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Burst Signal Detector Based on Signal Energy and Standard Deviation

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***Abstract*—Paper focuses on the spectrum sensing for cognitive radio solutions. The new algorithm is proposed for burst signal detection in frequency band where only this type of primary user signal appears (e.g. GSM band). Proposed spectrum sensor use signal energy and standard deviation estimates for primary user signal detection. A single perceptron is proposed to define a threshold for spectrum sensor. To investigate the efficiency of proposed spectrum sensor the real environment measurements were performed in the frequency band used by GSM system for downlink. An additional analysis of the signal energy estimates showed the periodicity of the energy changes in time domain. The calculation of FFT for signal energy changes in time has proven the performance of proposed spectrum detector for low power (situated far away from spectrum sensor) primary user signal detection in situations where it is covered by environment noise.**

***Index Terms*—Energy detector, spectrum sensor, cognitive radio, GSM, burst signal.**

I. INTRODUCTION

A number of papers in recent years focus on the effective utilization of the unused radio spectrum even if it is assigned for primary user [1]–[5]. A spectrum sensor added to a physical layer of communication systems in cognitive radio solution is responsible on the detection of primary user in noisy environment. An opportunistic spectrum access should be provided for secondary users only if primary user is absent. The paper focuses on burst signal detection in GSM band using spectrum sensor.

Five most common spectrum sensing methods could be found in literature [4]: Energy Detector based sensing; Waveform-Based Sensing; Cyclostationarity-Based Sensing; Radio Identification Based Sensing; Matched-Filtering. These spectrum sensing techniques varies in complexity and primary user detection performance. The high complexity of the spectrum sensing algorithm is challenging for use in real time by low power devices. In this paper a modified energy detector based spectrum sensor is proposed. As an additional feature the standard deviation of received signal is analysed.

The problem of automatic threshold selection for energy detector based spectrum sensors is widely analysed in literature [6]–[10]. However, the lack of experimental studies for establishing the efficiency of these algorithms in real environment [9] requires performing an additional investigation. In this paper a single perceptron is used to adapt spectrum sensor threshold to the environment noise.

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The performance of automatic threshold selection techniques highly depends on the environment in which the spectrum sensor is applied. Evaluation of detector performance in simulated environment relies on the selected noise model. In this paper the real measurements of GSM downlink channel using low cost SDR [11] is performed for experimental investigation. Evaluation of spectrum sensor proposed in this paper is performed using pattern analysis technique based on estimation of high energy primary user signal cyclostationary features.

While several methods for GSM signal detection are proposed in literature [12], an algorithm proposed in this paper could be used for any type of burst signal and do not require complex analysis of signal sequences. A GSM band is used just for the test purpose.

The identification of idle slots for opportunistic spectrum access in GSM band should work even for low signal to noise ratio. Ability to detect a low power primary user signal is highly important for single node sensing detectors. The presence of receiver and shadowing uncertainty may reduce signal level of the primary user. It may cause interferences with the secondary node in situations when secondary signal passes primary transmitters range [13]. Proposed pattern matching technique enable primary user signal detection in situations when signal to noise ratio is as low as 3 dB.

II. FREQUENCY BAND ANALYSIS FOR TRANSMISSION OPPORTUNITY DETECTION

An energy detector is used for the analysis of the received signal spectrum. For cognitive radio with dynamic spectrum access the availability of different frequency bands is scanned over time. Taking into account that for wireless devices one of most important parameters is energy consumption the use of simple spectrum sensing algorithm is preferable.

Two least computationally intensive spectrum analysis algorithms are based on energy detector and matching filter. In this paper the energy detector is selected as the base for spectrum sensor. The received signal energy for selected frequency band is calculated according to

$$AVG^2 = \frac{1}{N}\sum_{n=0}^{N-1}\left|H_{j\mu}(n)\right|^2, \tag{1}$$

where $\left|H_{j\mu}(n)\right|$ is the magnitude of received signal Discrete-Time Fourier Transform (DTFT); N is the number of DTFT samples and n is the sample number.

Additionally the parameter $\pounds$, similar to standard deviation, is estimated for analysed frequency band according to equation

$$\pounds = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left(H_{j\mu}(n) - AVG^2\right)^2}. \tag{2}$$

The modification of standard deviation formula is made to reduce the computational load of the algorithm and perform in parallel to energy calculation. The changes in standard deviation formula lead to the value differences (in comparison to the results with classical expression) of about 0.07 % and do not affect the precision of spectrum sensor.

