Cross-platform Demonstrator Combining Spectrum Sensing and a Geo-location Database

Rogério DIONÍSIO[1,2], José RIBEIRO[2], Jorge RIBEIRO[2], Paulo MARQUES[1,2],
Jonathan RODRIGUEZ[2],
[1]*Instituto Politécnico de Castelo Branco, 6000-767 Castelo Branco, Portugal*
Tel: +351 272 339 300, +351 272 339 399
Email: rdionisio@ieee.org
[2]*Instituto de Telecomunicações, 3810-193 Aveiro, Portugal*
Tel: +351 234 377 900, +351 234 377 901
Email: jcarlosvgr@av.it.pt, jorgeklx@gmail.com, pmarques@av.it.pt, jonathan@av.it.pt

Abstract: After the digital switchover, a secondary access of the so-called TV White Spaces should not interfere with primary users, such as DVB-T systems and local wireless microphone devices. One consensual method for secondary spectrum users to avoid interference is to combine geo-location database with spectrum sensing. This paper describes an experimental platform that combines wireless microphone sensors with a web-based geo-location database access. Software defined radios and Internet technologies are the enabling tools in use. From test trials in a real scenario, the platform was capable to update a list of vacant channel from the geo-location database, using reliable information from blind sensing algorithms.

Keywords: Cognitive radio, Wireless microphone, Sensing technique, Geo-location database.

1. Introduction

The radio spectrum suitable for the propagation of wireless signals is a limited resource and hence requires optimal allocation as collectively dictated by regulatory, technical and market domains. The current global move to switch from analogue to digital TV has opened up an opportunity for the re-allocation of this valuable resource. In one way, spectrum bands once used for analogue TV broadcasting will be completely cleared – leaving a space for deploying new licensed wireless services, and in another way, digital television technology geographically interleaves spectrum bands, or TV White Spaces (TVWS), to avoid interference between neighboring stations – leaving a space for deploying new wireless services. However, primary users of the spectrum, such as DVB-T systems, must be protected from interference, and one consensual method to protect them is based on geo-location databases, combined with spectrum sensing.

There are several advantages for the use of geo-location to support the detection of incumbent systems. The most important is that the database stores the required information to compute the TVWS spectrum pool available in a specific location. Information such as DVB-T protected areas; specifications of DVB-T transmitters, advanced propagation models, protection rules, can be used to compute the maximum transmit power. With a database, part of the complexity associated with sensing and maximum power computation is transferred to the core network, decreasing complexity and power demand of TVWS devices. The database has the ability to be dynamically updated to continuously adjust interference protection parameters in line with the evolution of incumbent standard' s evolution, e.g. DVB-T2.

For regulatory enforcement, the database can be used in identifying the source of harmful interference where it occurs and may enable a "remote de-activation" of the device. In addition, TVWS spectral utilization efficiency is better than using sensing-only techniques. This is primarily due to the ability of geo-location enabled TVWS devices to accurately determine protected service contours. Sensing-only must sense incumbent signals down to very low levels leading to a high level of probability of false alarms [1].

However, a database approach can only protect registered systems. In Europe and in many countries, Public Making and Special Events (PMSE) devices operates mostly in unlicensed basis, without any record. Even so, PMSEs are incumbent users of the spectrum and as such, they must be protected from secondary user's interference. Therefore, the only way to protect unregistered PMSE applications, wireless microphone (WM) or any other use, is through sensing. The combined sensing and geo-location approach has the advantage of reducing the risk of interference with PMSE compared to sensing only. Combining the two approaches relaxes the sensitivity required for sensing devices, which is a major limitation of TVWS developments. Also, since local sensing is only performed in a limited number of TV channels indicated by the database, a hybrid approach, as described in this paper, will speed up the sensing process: Autonomous sensing and geo-location database approaches are combined to detect the presence of primary users in a specific location, based on a "double affirmative", as depicted in Figure 1.

