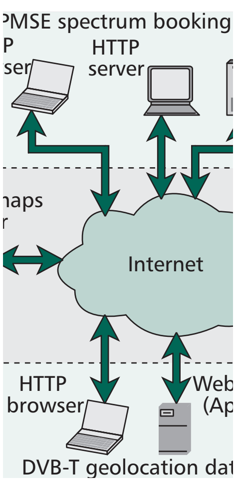
# TESTBED FOR COMBINATION OF LOCAL SENSING WITH GEOLOCATION DATABASE IN REAL ENVIRONMENTS

JOSÉ C. RIBEIRO, JORGE RIBEIRO, AND JONATHAN RODRIGUEZ,
INSTITUTO DE TELECOMUNICAÇÕES
ROGÉRIO DIONÍSIO, HUGO ESTEVES, PEDRO DUARTE, AND PAULO MARQUES,
INSTITUTO POLITÉCNICO DE CASTELO BRANCO




The authors describe an experimental testbed that combines wireless microphone sensors with a web-based Terrestrial Digital Video Broadcasting geo-location database and a Program Making and Special Events spectrum-booking platform.

## ABSTRACT

This article describes an experimental testbed that combines wireless microphone sensors with a web-based terrestrial digital video broadcasting geolocation database and a program making and special events spectrum-booking platform. Software defined radio and Internet technologies are the enabling tools in use. The key sensing techniques are identified and implemented. Test trials in a real scenario have shown that the platform was able to receive information from a DVB-T geolocation database and a PMSE spectrum-booking platform, updating the list of vacant channels with blind sensing techniques. The proposed method has shown capabilities to protect primary users of interferences from secondary users of the spectrum.

## INTRODUCTION

The current global analog TV switch-off has opened up an opportunity for re-allocation of the spectrum resource and opens an opportunity to introduce new business models in this area. Some spectrum bands once used for analog TV broadcasting will be completely cleared, leaving space for deploying new licensed wireless services. Additionally, digital television technology geographically interleaves spectrum bands, or TV white spaces (TVWS), to avoid interference between neighboring stations, leaving space for deploying new wireless services. However, primary users of the spectrum, such as terrestrial digital video broadcasting (DVB-T) systems, must be protected from interference. One consensual method to do so is based on geolocation databases, combined with local spectrum sensing. There are several advantages for the use of geolocation 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, and protection rules can be used to compute the maximum transmit power. With a database, part of the complexity associated with sensing and computation is transferred to the core network, decreasing complexity and power demand of portable TVWS devices (WSDs).

Program making and special events (PMSE) detection is also an important issue, due to low power transmissions and analog frequency modulation (FM). These are generally wireless microphones (WMs), talkback devices, or in-ear-monitors. The usage of PMSE devices can be professional or non-professional:

- Non-professional use may occur when the device is used in a small event for a short period of time, with restricted limitations on power transmission.
- Professional wireless microphone system (PWMS) devices are used at large events, like concerts, or by security agencies.

In Europe and in many countries, PMSE devices operate mostly on an 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. In some European countries like the United Kingdom [1], PWMS users must book spectrum in advance, and their location, bandwidth, usage period, and maximum allowed power are registered in a database. Such an approach can protect registered systems, but the only way to protect unregistered PMSE applications is through sensing.

This article describes a testbed that combines an autonomous sensing platform for PMSEs, a DVB-T geolocation database, and a PMSE spectrum-booking platform the sole purpose of which is to address the protection of primary users of

 1536-1284/12/$25.00 © 2012 IEEE 

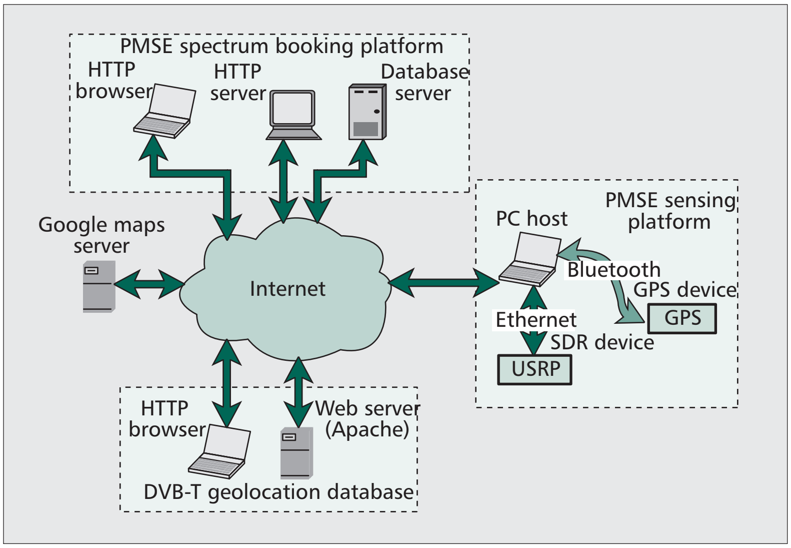



**Figure 1.** *Platform architecture, combining spectrum sensing, DVB-T geolocation database, and PMSE booking platform.*

the spectrum. Figure 1 shows the three main structural components of the testbed and their interconnections.

