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DISCOVERING SPECTRUM HOLES IN A SPECIFIC INDOOR ENVIRONMENT FOR COGNITIVE RADIO APPLICATION

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Abstract

This works makes a brief review of the current situation, first principles and objectives of cognitive radio, as well as, measurements of the electromagnetic environment in the 800-900MHz UHF Band are carried out in a specific indoor environment in order to analyze and discover spectrum holes to be used by a cognitive receiver for creating white spaces in the selected site, in accordance with its dynamic spectrum management capacity.

Keywords: cognitive radio, electromagnetic environment, spectrum hole, white space.

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1. Introduction

Nowadays the transmitted information quantity using the free space as a transmission media (radio communications services) is too much, that is, radio, TV, radio cellular, etc., which have saturated the electromagnetic spectrum causing slow communications and ineffective utilization of the radio spectrum.

Cognitive radio (CR) is now generating significant interest in the marketplace because of its robust application capabilities, as well as, an alternative solution, due to it is a smart radio which can be programmed and configured dynamically. This kind of radio automatically discover available frequency channels in the wireless spectrum, consequently change their transmission/reception parameters (waveform signal, protocol communication, operation frequency, etc.) in order to adapt to the achieved frequency channel, what is known as dynamic spectrum management.

During long time, the frequency bands have been assigned by the government through implemented laws by himself or by owners of big businesses, in this way some frequency bands are not occupied, and not used by other services, such frequency bands are known as "spectrum holes" (radio frequency (RF) emitters are switched off), which can be defined as a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, possibly this band is not being utilized by that user [1], then, in that case, it is named "white space" (free of RF interferes except for ambient noise), later named a spectrum hole, when this one is discovered by the CR in order to use it.

Radio cellular bands are overloaded in the most of countries, great part of the radio frequency electromagnetic spectrum is used in an inefficient way, most of the time some other frequency bands are only partially or largely unoccupied and the remaining frequency bands are heavily employed [1-3]. On the other hand, the assigned frequency bands are rarely used, but these ones cannot be utilized by unlicensed users, even when interference risk is minimum. In this way, the regulatory bodies have been considering the possibility to employ these assigned frequency bands by unlicensed users if as long as interference problems are not caused to licensed users.

So, in order to discover spectrum holes, we have been carried measurements out at particular indoor environment, specific time, and geographic location. The paper is organized as follows: In Section 2, the cognitive radio foundations are described, and a review of CR spectrum sensing models in order to be performed to the measured data; the Section 3 shows the measurement results, and finally Conclusion and References.

2. Cognitive Radio Foundations

A radio software term was coined by Joe Mitola to refer to reconfigurable radio communications. Radio software system is make up by hardware and software systems which carry out similar processes to a conventional system. Relative to a basic radio system, the antenna, R.F. section and part of the analogic conversion is responsibility of hardware and modulation/demodulation, coder/decoder are software processes.

The main purpose of software defined radio (SDR) is to offer a global coverage and establish interfaces with different systems and standards with no procedural irregularity through any region.

The basic characteristics that define a cognitive radio (CR) are the following:

- Environment perception through sensing spectrum techniques.
- Become aware about the operation environment, as well as, own capacities and resources.
- Alter and adapt their transmission/reception parameters.
- Decide to act as a transmitter or receiver.

Figure 1 shows licensed and unlicensed users (cognitive radios) sharing a communication network.

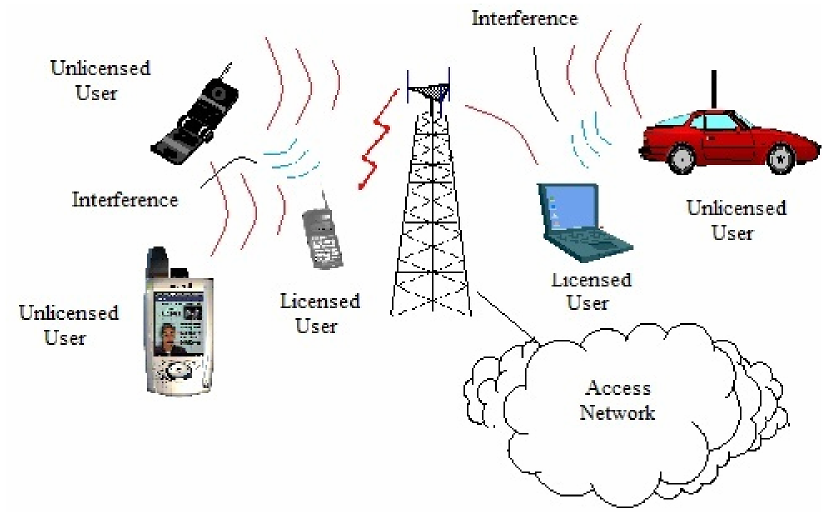

Figure 1. Cognitive radio concept.

