WhispPi: White Space Monitoring with Raspberry Pi

Andrés Arcia-Moret
T/ICT4D Lab
The Abdus Salam International Centre for Theoretical Physics
Trieste, Italy
Email: aarcia_m@ictp.it

Ermanno Pietrosemoli
T/ICT4D Lab
The Abdus Salam International Centre for Theoretical Physics
Trieste, Italy
Email: ermanno@ictp.it

Marco Zennaro
T/ICT4D Lab
The Abdus Salam International Centre for Theoretical Physics
Trieste, Italy
Email: mzennaro@ictp.it

***Abstract*—Recently a lot of attention has been given to the use of TV White Spaces for rural communications. Several monitoring campaigns have been carried out to measure spectrum occupancy worldwide, concluding that most of the spectrum is underutilized. In this paper we present the design and implementation of a low cost system to measure spectrum occupancy and to geo-tag the measurements to allow mobile measurement campaigns. The system is based on the Raspberry Pi system on chip and on an affordable spectrum analyser. After calibrating the system against a professional spectrum analyser, we measured the spectrum occupancy in urban and rural Venezuela, showing that there is plenty of vacant UHF TV spectrum.**

I. Introduction

We believe that TV White Spaces (TVWSs) are ripe to provide badly needed two way communications services in Developing Countries, where protection of the incumbent is easier to accomplish given that very few broadcasting services are currently being offered, specially in rural areas, where the return of investment from many TV broadcasters is very difficult to achieve. Furthermore, the market for TV broadcasting in rural areas is well served by satellite providers who have enjoyed a remarkable success given that they can serve huge geographical areas with a high number of channels to satisfy the customer whims. Satellites, however, while ideally suited for broadcasting services, have proved of limited success in providing Internet access and other bilateral services. For these services, terrestrial wireless is currently the most cost effective solution, and the UHF frequencies have well known propagation advantages as compared with higher frequencies. On the other hand, the availability of new spectrum to provide those services will surely benefit the customers by spurring competition among providers. For this to happen, the regulators must be convinced that the spectrum is really available and that its new use will not interfere with incumbents.

It is worth mentioning that the transition to digital terrestrial television has recently begun in the Venezuela, with actual coverage only in the capital, whereas in the rest of country there is only analog service, mostly in the VHF bands. There are several satellites TV broadcasters using the Ku and Ka bands, with country wide coverage and a significant customers uptake. Cable TV is also very popular in urban areas.

A. White Spaces and Spectum Monitoring

Although there have been many measurements efforts to ascertain the spectrum occupancy in the UHF frequency band allocated to TV broadcasting, most have been carried out in Developed Countries, using highly specialized equipment [1],[2],[3],[4],[8].

A measurement campaign carried out in Bogota is described in [7], using similar equipment, that is, a high cost spectrum analyzer with a steep learning curve and sophisticated signal processing equipment. This is often not affordable in Developing Countries, encumbered with limitations of financial resources and properly trained personnel.

Therefore, the deployment of a low cost and easy to use spectrum analysis system specifically geared to identify white spaces in UHF could be a valuable proposition. The use of such system in both rural and urban areas in Venezuela is presented to emphasize the differences in spectrum occupancy and expose the availability of wide swaths of spectrum that can be used to alleviate the existing digital divide not only with respect of Developed Countries but also between urban and rural areas in the same country.

B. Contribution

This paper describes the design of a low-cost system to measure spectrum occupancy and geo-tag spectrum measurements. This system has been tried as a prototype in Venezuela and will be used in other countries where the vacant spectrum could be used to connect rural communities. Our main contributions consists in tackling some important challenges that, to the best of our knowledge, have not been addressed by other solutions. These challenges include cost, power consumption, operator's skills, data logging capabilities and availability of source code. The main differentiators are:

- **Low cost.** With a total cost of less than $200, the system can be easily acquired by universities and civil society organizations worldwide. Similar systems cost one or two orders of magnitude more.
- **Low power consumption.** Based on low power devices, the system can run for about six hours with a small battery. This allows for measurements campaigns that can run for an entire working day.