We describe the design, functional features, and implementation techniques for each. Experimental results indicate that this combination is able to achieve better protection of primary users than sensing only. The conclusion of the article and future work are also presented.

## Geolocation Database Platform

This section present the details of the DVB-T geolocation database platform, including the structure of the database, the criteria used to compute and populate the database, and the graphical user interface (GUI).

### Platform Structure

Several web programming languages and technologies are used to develop the platform, fetch geolocated spectrum information, and display the results. The platform includes a web server running MySql to manage the database, access to a Google Maps server, and a PC with broadband connection.

The geolocation database has a simple data structure, storing the following information:

- Longitude and latitude coordinates: Each coordinates represents the center of a pixel, with an area of 200 × 200 m.
- UHF channel numbers: These range from channels 40 to 60.
- EIRP: Effective isotropic radiated power is the maximum power a WSD is allowed to transmit, in dBm, depending on the location and the channel number.

The actual database information is geographically centered in Munich, with a total area of 51 $km^2$, which makes a total of 65,000 pixels, each one with information on the maximum power allowed for TVWS devices, for each UHF channel. For the calculations, the operational data (i.e., the DVB-T stations actually in operation in the Munich area) were used.

### Protection Criteria for Computing TVWS Maps

At the time TVWS calculations were made, European regulatory and standardization bodies had not yet fixed all protection requirement parameters for primary users. Hence, some realistic assumptions were necessary, allowing us to identify available TVWS.

The methodology to estimate TVWS follows the procedure described in [2]. Therefore, the maximum acceptable WSD signal strength in the considered TV channel at the possible location of a DVB-T reception antenna can be calculated. We briefly describe the most important parameters to be considered to determine maximum WSD transmit power.

In a first step, for each considered location, the wanted and interfering field strengths need to be calculated. From this, the location probability for the case without active WSDs can be determined. Accepting a degradation of location probability allows a higher interfering signal.

An important parameter for describing broadcast signal availability is coverage. It describes the probability of successful broadcast reception over a given area (e.g., 200 × 200 m). The Geneva 06 plan agreement describes 70 percent coverage as "acceptable" and 95 percent coverage as "good." Although broadcast reception is possible in some locations outside a given coverage area, only broadcast reception within the coverage area is protected. For fixed DVB-T reception, 70 percent coverage is protected. In the calculations, portable outdoor reception is also considered, for 95 percent coverage. This area corresponds to more than 99.99 percent of a fixed reception coverage area. A degradation of 1 percent is assumed to be acceptable.

Outside a coverage area, the minimum distance a WSD may have from a DVB-T receiver operated in this channel is the shortest distance to the coverage area. Inside a coverage area, reasonable minimum distances are assumed, as described in Table 1.

For the propagation of DVB-T signals, a terrain-based model is used that also takes (to some extent) the morphology into account. For the propagation of WSD signals that range, due to the possible transmit power, distances typically below 10 km, simpler non-terrain-based models like extended Hata are selected.

Several types of WSDs are possible. A base station at a height of 10 m with directional antenna, a user terminal at 1.5 m with simple dipole antenna, or in a downlink only concept a WSD antenna at even higher distances can be imagined. For this database, a TVWS base station (BS) with a 10 m high antenna is considered (downlink only).

A WSD operating in a channel with some channel separation from the considered broadcast signal may harm broadcast reception according to the WSD transmitter's spectrum mask and the DVB-T receiver's input filters. The effect described by the protection ratio (PR) depends on the broadcast receiver and the type of interferer. For the WSD, a Long Term Evolution (LTE) like spectrum mask is assumed. Hence, for the PRs, values from [3] are taken. The same report also provides PRs for LTE base stations and LTE user terminals. The 10th percentile values are taken, which means that for these levels, 10 percent of the investigated receivers are already interfered. The PR values for can and silicon tuners for set-top boxes and integrated digital TV were averaged. Silicon USB tuners were not taken into consideration. In the same way, overloading of DVB-T receivers is also considered. These parameters should be more or less independent of channel separation. In a region with several DVB-T multiplexers on air, such as the Munich area, there is at least one channel occupied between $n \pm 9$ at each possible location. For the case of a can tuner, the protection ratio for $n \pm 9$ may be as bad as $n \pm 1$, due to the intermediate frequency (IF) in use. Hence, overloading limits the maximum transmit power, so nine adjacent channels to each side are taken into account. For a WSD BS scenario, the limit is approximately 30 dBm [2].

| Scenario | Distance | Comment |
|---|---|---|
| WSD base station — DVB-T fixed rooftop | 30 m | Directional DVB-T antenna |
| WSD base station — DVB-T portable reception | 10 m | DVB-T dipole antenna |
| WSD user terminal — DVB-T fixed rooftop | 20 m | Directional DVB-T antenna |
| WSD user terminal — DVB-T portable reception | 2 m | DVB-T dipole antenna |

**Table 1.** *Minimum distance between different WSDs and DVB-T receivers, inside a DVB-T coverage area.*

### User Interface

The geolocation database is presented with a GUI on the client side, implemented as an interactive web page using HTML. It provides an attractive view of the data stored. Moreover, the GUI does so in an orderly manner, so the user is able to see the TVWS availability of one or more channels, and change the way this information is presented. An online demonstration is accessible at http://projectos.est.ipcb.pt/cogeu2/index.php.

