On the Relevance of Using Affordable Tools for White Spaces Identification

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***Abstract*—It is widely recognized that white spaces identification is an important milestone for the wide deployment of next generation cognitive wireless networks. However, spectrum holes detection tools used for white spaces discovery are still either in the infancy stage or too expensive to enable massive white spaces exploitation. Building upon cheap hardware equipment, this paper presents experiments conducted in the town of Trieste in Italy to sense the environment and find out which frequencies are not being used in a particular place and time-of-the-day. As a a step towards white spaces exploitation, we believe that our experimental frequency exploration is an important milestone upon which white spaces patterns recognition will be built with the aim of using these patterns in wireless network planning and management.**

I. Introduction and Purpose

Spectrum allocation has always been associated with the actual technology that carries the information, and as the technology has evolved, so has the meaning of spectrum and its management. The concept of spectrum itself arose only when the technique for selecting a particular frequency became available. With digital communication, the use of Time Division Multiplexing (TDM) opened a new dimension in the spectrum usage. Advances in Integrated circuits technology made possible the cellular system in which Space Division Multiplexing has meant a quantum leap in terms of the number of possible simultaneous communications in a given place. These advances also made possible to distinguish a specific user by means of a mathematical code, in what is known as Code Division Multiple Access (CDMA), thus adding yet another dimension to the concept of spectrum.

As traditionally implemented, spectrum regulation has led to an apparent spectrum shortage resulting from competition in certain frequency bands, poor usage in some other frequency bands and multiple allocations proposed by regulatory bodies over all the available frequency bands. The Industrial Scientific and Medical (ISM) band, for example, has been experiencing a fierce competition in sharing the overcrowded 2.4 GHz frequency band between the well established WiFi, Bluetooth, Radio Frequency Identification, wireless sensor and various other proprietary devices which are emerging from niche applications into commodity products. On the other hand, some of the licensed bands which are usually most protected through regulation have revealed an inefficient frequency usage contrasting with the over-crowding and over-usage of the ISM band. This is the case, for example, of the frequencies reserved for TV broadcasting which usually show an overbooking of under-utilized frequencies. This discrepancy between frequency usage and allocation has raised the need for a redesign of the frequency regulation by taking advantage of the recent technological innovations. The state of the art in cognitive radio technology offers such support by enabling dynamic spectrum access; a frequency management technique which allows the radio to sense the environment and find out which frequencies are not being used in a particular time and use these frequencies opportunistically to maximize spectrum usage.

Cognitive radio has been defined by ITU [1] as *a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained*. The advances in cognitive radio systems combined with the recent transition from analog to digital television, freeing new spectrum which was once the preserve of TV broadcasters, can enable wireless device operation on multiple frequency bands, thus boosting the communication capabilities of various wireless applications operating both in the free and licensed frequency bands. Cognitive Radio has been widely researched during the last decades and numerous regulatory bodies have recognized the potential benefits of the newly available frequencies called TV white spaces (WSs) to future wireless networks. However, white space deployments are still in their infancy in many countries. As reported in [2], Radio-scene analysis is one of the major steps of Cognitive Radio which encompasses (1) the estimation of interference temperature of the radio environment and (2) the detection of spectrum holes. As a white spaces identification enabler, spectrum holes detection also referred to as spectrum sensing is an important step that has been recognized as a milestone towards white space deployments.

The fact that a sizable portion of the allocated spectrum lies fallow, raises the important issue of citizen's advocacy for a more efficient use of the spectrum. We believe that the availability of low cost tools for spectrum usage logging can provide valuable data to pinpoint specific frequency bands that are not currently being exploited and make them known to the spectrum regulator agency in the country, as well as publicize them in the media and relevant fora. This paper hopes to stimulate other actors to participate in the drive for a more efficient use of the spectrum. It is a fact that the real use of the spectrum in a given time is just a small fraction of what has been allocated, and to increase the efficiency of spectrum usage increasing awareness by the stakeholders of this reality is a must. Nevertheless, research and the telecommunication industry have provided only a small number of still expensive tools for spectrum sensing. There are more affordable tools but restricted to operation in the ISM band, and therefore not suited for TV Ws applications. Furthermore, when they are available, these tools are based on graphical interfaces that makes them hard to be integrated in any open spectrum sensing tool.

