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About Cognitive Radio Receiver under an Indoor Environment

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ABSTRACT

This small note makes an analysis of the current situation of the Cognitive Radio (CR) performance under an indoor environment. As well as, measurements of the electromagnetic environment in the 800-900 MHz UHF Band are carried out in a specific indoor environment, in order to discover a spectrum hole to be used by an cognitive radio unlicensed user.

***Keywords*:** Cognitive radio, indoor environment, spectrum hole, white space

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, a solution alternative, 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, or partially occupied, such frequency bands are known as "spectrum holes" (Radio Frequency (RF) emitters are switched off), which can be defined as a frequency bands assigned to a primary user, but, at a particular time and specific geographic location, possibly these bands can be utilized by secondary users, no licensed users [1], in this case, it is named "white space" (Free of RF interferes except for ambient noise), and later called 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 used [1-3]. On the other hand, the assigned frequency bands are rarely used, but these ones cannot be used by unlicensed users, even when interference risk is minimum. This way, the regulatory bodies have been considering the possibility to use these assigned frequency bands by unlicensed users if as long as interference problems are not caused to licensed users [4,5].

So, in order to discover spectrum holes, we have been carried measurements out at particular indoor environment and geographic location in the 800-900 MHz UHF Band. The paper is organized as follows: section II cognitive radio foundations are described, section III a description of CR spectrum sensing techniques, section IV shows measurement results and finally conclusion and references.

2. COGNITIVE RADIO FOUNDATIONS

2. 1. Characteristics

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, on the other hand, the modulation/demodulation coder/decoder sections is responsibility of the software processes.

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.

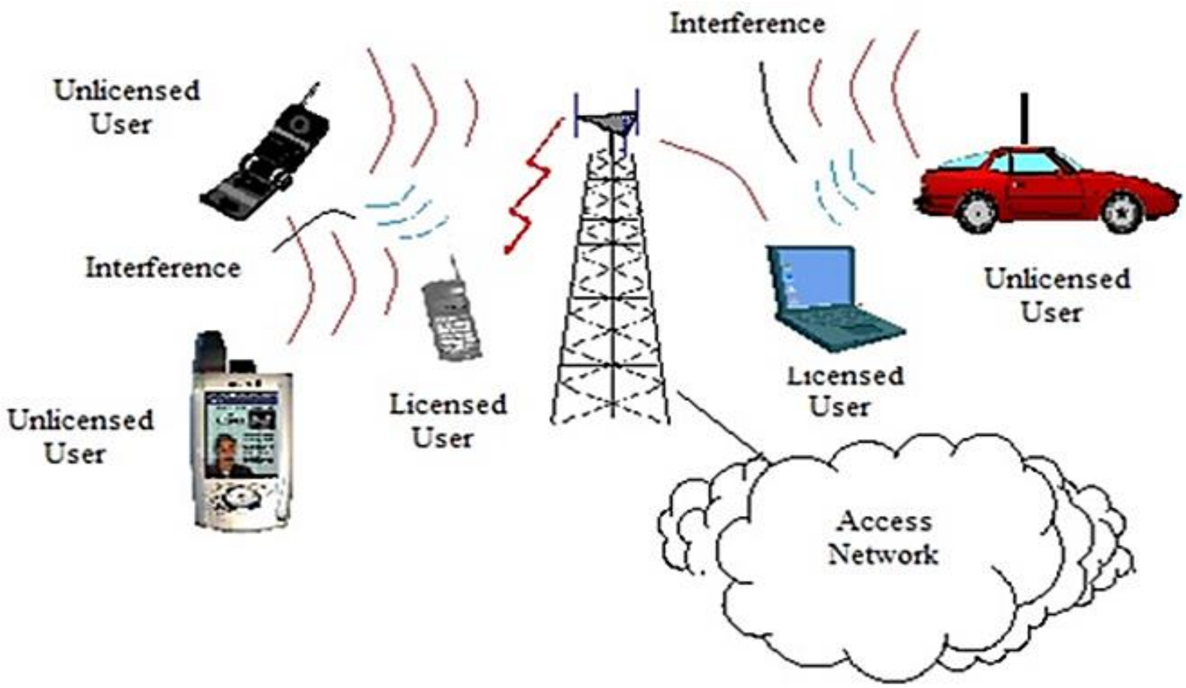

Figure 1. Cognitive radio concept.

