the possibility for the deployment of improved and emergent wireless and mobile applications, ranging from smart grid, public safety, and broadband cellular to medical applications [3]. The dynamic spectrum access (DSA) enabled by the cognitive radio (CR) technology would provide the technological solution for opportunistically accessing to the currently underutilized frequency bands [4]. In the DSA, a CR senses the licensed spectrum to find unoccupied frequency bands suitable for secondary use, and exploits the discovered spectrum in an interference-free manner such that the efficiency on the spectrum use is maximized. The key components of CR are the capability of sensing the radio spectrum to opportunely declare if a licensed band is vacant or if it is occupied by its incumbent. This would ascertain that the CR operation will not interfere with the licensees' transmissions, and that the spectrum reuse opportunities present in time and space will be efficiently exploited [5].

Spectrum sensing is defined as the stage of observation and analysis of the signals contained in the spectrum to gain radio awareness. To the date, there have been proposed a number of spectrum sensing techniques, each of them capable of offering a degree of accuracy and complexity when detecting the presence of primary signals, i.e., the signals transmitted by the incumbents of the licensed bands. Pros and cons of the spectrum sensing techniques are discussed in many studies, for example [6,7]. The constrained time dedicated for spectrum sensing, multipath fading and time dispersion of the wireless channel, the highly dynamic radio environment and the limited information regarding the signals transmitted in the spectrum are, to name a few, the major concerns in the design of reliable spectrum sensing algorithms [8].

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http://dx.doi.org/10.1016/j.compeleceng.2015.08.013

Energy detection (ED) is an appealing signal detection technique for spectrum sensing due to its low computational complexity and generic implementation, i.e., it does not require knowing the structure of the primary signal to make decisions regarding its presence. In the traditional approach for ED the energy is estimated and then compared against a detection threshold. The detection threshold is commonly set according to the expected noise floor. A fundamental issue with this approach stems from the fact that the noise in communications systems is the aggregation of random sources of power, including thermal noise, interference due to nearby unintended emissions or weak signals from transmitters located far away. Therefore, it is likely that the noise power changes randomly from a detection interval to another, particularly if the cognitive user changes continuously its radio environment, originating the so-called noise uncertainty problem. If the ED's detection threshold is not adjusted accordingly to the fluctuations in the noise power, then it is likely that its performance is reduced dramatically, giving place to a limit on the signal-to-noise ratio (SNR), known as *SNR-wall*, below of which signal detection becomes unreliable, or even impossible, regardless of the time the signal is observed [9].

Given that the decreased performance of the ED in the presence of noise uncertainty is due to the lack of correctness in the detection threshold, then a feasible approach is to adapt the detection threshold to the random fluctuations in the noise power [9]. This approach allows counteracting the negative effects of the noise uncertainty because the detection threshold changes as the noise power does. In this sense, in order to add robustness to the appealing ED technique, in this paper we propose an adaptive energy detector (AED) that includes a noise power estimation (NPE) stage with the aim of adapting the detection threshold to the noise power present at the time of spectrum sensing.

If we assume that spectrum sensing is carried out with the cooperation of multiple receivers, then it is possible to exploit the fact that when the signal received is composed by only noise samples the maximum likelihood (ML) estimate of the noise power can be derived by averaging the eigenvalues of the covariance matrix [10]. Furthermore, even if a primary signal is present in the received signal, it is possible to estimate the noise power to some exempt of accuracy, by averaging all but the largest of the eigenvalues. We consider this strategy for NPE and adapting the decision threshold to the noise power present at each sensing event. In this sense, the major contributions of this paper are the identification of a suitable strategy for NPE that works using the samples received for spectrum sensing even when the samples contain traces of a primary signal, and the integration of such a strategy in the formulation of the ED for addressing the noise uncertainty problem.

The rest of this paper is structured as follows: in Section 2, a summary of the most significant related works is presented. The system model along with the formulation of the spectrum sensing problem is presented in Section 3. The theoretical formulation of ED is described in Section 4, here its performance metrics are derived and a brief discussion of the noise uncertainty is presented, also the formulation of the proposed adaptive energy detector is presented in this section. The results of the performance evaluation of the proposed detector are described and discussed in Section 5. Finally, Section 6 presents the concluding remarks of our research work.

## 2. Related work

ED has been the most considered signal detection technique for spectrum sensing in CR systems [11], and several works presenting improvements for the ED have been published, see e.g. [12,13], and [14]. However, only a few published works are focused on addressing the problem of the noise uncertainty. An initial attempt to deal with the noise uncertainty is presented in [15]. The authors in [15] derive a statistical model for modifying the detection threshold as a function of the error in the noise power estimate, with the aim to maintain an expected performance for the ED. However, the authors do not figure out how to estimate the noise power. In [16], the noise uncertainty is counteracted by adapting the detection threshold to the noise fluctuation by means of noise and signal power estimation. The presented algorithm performs better than the traditional approach for ED under noise uncertainty. However its performance is affected if the primary signal is dispersed over the entire bandwidth monitored, because the proposed algorithm will not be able to perform a reliable estimation of the noise power. This indicates that its performance is affected by the spectral shape of the primary signal making it efficient only for certain types of primary signals. In [17], the effects of using a noise power estimate for determining the detection threshold for ED are analyzed. The approach for estimating the noise power is to perform periodical noise calibration by making use of noise-only samples. Nevertheless, if the noise power changes before the next calibration period, then the difference between the expected and the actual noise power may affect the performance of the ED. In [18], a double detection threshold strategy is proposed and evaluated. The results show that the detector performance can be improved by adapting the decision thresholds to the uncertainty range. However, if the expected range of the noise uncertainty changes, the performance of the detector is affected. Therefore, its robustness is still compromised by the lack of knowledge. In [19], a cross-correlation technique is proposed for reducing the noise uncertainty with the aim of lowering the SNR-wall in ED. The authors conclude that their proposal effectively improves the detection speed and sensibility of the ED as long as the noise samples are uncorrelated. However, when the noise samples present correlation, the proposed algorithm fails at mitigating the uncertainty and therefore, the performance of ED is reduced.

There exist other signal detection techniques that overcome the problem of noise uncertainty without requiring primary signal information. The covariance-based detection (CBD) [20] is able to identify the presence of a primary signal by observation of the covariance matrix of the received data. Eigenvalue-based detection (EBD) [21] and generalized likelihood ratio-based detection (GLRD) [10] exploit the spatial diversity gained in multiple-receiver systems for detecting primary signals. Nevertheless, CDB fails in detecting the presence of primary signal when the signal samples are independent and identically distributed (i.i.d.) as is the case, for example, of orthogonal frequency division multiplexed (OFDM) signals, which are considered in most of the modern communication systems. The performance of the EBD and GLRD is upper-bounded in practical implementations by the limited