COGEU

FP7 ICT-2009.1.1

COgnitive radio systems for efficient sharing of TV white spaces

in EUropean context

COGEU D7.2

COGEU demonstrator development and integration

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Abstract:

This deliverable reports on the work performed in COGEU T7.2. It describes the COGEU demonstrator development and integration process. The demonstration will focus on the critical functionalities of the COGEU dynamic secondary market of TV white spaces.

Keyword list: Cognitive Radio Demonstrator, Integration, Spectrum Trading Platform, Building blocks and Interfaces.

Executive Summary

This deliverable reports on the work performed in COGEU T7.2: “COGEU demonstrator development and integration”. The development and integration work was based on D7.1 which described in detail the specification and design guidelines for the COGEU demonstrator.

The main building blocks of the COGEU demonstrator developed in T7.2 are described in this Deliverable. The key achievements of the reported work are as follow:

- Implementation of COGEU geo-location database
- Implementation of COGEU geo-location database web services
- Implementation of a COGEU PMSE booing platform
- Implementation of the COGEU spectrum Broker web tool
- Implementation of the TVWS Repository
- Implementation of the Policy Repository and specification of the COGEU license terms
- Integration of TVWS Allocation mechanism in the COGEU demonstrator
- Integration of Dynamic Radio Engine in the COGEU demonstrator
- Integration of Coexistence emulator module in the COGEU demonstrator
- Integration of the COGEU transceiver with the geo-location database

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1 Introduction

The purpose of WP7 is to design and built components that prove the feasibility of the COGEU concepts and ideas through demonstrations of key aspects of the project. In particular this deliverable reports the work performed in T7.2 regarding the development and integration of the COGEU demonstrator. The development was based on the design guidelines and system architecture that emerged through T7.1 which was reported on D7.1.

In order to demonstrate the functionalities and concept of the COGEU project different modules have been developed. This deliverable has been structured based on these building blocks as described below.

In Chapter 2 an overview of the demonstration architecture and show case scenarios are explained.

In Chapter 3 several geo-location database web services are described: Show white spaces, Block white spaces, PMSE booking tool. The geo-location database is a key block of the COGEU architecture since the availability of TVWS is based on the information provided by the database.

Chapter 4 explains the COGEU spectrum broker interaction interface. There are two ways declaring interest for an available TVWS in a specific location. One way is through auctions when there is more demand than offer and the other is through an on-demand tool when there is less demand that the offer.

Chapters 5 and 6 explain the Broker's internal databases. TVWS occupancy repository and Policies repository details are mentioned, and also how these repositories are used inside the COGEU Broker architecture is also explained. The COGEU license terms are specified.

In Chapter 7 considerations regarding the coverage of TVWS Base-Station and the impact of interference from DVB-T's signals in White Space reception are presented.

In Chapter 8 the details of the Dynamic Radio Engine and the module that links the COGEU Broker with the 3DTruEM Ray Tracing Tool are laid out.

In Chapter 9, the coexistence emulator module which is responsible for tests that indicate whether a system causes interference to another system is explained.

Chapter 10 explains the implementation and the integration of the TVWS allocation mechanism developed in WP6 in the COGEU demonstrator.

In Chapter 10 the TVWS transceiver modules and its integration in the COGEU demonstrator architecture is explained.

Finally, Chapter 11 presents the main conclusions of the reported work as well as the next steps towards the validation of the COGEU concept in WP7.

2 Overview of COGEU demonstrator setup

An important innovation brought by COGEU model is in the combination of unlicensed access to TV white spaces with secondary spectrum trading mechanisms. COGEU considers a centralized topology with a Geo-location Spectrum database dealing directly with TVWS Devices (Spectrum Commons) or with Spectrum Broker (Secondary Spectrum Market).

Figure 1 shows the demonstrator architecture developed in D7.1. The focus of COGEU demonstrator is to demonstrate parts of the COGEU system that have been designed based on a dynamic secondary spectrum market of TVWS. Moreover some functionality such as sensing and spectrum aggregation will be demonstrated considered the spectrum commons scenario such as the direct connection of the WSD (White Space Device) master with the geo-location database.

As can be seen for the architecture the central entity of the COGEU spectrum trading demonstrator is the Broker that acts as an intermediary between the geo-location database and the players. Figure 2 shows the COGEU secondary market framework with its main modules.

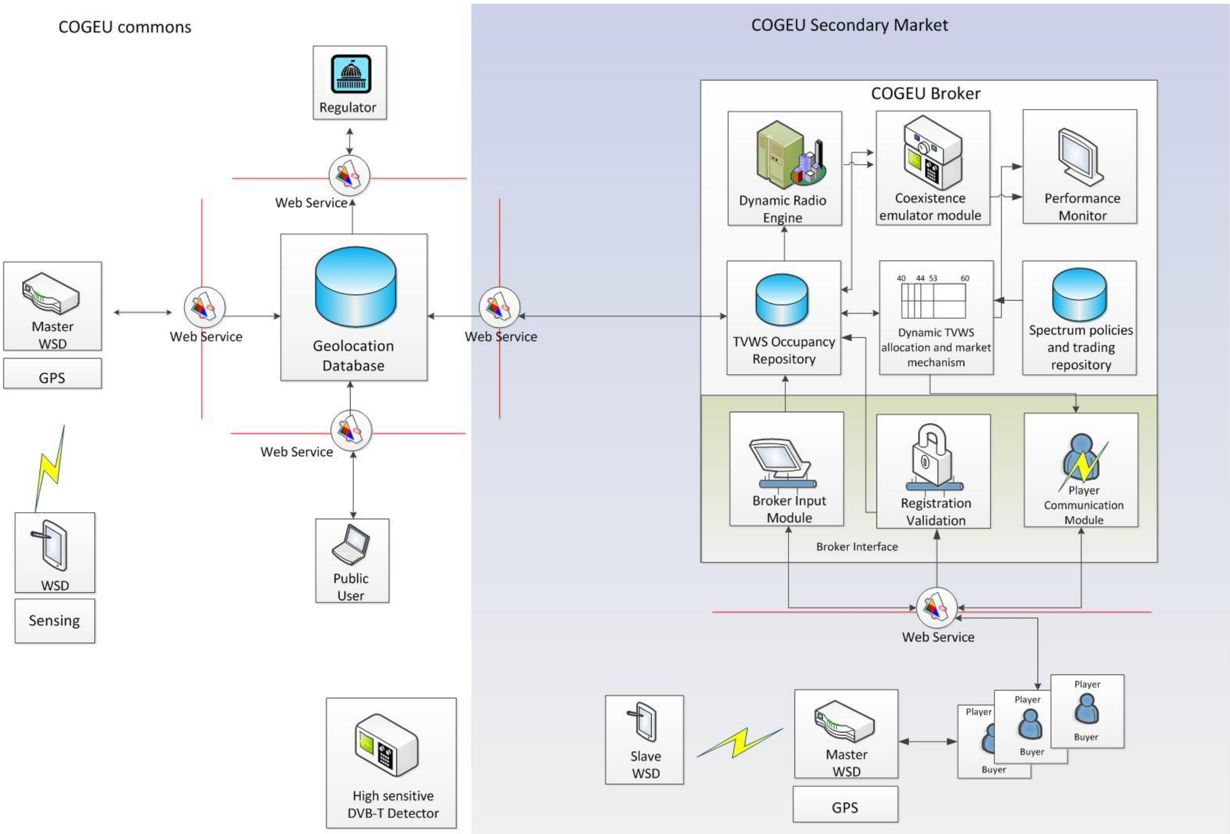

Figure 1: COGEU Demonstrator Architecture [D7.1].

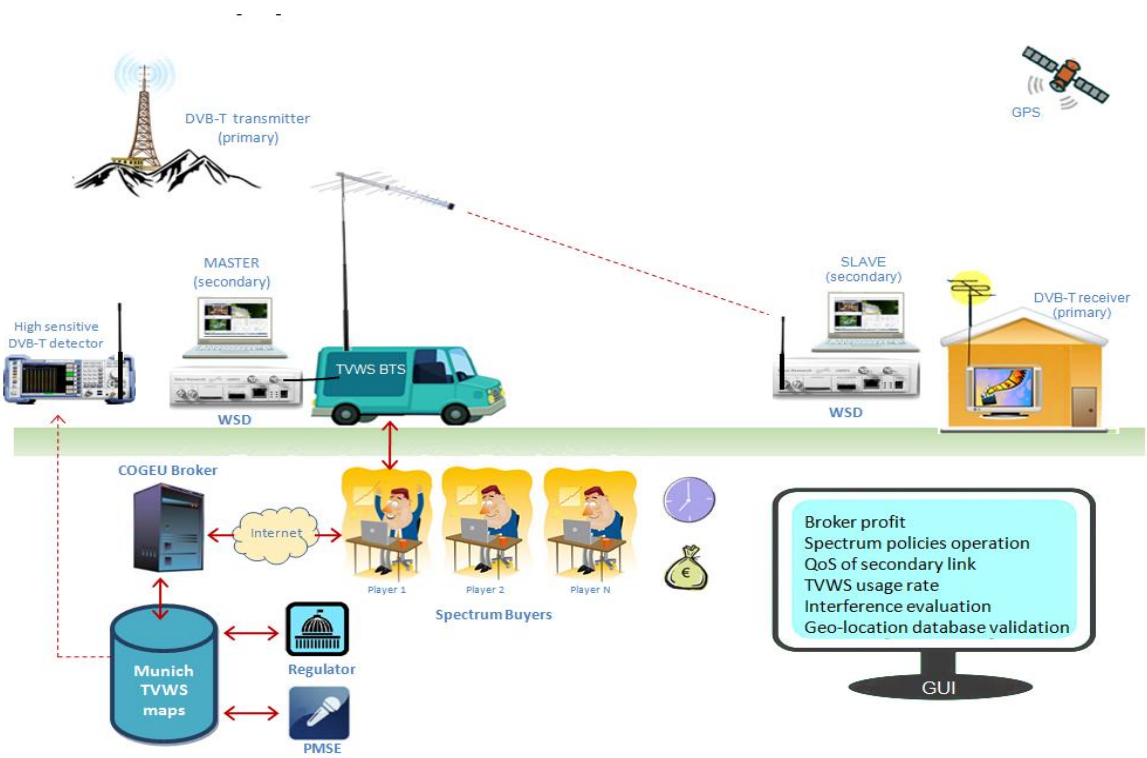

Figure 2: COGEU spectrum trading demonstrator [D7.1].

The added value of COGEU demonstrator is summarized below:

- Integration of technical, economic and regulatory aspects in a single framework;
- Secondary TVWS trading framework through a centralized broker emulating a TVWS dynamic market with automatic spectrum auctions (beyond the unlicensed model proposed by FCC and Ofcom UK);
- External geo-location database populated to protect DVB-T and PMSE with realistic TVWS maps computed with suitable protection criteria;
- TVWS allocation mechanisms that considers coexistence requirements between secondary users to guarantee QoS (beyond unlicensed model);
- Combination of local PMSE sensing with geo-location database access;
- Advance spectrum shaping algorithms for an efficient TVWS exploitation;
- Rendezvous techniques for in-band signalling between Master and Slave nodes;
- Implementation of geo-location database features: Possibility of book spectrum in advance; Regulatory enforcement and geo-location database update;
- Testing of different spectrum policies: spectrum caps and prioritization for public safety applications;
- Cross check of TVWS availability information from the geo-location database with local sensing through high sensitive DVB-T detector;
- Validation with off the air outdoor transmission in TV bands in urban, suburban and rural scenarios using trial licenses (beyond in-lab validation);
- Analysis of potential interference from WSD activity on several DVB-T commercial receivers operating in adjacent channels.

A set of showcases were identified in D7.1 to validate the key functionalities of the COGEU system:

- Demonstration of a dynamic TVWS market operating in auction mode or merchant mode depending on the market conditions. The Players will represent different types of users; Wi-Fi users, WiMAX users, Public Safety operators, etc. Players will actually be realised by people operating on behalf of the telecommunication companies seeking to purchase spectrum through a web interface. The performance of the spectrum market will be evaluated.
- Showcase the operation of spectrum policies on the market mechanism: showcase spectrum caps for anti-monopolization and prioritization policies for public safety applications;

- Demonstration of several geo-location database features: spectrum booking for PMSE usage, regulatory enforcement and geo-location database update;
- Showcase the combination of local sensing of wireless microphones (PMSE) with TVWS information from the Munich geo-location database;
- Showcase the high sensitive DVB-T detector developed in WP4 for cross-checking entries on geo-location database and field measurements of foreign DVB-T channels in Munich area;
- Showcase the spectrum aggregation within a TV channel where a PMSE user occupies a narrow bandwidth on a protected basis. Spectrum shaping algorithms (OFDM- based) will be evaluated in real outdoor scenarios;
- Outdoor tests using trial licenses will be carried out in the three Munich scenarios to showcase the work validated in previous laboratory testing. Evaluation of the TVWS link capacity, coverage and QoS (audio and video streams).
- Assessment of the interference caused by the TVWS secondary link on DVB-T commercial receivers operating in adjacent DVB-T channels in Munich scenarios (due the protection mechanisms in place, geo-location database and sensing, no harmful interference is expected).

The scenarios and showcases have been selected and identified in order to demonstrate a broad set of functionalities of the COGEU system concept.

3 COGEU geo-location database web services

The COGEU project has developed an integrated web platform able to show case many aspects of the COGEU geo-location database and Broker mechanism as illustrated in Figure 3.

Figure 3: The COGEU framework is accessible online for experimentation and feedback: http://projectos.est.ipcb.pt/cogeu2/

Several web-programming languages and technologies are used to develop the platform, fetch for geo-located spectrum information and display the results, as shown in Figure 4. The platform includes a web server running MySql to manage the database, an access to a Google Maps server, and a user PC with a browser and Internet connection.

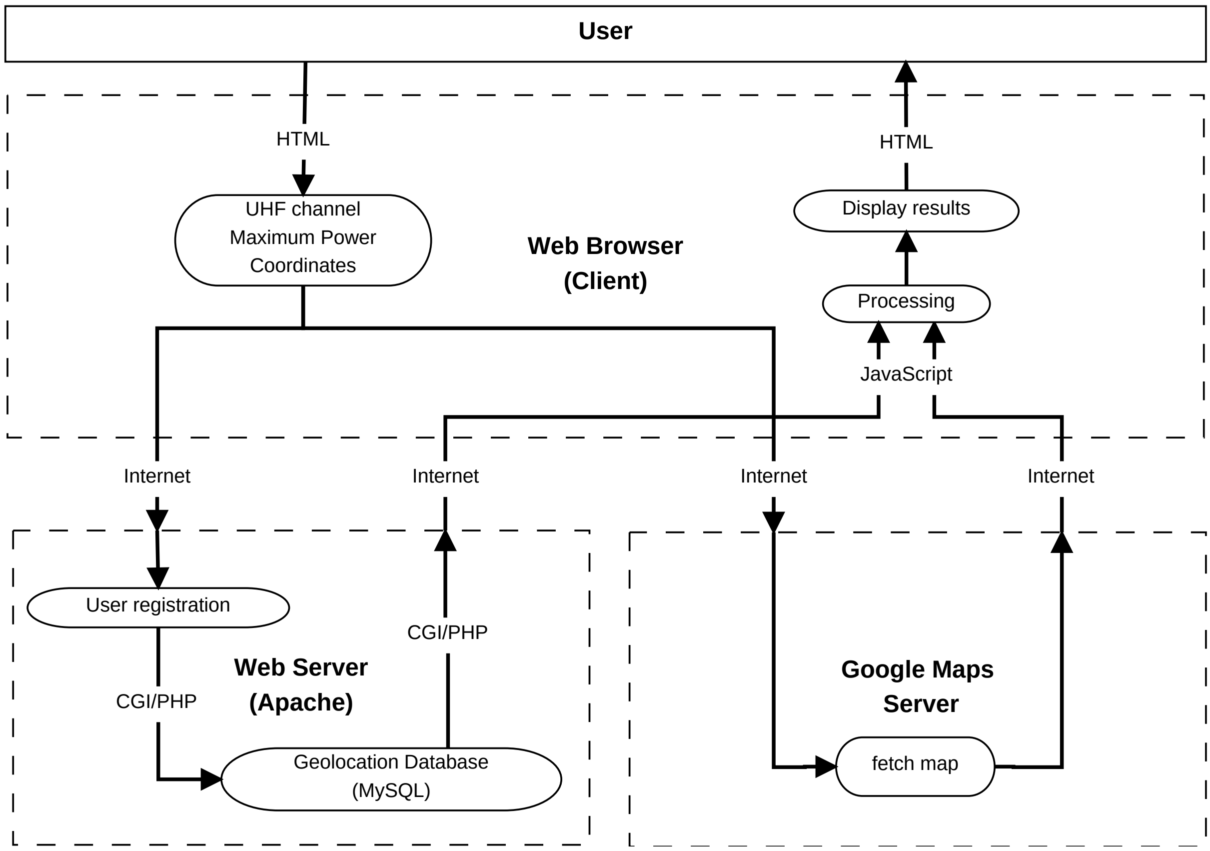

Figure 4: Schematic of web-based geo-location database platform.

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.

3.1 Show White Spaces tool

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:

- TV channel: DVB channel selection (any integer number between 40 and 60).
- Max EIRP: Specification of the Maximum power for the operation of the WSD (typically between 0 dBm and 40 dBm).
- Map type: Several formats to show white spaces maps are available: They can be specified as 'White spaces', 'Grey scale', 'Color scale' or 'Chart point'.

If 'White spaces' is selected (Figure 5), a black-and-white map shows TVWS availability for the selected DVB channel and the maximum allowed EIRP in dBm with 200m resolution. The white color area represents the locations where secondary users can operate, the black areas are forbidden for the selected amount of power.

'Color scale' presents the maximum power that can be transmitted in a selected DVB channel, for all pixels in the chosen area (Figure 6). A color bar in dBm is used to show the maximum allowed power.

'Chart point' shows a pixel grid overlaid to Google maps, with 200 m resolution. By clicking on a pixel, a new chart is produced, giving information of the maximum power available for all channels in the database for that pixel area (See Figure 7c).

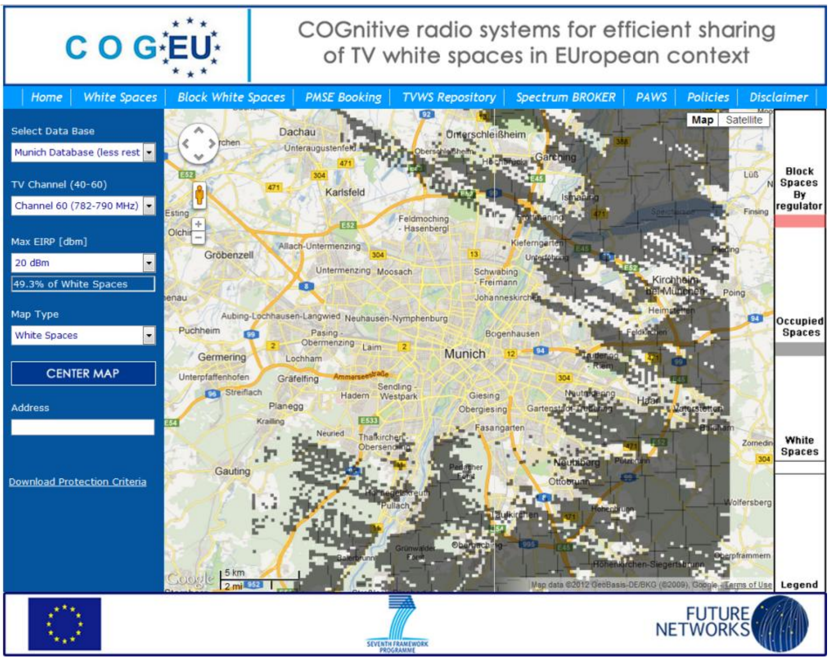

Figure 5: Output from the Show white spaces tool, Munich database, Channel 60 and for a maximum transmitted power of 20 dBm. In this case 49.3% of the considered area is marked as white space.

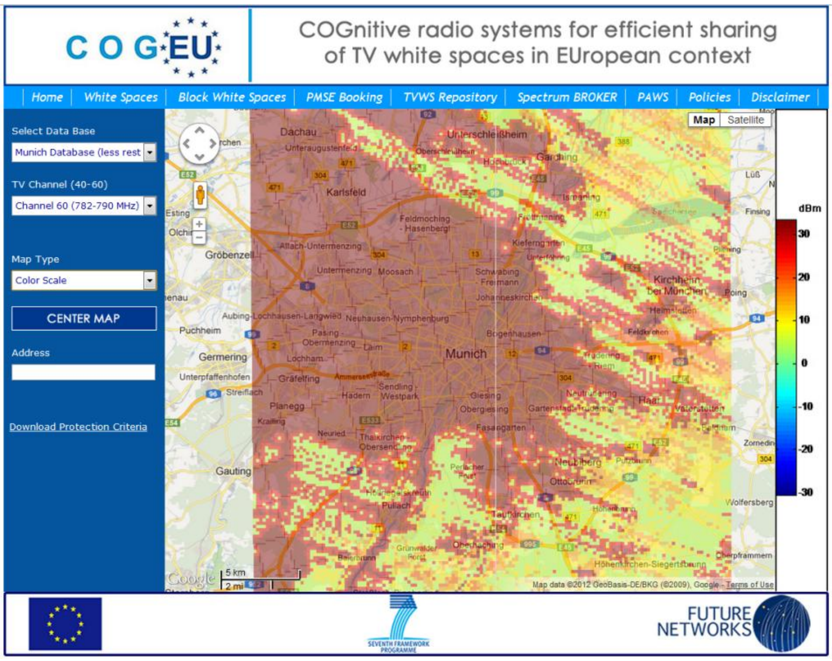

Figure 6: Output from the Show white spaces – color map tool, Munich database, Channel 60. In central Munich is possible to transmit up to 30 dBm without armful interference with DVB-T reception.

