COGEU

FP7 ICT-2009.1.1

COgnitive radio systems for efficient sharing of TV white spaces

in EUropean context

COGEU D3.2

Initial Architecture for TVWS Spectrum Sharing Systems

Contractual Date of Delivery to the CEC: December 2010

Actual Date of Delivery to the CEC: 17th January, 2011

Author(s): Damien Lavaux (TC), Paulo Marques (IT), Joseph Mwangoka (IT), Álvaro Gomes (PTI), Helder Alves (PTI), Carlos Silva (PTI), Evagoras Charalambous (SIGINT)

Participant(s): IT, TC, PTI, SIGINT

Workpackage: WP3

Est. person months: 16

Security: Internal

Nature: Report

Version: 3.0

Total number of pages: 64

Abstract:

This Deliverable is related to tasks T3.3 "COGEU Reference Architecture for Spectrum Commons" and T3.4 "COGEU Reference Architecture for Secondary Spectrum Market". It provides an overview of system architectures proposed by TV White-space standards, present the COGEU vision on spectrum sharing and introduces the COGEU Initial Reference Architecture that will be used as a basis for cross-work-packages discussions.

Keyword list: TVWS, Architecture, Design, Dynamic Spectrum Management, Secondary spectrum trading, spectrum broker, regulatory scenarios, COGEU reference model, TVWS allocation, Geolocation Database.

Executive Summary

COGEU investigates both the commons and secondary spectrum trading approaches in the TVWS. In a commons spectrum usage model, there is no spectrum manager to preside over the resource allocation. Spectrum commons regime promotes sharing, but does not provide adequate QoS for some applications. However, for applications that require sporadic access to spectrum and for which QoS guarantees are important, temporary licensed spectrum with real-time secondary markets may be the best solution. Trading allows players to directly trade spectrum usage rights, thereby establishing a secondary market for spectrum leasing and spectrum auction. Of course, both regimes, spectrum commons and spectrum trading, are only possible to the extent allowed by national regulation. This deliverable presents an initial COGEU architecture (ICA) taking into account possible regulatory scenarios in the future.

Key conclusions:

Overview of system architectures proposed by TV White-space standards

- An overview of current standards and an analysis of the architectural trends that are of particular interest for the COGEU architecture have been performed.
- To our knowledge, **there is no current architecture** proposed by standardization bodies for **secondary spectrum trading**, indeed all of them assume unlicensed access (spectrum commons regime).
- COGEU align the proposed ICA with the ongoing worldwide standardization efforts on the TVWS.
- Architecture mapping is defined between 802.19.1 and 802.21; it could be of particular interest for handover preparation in the scope of mobility management studies in COGEU.
- There is a clear need for adaptation of current technologies/standards in order to answer the specific system requirements as introduced in Task 3.1 “Use-Cases Analysis & System Requirements” of COGEU WP3.
- Geolocation database-driven access to TVWS seems particularly relevant in regard of current regulatory/standardisation trends. Nevertheless **the high diversity of database proposed** so far have to be analysed carefully and adopted with respect to the issues targeted (co-existence, mobility management, spectrum access discovery, reconfiguration, spectrum management)

COGEU approach, spectrum sharing vision

- Neither current approaches nor a single reference model could fit all possible European regulatory scenarios. Indeed the two legacy regimes, spectrum commons and spectrum trading, are only possible to the extent allowed by each national regulation. For that matter, COGEU assumes two regulatory scenarios as follows:
    - **1st regulatory scenario**: where **Both geo-location database** access and **spectrum sensing** are required for the protection of Incumbents
    - **2st regulatory scenario**: where **Only geo-location database** access is required for the protection of the Incumbents.

First regulatory scenarios, reference model, and initial architecture

- The implications of **the 1st Regulatory Scenario** are as follows
    - Combining the use of geo-location database together with autonomous sensing seems plausible. The database protects Digital Video Broadcasting – Terrestrial (DVB-T) and professional Programme Making and Special Events (PMSE) systems that can be planned in advance. Other PMSE users (not planned, not registered) such as Electronic News Gathering (ENG) shall be protected trough autonomous sensing.
    - Autonomous sensing should be mandatory for PMSE and optional for DVB-T. The system should provide a signaling channel for reporting of local sensing data and supports centralized cooperative sensing. Even if there is no clear regulatory framework so far, regarding sensing requirements in Europe.
- Reference model considering the 1st regulatory scenario is illustrated in Figure 1:

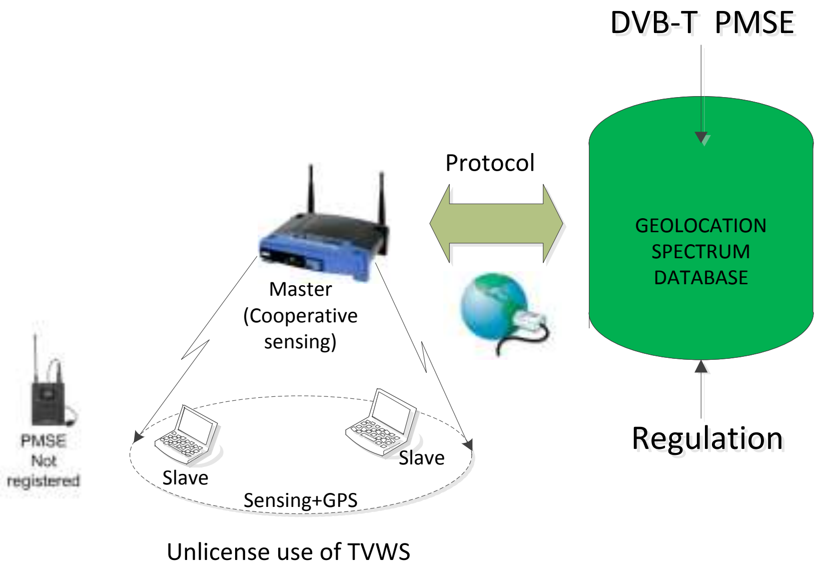

Figure 1: COGEU Reference Model assuming 1st regulatory scenario

- COGEU considers two types of TV White Spaces Devices (TVWSD):
  - "**master devices**" that contact a database to obtain a set of available frequencies in their area; and
  - "**slave devices**" which obtain the relevant information from master devices but do not contact the database themselves.
- The Main information needs to be communicated **by the TVWSD** (the "master devices") to the geo-location database are expected to be:
  - Location
  - Location accuracy
  - Expected area of operation (optional) – coverage area
  - Device type
  - In the case of a master/slave WSD configuration, the above information will be obtained by the WSD master by requesting it from its associated slaves or deriving it by other reliable means.
- Technical information to be communicated **to the TVWSD** originating from the geolocation database:
  - Available frequencies (minimum requirement)
  - Maximum transmit power
  - The appropriate national/regional database to consult
- Although the recent moves from FCC and OFCOM to remove sensing requirements, COGEU has to accommodate some level of local sensing because:
  - Protection of non registered wireless microphones (PMSE).
  - The process of moving PMSEs to specific channels and store them in a database will take years to be finished.
  - Few EU countries have a database for wireless microphones.
  - PMSE usually operates indoors.
- COGEU defines an initial **Architecture for combination of geo-location database with sensing**. This first attempt of specification includes:
  - Methodology for combination sensing with geo-location database
  - A General Architecture Description
  - Relevant actions for combining geolocation and sensing information

Second regulatory scenarios, reference model, and initial architecture

- For reliable access to the TV white-spaces and the guarantee of the QoS for wireless service providers, COGEU envisions a scenario where geo-location database access and "safe harbor" channels for non-registered PMSE will be required. Within this scenario we assume that sensing is not necessary.
- The main innovation brought by COGEU is in the combination of unlicensed access to TV white spaces with secondary spectrum trading mechanisms.

