Spectrum Sensing based on Energy Detection Algorithms using GNU Radio and USRP for Cognitive Radio

Cosmina-Valentina Năstase, Alexandru Marțian, Călin Vlădeanu, Ion Marghescu
Telecommunications Department
University Politehnica of Bucharest
Bucharest, Romania
E-mail: nastase.cosmina@gmail.com

***Abstract*—Cognitive Radio technology focuses on the efficient use of the radio frequency spectrum. One of the challenging tasks for secondary users (SUs) is Spectrum Sensing, used to accurately detect primary users (PUs) and not to interfere with their signals. In this paper, we design a CR system in a real environment and test three spectrum sensing algorithms based on Energy Detection (ED). The capability of sensing the radio spectrum is implemented using two Universal Software Radio Peripheral (USRP) platforms combined with the GNU Radio software toolkit. The three ED algorithms are compared in terms of performance, taking into account the PU activity duty cycle in a low SNR scenario. We present the performance of these three algorithms for DPSK modulation as a primary signal to check the feasibility of these methods.**

***Keywords*— Energy Detection, GNU Radio, Spectrum Sensing, USRP, Cognitive Radio**

I. Introduction

In the last decades, wireless communications systems have rapidly developed, which has led to a radio spectrum overloading in almost all regions of the world. Classical radio spectrum management policy and strategies can no longer meet current users' demands. More than that, many measurement campaigns confirmed the fact that the frequency spectrum is inefficiently used [1]-[2]. Electromagnetic spectrum management has caught the scientists' attention with the emergence and development of new technologies. Awareness of the need for efficient use of RF spectrum resources has led to the dynamic approaches of allocating radio resources, instead of the static variants. Cognitive Radio (CR) technology is increasingly used in order to solve this spectrum scarcity problem.

A CR solution focused on the efficient use of RF spectrum is based on the idea that there are licensed primary users (PUs) and unlicensed secondary users (SUs). Each SU has the right to access the radio spectrum temporarily not used by the PU, but it must not interfere with the primary user activity. For this purpose, the SU should detect the presence or absence of the PU. To achieve this goal as accurately as possible, each SU must perform the real-time RF spectrum sensing process.

There are several methods to implement this function, the most commonly used being Energy Detection (ED). This method is frequently used because of its low complexity, i.e., it is easy to implement and does not require any priori information about the signals used by the PU.

In [3] an Improved Energy Detection (IED) is proposed, using a supplementary decision test based on the average energy of a defined number of consecutive events. In [4], we deployed a more accurate algorithm by removing the current observation event from the average energy calculation. In [5], another improved energy detection algorithm, named Three-Event ED (3EED), was introduced. In this case, the decision for the current event is taken using three consecutive events, i.e., the current event, the previous one and the next one. More than that, this last mentioned algorithm exploits also the knowledge of the PU activity duty cycle parameters and proves the relationship between these parameters and the detection performance.

The performance of these advanced energy detection methods mentioned above was analyzed theoretically and by simulation, but it is also necessary to check its performance in a real scenario. In this paper, we implement a CR scenario and apply the advanced energy detection methods on real received signal samples. In order to implement this spectrum sensing CR capability, we used Universal Software Radio Peripheral (USRP) platforms, viewed as a low-cost and high-quality SDR and used in many experimental studies [6]-[8]. The accelerated hardware development of the SDR has led to an increasing software development process, in order to provide improved capabilities. GNU Radio is an open source software toolkit suitable to CR applications, due to a wide range of signal processing functions.

The rest of the paper is organized as following: Energy detection algorithms are introduced in Section II. In Section III, the experimental scenario and the main signal processing steps are described. The experimental results and performance comparison of the three ED algorithms are shown in Section IV. Conclusions are presented in Section V.