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.

Three keys aspects of a cognitive radio are:

- Sensing – A cognitive radio must be able to identify the spectrum holes (unused spectrum segments).
- Flexible- A cognitive radio must be able to change signal frequency and spectrum shape to fit into the discovered spectrum hole.
- Non-interfernig – A cognitive radio must not cause harmful interference to the licensed users.

If a licensed user spectrum has fixed channelization, for instance TV bands, a wideband cognitive radio system may use either time based or frequency based signals.

When licensed user doesn't support fixed channelization, frequency base signals are preferred, due to, it is difficult to dynamically generate a time-based signal, this way, OFDM, Orthogonal Frequency Division Multiplex, is the ideal signal structure for wideband cognitive radio systems, due to OFDM divides the discovered free spectrum into narrow bands sub channels and the signal values are modulated on the sub channels in frequency domain. Interference to the licensed users can be cancelled nullifying the sub channels in the licensed user spectrum and modulating only the sub channels in the white spaces.

2. 2. Energy Detection (Power Based Sensing)

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].

Two fundamental and basic techniques are used for cognitive radio spectrum sensing, being, energy detection (power sensing) and waveform sensing (adaptive filter detection and detection based on stationary cycle test). The energy detection is prone to false detections and usually poorly when received signal SNR is low, since it only measures signal power and could be easily triggered by unintended signals, due to small and large scale fading in the wireless channel [7]. 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. On the other hand, when the received signal contains known signal patterns, for instance, DTV or even NTSC signals if they are still alive, waveform based sensing can be performed, which usually gives far better performance than energy detection sensing in terms of sensing sensitivity and reliability.

Let us consider the received signal, which typical model for the cognitive radio detection [8], is given by:

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

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

where:

$y[n]$, received signal

$x(n)$, transmitted signal

$r(n)$, white Gaussian noise

n, sample index (time domain sensing), FFT symbol index (frequency domain sensing)

N_B, licensed user samples number capacity buffer

$x(n)$, $r(n)$ and $y(n)$ are independent.

This way, if the power sensing technique is applied, the metric is:

$$S_M = \sum_{n=0}^{N_B} \left| y(n) \right|^2 \tag{3}$$

Due to $x(n)$, $r(n)$ and $y(n)$ are a sequence of independent and identically distributed random variables, IID, with mean and variance, given by:

$$\langle \left| y(n) \right|^2 \rangle = \mu \tag{4}$$

$$\langle \{ \left| y(n) \right|^2 - \mu \}^2 \rangle = \sigma^2 \tag{5}$$

In view of N_B is large, applying the central limit theorem and considering *SM* Gaussian random variable, we have now:

$$\mu_{S_M} = N_B \mu \qquad \sigma_{S_M} = N_B \sigma^2 \tag{6}$$

So, when the signal is present, S_M, is given by:

$$S_M = \Psi_1 = \sum_{n=0}^{N_B - 1} \left| y(n) \right|^2 \tag{7}$$

and when the signal is not present, S_M, is given by:

$$S_M = \Psi_0 = \sum_{n=0}^{N_B - 1} \left| r(n) \right|^2 \tag{8}$$

On the other hand, T_V, threshold value should be determined in order to define signal presence, that is, if $S_M > T_V$, in the case of there is not signal, it means false detection, in the opposite case, if $S_M < T_V$ and the signal is present, it means a loss detection.

This way, it is possible to know if a licensed user is using the band when S_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.