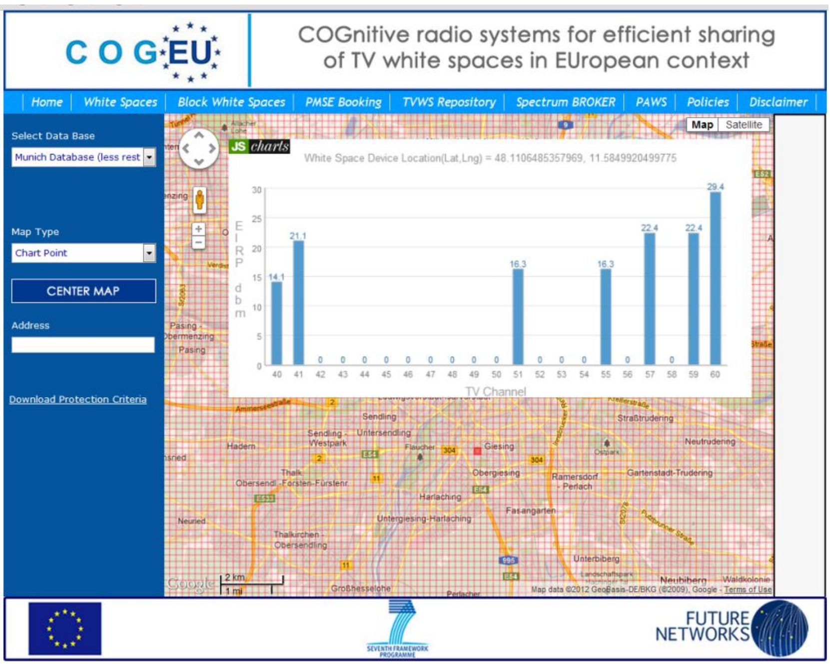

Figure 7: Output from the Show white spaces – chart point tool, Munich database. In this specific geo-pixel four vacant DVB channels allow more than 20 dBm for white space operation.

In the 'White Spaces' mode the system automatically compute the percentage of TVWS available for the specific Max. transmitted power, obtained based on the information available for the 50 Km^2 area around Munich. A summary of the the protection criteria and the methodology used to compute the TVWS maps is available for download in the 'White Spaces' menu.

3.2 Block White Spaces tool

National regulators are in charge to assure non-interfered operation of licensed services in the assigned bands. To accomplish this task, some restrictions to access to the geo-location database are indispensable and the regulator also requires access to all data of the broker, related to TVWS devices:

- The regulator hosts all the data on broadcast transmitter and other protected services in his (confidential) databases. Based on these data the regulator calculates the TVWS maps to fill the geo location database.
- The geo-location database describes maximum transmit power for a TVWS device for a channel at a given location and builds the basis for secondary spectrum use. Only the regulator has the permission to write these data or replace the data as a whole, either on a regular basis or if modifications are required.
- Depending on the national situation the regulator may also register PMSE data. If the regulator also hosts these PMSE data, then they can be as well considered in the TVWS maps.
- Based on the TVWS maps and with the PMSE entries, the broker has the basis for assigning the available channels for spectrum trading.
- In case the regulator becomes aware on interference to incumbent systems, either by own measurements or by complaints from incumbent users, the regulator has the authority to get insight into the Broker’s TVWS repository. The broker has the obligation to provide these data.
- The regulator has the exclusive right to impose a stop of transmission to a TVWS device if this device interferes with incumbent systems. The broker has to withdraw the license from the licensee immediately.

With this two-tiered design, where only the regulator has write-access to the TVWS maps and also holds the indispensable right to stop transmission of TVWS devices interfering incumbent systems, the regulator is in the position to guarantee non-interfered operation of incumbent systems. ‘Block White Spaces’ is an option from the geo-location database GUI programmed to achieve such a task.

‘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 8). 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. This way, Regulatory Authorities can easily block\unblock TV channels from the TVWS database for a specific pixel area.

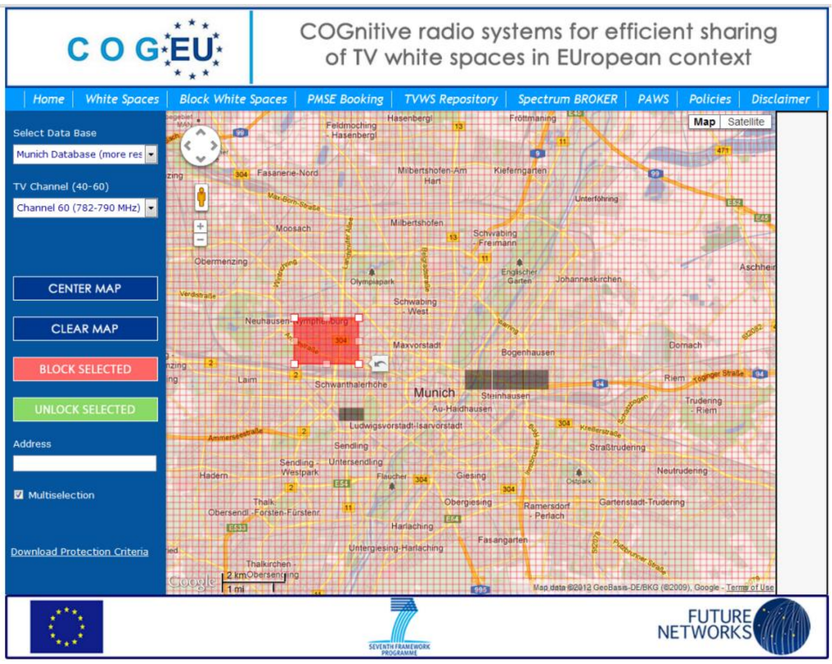

Figure 8: Block White Spaces menu. The regulator can remove areas from the geo-location database.

3.3 PMSE booking platform

3.3.1 Description

The PMSE booking platform is an online application that allows users to search for spectral occupation in a given place and time, and books spectrum for Programme Making and Special Events (PMSE) usage in time, spatial and frequency domain. The primary targets of the platform are Professional Wireless Microphone Systems (PWMS) devices in the UHF band. However, we programed it to be scalable to any other equipment or frequencies, and bearing in mind also those that have no technical knowledge of the spectrum or spectrum devices. This section presents the main features and techniques. A diagram of the booking platform elements and their interconnection is represented in Figure 9.

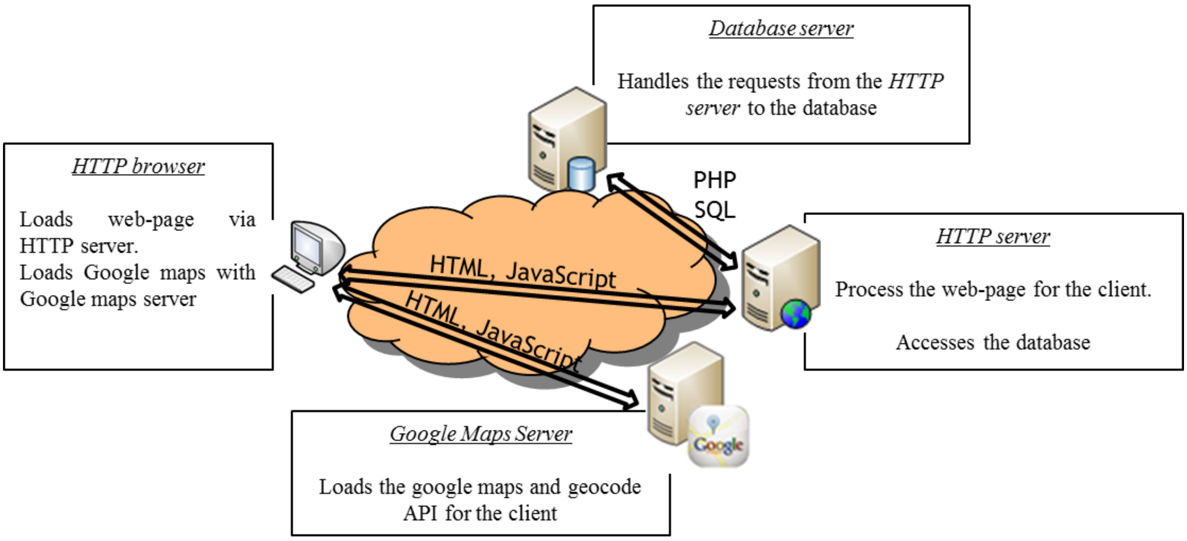

Figure 9: Communication between the four intervenient of the booking platform.

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 upon open-source technology MySql and has several tables organized to safeguard all the information regarding PMSE booking, such as the user ID, spectrum occupancy, time and location of spectrum booking. Figure 10 shows a list of parameters in each table, and their interconnections.

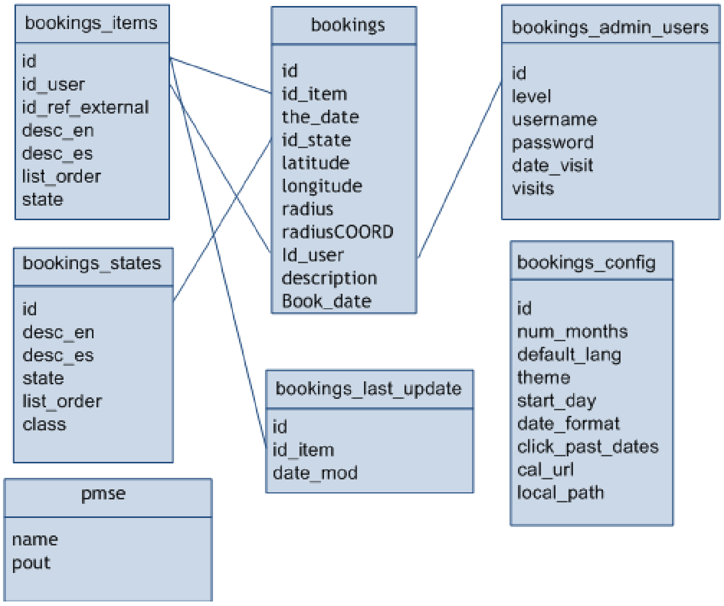

Figure 10: Database tables and interconnections.

The platform uses a secure access (https) to the PMSE database, done by PHP and using SQL commands. This process ensures integrity and confidentiality to users data and bookings operations.

Just like the geo-location database, we develop a GUI to ease the interaction of the user with the PMSE database. Some of the features are briefly described here:

- Development and integration with digital maps.
- Time booking is done through a calendar interaction.
- The spectral booking is made through the selection of the wanted channel.
- A section for spectrum search was taken in consideration. Interacting with a map, the user can check on the existing reservations, 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 the competent authorities.

The PMSE booking tool prototype developed by COGEU is accessible at https://www.est.ipcb.pt/pessoais/alter_mann/index.php. Figure 11 shows the home page of this tool.

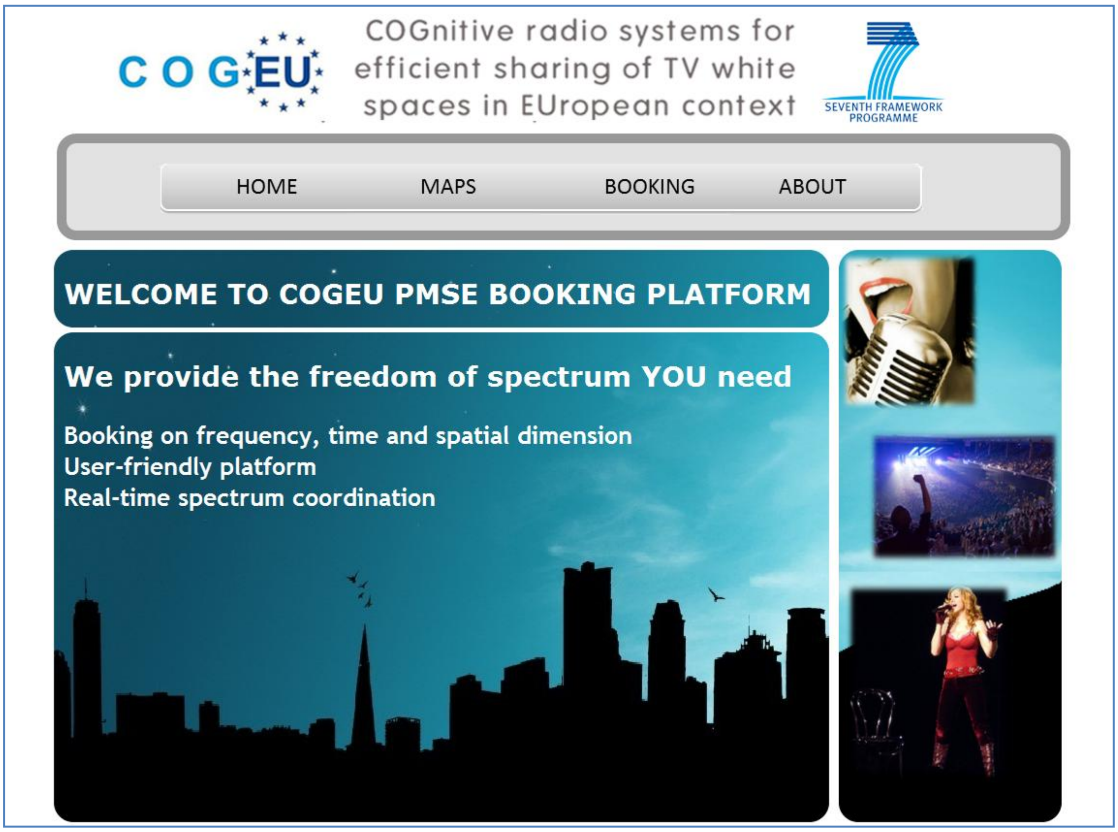

Figure 11: Home page of the online COGEU booking tool for PMSE.

3.3.2 Spectrum search

This area allows the user to search and check the state of the spectrum. The platform has now geographic limitations. Figure 12 shows PMSE bookings in Germany (Munich area).

There are 3 different sections:

- Summary: In this field are shown spectrum statistics: total number of reservations and daily reservations
- Map: The user can interact with the map via drag and drop, etc. When the map is loaded it is automatically filled with circumferences corresponding to the existing PMSE reservations.
- Queries: In this area the user can apply certain filters like show “PMSEs TODAY” or show “ALL PMSEs”, etc.

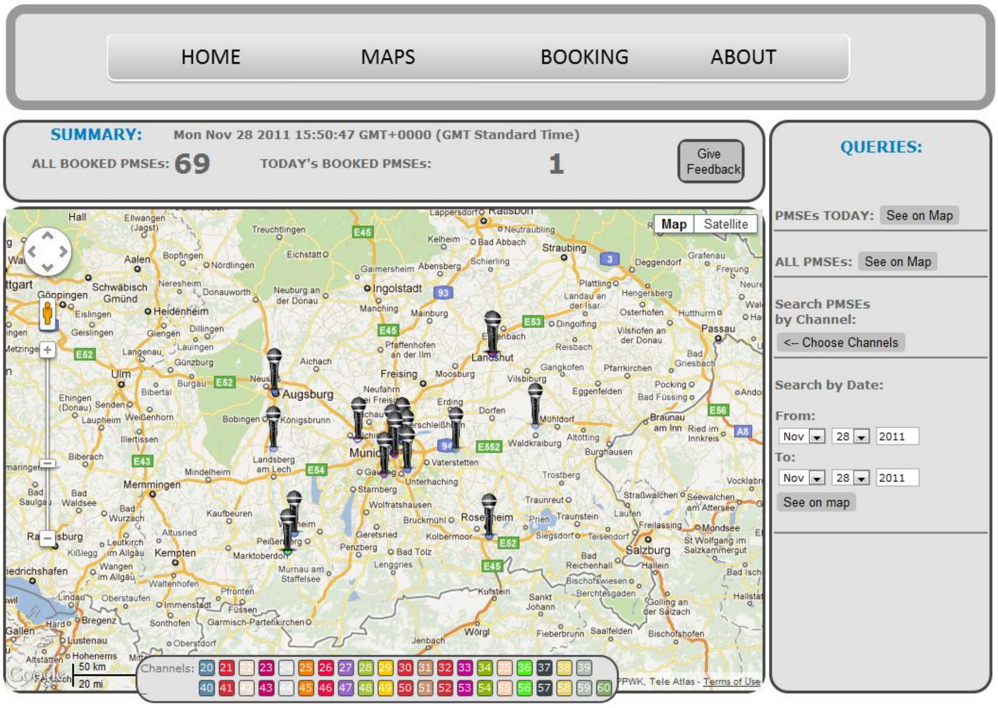

Figure 12: PMSE booking platform: Checking bookings in Munich area.

3.3.3 Spectrum booking

The main area of the booking platform is the user management area. After login in, the interface of Figure 13 accessible to the registered user is composed of the following elements:

- *Summary:* In this field are shown spectrum statistics: total number of reservations and daily reservations
- *Id:* Shows the user number, username and user account balance
- *Map:* Similar to the map on the spectrum search area.
- *Legend:* Legend of the map. For each channel there's a color.
- *Queries:* Similar to the queries in the spectrum search area.
- *User bookings:* Here the user bookings are loaded. The user can see on the map each booking and erase them if they haven't been authenticated yet.

When a client wants to book a new PMSE, after clicking the "Add new book" in the user area, he is taken to the webpage of Figure 14.

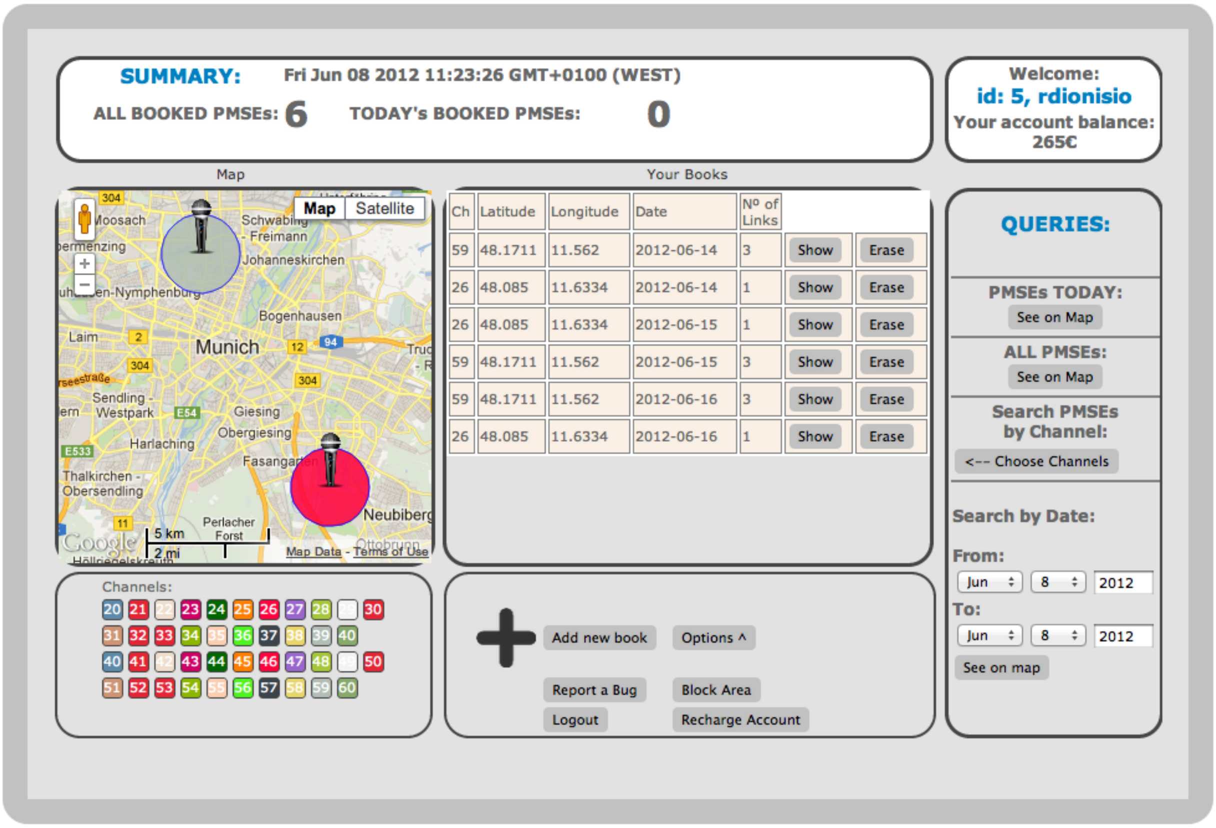

Figure 13: PMSE booking platform: user area.

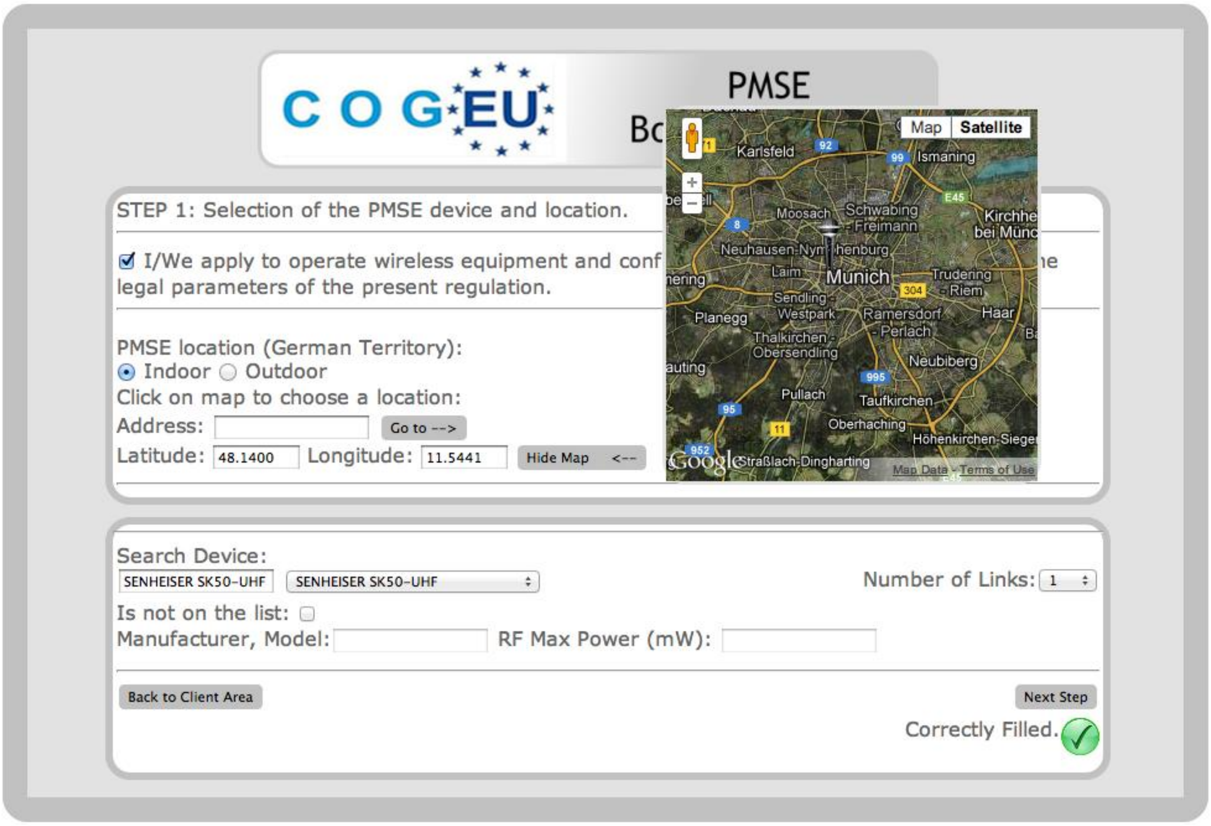

Figure 14: PMSE booking platform: choosing the location and the equipment.