On the other hand, a cognitive radio must be able to reconfigure the following parameters:

● Communication system: Operate in different communication systems.

● Modulation: Select the modulation technique appropriate to channel characteristics and user requirements.

● Carrier frequency: Based on available radio electric spectrum information and the transmission type, it should be able to select the appropriate carrier frequency.

● Transmitted power: If the environment characteristics allow power reduction, the cognitive radio must decrease the transmitted power to low level not affecting the transmission quality, and at the same time, increase the number of users sharing the piece of spectrum with no interference between them.

2.1. Spectrum sensing

Three fundamental and basic techniques are used for cognitive radio spectrum sensing, being, energy detection, adaptive filter detection and detection based on stationary cycle test. In a specific way, it is possible to mention coherent detection, radio transmitter identification detection, multi taper spectrum detection and local oscillator leakage power detection. The above techniques mentioned form the basis to develop complex detection algorithms.

Spectrum sensing has been defined as the work to obtain available spectrum and establish the licensed user number inside a specific geographic location. The available spectrum is obtained by different ways, particularly by the spectrum local detection technique [4, 5], and due to a cognitive radio user (unlicensed user) transmits only in the frequency band not used by licensed users, this way, the CR must monitor the considered frequency band and capture information in order to decide if this band is available, to create white spaces in accordance with its dynamic spectrum management capacity [6].

2.2. CR spectrum sensing models

Due to small and large scale fading in the wireless channel, the no occupied frequency bands detection is hard task, particularly when the received SNR is low, in this case, spectrum sensing, and any known transmitted signal characteristic should be used in the energy detection technique. The typical model for the cognitive radio detection [7] is given by

$$\Psi_1 : y[n] = x[n] + r[n], \quad n = 0, \dots, N-1, \tag{1}$$

$$\Psi_2 : y[n] = r[n], \quad n = 0, \dots, N-1, \tag{2}$$

where

$y[n]$, received signal; $x(n)$, transmitted signal;

$r(n)$, noise; n, index sample (time), index symbol (frequency); N, licensed user samples number capacity buffer; $x(n)$, $r(n)$, and $y(n)$ samples are independent.

For this kind of model if the noise $r[n]$ is Gaussian and the signal $x[n]$ is known, the optimum detector is the adaptive filter, which is given by

$$M = \sum_{n=0}^{N-1} y^*[n]x[n]. \tag{3}$$

This technique shows a disadvantage, it is imperative to know the transmitted signal to implement the detector, expression (1). If means no licensed users, expression (2), in this way, it is possible to know if a licensed user is using the band when M is higher than a specific threshold, and the receiver does not need to know the signal knowledge, due to the detected signals are compared with the energy detector output level respect to noise threshold level. Above expressions need to be synchronized with the received signal, but it can be no reliable if the SNR is low, in this case, it is necessary to implement asynchronous detectors, which of them, the energy detector is the most used [8], an optimum detector for the signal/noise model above mentioned, if $x[n]$ is an unknown signal without time correlation. For this case, the model is given by

$$M = \sum_{n=0}^{N-1} |y(n)|^2, \tag{4}$$

where

N, licensed user samples number capacity buffer;

$|y(n)|^2$, independent variables sequence, media μ_M and variance σ_M^2.

The energy detector shows a big problem which consists of estimate the value of variance of the noise in order to calculate the SNR wall. Any variance estimation deviation leads to a wrong SNR value calculation below of threshold value, as a result, it is not possible the energy detection [9]. Detector with multiple antennas is an alternative solution for this problem, due to it is possible apply a uncorrelated spatial noise technique in the detection process, based on the following models: "IID noises, white stationary signals, with Rank-P structure", INWSPS, and "NID noises, white stationary signals, with Rank-P structure", NNWPS, detectors for this model is given by [10], whose expressions are given by (5) and (6):

$$\Psi_1 : y[n] = \boldsymbol{h}x[n] + r[n], \quad n = 0, \ldots, N-1, \tag{5}$$

$$\Psi_2 : y[n] = r[n], \quad n = 0, \ldots, N-1, \tag{6}$$

where

$y[n] \in C^L$, received signal by L antennas;

$\boldsymbol{h} \in C^L$, one single input and multiple outputs (SIMO) channel;

$x(n)$, transmitted signal; $r(n)$, uncorrelated spatial noise.