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 [9], given by (9). 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 [9,10].

$$SNR = \frac{\langle |x(n)|^2 \rangle}{\langle |r(n)|^2 \rangle} \tag{9}$$

So, in order to give an alternative solution for this problem, a detector with multiple antennas can be applied, due to it is an uncorrelated spatial noise technique in the detection process, based on the following models: "independent and identically distributed noises, wide stationary signals, with Rank-P structure", INWSPS, and "no independent and identically distributed noises, wide stationary signals, with Rank-P structure", NNWSPS. Detectors for this model are described by [11], which expression are given by (10) and (11):

$$\Psi_1 : \quad y[n] = h\, x[n] + r[n] \quad n = 0,\ \ldots,\ N-1 \tag{10}$$

$$\Psi_2 : \quad y[n] = r[n] \quad n = 0,\ \ldots,\ N-1 \tag{11}$$

where:

$y[n] \in \mathrm{C}^{\mathrm{L}}$, received signal by L antennas

$h \in \mathrm{C}^{\mathrm{L}}$, one 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 expression (10) is modified as following:

$$\Psi_1 : \quad y[n] = H\ x[n] + r[n] \quad n = 0,\ \ldots\ N_B - 1 \tag{12}$$

$$\Psi_2 : \quad y[n] = r[n] \quad n = 0,\ \ldots N_B - 1 \tag{13}$$

where:

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

$H \in \mathrm{C}^{\mathrm{LxP}}$, multiple inputs and multiple outputs (MIMO) channel

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, jointly with the energy detector, that is, an optimum detector for the signal/noise method above mentioned, if $x[n]$ is an unknown signal without time correlation [12].

This way, the methods 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.

2. 3. Waveform-based sensing

In this kind of sensing, the noise r[n] is Gaussian and the signal x[n] should be known, this way, the optimum detector is the adaptive filter, which is given by:

$$S_M = \sum_{n=0}^{N_B-1} y^*[n]x[n] \tag{14}$$

It is imperative to know the transmitted signal to implement the detector, hence, when there is signal present, the sensing metric is given by:

$$S_M = \Psi_1 = \sum_{n=0}^{N_B-1} |x(n)|^2 + \mathrm{Re}\left[\sum_{n=0}^{N_B-1} r(n)x^*(n)\right] \tag{15}$$

In the case of there is not signal present, the sensing metric is given by:

$$S_M = \Psi_0 = \mathrm{Re}\left[\sum_{n=0}^{N_B-1} r(n)x^*(n)\right] \tag{16}$$

2. 4. Cognitive radio user under an indoor environment

The cognitive radio analysis scene under an indoor environment includes the detection of spectrum holes, sensing the radio frequency spectrum, applying at least one of the methods above mentioned, as well as, determine the way of the environment responds to the transmitted signal, so, an estimation of the channel state is necessary, that is, nature of transmitted signal, which will suffer small scale fading due to small changes in objects position, people moving, constructive and destructive reflections, etc., hence, the cognitive radio receiver ought to consider time spreading and/or time variance of the channel, and the indoor environment must be considered as a complex electromagnetic environment, and, once a white hole has been discovered, the CR acts an unlicensed user and it should cause no harmful interference to the licensed user. In this way, the received signal may be characterized as:

$$y(t) = A_0 g(t) x(t) \tag{17}$$

where:

A_0, mean path loss

$g(t)$, random process, shadowing effect

$x(t)$, received signal

In the 800-900 MHz Band the licensed spectrum has fixed channelization, for instance TV Bands and Radio Cellular Bands, the CR may use time based or frequency based signals, in the case of the CR does not support fixed channelization, frequency based signals are preferred, hence, OFDM is the signal structure for cognitive radio systems, which the time domain OFDM signal [7] is given by:

$$x(t)=\sum_{n}\left[w(t-nT_W)\sum_{k\in\Omega}X(n,k)e^{j2\pi\frac{k}{T}(t-nT_W)}\right] \tag{18}$$

where:

n, OFDM symbol index

k, subchannel index

Ω, data subchannels collection

$X(n,k)$, transmitted signal

T, FFT symbol period

OFDM symbol window width $T_W > T$, hence $T_G = T_W - T$, is an extra period.

Then, let us apply the energy detection technique, classify occupied spectrum and free spectrum, that is, based on (1) and (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, μ1, is calculated. Magnitudes in the spectrum vector above μ1 are ignored, and the mean μ2 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 μ3 is calculated. When μ3 − μ2 value is greater than 3σ, a peak or occupied station is recognized. The process continues until the entire band is completed.

