Spectrum Occupancy Using Cyclostationary Detection

Andrés Navarro
i2t Research Group
Universidad Icesi
Cali, Colombia
anavarro@icesi.edu.co

Leonardo Vargas
i2t Research Group
Universidad Icesi
Cali, Colombia
lvargas@icesi.edu.co

Jaime Aristizabal
i2t Research Group
Universidad Icesi
Cali, Colombia
jaime.aristizabal@correo.icesi.edu.co

***Abstract*—In this paper we show the results of an occupancy measurement algorithm using cyclostationary detection, according to ITU-R SM.1880 Recommendation, in an unattended, cloud-based monitoring ecosystem. We compare the results with the traditional energy detection procedure and evaluate them against information from the national regulator in the FM broadcast service, which includes authorized and illegal transmissions.**

Keywords—spectrum monitoring, occupancy, software defined radio, automation, cyclostationarity.

I. Introduction

In previous works, we highlight the importance of radio monitoring as a support activity of Spectrum Management, Regulation and Enforcement, and describe the build of a monitoring unit (SIMON) capable of executing automated spectrum monitoring tasks such as occupancy, frequency, and bandwidth measurements, according to the ITU Spectrum Monitoring Handbook and Reports and Recommendations referenced in the ITU-R SM.1392-2 [1].

The Spectrum Occupancy task determines whether a channel is occupied according to a power threshold [2]; if the channel power level is higher than the threshold, then it is considered to be occupied. The measurement is performed during an extended period of time, following ITU-R SM.1880 Recommendation. Then the user can obtain the occupancy rate in the observed time or a channel occupancy in a specific hour. Despite its low reliability, energy detection (also known as threshold detection), is the simplest of the commonly used algorithms for spectrum sensing and occupancy calculation. However, different and more accurate methods have been proposed [3][4], such as cyclostationarity and matched filter.

In this paper, we show the validation study of a cyclostationary detector using the SIMON system, for spectrum occupancy measurements according to ITU-R SM.1880 Recommendation.

II. Measurement Equipment

The SIMON is an SDR monitoring unit built with an SDR device (Nuand's bladeRF), a processing unit (Raspberry Pi), a GPS for localization and PPS synchronization and a 3G/4G gateway. It is capable to reach frequencies between 60 kHz and 3.8 GHz and bandwidths from 1.5 MHz to 28 MHz. Its compliance with ITU Recommendations is described in [5]. It includes algorithms written in Python and uses GNU Radio as its main toolkit for managing the hardware.

The general software components of the SIMON are shown in Fig. 1.

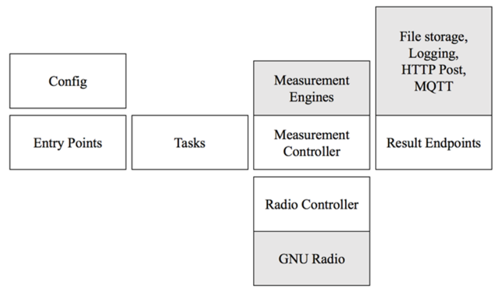

Fig. 1. Software components.

III. Occupancy Measurement Using Cyclostationary Detection

The procedure is divided in two stages. The first one includes the sampling mechanisms and the measurement conditions over the SDR architecture. The second, the processing techniques and the signal analysis involved in the channel occupancy calculations.

One *cyclostationary sample* [6], in the frequency domain, is composed of two set of samples, each one used to calculate the average values during a period of time L seconds, and separated by Δt seconds, so that the time required to obtain a cyclostationary sample is $T = 2L + \Delta t$.

For a study within a band of frequencies, the samples must be built in chunks (n), preferably of the minimum bandwidth supported by the SDR device. In that situation, $Tb = T \times n$. Then it should be divided in channels, considering the channel plan and the channel bandwidth of the band.

The autocorrelation is calculated between the two sub-samples of each channel, as in (1), to obtain the final array [7].

$$R(j) = \sum_n x_n x_{n-j} \quad (1)$$

Fig. 2 shows the correlation between the two sub-samples of an occupied channel.

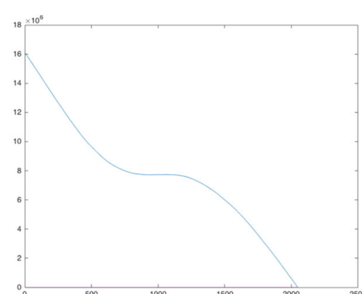

Fig. 2. Occupied channel.

From that, it is possible to measure the occupancy by calculating the Pearson Coefficient r^2, as shown in (2), so that the closer r^2 is from 0, the more occupied the channel is. r^2 values are between 0 and 1 [8].

$$r^2 = \frac{n\sum xy - \sum x \sum y}{(n\sum x^2 - (\sum x)^2)^2 * (n\sum y^2 - (\sum y)^2)^2} \quad (2)$$

The coefficient indicates if the lobe of Fig. 2 exists; if the value is 1, we can be sure that there are no signals in the channel. For this experiment, we suppose that the channel is occupied if $m - r^2 > s$, where m is the maximum r^2 of the band or the r^2 of the noise floor and s is the standard deviation of the noise floor coefficients.