- **Ease of use.** Once switched on, the system runs automatically without any human intervention. Non technical personnel can carry the system around and collect measurements. Technical personnel can easily select the frequencies of interest with only a basic knowledge of Linux.
- **Data logging.** As the measures are stored in an SD card, weeks of measurements can be stored in the device with no need to download them on a PC.
- **Open Source.** The components of the system are based on the open source concept. The system we developed can be easily modified thanks to the availability of the source code.

Furthermore,the proposed system is particularly suited to perform measurements while moving, either on foot or in a vehicle, thus facilitating the gathering of spectrum occupancy in relation with geographical deployment.

The rest of this paper is organized as follows. In Section II we describe the system design, then proceed with the calibration in III. In Section IV we describe the measurement campaign and the results obtained, and finally, in Section V we present our conclusions.

II. System Design

The proposed system was designed on the principle that data from the spectrum analyzer have to be stored in a device with a battery backup for mobile measurements. In addition to spectrum, the position and the time of measurements are saved on the same device. The lower the power used by the device, the longer it can work without recharging. Furthermore, measured data have to be available in a user friendly way.

The system is composed of four components:

1) A Raspberry Pi, which is a low cost computing device that can be used to control the data acquisition.
2) An RF Explorer, an affordable spectrum analyzer that has already proved its usefulness for spectrum efficiency advocacy [5].
3) A USB GPS, to collect the exact position of the measurement.
4) A small battery with micro USB output to power the Raspberry Pi which then powers the spectrum analyzer.

The spectrum analyzer, the GPS and the battery are connected to the Raspberry Pi via USB cables. To make the system easier to carry, an enclosure has been designed and printed with a 3D printer [6]. The overall system is shown in Figure 1. Following is a description of the main components: the spectrum analyzer and the Raspberry Pi.

A. RF Explorer

Monitoring the RF spectrum requires a spectrum analyzer. High-end spectrum analyzers are traditionally expensive (in the order of many thousand dollars) [9] and bulky, so they are not suited for nomadic use. Some portable Spectrum Analyzers have a GPS on board, but are out of reach for most Universities. New affordable devices such as the ones listed below enabled us to develop a low cost solution for spectrum monitoring.

Fig. 1: The overall system.

Recently an affordable and easy to use device to make spectrum measurements has become available, the RF Explorer [10] shown in in Fig. 1. There are five RF Explorer models, covering the most-used bands below 2.5 GHz. In our system we use the Sub 1 GHz model, employing the Silicon Labs Si4431 receiver chip (covering 240 MHz to 960 MHz). The price of this model is 120 $ (as of August 2013).

The main features of the RF Explorer are:

- Spectrum Analyzer measurements with Peak Max and Hold, Normal, Overwrite and Averaging modes
- High capacity Lipo battery for 16 hours of continuous run, rechargeable through USB port
- SMA antenna connector (50 ohms)
- Dynamic range: -115 dBm to 0 dBm
- Absolute Max input power: +5 dBm
- Can be fitted with internal Expansion Modules for additional band and functionality (signal generator)

It has an LCD display (128x64 pixels) that offers great visibility outdoors. While is fully functional as an independent unit, optionally can be connected to a PC via USB for additional features.

There are some USB dongles based on the SDR (Software Defined Radio) concept [11] that offer similar features also at low cost. We did not choose them for our system because their development environment has a steep learning curve and they lack of a display to check the measured value.

B. Raspberry Pi

The Raspberry Pi [12] is a credit-card-sized single-board computer developed in the UK to promote the teaching of basic computer science in schools. It has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU and 512 megabytes of RAM. It does not include a built-in hard disk or solid-state drive, using instead an SD card for booting and long-term storage. The B model with two USB sockets and an Ethernet connection sells for $35. The A model, with only one USB socket, sells for $25. The Raspberry Pi runs a Debian ARM distribution so it can use any Linux based software.

Power is provided via a micro USB connector, compatible with mobile phone chargers or any other 5 V supply (such as batteries, solar panels, etc). The B model requires about 5 W of power, while the A model requires 2 W [13].