Building upon cheap hardware equipment, this paper describes the implementation of a white space identification software tool using spectrum sensing. The remainder of this paper is presented as follows. Section 2 presents related white spaces identification work while Section 3 describes the main components of the WS identification system. The experimental measurements made in Trieste/Italy are presented in section 4 while our conclusions and future work are presented in section 5.

II. Literature Review

Dynamic spectrum access has been touted as a candidate solution to the spectrum scarcity problem. However, a fundamental prerequisite for the efficient dynamic access of spectrum is the effective and reliable sensing of this spectrum through spectrum occupancy measurements. Spectrum occupancy describes the efficiency of spectrum use in terms of the proportion of time that the spectral bands are occupied. Recently spectrum occupancy has become topical in the field of cognitive radio as the quest for efficient access to the spectrum continues. This is evidenced by empirical measurements of the radio environment in a bid to ascertain the spectrum usage by different wireless services [3]. A number of occupancy measurement campaigns efforts where initially carried out in USA with the aid of discone antennas, spectrum analyzers and a laptop [4-7]. These occupancy measurements regrettably showed information only about American spectrum regulation and utilization. The efforts soon spread to the UK[8][9], and then were extended gradually to the rest of European countries with more recent spectrum occupancy measurements conducted in the frequency range from 75 MHz to 3 GHz in an outdoor environment in urban Barcelona, Spain [10]. In Germany the campaigns are carried out nearly in the same range, though the investigators choose to span 20 MHz to 3 GHz and carried both indoor and outdoor measurements. Furthermore [11] takes a survey of Spectrum utilization in Europe and reports three major campaigns namely in the suburb of the city of Brno in the Czech Republic and in the suburb and the city of Paris in France during years 2008 and 2009 respectively. More studies pertaining other bands have been reported in [12] [13].

In Oceania only New Zealand [14] appears to be making efforts with measurement campaigns conducted in the 806 MHz and 2750 MHz in urban Auckland. There is clearly an urgent need for increased measurement campaigns in this particular area for a multitude of locations.

In Asia, there appears to be an increasing realization of the need for the campaigns. To this end efforts have already been reported in Singapore [15] of a 24 hour spectrum usage in12 weekdays on the band 80 MHz-5850 MHz. The authors conclude from their measurements that their work is preliminary in its nature and future long term studies need to be performed to determine any potential secondary usage on those channels that have low or no active utilization. The Malaysian efforts are reported in [16] with a focus on the 470-498 MHz band in an outdoor environment of a suburban area in Johor Bahru. The investigators conclusively plan to extend these efforts to cover the whole spectrum in the VHF and UHF with different environments. In China, measurements have been focussed in the range 694-806 MHz [17] in the Chengdu area. More recently in Vietnam [18], in the frequency bands ranging from 20 MHz to 3000 MHz in Ho Chi Minh City and Long An province, in Japan [19] three particular locations of Kanto area spanning the 90 Mhz-3 GHz band. There have been other efforts in Qatar [20].

The majority of these investigations reach a common conclusion on the necessity for further occupancy measurements at different locations over varied times. Furthermore researchers are cognizant of the fact that wide scale deployment of CR technology cannot be developed based on the conclusions derived from a few geographical locations or under a specific spectrum regulation. Cognitive radio technology should envisage operation under many different spectrum regulations as well as a wide variety of scenarios. This thus motivates the need for more occupancy measurement elsewhere. On concluding their investigations, the authors in [18] affirm that the challenges of their campaign is not only cost (equipment) but also time (deployment) where multiple locations are to be measured to obtain local spectral pattern usage. Ultimately, [21] points out the numerous arguments regarding the technical efficacy of spectrum sensing technologies, the high cost of building devices incorporating such technologies and how the sensing requirement would limit innovation and commercial investment. Furthermore sensing to very low levels is very costly and possibly not achievable.

III. The WS Identification System

The enormous success of WiFi is an example of the concept of sharing the spectrum in an opportunistic way, that should be extended to other frequencies band. An inexpensive system

Fig. 1. The RF Explorer spectrum analyzer.