- COGEU will consider a centralized topology with a **Geolocation Spectrum database** dealing directly with TVWS Devices (Spectrum Commons world) or with **Spectrum Broker** (Secondary Spectrum Market). An overview of the spectrum broker is illustrated in the reference model shown in Figure 2.

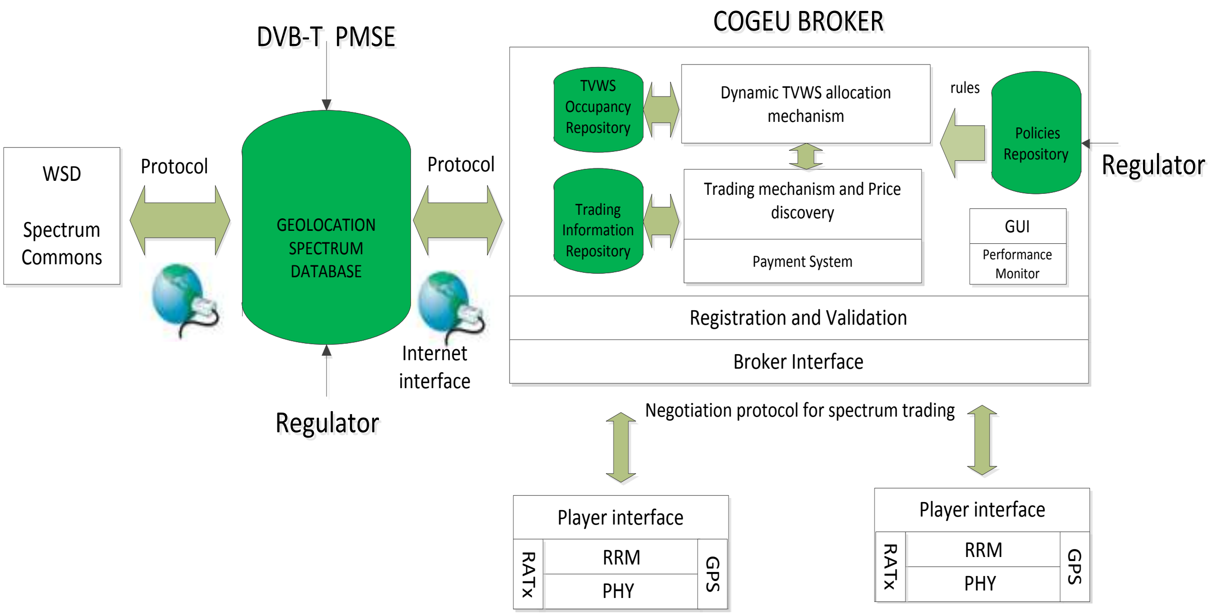

Figure 2: Initial COGEU reference architecture for commons and secondary trading, only geo-location access required.

- The **COGEU Spectrum Broker** determines how spectrum are allocated among secondary users (or players), and also how much each player pays for the acquired spectrum. Therefore, TVWS allocation and trading mechanism are important functions of the COGEU broker.
  - **Broker internal repositories** have to be maintained by the COGEU Broker:
    - TVWS Occupancy Repository dealing with secondary users co-existence, and Primary user protection.
    - Spectrum Policies Repository securing the policy management and distribution mechanisms, it also includes policy management tools
    - Trading Information Repository: responsible for past transaction retrieval
  - **Initial interfaces specification** is provided in order for the Broker to communicate with:
    - Secondary Users (seen as players): a dedicated communication channel is mandatory in order to TVWS to request spectrum access.
    - Geolocation database: there is a two-way communication pattern in order to retrieve information or to be notified when TVWS availability change in the DB.
    - Regulator: in order for regulatory bodies to keep control of spectrum allocation and advertise specific regulatory policies.

- The **spectrum trading mechanism** will be realized through an auction mechanism in which the broker collects bids to buy from the service providers, bids to sell from the geolocation database, and subsequently determines the allocation along with the price for each spectrum asset.
- Signalling between the broker and the spectrum user are introduced. The signalling interface is the protocols that enable the transaction of spectrum between the broker and the user to take place efficiently. Through these **negotiation protocols**, the Broker maximizes its revenue as well as ensures fairness between players. Since both pricing and auction mode are supported by the broker as spectrum allocation schemes, the negotiation protocols include:
  - Pricing mode protocol
  - Auction mode protocol
- **A Payment system** is introduce, Providing the facility that from the spectrum broker side allows to deliver and check out bills (either repeatedly or only once) from the TVWS users to pay them.
- **COGEU geo-location database** is defined based on section 1 overview analysis. It has to deal with two operation models. Indeed, the COGEU geo-location database receives enquires from

both, unlicensed TVWSD's (pretty similar to 1st regulatory scenario minus sensing) and from entities running spectrum brokers. COGEU geo-location database will be accessible by the following interfaces:
  - ***Interface A*** is to provide communication with the TVWSD repository that operates under the spectrum of commons operations;
  - ***Interface B*** is to give access to the COGEU Broker entity that will handle the secondary spectrum market;
  - ***Interface C*** is connected to a regulation and policies repository for the current area that the database is operating;
  - ***Interface D*** will be by the Incumbent systems repository which will provide information for the protected incumbent systems;
  - ***Interface E*** is public access interface that would enable anyone to search the Database's non-confidential publicly available information.
  - ***Interface F*** connects the local database with the central database in order to retrieve updates on policies and information regarding the close border areas. Each of interfaces will use IP security.
- **Authentication and Authorization architecture** is presented. Briefly, it is designed around an Authentication Server (AS); in charge of generating the certificates for the players and broker, verify the authenticity of the requests, and sign/encrypt the response.