III. Calibration

To assess the reliability of RF Explorer's measurements, we compared it against a professional Agilent N9344C recently calibrated spectrum analyzer. A calibrated Agilent 8648C signal generator provided signals at 10 different power levels, i.e., from -95 dBm to -50 dBm in 5 dB steps, for each of the 113 measured frequencies. From the results displayed in Fig.2, we can infer that in the frequency range from 300 MHz to 900 MHz, the RF Explorer displayed value is consistently slightly less than the power applied to its input, with a maximum discrepancy of 4.5 dB. In the UHF TV spectrum range that extends up to 806 MHz the under estimation is bounded to 2.8 dB. It is worth noting that the instrument underestimates the higher frequencies which correspond to the cellular telephone system and it is more accurate in the frequencies of our interest. Nevertheless we also measured the cellular frequencies since they are present along the main roads in Venezuela and therefore serve as a sort of bench mark for our measurement campaign.

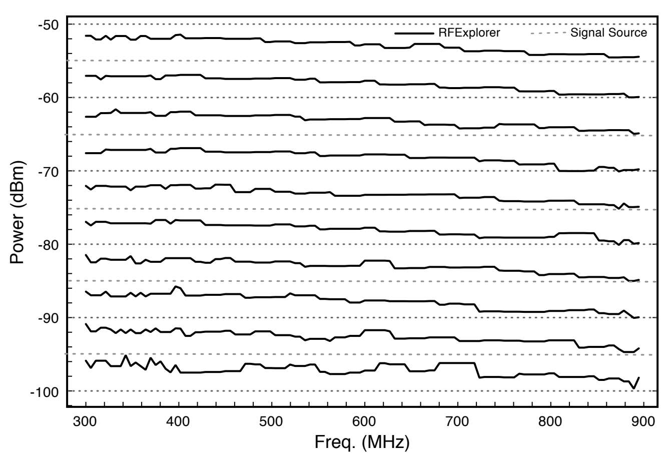


Fig. 2: Calibration of the RF Explorer.

IV. Results

During July 2013 we performed two measurement campaigns in Venezuela, both starting at the city of Mérida. The first one extended along the route betweeen Mérida and El Vigia. The second one went from Mérida to Barquisimeto. In total we made measurements along 1000 kilometers in different types of roads and terrains, spanning from sea level to a 4000 meter high mountain pass, encompassing urban, suburban and rural areas.

Site	Leg length (km)	Population	Active Freqs
Mérida (city)	20	330 537	17
Ejido	10	99 837	10
Lagunillas	85	42 717	6
El Vigía	20	250 257	6
Santa Cruz de Mora	9	23 276	9

TABLE I: Measurement campaign in southern region.

Site	Leg length (km)	Population	Active Freqs
Mucuchies	10	6 354	3
Barinitas	20	52 872	7
Barinas	23	353 442	11
Guanare	41	235 201	10
Acarigua	50	203 358	7
Barquisimeto	20	1 600 000	24

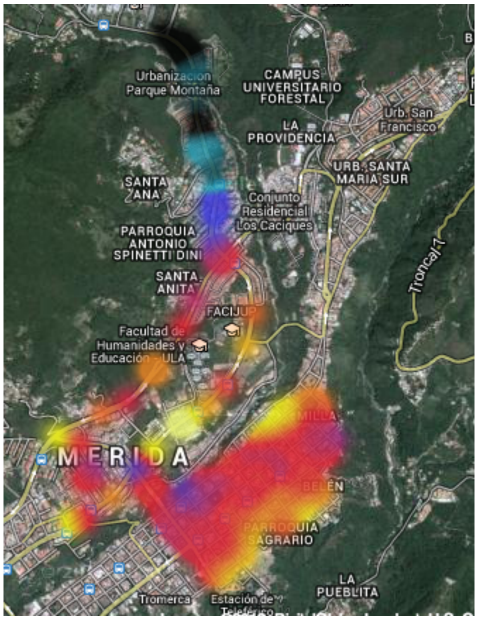
TABLE II: Measurement campaign in northern region

Tables I and II show the distances covered in each town along with the population (based in the 2011 census) and the number of occupied frequencies. The spectrum and the position along the route were continuously recorded using the setup described in section II, to later process the data in order to draw conclusions about spectrum occupancy from a mobile perspective.