In the same way, let us apply the waveform sensing technique. For this case it is imperative to know the transmitted signal, which, it is possible for the CR receiver, but at the instant that the signal comes filtering through the walls, this one is impacted by the indoor environment, modifying frequency and/or phase in some or all sub channels, in accordance with the indoor propagation model, either, Rayleigh or Rician. That is, the environment just has an influence on the A_0 term, mean path loss, of expression (17), due to multipath fading, and g(t) represents challenges of the channel state estimation due to interference, noise uncertainty and nonstationary effects caused by shadowing, and giving rise to transients in the estimation in the beginning and at the end of the packets, as well as, the channel will be dependent of the frequency if it is a wide bandwidth channel. Consequently, if this modification is significant, the CR receiver will not be able to recover the information, even though, OFDM has the advantage to use a guard period, interval or cyclic prefix in order to protect the signal against the multipath delay spread, if this advantage is not enough, ACL (adjacent channel leakage) will be present, causing interference to the licensed users sharing the same area.

On the other hand, in practical conditions SNR is not fixed, and considering a slow fading scenario during the sensing window with not changes in the channel, the mean value of the SNR [13] is given by:

$$\langle SNR \rangle = \int_0^{\infty} f_Y(y) P_D(y) dy \tag{19}$$

where:

$f_Y(y)$, probability density function

P_D, detection probability

So, in order to might as well look on the bright side, it is necessary to implement the two sensing methods in the CR receiver, and take the better of the two.

3. MEASUREMENTS

3. 1. Monitoring the 800-900 MHz 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 800-900 MHz Band, and specifically GSM occupies from 806 MHz along all the band, not at uniform way, that is, with some no occupied segments, and TDT occupies 758-830 MHz Band, Channel 57-65 and 830-862 MHz Band, Channel 66-69. In this way, 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. The CEM Lab furniture consists of objects such as bricks, chairs, tables, measurement equipment and an anechoic camera, this way, the presence of multiple scatters, 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 due to 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.

3. 2. Measurement results analysis

Figure 2a shows 800-900 MHz band spectrum sensing achieved measurement when the objects and people kept a particular and fixed position, and Figure 2b shows the achieved measurement, when the objects were moved to other position and the people was in movement. Comparing the graphics, practically, show the same performance between 800-850 MHz. At this frequency band GSM-850 service (824.0-849.0 uplink) is allocated. But, along 850-900 MHz great activity can be seen, TV broadcast signal and other GSM signal bands have penetrated the walls and different objects, bouncing in every point of reflection, finally falling on the dipole receiver antenna connected to the spectrum analyzer. It is possible to observe difference between the graphics, due to the influence of indoor environment on the 850-860 MHz band, that is, the change of the objects position configuration and the movement of the people, led to different readings on this band.