The platform access to Google Maps resources and displays a digital map. A second screen, representing TVWS maps computed from DVB-T geolocation data, overlay Google digital maps as a new dynamic layer. "White spaces" in Fig. 2a or "color scale" in Fig. 2b are features for a chosen channel, and represent spectrum availability and maximum power for a secondary device to operate. "Chart point" in Fig. 2c is another feature that shows all available channels and maximum allowed power, in a selected pixel with 200 squared meters. "Block white spaces" is an administrative feature, only available to the platform administrator. TVWS can be blocked for secondary usage, and access to information on the specified areas is denied. An example of a blocked area is visible on the lower right side of Fig. 2a.

## PMSE Spectrum Booking Platform

The PMSE booking platform is an online application that allows users to search for spectral occupation on the DVB-T geolocation database, and books spectrum for PMSEs for a given place and time. The primary targets of the platform are PWMS devices. However, we programmed it to be scalable to any other equipment or frequencies, bearing in mind those who have no technical knowledge of the spectrum or spectrum devices. This section presents the main features and techniques.

### Technical Functionalities

The client side of the platform employs HTML, JavaScript, and CSS web languages. From the server side, the code is implemented using PHP. Any code processing is done in the server, and the page is sent to the client. The database is built on open source technology MySql and has several organized tables to safeguard all the information regarding PMSE booking, such as the user ID, spectrum occupancy, and time and location of spectrum booking. The platform access uses a mandatory secure connection (HTTPS), and PHP with Sql commands to check-in the PMSE database. This process ensures integrity and confidentiality to users, data, and booking operations.

### Exclusion Area for PMSE

When a new PMSE booking is authorized, the platform automatically sets an exclusion radius guaranteeing non-interference with other reservations. This calculation can be done in two different forms, chosen by the platform administrator:

- Automatic mode: The protection radius is computed taking into account technical parameters of the WM (power output, antenna gain, central frequency) and using the free space attenuation model.
- Manual mode: This input mode was developed for scenarios where field strength measurements are available, allowing the administrator to set these values statically. This is done through an input table, only available to the administrator, where s/he can define a protection distance as a function of PMSE power range.

In a natural or man-made catastrophe scenario, emergency forces may require additional spectrum channels for radio communications. The administrator has the possibility of locking down part of the spectrum in an area. This functionality is similar to the one implemented for the DVB-T geolocation database to limit TVWS availability. When an area is locked, new reservations cannot be booked there.

### User Interface

Just like the DVB-T geolocation database, we develop a GUI to facilitate the interaction of the user with the PMSE database. Figure 3 shows one of the interfaces. Some of the features are briefly described here:

- Development and integration with digital maps.
- Time booking is done through a calendar interaction.
- Spectral booking is made through the selection of a wanted channel.
- A section for spectrum search was taken into consideration. Interacting with a digital map, the user can check on the existing and daily reservations, and apply certain filters to limit search criteria.
- The platform is implemented to enable users to pay for their bookings. This makes the platform autonomous and leads to on-the-fly payment to competent authorities.

An online demonstration is accessible at https://www.est.ipcb.pt/pessoais/alter_mann/index.php.