The first step in the booking process is to choose the location of the event. The user can use a map and click on the place of the reservation, write the address or a postal code on the box, or can use both (to faster pinpoint the correct place). Here the platform uses Google Maps and Google Maps API for translation of the coordinates.

In the second part in this page, the user has to select the wireless devices to be used. As already mentioned, the event organization may not have technical knowledge of the equipment they're using. Taking that into account there's a list of devices, allowing the user to choose the brand of their equipment. If the device is not on the list, the user can then write the brand and the power output. Finally the user has to choose the number of links. It's important to elaborate the concept of links. Each PMSE has a theoretical bandwidth of 200 kHz. To avoid spectrum “waste” (the scenario of only one PMSE per channel) the platform supports up to 5 links per digital TV channel (using a bandwidth of 8 MHz per TV channel). This method safeguards the users from interferences and increases spectrum efficiency. Then, the user proceeds to book the event, using a calendar, as the one in Figure 15, to complete time booking.

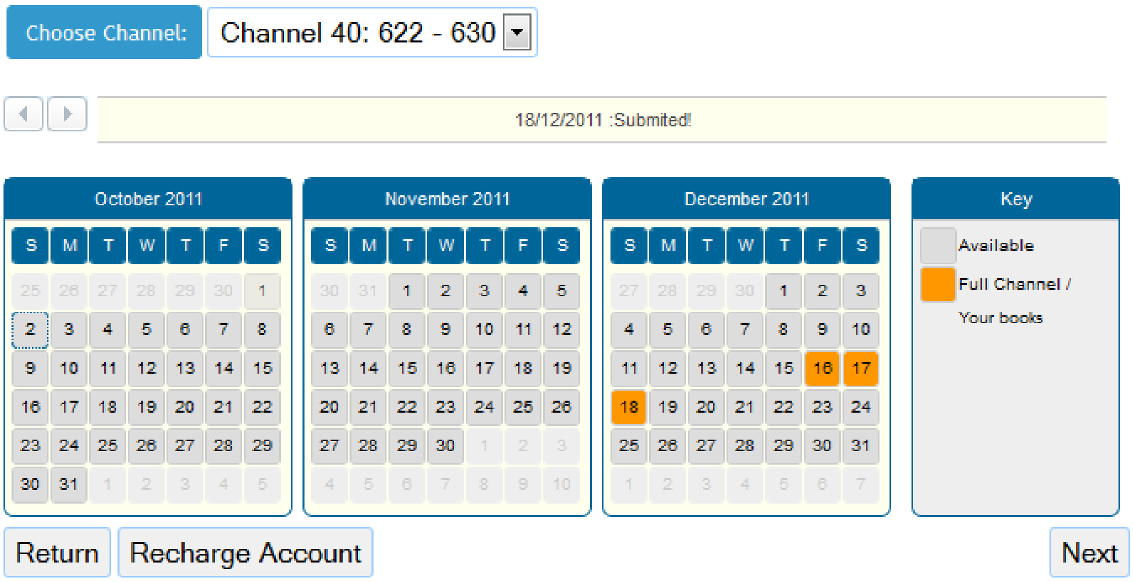

Figure 15: PMSE booking platform: Calendar for temporal booking.

Here the user can start by choosing the channel in which is PMSEs operate. Currently available channels go from channel 21 to 60 (easy changeable and scalable). After selecting the channel, the calendar is automatically refilled with the current reservations for this channel. This allows the user to check the availability (or unavailability) of the spectrum for the fore coming months. When a channel is occupied (or if the numbers of links the user choose is not available) the channel is reported as “full channel”. If for some reason the user runs out of account balance in the middle of the booking process, there's a button leading to Paypal to recharge the account.

In the last page (shown in Figure 16), the user is briefed about the place of the booking, reservations for the day and the geographic data. The account balance and a history of all his reservations are also shown.

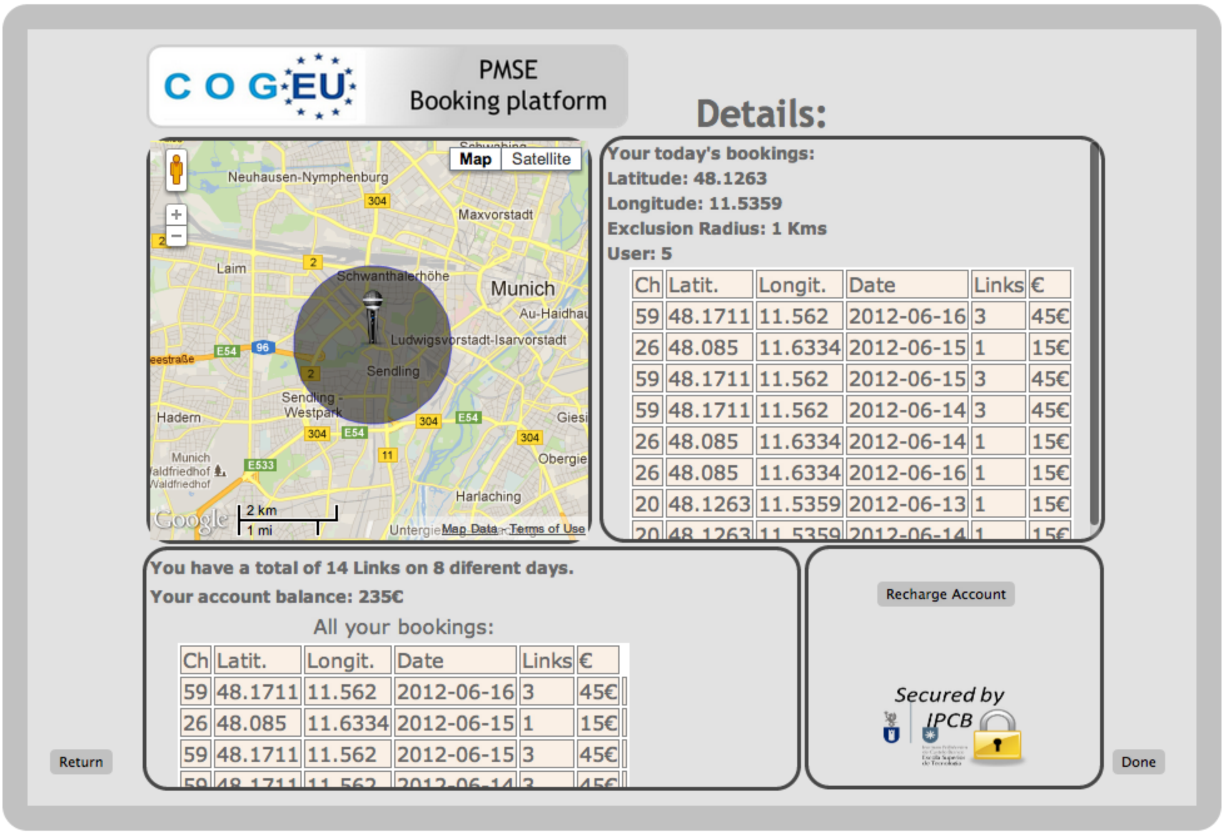

Figure 16: PMSE booking platform: Checkout page

3.3.4 Exclusion radius

When a new booking is started, the system automatically sets an exclusion radius guaranteeing the non-interference with other reservations. This calculation can be done in two ways (chosen by the administrator):

- Automatic mode: The radius is calculated taking into account the power output of the microphone and using the free space propagation model.
- Manual mode: There's a table available only for the administrator (Figure 17) that has a line for each interval of power outputs. This mode was developed for scenarios where files measurements are available, allowing for the administrator to set these values statically.

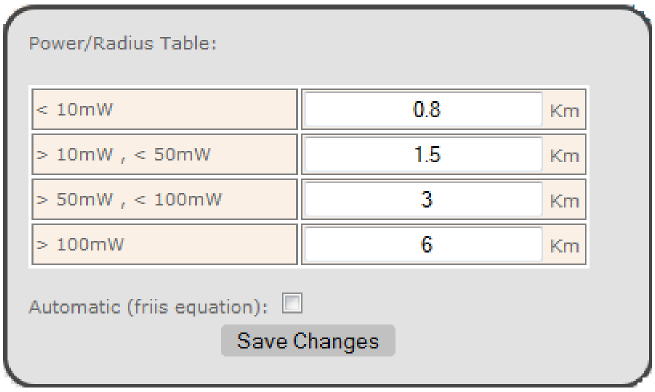

Figure 17: Power tables

3.3.5 Block PMSE booking

In case of catastrophic event, the emergency forces may require additional spectrum bands for emergency radio communications. Just like the TVWS geo-location database, The PMSE platform administrator has the ability to lock down part of the spectrum in an area. This functionality is shown in Figure 18. When the area is locked, new reservations can't be booked for PMSE usage.

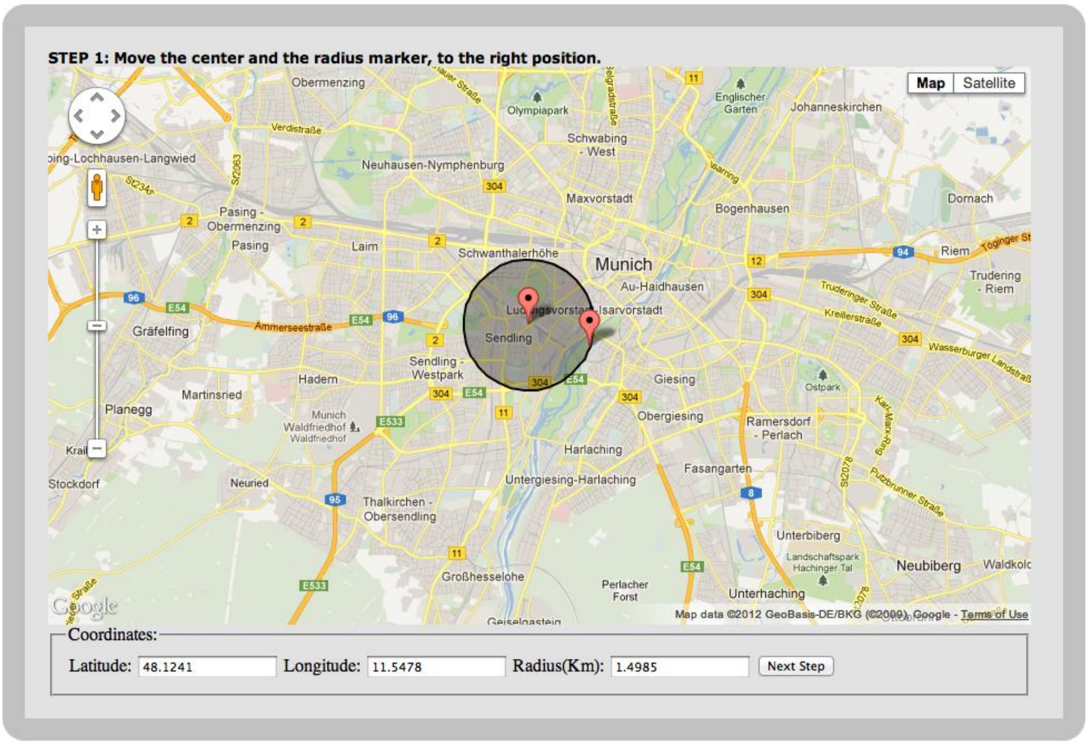

Figure 18: PMSE booking platform: Definition of the location and radius of the locked area, forbidden for PMSE usage and booking.

4 COGEU spectrum broker

4.1 COGEU auctions web tool

The COGEU spectrum broker online tool runs a secondary market of TVWS and implements an English auction mechanism. The COGEU broker was developed using the WeBid™ open-source auction script package [1]. WeBid™ is written in the scripting language PHP and has a large collection of highly customizable features, therefore was selected for setting up the COGEU spectrum auction site.

After registration in the COGEU Broker, spectrum seekers, such as Mobile Network Operators, can submit bids and buy temporally licenses for exclusive use of TVWS in a local area (e.g. to provide extra capacity in a LTE cell). Multiple local-auctions are running through this micro-trading platform, as shown in Figure 19. TVWS allocation has to satisfy the COGEU spectrum trading policies, which include antimonopoly, priorities, restrictions, etc. The spectrum policies are stored in the Policies Repository, described in Chapter 6.

The Broker will continually monitor Player bids against the policies that it enforces. If the Broker detects that a Player's bid is at variance with market policies, e.g. the Player is exceeding the maximum spectrum acquisition cap, the Player is placing bids which could unreasonably fragment spectrum assignment possibilities etc, then the Broker will issue a warning message to the Player notifying them of how they are breaching policies and rejecting their bid.

As the Broker is designed to have full knowledge of all spectrum users and spectrum uses it is reasonable to expect that its intervention in the market occur in an *ex ante* fashion, as described above.

The COGEU spectrum broker tool is online accessible for testing at and feedback as shown in Figure 19 (http://projectos.est.ipcb.pt/webbid/browse.php?id=2).

The main features of the COGEU online spectrum broker are:

- Registration of users (spectrum bidders)
- Users authentication through login and password
- Administrator area with statistics information about the spectrum market
- Show the spectrum portfolio by areas and associated license terms (e.g. Munich, Bratislava,...)
- Multiple and independent spectrum auctions (micro trading platform)
- Automatic notification by email when a user is outbid and when a user win an auction
- Configuration of the auction parameters: initial price, step, auction duration, spectrum caps
- Link with PayPal™ system

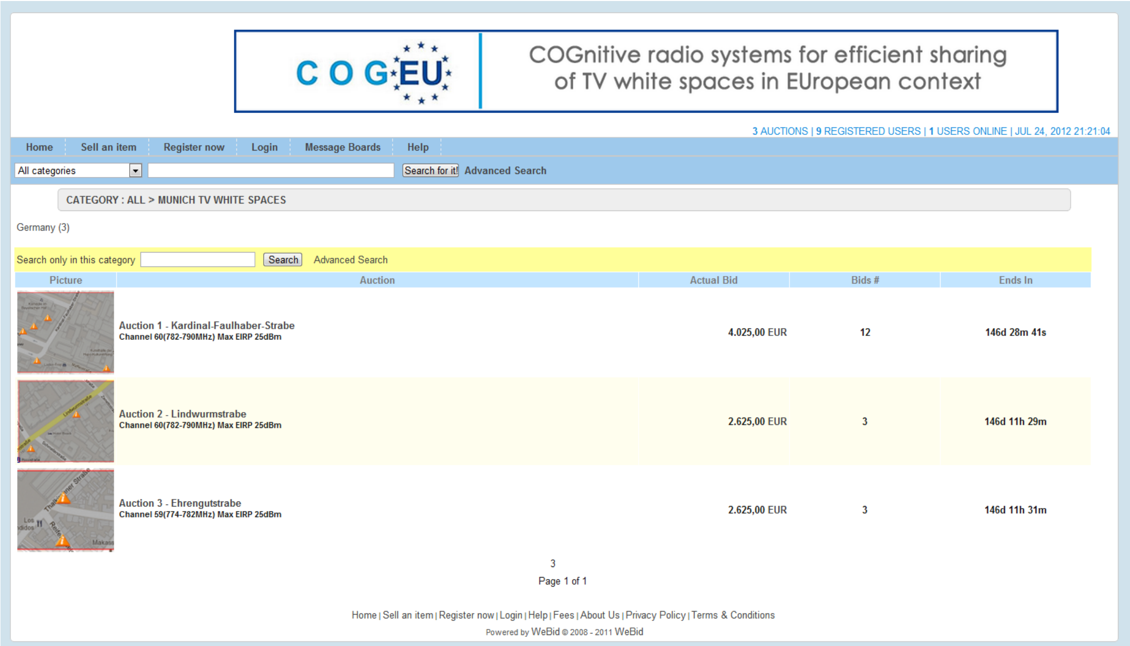

Figure 19: Auction web tool: An example in the Munich area with 3 items (spectrum licenses) on the spectrum market.

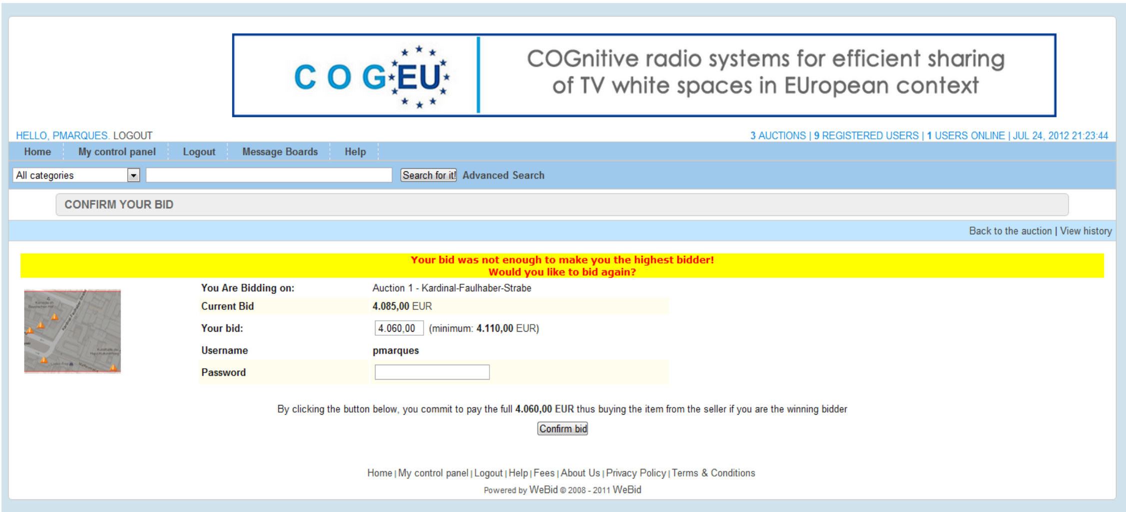

Figure 20: The online English auction tool in run mode, submitting a bid after login.

4.2 TVWS On-demand tool

This tool operates in the case when there is available one or more TVWS in a specific location pixel and there are some candidates to use the TVWS. This tool is used in order to showcase the Dynamic Radio Engine, Coexistence test bed and TVWS allocation process. Figure 21 shows the interface of the TVWS on demand tool. The functionalities that can be achieved with the tool are described below:

- Show the current secondary systems in a location
- Add a new secondary system
- Save the current configuration
- Store the environment in the TVWS database
- Allow for dynamic radio engine to take the environment as an input

This tool is the entry point to check an environment with a group of secondary systems if they cause interference to each other.

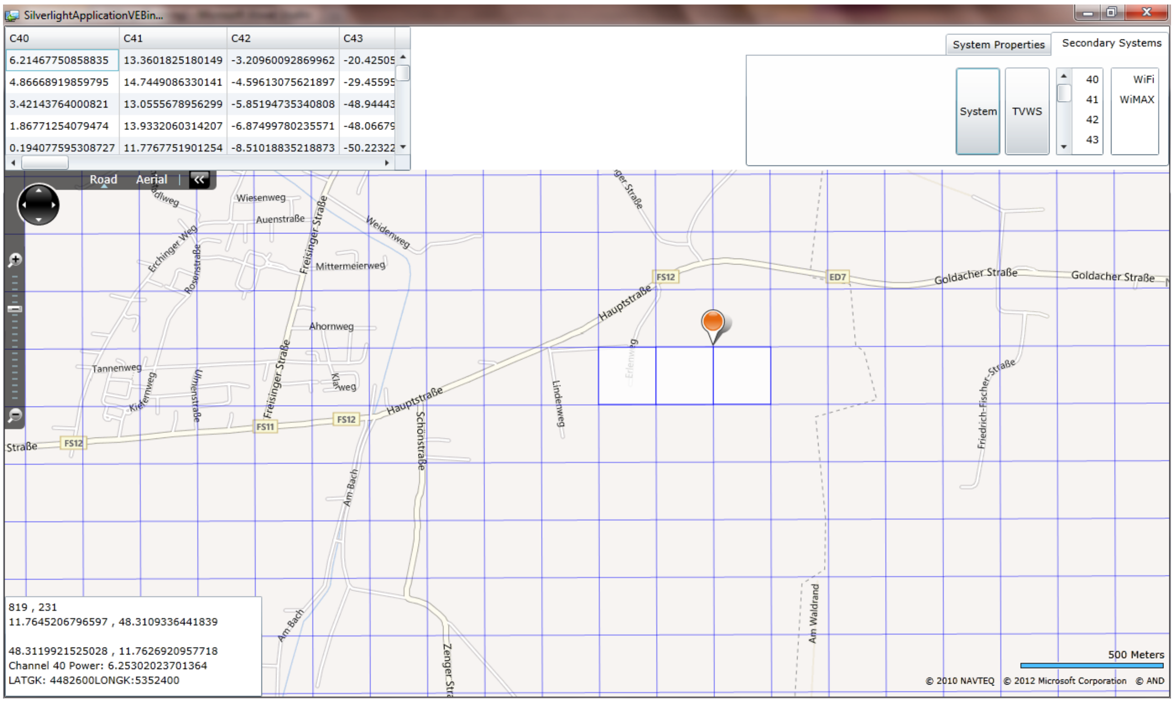

Figure 21: Interface for TVWS On-Demand tool

When a request is made by a secondary player, an evaluation process is taking place that the current request will not cause harmful interference to the already allocated secondary systems. This is important, since in COGEU model the Broker has to guarantee temporally exclusive rights for TVWS usage (clean spectrum). The coexistence evaluation is performed by the Dynamic radio Engine and the Coexistence emulator module described in the following sections, but the initial input is entered using the TVWS on demand tool.

Moreover, when a specific band is allocated to a secondary player for usage with a specific technology, the band is marked as “in use” status with the expiration of the licence of usage noted as well in order to avoid the reallocation of the same spectrum during the periods that is already allocated. The updated status can be seen using the current tool.

5 COGEU TVWS occupancy repository

The TVWS occupancy repository is an internal geo-location database that holds information about other secondary networks operating over TVWS in a given geographical area. The main objective is to keep the track of the allocated TVWS spectrum, provide data to the TVWS allocation mechanism for the provision of QoS to the secondary players in the TVWS bands and advertises the TVWS portfolio available for trading. The technical characteristics of the already deployed secondary networks operating in TVWS are stored in the repository. These information entities will be needed in order to evaluate current and future requests from spectrum buyers (players).