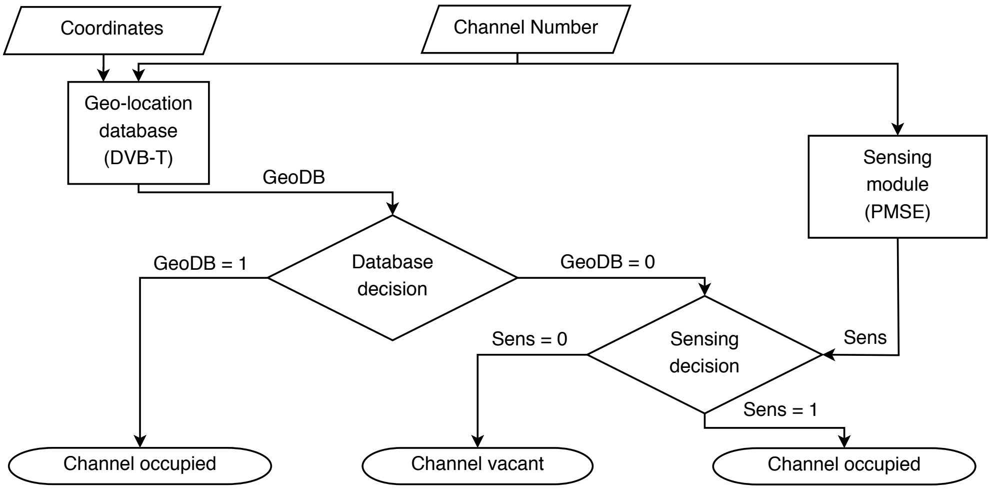


Figure 1 - Flow chart of the decision-making process for combination of geo-location data with local sensing.

Chapter 2 describes the sensing platform, including the hardware and software used to implement sensing algorithms. Chapter 3 explains the design and functional features of a geo-location database using web-based technologies. In chapter 4, we describe the measurement scenarios and explain the results from field trials. Chapter 5 follows with conclusions and future work.

2. Sensing platform for PMSE

2.1- Structure of the sensing platform

We use Labview from National Instruments [4] to program the software application for PMSE sensing and interact with the hardware used for sensing. Labview combines a graphical programming language with the capability to create user-friendly user interfaces, which makes it a preferred choice compared with other software solutions. This particular combination of hardware and software was chosen due to the recent development of

USRP2 drivers for Labview [3]. Figure 2 shows a diagram of the sensing platform. The following sub-chapters will describe in detail all the important features of the sensing module.

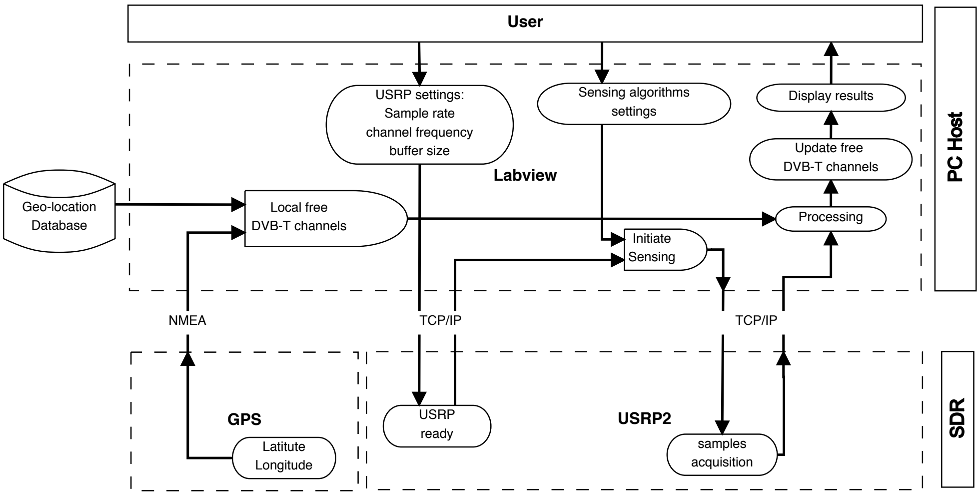


Figure 2 – Structural and functional diagram of the sensing tool.