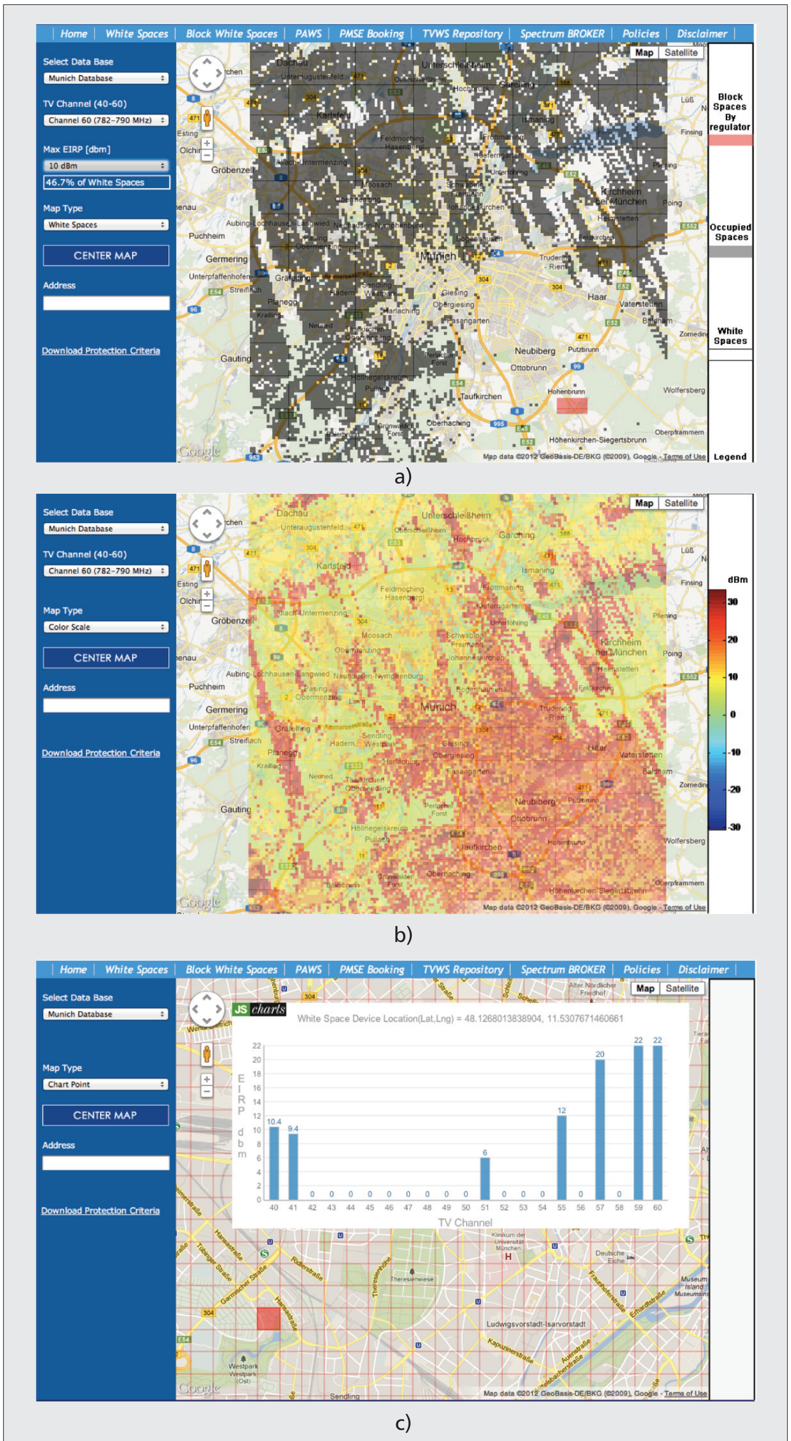



**Figure 2.** *Two different views for the same channel: a) "white spaces" show the region where a secondary user of UHF DVB-T channel 60 may transmit power with 10 dBm; a rectangle on the lower right side of the same figure represents a blocked region; b) "color scale" shows the maximum power that can be transmitted by a WSD at channel 60, for all pixels; c) "chart point" shows the channel and power availability for a selected pixel.*

## PMSE Sensing Platform

The following section describes the main features of the testbed sensing module, and the interaction with DVB-T and PMSE booking databases.

### Hardware

The sensing platform relies on USRP2 software-defined radios [4], a GPS receiver, and a host PC. USRP2 is equipped with a transceiver combining two channels (TX/RX, RX2), tunable from 50 MHz to 2.2 GHz, and provides output power up to 100 mW. The host is a laptop with Windows OS, a Gigabit Ethernet port to connect to the USRP2, and a wireless broadband connection for Internet access to DVB-T, PMSE, and Google Maps databases. A GPS device connects to the host PC by Bluetooth. Commercial tunable FM wireless microphones are used as primary users, to benchmark the sensing capabilities of the testbed.

### Combination with TVWS and PMSE Databases

Before sensing is started, the platform retrieves TV channel occupancy from the DVB-T geolocation database, and also channels reserved for WMs from the PMSE booking database, following the diagram of Fig. 4a. This way, local sensing is performed only on a limited number of potentially vacant TV channels.

Compared to sensing only, a combination of sensing and geolocation database access has the advantage of reducing the risk of WSDs interfering with PMSE and DVB-T. For a sensing only approach, the hidden terminal problem (HTP) could result in underestimation of the primary signal power in the vicinity of the WSD, and could lead secondary users to use that channel and interfere with the primary user of the spectrum. Moreover, detection thresholds needed to overcome the HTP are difficult to reach by current technology [4]. Thus, a hybrid approach will speed up the sensing process, but also relaxes the sensitivity and processing capabilities required for WSDs, which is a major limitation of TVWS developments [2].

### Sensing Techniques

We have formulated the sensing problem as a binary hypothesis-testing problem,

$$H_0 : x[n] = u[n]$$
$$H_1 : x[n] = s[n] + u[n], n = 1, 2, \ldots, N_s \quad (1)$$

$H_0$ and $H_1$ are the hypotheses expressing the absence and presence of the WM, respectively, and $N_s$ is the number of samples. The terms $s[n]$ and $u[n]$ are sampled versions of the WM signal