978-1-5386-2350-3/18/$31.00 ©2018 IEEE

II. ENERGY DETECTION ALGORITHMS

Energy detection method is an attractive approach of the radio activity detection in cognitive radio technology. Spectrum sensing can be described as how can we decide between two hypotheses of the received signal in the Additive White Gaussian Noise (AWGN) channel:

$$\begin{aligned} H_0 &: y(n) = w(n),\ n = 1,\dots,N \\ H_1 &: y(n) = x(n) + w(n),\ n = 1,\dots,N \end{aligned} \tag{1}$$

where H_0 is the hypothesis of primary signal absence, when the received signal y[n] corresponds to noise samples w[n] and H_1 hypothesis indicates the presence of licensed users signals, x[n]. N is the number of samples considered in the signal sensing event.

A. Classical Energy Detection (CED)

The classical method of energy detection consists of measuring the received PU signal energy during a sensing window and comparing it with a predefined threshold. The test statistic $\varphi_i(\boldsymbol{y}_i)$ for the *i*-th sensing event is written as:

$$\varphi_i(\boldsymbol{y}_i) = \sum_{n=1}^{N} |y_i[n]|^2 \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \tag{2}$$

In practice, the threshold λ is computed to satisfy a certain probability of false alarm:

$$\lambda = \left(Q^{-1}\left(P_{fa,target}^{CED}\right)\sqrt{2N} + N\right)\sigma_w^2 \tag{3}$$

where the σ_w^2 is the noise variance.

B. Improved Energy Detection (IED)

Compared to CED, the IED algorithm takes the decision based on other two supplementary tests: one using the average value of the test statistic calculated in the *i*-th sensing event and noted as $\Phi_i^{avg}(\boldsymbol{T}_i)$ and the other one using the test statistic of the previous event $\varphi_{i-1}(\boldsymbol{y}_{i-1})$. The average value of the consecutive test statistics is written as following:

$$\Phi_i^{avg}(\boldsymbol{T}_i) = \frac{1}{L}\sum_{l=1}^{L} \varphi_{i-L+l}(\boldsymbol{y}_{i-L+l}) \tag{4}$$

For the IED algorithm, the threshold is calculated with the same formula as in the CED algorithm.

Taking into account this approach, it can be avoided the missed detections caused by signal energy drops that will lead to lower false alarm probability.

C. Three-Event Energy Detection (3EED)

Theoretical performance of this algorithm was described in detail in [5]. To design this algorithm, it was assumed that the PU activity includes two states: the "busy" period characterized by an average number of *B* sensing events (or time slots) in which the primary user transmits and the "idle" period including *T-B* slots when the primary user does not transmit. It was also considered that PU transmits in bursts, i.e., without interruption during a certain period of time.

First, 3EED computes the test statistic in three consecutive events, $\varphi_{i-1}(\boldsymbol{y}_{i-1}), \varphi_i(\boldsymbol{y}_i), \varphi_{i+1}(\boldsymbol{y}_{i+1})$. The algorithm takes the decision of the PU presence in the current event, if the energy surpasses the threshold value in any of these three observation intervals. Otherwise, the PU is considered as absent if the energy is under the threshold value in any of these sensing events.

Assuming that a PU activity duty cycle characterized by $T - B \to \infty$ is more suitable for CR systems, the probability of false alarm is written as following [5]:

$$P_{fa,T-B\to\infty}^{3EED} = 3P_{fa}^{CED} - 3\left(P_{fa}^{CED}\right)^2 + \left(P_{fa}^{CED}\right)^3 \tag{5}$$

Using the equation solution for (5) in (3), the threshold expression for 3EED algorithm was given by:

$$\lambda = \left[Q^{-1}\left(1 + \sqrt[3]{P_{fa,target}^{3EED} - 1}\right)\sqrt{2N} + N\right]\sigma_w^2 \tag{6}$$

It is important to notice that, even if the proposed algorithm was defined taking in account the PU activity parameters, the value of the threshold given by (6) is independent of these parameters.