2.2- Autonomous Sensing Techniques

Sensing algorithms can be classified into three main categories, based on the information used for sensing:

1. Noise dependent detection, that requires information on noise power only:
   No assumption is made on wireless microphones signal characteristics. Basically these techniques are detecting random signal in noise. They do not need prior information on the signal but on the other hand, very accurate information on noise statistics is necessary in order to obtain reliable detection performance.
2. Features detection, that requires both source signal and noise power to be known:
   These algorithms employ knowledge of structural and statistical properties of primary user signals in the decision-making. The majority of the PMSE systems are currently using FM modulation to transmit signals; when a WM is set to silent mode (no voice signal), only the frequency carrier is transmitted, and no features can be detected since they are non-existent. Moreover, due to the lack of a common standard for PMSE devices, feature detection of WM signals is not suitable.
3. Blind detection, that doesn´t requires information on source signal or noise power:
   Blind methods require little information on the signal or the channel and have some immunity to synchronization error, fading and multipath, noise uncertainty, and unknown interference. These algorithms rely on a statistical analysis, using covariance or eigenvalue matrix to identify the properties of a signal. They overcome the noise uncertainty problem and can even perform better than energy detection when the signals to be detected are highly correlated, as in the case of PMSE signals.

An extensive study and simulation of several sensing algorithms, reported in [2], have shown that blind methods, in particular Covariance Absolute Value (CAV) and Blindly Combined Energy Detection (BCED), presented a superior performance compared to other algorithms, for PMSE detection. They are implemented into the sensing platform, and their performances are measured against the Energy Detection (ED) algorithm, to evaluate if the higher complexity of CAV and BCED algorithms results in significant gains. Metrics used to evaluate each algorithm are the probability of false alarm (P_{FA}), the probability of detection (P_D) and the Receiver Operating Characteristic (ROC).

Labview has many pre-defined objects and functions for math, flow control, conditional or Boolean operations, among many others. However, to increase speed and reduce complexity of the program, all sensing algorithms (CAV, BCED and ED) are coded in C^{++} and integrated as new Labview functions.

2.3- User Interface

The Graphical User Interface (GUI) is organized in two pages, according to their functionalities:

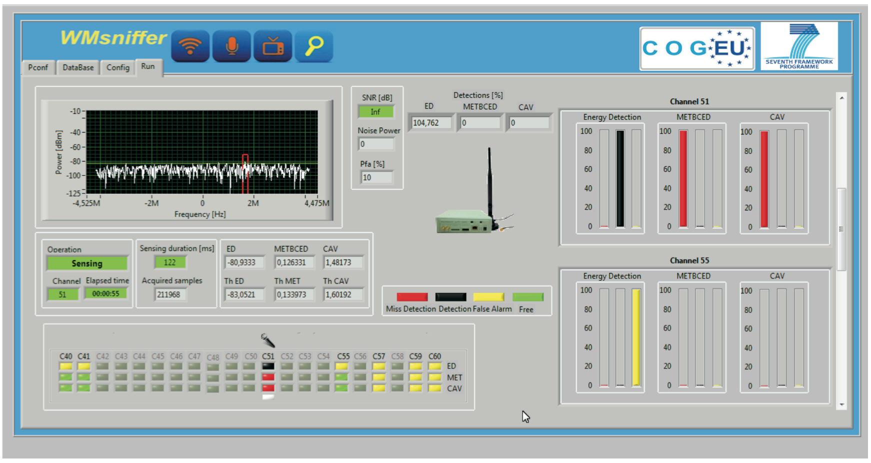
1. Setup interface (Figure 3):
   Following an initial configuration stage, the GUI triggers the communication process between the host PC and the USRP, the program acquires local coordinates with a GPS receiver (if no GPS signal is available, coordinates can be inserted manually) and displays a map centered on the sensing device. After a query from the geo-location database, (chapter 3 has a detailed description of the database), a list of all available DVB-T channels is received and displayed as LED indicators with different colors and symbols: red (cross symbol) means that the channels is already occupied by a DVB-T channel, and green (check symbol) means that the channel is free of DVB-T signals. Each time the user wants to reserve (book) a free channel for PMSE usage, he can do so by clicking on a free channel indicator that will change to a WM symbol, as represented in at the bottom of Figure 3. From the setup interface, the user can also define sensing parameters, such as detection threshold, sensing time and the sensing algorithm itself.