The TVWS occupancy repository is the unit that contains information on active TVWS networks and their operational parameters. The repository carries all the information required to compute mutual interference between TVWS systems. The TVWS occupancy repository not only contains the data, it also hosts the methods to manage the database and generate events or reacts on external events relevant for the management of TVWS systems:

- Data
    - TVWS (channels unused by primary services and maximum allowed transmit power), supplied by the external geo-location database.
    - All TVWS secondary systems in use in the considered area with its describing parameters (Base station position, antenna height, Tx power, antenna radiation pattern and RAT)
- Methods
    - How to fill the database / updating the database
    - Management of database (add/modify/remove TVWS service)
- Events
    - Trigger TVWS Update (periodically / on external trigger)

Figure 22 shows the structure of the repository and the main entities are highlighted. As can be seen, the main entities are the “TVWS” which holds the available TVWS and the SYSTEMS and PLAYERS, which hold the registered respective systems, and players. Table ACTIVE_SYSTEMS has the current active systems that are operating under the Broker and have been allocated band through the TVWS allocation process.

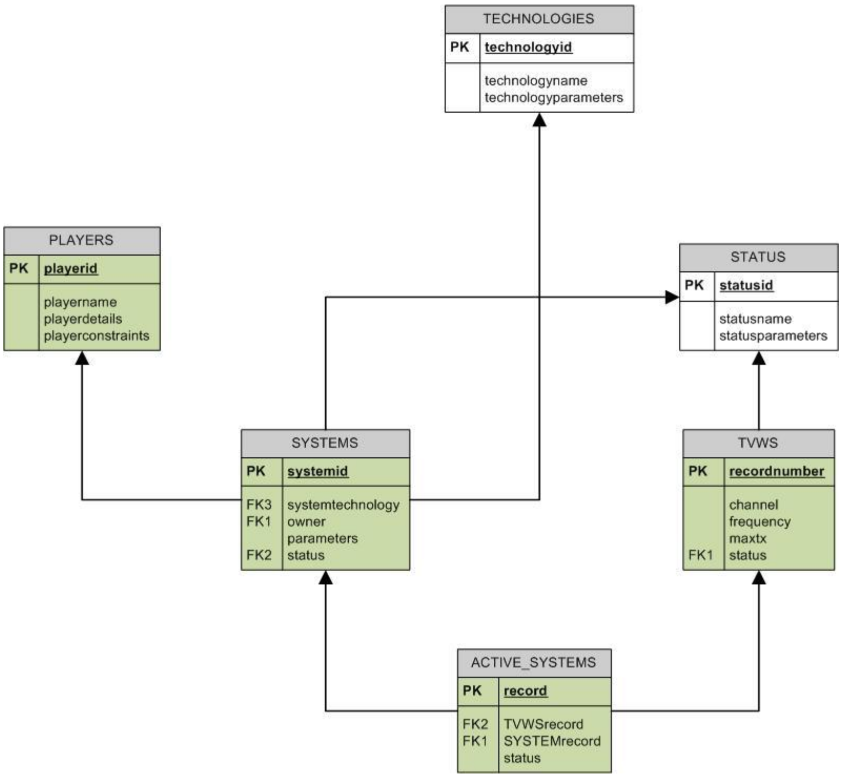

Figure 22: Broker TVWS occupancy repository database structure.

The repository is divided in 3 time periods, two during the day, and one for the night. During the day period (Figure 23), specific sites are on the market, in these sites, existing Mobile Network Operators can buy TVWS to operate extra LTE-downlink carriers over TVWS. An auction-based approach is used for the day period (COGEU Broker). During the night period (Figure 24), spectrum demand is lower than the spectrum supply; therefore the available TVWS are sold with a fix\benchmark price, for instance, to a M2M network operator that implements smart metering applications. Figure 25 illustrates a LTE base station operating in downlink, channel 60 and Figure 26associated estimated coverage area.

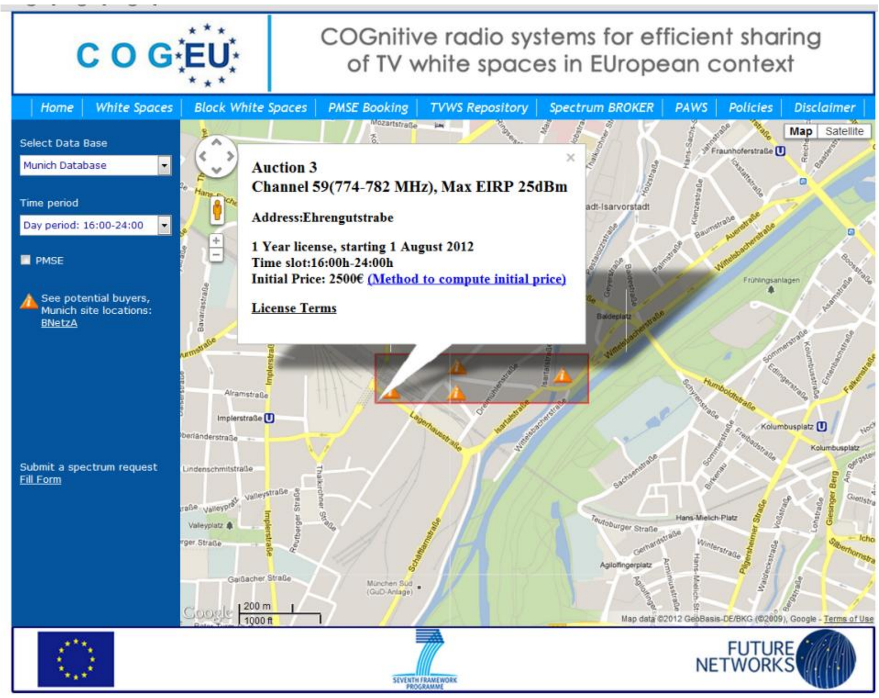

Figure 23: Example of a spectrum item showed in the portfolio repository in the day period (Munich area).

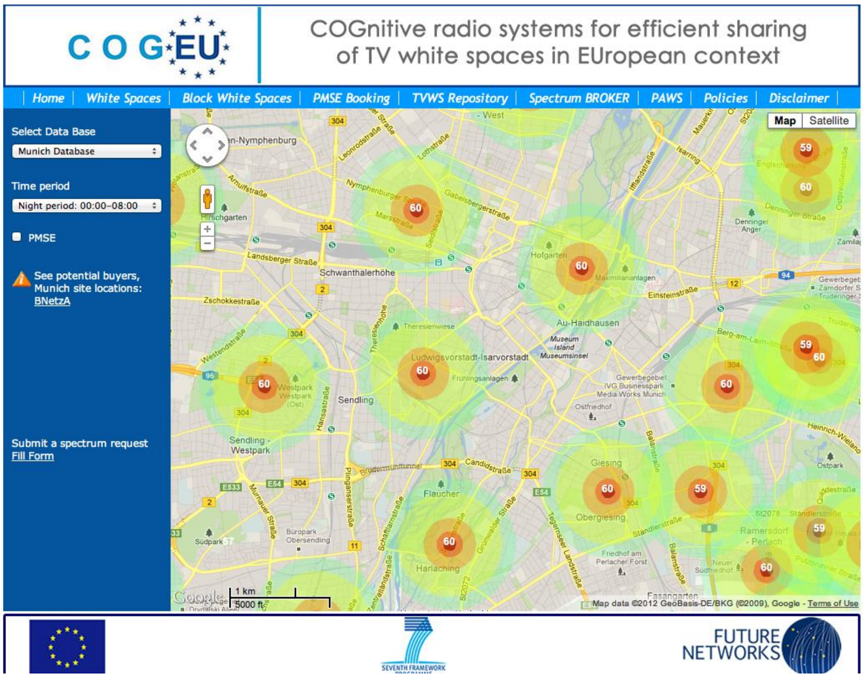

Figure 24: Illustrative example for secondary channel assignment during the night period in the Munich area (e.g. for a M2M application scenario).

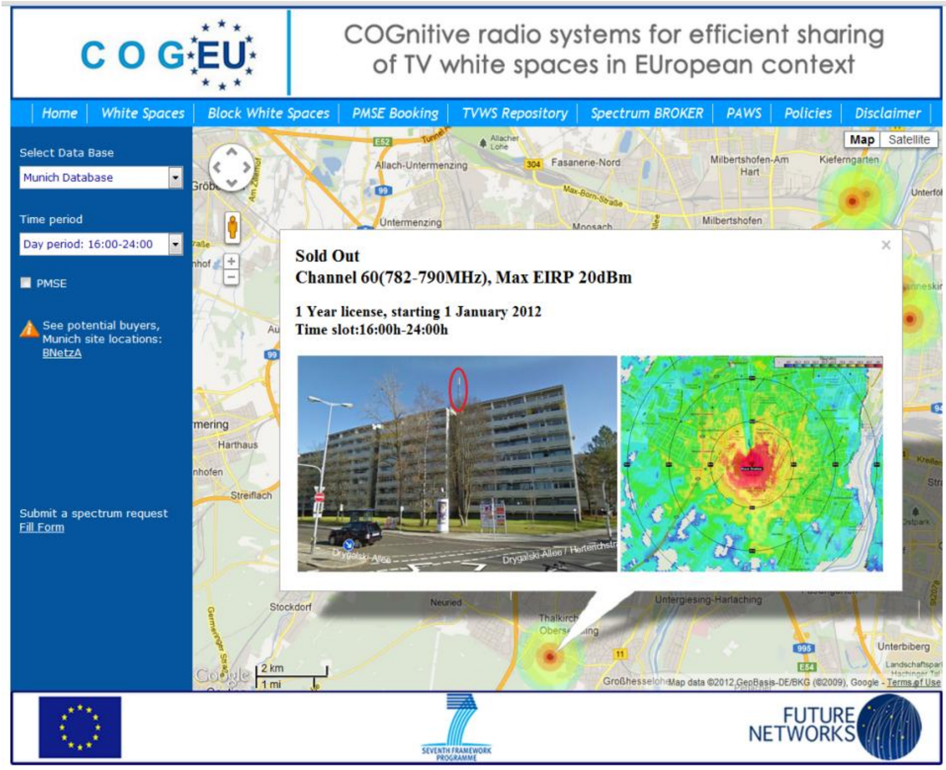

Figure 25: Example of a potential LTE Base Station operating in downlink with a temporarily license for Channel 60 bought through the COGEU Broker.

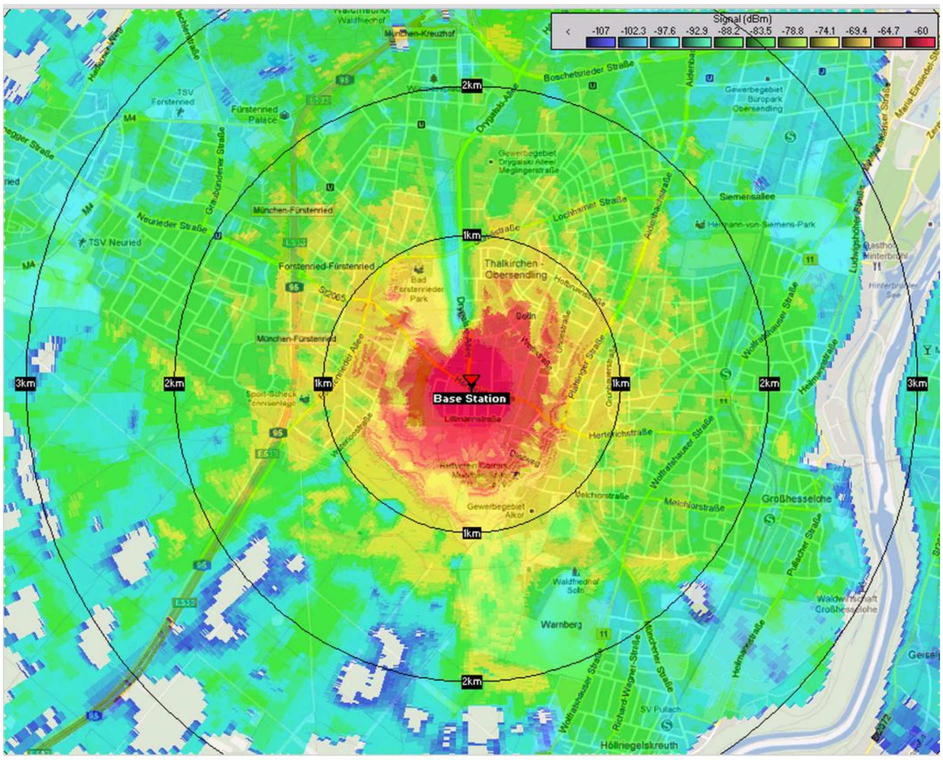

Figure 26: The TVWS repository keeps record of the estimated coverage area of the TVWS Base Stations in use. Example for a LTE Base Station in Channel 60, EIRP 20 dBm, height 10 m, suburban Munich, coverage area around 500 m.

6 COGEU Policies repository

The policies repository stores the operational policies and allows the broker to operate with flexibility and adaptability in relation to the current market and regulatory conditions.

6.1 Policy Repository structure

For the COGEU demonstrator, a functional Policies repository structure is essential. Policies repository is aimed to allow the policies to be part of the system and also enable different entities of the COGEU demonstrator to use policies as behaviour and operational guidelines.

Policies that are stored in the COGEU Policies Repository are primarily used by the Broker allocation process (see Figure 27). The format and design of policies need to be implementable and functional. A structure that enables this logic is presented in the Figure 27.

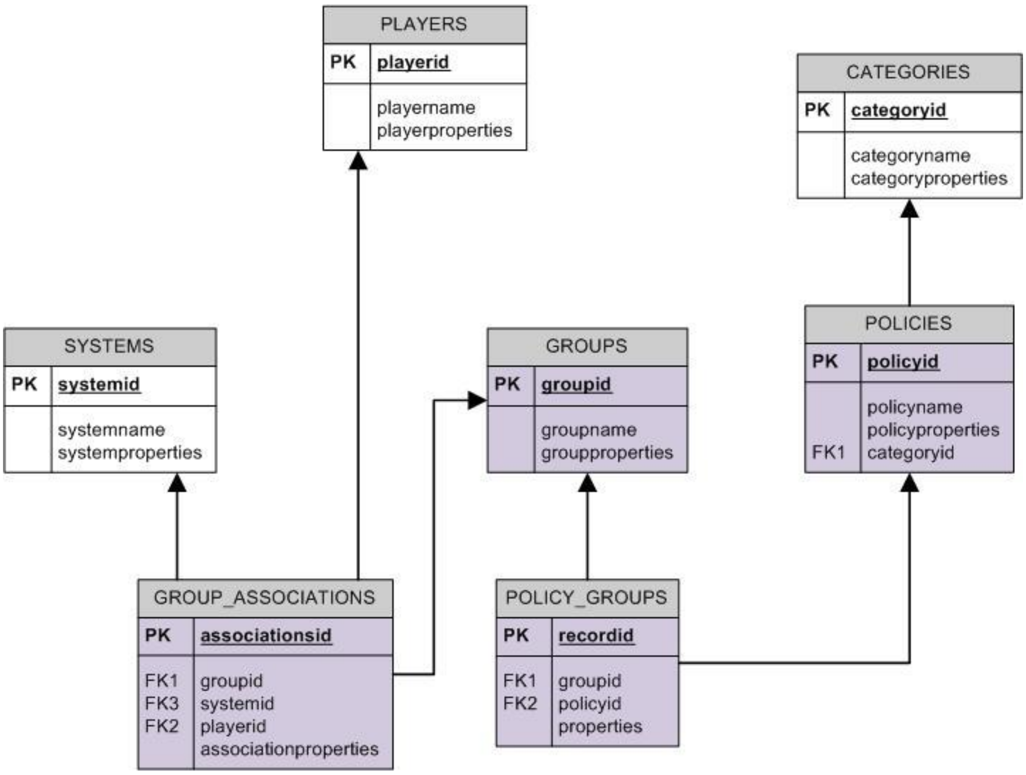

Figure 27: Broker policies repository structure.

In general the repository has the characteristics of a relational database that allows access through specific functions which are made available to other modules through web services.

The main information entities in the database are the POLICIES and the GROUPS. POLICIES hold the policy defined in a binary or numerical format. Policies are characterised at least by the category which are part of. CATEGORIES table holds all the possible categories for the defined policies. GROUP allows the formation of a group of policies that can be applied through the GROUP_ASSOCIATIONS to the current systems that operate under the Broker. The result of this structure is the ability to have systems that operate using differentiation regarding the applied policies and operation variables.

6.2 Broker available policies

The policy repository holds policies that indicate to spectrum buyers the rules that are in operation in the market. In this section we give illustrative examples of three possible policies; one for spectrum caps, one for spectrum fragmentation limitation and one regarding spectrum interruption under a licensed shared access regime.

The **spectrum caps policy**, the motivation for which was described in D2.3, sets out the limits for each buyer on the amount of spectrum that it will be allowed to acquire from the COGEU Broker. In this scenario we impose 3 separate caps, each of which must be respected. The first cap relates to the amount of TVWS spectrum that can be acquired by an individual spectrum consumer, e.g. 16 MHz. The second cap relates to the total amount of sub-1 GHz spectrum that a spectrum consumer can acquire, e.g. 40 MHz; this includes the TVWS spectrum. The last cap relates to all spectrum, both above and below 1 GHz.

```
<?xml version="1.0" encoding="UTF-8"?>
<cogeubroker name="SpectrumCapsPolicy">
      <TVWScap>
             <parameter name="cap" value="16"/>
      </TVWScap >

      <Sub1GHzCap>
             <parameter name="cap" value="40"/>
      </Sub1GHzCap>

      <AllSpectrumCap>
             <parameter name="cap" value="80"/>
      </AllSpectrumCap>
</cogeubroker>
```

The **Spectrum Fragmentation policy** relates to the manner in which the COGEU Broker allows players to acquire spectrum. The Broker may want to avoid the undue fragmentation of the spectrum such that the bandwidth of blocks that are available are desirable for many market participants. To this end it may not allow player to ask for odd amounts of spectrum that may leave undesirable residual spectrum in each of the unused 8MHz TV bands. The policy exampled here specifies that a player may not ask for less than 4MHz of spectrum and not more than 16MHz, in line with the spectrum cap policy. It also states that the players may ask for 6MHz, 8MHz, 10MHz, 12MHz and 14 MHz.

```
<cogeubroker name="SpectrumFragmentationPolicy">
      <TVWSfragmentation>
             <parameter name="minask" value="4"/>
             <parameter name="minask" value="16"/>
             <parameter name="askincremenet" value="2"/>
      </ TVWSfragmentation >
</cogeubroker>
```

The final policy we example in this section regards **the possibility of interruption of service for a licensed user of the TVWS**. As certain PMSE users, such as ENG (Electronic News Gathering) users, may require anticipatable but authorized access to the licensed spectrum the Broker may have to direct the licensed user to cease transmissions for a temporary period. The following policy specifies to potential buyers whether or not a Shared Spectrum Interruption policy is in place across the frequencies of interest, how much interruption is anticipated and whether any compensation is forthcoming for interruption events beyond the indicated Interruption Rate.

```
<cogeubroker name="SharedSpectrumInterruptionPolicy">
      <frequency>
            <parameter name="StartFrequency" value="470"/>
            <parameter name="StopFrequency" value="630"/>
            <Interruption>
                   <parameter name="InterruptionPossible" value="true"/>
                   <parameter name="InterruptionRate " value="4"/>
                   <parameter name="Compensation″ value="true"/>
            </Interruption>
      </frequency>
      <frequency>
            <parameter name="StartFrequency" value="630"/>
            <parameter name="StopFrequency" value="790"/>
            <Interruption>
                   <parameter name="InterruptionPossible" value="true"/>
                   <parameter name="InterruptionRate " value="1"/>
                   <parameter name="Compensation″ value="false"/>
            </Interruption>
      </frequency>
</cogeubroker>
```

6.3 COGEU license terms specification

The COGEU licenses issued by the Broker will be issued under circumstances that provide for certainty on the behalf of all participants. As this spectrum is being shared by incumbent services, i.e the DVB-T and PMSE community, and new users, i.e. those that buy temporary spectrum rights from the broker, the license terms must account for this mixed use scenario.

COGEU has developed a framework for sharing the TVWS spectrum which is very much in line with the emerging concept of Authorized Shared Access [8] or Licensed Shared Access (LSA) [9]. This licensing paradigm envisages the kind of mixed use licensed access to spectrum which has primarily been used, heretofore, by an incumbent service. The online COGEU spectrum broker advertise the License Terms for each item on the market (Figure 28).

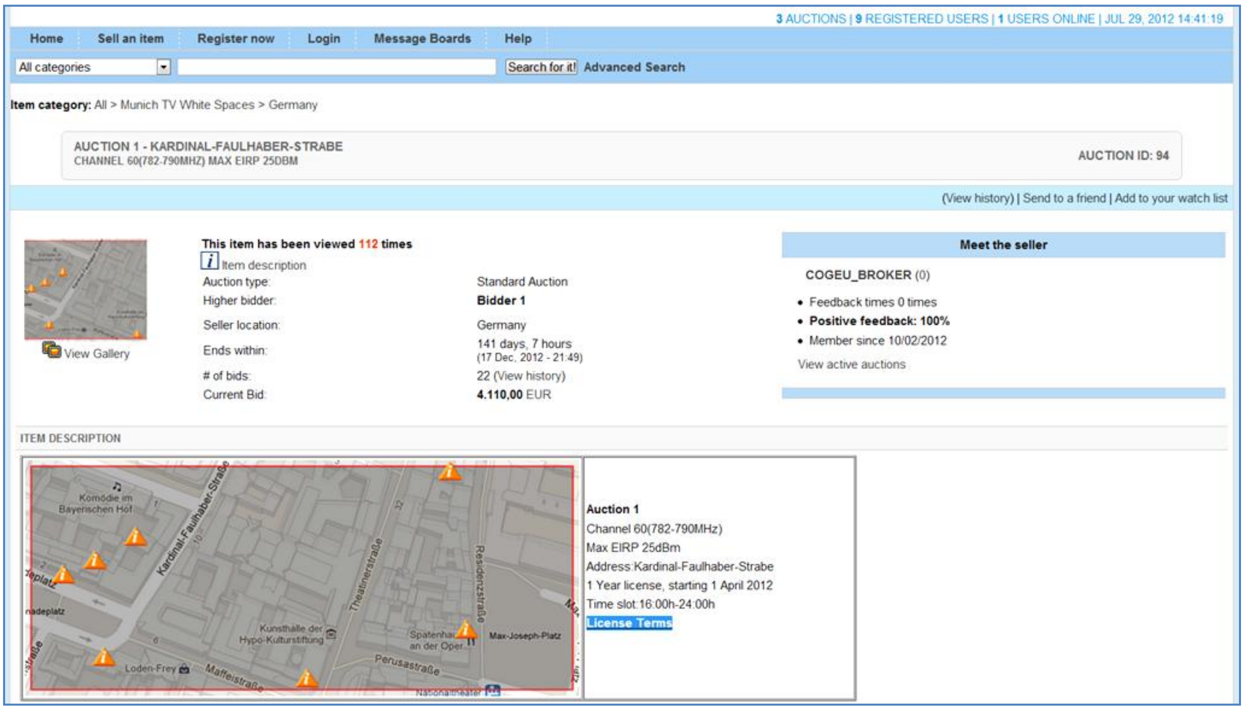

Figure 28 The COGEU broker advertises the License Terms for each item on the market. Available at: http://projectos.est.ipcb.pt/webbid/index.php?