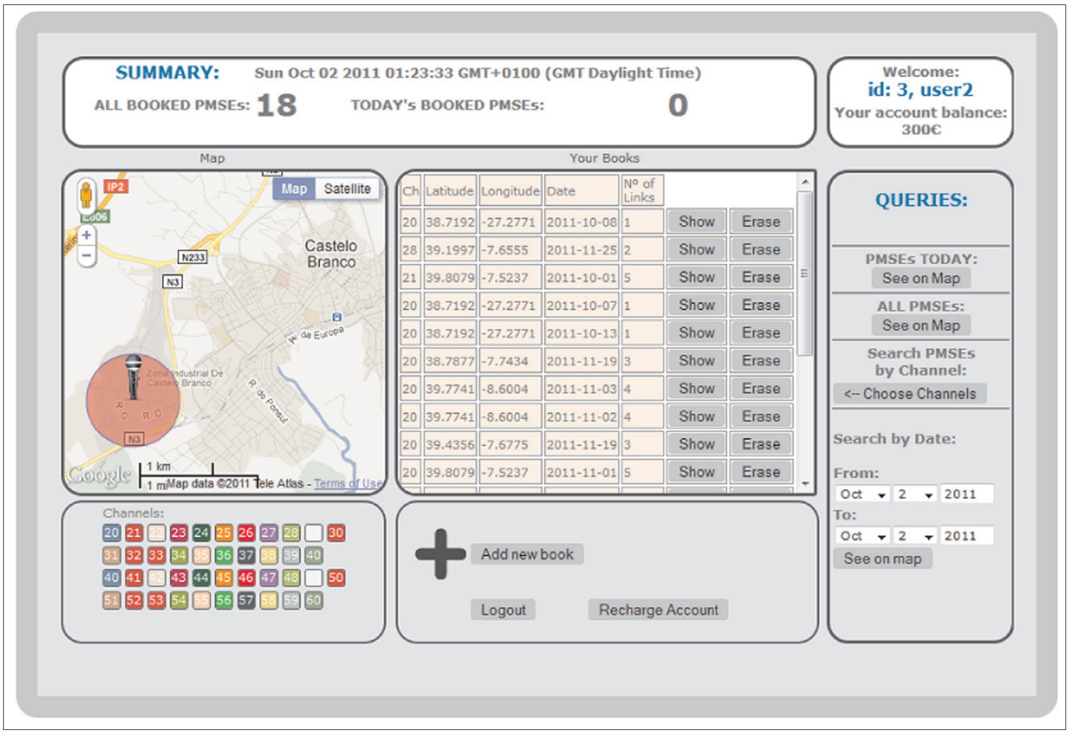



**Figure 3.** *User area of the PMSE booking platform. The exclusion area around a booked PMSE is visible on the left side.*

These detection algorithms rely on a statistical analysis, using covariance or Eigen value matrix to identify the properties of a signal. Blind methods are independent of the noise power and require no information on source signal or noise power.

$s(t)$ and the noise $u(t)$ present in the system, respectively. From the Neyman-Pearson criterion, the hypothesis test is stated in terms of probability of false alarm ($P_{FA}$) and probability of detection ($P_D$). We set minimum metrics requirements of $P_D$ higher than 90 percent and $P_{FA}$ lower than 10 percent [6].

The WM signal is detected by comparing the output d of the sensing algorithm, with a threshold level (TH). Depending on the sensing technique, $d$ is given by a test statistic. Detection threshold TH is determined based on a given PFA and is also dependent on the sensing algorithm. We calculate TH based on a heuristic method, using the following methodology, for each sensing location:

- Compute the test statistic of the sensed channel, when no primary signal is present (noise only).
- Repeat the measurement to create a histogram of the results.
- Compute the complementary cumulative density function (CCDF) from the histogram.
- From the CCDF, search for the threshold value associated with the desired $P_{FA}$.

We previously conducted an extensive study and simulation of several sensing algorithms for PMSE detection [7], and the results have shown that blind sensing methods, in particular covariance absolute value (CAV) [8] and blindly combined energy detection (BCED) [9], presented superior performance compared to other algorithms. These detection algorithms rely on statistical analysis, using covariance or eigenvalue matrix to identify the properties of a signal. Blind methods are independent of the noise power and require no information on source signal or noise power.

An energy detection (ED) algorithm is also implemented on the sensing platform, and is used here as a reference to evaluate if the higher complexity of CAV and BCED algorithms results in significant gains and higher performance. The ED algorithm estimates the signal power in the channel and compares that estimate to a threshold. A signal $x[n]$ is assumed to be present if the test statistic is above the threshold. Since WM signals manifest as a group of tones that can span over a 200 kHz range in the frequency domain, spectrum sensing is performed by detecting the maximum peak of the estimated power spectral density (PSD) of the received signal [10].

## Software Platform

We use Labview from National Instruments to program the software application of the sensing module and interact with USRP2 software defined radios. Labview combines a graphical programming language with the capability to create user-friendly user interfaces, which makes it a preferred choice over other software solutions. This particular combination of hardware and software was chosen due to the recent development of USRP2 drivers for Labview [11]. CAV, BCED, and ED sensing algorithms are implemented in C++ to increase processing speed, and imported into Labview as new functions (DLLs). We have also developed other functions for location coordinates extraction from a GPS receiver and Internet access to retrieve digital maps from a Google Maps server, and TVWS and PMSE databases.