Instantiation of the COGEU reference architecture

- Based on the reference model and initial architecture components, three scenario identified in D3.1 are discussed. It does not meant to be a complete mapping of functionality derived from the initial architecture, but this exercise is intended to identify where does the specific needs lies for each application scenario.
- **LTE-over-TVWS** scenario instantiation highlights possible steps and specific components interactions required in order benefits from TVWS access. Phases identified can be summarised as:
  - Network monitoring
  - Carrier request
  - COGEU Broker inquiry
  - Carrier allocation
- As the **WiFi-over-TVWS** scenario can be implemented under the two
- Public **Safety over TVWS** focuses on the specific emergency communication systems requirements in order to identify the optional functionalities to be added to the initial reference architecture. An example is given for the optional "priority TVWS access" that could be a possible enhancement of the TVWS allocation mechanism.

Table of Contents

1- Introduction

This Deliverable is related to tasks T3.3 “COGEU Reference Architecture for Spectrum Commons “and T3.4 “COGEU Reference Architecture for Secondary Spectrum Market”. The main objectives of those tasks are to derive the COGEU reference architecture, and define the basic functional blocks and their interoperations to implement a real time spectrum management platform for both Spectrum Commons and Secondary Spectrum Market.

This deliverable is arranged as follows. Chapter 2- presents an overview of current standards and an analysis of the architectural trends that are of particular interest for the COGEU architecture. The objective of this study is to align the proposed COGEU architecture with the ongoing worldwide standardization effort. Combined with the previous use-cases analysis available in D3.1, it is expected to identify technology adaptation needs corresponding to the specificity of COGEU.

Chapter 3- introduces COGEU approach and regulatory scenarios. Since no reference model can be generic enough to fit to all possible European Regulatory rules, two main Regulatory scenarios are defined and motivated to be used as a basis for discussions.

Then chapter 4- and chapter 5 are attempts to design an initial reference architecture corresponding to the previously introduced Regulatory scenarios. It defines functional blocks, interfaces, protocols and maps the research studies done in complementary work-packages to modules of the Initial Reference Architecture.

Finally, chapter 6- can be understood as an exercise to validate COGEU design, by instantiating three application scenarios based on the Initial Reference Architecture. It does not mean to be a complete mapping of functionality derived from the initial architecture, but it is intended to identify where does the specific needs lies for each application scenario.

2- Overview of system architectures proposed by TV White-space standards

This section provides an overview of current standards and an analysis of the architectural trends that are of particular interest for the COGEU architecture. The objective of this study is to align the proposed COGEU architecture with the ongoing worldwide standardization effort. We introduce the activities in Cognitive Radio research communities and industry related to architecture and spectrum management, such as IEEE 802.22, ECMA 392, and IEEE 802.11af (also known as Wi-Fi 2.0 or White-Fi).

2.1- ECMA 392

This Standard specifies a medium access control (MAC) sub-layer and a physical (PHY) layer for personal/portable cognitive wireless networks operating in TV bands. This Standard also specifies a MUX sub-layer for higher layer protocols. It also specifies a number of incumbent protection mechanisms which may be used to meet regulatory requirements (which are out of the scope of ECMA392). ECMA 392 is the first Cognitive Radio standard for personal/portable devices to exploit the TVWS. It was started by the Cognitive Networking Alliance (CogNeA), and a draft specification was later transferred to TC48-TG1. The standard specifies PHY and MAC layers with several characteristics: flexible network formation, adaptation to different regulatory requirements, and support for real-time multimedia traffic. Ecma 392 is expected to enable new applications using TVWS such as in-home HD video transmission, campus-wide wireless coverage, and interactive TV broadcasting services. Ecma 392 has potential to deliver high-quality WS services in developed areas. However, such populated regions will introduce a more challenging environment for PU protection due to the high volume of DTV receivers and WMs. Therefore, it is important to determine safe operational conditions according to various service scenarios. TVWS may also create an interference-prone environment between neighbouring CRNs due to the characteristics of TV bands offering wider coverage, unlike the 60 GHz band in-home networks targeting short-range communications

Figure 3 gives an example scenario for the Ecma 392 standard. A master device as defined in this standard will meet the requirements of the FCC defined Mode II device by including geolocation (and sensing) functions and periodically obtaining available channels list from an authorized spectrum database via the internet. All slave devices (with sensing function) associated with such a master device will comply with the requirements of an FCC defined Mode I device.

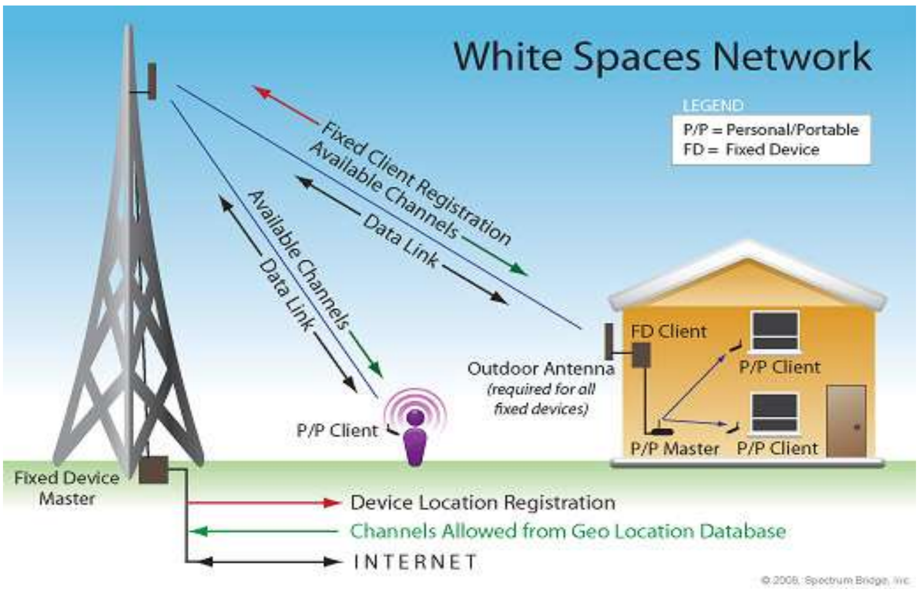

Figure 3: White Spaces Network [Spectrum Bridge Inc.]

2.2- IEEE P1900.4a

IEEE P1900.4 is a working group within SCC41 (Standards Coordinating Committee 41) aiming at defining "Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks". A standard, IEEE 1900.4-2009, has been published in February 2009. This standard defines the architectural building blocks, the interfaces, the information model and the procedures for optimized radio resource usage in heterogeneous wireless access networks. Three use cases are addressed by the IEEE 1900.4-2009 architecture:

- Dynamic Spectrum Assignment: frequencies are dynamically assigned to Radio Access Networks (RAN);
- Dynamic Spectrum Sharing: frequency bands assigned to RANs are fixed but a given band is potentially shared between several RANs;
- Dynamic Radio Resource Usage Optimization: terminals choose, in a distributed manner, which radio access technology/technologies (RATs) to connect to.