The RSPG (Radio Spectrum Policy Group) would envisage that spectrum can be shared by a known number of independent users accessing the same range of frequencies in a controlled manner. While the COGEU Broker model predates the formalization of the Licensed Shared Access (LSA) concept by the RSPG in our model the COGEU Broker undertakes the role of a LSA authority.

The format of the COGEU license set out in this document is a modified version of the format of the UK public wireless licenses issued for cellular mobile communication use [10]. Specifically, modifications to the standard license are required to address the nature of the delegation of licensing authority to the COGEU Broker, to address the concept of LSA and to allow for the use of electronic communication techniques between the Broker and the licensees.

The COGEU Broker takes on the role traditionally held by the National Regulatory Authority in this license as this authority that been delegated to it subject as the LSA and Spectrum.
The Relevant Statutory Acts refers to any acts underpinning the COGEU Broker regime. These acts would include the Wireless Telegraphy Acts of a jurisdiction, acts enabling Spectrum Trading and acts enabling Licensed Shared Access.
The **COGEU Broker** takes on the role traditionally held by the National Regulatory Authority in this license as this authority that been delegated to it subject as the LSA and Spectrum.

The **Relevant Statutory Acts** refers to any acts underpinning the COGEU Broker regime. These acts would include the Wireless Telegraphy Acts of a jurisdiction, acts enabling Spectrum Trading and acts enabling Licensed Shared Access.

Electronic Agents must be established by both the licensing authority and the licensees. These could be in addition to, or co-existent with, the emerging geo-location database entities that are being developed by NRAs, or their delegated agents.

The concept of an **electronic notice** is also introduced. While NRAs typically reserve the right to inspect and modify license terms if they believe that undue interference is being caused by a licensees operations, this process is paper-based, time-consuming and not immediate in execution. In order to address the requirements of a TVWS LSA-based system which accounts for the possibility of situations in which PMSE users such as unforeseen electronic news gathering (ENG) events the Broker may invoke its right to either interrupt the licensed TVWS user to allow for the safe use of the spectrum by another authorized party, i.e. the PMSE user. This interruption may take the form of a license modification notification, i.e. detailing a restricted bandwidth on which to operate or reduced power. Or, it may take the form of a closedown notification. These notifications, by their nature, will occur in an urgent manner and will be temporary. A notification allowing for resumption of normal services will likely follow within hours.

The final element that we see as being necessary is the introduction of a **Machine Readable Technical License Conditions**. A machine readable version of the existing licenses, detailing the technical operating parameters for the licensee, must be issued by the Broker/NRA in addition to the regular paper license such that electronic agents, e.g. cognitive radios or policy-enabled radios, operating on behalf of the licensee can immediately interpret and execute the license requirements as they are both introduced, modified and revoked from time to time.

COGEU TVWS Shared Access Licence

Licence no. **1234XYZ**

Date of issue: **dd m yyyy**

Fee payment date: **date of issue + 10 business days**

1. **COGEU Broker** (“the Broker”) grants this licence to

Ersatz Zellularnetz *GmbH* ("the Licensee")
Marienplatz,
München,
DE

to establish, install and use radio transmitting and receiving stations and/or radio apparatus as described in the schedule(s) (herein after together called "the Radio Equipment") subject to the terms, set out below.

Licence Term

2. This Licence shall continue in force until *dd mm yyyy* [*normally less than 1 year later than the date of issue noted above*] ***or***
until revoked by the COGEU Broker ***or***
Surrendered by the Licensee.

Licence Variation and Revocation

3. Pursuant to the *Relevant Statutory Acts* the Broker may not revoke or vary this Licence save at the request or with the consent of the Licensee except:

(a) in accordance with clause 6 of this Licence;

(b) if there has been a breach of any of the terms of this Licence or the schedule hereto;

(c) if under the terms of this Shared Access Licence, as stated in paragraph 13, it is necessary to issue a Shared Access Interrupt.

Changes

4. This Licence may not be transferred, i.e. the Licensee shall not trade this license with another party.

5. The Licensee must give prior or immediate notice to the Broker in writing of any change in the details of the name and/or address and/or electronic address/identifier recorded in paragraph 1 of this licence.

Fees

6. The Licensee shall pay the Broker the relevant fee as decided at the time of sale of this Licence to the Licensee under market mechanisms provided for in the *Relevant Statutory Acts* on or before a date as shall be notified in writing to the Licensee, failing which the Broker may revoke this Licence.

Radio Equipment Use

7. The Licensee must ensure that the Radio Equipment is constructed and used only in accordance with the provisions specified in Schedule 1 of this Licence. Any proposal to amend any detail specified in Schedule 1 of this Licence must be agreed with the Broker in advance and implemented only after this Licence has been varied or reissued accordingly.

8. The Licensee must ensure that the Radio Equipment is operated in compliance with the terms of this Licence and is used only by persons who have been authorised in writing by the Licensee to do so and that such persons are made aware of, and of the requirement to comply with, the terms of this Licence.

Where Licence terms are modified under paragraph 13 of this Licence, the licensee must ensure that the Radio Equipment is complies with such variations within the time limits specified under that paragraph.

Electronic Agents, Machine Readable Licence Conditions

9. The Licensee shall maintain an Electronic Agent that is capable of receiving electronic notifications from an electronic agent authorised to act for the Broker and/or the NRA. The specifications of such an agent are described in Schedule 1 of this Licence.

10. The technical licence conditions attached to this Licence for the operation of Radio Equipment, as laid out in Schedule 1 of this Licence, will also be available in electronic form as Machine Readable Technical Licence Conditions. The Licensee's paragraph 9 Electronic Agent shall be capable of interpreting such Machine Readable Technical Licence Conditions, the specifications of which are described in Schedule 1 of this Licence.

Access and Inspection

11. The Licensee shall permit a person authorised by the Broker:

(a) to have access to the Radio Equipment; and

(b) to inspect this Licence and the Radio Equipment,

at any and all reasonable times or, when in the opinion of that person an urgent situation exists, at any time to ensure the Radio Equipment is being used in accordance with the terms of this Licence.

12. The Licensee shall permit an Electronic Agent authorised by the Broker or NRA to have access to information regarding the current operating status of the Radio Equipment.

Modification, Restriction, and Closedown

13. A person or electronic agent authorised by the Broker may require the Radio Equipment, or any part thereof, to be modified or restricted in use, or temporarily or permanently closed down immediately if in the opinion of the person authorised by the Broker:

(a) a breach of this Licence has occurred; and/or

(b) the use of the Radio Equipment is causing or contributing to undue interference to the use of other authorised radio equipment.

14. The Broker may in the event of a national or local state of emergency being declared require the Radio Equipment to be modified or restricted in use, or temporarily or permanently closed down either immediately or on the expiry of such period as the Broker may specify. The Broker shall exercise this power either by written notice served on the Licensee or by general notice issued to holders of this class of Licence or by delivery of an electronic notification of the kind described in paragraph 9.

Shared Access Interrupts

13. In accordance with the explicit licensed shared access conditions of this class of Licence, as provided for in the *Relevant Statutory Acts*, the Broker may issue Shared Access Interrupt electronic notifications, from time to time, requiring the immediate temporary modification, restriction or closedown of the operation of the Radio Equipment to allow for the safe operation of other authorised users of the frequencies specified in Schedule 1 of this Licence.

Such modifications, restrictions or closedown of the License will be communicated to the Licensee's Electronic Agent in the form of amended Machine Readable Technical Licence Conditions.

The conditions under which paragraph 12 Sharing Interrupts may be issued by the Broker to the Licensee are specified in Schedule 1 of this License.

Geographical Boundaries

12. This Licence only authorises the establishment and use of the Radio Equipment at the sites specified in Schedule 1.

Issued by the COGEU Broker

SCHEDULE 1 TO LICENCE NUMBER: **1234XYZ**

Licence Category: **TVWS Shared Access Licence**

This schedule forms part of licence no **1234XYZ**, issued to **Ersatz Zellularnetz *GmbH***, the Licensee on **dd mm yyyy**, and describes the Radio Equipment covered by the Licence and the purpose for which the Radio Equipment may be used.

Description of Radio Equipment Licensed

1. In this Licence, the Radio Equipment means the base transceiver station or repeater stations forming part of the Network (as defined in paragraph 2 below).

Purpose of the Radio Equipment

2. The Radio Equipment shall form part of a radio telecommunications network ("the Network"), in which User Stations which meet the appropriate technical performance requirements as set out in the *Relevant Statutory Acts* communicate by radio with the Radio Equipment to provide a telecommunications service.

Approved Standards for the Radio Equipment

3. The Radio Equipment covered by this Licence shall comply with the appropriate TVWS Radio Equipment Standards and is required to be type approved in accordance with a recognised technical performance standard relating to the licensed service.

Special Conditions relating to the Operation of the Radio Equipment

4.
(a) During the period that this Licence remains in force and for 6 months thereafter, the Licensee shall compile and maintain accurate electronic records of:

(i) The following details relating to the Radio Equipment:

a) Postal address;

b) National Grid Reference, (to 100 Metres resolution); German **version of these coordinates.**

c) Antenna height (AGL) and type;

d) Radio frequencies in operation;

(ii) A statement of the number of subscribing customers using the Network;

And the Licensee must produce the above records when a person or electronic agent authorised by the Broker requires him to do so.

(b) The Licensee shall inform the Broker of the address of the premises at which this Licence and the information detailed at sub-paragraph (a) above shall be kept.

(c) The Licensee must submit to the Broker copies of the records detailed in sub- paragraph (a) above at such intervals as Ofcom shall notify to the Licensee.

(d) The Licensee shall, upon request, supply the Broker or any person authorised on their behalf with the name and address of any subscribing customers to the Network, or require its agents to provide such information on its behalf.

TECHNICAL LICENCE CONDITIONS

The Licensee must ensure that the Radio Equipment performs in accordance with the following technical performance requirements.

Frequencies of Operation

5. The Radio Equipment may operate on any of the following frequency bands:

[630 MHz – 638 MHz]
[742 MHz - 746 MHz]

Location of Operation

6. The Radio Equipment may operate at the following location:

One of the German coordinates.

ITU Class of Emission

7. For OFDM based transmission:

For 8MHz OFDM based system: 8M00A7W
For 4MHz OFDM based system: 4M00A7W

Maximum Permissible In-band E.I.R.P

8.

The maximum E.I.R.P for **[630 MHz – 638 MHz]** is **30** dBm/4kHz.
The maximum E.I.R.P for **[742 MHz – 746 MHz]** is **25** dBm/4kHz.

Maximum out-of-band emission limits

9.

For **[630 MHz – 638 MHz]** the following out-of-band emission limits apply:

Δf from band edge	Max PSD for OOB emissions (dBm/4kHz)
0-2 kHz	9.03- (15xΔf)
2-14 kHz	-19.30 –(0.833xΔf)
14-31.25 kHz	-30.97

For **[742 MHz – 746 MHz]** the following out-of-band emission limits apply:

Δf from band edge	Max PSD for OOB emissions (dBm/4kHz)
0-4.5 kHz	2.04-(6.667xΔf)
4.5-29.5kHz	-26.16-(0.4xΔf)
29.5-62.5kHz	-37.96

Interpretation

10. This Schedule shall be interpreted as per the interpretation section of the Relevant Statutory Acts.

Electronic Agents
11. The Broker shall maintain an electronic agent that shall be capable of interpreting electronic notifications, responding to Section requests and executing changes in its technical licence conditions.

The Electronic Agent shall be contactable at the electronic address/identifier named in paragraph 1 of the Licence.

The Electronic Agent shall be capable of communicating using SOAP/PAWS/XML

Electronic Notifications
12. All electronic notifications and communications between the Broker/NRA's Electronic Agent and the Licensee's Electronic Agent shall use the following standardised formats.
Notification messages shall use an XML format.

Shared Access Interrupts

13. Shared Access Interrupts may be issued by the Broker from time to time as the need arises to provide safe access to the frequencies listed in this schedule at paragraph 8 for another authorised user. The Shared Access Interrupt will detail the modification, restriction or closedown of the operation of the Radio Equipment of the Licensee in the form of Machine Readable Technical License Conditions.

On receipt of a Shared Access Interrupt, the Licensee shall acknowledge receipt of the notification within 5 minutes and shall give effect to the amended Technical License Conditions within 15 minutes from the time at which the Shared Access Interrupt was issued.

The Broker shall notify the Licensee of the termination of the Shared Access Interrupt by further electronic notification upon receipt of which the Licensee may recommence normal operation.

The Licensee may be subject to **2** Shared Access Interrupt Events every month, the Anticipated Interruption Rate, without compensation. Each continuous period of up to 3 hours shall be considered as one Shared Access Interrupt Event such that an interrupt of 4 hours would be counted as 2 Shared Access Interrupt Events, etc.

If the rate of Shared Access Interrupts exceeds the Anticipated Interruption Rate the Licensee shall receive a pro-rata refund of its License fee for that period.

.

7 Coverage calculation for TVWS Base-Stations

So far for TVWS investigations the maximum WSD transmit power was the prominent feature in valuating white spaces coverage. However as WSD have to cope with interfering signals caused by incumbent systems, the negative effect of reducing the operational distance of white space links has to be considered. This section addresses the coverage of TVWS Base Station considering the interference from DVB in WSD reception.

7.1 Interference levels for White Space reception

For the calculations made so far the DVB-T signals can be classified as follows:

- Within the coverage area of a broadcast transmitter this transmitted signal represents the wanted signal
- DVB-T signals from other transmitters, operating on the same channel but transmitting different programs are seen as interfering signals to the wanted signals (co channel interferer)
- DVB-T signals from other channels also contribute to the interfering signal (adjacent channel interferer).

The wanted signal's transmit power is the prominent parameter which determines the operational range of the broadcast system. At the location of the receiver only a small portion of this power arrives and the signal strength varies over a given area, e.g. 200 m x 200 m, in a log-normal manner.
In the same way the interfering signals arrive at the receiver. The relative strengths of wanted to interfering signal determine the probability to successfully receive the broadcasted DVB program. If the interfering signal strength increases, the location probability decreases.

Example:

a) Noise limited case
N = -98 dBm
Min. C/I for DVB-T reception [GE06 or ECC159 table 1]: SNR = 21 dB
The signal from a transmitter shows a log normal distribution and can be described with median value m_s and standard deviation σ_s. The standard deviation for DVB-T signals is 5.5 dB.
If the median signal strength of the wanted signal P_s is N + SNR = -77 dBm then DVB-T reception is possible in 50 % of the locations of a considered pixel (e.g. 200 m x 200 m). If the signal strength of the wanted signal becomes higher, the probability for DVB-T reception also increases.
Due to the log normal nature of the signals, this can be described by Gaussian statistics: $m_s[dBm] = (N + SNR) + \varepsilon(q)\sigma$, where ε represents the confidence factor which is related to the location probability q by the Gaussian error function: $\varepsilon(q) = \sqrt{2}\ erfinv(2q - 1)$ [see COGEU deliverable D6.2]
If the wanted signal strength becomes -67.95 dBm then ε(q) = 1.64 and q = 95 %.

b) With additional interfering signal
Let's assume that there is an unwanted signal with m_u = -73.7 dBm. This has to be power summed with Nu_{noise} = N + SNR to find the total nuisance field: Nu_{total} = -72.03 dBm.
Taking into account that the unwanted signal is as well log normal distributed, with $\sigma_{eff} = \sqrt{\sigma_s^2 + \sigma_u^2}$ the new location probability can be determined and is found to be 70 %

→ So, in this example the additional interference reduces the location probability of the wanted signal from 95% to 70%.

This is the basis for the White Space calculations where the WSD is considered as an additional interferer and a degradation of TV reception (reduction of location probability of 1 %) is accepted. The calculations were done in WP6 [see deliverable D6.2] leading to maximum transmit power for White Space Devices in a given channel and at a given location.

As for DVB-T receivers, for a WSD receiver to be able to receive the signal from the WSD base station a minimum signal-to-noise ratio C/I is required.

In a “clean” environment with only one interferer I is the signal strength from the interferer at the location of the WSD receiver (plus noise). Adding the minimum SNR (i.e. the protection ratio PR) to this I provides the level for 50% location probability (which is the nuisance field):
Nu = I + PR.

In case of a realistic environment with noise, co-channel and adjacent channel interferers the total nuisance field becomes:

$$Nu_{total} = Nu_{noise} \oplus \sum\nolimits_{\oplus} Nu_i$$

From the point of view of a white space receiver all the broadcast signals are interfering signals. Hence all broadcast signals, including the “wanted” DVB-T signal have to be added. As the broadcast signals may become quite high within coverage areas, consequentially the nuisance fields as well can be high at some locations of WSD receivers.

Figure 29 shows on the left hand side the calculated P_{max} for a TVWS device operating in channel 51. On the right hand side the total nuisance field for WSD operation is shown, i.e. all the contributions from the broadcast transmissions. For ease only that channel and one adjacent channel to each side are considered. Although there is no broadcast coverage for ch51 in the area and hence only low co channel interfering signals, there are locations with very strong nuisance fields. These are caused by transmitters in channel 50 operated at Munich Olympiatower, Munich Freimann and Ismaning.

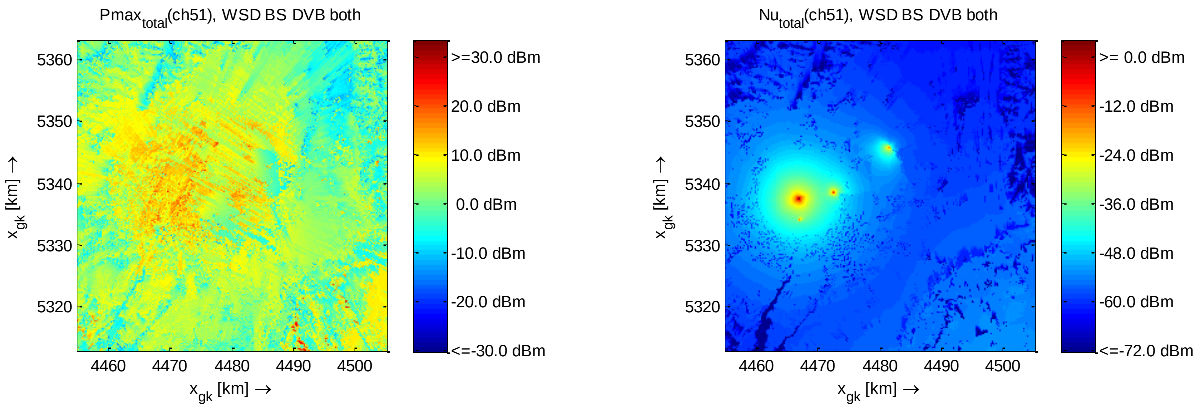

Figure 29: WSD P_{max} and nuisance field map for channel 51

As a consequence the reception conditions may be poor, even if the WSD signal is high. Therefore reception of WSD signals from the base station could be possible only for short distances. To describe the range of successful WSD reception coverage calculations for WSD base station operation are necessary.

In the following the location probability for WSD signal reception around a WS base station is estimated. The amount of pixels where the location probability is above a given threshold, e.g. 70% or 95% describes the coverage area of that WS transmitter.

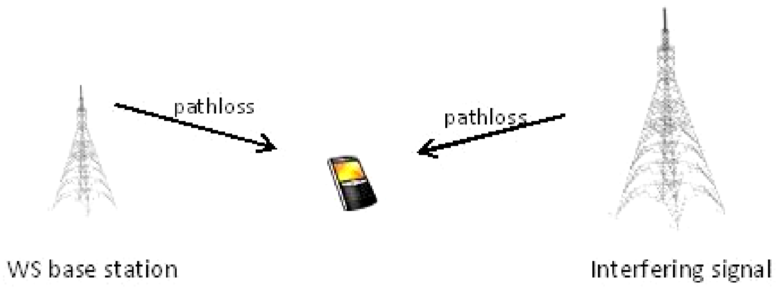

Figure 30: Incumbent signals interfering WSD reception.

The maximum transmit power for a white space base station at a given location and a given channel is determined by COGEU's TVWS database. Assume a white space base station emitting that power from a 10 m mast with a dipole antenna. On its way to the WSD receiver the signal experiences some degradation described by modified Hata propagation model[1] [ERC report 68, Appendix 1 to Annex 2].

Then, at the location of the WSD receiver the wanted signal arrives with strength $P_{r,w}$ which has to be compared to the total nuisance field Nu_{total}. The location probability is then calculated from the Gaussian statistics:

$$q_{wsd} = \frac{1}{2}\left(1 + erf\left(\frac{1}{\sqrt{2}}\frac{P_{r,w} - Nu_{total}}{\sigma_{eff}}\right)\right)$$

With $\sigma_{eff} = \sqrt{\sigma_s^2 + \sigma_u^2}$ where σ_u = 5.5 dB for broadcast signals and σ_s is from modified Hata model.

Other than for TVWS transmit power it is not possible to generate one universal map (for each channel) describing the coverage for any white space base station location. Instead for each chosen location the coverage has to be calculated individually. The following figures show examples for some representative locations (for a better understanding only co channel and one adjacent channel to each side are considered).

(Note: as the resulting operational distances are quite short compared to the cell size (less than 1 km compared to 200 m), to get a better resolution the grid was refined by a factor of ten and the values in between were linear interpolated. There is no additional information contained in the data. It is just to get smoother figures.)