## SNR Estimation

For each channel sensed, we have implemented a method for the testbed to estimate the signal-to-noise ratio (SNR):

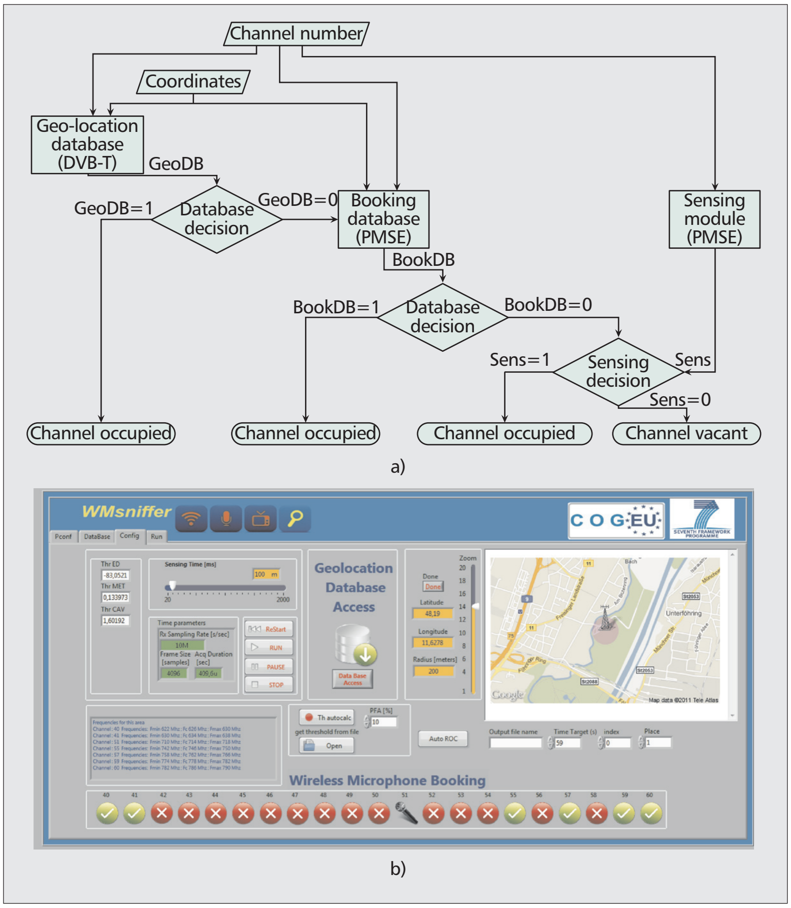



**Figure 4.** *a) Diagram of the interaction between DVB-T database, PMSE booking database, and sensing module channel availability computation; b) setup interface of the sensing module after the reception of a list of vacant channels from DVB-T and PMSE databases; the bottom rectangle shows six available channels (check symbol), one channel reserved for WM (microphone symbol) and the remaining channels used by DVB-T broadcast signals (cross symbol).*

1 Compute the sum of the squared amplitude of all the signal samples when only noise $u[n]$ is present.
2 Take the sum of the squared amplitude of all the samples when a WM is present (i.e., $x[n] = s[n] + u[n]$).
3 Compute the SNR, in dB, using the following expression:

$$SNR = 10\log\left(\frac{x^2[n] - u^2[n]}{u^2[n]}\right). \quad (2)$$

### User Interface

The GUI is organized in three functional pages that allow the user to configure the device, set up parameters, and view the results.

Figure 4b shows one of the main pages of the interface. After geolocation coordinates are acquired, a query is sent to both the DVB-T geo-location database and the PMSE booking platform. The received information is shown in a text box where we can verify the available channels and the maximum transmission power for each. Vacant channels are also symbolized in an indicators bar as green checked symbols. Red crosses or microphone symbols mean that the channel is occupied with DVB-T or PMSE signals, respectively.

## Experimental Results

This section presents the deployment strategy of the testbed and performance results from PMSE sensing in a real environment.

### Deployment Strategy of Sensing Devices

We assess the performance of the testbed in a school floor, as illustrated in Fig. 5a. The primary system transmitter (WM) was located inside an empty auditorium. Sensing was done in two distinct places: inside the library (L1) and outside the school walls (L2), with non-line-of-sight propagation between the sensing module and the WM. The distance between both locations and the wireless microphone was 45 m. Booth WM and sensor antennas were placed at 1.5 m height.

Locations L1 and L2 were chosen to simplify the comparison between sensing techniques performance, and avoid external factors to influence the results: If the sensing device is located too close to the WM (transmitter), all the sensing techniques gives a $P_D$ close to 100 percent, independent of the value of $P_{FA}$ used, which does allow an adequate comparison. Otherwise, if the sensing device is located too far from the WM, the detection performance is limited by the sensitivity of the sensing device rather than the performance of the sensing algorithms.

### Sensing Measurements

Sensing algorithms' performance is tested on all channels free from DVB-T signals, even if they were booked for PMSE usage. If the test statistic $d$ is above the threshold and is a WM booked in that channel, status is set to "detection." If there is no previous booking of a WM, status is set to "false alarm." 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," and finally, if there is no booking of WMs, the status is "free channel." In normal conditions, channels already reserved for PMSE usage do not need to be "sensed," since they are already blocked by the PMSE booking database to secondary users of the spectrum.

The thresholds were determined using the heuristic method already described in the previous chapter, for a set of eight $P_{FA}$ values distributed logarithmically from 0.1 to 22 percent. Higher values of $P_{FA}$ would result in underuse of spectral opportunities, and as such they are discarded. The testbed was set to automatically sense each channel during one hour for each $P_{FA}$ value, with sensing time of 100 ms. We repeated the measurement for both mute and soft speaker operational modes.