On April 2009, P1900.4 working group has been working on two subsequent projects, namely P1900.4a and P1900.4.1. P1900.4a, entitled "Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks - Amendment: Architecture and Interfaces for Dynamic Spectrum Access Networks in White Space Frequency Bands", aims at developing an amendment to the standard published in February 2009. The draft amendment consists in modifications the architecture, interfaces, information model and procedures of IEEE 1900.4-2009 for the P1900.4a system to operate in white space frequency bands. The P1900.4a system aims at enabling the coexistence of secondary systems operating in white spaces by providing the Base Stations (Cognitive Base Stations – CBSs – in the P1900.4a terminology) and the terminals with the following capabilities: spectrum sensing control, silent period management, white space classification and access to white space database. Additionally, the integration of a system operating in white space frequency bands into the heterogeneous wireless system of an operator is part of the P1900.4a use cases. In this use case, CBSs are capable of operating in white spaces and in licensed spectrum.

The second project, P1900.4.1 aims at defining the protocols and the Service Access Points (SAPs) associated with the interfaces standardized in IEEE 1900.4-2009. Some of these protocols and SAPs are likely to be reused in the P1900.4a system.

Relevance to COGEU architecture specification:

The architecture developed in P1900.4a has a scope similar to the COGEU architecture since it addresses the coexistence of secondary systems and spectrum management in TV white space bands. Protocols defined in P1900.4.1 can be of interest to COGEU since they will be used in the system operating in white space frequency bands (developed in P1900.4a project).

2.3- IEEE 802.19

IEEE 802.19 is the Wireless Coexistence Technical Advisory Group (TAG) within the IEEE 802 LAN/MAN Standards Committee. The purpose of the standard is to enable the family of IEEE 802 Wireless Standards to most effectively use TV White Space by providing standard coexistence methods among dissimilar or independently operated TVWS networks and dissimilar TVWS Devices. This standard addresses coexistence for IEEE 802 networks and devices and will also be useful for non IEEE 802 networks and TVWS Devices. IEEE802.19.1 logical system architecture defines the system entities, which are the core of providing the coexistence for the TV band networks, and external entities which provide information to the coexistence system.

IEEE 802.19.1 coexistence system consists of three logical entities, Coexistence Enabler, Coexistence Manager, and Coexistence Discovery and Information Server. A logical entity is defined by its functional role and its interfaces with other IEEE 802.19.1 coexistence system entities, or external elements. The system may interact with two external entities, TVBD and TVWS database. They are defined outside this standard.

The TAG deals with coexistence between unlicensed wireless networks. Many of the IEEE 802 wireless standards use unlicensed spectrum and hence need to address the issue of coexistence. These unlicensed wireless devices may operate in the same unlicensed frequency band in the same location. This can lead to interference between these two wireless networks.

2.4- IEEE 802.22

The IEEE 802.22 working group was formed in November 2004 as the first worldwide effort to define a novel wireless air interface (i.e. MAC and PHY) based on Cognitive Radios. The IEEE 802.22 WG is given the task to develop a CR based Wireless Regional Area Network PHY and MAC layers for use by license–exempt devices in the TV white space spectrum. Since IEEE 802.22 is required to reuse the fallow TV spectrum without causing any harmful interference to incumbents (i.e., the TV receivers), cognitive radio techniques are of primary importance in order to sense and measure the spectrum and detect the presence/absence of incumbent signals.

802.22 focus on **Rural Broadband Wireless Access**, a brief overview of the main interest of 802.22 are given below:

- Core Technology - Cognitive radio technology based un-licensed use, primarily designed to operate in the TV White-spaces from 54-862 MHz, on a non-interfering basis with the primary users (incumbents).
- Representation – Commercial industry, Broadcasters, Govt., regulators, and Academia
- Projects – IEEE 802.22, IEEE 802.22.1, IEEE 802.22.1
- PHY - Optimized for long channel response times and highly frequency selective fading channels.
- MAC – Provides compensation for long round trip delays. The current 802.22 draft MAC employs the superframe structure. At the beginning of every superframe, the BS sends special preamble and SCH (superframe control header) through each and every TV channel (up to 3 contiguous) that can be used for communication and that is guaranteed to meet the incumbent protection requirements. During the lifetime of a superframe, multiple MAC frames are transmitted which may span multiple channels and hence can provide better system capacity, range, multipath diversity, and data rate.
- Unique features introduced for Cognitive Radio based operation: spectrum sensing, spectrum management, intra-system co-existence, geo-location and security.
- Mobility and Portability - Portability – IEEE 802.22 allows portability (nomadic use). In case the rules do change, IEEE 802.22 PHY is designed to support mobility of up to 114 km/hr (no hand-off is included in the current version).

TVWSDs connect in a point-to-multipoint architecture where the customer premises equipments (CPEs) are controlled by the centralized base station (BS). The BS not only controls the operational parameters of all its registered CPEs but also acts as a proxy to the database service. A CPE reports its location information to the BS and the BS uses this information to query for available TV channels from the database on behalf of the CPE. The BS manages TV channel selection for its network using an integrated cognitive brain – called the “spectrum manager.”

Each of devices on the network is capable of spectrum sensing. The exact spectrum sensing capability employed is left open to implementation. However, the BS keeps track of the statistical performance of the spectrum sensing capabilities. These statistics along with the individual sensing measurements made by the individual devices on the network can be combined to accomplish distributed sensing.

Relevance to COGEU architecture specification:

One key feature of the WRAN Base Stations is that they will be capable of performing a distributed sensing. This is to say that the CPEs will be sensing the spectrum and will be sending periodic reports to the BS informing it about what they sense. The BS, with the information gathered, will evaluate whether a change is necessary in the channel used, or on the contrary, if it should stay transmitting and receiving in the same one.

2.5- IEEE 802.11af (White-Fi)

FCC's allowance of personal/portable devices in TVWS introduces another interesting standard named: IEEE 802.11af. In 2008 Google and Microsoft announced their interest in using TVWS for an enhanced type of Wi-Fi like Internet access, called Wi-Fi 2.0, Wi-Fi on steroids, or White-Fi. The idea was later formalized as a new standard called IEEE 802.11af, for which an 802.11 task group was chartered. 802.11af is expected to provide much higher speed and wider coverage than current Wi-Fi, thanks to the better propagation characteristics of the VHF/UHF bands. IEEE 802.11af can be understood as a wireless network with a CR-enabled access point (AP) and associated CR devices as end-user terminals. The CR APs operate on TVWS via spectrum sharing schemes, and the thus incurred time varying spectrum availability introduces new challenges. For example, upon appearance of PUs in a leased channel, the AP should relocate the CRs in the channel, which requires eviction control of in-service customers in case the remaining idle channels cannot accommodate all the spectrum demands. Although Wi-Fi over TVWS is still in its infancy, its resemblance to today's Wi-Fi hotspots suggests that it may have a huge market potential in CR-based wireless networks.