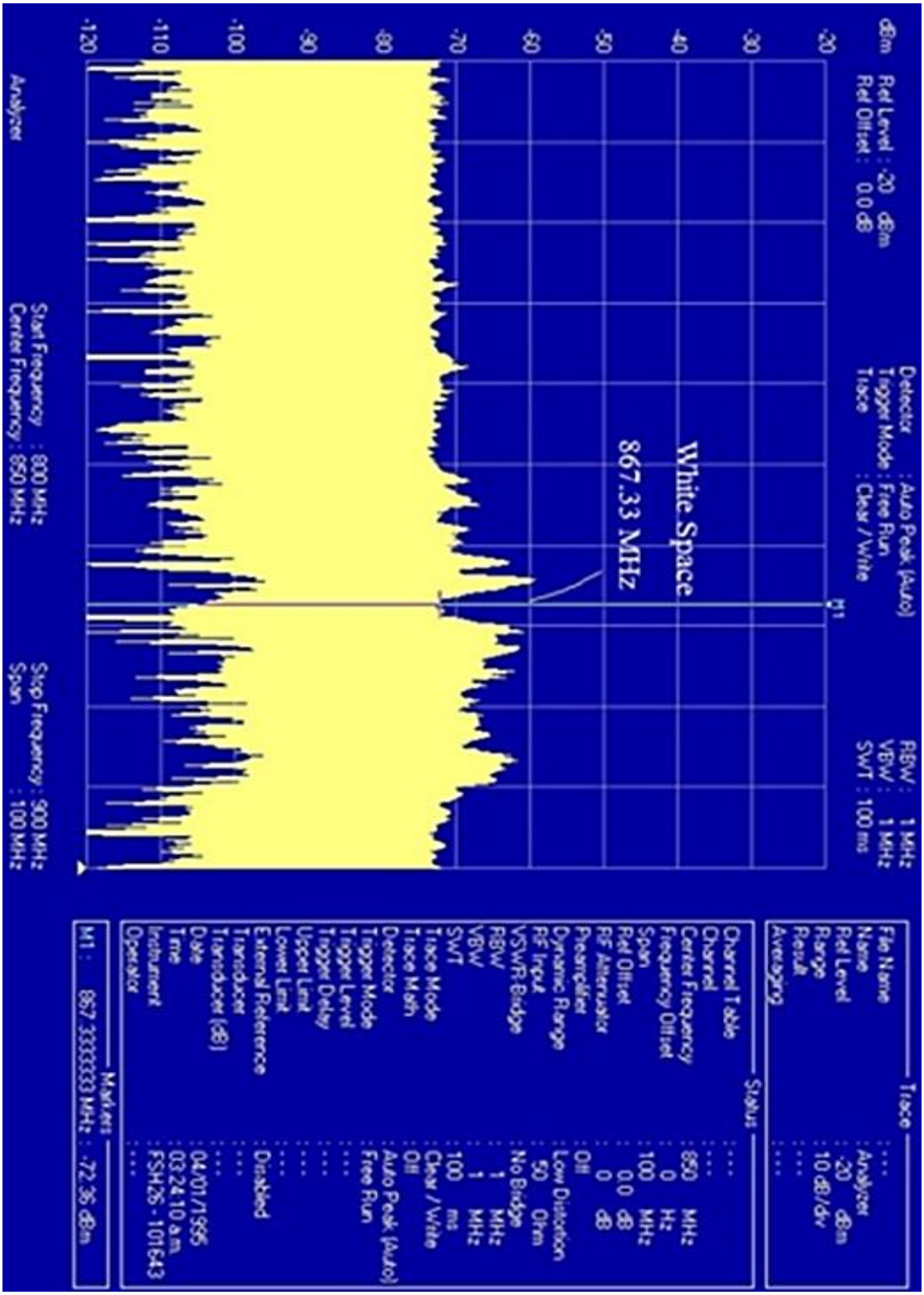

Figure 2a. 800-900 MHz band spectrum (first position configuration).