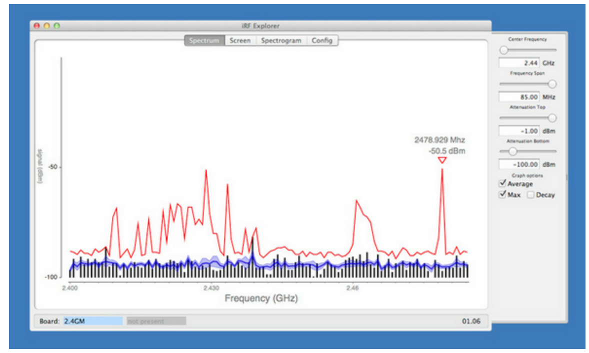

Fig. 2. RF Explorer Mac Client GUI.

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2012-04-13-12:08:15


Frequency(mHZ)  Signal (dBm)
400000000.000000        -92.500000
400892848.000000        -107.500000
401785696.000000        -102.000000
402678544.000000        -101.500000
403571392.000000        -109.500000
404464240.000000        -104.000000
405357088.000000        -103.000000
406249936.000000        -104.500000
407142784.000000        -103.500000
408035632.000000        -106.000000
408928480.000000        -107.000000
409821328.000000        -103.000000
410714176.000000        -104.500000
411607024.000000        -100.000000
412499872.000000        -100.000000
413392720.000000        -104.000000
414285568.000000        -100.500000
415178416.000000        -104.500000
416071264.000000        -102.000000
416964112.000000        -103.000000
417856960.000000        -107.000000
418749808.000000        -104.000000
419642656.000000        -108.500000
420535504.000000        -100.500000
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Fig. 3. Measurement output.

that can be used to effectively monitor the real spectrum usage in the TV bands over time, constitutes an important tool that can be used for activist to acquire hard data, enabling them to argue for a more efficient use of the spectrum. The rest of this section presents both the hardware and software components of the system used in our WS identification.

A. The WS Systemen Hardware

Monitoring the RF spectrum requires a spectrum analyzer. Commercial high-end spectrum analyzers are traditionally expensive and bulky, in the order of many thousand dollars, and require a steep learning curve to master. Recently an affordable and easy to use device has become available, to analyze the frequency band between 240 MHz and 960 MHz, which encompasses the higher part of the TV band. This device is called RF Explorer [22] and can be seen in Figure 1. RF Explorer will display full frequency spectrum in the band, including carrier and modulated shape, will display Spread Spectrum activity if that exist, and will show bandwidth to monitor collisions, frequency deviation from expected tone, etc. There are some other devices of reasonable cost in the market which offers some of these features in an USB dongle, but they are restricted to the ISM bands and do not cover TV frequencies. Furthermore, they always depend on a PC connection, and that is very inconvenient for outdoor work. You can connect RF Explorer to your PC for additional features and display quality, but that is optional; RF Explorer is fully functional as an independent unit. The price on the market as of May 2012 is 120 $.

B. The WS System Software

The software provided with the RF Explorer was not suited for the type of measurements we planned. There are both Windows and a Mac clients, free to use, but they are based on a GUI. This means that an operator must insert the information needed for the measurement: the center frequency, the frequency span and so on, as shows in Figure 2. Doing so for a number of measurements is cumbersome and prone to errors, especially if they are done on the move. Furthermore, the results are presented in form of a graph (a jpg image) than cannot be analyzed easily. We decided to automatize the process by writing a script that inserts the frequencies in the GUI and then saves the results as text files. In this way we could produce comparable graph and analyze the results. Writing a script to automate a GUI can be done in the Mac OS by using Apple's scripting language Applescript and by adopting techniques that virtually press the GUI's buttons and selects the menus. The output had to be in the form of a text file containing the time and date of the measurement as well as the signal level measured at different frequencies. An output file is shown as example in Figure 3.