Two hypothesis of spectral opportunity could be made accordingly to calculated features (energy, modified standard deviation):

$$\mathrm{H}_0 : H_{j\mu}(n) = t(n), \tag{3}$$

$$\mathrm{H}_1 : H_{j\mu}(n) = t(n) + s(n). \tag{4}$$

The first hypothesis H_0 is accepted when received signal contains only noise components $t(n)$. Second hypothesis H_1 is accepted when received signal also have components of primary user signal $s(n)$.

Decision about hypothesis is made by estimating the threshold THD for energy estimate AVG^2 or modified standard deviation $\pounds$ according to equation [14]

$$THD = \pm_{noise}{}^2\left(1 + Q^{-1}(\mathrm{P_{fa}})\big/\sqrt{N/2}\right), \tag{5}$$

where $\pm_{noise}{}^2$ is the standard deviation of the noise and $\mathrm{P_{fa}}$ is the probability of false alarm. The estimation of noise standard deviation is made by additional analysis of selected frequency band. The $\mathrm{P_{fa}}$ is selected manually. The method is sensitive to the selection of false alarm probability. The low value of $\mathrm{P_{fa}}$ leads to missed low energy primary user signals and high values makes algorithm sensitive to noise fluctuations.

As an alternative threshold estimation method we propose a single perceptron with threshold activation function. At least two parameters are adjusted: input weight and bias of the neuron. The adjustment of these parameters is made using perceptron learning technique by giving the desired response examples to gives features. As an input of the perceptron we may use signal energy or modified standard deviation estimates (Fig. 1(a)). Also there is a possibility to use both features at once (Fig. 1(b)).

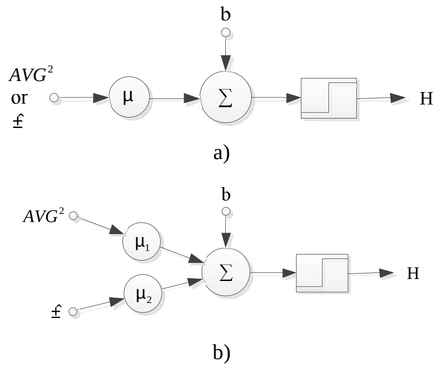


Fig. 1. A single perceptron for setting the hypothesis, a) – based on one feature; b) – based on two features.

The performance of perceptron depends on the training data. The collected data should contain noisy primary signal records of various intensity (signal to noise ratio) and noise records without primary user signal. The training of the perceptron is performed using stochastic gradient method. During training procedure the weights and the bias values are updated until the response of the perceptron (generated hypothesis) corresponds to the desired responses given in the training set. In the future research, it is appropriate to build algorithm with periodical perceptron training.

III. Experiment Setup

For the experimental investigation a low cost software defined radio (SDR) is selected. The records of the environment were made by USB dongle with RTL2832u demodulator and Elonics E4000 receiver (Fig. 2). The maximum bandwidth available using this receiver is equal to 2.8 MHz.

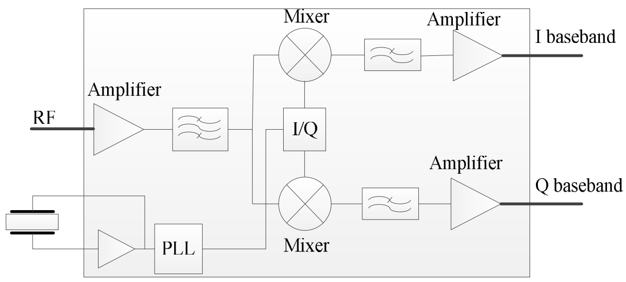


Fig. 2. The structure diagram of Elonics receiver.

The Elonics receiver gives two outputs: I baseband and Q baseband. To reconstruct full signal spectrum $H_{j\mu}$ these components are added together (Fig. 3)

$$H_{j\mu}(n) = \mathbf{I}(n) + j\mathbf{Q}(n). \tag{6}$$

A simplified structure of received signal analysis procedure is given in Fig. 3. A central frequency of the receiver is set to 888 MHz (a downlink frequency used by GSM).

As it is seen in the structure (Fig. 3), $H_{j\mu}(n)$ signal is passed throw a band-pass filter to select a particular frequency band. The created finite impulse response (FIR) band-pass filter has 250 kHz wide pass-band and is of order 67.

