Spectrum Occupancy Measurements below 1 GHz in the City of San Luis Potosi, Mexico.

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Abstract—The cognitive radio technology is a promising solution to solve the scarcity problem of electromagnetic spectrum caused by the increase in the demand of wireless communications. Throughout the world, several measurement campaigns have been conducted to determine the real occupancy of the spectrum. In several countries, including Mexico, these measurements have not been realized yet. In this paper, we present results of the spectral power and duty cycle of the first measurement campaign conducted in the city of San Luis Potosi and in Mexico. The frequencies of interest considered in this study lies within the range of 30 MHz to 910 MHz. In order to improve system sensitivity, the measurements were made with a directional antenna considering the four cardinal points. The study measures the power spectrum for 7.5 hours on a weekday. The results clearly show the critical underutilization of the spectrum in our country since it shows an average duty cycle of 12.5% in the above mentioned frequency range.

I. INTRODUCTION

Historically, the electromagnetic spectrum has been regulated by governmental authorities, mainly because of the inherent importance of controlling communications and the high investment in infrastructural deployment. Traditionally, regulators allocate specific frequency bands to primary users based on a fixed spectrum access (FSA) policy, which has lead the usable electromagnetic spectrum to become apparently saturated. This scenario has created a spectrum shortage scenario, mainly because in recent times wireless communication systems have shown an exponentially spread and currently the spectrum is fully assigned, which inhibits the inclusion of new services [1]. In light of this problem, cognitive radio (CR) [2] represents a feasible solution to the spectrum scarcity problem. The core idea behind CR is based on the fact that primary (or licensed) users might not use their allocated frequency band at the same time and/or geographical location. Therefore, unused spectrum spaces, known in the literature as spectrum holes, may thus be accessed dynamically with CR-enabled communication devices by secondary (or unlicensed) users to whom the frequency band has not been allocated.

In first instance, knowing the spectrum usage allows the identification of potential frequency bands that might be accessed opportunistically by secondary users. Moreover, results generated from an analysis of the electromagnetic spectrum can be used to develop realistic models of spectrum occupancy to evaluate the performance of new CR algorithms and techniques that cannot be implemented experimentally when the necessary equipment is not available [3]. Furthermore, the usage of statistics of the electromagnetic spectrum occupancy will play an important role in defining new public policies regarding the electromagnetic spectrum in the near future. In recent years, spectrum occupancy measurement campaigns have been performed in several countries around the world [4]–[10]. However, in Mexico, such measurements have not been carried out yet. In Mexico, there are several regulatory studies conducted by the Federal Telecommunications Commission (COFETEL), which only describe and focus on the status of the current allocation of spectrum bands in Mexico [11]. Although the methodologies used in the different measurement campaigns are not identical, all of them share the objective of knowing the actual spectrum occupancy in different geographical regions. Indeed, assuming the same spectrum occupancy in different countries is practically unrealistic since this is influenced by regional regulations and also by other factors like the economy and technological development of the country. Thus the importance of carrying out spectrum measurements campaigns in new places around the globe.

In this paper, spectrum occupancy measurements are conducted for first time in the city of San Luis Potosi, Mexico. Spectrum measurements are performed considering a study relying on approximately seven hours of measurements around a single and busy observation point, using a directional antenna. This is done by utilizing a portable spectrum analyzer. We expect the results of this work to be useful to the scientific community, telecommunications operators, and the regulatory agency in our country to evaluate a shift towards a dynamic spectrum access (DSA) scheme, for which a consensus of all these actors is needed.

The rest of the paper is organized as follows. Section II describes the location and the method used to perform the spectral measurements, the equipment used, and how the collected data is processed, respectively. Then, power spectrum measurement results are presented and analyzed in Section III. Finally, Section IV provides the conclusions of our spectrum occupancy measurement study.
II. MEASUREMENT STUDY: SPECTRUM OCCUPANCY AROUND ONE OBSERVATION POINT

A. Methodology

The methodology is presented in three parts. Firstly, a description about the location where the measurements were conducted is given. Second, the equipment used in the experiments is detailed and the measurements approach is described. Third, the data processing stage is explained. Finally, presents the duty cycle calculation.