IV. Occupancy Measurement in the FM Band

To calculate the occupancy of the FM broadcasting service band, from 88 MHz to 108 MHz, we obtained 135 cyclostationary samples within 24 hours, with L=10, Δt=0, a channel plan of 100 kHz and a channel bandwidth of 240 kHz.

We obtained the real occupancy of the band from the Colombian National Spectrum Agency (ANE) [9], with authorized and known-unauthorized channels and created a representation of the expected results of the experiment.

Then we calculated the occupancy average of the 24 hours and compared the data.

Considering the existing restrictions and to obtain an approximate quantitative evaluation, we performed the sensitivity and specificity analysis of the algorithm, validating against the official data whereas it was correct or not, and considering a channel as occupied if its occupancy average is above 45%. The analysis consists of counting the successes and failures of the outcomes of the algorithm (predicted), against its expected values. It has an effectiveness of 62.8% on the prediction of occupied vs. unoccupied channels compared to the official data, as shown in Table I.

TABLE I. Sensitivity and Specificity Analysis

	Predicted (occupied)	*Predicted (unoccupied)*
Expected (occupied)	26	19
Expected (unoccupied)	55	99

V. Comparison With Traditional Algorithm

The occupancy measurement using the threshold algorithm, also known as energy detection, is described in ITU-R SM.2256 Report and is widely used in cognitive radio because it is simple to implement. It states that a channel is considered as occupied if the number of components above the noise floor of the band exceeds 80% of the total points of the channel.

We calculated the occupancy of the band using the threshold algorithm, but manually increased the threshold by 5 dB to obtain the best results from it, by discarding noise and intermodulation components. The results are shown in Fig. 6. We also performed the sensitivity and specificity analysis, as shown in Table II, that resulted in an effectiveness of 66.8%.

TABLE II. Sensitivity and Specificity Analysis - Threshold

	Predicted (occupied)	*Predicted (unoccupied)*
Expected (occupied)	15	30
Expected (unoccupied)	36	118

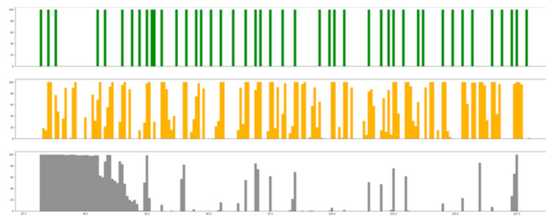

Fig. 3. Comparison between the official occupancy report (green), the cyclostationary algorithm (orange) and the threshold algoritm (gray).

Despite the threshold implementation seems to be more accurate, the cyclostationary part identifies 73% more occupied channels. It also identifies occupancy not only in the channel with the carrier but in the adjacent. Besides it can be optimized and used with spread spectrum signals because it is based on correlation calculations; it is well known that the threshold algorithm does not work with spread spectrum signals, like UMTS, or is highly unreliable.

VI. Conclussions

We validated an experimental occupancy measurement algorithm using cyclostationary detection, with affordable SDR devices, in a real environment and against official occupancy data from the national regulator. It outperforms the traditional threshold algorithm in the FM band.

We also used the autocorrelation and the Pearson correlation coefficient functions to perform a radio monitoring task. Those functions could be applied to other measurements included in the ITU-R SM.1392-2 [11], such as bandwidth.

References

[1] A. Navarro, A. Arteaga, L. Vargas, J. H. Aguilar, and M. Arciniegas, “Spectrum monitoring system and benchmarking of mobile networks using open software radios SIMONES,” IEEE Lat. Am. Trans., vol. 13, pp. 3592–3597, November 2015.

[2] E. Salman, N. Noordin, S. Hashim, F. Hashim, and C. Ng, “An overview of spectrum sensing techniques for cognitive LTE and LTE-A radio systems,” Telecommunication Systems, vol. 65, no. 2. pp. 215–228, Jun-2017.

[3] Lunden, J., Koivunen, V., Huttunen, A. & Poor, H. (2007). Spectrum sensing in cognitive radios based on multiple cyclic frequencies. In 2nd international conference on cognitive radio oriented wireless networks and communications, 2007 (CrownCom 2007). August 1–3, 2007.

[4] A. Navarro, L. Vargas, C. Urcuqui, J. Aristizabal, and A. Arteaga, “Automated bandwidth measurements using ITU-R SM.443 and GNU radio devices,” 32nd URSI GASS, August 2017. In press.

[5] U. Polit, C. C. Tecnol, T. M. Garrote, and C. Fern, “Proyecto Final de Carrera “Detección de señal basada en cicloestacionariedad para cognitive radio,” pp. 80–96, 2009.

[6] J. G. Proakis, D. S. G. Manolakis, V. del Rio, A. Castro, J. Luis, and others, Tratamiento digital de señales. 1998.

[7] Glen, S. (2018). Correlation Coefficient: Simple Definition, Formula, Easy Steps. [online] Statistics How To. Available at: http://www.statisticshowto.com/probability-and-statistics/correlation-coefficient-formula/ [Accessed 5 april. 2018].

[8] ANE, “Emisoras de Colombia,” 2016. [Online]. Available: http://mintic.gov.co/portal/604/w3-article-9214.html. [Accessed: 06-May-2018].