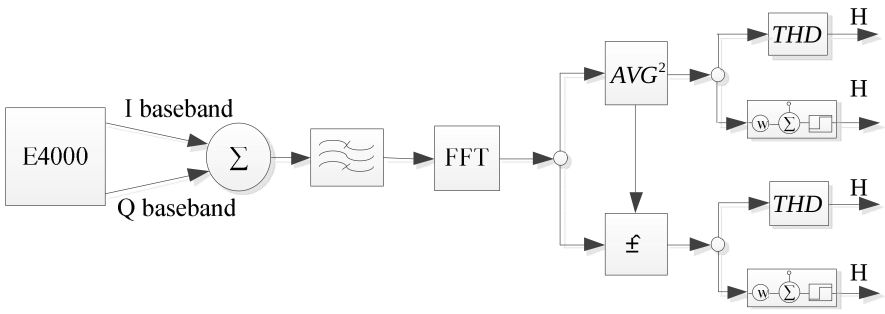


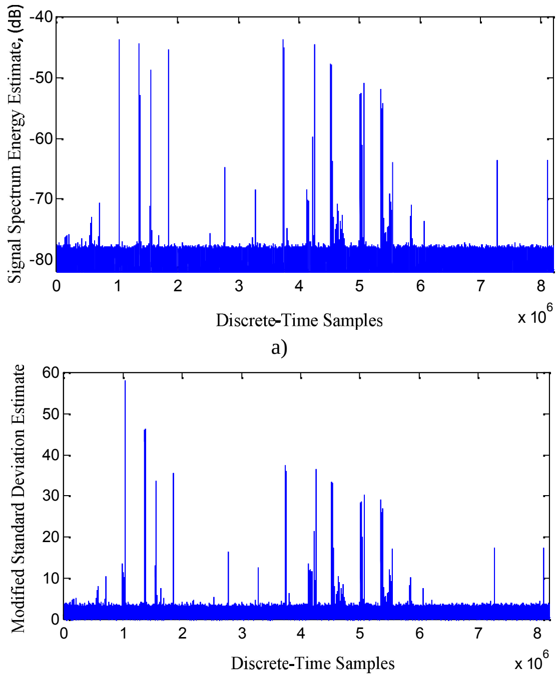
Fig. 3. A simplified structure of received signal analysis procedure.

Stop-band attenuation is selected equal to 80 dB at frequencies 25 kHz before lower cutoff frequency and 25 kHz above upper cutoff frequency of the filter. The DTFT is applied to filtered signal using 2500 samples wide analysis window (0.1 kHz width band is analysed in every window).

For the analysed band the energy AVG^2 and modified standard deviation $\pm$ are calculated. The connection between AVG^2 and $\pm$ showed in Fig. 3 is given because $\pm$ is calculated by using previously calculated values of AVG^2. The calculated spectrum features are compared to the THD estimated by (5) or applied to individually trained perceptron-based classifier.

IV. ANALYSIS OF THE EXPERIMENT RESULTS

The experimental investigation performed in real environment by recording more than 2 hours of radio signal in the city at 888 MHz frequency, used as downlink by GSM. The estimated energy of received signal spectrum is shown in Fig. 4(a).

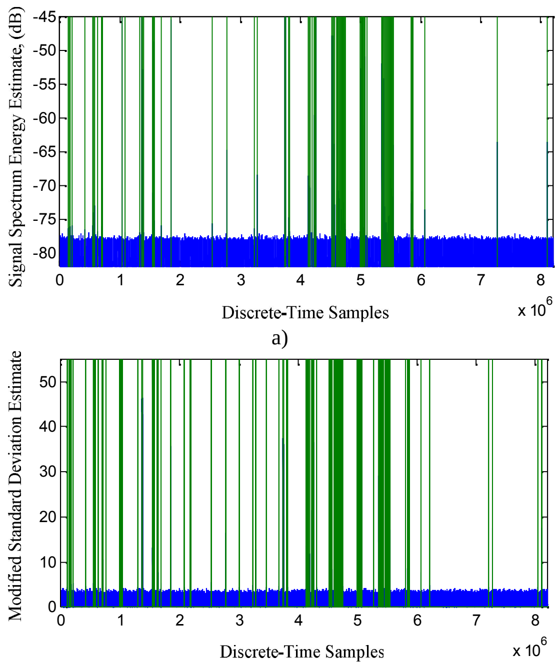


b)

Fig. 4. Graphical representation of received signal, a – spectrum energy estimates; b – modified standard deviation estimates.

The activity of primary users seen in the Fig. 4 also reflects on the modified standard deviation (Fig. 4(b)).

Two spectrum sensors were applied for received signal: based on energy estimates and based on modified standard deviation estimates. For each spectrum sensor an individual threshold THD value calculated. Figure 5 shows all indicated by sensors primary user activities.



b)

Fig. 5. Marked primary user signals, a – indicated by energy detector; b – indicated by modified standard deviation detector.

Figure 5 shows that the indications of primary user (indicated by vertical lines in the figure) are mostly at the same time in analysis of energy estimates (Fig. 5(a)) and analysis of modified standard deviation estimates (Fig. 5(b)).