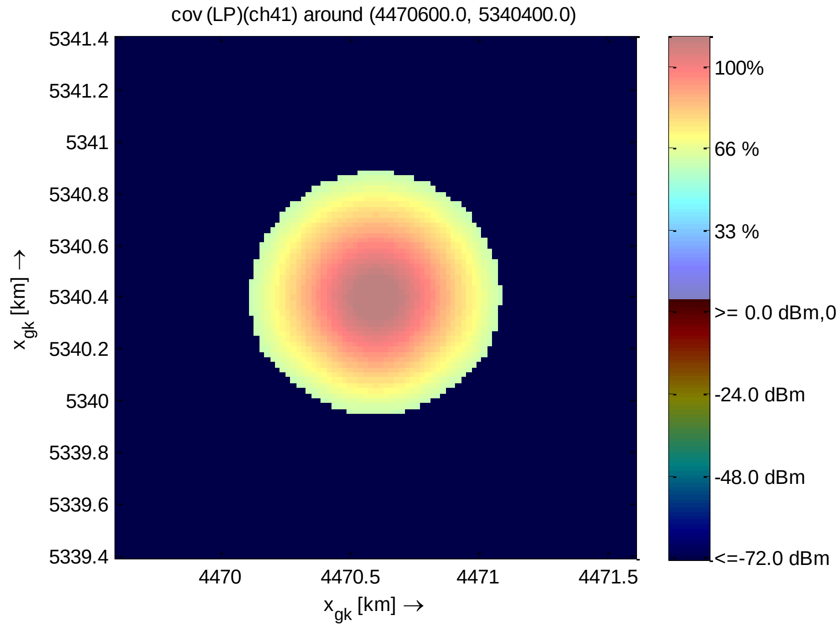

Figure 31: WSD coverage in ch41 at (4470.6,5340.4)GK

Figure 31 shows the calculated coverage at (48.2018,11.6044). The dark colors (in the background) show the nuisance field for that situation. The bright colors in the center show the coverage in the range 50 % (yellow) to 100% (dark red). From this figure it can be seen that the nuisance is more or less

[1] For the white space links considered here only short distances of up to few km are relevant. Hata model is well appropriate

constant (see table below) and hence the locations of equal coverage are represented by circles. The size of the area is chosen such that in a noise limited case the 50% coverage circle would fit perfectly into the square (i.e. touch the border lines). So, due to nuisance the operational distance is only half the distance of the noise limited case. **With P_{wsd} = 18.8 dBm the range is ≈ 450 m.**

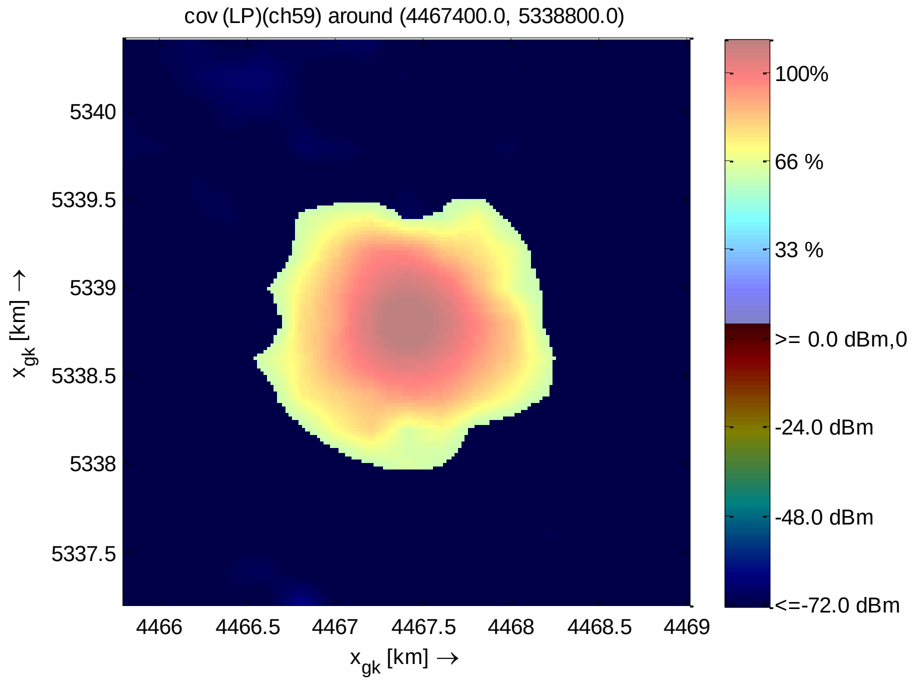

Figure 32: WSD coverage in ch59 at (4467.4,5338.8)GK

In Figure 32 the nuisance is of the same size as for figure 3 but the variation over the area is higher. This variation causes the lines of equal coverage no longer to be circular. Instead they have an irregular shape. For this location a higher transmit power is possible (28.8 dBm) and hence the coverage is further, around 800 m.

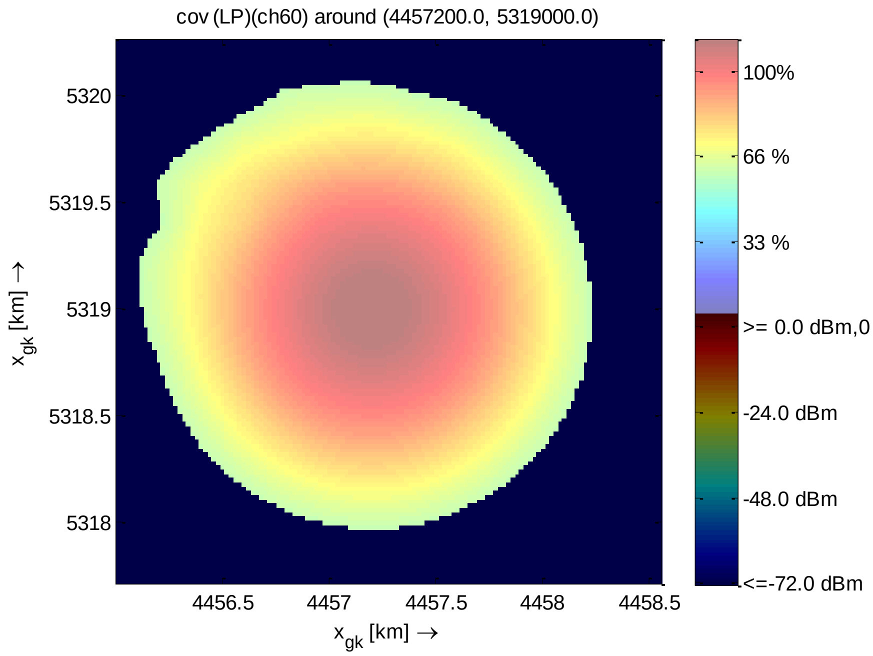

Figure 33: WSD coverage in ch60 at (4457.2,5319.0)GK

Figure 33 is just to show that for the case of high transmit power and low nuisance the coverage approaches the coverage of noise limited case.

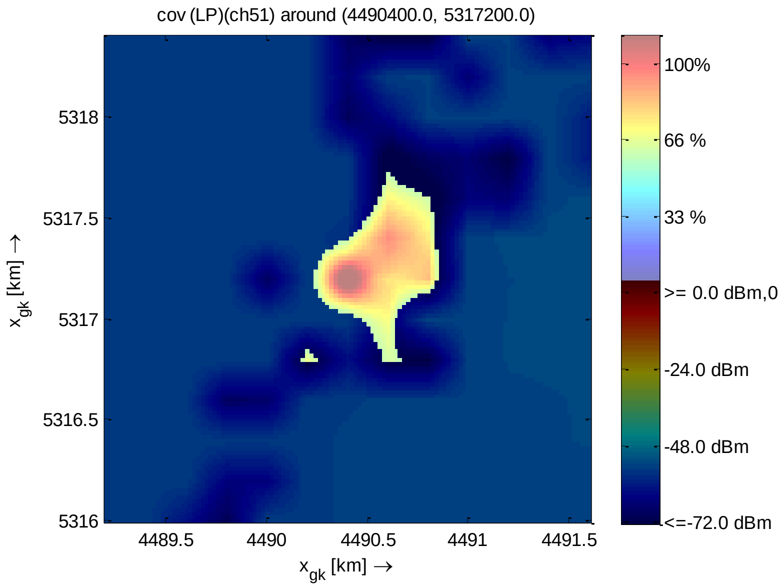

Figure 34: coverage in ch51 at (4490.4,5317.2)GK

For Figure 34 a location was chosen where the nuisance field shows stronger variations with the location. As a consequence the coverage area is no longer convex and isolated coverage areas may evolve. In Table 1 the results of coverage calculations are summarized. To describe the strength and variation of the nuisance over the noise limited coverage area the mean and standard deviation are given as an indicator.

In the cases where the variation is weak (≤ 1 dB) the coverage areas are bounded by circles. If the variation is in the range of 2 dB coverage areas may be flattened or look like potatoes, and if the variation is high (≥ 5 dB) coverage area becomes diffuse. So by checking the behavior of the nuisance around the considered location it is possible to get a rough idea on the coverage area. This could be helpful for COGEU database when assuming as a first approximation concentric circles around the transmitter location.

ch	f [MHz]	Location (Gauss–Krüger coordinate system)	WSD Pmax [dBm]	range [km] (50% LP)	ratio to noise ltd. case [%]	mean(Nu) [dBm]	sig(Nu) [dB]
41	634	(4470,6;5340,4)	18,8	450m circle	50%	-74,9	0,5
41	634	(4487,8;5346,6)	13,6	400m circle	50%	-75,6	0,7
41	634	(4490,6;5317,2)	20,2	600m flattened	50%	-75,4	1,6
43	650	(4494,8;5321,6)	-5,6	<40m	10%	-64,7	0,4
45	666	(4500,4;5317,4)	11,3	50m circle	10%	-60,3	2,1
49	698	(4465,8;5335,4)	12,3	no cov	0	-35,7	2,0
51	714	(4490,4;5317,2)	22,7	diffuse	20%	-58,2	5,7
51	714	(4490,4;5317,0)	22,8	diffuse	20%	-58,0	5,6
55	746	(4469,6;5338,8)	26,6	<40m	<5%	-35,3	4,0
55	746	(4475,8;5319,0)	18,8	100m circle	10%	-55,0	0,3
58	770	(4457,4;5337,8)	18,4	200m potato	20%	-63,5	1,6
59	778	(4467,4;5338,8)	28,8	800m diffuse	<50%	-74,0	2,0
60	786	(4457,2;5319,0)	32,9	1000m circle	60%	-74,4	0,5
60	786	(4466,2;5356,6)	30,3	700m potato	40%	-69,8	2,6

Table 1: Evaluation of coverage calculations for different channels and locations.

7.2 Discussion of operational range of TVWS Base-Station

Having a look at the Munich's COGEU database it can be concluded that in the area of investigation the maximum WSD transmit power is approximately 1 W (30 dBm). The best case concerning interference is the noise limited case (Nu_{noise} = -77 dBm). So for a 50 % probability of reception the path loss is 107 dB. Figure 7 shows the propagation curves for the modified Hata model.

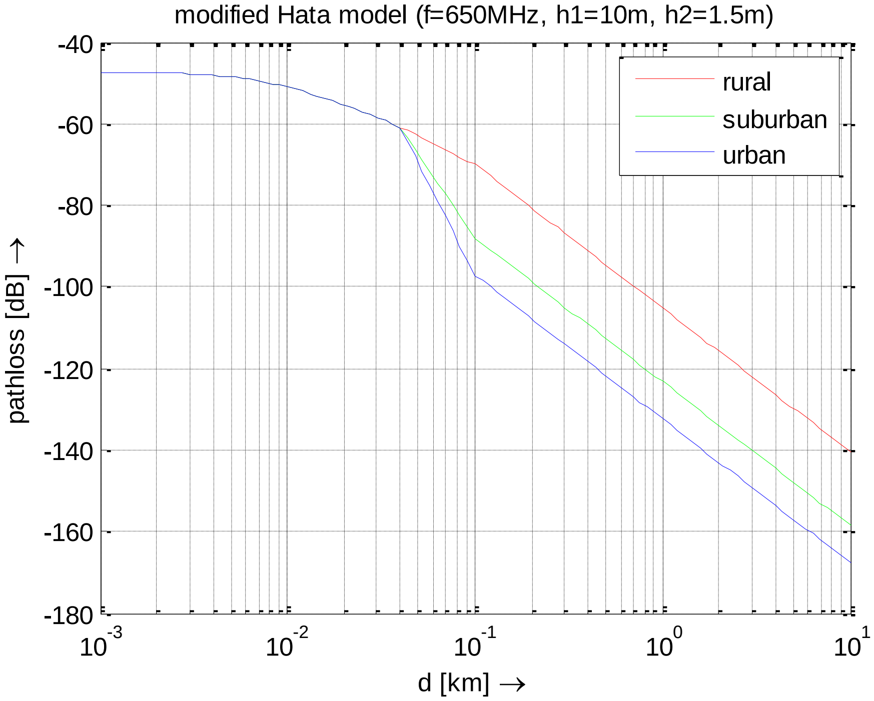

Figure 35: modified Hata model

According to the model the maximum operational ranges become:

Rural scenario:	1.2 km
Suburban scenario:	350 m
Urban scenario:	200 m

Would the maximum transmit power be 10 times higher (10 W, 40 dBm) the operational distances would increase to 2.2 km, 650 m and 360 m (for the favorable noise limited case). Taking into account ubiquitous noise caused by incumbent broadcast systems and having a look at Table 1 the conclusions are:

- In realistic scenarios the operational range for WSD operation is limited to few hundred meters.
- Due to this short distance the consequences for the business models are:
  - For a system using base stations the density of base stations has to be quite high
  - For TVWS systems like extended Wi-Fi or M2M operating on short ranges the found operational distances do not really limit the operation

8 Dynamic radio engine

The Dynamic Radio Engine is a propagation analysis tool based on ray tracing techniques that gets the proposed deployments from players (secondary users) and produces the signal maps for the specific radio environment. It forwards the data to the Coexistence emulator module (Chapter 9) for interference calculations for the specific area with the specified radio environment. Figure 36 the high level interconnection between the modules that are part of the evaluation process.

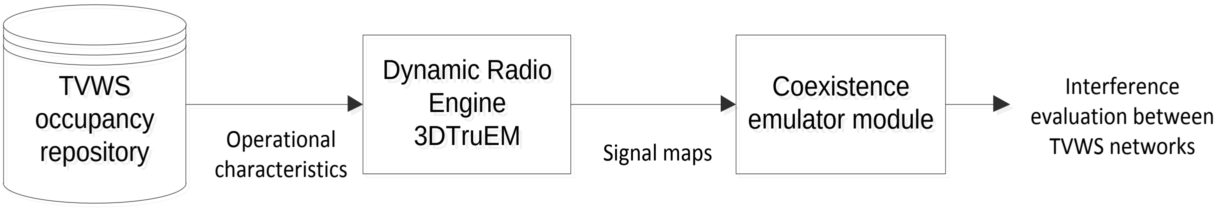

Figure 36: Interference Evaluation Flow.

The Dynamic Radio Engine is based on SIGINT's radio planning engine/tool (3DTruEM) which will take as input the players' radio network configurations/deployments. In this context, the radio network configuration includes the operating characteristics and position of the TVWS base stations, terminals etc. This information is passed to the radio planning tool from the Broker's TVWS repository. The main purpose of the dynamic radio engine is to calculate realistic received signal strength values at any point in the area of interest for any given secondary system base station / terminal / transmitter. These values are then utilized to drive the Coexistence evaluation emulator which will decide if a secondary system causes interference to already licensed secondary systems.

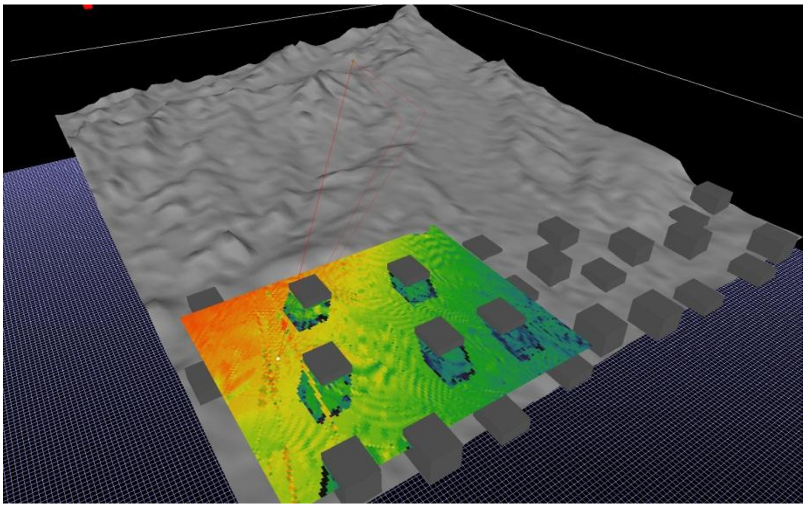

Figure 37: 3DTruEM Dynamic Radio Engine environment.

In order to integrate the COGEU architecture with the Dynamic Radio Engine, a module has been developed inside the 3DTruEM platform to allow communication with the COGEU Broker modules. Figure 38 and Figure 39, shows the interface of the module and the process flow of the module.

The COGEU module has the following functionalities:

- Configure COGEU module interface
- Configure environment variables
- Retrieve information from TVWS repository
- Initiate simulation creation
- Create simulation environment
- Run the simulation
- Store the signal maps for use to the coexistence emulator module

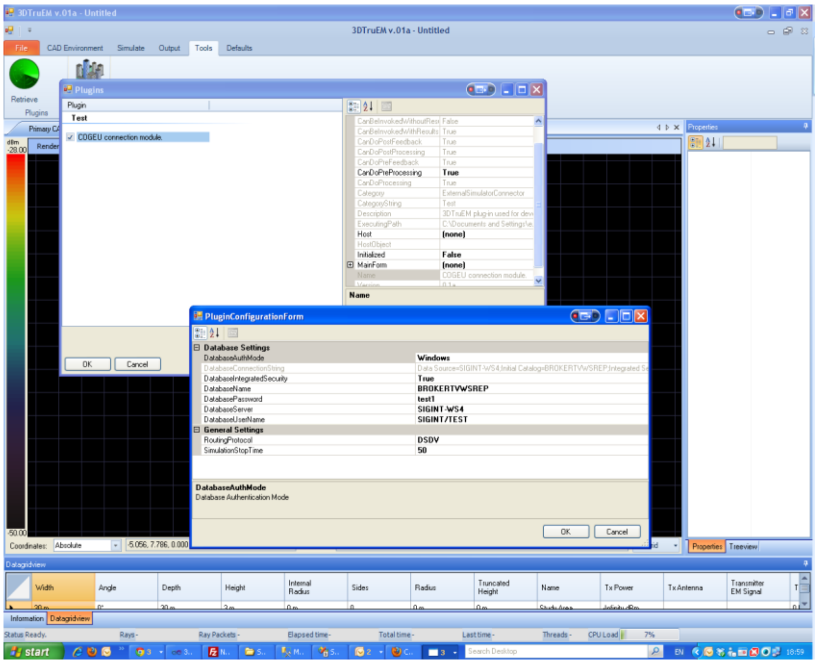

Figure 38: Dynamic Radio Engine COGEU module Interface

The module operates based on the process flow that is presented on Figure 39. Using the developed module the demonstrator integrates the TVWS repository, Dynamic Radio Engine and the Coexistence emulator module.

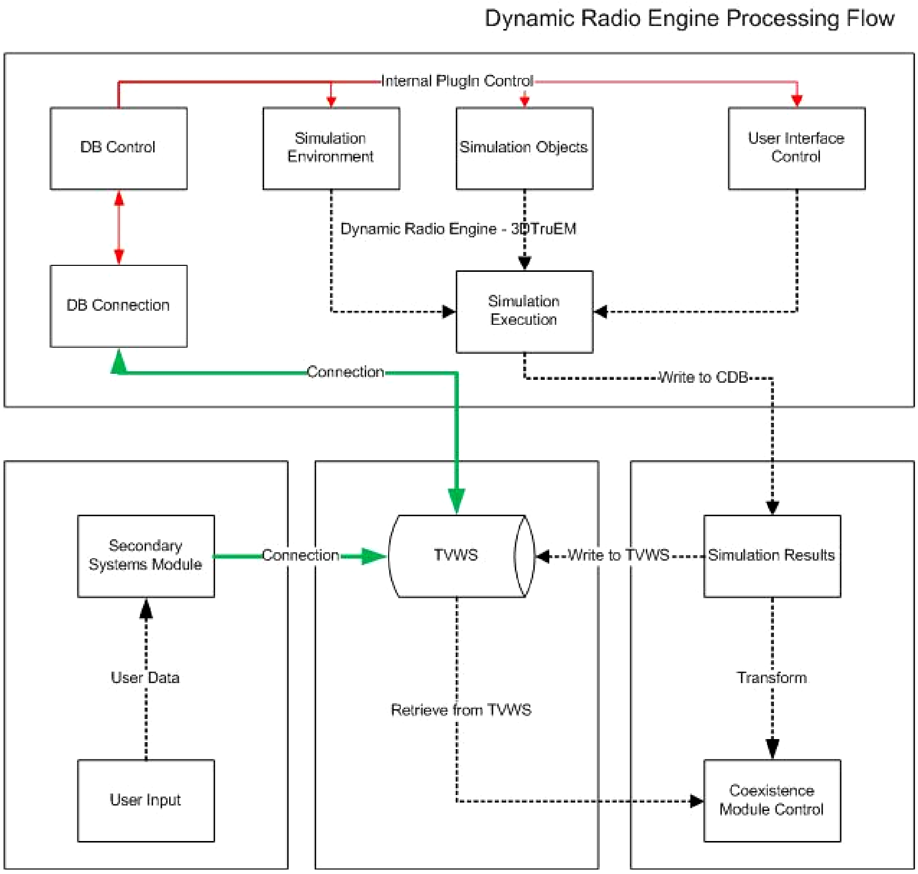

Figure 39: Dynamic Radio Engine Flow

9 Coexistence emulator module

The Dynamic Coexistence test bed is completely software controlled. Specialized software drivers have been developed in order to allow the communication with the hardware part of the test bed. Using the driver software as base, a framework has been developed to effectively control the entire system.

This framework allows the configuration and parameterization of the hardware units towards the creation of the network environment and measurement of the caused interference and coexistence consequences in the current setup, with the current system.