Sensing performance is measured by means of a receiver operational curve (ROC) for a WM in silent mode or using a soft speaker. Figures 5b and 5c present the measurement for locations L1 and L2, respectively. The result shows that a WM in silent mode is easier to detect. This is due to the high peak correlation of the FM carrier without a modulation signal. Also, there is a

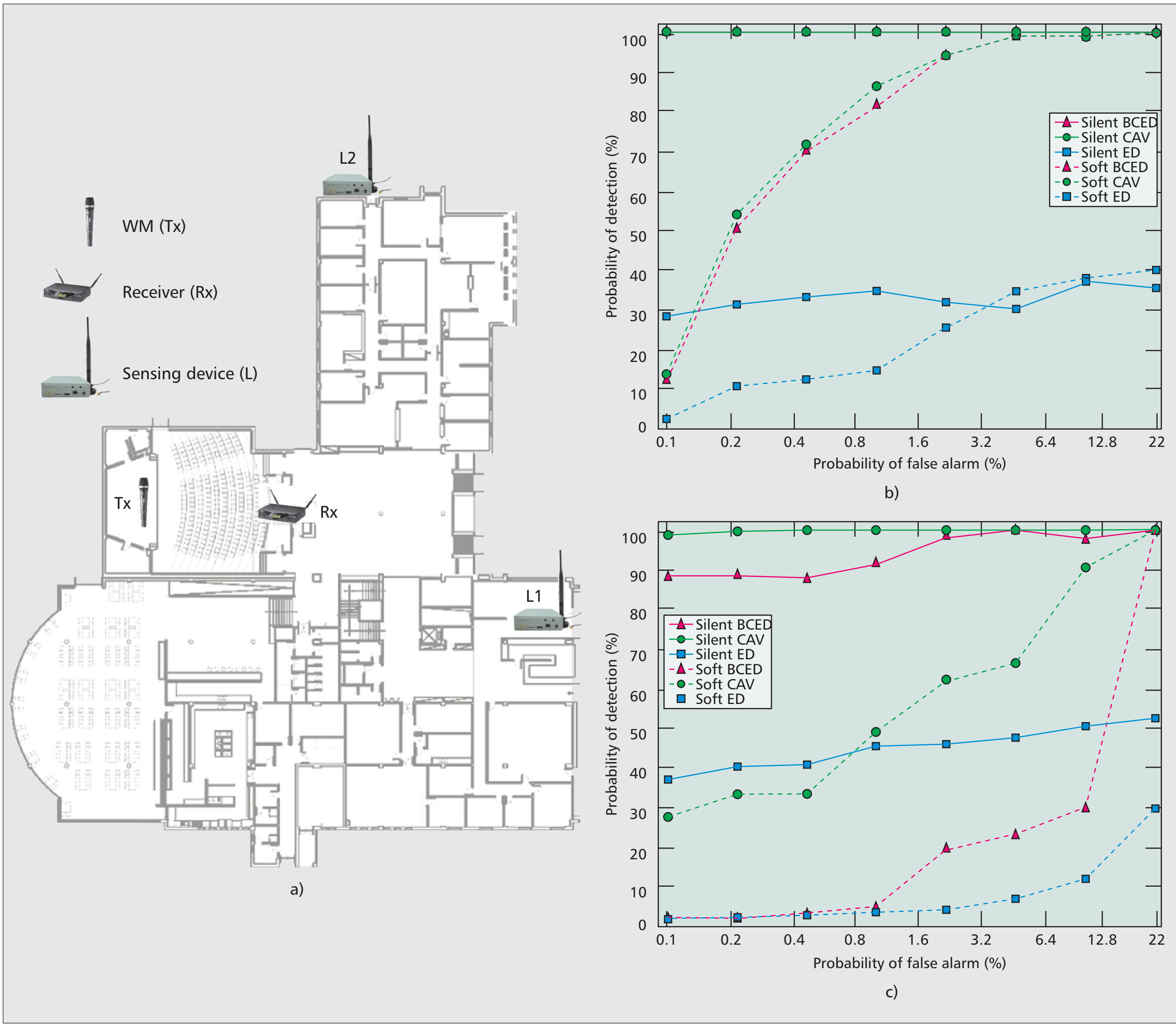



**Figure 5.** *a) Building plant where field measurements were made;; measured ROC from: b) location L1; c) location L2. Estimated SNR is –6 dB for both locations.*

significant improvement in the $P_D$ in all scenarios and locations, using blind detection algorithms (CAV or BCED) instead of ED. The SNR obtained for each measurement was estimated based on Eq, 2, and gave an SNR of –6 dB for both locations, L1 and L2.

## Conclusions and Future Work

The testbed presented in this article has shown capabilities to sense PMSE signals with advanced blind sensing algorithms, and update a list of vacant DVB-T channels received from a web-based geolocation database and a PMSE spectrum-booking platform. At the demonstration level, as far as the authors are aware, this is the first time that such a demonstration has been tested and evaluated. In the following versions, the demonstrator will be updated with a technique for identification of the central frequency and bandwidth of multiple WMs present in a single DVB-T channel. This feature is crucial for spectrum shaping and spectrum aggregation techniques, allowing coexistence between WSDs and PMSE systems. Furthermore, Internet communication protocols between all the different elements should be adapted to improve reliability and scalability.