III. EXPERIMENTAL SCENARIO

For testing the energy detection algorithms previously mentioned in Section II, the experimental scenario shown in Fig.1 was chosen. Two USRP platforms, one from the High Performance category (X310) and one from the Networked category (N210), were used for the CR scenario. Two Intel Core i5 processor laptops running Ubuntu Linux and the GNU Radio and Mathworks MATLAB environments were used for primary user signal generation at the transmission part and for the received signal processing at the reception part. Thus, one laptop and X310 USRP platform acted as the transmitter (primary user), while the other laptop and N210 USRP platform were used as the receiver (secondary user). The two USRP platforms were connected with a 1m length SMA-SMA coaxial cable with a very low attenuation at GHz frequency transmissions. This configuration was chosen to create a controlled radio environment in terms of external noise.

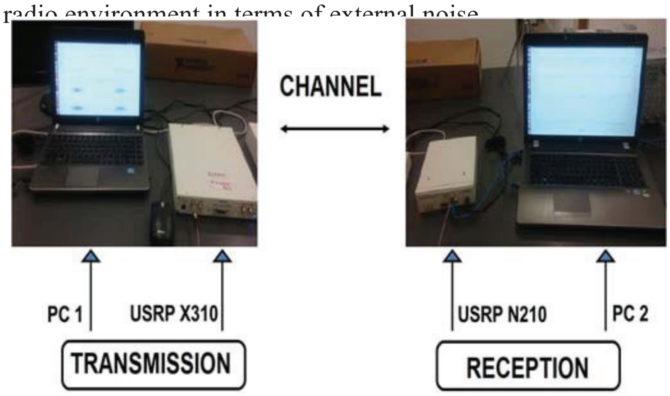

Fig. 1. Experimental setup

According to the hypothesis of the algorithms, the noise should be white, Gaussian and additive and the SNR should have a fixed and well-defined value. Thus, it was chosen to introduce this requested noise using software tools, assuming there is no noise through the coaxial cable.

The GNU Radio Companion Graphic Interface was used to generate the primary user signal and set the desired parameters. A signal generated by a **Random Source** block, was modulated with a **DPSK Mod** block and after that, sent to the USRPX310 using the **UHD:USRP Sink** block. The central transmission frequency was set to 1.8GHz, samples/symbol of 4, bandwidth of 6MHz, FFT size of 2048 and level of transmitted signal of -30dBm.

In order to receive, analyze and view the PU signal, different approaches have been pursued.

A. GNU Radio Companion Graphic Interface

A similar chain of blocks as the one from the transmission module is used. At reception, the signal was received from the N210 USRP using the **UHD: USRP Source** and the signal spectrum was viewed using the **QT GUI Frequency Sink**. The level of the received signal centered on 1.8GHz was -82dBm. Compared with the generated signal level, we can observe that an attenuation of 52dB was introduced in the communication channel.

B. GNU Radio uhd_fft Application

Using the *uhd_fft* application, the signal can be received and graphically represented in terms of power, time and amplitude. More than that, we could also manually adjust the reception parameters.

C. Usrp_spectrum_sense.py python script

The application provided by GNU Radio for the data acquisition received from an USRP in order to obtain spectrum information in a particular frequency band, consists of a set of blocks that contribute to the processing of the signal received through the UHD driver. The frequency band can be selected by the user, changing the input parameters values. The chain uses the *uhd.usrp_souce*, *gr.stream_to_vector, gr.fft_vcc, gr.complex_to_mag_squared and gr.bin_statistics* blocks to capture, convert and process the received signal.

D. Data processing using the MATLAB environment

The output files generated using the python script were imported in the MATLAB environment as input data for the energy detection algorithms presented in Section II.