Thr ED -83,0521
Thr MET 0,133973
Thr CAV 1,60192
Sensing Time [ms] 100 m
Rx Sampling Rate [s/sec] 10M
Frame Size [samples] 4096
Acq Duration [sec] 409,6u
Latitude 48,19
Longitude 11,6278
Radius [meters] 200
PFA [%] 10
Time Target (s) 59
index 0
Place 1

Frequencies for this area
Channel : 40 Frequencies: Fmin 622 Mhz ; Fc 626 Mhz ; Fmax 630 Mhz
Channel : 41 Frequencies: Fmin 630 Mhz ; Fc 634 Mhz ; Fmax 638 Mhz
Channel : 51 Frequencies: Fmin 710 Mhz ; Fc 714 Mhz ; Fmax 718 Mhz
Channel : 55 Frequencies: Fmin 742 Mhz ; Fc 746 Mhz ; Fmax 750 Mhz
Channel : 57 Frequencies: Fmin 758 Mhz ; Fc 762 Mhz ; Fmax 766 Mhz
Channel : 59 Frequencies: Fmin 774 Mhz ; Fc 778 Mhz ; Fmax 782 Mhz
Channel : 60 Frequencies: Fmin 782 Mhz ; Fc 786 Mhz ; Fmax 790 Mhz

Figure 3 – Setup interface of the PMSE sensing platform.

2. Sensing interface (Figure 4):
   After pressing the RUN button from the setup interface, the USRP starts to sense for signals only on the free channels list indicated by the geo-location database. For each sensing algorithms (CAV, BCED and ED), the result of sensing is compared with a threshold. If the result is above the threshold and there is booking of a WM in that channel, status is set to ‘detection’ (color black), and if there’s no previous booking of WM, then status is set to ‘false alarm’ (color yellow). On the other hand, if the result from sensing is below the threshold and there is a WM booking for that channel, status is ‘miss detection’ (color red), if there is no booking of WM, the status is ‘free channel’, (color green). This method is continuously repeated and produces statistical results, dependent on preliminary information about WM booking on free channels, i.e. without DVB-T signal: If a PMSE is booked for one channel, the measurement results for that channel, after sensing, will be ‘detection’ or ‘miss detection’. Otherwise, if no PMSEs are booked for a channel, measurement results may be ‘free channel’ or ‘false alarm’. All results from measurements are saved in a spreadsheet file for post-processing. The sensing interface also automatically presents the power spectrum and an estimate of the SNR, for each DVB-T channel sensed [2].



SNR [dB] Inf
Noise Power 0
Pfa [%] 10

Detections [%]	ED	METBCED	CAV
	104,762	0	0

Operation Sensing
Channel 51
Elapsed time 00:00:55
Sensing duration [ms] 122
Acquired samples 211968

ED	METBCED	CAV
-80,9333	0,126331	1,48173

Th ED	Th MET	Th CAV
-83,0521	0,133973	1,60192

Figure 4 – Sensing interface of the PMSE sensing platform.

2.4- Hardware platform

The sensing platform relies on software-defined radios (SDR), a GPS receiver and a host PC, as depicted in Figure 5. The SDR platform is based on USRP2 hardware prototyping [3]. The USRP2 has a WBX daughterboard with two antenna channels (TX/RX, RX2), tunable from 18 MHz to 2.0 GHz. The host is a laptop with Windows OS and Gigabit Ethernet connection to link to USRP2 and a wireless connection for Internet access. GPS device is independent and is connected to the host PC by a Bluetooth connection. Since PMSE signals presence is not guaranteed in the demonstration sites, commercial tunable FM wireless microphones are also used, as primary users. This way, we can define a variety of sensing scenarios and measure the performance of sensing algorithms, for indoor and outdoor tests, under different propagation conditions.

Figure 5 – Photo of the deployed demonstrator, together with two wireless microphones. Both DVB-T geo-location database information (laptop screen) and PMSE sensing results (LCD screen) are displayed.

3. Geo-location database platform

3.1- Structure of the platform

Several web-programming languages and technologies are used to develop the platform, fetch for geo-located spectrum information and display the results. Figure 6 shows the architecture and platform operations. The platform includes a web server running MySql to manage the database, access to a Google Maps server, and a user PC with a browser and Internet connection. Once registered and brought online, the user enter the web server address. Meanwhile, the platform access to Google Maps resources and displays a digital map. A second screen, representing TVWS information from the geo-location database, is processed and overlay Google digital maps as a new dynamic layer.