But in realistic scenarios, experiment with multiple transmitted signals at indoor and outdoor environments, that is, a MIMO channel, the expressions (5) and (6) are modified as following:

$$\Psi_1 : y[n] = \boldsymbol{H}x[n] + r[n] \quad n = 0, \ldots, N-1, \tag{7}$$

$$\Psi_2 : y[n] = r[n] \quad n = 0, \ldots, N-1, \tag{8}$$

where

$x[n] \in C^P$, transmitted signal by multiple antennas (vectorial signal);

$\boldsymbol{H} \in C^{L \times P}$, multiple inputs and multiple outputs (MIMO) channel.

In this way, all the models and considered detectors are based on uncorrelated spatial signals and flat frequency channels, however, the great demand of high data rate in wireless communication requires wide band signals transmission, so, it is necessary to know another signal properties, not only spatial structure, in order to apply multichannel detection.

3. Measurements

3.1. Monitoring 800-900MHz band

This band offers excellent radio wave propagation properties, that is, depth of penetration, wave length, etc. reason why this band is extremely requested by telecommunication companies, for example, GSM service, and TDT, terrestrial digital television. TDT operates in the 800-900MHz Band, and specifically GSM occupies from 806MHz along all the band, not at uniform way, that is, with some no occupied segments, and TDT occupies 758-830MHz Band, Channel 57-65 and 830-862MHz Band, Channel 66-69. Thus, in order to discover white spaces [11, 12], the spectrum monitoring was carried out in this band due to the users do not use it permanently.

The measurement point is the electromagnetic compatibility laboratory (CEM Lab.), which it is located in the North of Mexico City, specifically Instituto Politécnico Nacional, Campus Zacatenco, as shown in the map of Figure 2. The CEM Lab furniture consists of components such as bricks, chairs, tables, measurement equipment and an anechoic camera, this way, the presence of multiple scatterers, result in effects such as edge diffraction and diffused scattering due to irregularities within the walls or the presence of penetrable structures. This scenario was selected because it is an ordinary environment where the CR works daily, a complex electromagnetic environment. An outdoor environment site with not reflecting objects (terraced roof) to be selected for experimental tests was rejected.

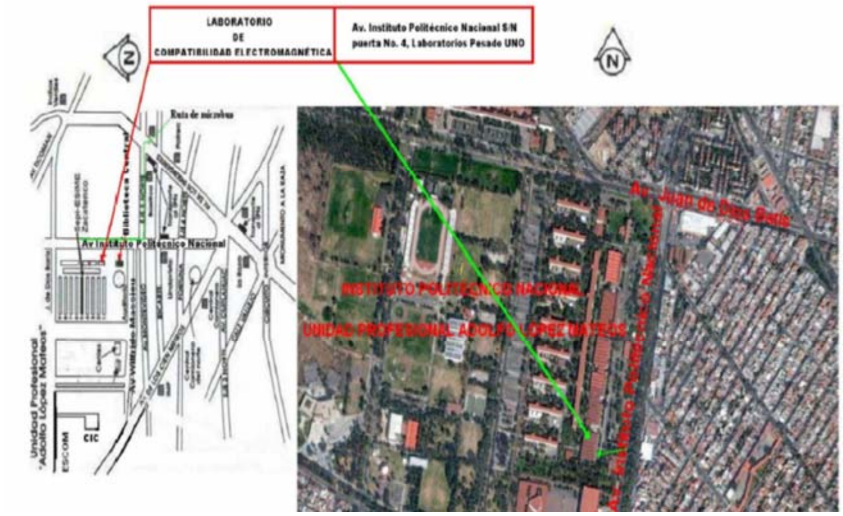

Figure 2. Measurement point geographic location.

In such a setting, the 800-900MHz Band was monitored daily during several days at 14:00-16:00hrs, using measurement equipment which consists of spectrum analyzer, laptop and a dipole antenna as shown in Figure 3.

Figure 3. Measurement equipment.

3.2. Analyzing the measurement results

Figure 4(a) shows 800-900MHz Band spectrum sensing graphic when dipole is horizontally polarized and Figure 4(b) vertically polarized. It is appropriate to mention that during the monitoring time no changes were observed. Comparing the graphics, the Figures 4 practically show the same performance between 800-850MHz, which are free of RF signal in this indoor environment except for ambient noise, the only difference in this frequency segment can be seen in Figure 4(a), a low level signal around 838MHz central frequency, a signal horizontally polarized. At this frequency GSM-850 service (824.0-849.0 uplink) is allocated. But, along 850-900MHz great activity can be seen, TV broadcast signal and other GSM signal bands have penetrated the walls and different objects and bouncing in every point of reflection falling into the dipole receiver antenna, nevertheless, it is possible to observe in both graphics a white space around 867.333MHz, a blue line was marked in that point on them, and the spectrum hole is approximately equal to 2MHz (866-868MHz). Adjacent channels to this band are assigned to T-GSM-810, 851.0-866.0, downlink and GSM-850, 869.0-894.0, downlink.