IV. Measurements in Trieste as an Example

Using the RF Explorer, an external antenna, a laptop and a GPS we performed a series of measurements in Trieste, Italy, where the Abdus Salam International Centre for Theoretical Physics is located [23]. Trieste is a hilly city, located on the boundary with Slovenia. The measurements were carried out

Fig. 4. Laptop and RF Explorer inside the car during a measurement.

during one single day, with an omnidirectional antenna fixed on the top of a car's roof and the laptop and GPS inside the car, as shown in Figure 4. The antenna height is 1,5 m above the ground at all sites.

The authors drove around town and made measurements in different environments (urban, semi-urban, industrial and rural areas). We made a total of 14 measurements around Trieste. In Figure 5 we show the places where we carried out the measurements, while in Table 1 we list their positions.

TABLE I
POSITIONS OF THE SITES.

Site number	Site name	Latitude	Longitude
1	Barcola	45.698442	13.727986
2	Nettuno	45.681260	13.752007
3	Rive	45.649524	13.765301
4	Porto	45.636601	13.777263
5	Stadio	45.625287	13.794225
6	Altura	45.609403	13.840279
7	Cattinara	45.634965	13.825403
8	San Giovanni	45.656111	13.805196
9	Via Carducci	45.652201	13.776909
10	Universita'	45.667812	13.791720
11	Opicina	45.679436	13.780503
12	Bonomea	45.676244	13.768101
13	San Giusto	45.647850	13.772049
14	Conconello	45.669946	13.794327

We labeled with A the broadcasting transmitters in Conconello and with B the ones in Muggia. We have not gathered information about the transmitters in nearby Slovenia and Croatia, that are within RF reach.

In each site we measured the spectrum usage from 400 MHz up to 800 MHz, logging the latitude, longitude and environment description. Besides TV Broadcasting, other services also use portions of this spectrum, like the emergency communications systems around 400 MHz, the TETRA trunking system at 415-420 MHz, mobile services in the 440-470 MHz range, Radio Amateurs, Radio Astronomy in the 608-614 MHz and so on.

Following is a description of some of the most interesting measurements performed:

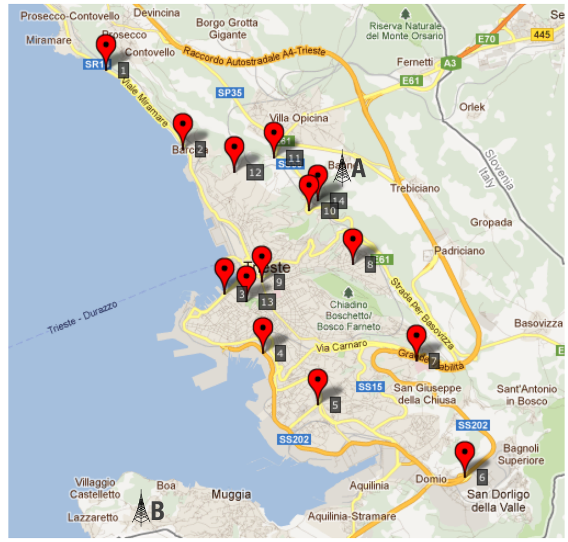

Fig. 5. Measurements were performed in 14 sites around Trieste.

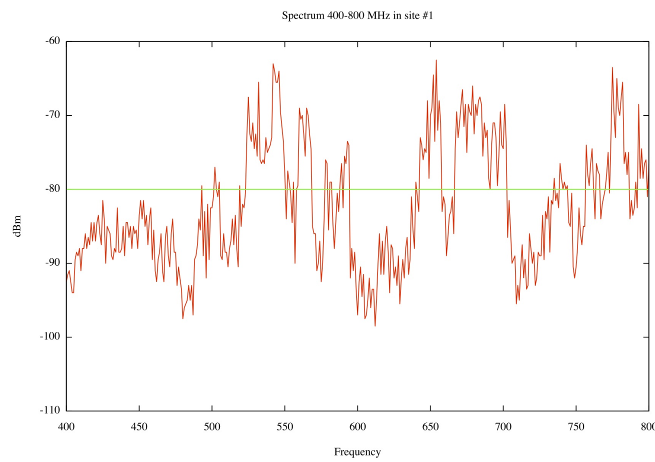

Fig. 6. Spectrum usage at site #1.

