A Spectrum Sensing Algorithm for White Spaces Detection Validated in Real Environments

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Abstract. Cognitive Radio Systems have been proposed as the solution to spectrum scarcity, and Spectrum Sensing a good way to detect which frequencies are being used by primary users and avoid interferences. When primary signals are unknown, energy detection is the best while easiest technique for the sensing process. In this paper, we consider energy detection based spectrum sensing for narrowband signals in the TV wideband. Simulations are performed to obtain ROC curves. Designed detector has been validated both with signals generated in the laboratory and with real signals captured from the radio space.

Keywords: Energy detection, Spectrum Sensing, Cognitive Radio.

1 Introduction

Nowadays, due to spectrum scarcity, there is a big interest in a more efficient use of the spectrum by using Cognitive Radio systems. Spectrum Sensing techniques provide very useful information about spectrum occupancy and the presence of white spaces.

Many spectrum sensing methods have been proposed and theoretically analyzed in the literature. Matched filter has demonstrated good performance when primary user's signal is known [1]. Cyclostationary detection is based on the cyclic characteristics of primary signals to obtain good results [2]. Energy detection is a very used technique to detect the presence of unknown primary signals [3]. It is very flexible because it can detect many types of signal and it is not necessary to have any knowledge about them.

Up to now, there have been many theoretical studies of algorithms for finding spectrum holes, but it arises necessary to validate the good operation of this kind of algorithm with signals received in real environments and to obtain empirical results.

The main goal of this project is to develop an energy detection algorithm on the Matlab environment and to validate it with real signals. The algorithm is valid for detecting signals of different bandwidths along TV wideband.

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2 Energy Detector

In order to detect the presence of narrowband signals in a wideband, frequency domain energy detector has been developed. Consequently detection process results as follows [4]:

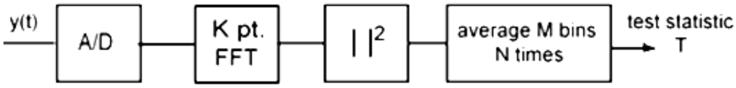

Fig. 1. Block diagram of energy detector in frequency domain

After digitizing, the time domain signal *y[n]* is transformed into the frequency domain signal *Y[k]* by applying a *K*-point FFT. The number of points of the FFT (*K*) is a function of the desired frequency resolution.

The detection is based on the test of two following hypotheses:

$$\begin{array}{lll} H_0: & Y[k] = W[k] & \text{signal absent.} \\ H_1: & Y[k] = X[k] + W[k] & \text{signal present.} \\ \multicolumn{3}{l}{k = 1\ldots K;\ \text{where K is the number of points of the FFT.}} \end{array} \tag{1}$$

W[k] is additive white Gaussian noise with zero mean and variance σ_w^2. *X[k]* can also be considered as a Gaussian distributed variable with zero mean and variance equal to signal average power P_x.

To measure energy, *M* continuous *K*-point FFTs are done and, then, power is averaged over each frequency bin. The test statistic is:

$$T[k] = \frac{1}{M}\sum_{m=1}^{M} \left|Y_m[k]\right|^2 . \tag{2}$$

where $Y_m[k]$ is the *m*-th FFT of *y[n]*.

The decision test consists on deciding that primary signal is present at bin *k* when *T[k]* is greater than a threshold γ. Otherwise, it should decide that primary signal is absent.

Detection probability (P_d) and false alarm probability (P_{fa}) are given by:

$$P_{fa} = Q\left(\sqrt{M}\,\frac{\gamma - \sigma_w^2}{\sigma_w^2}\right). \qquad P_d = Q\left(\sqrt{M}\,\frac{\gamma - (\sigma_w^2 + P_x)}{(\sigma_w^2 + P_x)}\right). \tag{3}$$

For a desired false alarm probability, threshold value (γ) can be set without the knowledge of primary signal power by P_{fa} equation. Once threshold value is obtained, P_d can be calculated by substituting the threshold in P_d equation.

For fixed P_{fa} and P_d, it is possible to calculate the minimum number of K-point FFTs (M) required for achieving that pair of probabilities. Representing signal to noise ratio as $SNR = P_x / \sigma_w^2$:

$$M = \left[\left(Q^{-1}\left(P_{fa}\right) - Q^{-1}\left(P_d\right)\right) \cdot SNR^{-1} - Q^{-1}\left(P_d\right)\right]^2 . \quad (4)$$

3 Experimental Results

Experiments have consisted of a comparison between measuring noise power by two different methods. In *method 1* it is measured on a previously known free channel and in *method 2* equipment's noise power is considered.

First, we have used signals generated in the laboratory with the Alitronika AT2780 modulator for generating a DVBT signal of 5 MHz bandwidth. Then, we have used the Anritsu MS2690A Vector Signal Analyzer in order to save the IQ samples with a sampling frequency of 50 Msamples/sec and an observation interval of 50 msec. We have added Gaussian noise to get a desired SNR. We have realized the minimum number of averages necessary to achieve a desired P_d and P_{fa} (equation (4)). By doing 5000 experiments we have obtained the results of figure 2 and 3. These results have been obtained for a desired $P_d = 0.9$, a desired $P_{fa} = 0.1$, spectral resolution of 0.2MHz and a SNR = -15 dB.