IEEE 802.11af is an amendment to 802.11mb/D6.0 whose implementation in solutions is likely to receive FCC approval for operation in the TV White Spaces. It follow the following main principles:

- The amendment should not duplicate functionality that is being standardized in other Task Groups that are likely to complete before 802.11af.
- There is no need for backwards compatibility with 2.4 GHz ISM operation.
- Use the OFDM PHYs with 5-, 10- and 20-MHz channel widths to specify the basis for a system that the regulators can approve for operation in the TVWS bands.
- If the FCC changes the rules, the Task Group should change the amendment accordingly.

As introduced by the last bullet point above, 802.11af is a regulatory-driven amendment. Moreover, regulatory (US) rule did change recently by releasing rule FCC 10-174 [19]. The main changes in the rule can be summarised as follow:

- Sensing requirements dropped
    - this was the biggest hurdle for low-cost TVWSDs
    - Sensing-only devices now a future option
- Two TV channels will be reserved nationwide for protected wireless microphones; licensed microphone category expanding to include theatres, sports arenas and churches
- Incumbents needing more than two TV channels in any market for special events and sports venues can register for and reserve additional TV channels for wireless microphone use for these special events

Eventually, the 802.11af amendment is currently being extensively updated taking into consideration those last rule changes. Members of the Task Group are already confident that it will reach stability by the end of the second semester of 2011 but there's much to be figured out regarding modulation techniques and data rates, so it wouldn't be surprising if the actual date is wrong. Given that the Wi-Fi Alliance's efforts largely parallel the IEEE's, it can be expected to see something akin to the "11n Draft 2.0" step hit the market for 802.11af before full standards ratification, given the declared hunger for product in the white space frequencies.

Relevance to COGEU architecture specification:

In the case above, maybe IEEE 802.11af will be seen commercially before IEEE 802.22 due to the speed of standardization and the ecosystem inherited from the WiFi alliance, even though IEEE 802.22 have existed for many years now. COGEU consortium will be following very closely this standardisation process by keeping a privileged relationship with RIM (Research In Motion) EAB members who chair the 802.11af Task Group. While the 802.11af do not really deal with network architecture, it will be very interesting If commercial products are available before the end of the COGEU project. 802.11af could then be the perfect candidate to implement scenarios as described in section 6.2-.

2.6- ETSI RRS

ETSI RRS currently considers the usage of TVWS for adapting existing and/or evolving Radio Standards, such as 3GPP Long Term Evolution, to a possible operation in UHF White Space bands. The following Use Case extracted from [1] is given as an example.

Multimode user terminals (i.e. terminals that support multi-RAT in licensed spectrums for instance HSPA and LTE) are also provided with the capability of accessing TVWS spectrum bands in order to provide wireless broadband access (e.g. TDLTE) for instance in rural areas where high data rate connections are commonly not available. This use case takes the benefit of the excellent propagation performance of a radio network operating in TV White Space frequency bands i.e. 470-790 MHz in Europe/Region 1. TDD can be considered suitable for a secondary/overlay spectrum access compared with FDD.

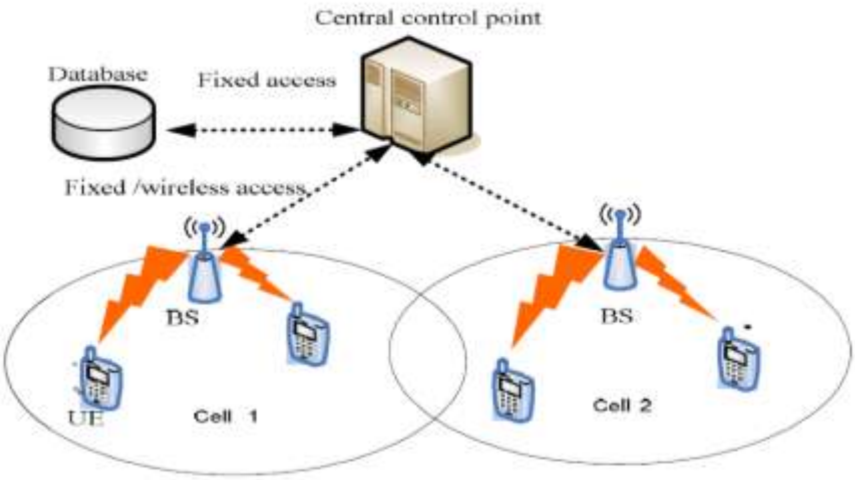

Figure 4: Database driven access to TVWS as seen in ETSI RRS

A network centric solution is considered in allocating available TVWS for the user terminal to get connectivity. In this scenario, available TVWS frequency band is considered based on location rather than on time; it is assumed that TVWS would be largely available in rural area and in time. However, a dynamic change in the availability of the bands cannot be excluded and thus shall be taken into account by the system. In the case of a Network Centric solution, the terminal can get the required information from its current connectivity and its current RAT i.e. TD-LTE operating in TVWS, or from another RAT e.g. HSPA in 3G bands. The general principles are illustrated by Figure 4. The optimization of Radio Resource usage in proposed to be performed as follows:

I. eNodeB operating on the TD-LTE frequency sends TVWS Allocation Request to the central control point periodically;
II. The central control point inquires the database if there are any available TVWS frequency bands at the location of the eNodeB;
III. If available TVWS frequency existing at the location of eNodeB, the central control point sends TVWS Allocation Response which includes the information of allocated TVWS to the eNodeB. Other configuration parameters may be sent to eNodeB as well. Otherwise, the central control point will notify eNodeB that no TVWS is available at its location;
IV. eNodeB decides to switch the operating frequency to allocated TVWS frequency band and notify UE(s) about the change of the frequency;
V. eNodeB buffers the downlink transmitting packets of the connected mode UE(s) and then switches to the allocated TVWS frequency after all the UE(s) have been informed;
VI. The related UE(s) will switch to the frequency accordingly at the occasion indicated by the eNodeB.
VII. The buffered downlink packets in eNodeB are sent to UE(s) in order to ensure the service continuity;
VIII. eNodeB sends eNB Configuration Update message including the updated configuration parameters to the central control point. The central control point responds with eNB Configuration Update Ack message to acknowledge that it successfully updated the configuration data;
IX. The central control point sends Database Update Request message including the updated configuration parameters to the database. The database responds with Database Update Ack message to acknowledge that it successfully updated the configuration data.