1) Barcola, site #1: this site is at sea level and covered mainly by the transmitter labeled as B in the map and has a clear line of sight to it. This point can be considered semi-urban. The graph in Figure 6 shows ample areas of spectrum below -80 dBm of received power. We can consider this as the threshold of available spectrum in all that follows.

2) Rive, site #3: this site is in the city centre, in a urban environment. We made the measurements near the sea, where both transmitters A and B can be seen. The graph in Figure 7 reveals a busier spectrum, but there are still available spaces.

3) Altura, site #6: this can be considered rural area, not a target area for the broadcasters. Measurement show a lots of available spectrum, as depicted in Figure 8.

4) Cattinara, site #7: this site, in a semi-urban area, is near the biggest local hospital where plenty of electronic instruments for medical applications are being used. The spectrum shown in Figure 9 shows significant availability.

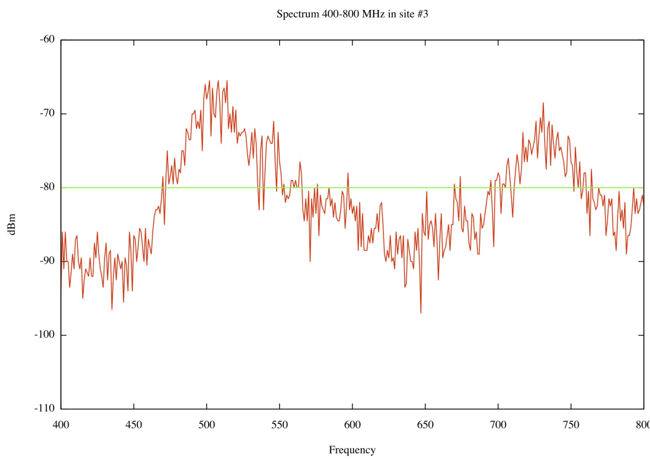

Fig. 7. Spectrum usage at site #3.

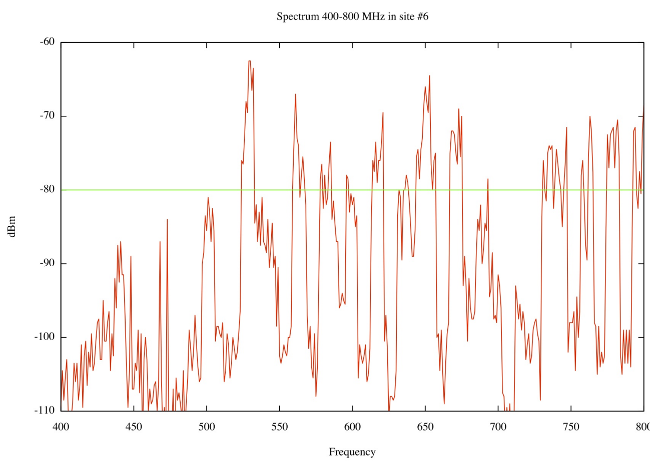

Fig. 8. Spectrum usage at site #6.

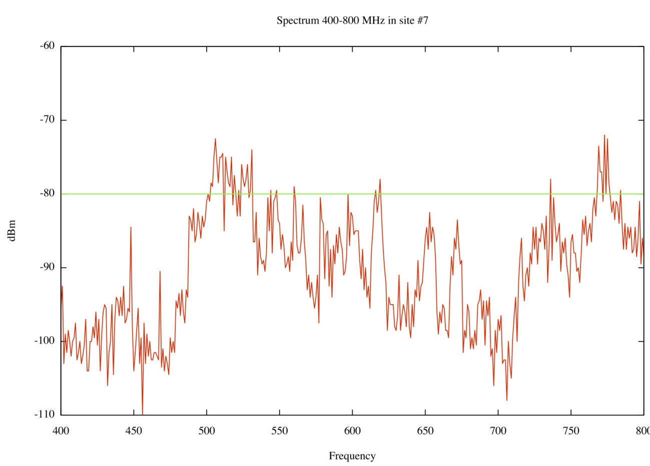

Fig. 9. Spectrum usage at site #7.