As seen in figures 2 and 3, it is possible to obtain good results by using only the minimum number of averages. It is appreciable that better performance is achievable when using noise power of a previously known free channel (method 1).

The algorithm has been validated with field trials carried out in Bilbao (Spain). Channels from 58 to 63 (766-814 MHz) have been recorded at different locations and with different antennas. Previously mentioned methods for estimating noise power have been compared.

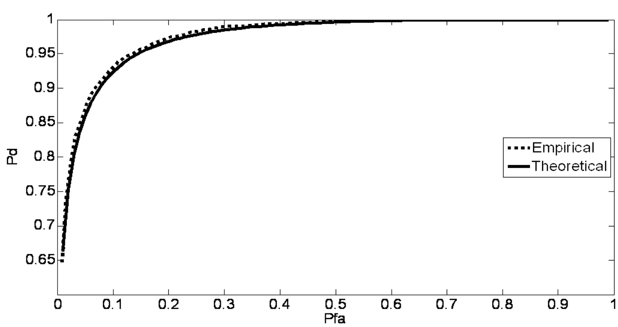

Fig. 2. ROC for method 1 (noise power in free channel)

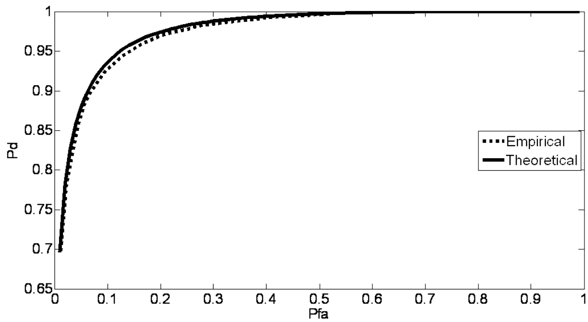

Fig. 3. ROC for method 2 (equipment's noise power)

Real TV broadcasting signals usually have high SNRs. Therefore, few averages are necessary to obtain good performance (high P_d and low P_{fa}). For example, for a *SNR* of 0 dB, a P_d of 0.99 and a P_{fa} of 0.01, only 49 averages are necessary (by equation (4)). In this case, central limit theorem (CLT) [5] can't be applied. Hence, we have realized the minimum number of averages to satisfy the CLT, M = 125. In that minimum sensing time the algorithm has decided that the frequency is occupied or free. After realizing this process many times, a percentage of occupancy has been obtained.

In figure 4, a comparison between both methods of measuring noise power can be observed, for one location where the primary signal has been captured with a log-periodic antenna located in a window of a building facing a transmitter. Channels 59, 61 and 63 are really occupied and 58, 60 and 62 are unoccupied.

For the representation, white color has been used for 'occupied' detected frequencies and black color for 'unoccupied' detected frequencies. It can be seen the evolution over time for all the frequencies. In the last column, on the right of each image, the percentage of occupancy of each frequency bin has been represented following the legend.

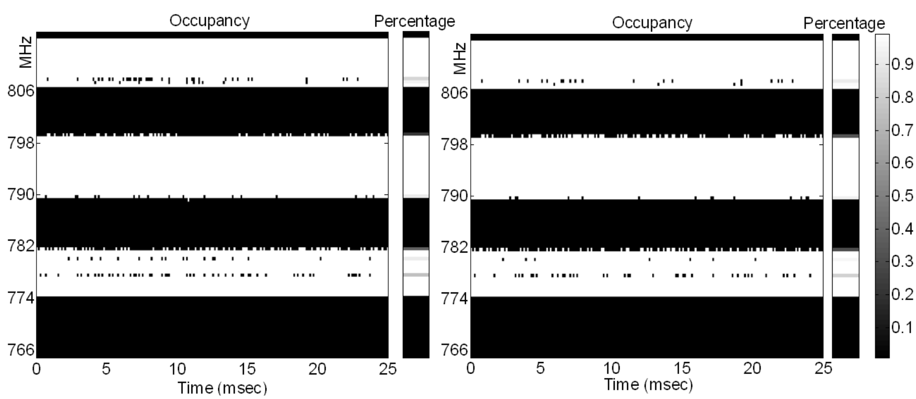

Fig. 4. Algorithm's decision results using Method 1(left) and Method 2 (right)

It can be observed that with method 2, P_d is higher than with method 1, but also P_{fa} increases with this method. However, there aren't significant differences. So it can be said that the equipment's noise power is a good approximation for estimating noise power and calculating the decision threshold.

More experiments have been carried out, analyzing the influence of measuring the noise power in an unoccupied channel with different bandwidths (1MHz, 4MHz and 8MHz). Results demonstrate that better performance is achievable when using a bandwidth of 8MHz. This is because when using the whole unoccupied channel, we are also considering the power introduced by the tails of adjacent channels. Therefore, a lower P_{fa} is obtained.

When using a higher sensing time (product of K and M), we can achieve better performance. Nevertheless, with a higher sensing time, the algorithm is slower and loses the capability to be used for 'real-time' applications.

4 Conclusions

For real TV broadcasting signals, equipment's noise power is a good estimation of real noise in the sensing channel. At these frequencies, atmospheric noise is very low and the unique measurable noise is equipment's noise.

When measuring noise power in an unoccupied channel it achieves better performance by considering the full channel (8 MHz) instead of considering a narrower bandwidth.

By increasing the number of averages (M) it is possible to get better results but at the expense of losing speed.

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