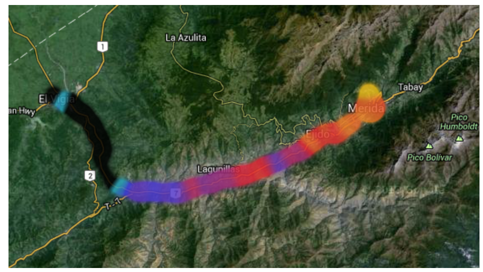
We focus on the difference among the measured power in different points rather on the absolute power, and this strategy allowed us to identify populated areas just by looking at the spectrum measurements, and to draw general conclusions about spectrum occupancy, markedly different in urban, suburban and rural areas. For instance, the frequencies between 868 to 960 MHz show the highest occupation. These frequencies corresponds to the cellular services in Venezuela (both CDMA and GSM) which have good coverage along the roads even in rural regions, and we were able to capture them in nearly 100% of our journey. This is in contrast with the UHF TV broadcasting frequencies, that were observed only in urban and suburban areas, as clearly visible in Figure 3, where yellow corresponds to a very strong signal, red to a strong signal, blue to a weak signal and no color or black to lack of signal.

Figure 3a shows the heat map of the city of Mérida corresponding to the TV channel from 554 to 560 MHz (channel 28), with strong signal in the downtown area, falling off rapidly in the adjacent zone. Figure 3b illustrates that channel 22, from 518 MHz to 524 MHz has a strong signal in the city of Mérida, which decreases along the road as it goes through suburban and rural areas. This corresponds to a local TV broadcasting station operated by the University of Los Andes (ULA). The black portion on the road at the left corresponds to a tunnel that blocks all the signals and, a track of the road that goes through a canyon with steep slopes on the sides that essentially block any radio signal.

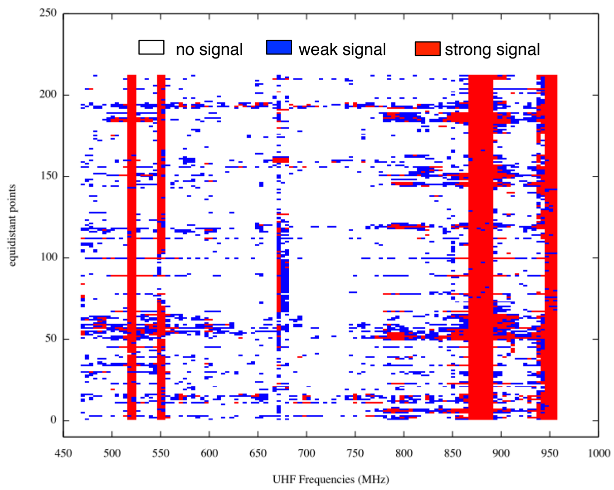
Figure 3c depicts the spectrum occupancy along a route in downtown Mérida, in which the cellular frequencies from 868 to 890 MHz and from 938 to 960 MHZ are clearly visible along the whole stretch as are the one corresponding to 554-560 MHz (TV Channel 28) and 608-614 MHz (TV channel



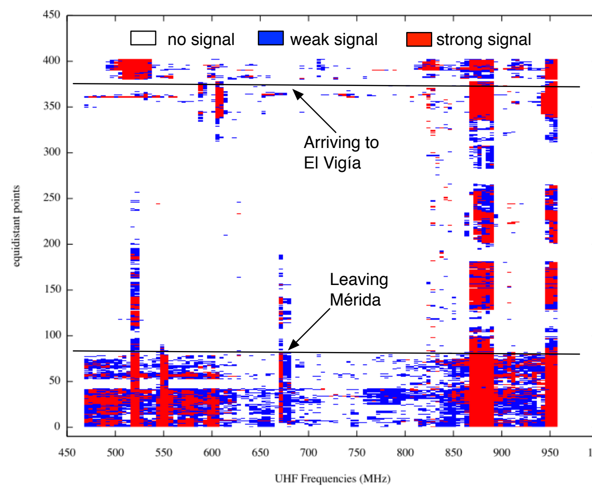
(a) Heatmap of channel 28 (554-560 MHz) in Mérida downtown.