5) Conconello, site #14: the measurements performed here were very close to the group of broadcast transmitters identified as A (around 180 meters of distance, as shown in Figure 10). In this spot, the measurements showed a saturated spectrum, with no frequency availability over the whole range. The signals over all the measured frequency range were above -85 dBm. This is to be expected, given the great power used in broadcasting, and the limited performance of the filters. So, the use of White Space Devices is not feasible in the close proximity of broadcasting stations. This is also a benchmark for showing what a crowded spectrum would look like.

Fig. 10. Test antenna in the foreground, broadcasting tower A in the background.

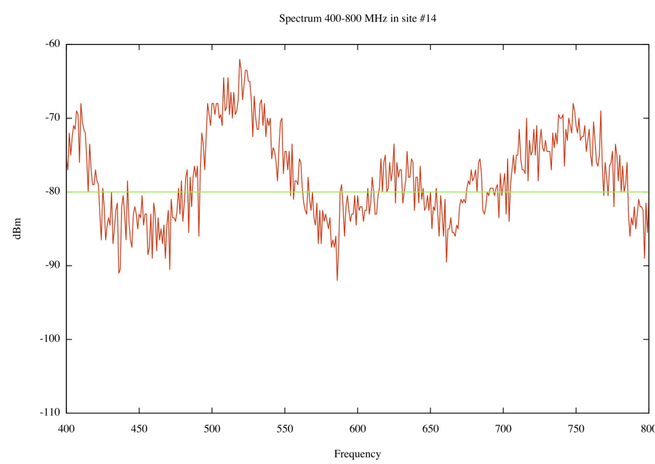

Fig. 11. Spectrum usage at site #14.

6) Heatmap: as a compact way to show the overall result at the 14 sites surveyed, we produced the false color graph showed in Figure 12. Frequencies from 400 to 800 MHz in the Y axis, whereas the X axis represents the different measurements sites from 1 to 14, and the color the strength of the received spectrum at the site with red the strongest signal

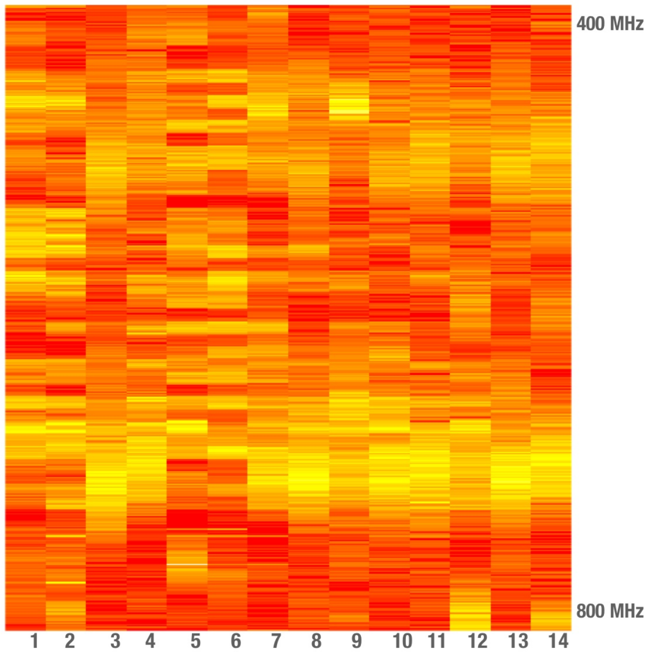

Fig. 12. Overall spectrum usage in Trieste.

and light yellow the absence of a significant signal.

V. Conclusions

This paper demonstrates the use of a software tool built around a low cost RF spectrum analyzer to enable white spaces identification. We describe the design and implementation of the tool and its application in sensing frequency availability in the 400 MHz to 800 MHz in 14 locations of the town of Trieste in Italy. Our experimental results are in agreement with frequency patterns expected from different frequency usages in different areas: urban, semi-urban and rural. As a first step towards white spaces exploitation, the experiments conducted to identify white spaces patterns reveal that fine-tuning existing software tools may enable frequency holes detection and thus push white spaces identification boundaries beyond current research and practice. There is room for extensions of our work to achieve time-of-the-day and day-of-the-week WS patterns identification.

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