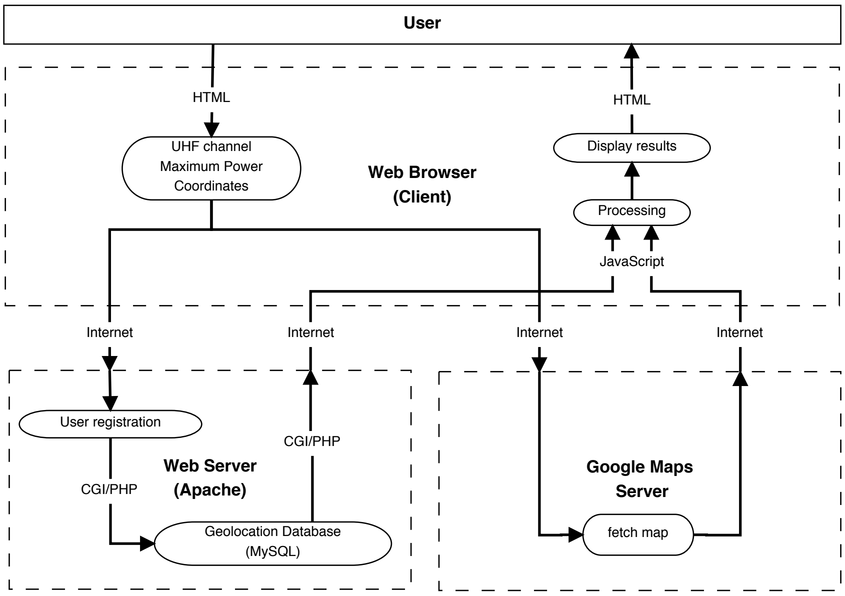


Figure 6 – Schematic of web-based geo-location database platform.

The geo-location database is a simple data structure, storing the following information:

- Longitude and latitude coordinates: Each coordinates represents the center of a pixel area of 200 × 200 square meters.
- UHF channel number: Range from channel 40 to channel 60.
- EIRP: Maximum power that a TVWS may emit, in dBm, depending on the coordinates and the channel number.

The database information is geographically centered in Munich, with a total area of 51 square km, which makes a total of 65000 pixels, each one with information on the maximum power allowed for TVWS devices, for each UHF channel.

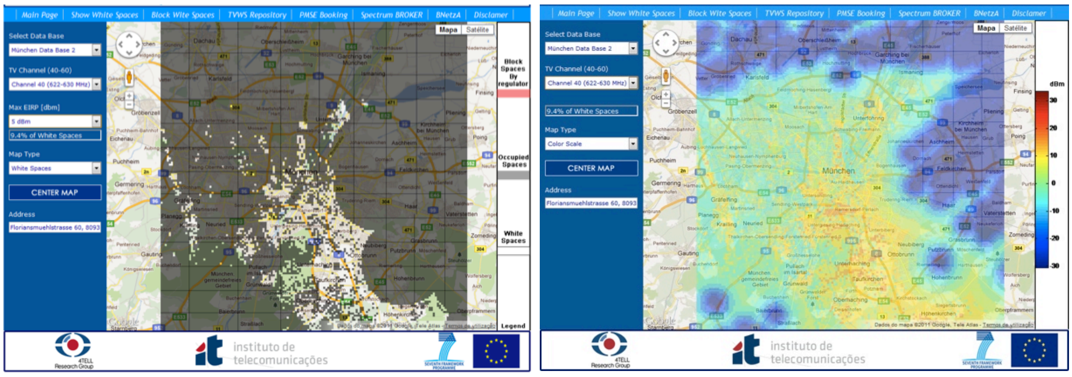
3.2- User interface

The geo-location database has a graphical user interface (GUI) implemented as an interactive web page using HTML language. It provides an eye-catching view of the data stored in the database. Moreover, the GUI does so in an orderly manner, therefore the user is able to see the information of a particular channel, and change the way this information is presented. The TVWS map is defined by specifying:

1. TV channel: UHF channel selection (any integer number between 40 and 60).
2. Max EIRP: Maximum power (between 0 and 30 dBm) that may be used for a TVWS device to transmit and for one channel.
3. Map type: Can be specified as ‘White spaces’, ‘Grey scale’, ‘Color scale’ or ‘Chart point’. If ‘White spaces’ (see Figure 7a)), a two color map shows TVWS availability, for the selected channel and maximum radiated power. The white color represents the locations where secondary users may use the spectrum, and black areas are forbidden. ‘Grey scale’ present the maximum power that can be transmitted in one UHF channel, for all pixels in the chosen area. ‘Color scale’ shows the same information with a color map (see Figure 7b)). With either ‘Grey scale’ or ‘Color scale’ options, the input parameter ‘Max EIRP’ is no longer available. ‘Chart point’ shows a pixel grid overlaid to a map, with 200 m resolution. By clicking on a pixel, a new chart is produced, giving information of the maximum power available for all channels for that pixel area (See Figure 8a)).