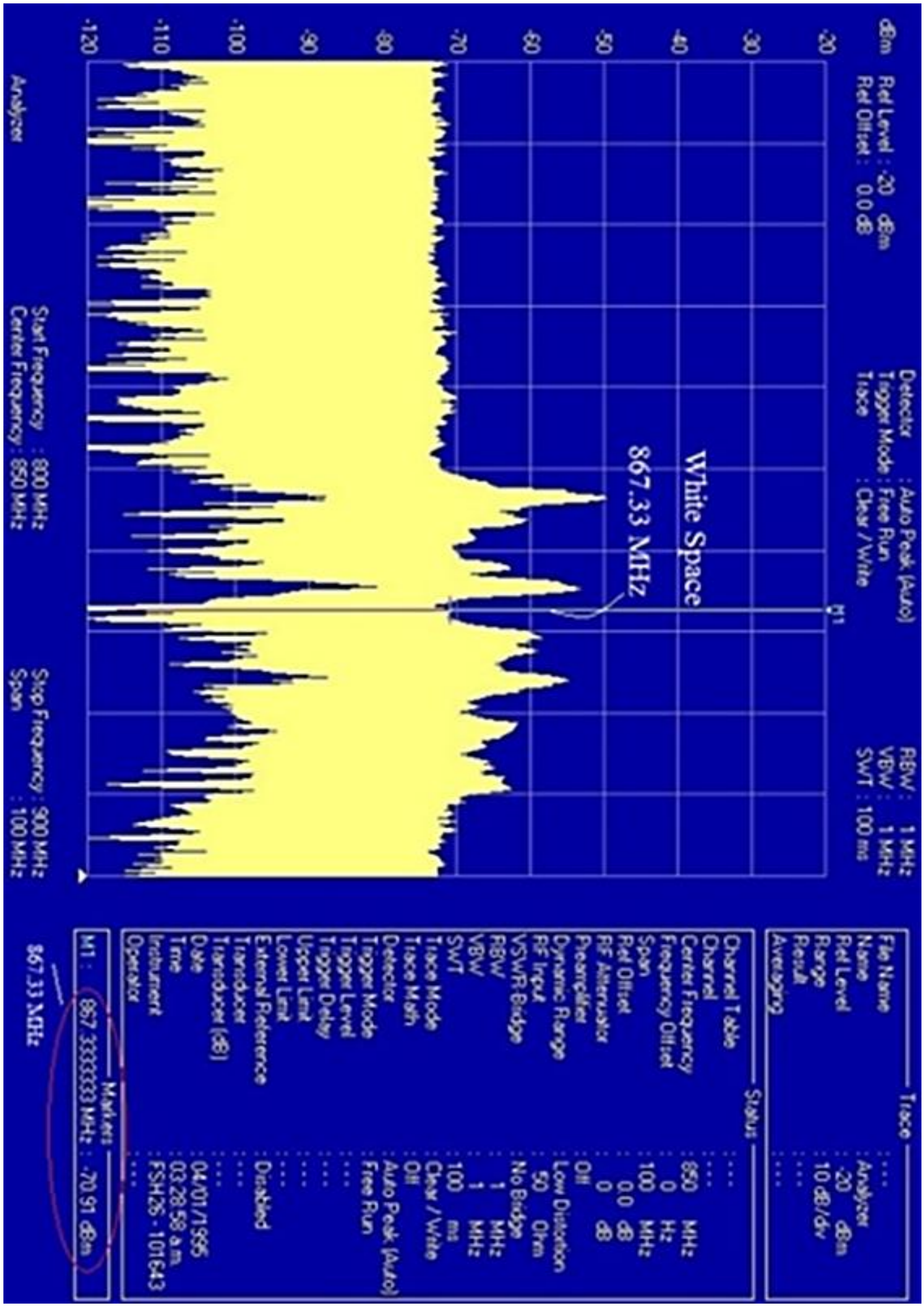

Figure 2b. 800-900 MHz band spectrum (second position configuration).

However, under these conditions the detection energy (power sensing) was applied discovering a small spectrum hole, and following the procedure above mentioned, resulted a white space, which it is showed in both graphics, around 867.333 MHz, indicated by a blue line, with a wideband approximately equal to 2 MHz (866-868 MHz). Adjacent channels to this band are assigned to GSM-810, 851.0–866.0, uplink and GSM-850, 869.0–894.0, downlink. On the other hand, it´s possible to observe, too, that, the indoor environment has influenced constructively on the received signal in the 850-860 Band, the radio waves are propagated through free space, and during its trajectory are reflected from the ground and by surrounding objects, the reflected waves, multipath components are added to the first ray, if there is a line of sight path, on the contrary, with not line of sight path, the rays arrive to the receiver antenna as a shape of a cluster. Anyway, constructive or destructive contributions mean false detection, if this level energy is above of threshold level and there is not signal, and loss detection, if it is below of threshold level and the signal is present.

3. CONCLUSIONS

Sensing spectrum technique was used to explore and discover spectrum holes in the 800-900 MHz Band. A free band was discovered at 867.33 MHz frequency central in a specific indoor environment site, at a specific time, in order to be used by a cognitive radio. Various measurement were carried out in order to observe the influence of the indoor environment (objects, people, etc.) on the received signal., which impacted on a small band, but the spectrum hole was unaffected.

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.

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.

Biography

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