B. Location

These spectrum measurements were conducted in the city of San Luis Potosi, Mexico. The Greater San Luis Potosi area has a population of around 1,000,000 inhabitants and is one of the ten largest metropolitan areas in the country. To perform the measurements, in this study we considered only one observation point near our laboratory because of simplicity and accessibility. Therefore, the University’s parking building located on the northeast side of the main campus of the Autonomous University of San Luis Potosi (UASLP) was selected. Figure 1 shows the abovementioned building and its surrounding. This point is located in an urban environment; it is surrounded by shopping centers, schools, offices, banks, established businesses, hospitals and parks, and has a great flow of people throughout the day. The official height of the city of San Luis Potosi is 1860 m above sea level and the building has an approximate height of 15 m. The observation point has the following geographical features: latitude 22° 8’42”, longitude: −100° 0’51”, and altitude: 1875 m.

C. Equipment and Measurements

To carry out the study of power spectrum measurements, we used the equipment and specifications described in Table I. Measurements are made with the directional antenna taking into account the four cardinal points and following the methodology described in [12]. A directional antenna was selected to increase the system’s sensitivity. A schematic representation of the methods and procedures can be seen in Figure 2. For the measurements, we started at the frequency range of 30 MHz to 70 MHz and advance in ranges from 40 MHz to 40 MHz until stop in 910 MHz. Each round of measurements is started by placing the boresight of the antenna reception northward. Once in that position, ten samples of spectrum are taken at regular intervals of approximately five seconds each. Then the antenna is turned eastward where ten samples are also taken. The process is repeated sequentially until completing the three hundred and sixty degrees round. This procedure setup is also shown in Figure 2. Thus, for each range of 40 MHz, forty samples are taken in total, which are measured in twenty two turns making a total of eight hundred and eighty samples in the aforementioned range of 30 MHz to 910 MHz. The experiments are carried out during an ordinary week day for periods of time of approximately two and a half hours, which included the morning, afternoon and evening. Therefore, the measurements cover a total of seven and a half hours of spectral activity.

D. Data processing

In this investigation, the spectrum analyzer used to carry out the spectrum measurements provides the option to store all samples of a measurement as a .csv file, which has the power spectrum information which occupies each frequency range. Then, after storing the samples the information is post-processed using Matlab. The off-line post-processing is explained in what follows.

In (1), it is shown the arrangement of how the analyzer stores information, \( D \) is a matrix formed by two columns \((N_s = 2)\), in which the first column \((d_{i1}) \) represents the frequency value and the second column \((d_{i2}) \) the measured power value. \( M_s \) is the length of each file that contains three hundred and twenty one dot resolutions in total. Hence \( M_s = 321 \), this part is represented by the rows of \( D \), therefore

\[
D = [d_{ij}]_{M_s \times N_s}
\]  

(1)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Frequency Range: 54 MHz - 890 MHz</th>
<th>Gain: 10 dB</th>
<th>16 elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum Analyzer</td>
<td>Frequency Range: 1 MHz - 2700 MHz</td>
<td>Maximum Span: 2699 MHz</td>
<td>Minimum Span: 320 kHz</td>
</tr>
</tbody>
</table>

Table I

Table I

Equipment Characteristics.
For each frequency interval of 40 MHz there are forty samples captured at different times, which were obtained from ten samples taken in each of the four cardinal points. Therefore, forty matrices in the form of (1) exist. This information was processed and accommodated in the matrix given by (2), wherein \( g = i \) of the previous equation and \( h \) are the forty samples captured in each frequency range, then \( F_s = 40 \) and therefore \( h = 1, 2, ..., F_s \).

\[
R = [r_{gh}]_{M \times F_s}.
\] (2)

The information collected in one day is placed in a matrix in (3), the subscript \( v = h \) are the forty samples captured in each frequency range and \( c \) is all the frequency ranges of three hundred and twenty samples, therefore \( K_s = 7062 \) and \( c = 1, 2, ..., K_s \).

\[
G = [g_{cv}]_{K_s \times F_s}.
\] (3)

A final matrix with the samples of the three days of measurements and all the samples the frequency ranges is expressed in (4), in which \( q = c \) and the three measurements of forty samples each one with \( L_s = 120 \) are included in \( w = 1, 2, ..., L_s \).

\[
A = [a_{qw}]_{K_s \times L_s}.
\] (4)

Finally, to obtain the average of the power spectrum samples, (5) is used, where the vector \( \bar{a}_q \) contains the average samples used for the graphics of the next section.