ETSI RRS considers SDR related standardization for both, Base Stations (BS) and Mobile Devices. The current focus in ETSI RRS WG2 relies mainly on Mobile Device SDR as the underlying implementation technology and enabler for CR, as well as related interface standardization between distinct stakeholder domains, such as SDR chipset vendors and Mobile Device manufacturers. In this framework, a reference architecture has been derived, which outlines the relevant interfaces and concerned building blocks – this architecture, however, is not meant to be normative.

Relevance to COGEU architecture specification:

ETSI RRS considers an important issue might be coordination of band allocation or utilization in the case of TVWS. Opportunistic TVWS usage involving additional eNodeBs in order to off-load traffic from congested licensed cellular bands must be accompanied by smart TVWS band allocation/sharing strategies. Since the activation and utilization of some or many bands in TVWS may change locally over time, this corresponds to a kind of changing infrastructure of active network elements in a particular band. This Scenario fits very well with current COGEU studies, and more specifically LTE-over-White-space Scenario defined in COGEU Deliverable 3.1.

2.7- CEPT/ECC SE43

The ECC WGSE (Spectrum Engineering) has set up a special project dealing with cognitive radio matters. The SE43 was set up in May 2009 and is to finish its work in January 2011 by completing the ECC Report “Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the ‘White Spaces’ of the Frequency Band 470-790 MHz”.

This report currently exists in draft format which can be downloaded from the CEPT/ECC website. Status as of September, 2010: provisionally approved for public consultation. The final ECC Report is planned to be release January 2011.

The main focus of the report is, as the title suggest, on coexistence with incumbent or primary systems. It introduces definitions of “White Space”. The definition of “White Space” is taken from CEPT Report 24 “Technical considerations regarding harmonisation options for the Digital Dividend.” The report defines different scenarios for CR operation in terms of TVWSD types (personal/portable, home/office and public access points) and also discusses the three well known types of cognitive techniques: spectrum sensing, geo-location and beacons.

The report is focussed on protection of four possible incumbent systems: broadcast systems (BS), Program making and special events (PMSE), radio astronomy (RAS) and aeronautical radio navigation systems (ARNS). Comprehensive data on possible sensing and separation distances are given, and ends in operational and technical characteristics for white spaces devices to operate in the band. An estimate of available white space is also included.

Relevance to COGEU architecture specification

COGEU considers the requirements of the draft report from SE43 of high importance. This report is intended to be the basis for a future recommendation for cognitive radio operation in Europe, a recommendation which most regulators will probably endorse.

2.8- Cross analysis for COGEU system architecture

To our knowledge, there is no current architecture proposed by standardization bodies for secondary spectrum trading, indeed all of them assume unlicensed access (spectrum commons regime). Spectrum commons regimes promote sharing, but do not provide adequate quality of service (QoS) for some applications. COGEU consortium is convinced that unlicensed use of TVWS bands is not fully adequate solution for all possible applications which may apply in Europe. Therefore we strongly promote the combination of spectrum commons regimes and temporally exclusive rights for use within Europe.

The State-of-the-art above, provides an analysis of various IEEE bodies, and ETSI RRS, which are relevant to COGEU. Some of them have a high-level scope, addressing system architecture issues, while others address more specific aspects like radio access techniques, sensing, and incumbent protection. Moreover, the cross-analysis between those technologies and the requirements coming from WP2 show that a lot of concepts can be re-used, e.g., the Dynamic Spectrum Manager defined in ETSI RRS or the Centralized spectrum management concept introduced in 802.22 (see Figure 5) as a baseline for the COGEU reference model. Distributed sensing and measurements concept specified in IEEE 802.22.1 is also considered for one of the possible regulatory scenario (see section 3.2).

The following is an attempt to highlight the high **diversity of database proposals**. The following figures obviously emphasize that no standardized architecture can fit all the specific needs of COGEU system requirements, if taken as it is.

For example, main achievements of 802.22 Wireless Regional Area Network related to COGEU architecture analyses are:

- 802.22 has established spectrum sharing techniques that can be readily adapted to enable coexistence with other 802 technologies
- 802.22 spectrum manager is capable of autonomously deciding which coexistence mechanism to use and how
- 802.22 has developed a basic interface for incumbent database service
- 802.22 will consider providing interface between its spectrum manager and 802.19 coexistence manager

Figure 5 shows an overview of interfaces provided by 802.22 spectrum manager.

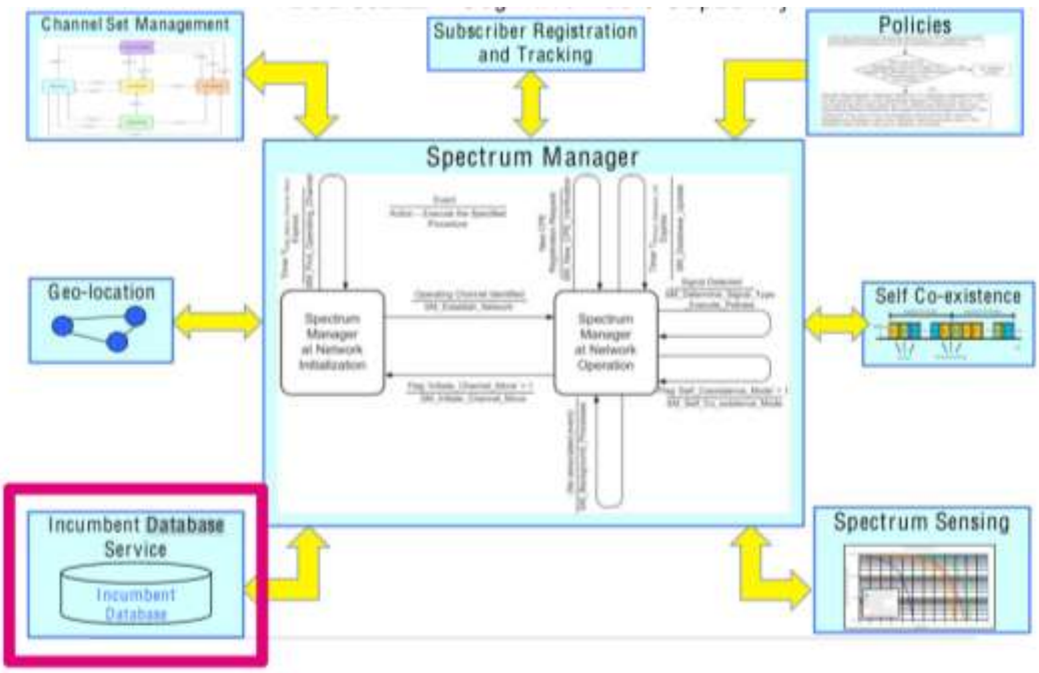

Figure 5: Spectrum manager interfaces. Source:[21]

A second example highlighting current database diversity is the shown in Figure 6 from The White Space Database Group, created by Google while introducing their geolocation database proposal. It has been useful for COGEU reference model definition, in order to identify the specific need for regulatory enforcement interface.