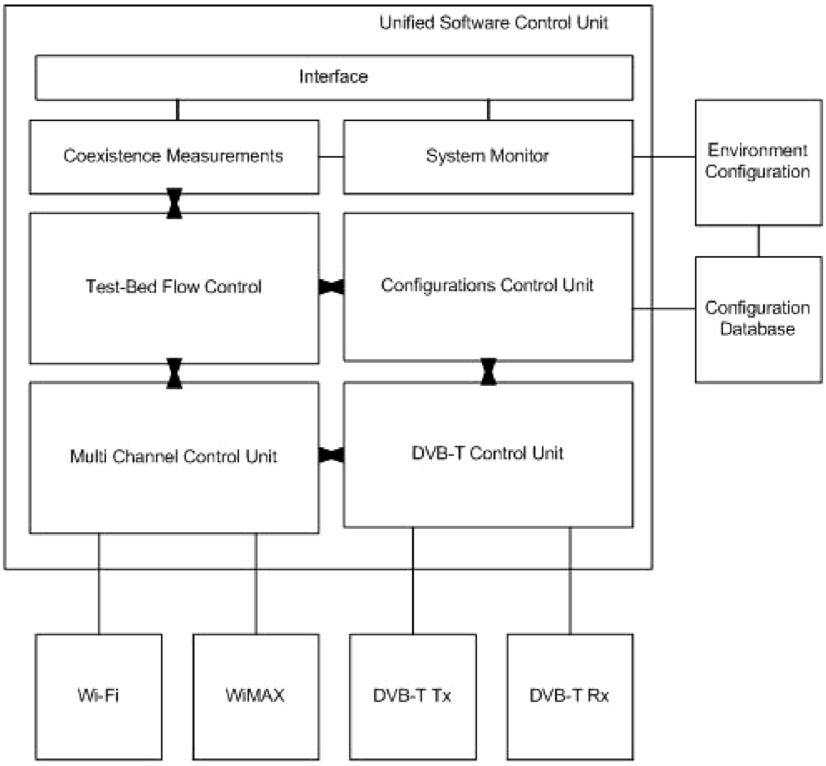

Figure 40: Unified Software Unit

Figure 40, identifies the components that consist of the main functionalities of the dynamic coexistence test bed framework (DYCOT Framework). The Software unit is designed to control and allow the expandability of the platform without any additional major development. The DYCOT framework allows the test-bed to be dynamic, expandable and modular.

Another important aspect of the software unit is the fact that is able to facilitate the testing of various hardware components as interferers, and as receivers of different technologies. These tests will be against each other based on the same software and measurements allowing for direct performance and characteristics comparison. Furthermore, different calculation algorithms can be tested and applied in the step where the interference is calculated since is an independent process inside the Unified Software Control Unit. Figure 41 demonstrates the Coexistence emulator interface which can operate autonomously or using the signal maps produced by the Dynamic Radio Engine.

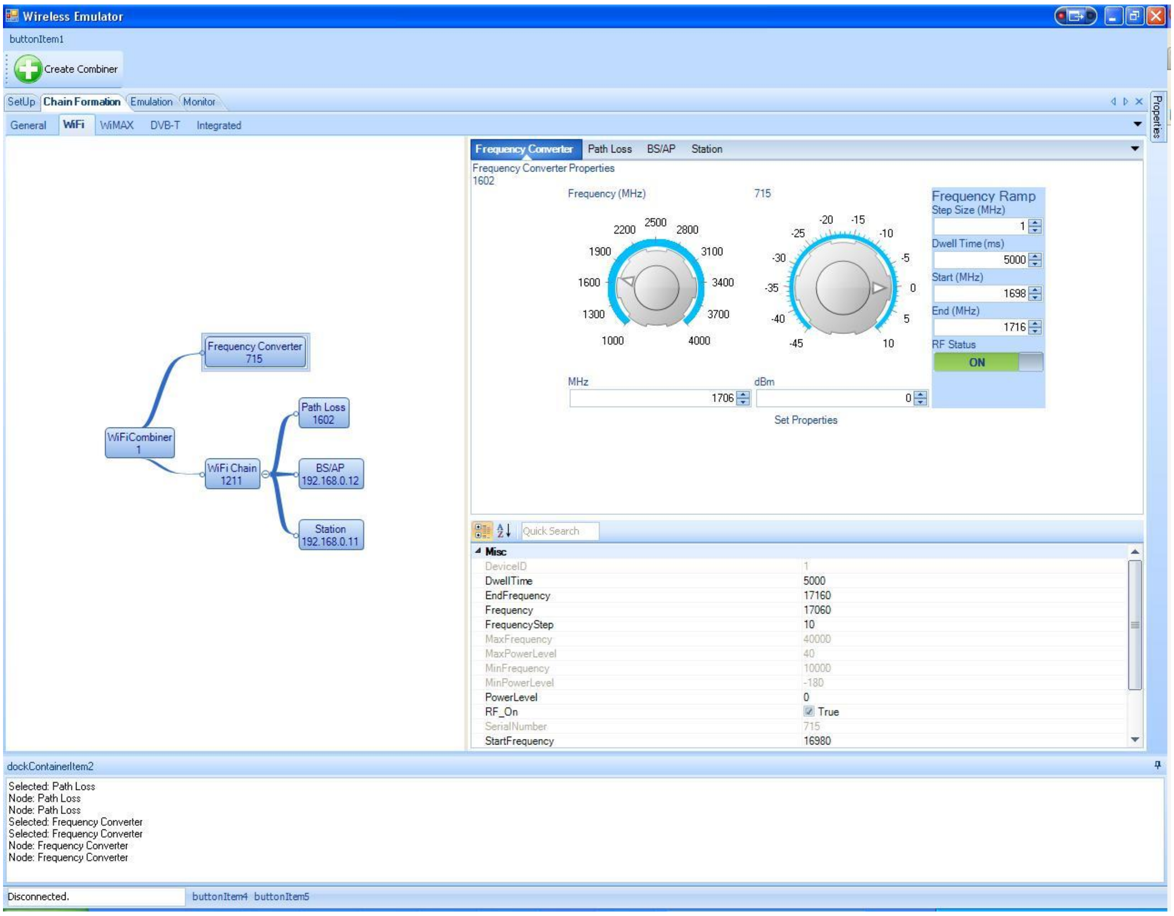

Figure 41: Broker Coexistence Emulator Interface

9.1 Dynamic Coexistence Test-bed Prototype

Based on the description provided before, an initial prototype test bed has been developed in WP4 and is reported in D4.3. As can be shown from Figure 42 and Figure 43, the system has been setup in order to test and resolve possible integration issues. Moreover Initial test has been taken place, proving that the platform works and that the development of the tool will be adding invaluable novelty and information under the COGEU scope.

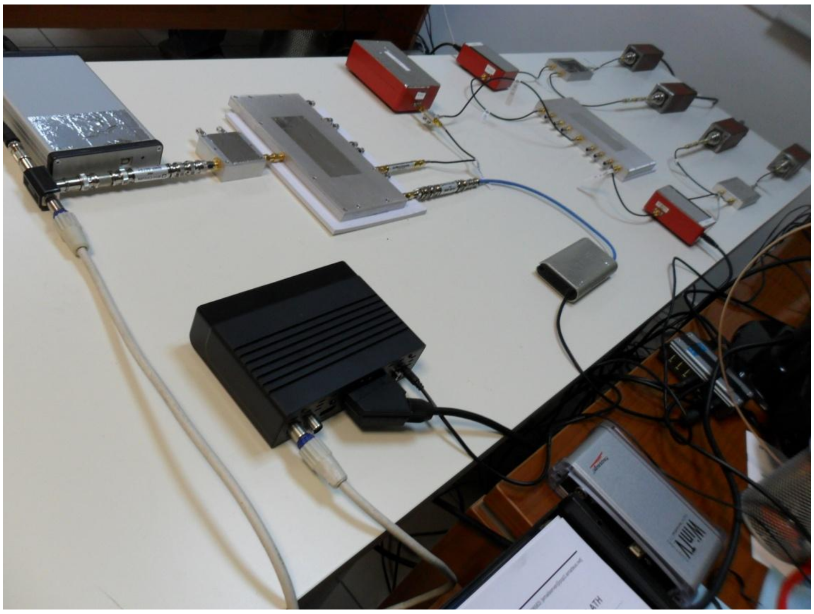

Figure 42: Coexistence emulator prototype view 1.

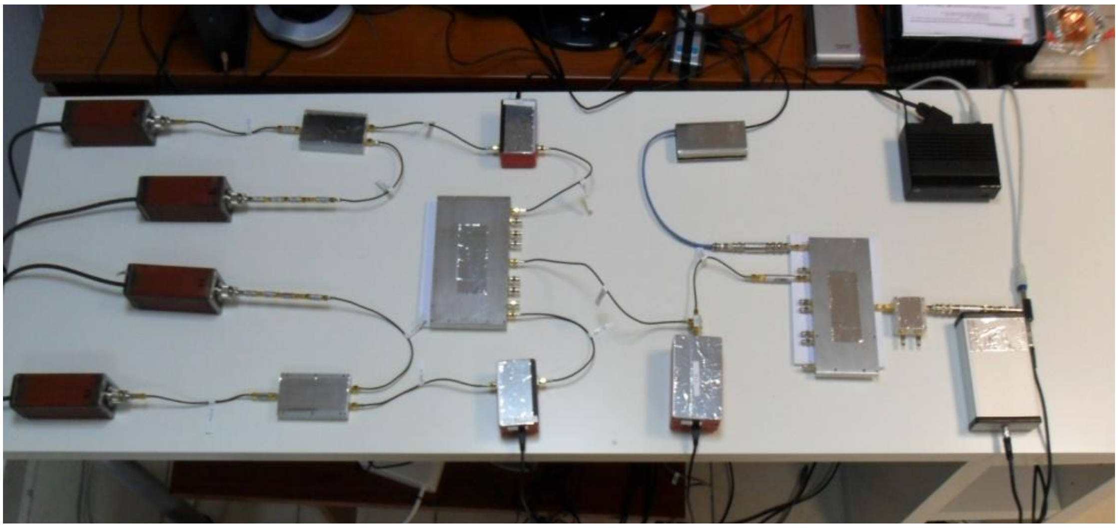

Figure 43: Coexistence emulator prototype view 2.

For WP7 and T 7.2 an adaptation of the WP4 emulator has been designed and builds in order to take into account the interference between secondary users since in the scope of the COGEU Broker all primary systems are protected through Geo-location database

9.2 Operation Process

In Figure 44, the operation process of the coexistence emulator module is described. The On-demand TVWS tool provides the input. The input is a new secondary system and its operation details including location. This information is stored in the TVWS repository which also contains the current active systems that are possible to be affected by the new deployment. The new system with the affected active systems is then transferred through a purposed build 3DTruEM module to the simulator.

The results of the simulations and more specifically signal maps are forwarded to the coexistence module that emulates the signals in each location pixel and studies the interference between the systems. The results of this process are transferred to the TVWS repository and are being used by the TVWS allocation process as an exclusion criterion. After the TVWS allocation process decides if and when a secondary system should operate the transceiver is informed to operate in these parameters.

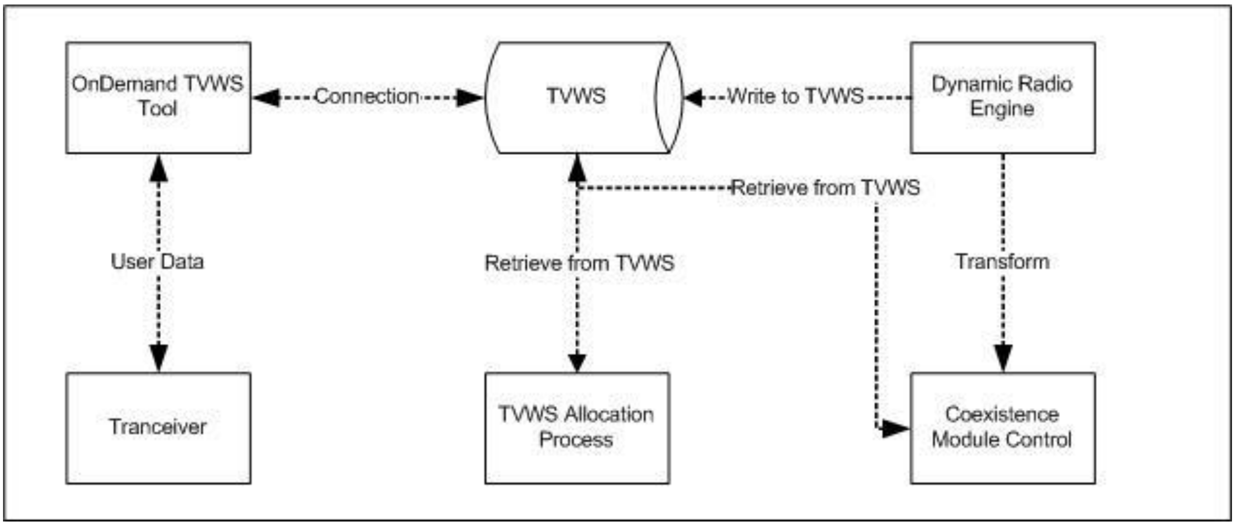

Figure 44: Operation process of the coexistence emulator module.

10 Integration of the dynamic TVWS allocation mechanism

This Chapter describes the integration of the TVWS allocation mechanism developed in WP6 in the COGEU demonstrator. Figure 45 presents the overall COGEU architecture with the Dynamic TVWS allocation module.

TVWS allocation, which is orchestrated by Spectrum Broker, is formulated as an optimization problem from the technical point of view (matching problem with interference constrains) and as an optimization problem from an economic point of view (maximization of COGEU broker's profit). For Demonstrator purposes, the allocation mechanism is implemented by exploiting Backtracking algorithm, which was reported in D6.1. The objective is to match spectrum supply from the TVWS Geo-location database and spectrum demand from secondary systems requests.

Figure 46 presents the overall allocation process of the spectrum broker, while the allocation mechanism based on the Backtracking is implemented when the Broker operates in **Merchant mode.** This merchant mechanism is applied in cases, where spectrum demand is lower than spectrum supply under a fixed-price policy, in the overall allocation process adopted in COGEU broker. **The allocation mechanism implementation based on backtracking uses information from the database to determine the TVWS bands and power at which a secondary user (player) should be allowed to operate to avoid spectrum fragmentation, optimize QoS and prevent monopolization of TVWS access.**

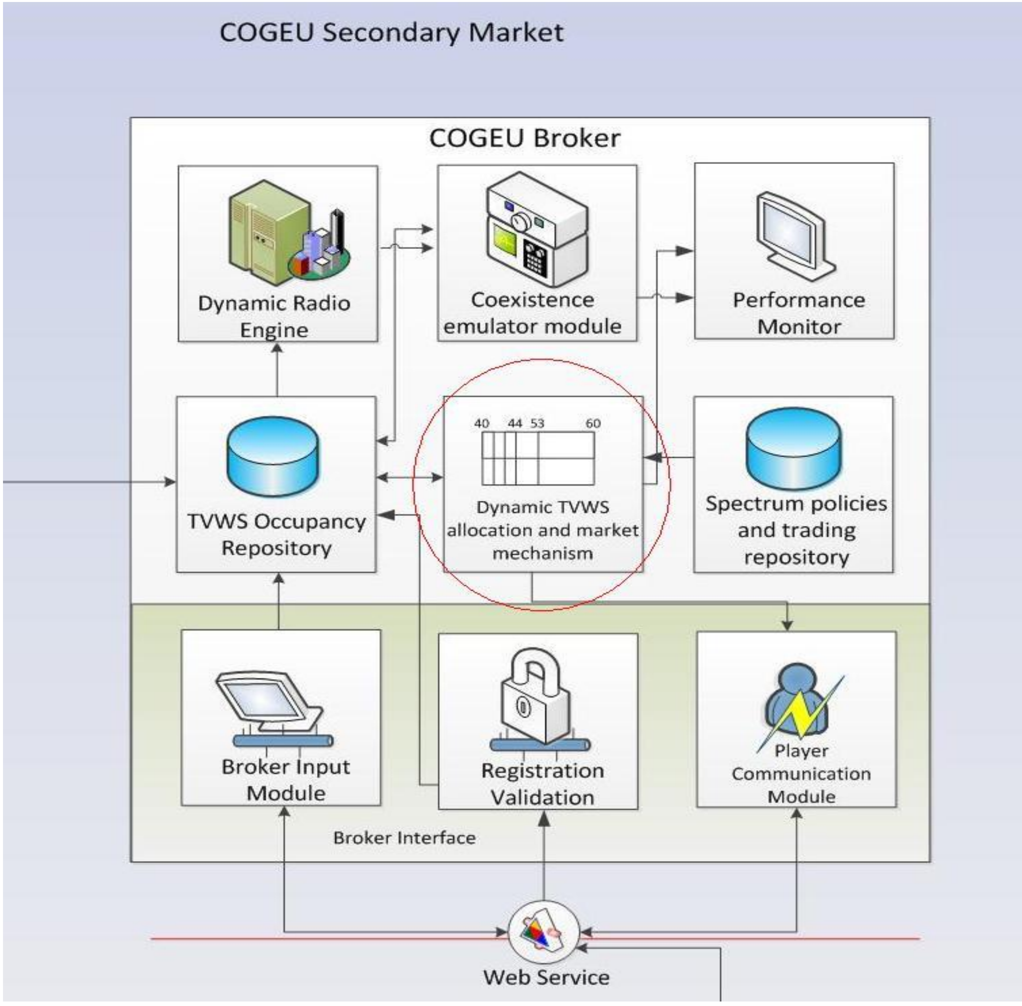

Figure 45: Demonstrator architecture and integration of Dynamic TVWS allocation & market mechanism.

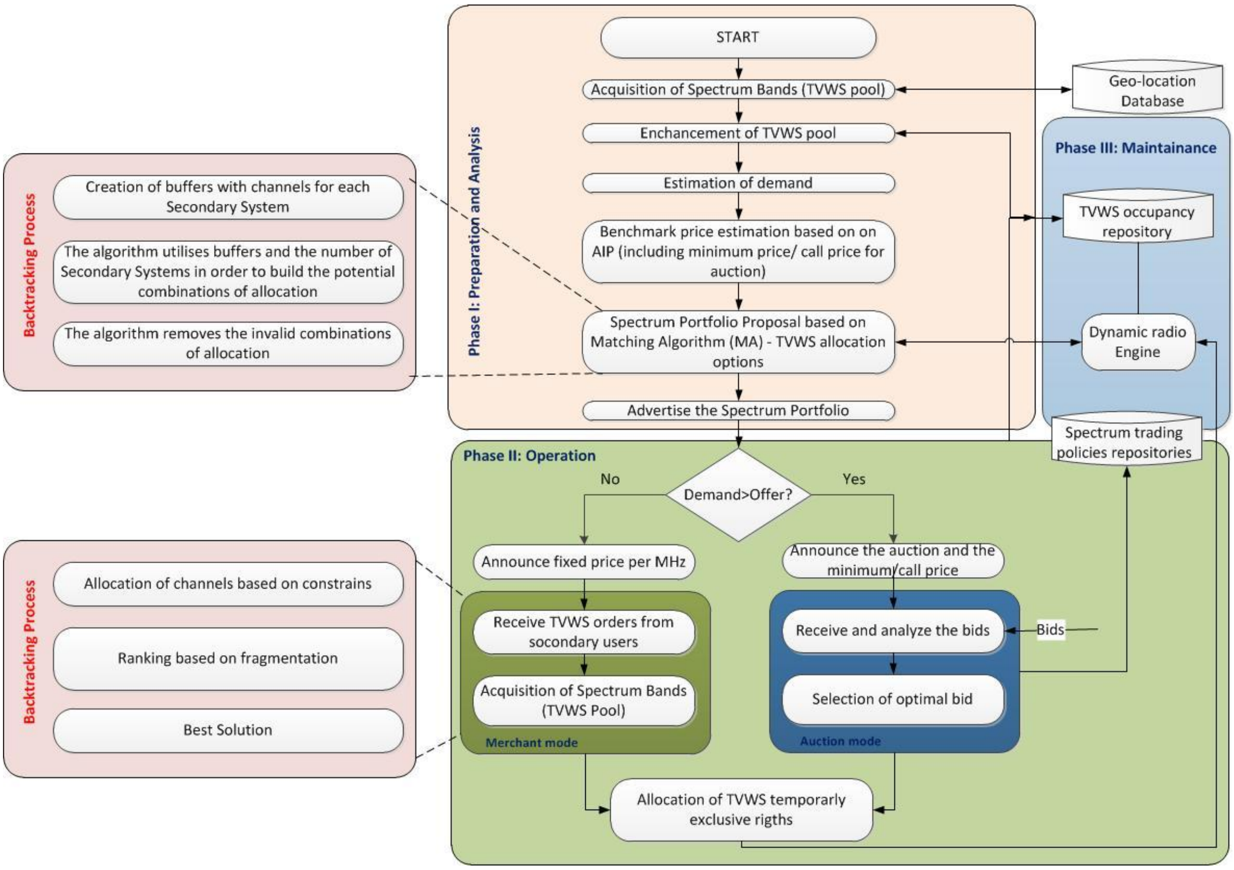

Figure 46: Backtracking integration in Spectrum Broker process

More specifically, there are two important phases on the Broker process. Phase I starts with the external database providing the TVWS availability information in a specific geographic area. Then the TVWS pool is updated with information provided by the internal TVWS repository. Backtracking process in Phase I takes into account the TVWS pool and the demand (system requirements) to create a spectrum portfolio, i.e. all possible matching solutions between secondary systems and the available TVWS. More specifically, in this process, a number of combinations of the available TVWS spectrum allocation to the secondary systems is provided. Some of them are not valid by taking into account the system requirements. Therefore, the next step is responsible to discard these combinations. At this point, it has to be noted that backtracking creates spectrum portfolio utilizing two buffers with possible solutions. The first buffer is named strict buffer and contains all possible solutions that satisfy all constraints. Since it is possible, not all constraints to be satisfied, backtracking creates a second buffer, namely relax buffer, which includes all solutions that do not satisfy all constraints. In every case, backtracking, chooses, one of two buffers to be considered as the spectrum portfolio. In the case where there is one or more strict solutions, the spectrum portfolio is considered the strict buffer.

In Phase II and in case, where demand of TVWS is lower than offer, backtracking algorithm is operating in order to allocate TVWS avoiding fragmentation of spectrum, respect priority policies and guarantee QoS, as well as to maximize spectrum utilization. More specifically, backtracking process provides all possible solutions, either complete or partial, for service allocation on the available spectrum. For the case of partial ones, all solutions are ranked based on services priority and the solution that includes the highest priority services is selected. In case, there are multiple complete solutions, these are further analyzed and the one that provides the least fragmentation in the spectrum is selected. The available solutions are ranked based on the size of contiguous remaining white-spaces and favor those that provide for tighter allocation of services, in order to allow for additional services in future deployments. Ranking is determined according to how much fragmented is the spectrum after the allocation process. Finally, the ranking module provides the best solution regarding the frequency allocation.

10.1 Requirements for integration of the TVWS allocation mechanism

Towards integrating the radio resource management algorithm into the spectrum broker of COGEU demonstrator, a number of input data is required in order to initiate the process. A short description of this information is listed below.

- **Secondary User Demand**
    - Number of required TVWS. This input determines the request of secondary systems regarding the desired bandwidth. The minimum request value for bandwidth is 1MHz, while each TVWS consist of 8MHz. The 8MHz bandwidth can be assigned to more than one secondary system, if it is allowed by the transmission/technical characteristics. The requested bandwidth must be un-fragmented in order to operate a secondary system, apart from cases, such as LTE FDD that requires a minimum cap/gap between the uplink and downlink channel.
    - Transmission power. The transmission power of the secondary system has to respect the maximum allowable power of the TVWS.
    - Duration of TVWS exploitation. This input derives also from secondary systems and determines the duration (i.e. months, days, hours, time periods) of TVWS usage.