Let us apply the energy detection technique, in order to validate the results and classify occupied spectrum and free spectrum, that is, based on (2), consider that the receiver does not know the received signal and due to the detected signals are compared with the energy detector output level respect to noise threshold level, a threshold value has to be determined, following the next procedure: Spectrum vector magnitude mean, μ_1, is calculated. Magnitudes in the spectrum vector above μ_1 are ignored, and the mean μ_2 of the resulting vector and standard deviation, σ, of the same is calculated. Sliding window of narrow bandwidth is used to scan through the band, and the mean of the magnitude of the sliding window μ_3 is calculated. When $\mu_3 - \mu_2$ value is greater than 3σ, a peak or occupied station is recognized. The process continues until the entire band is completed. Thus, the discovered spectrum holes have been validated.

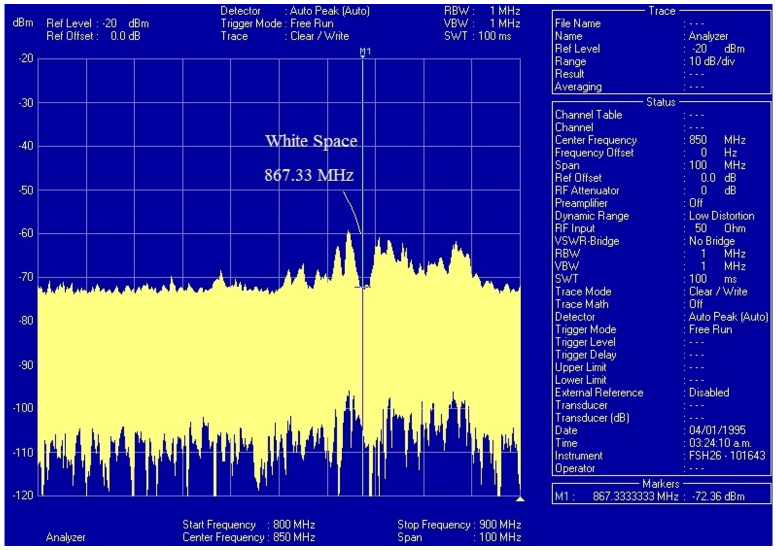

Figure 4(a). Horizontal polarization spectrum sensing.

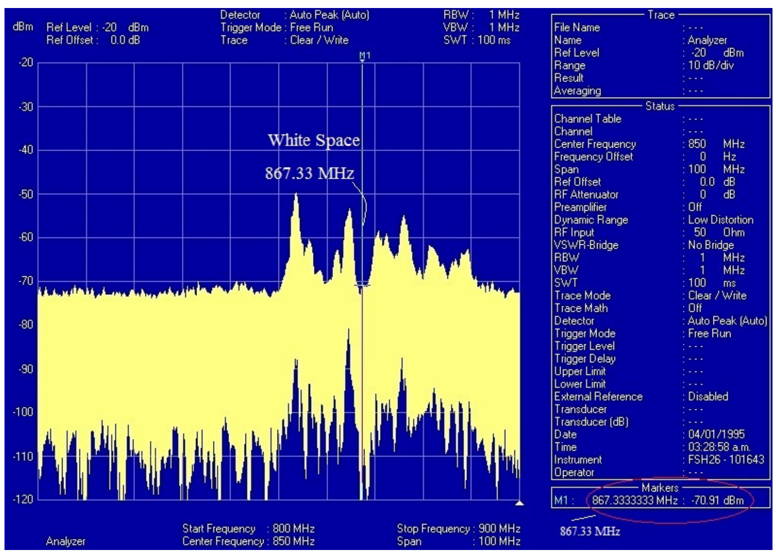

Figure 4(b). Vertical polarization spectrum sensing.

4. Conclusion

Sensing spectrum technique was used to explore and discover spectrum holes in the 800-900MHz Band. A free band was discovered at 867.33MHz frequency central in a specific indoor environment site and at a specific time, above mentioned, in order to be used by a cognitive radio.

Even though, spectrum sensing is considered as radio frequency energy measurement along the radio electric spectrum, this one must be understood in a wide way due to space, time, frequency, and code are involved. That is, once the spectrum hole has been discovered, detection techniques should be applied in order to CR creates white spaces. A short resumé about detection techniques and three models has been included, considering the spatial structure signal type, which energy detection techniques are: Known received signal, SIMO channel and MIMO channel. Finally, cognitive radio is actually a wireless communication paradigm, which objective is to take advantage of temporal spectrum holes in order to make effective utilization of the radio spectrum.

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