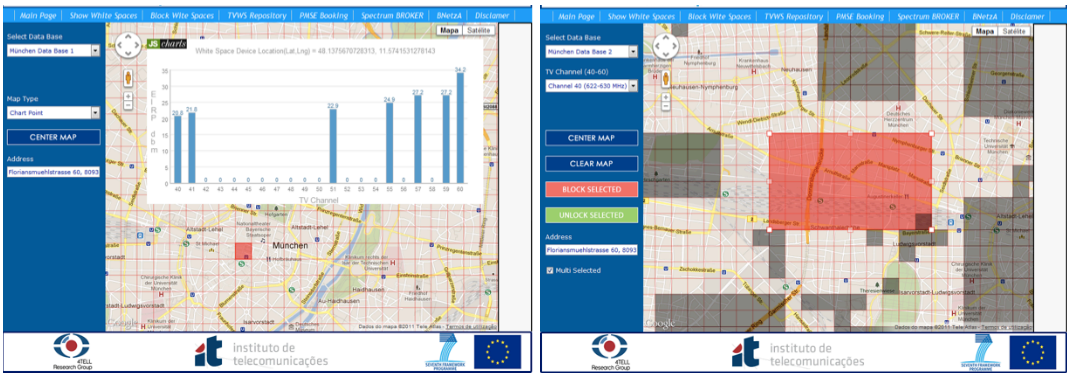
‘Block white spaces’ is used to hide or unhide the information from one or more pixels, and control the access and usage of the spectrum. The pixels are selected by dragging the

mouse over the map (Figure 8b)). They are two options: ‘Block selected’ prevent the access and usage of the information, and ‘Unlock selected’ returns the access back to the user. This functionality is available only to users with administrative rights.
The options ‘Center map’ returns the map to its original size (51 km^2), and ‘Address’ gives to the user an easy method to find specific areas by their addresses or postal codes, through Google Maps API.



a) *b)*

Figure 7 – Two different views for the same channel: a) ‘White Spaces’ and b) ‘Color Scale’.



a) *b)*

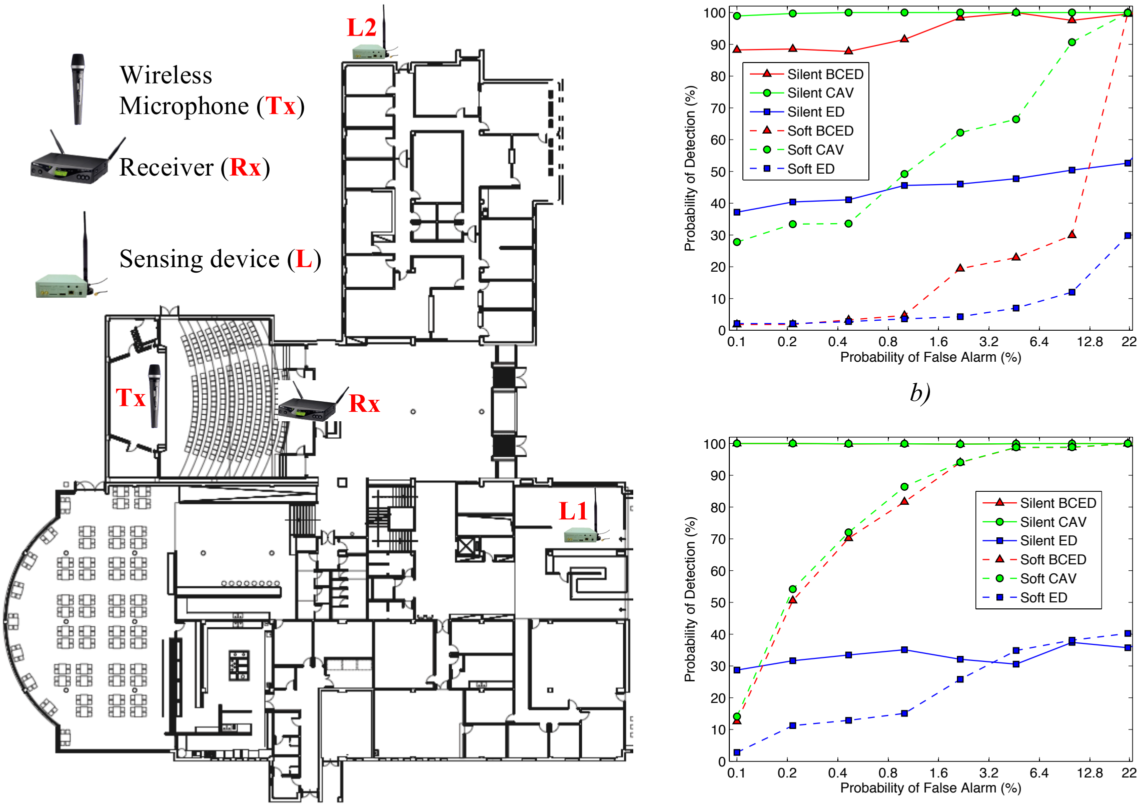
Figure 8 – View of a) ‘Chart point’ and b) ‘Block white spaces’ menus.