\[
\bar{a}_q = \frac{\sum_{q=1}^{K_s} A = [a_{qw}]_{K_s \times L_s}}{L_s}.
\] (5)

### E. Duty Cycle

One of the most used and important parameters to determine the spectral occupation is the duty cycle. It is defined as the amount of time that the power value of signal is maintained above a certain threshold [7]. In the majority of the spectrum measurement campaigns, the only information available is samples of power spectral density (PSD). These samples should be able to determine the status of the frequency bands. In these cases, the method of energy detection is performed to determine if a channel is occupied or empty. The method of detection requires a threshold energy, which must be carefully selected to avoid making errors in estimating the state of a channel. In this study, we set the threshold value according to the methodology suggestions made in [7], [12], and by the International Telecommunications Union (ITU) in [13].

The threshold \( \gamma \) was fixed in the frequency range 30 MHz - 400 MHz in 10 dBm above the background noise and for the range 400 MHz - 910 MHz in 6 dBm above the background noise. The matrix in (5) is used to obtain the duty cycle in (6), where \( count \) is a variable which increases its value every time a sample exceeds the threshold \( \gamma \), this information is stored in vector \( \mathbf{dc}_q \), where \( q \) is all the frequency ranges as previously mentioned.

\[
\mathbf{dc}_q = \begin{cases} 
1 & \text{if } A = [a_{qw}] \geq \gamma_q; \quad count = count + 1, \\
0 & \text{if } A = [a_{qw}] < \gamma_q.
\end{cases}
\] (6)

Finally, the vector \( \mathbf{dc}_q \) is averaged by the number of samples of each frequency, in this case \( L_s \), as shows in (7). The vector used to obtain the graphics of the results is \( \beta_q \).

\[
\beta_q = \frac{\mathbf{dc}_q}{L_s}.
\] (7)

### III. Results of Measurement Study

Taking as a reference the official frequency allocation of the National Chart of Frequencies Allocation (CNAF) provided by COFETEL [11], the following analysis is presented. For Very High Frequency (VHF) bands, it can be seen from Figure 3 that very little presence of activity exists since most of the time the power spectrum is below \(-70 \text{ dBm}\) and the average duty cycle is very small in the band from 30 MHz to 50 MHz, where spectrum is assigned to private radio communication services. It is clearly shown the presence of activity in the 54 MHz - 72 MHz frequency range corresponding to TV channels 2, 3, and 4 wherein the channel 2 has an average duty cycle of the three TV channels with 80%. Applications such as radio astronomy, short range mobile service, aeronautical radio navigation systems and radio static or mobile phone have a space reserved within the 72 MHz - 76 MHz range, with an average duty cycle of 1%. TV channels 5 and 6 show activity in the range from 76 MHz to 88 MHz, in which the average duty cycle of the TV channel 6 is 90%. FM broadcast stations are allocated from 88 MHz to 108 MHz where the power of each station varies, in this range of frequencies the transmissions are continuous and it is difficult to appreciate an empty space. The average duty cycle is 100% for this range, which is consistent, since it is difficult for a radio station to interrupt its broadcasts. It is worth to point out that, within the range of 108 MHz to 148 MHz there are frequency bands that are used exclusively for emergency services, aeronautical navigation, mobile satellite, and non-geo stationary services. However these frequencies bands exhibit large portions of electromagnetic spectrum empty. Thus, these empty spaces might be available for opportunistic transmissions. On the contrary, TV channels 7 to 13 operating within the frequencies of 174 MHz to 216 MHz, shows a busy activity for continuous periods of time. It is interesting to mention that in Mexico several broadcasting channels stop their transmissions late at night, as it is the case of the local TV channels 7, 9, and 13. However, since the spectrum measurements presented here are not made during the early morning those empty spaces cannot be appreciated in Figure 3, due to this, average duty cycles are 50% to 100%. The ranges from 216 MHz to 220 MHz and from 225 MHz to 243 MHz, which are allocated to studio-transmitter links for AM and FM broadcasting stations, presents great power and a permanent activity during the day, here appear with an average duty cycle 100%, but only for one channel, which causes in these frequencies blank spaces. Also, there are other spaces allocated to TV studio-transmitter link within the range of 251 MHz to 323 MHz that exhibit the average duty cycles between 20% to 50%, as it is shown in Figure 3.
Finally, there is no duty cycle in the range of 251 MHz to 270 MHz, nor in the range of 310 MHz to 323 MHz. Hence, it is shown this way that these spaces could be used dynamically by other unlicensed users. Figure 4 shows the power spectrum measurements in the range of 30 MHz to 600 MHz. The 328 MHz - 380 MHz spectrum band is used for aeronautical mobile and point-to-point multi-channel communications. Figure 4 shows that there are several primary users’ signals with an average duty cycle of 8% and hence a reasonable empty space of spectrum that could be reutilized.