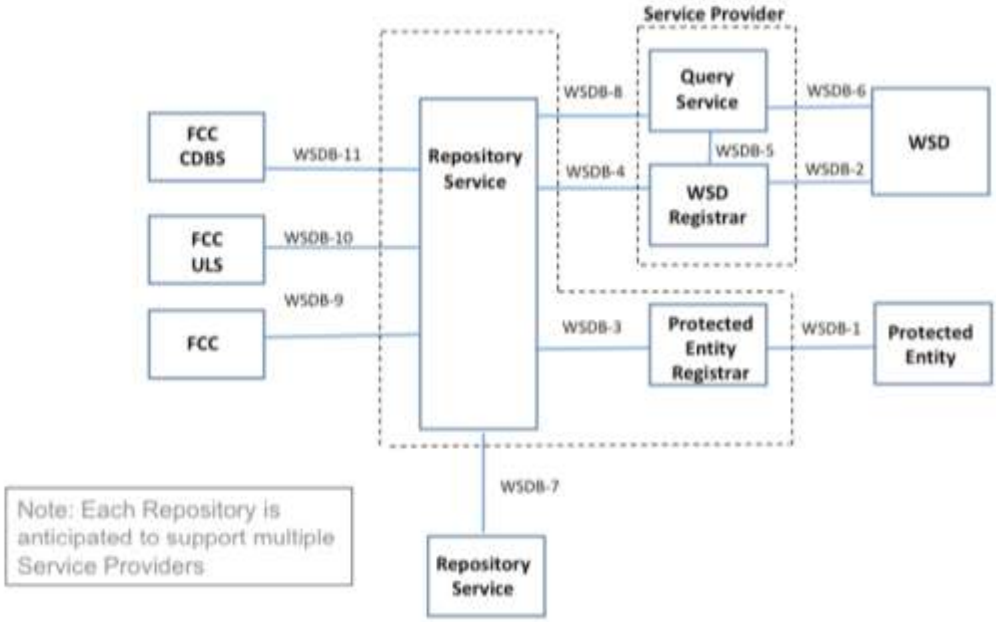

Figure 6: Unlicensed Operation in the TV Broadcast Bands Source: [20])

While there is no need in COGEU for CPC (Cognitive Pilot Channel) to support the user terminal for discovery of available radio access and reconfiguration, another architecture consideration relevant to COGEU is ETSI RRS Database access proposal seen in Figure 7. The CPC is defined as a channel that conveys the elements of necessary information facilitating the operations of the Cognitive Radio Systems. The CPC provides information on which radio accesses can be expected in a certain geographical area. This information includes operator information, RAT type as well as used frequencies. In COGEU we consider our centralised database/broker based allocation slightly different than the CPC approach since TVWSD are not necessary very complex Cognitive Radio Systems.

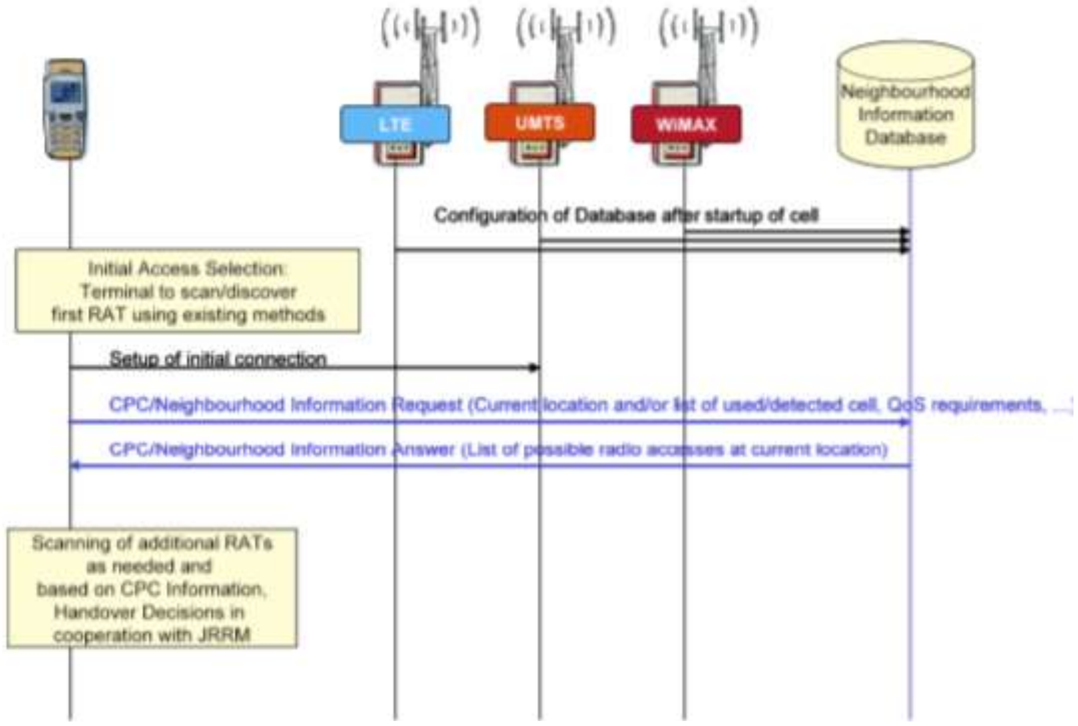

Figure 7: ETSI RRS Database Access (Source:[19])

Finally, considerations as expressed in 802.19.1 (see Figure 8) are of particular interest in dealing with coexistence. In order to insure coexistence, the 802.19.1 architecture specification draft defines:

- Coexistence Enabler
  - Request and obtain information, required for coexistence, from TVBD network or device
  - Translate reconfiguration requests/commands to TVBD-specific

- Coexistence Manager
  - Discovery of other CMs
  - Decision Making
  - Support exchange of information
- Coexistence Discovery and Information Server
  - Support Discovery of CMs
  - Collect, aggregate information