- **TVWS Availability (Geo-location Database)**
    - Number of available TVWS. This input data derives from the Geo-location database through the TVWS occupancy repository of the spectrum broker. This information is required by the algorithm in order to define the availability of the spectrum, as well as the type of the spectrum, which is marked as fragmented or un-fragmented.
    - Max. allowable transmission power of each available TVWS. This information determines the maximum power of the secondary systems in order to operate, without causing interference to the incumbent systems.

- **Spectrum policies (Spectrum policy and trading repository)**
    - Spectrum caps/gaps.
    - Priority level/QoS. Priority level is defined as a factor that determines which secondary system has to be accommodated in case of an emergence situation or in case of a best effort contract between the users and the operator.

The most significant parameter that determines the allocation results taking into account the above-mentioned input data is the spectrum fragmentation. This radio resource management algorithm performs the allocation solution according to the fragmentation factor that defines the optimal spectrum usage over time, by avoiding TVWS division into discrete unusable fragments.

Finally, the output of this process, which is the spectrum allocation solution, is sendt to the performance monitor, as well as to the secondary systems. Also, the TVWS occupancy repository is updated in order to keep a record of the updated spectrum.

10.2 Implementation of TVWS allocation mechanism based on Backtracking

The TVWS allocation mechanism algorithm was developed in visual basic programming language, exploiting .NET framework, as it is depicted in **Error! Reference source not found.**. This sub-section elaborates on a short description of code classes implemented in WP7.

- <u>Backtracking.vb</u>: This file includes all functions in order to evaluate the optimal allocation solution. It check fragmentation, priority, spectrum caps/gaps if necessary, evaluates the allocation and calculates utilization, fragmentation and bandwidth exploited.

- <u>InitializeData.vb</u>: This file initializes the variables of the algorithm and checks if the allocation solutions/combinations are valid based on the constraints set or if are invalid.

- <u>Main.vb</u>: This file keeps the input data and values in order to initiate the algorithm.

- <u>Myproblem.vb</u>: This function calls inputs from other classes (i.e. backtracking.vb, main.vb, initializeData.vb), in order to solve the problem. Then it prints the results.

- <u>RoundTimeSolution.vb</u> and <u>ShowDialog.vd</u>: The usage of these files are optional for the demonstrator and created for integration purposes.
- <u>Start.vb</u>: This file initiates the main project.

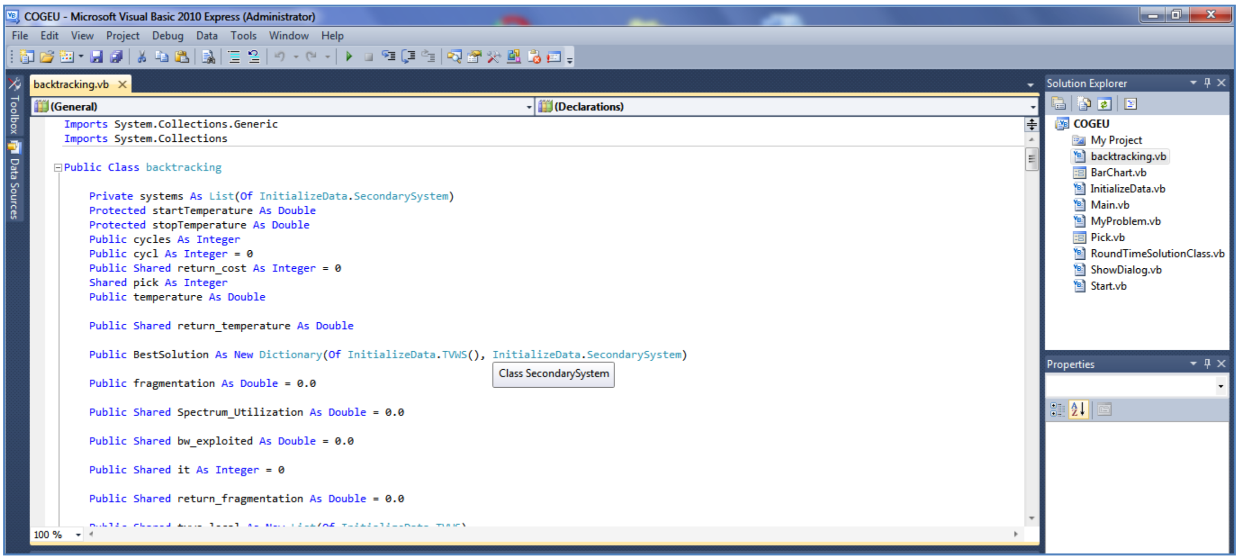

Figure 47: Implementation of RRM algorithm based on Backtracking

11 TVWS transceiver integration

As described in D5.3, the Master-Slave TVWS transceiver will take the form of a two host solution. The two host solution arises primarily for two reasons. Firstly, the sensing module uses different software radio option (Labview™) to the shaping and rendezvous modules which use IRIS. All modules rely on the Ettus USRP hardware (Figure 48).

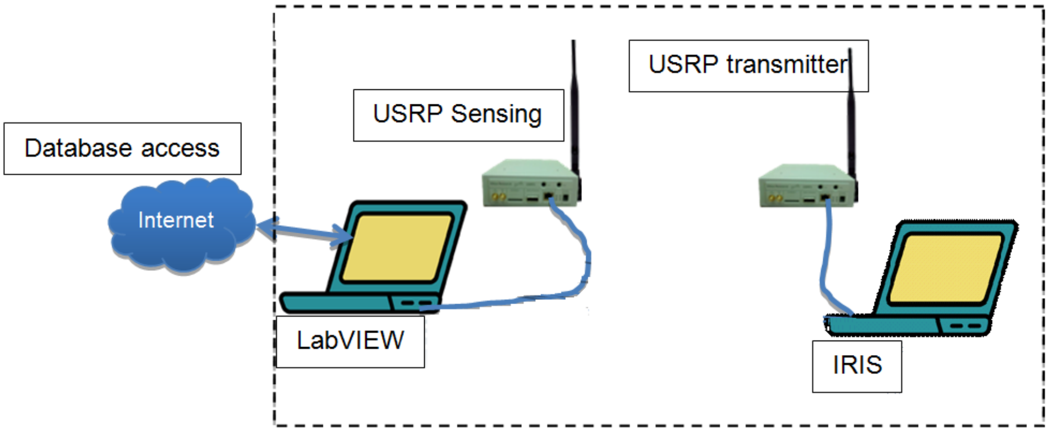

Figure 48: COGEU TVWS transceiver.

The TVWS transceiver was demonstrated at the 2nd COGEU Review in Brussels in March 2012. A number of issues were identified that required further modification. A workshop was held at IT (Aveiro, Portuga) in May 2012 to address these issues.

The IRIS-based element of the transceiver now consists of a fully integrated OFDM modulator and demodulator component, incorporating the rendezvous and shaping modules. The Iris elements are not manipulated manually at runtime, rather they react to changes triggered by information from external sources, e.g. the sensing component will indicate the presence of a PMSE device for which a notch must be created in the TVWS OFDM transmission or the geo-location database will indicate which channels the radio can transmit on.

The COGEU TVWS transceiver combines an autonomous sensing platform for PMSEs, a DVB-T geo-location database and a PMSE spectrum-booking platform which sole purpose is to address the protection of primary users of the spectrum. Figure 49 shows the three main structural components of the testbed and their interconnections. This section describes main features of the testbed sensing module, and the interaction with DVB-T and PMSE booking databases.

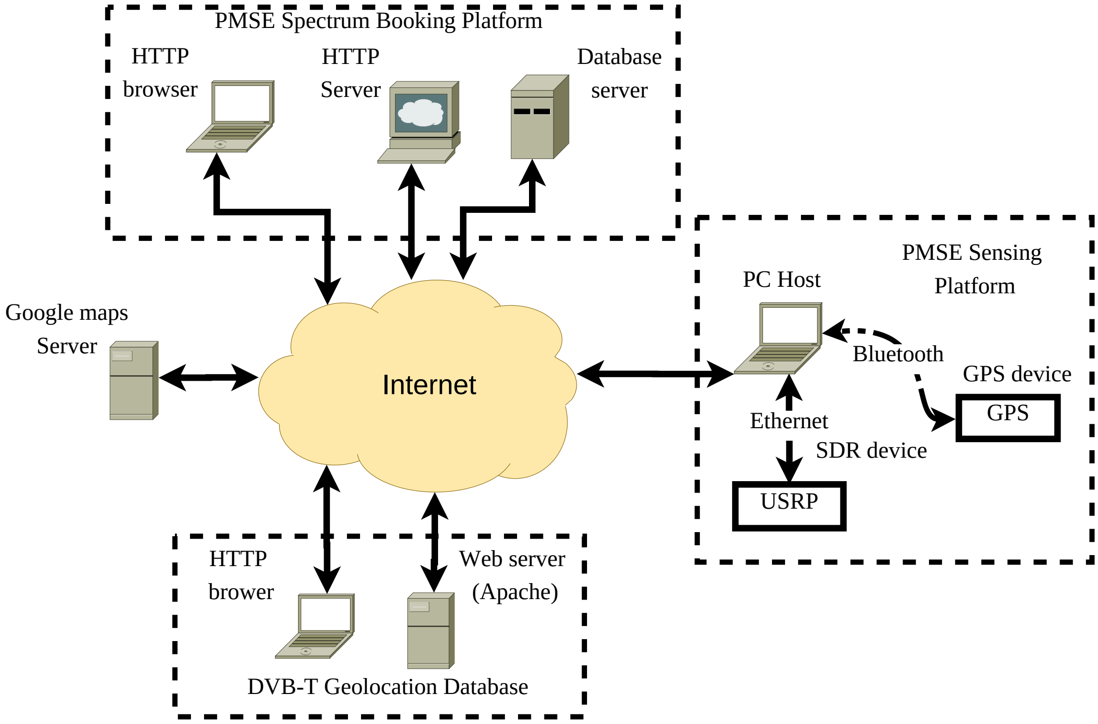

Figure 49: Platform architecture, combining spectrum sensing, DVB-T geo-location database and PMSE booking platform.

11.1 COGEU transceiver hardware

The sensing platform relies on USRP2 software-defined radios [2], 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.

Figure 50: 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.

11.2 Integration of sensing with database access

Before sensing is started, the platform retrieves TV channel occupancy from the DVB-T geo-location database, and also channels reserved for WMs (Wireless Microphones) from the PMSE booking database, following the diagram of Figure 51 . Following this strategy, local sensing is performed only on a limited number of potentially vacant TV channels.

Compared to sensing only, a combination of sensing and geo-location database access has the advantage of reducing the risk of WSDs interference with PMSE and DVB-T. For a sensing only approach, the Hidden Terminal Problem (HTP) could result in underestimation of the primary signal power on 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 [3]. 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 [4].

Software Platform

We use Labview, from National Instruments, to program the software application of the sensing module and to 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 compared with other software solutions. This particular combination of hardware and software was chosen due to the recent development of USRP2 drivers for Labview [5]. Covariance Absolute Value (CAV) [6], Blindly Combined Energy Detection (BCED) [7] and the simple Energy Detector (ED) 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 Google maps server, TVWS and PMSE databases.

User Interface

The GUI is organized in three functional pages that allow the user to configure the device, setup parameters and view the results. Figure 52 shows the set up interface. After geo-location coordinates are acquired, a query is sent to both DVB-T geo-location database and 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 signalized in an indicators bar, as green checked symbol. Red-crosses or microphone symbols means that the channel is occupied with DVB-T or PMSE signals, respectively.

Figure 53 shows the sensing module in run mode. A PMSE signals with 200 KHz bandwidth is detected in channel 48. This channel that was initial indicated by the geo-location database as vacant, is actually occupied because the presence of a no-registered Wireless Microphone device. The COGEU local sensing algorithm was able to detect the WM signal and remove channel 48 from the list of available channels in this area.

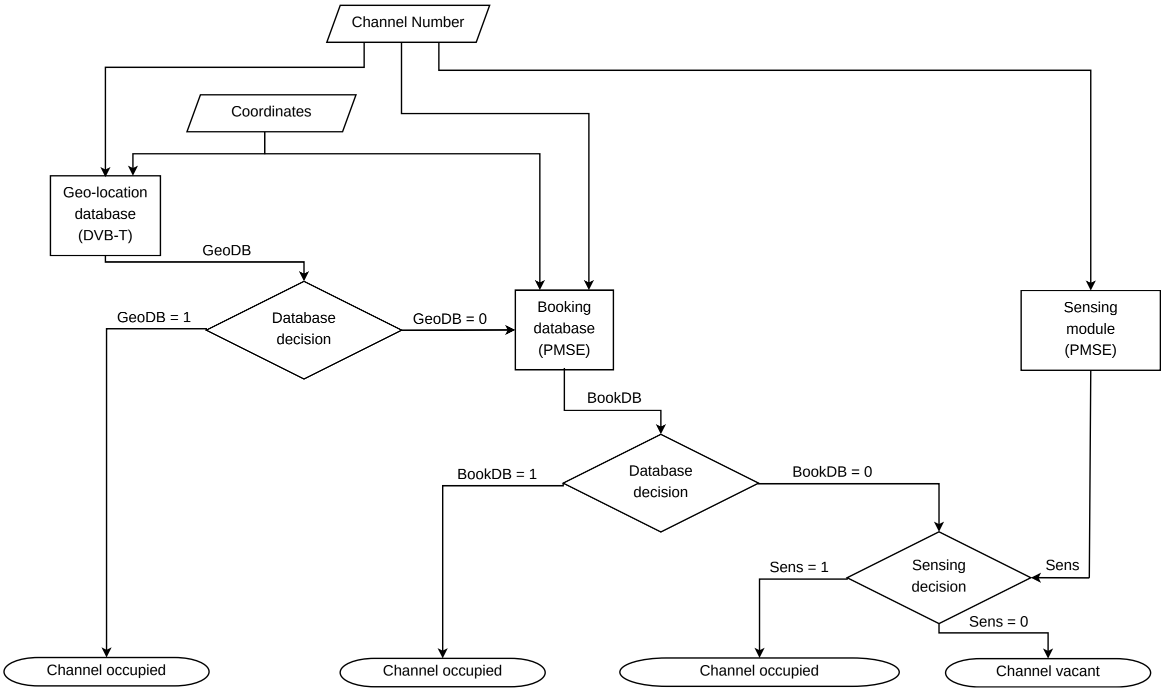

Figure 51: Diagram of the interaction between the geo-location database (DVB-T and PMSE) and the sensing module at the COGEU transceiver.

Figure 52: Setup interface for the COGEU sensing module: sensing time, threshold levels and the sensing algorithm are configuration parameters.

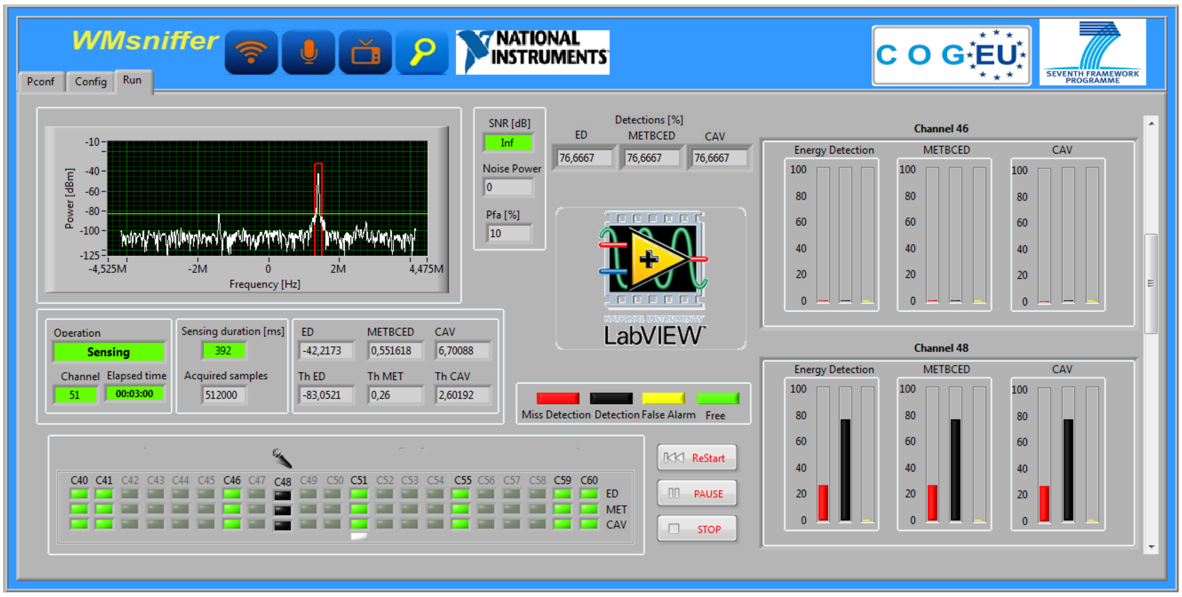

Figure 53: The sensing module in run mode. A PMSE signals with 200 KHz bandwidth is detected in channel 48.

12 Conclusions

The development and integration work that was reported in this deliverable aims to showcase the COGEU concept of dynamic spectrum trading of TVWS. The main conclusions are listed below.

- Several COGEU geo-location database web-services were developed and integrated in an online public available framework which includes: Show White Spaces, Block White Spaces, PMSE booking, TVWS repository, Spectrum Broker and the Policies repository:
  - Show White Spaces - show TVWS maps, i.e., the maximum allowed EIRP in dBm with 200m resolution for the Munich area and the Slovakian areas of Bratislava and Banska Bystrica. Several intuitive formats to show white spaces maps are available. The protection criteria used to compute the TVWS maps are available for download;
  - Block White Spaces - support for Regulatory enforcement. A Regulatory Authority can easily block\unblock TV channels from the TVWS database for a specific pixel area.
  - PMSE Booking - is a web-based booking platform for Programme Making and Special Events systems (PMSE- professional Wireless Microphones) in time, spatial and frequency domain. The channels reserved for PMSEs are automatically removed from the COGEU database, an exclusion area ensures protection of PMSEs;
  - TVWS repository - contains the actual state of the TVWS channels and advertises the TVWS portfolio available for trading. The repository is divided in 3 periods. During the day periods, specific sites are on the market, in these sites, existing Mobile Network Operators can buy TVWS to operate extra LTE-downlink carriers over TVWS. An auction-based approach is used for the day period (COGEU Broker).
  - Spectrum Broker- online tool that runs a secondary market of TVWS based on an English auction, after registration, spectrum seekers, such as Mobile Network Operators, can submit bids and buy temporally licenses for exclusive use of TVWS in a local area (e.g. to provide extra capacity in a LTE cell). Multiple local-auctions are running through this micro-trading platform.
  - Policies repository - is aimed to allow the policies to be part of the system and also enable different entities of the COGEU demonstrator to use policies as behavior and operational guidelines. The policy repository holds policies that indicate to spectrum buyers the rules that are in operation in the market. In COGEU spectrum trading framework three policies are implemented: spectrum caps, spectrum fragmentation limitation and one regarding spectrum interruption under a licensed shared access regime.

- COGEU has developed a framework for sharing the TVWS spectrum which is very much in line with the emerging concept Licensed Shared Access (LSA). This licensing paradigm envisages the kind of mixed use licensed access to spectrum which has primarily been used, heretofore, by an incumbent service. Specifically, modifications to the standard license format are required to address the nature of the delegation of licensing authority to the COGEU Broker, to address the concept of LSA and to allow for the use of electronic communication techniques between the Broker and the licensees. The detailed specification of COGEU license terms can be downloaded from the online COGEU Broker tool.

- The COGEU TVWS transceiver that combines autonomous sensing of no registered PMSEs, with geo-location database access and spectrum shaping was fully integrated in the COGEU demonstrator architecture.

- When a request is made by a secondary user, an evaluation process is taking place that the current request will not cause harmful interference to the already allocated secondary systems operating over TVWS. This is important, since in COGEU model the Broker has to guarantee temporally exclusive rights for TVWS usage (clean spectrum). The coexistence evaluation is performed by the Dynamic radio Engine and the Coexistence emulator module (developed in WP4). The Dynamic Radio Engine which is a propagation analysis tool based on ray tracing technique that gets the proposed deployments from secondary users and produces the signal maps for interference calculations was integrated in the COGEU demonstrator.

- The TVWS allocation algorithm developed in WP6 was integrated in the COGEU demonstrator. The algorithm matches spectrum supply from the TVWS geo-location database with spectrum demand from secondary systems requests in a Merchant mechanism, where the Spectrum broker directly charge secondary spectrum users based on fixed or negotiated fees. This Merchant mechanism is applied in cases, where spectrum demand is lower than spectrum supply.

- So far for TVWS investigations the maximum WSD transmit power was the prominent feature in valuating white spaces. However as WSD have to cope with interfering signals caused by DVB incumbent systems, the negative effect of reducing the operational distance of TVWS links was considered in this deliverable. Taking into account ubiquitous noise caused by incumbent broadcast systems the operational range for WSD operation is limited to few hundred meters. For the case of 1 W transmitted power in Munich's area and according to the modified Hata model the maximum operational ranges become: Rural scenario: 1.2 km ; Suburban scenario:350 m; Urban scenario: 200 m.

In the final WP7 deliverable (D7.3) the outdoor tests and trials using TV band spectrum in Munich area and Slovakian areas of Bratislava and Banska Bystrica will demonstrate and validate the COGEU concept and main assumptions.

13 References

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14 List of Figures

15 List of Abbreviations

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
CEPT	Conference of European Postal & Telecommunications
CR	Cognitive Radio
DVB-T	Digital Video Broadcasting - Terrestrial
DTV	Digital Television
ETSI	European Telecommunication Standards Institute
EU	European Union
FCC	Federal Communications Commission
IEEE	The Institute of Electrical and Electronics Engineers
ICT	Information and Communications Technologies
ISM	Industrial Scientific and Medical (band)
ITU	International Telecommunication Union
LAN	Local Area Network
LTE	Long Term Evolution
MAC	Medium Access Control
MIMO	Multiple-Input Multiple-Output
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out-of-band
PAPR	Peak to Average Power Ratio
PMSE	Programme Making and Special Events
QoS	Quality of Service
R&D	Research and Development
RF	Radio Frequency
RRM	Radio Resource Management
SDR	Software Defined Radio
TV	Television
TVWS	TV White Spaces
UHF	Ultra High Frequency
US	Unites States of America
USRP	Universal Software Radio Peripheral
VHF	Very High Frequency
WiMAX	Worldwide Interoperability for Microwave Access
WiFi	IEEE 802.11
WLAN	Wireless Local Area Network
WP	Work Package
WSD	White Space Device