We chose the addition of a white Gaussian additive noise generated using the *awgn* function, assuming there is no noise on the coaxial cable between transmission and reception, in order to be able to follow the assumptions of the algorithms presented above. Moreover, in order to reproduce the primary user's activity as accurately as possible and to capture *idle -> busy* or *busy -> idle* transactions, it was decided to set a continuous transmission of the primary user signal and apply a mask at the reception to stop the reception of the signal for a certain number of samples. In this way, we can reproduce the absence of the primary user for a certain period of time. Otherwise, another possibility would have been a discontinuous and controlled transmission of the primary signal, but this requires a high-precision synchronization between the two USRPs. Fig.2 illustrates the experimental scenario diagram that was used in the laboratory.

IV. Results

The energy detection algorithms that were presented in section II (CED, IED and 3EED) were tested in the MATLAB environment, using the received data acquired with the python script approach. The three algorithms were run for 50,000 sensing events and N=1000 signal samples in each event. The IED computes the average energy for L=M=3 sensing events, SNR=-9.15dB, and variable primary user duty cycle parameters. Also, it was defined a target false alarm probability vector used to set the threshold value.

In Fig.3, the receiver operating characteristics (ROCs) of CED, IED and 3EED are presented for B=20 and T=100 values of the PU activity.

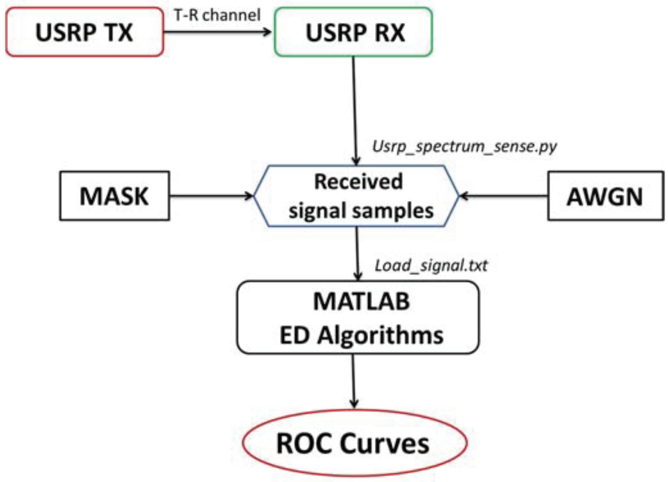

Fig. 2. Signal processing steps performed in the laboratory

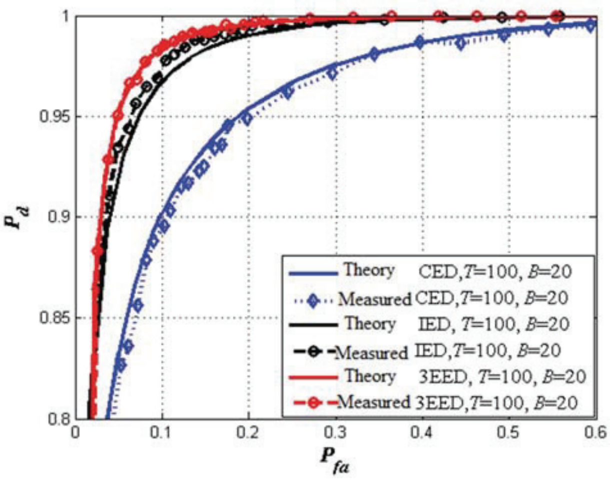

Fig. 3. ROC curves for ED algorithms for T=100 and B=20

We compare here the theoretical curves and the ones obtained using the real signal samples, for the three algorithms run in the same conditions. We can clearly notice that the 3EED and IED algorithms surpass in performance the CED algorithm. For example, for a false alarm probability equal with 0.1, IED and 3EED have a correct detection probability grater with more than 7% than the classical algorithm. These results confirm those of [5] in terms of shape and values.

Challenged by the idea of applying energy detection algorithms on buried signals, in Fig.4, is presented the dependency between SNR level and performance of the 3EED algorithm in terms of detection probability. Buried signals are characterized by a negative SNR. For our experiment, we added the AWGN noise so we can set some particular SNR values.