Visually it is hard to test the efficiency of primary user detection on real environment data. As a solution for this situation we propose additional analysis of signal spectrum time window for detection of signal spectrum cyclostationary features.

Depending on the distance from SDR antenna to GSM receiver, the energy of the primary user signal varies from noise level (Fig. 6(d)) to more than 30 dB higher values.

A FFT applied to the estimated signal spectrum energy samples (Fig. 7) shows a characteristic peaks in the spectrum at the same normalized frequencies for all four sets of samples, shown in Fig. 6. This confirms the presence of the same type cyclostationary signal in all four cases.

To evaluate the performance of proposed spectrum sensors (based on energy detector and modified standard deviation), additional analysis of all measured energy and modified standard deviation estimates were performed using FFT. The results of evaluation are presented in Table I.

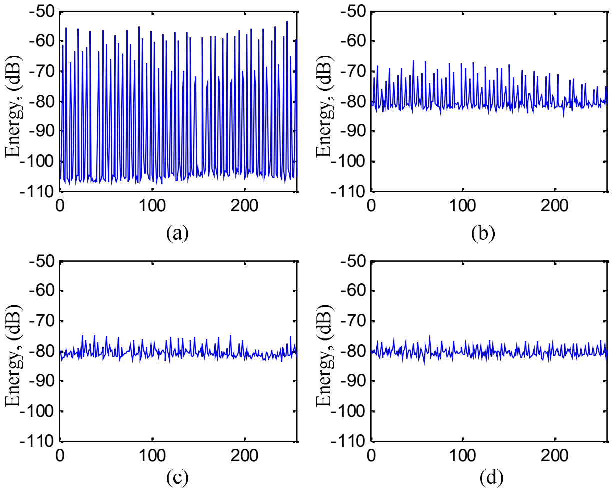


Fig. 6. Spectrum energy samples at different primary user indications.

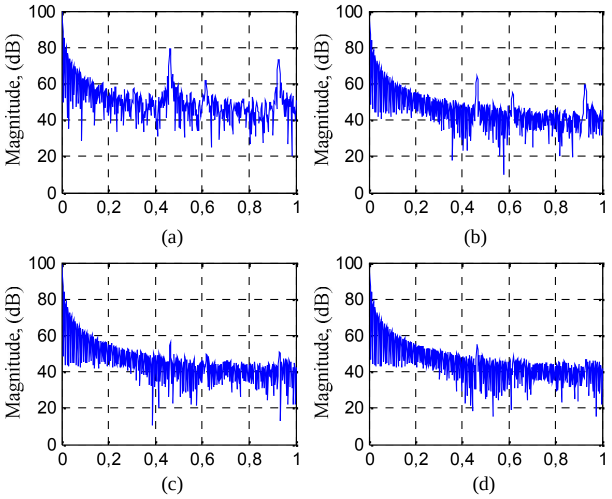


Fig. 7. Spectrum calculated for the spectrum energy samples.

TABLE I. SPECTRUM SENSOR PERFORMANCE EVALUATION RESULTS.

Sensor type	Indicated	False alarm	Not detected
Energy detector with *THD*	31 089 (38.92 %)	77 (0.1 %)	49 028 (61.08 %)
Modified standard deviation detector with *THD*	77 977 (97.21 %)	99 (0.12 %)	2 238 (2.79 %)
Energy detector with perceptron	29 715 (37.24 %)	52 (0.06 %)	50 377 (62.76 %)
Modified standard deviation detector with perceptron	80 228 (99.96 %)	150 (0.19 %)	38 (0.04 %)

The results of experimental investigation showed a very good performance of spectrum sensor, based on modified standard deviation. Only 0.04 %–2.79 % of all 80 266 received signals with cyclostationary features were not detected by this detector. The proposed threshold setting method, based on single perceptron, shows that there is a possibility to train the perceptron in order to increase the efficiency of primary user detection to only 0.04 % missed signals.

The lack of method for automatic training of perceptron is still a challenge for the threshold estimation. For frequency bands with known cyclostationary features of primary user signal, the threshold estimation could be performed using a generator of signal, having the same cyclostationary features.

V. CONCLUSIONS

The used of modified standard deviation estimate makes possible to identify 2.6–2.7 times more primary user signals comparing to the energy detector.

A single perceptron, proposed as an alternative to manual threshold setting method may increase the False Alarm ratio for the modified standard deviation based detector from 0.12 % to 0.19 %, however only 0.04 % of primary user signals remains not detected comparing to 2.79 % not detected signals using previous threshold setting techniques.

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