(b) Heatmap of channel 22 (518-524 MHz) in the route from Mérida to El Vigía.



(c) Spectrum from 470 to 960 MHz in Mérida downtown.

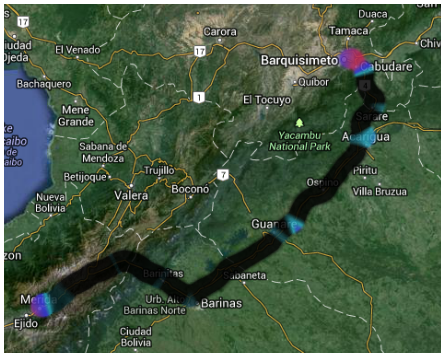


(d) Spectrum distribution from 470 to 960 MHz within the route from Mérida to El Vigía.

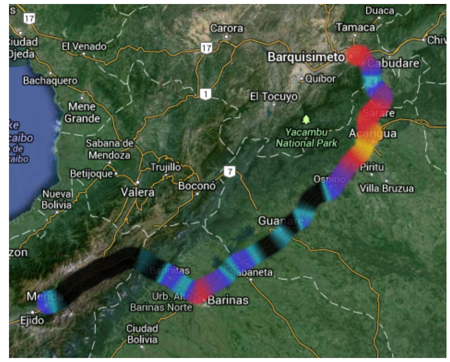
Fig. 3: General overview of the spectrum in the 470 to 960 MHz range within the route from Mérida to El Vigía (Venezuela).

37), while the rest of the spectrum shows very little activity with plenty of potential white spaces. The ordinate in these figures corresponds to acquisition points along the trajectory and the abscissa to the frequency. Figure 3d records the data gathered traveling from Mérida to El Vigía, along 80 kilometers, and one can see that after acquisition point 75, which corresponds to the outskirt of Mérida, the white spaces become predominant, where only the cellular frequencies maintain their integrity in most of the route, with the interesting exception of the tunnel before the entrance of El Vigía, where even the cellular coverage is lost, only to reappear after exiting the tunnel and secluded track of road that block radio signal. Most of the route between the two cities has a low density of population and there is plenty of vacant spectrum. On arriving at El Vigía, strong signals show up in the 500 MHz region and minor ones in the 600 MHz zone, with a few scattered elsewhere, as is to be expected in a city of 250 thousand people.

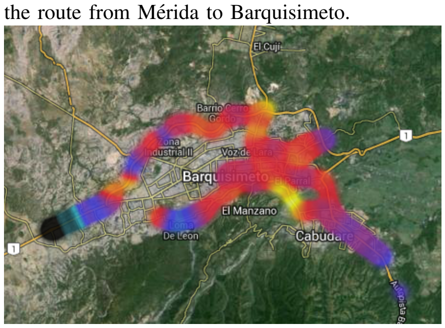
Similar results where obtained in the route from Mérida to Barquisimeto, as shown in Figure 4a, where the heat map of channel 16 (482-488 MHz) shows only slight activity in four places of the 400 km route, with strong activity only in the city of Barquisimeto. Channel 23 (524-530 MHz) shows greater occupancy along the same route, with hot spots corresponding to the cities of Barinas, Guanare and Acarigua as evidenced in Figure 4b. Upon arriving to Barquisimeto, the heat map of figure 4c shows that channel 24 (530-536 MHz) is widely used in the city and its suburbs, while channel 62 (758-764 Mhz), depicted in figure 4d has a more limited coverage over the same geographical area. Figure 4e is a graph of the spectrum from 300 to 900 MHz in Barquisimeto downtown, in which



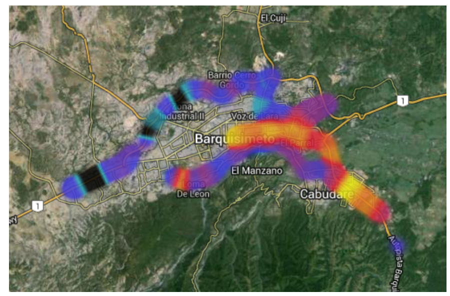
(a) Heatmap of channel 16 (482 - 488 MHz) within the route from Mérida to Barquisimeto.