We can state that the performance of 3EED algorithm is improved with the SNR value, which was what we expected.

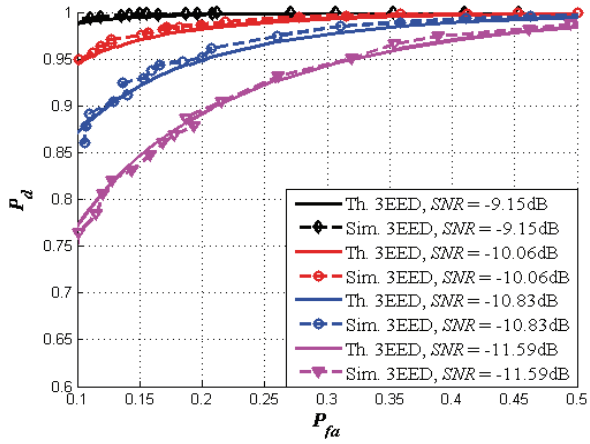

Fig. 4. The effect of SNR level on the performance of the 3EED algorithm

V. CONCLUSION

In this paper, we have presented an implementation of a cognitive radio scenario using GNU Radio and two USRP platforms to test the performance of three energy detection methods in low SNR environment and compare the results with the theoretical ones. It was confirmed that the 3EED algorithm provides an improved performance as compared to the classical method with more than 7% and the experimental ROC follows the theoretical one. The contribution of this paper consists in the fact that we have experimentally demonstrated that both advanced ED algorithms outperform the classical ED method in practical implementations. In order to have an experimental approach that is closer to real life situations, in the future we intend to extend our analysis using RF signal samples captured from a real radio environment.

ACKNOWLEDGEMENT

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398 and by University Politehnica of Bucharest, through the "Excellence Research Grants" Program, UPB – GEX 2017 (Identifier: UPB- GEX2017, Ctr. No. 34/2017).

REFERENCES

[1] M. Wellens, J. Wu, and P. Mähönen, Evaluation of spectrum occupancy in indoor and outdoor scenario in the context of cognitive radio, in Proc. Second International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrowCom 2007), pp. 420-427, August 2007.

[2] A. Marțian, Evaluation of Spectrum Occupancy in Urban and Rural Environments of Romania, in Revue Roumaine des Sciences Techniques - Serie Electrotechnique et Energetique, issue 1, pp 87-96, April 2014.

[3] M. López-Benítez and F. Casadevall, "Improved energy detection spectrum sensing for cognitive radio," IET Communications, Special Issue on Cognitive Communications, vol. 6, no. 8, pp. 785-796, May 2012.

[4] C.-V. Năstase, A. Marțian, C. Vlădeanu, and I. Marghescu, An Accurate Average Energy Detection Algorithm for Spectrum Sensing in Cognitive Radio Systems, in Proc. IEEE 11th International Symposium on Electronics and Telecommunications (ISETC14), Timişoara, pp. 131-134, November 2014.

[5] C. Vlădeanu, C.-V. Năstase, A. Marțian, Energy Detection Algorithm for Spectrum Sensing Using Three Consecutive Sensing Events, IEEE Wireless Communications Letters, Martie 2016.

[6] E-I. Dobre, A. Marțian, C. Vlădeanu, USRP-based Experimental Platform for Energy Detection in Cognitive Radio Systems,International Conference on Communication (COMM), 9-10 June, 2016.

[7] A. Mate, K-H Lee, I-T Lu, Spectrum Sensing Based on Time Covariance Matrix Using GNU Radio and USRP for Cognitive Radio, Long Island Systems, Applications and Technology Conference (LISAT), 6 May, 2011.

[8] N. M. Anas, H. Mohamad, M.Tahir, Cognitive Radio Test Bed Experimentation using USRP and Matlab/Simulink, International Symposium on Computer Applications and Industrial Electronics (ISCAIE 2012).