## Acknowledgment

The work presented in this article was supported by the European Commission Seventh Framework Program under project 248560, ICT-COGEU.

## References

[1] July 2011, JFMG — Radio Spectrum for Program Making and Entertainment; http://www.jfmg.co.uk/

[2] "Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'Whitespaces' of the Frequency Band 470–790 MHz," ECC report 159, Cardiff, Wales, 2011.

[3] "Measurements On The Performance Of DVB-T Receivers in the Presence of Interference From The Mobile Service (Especially From LTE)," ECC report 148, Marseille, France, 2010.

[4] Feb. 2011, Ettus Research LLC; http://www.ettus.com/
[5] M. Ettus, 2010, May, WBX Receiver Performance Plots: http://code.ettus.com/redmine/ettus/documents/16.
[6] COGEU (ICT-248560), "Use-Cases Analysis and TVWS Requirements," Report D3.1, July 2010.
[7] COGEU (ICT-248560), "Sensing algorithms for TVWS operations," Report D4.2, June 2011.
[8] Z. Yonghong and L. Ying-Chang, "Covariance Based Signal Detections for Cognitive Radio," *IEEE DySPAN '07*, 2007, pp. 202–07.
[9] Z. Yonghong, L. Ying Chang, and Z. Rui, "Blindly Combined Energy Detection for Spectrum Sensing in Cognitive Radio," *IEEE Sig. Proc. Letters*, vol. 15, 2008, pp. 649–52.
[10] S. J. Shellhammer, S. S. N, R. Tandra, and J. Tomcik, "Performance of Power Detector Sensors of DTV Signals in IEEE 802.22 WRANs," *Proc. 1st Int'l. Wksp. Technology and Policy for Accessing Spectrum*, Boston, MA, 2006.
[11] Feb. 2011, National Instruments LABVIEW, "Universal Software Radio Peripheral (USRP) Pre-Release Driver for LabVIEW," http://decibel.ni.com/content/docs/DOC-14531.

## Biographies

José Ribeiro (jcarlosvgr@av.it.pt) received his B.Sc. and Master's degree in electronic and telecommunications engineering from Castelo Branco Polytechnic Institute, Portugal. In 2007 he joined the Instituto de Telecomunicações Aveiro as a researcher. He has been involved in European research projects; his main research interests include PHY, MAC advanced techniques for wireless mobile communications, and recently, signal processing and sensing algorithms for wireless microphones and DVB-T detection. He has some knowledge of programming languages.

Rogério Dionisio (rdionisio@ieee.org) received his Bachelor's and Master's degree in electronics and telecommunications engineering from the University of Aveiro in 1997 and 2004, respectively. Since 1999 he is an assistant professor at Castelo Branco Polytechnic Institute. He participates in several national and European research projects on optical and wireless communications. He is the author of several journal and conference publications. His research interests are all-optical signal processing for wideband communication systems and radio spectral coexistence analysis.

Jorge Ribeiro received his degree (five-year course) in telecommunications and electronic engineering from the Castelo Branco Polytechnic Institute. He started working as software developer, network manager, and electronic developer at Mind Solutions (www.mindsolutions.pt) in 2006. In June 2011 he joined the Instituto de Telecomunicações Aveiro, working as a software engineer on the FP7 COGEU project. His main interests are software development, web and mobile phone applications, and databases for wireless communication networks.

Hugo Esteves received his Bachelor's in electronics and telecommunications engineering from Castelo Branco School of Engineering in 2011. Presently, he is working for IRT — Institut für Rundfunktechnik GmbH, Munich, Germany, as a Software Engineer. He participates in German and European research projects, on cognitive use of radio-spectrum. His main interests are computer networking, software development and software-defined radio systems.

Pedro Duarte received his Bachelor's in electronics and telecommunications engineering from Castelo Branco Polytechnic Institute in 2011. His main areas of study are wireless telecommunications and IP-based computer networks (CISCO CCNP Routing & Switching certification). Presently, he is working at Nokia Siemens Networks, Amadora, Portugal, as a case handling engineer in the mobile switching field. His main interests are designing and troubleshooting computer networks.

Paulo Marques received his Ph.D. from the University of Aveiro in 2006. He is a senior researcher at the Instituto de Telecomunicações Aveiro and a professor at Castelo Branco Polytechnic Institute. He is the scientific coordinator of the European research project FP7 COGEU and co-author of the IEEE P1900.6 cognitive radio standard.

Jonathan Rodriguez received his Master's degree and Ph.D. in electronic and electrical engineering from the University of Surrey, United Kingdom, in 1998 and 2004, respectively. Since 2005 he has been a senior researcher at the Instituto de Telecomunicações, and founded the 4TELL Wireless Communication Research Group. His research interests include green communications, cognitive radio cooperative strategies, radio resource management cross-layer design, and baseband digital signal processing.

The testbed presented in this article has shown capabilities to sense PMSE signals with advanced blind sensing algorithms, and update a list of vacant DVB-T channels received from a web-based geo-location database and a PMSE spectrum-booking platform.