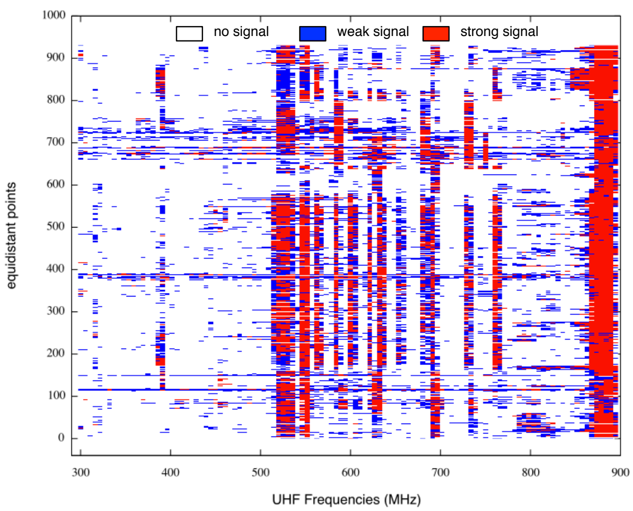
(b) Heatmap of channel 23 (524 - 530 MHz) within the route from Mérida to Barquisimeto.



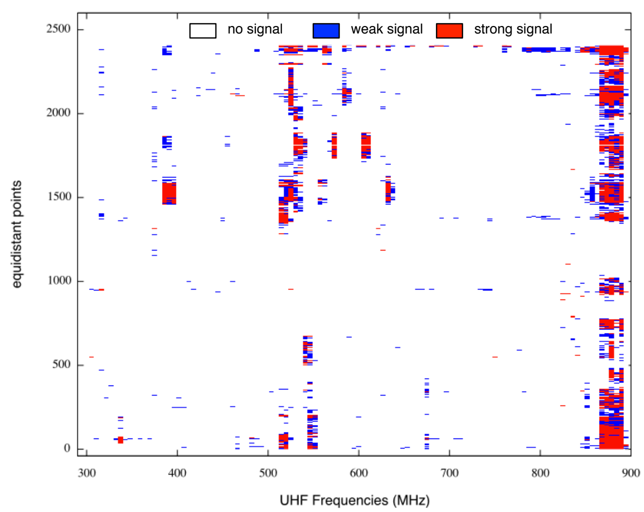
(c) Heatmap of channel 24 (530 - 536 MHz) in down town and suburbs of Barquisimeto.



(d) Heatmap of channel 62 (758 - 764 MHz) in down town and suburbs of Barquisimeto.



(e) Spectrum distribution from 300 to 900 MHz in downtown and suburbs of Barquisimeto.



(f) Spectrum distribution from 300 to 900 MHz in the route from Mérida to Barquisimeto.

Fig. 4: Spectrum in the 300 to 900 MHz range in down town and suburbs of Barquisimeto.

it is apparent the presence of 24 TV channels (out of the 45 UHF TV channels allocated in Venezuela) in this city of 1 600 000 inhabitants. This is in stark contrast with the heat map of figure 4f, corresponding to the 400 km route between Mérida and Barquisimeto, in which it is evident that most of the UHF TV spectrum is literally white.

V. Conclusions

We present an affordable and easy to use set up system well suited to the requirements of both mobile and long term stationary spectrum measurements. With it, we undertook an extensive campaign to asses the UHF TV spectrum occupancy in Venezuela. As predicted, there is plenty of potential white spaces even in main cities, and in the rural areas this portion of the spectrum is essentially fallow, ready to be put to new use. Since the TV needs of Venezuelans are already well served by satellite, cable, and even telephone operators, we suggest that a better use for these vacant frequencies is for the building of community networks, specially to provide Internet access in rural areas where the service is currently very poor.

Currently we are developing a methodology to determine potential white spaces more accurately, not only from the mobile perspective, but also from static campaigns. Moreover, to provide better guidelines to regulators, we plan to compare existent coverage models for TV transmitters, with measurements produced by the system described in this paper.

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