4. Trials and results

We test the demonstrator in a school floor. The primary system (PMSE) is located inside an empty auditorium, as shown in Figure 9a). Sensing is done in two distinct places: inside the library (L1) and outside the school walls (L2), with non-line-of-sight propagation between the sensing device and the primary system. The distance between both locations and the wireless microphone is 45 m.

The threshold of each sensing algorithms is measured with a heuristic method described in [2]. After the WM is switched on, the platform is programmed to automatically sense a DVB-T channel during one hour, with sensing time of 100 ms. This process is repeated several time, depending on the probability of false alarm (between 1% and 22%), the number of channels to be sensed and the WM operation mode (mute or soft speaker mode).

Figure 9b) and Figure 9c) presents ROC for locations L1 and L2, respectively, and shows that WM in silent mode are easier to detect. This is due to the high peak correlation of the FM carrier without a modulation signal. Also, there is a significant improvement in the P_D in all scenarios and locations, using blind detection algorithms instead of ED algorithm. These measurements confirms simulation results from [2].



a) b) c)

Figure 9 – a) Building plant where field measurements were realized; Measured ROC curves from: b) locations L1 and c) Location L2.

5. Conclusions

The cross-platform presented in this paper has shown capabilities to sense PMSE signals with advanced sensing algorithms, and use this information to update the list of vacant DVB-T channels, received from a geo-location database. In future versions, the demonstrator will be updated with advanced functionalities:

- Identification of the central frequency and bandwidth of multiple WMs present in a DVB-T channel. This feature is crucial for spectrum shaping and spectrum aggregation techniques, allowing coexistence between TVWS devices and PMSEs systems.
- Inclusion of a web-based PMSE platform, to automatically update the sensing platform not only with DVB-T occupancy, but also with information on PMSE usage.

Acknowledgments

The study presented in this paper was supported by the European Commission, Seventh Framework Programme, under the project COGEU (contract nº. ICT-248560) and by the Portuguese Agência de Inovação (ADI-QREN) under the project Green-T: Green Terminals for Next Generation Wireless Systems.

References

[1] D. Gurney, G. Buchwald, L. Ecklund, S. L. Kuffner, and J. Grosspietsch, "Geo-Location Database Techniques for Incumbent Protection in the TV White Space," *DySPAN 2008*, 2008, pp. 1-9.

[2] COGEU (ICT_248560), "Sensing algorithms for TVWS operations," Report D4.2, June 2011. Available: http://www.ict-cogeu.eu/

[3] (February 2011). *Ettus Research LLC*. Available: http://www.ettus.com/

[4] (February 2011). *National Instruments LABVIEW, "Universal Software Radio Peripheral (USRP) Pre-Release Driver for LabVIEW,"*. Available: http://decibel.ni.com/content/docs/DOC-14531.