A continuous signal with considerable power and with an average duty cycle of 100% within the range from 380 MHz to 400 MHz is allocated to security applications. The signal of digital trunking services appears in the range from 410 MHz to 430 MHz with an average duty cycle of 80%. Therefore, there are several underutilized spaces in this frequency band. An interesting activity that does not remain constant with average duty cycles between 20% to 40% corresponds to private services wireless local access, which appears within the frequency bands from 440 MHz to 450 MHz and from 485 MHz to 495 MHz. These areas present a lot of activity and few voids. By agreement of the ITU, international mobile communications technologies for CDMA are allocated within the range of 450 MHz to 470 MHz. Figure 5 shows the power spectrum measurements in the range from 600 MHz to 910 MHz. TV channels 14 to 51 are distributed in the large frequency range from 470 MHz to 806 MHz. Figures 4 and 5 show that there are primary users’ signals present in the frequency ranges of 470 MHz to 510 MHz with an average duty cycle of 30%, 540 MHz to 560 MHz with an average duty cycle of 70%, and 640 MHz to 660 MHz with an average duty cycle of 15%. Nevertheless, there are no primary users’ signals in other frequency bands, which leave large gaps in the spectrum bands of 520 MHz - 540 MHz and 570 MHz - 640 MHz, both bands highly underutilized and thus potentially suitable for opportunistic use. Such spaces are commonly named the TV white space bands. Another large spectrum portion with low activity appears within the range from 698 MHz to 806 MHz, such space is officially assigned to TV channels 52 to 69 and currently are in the process for being assigned to Digital TV.

Mobile phone services, air-ground communications services, telemetry applications, and remote controls are allocated for the frequency range from 806 MHz to 902 MHz. By analyzing the previous frequency range, it can be seen that from 806 MHz to 850 MHz, the average duty cycle in this frequencies is 10%. Consequently, this represents a spectrum opportunity that could be used by unlicensed users. On the contrary, the range from 850 MHz to 890 MHz is plenty of activity; the average duty cycle is 100%. This is expected since the frequency band is allocated to mobile phone users. Therefore, the presence of primary users’ signals is constant and this characteristic does not change throughout the day. The average duty cycle for the frequencies in the range of 30 MHz to 910 MHz measured and processed is 12.5%.

IV. CONCLUSIONS

In this paper, it is presented a spectrum occupancy study conducted in the city of San Luis Potosi, Mexico. The results presented in our first study are significant in at least major two respects. First, they quantify the spectrum underutilization in a Mexican city for the first time. Second, a directional antenna was used for taking measurements, which improves the systems sensitivity at the cost of increasing the measurement complexity since these had to be repeated 4 times in different angles. In reviewing the literature, it was found that generally an omni-directional antenna was used in similar studies for simplicity. Results quantify the average duty cycle for all frequencies inside the range from 30 MHz to 910 MHz in approximately 12.5%. As future work, we plan to perform spectrum measurements for larger amounts of time and in different areas of the city.

ACKNOWLEDGMENT

This work was supported by the Program for the Improvement of the Teachers Faculty (PROMEP) and the Mexican National Council for Science and Technology (CONACYT).

REFERENCES

Fig. 3. Frequency spectrum from 30 MHz to 310 MHz corresponding to the minimum, maximum and average spectrum power and duty cycle of seven and a half hours of measurements

Fig. 4. Frequency spectrum from 310 MHz to 600 MHz corresponding to the minimum, maximum and average spectrum power and duty cycle of seven and a half hours of measurements

Fig. 5. Frequency spectrum from 600 MHz to 910 MHz corresponding to the minimum, maximum and average spectrum power and duty cycle of seven and a half hours of measurements