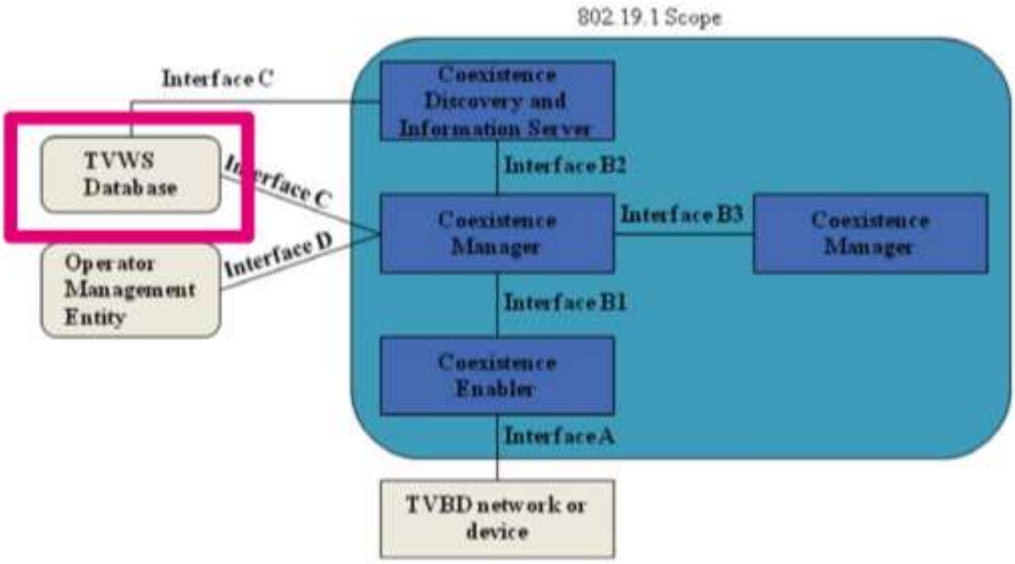

Figure 8: 802.19 co-existence framework (Source: [22])

Moreover, an architecture mapping is defined between 802.19.1 and 802.21 that could be of particular interest for handover preparation in the scope of mobility management studies in COGEU.

In conclusion, one of the main statements made through this analysis concerns the diversity on databases proposal for spectrum management. Indeed, standards and technology proposals presented above have different visions on what a spectrum database should be, depending on the context and issues considered. Nevertheless, there is a clear need to **adapt the state of the art** in order to fully satisfy COGEU requirements. The rest of this deliverable will provide a first analysis about which type of adaptations are needed, and present the first Initial COGEU Architecture.

3- COGEU approach and regulatory scenarios

COGEU investigates both the commons and secondary spectrum trading approaches in the TVWS. In a commons spectrum usage model, there is no spectrum manager to preside over the resource allocation. Spectrum commons regimes promote sharing, but do not provide adequate QoS for some applications. However, for applications that require sporadic access to spectrum and for which QoS guarantees are important, temporary licensed spectrum with real-time secondary markets may be the best solution. Trading allows players to directly trade spectrum usage rights, thereby establishing a secondary market for spectrum leasing and spectrum auction. Of course, both regimes, spectrum commons and spectrum trading, are only possible to the extent allowed by national regulation.

For that matter, COGEU assumes two regulatory scenarios as follows:

1. **Both geo-location** database access and **spectrum sensing** are required for the protection of Incumbents
2. **Only geo-location** database access is required for the protection of the Incumbents.

Before giving the details of these two scenarios, we first present an overview of the COGEU system requirements from previous deliverables.

3.1- Overview of COGEU system requirements

The following is the list of general COGEU system requirements identified in previous deliverables with impact on COGEU architecture:

- COGEU will follow CEPT definition of TVWS as a part of the spectrum, which is available for a radio-communication application (service, system) at a given time in a given geographical area on a non-interfering non-protected basis with regard to primary services and other services with a higher priority on a national basis. [D2.1]
- COGEU operation band starts from channel 40 to channel 60 (622 MHz-790MHz). Efficient SDR platform, RF modules and compact antennas are required to operate in this band. [D3.1]
- The system shall provide means to protect incumbent systems. COGEU approach is combining the use of geo-location database together with autonomous sensing. [D2.1]
- The system should provide a signaling channel for reporting of local sensing data and supports centralized cooperative sensing. [D2.1] [D3.1]
- The database protects DVB-T and professional PMSE systems that can be planned in advance. Other PMSE users such as ENG (Electronic News Gathering) shall be protected trough autonomous sensing. [D3.1]
- The maximum allowed power for TVWS operation is not pre-fixed. The power level is limited by the geo-location database information for protection of incumbent systems. Power control shall be implemented in COGEU transceivers. The maximum allowed transmit power in a specific vacant DVB channel is computed based on co-channel and adjacent channel protection ratios. [D3.1]
- COGEU database will provide the “validity period of information” i.e. a period after which a database query should be repeated. This would allow for flexibility and minimization of the overhead if, for instance, no PMSE users are at the specific location. Note that if time validity is provided then a general update frequency is not needed (2h in initial OFCOM proposal). [D4.1]
- Cross-border issues have to be considered in the specification of the database. [D4.1].
- COGEU devices acquire white space interfaces alongside other more established radio interfaces. COGEU envisage that the initial access to the geo-location database by unlicensed WSD will use existing radio interfaces such as WiFi, LTE or WiMax. [D4.1]
- The system shall be able to facilitate coexistence with other secondary systems operating in TVWS. This is done through dynamic TVWS allocation mechanisms based on protection rules specified for each combination (e.g. LTE over TVWS vs. WiMAX over TVWS). [D3.1]
- The system should provide a means to support applications with different QoS parameters, such as transmission rate, delay and delay jitter. Thus, COGEU system should be flexible enough to satisfy different QoS requirements. Because TVWS devices have to do spectrum

sensing, database access and reconfiguration before transmitting, some delay sensitive services, such as voice service, should be considered when designing the RRM strategies (WP6). [D3.1]

- The COGEU WSDs\Broker are prohibited from make use of TVWS until they have successfully determined from the database which frequencies, if any, they are able to transmit on in their location. [D4.1]
- For the COGEU WSDs (spectrum commons) a master-slave configuration is envisage, where the master connects to the database and the slaves are managed by the master, without access to the database [D4.1].
- In line with the trading mechanism, price discovery is an important requirement to enable the Broker to allocate the spectrum to the most valuable players. Efficient spectrum policies to enable fairness in the spectrum sharing models needs to be implemented. COGEU considers a regulatory regime that allows a fast re-assignment of spectrum ownership. [D3.1]
- The centralized point in the COGEU system allows, in the event of an emergency, a higher priority policy be propagated into the spectrum broker temporarily rescinding non-emergency utilization of the TVWS in the specific areas of need. Moreover, service prioritization can be incorporated into the database. Public Safety systems would have the highest priority. [D3.1]
- For regulatory enforcement, the database can be used in identifying the source of harmful interference where it occurs and may enable a “remote de-activation” of the device. [D3.1]
- The system should have a web interface able to allow players to follow the secondary market activity, communicate with the broker and negotiate spectrum rights in real time. [D3.1]
- COGEU will adopt Internet-based protocols and standard enquiry languages. The proposed database access procedure includes XML through web services. [D4.1]
- The COGEU system should be able take advantage of regulatory changes in incumbent protection requirements, like the reduction or elimination of autonomous sensing requirements. [D3.1]
- COGEU must not block the evolution of incumbent systems such as DVB-T2. [D3.1]

The following sections present the assumed regulatory scenarios under which these requirements will be fulfilled accordingly.

3.2- Regulatory scenario 1: Spectrum commons with sensing and geo-location access required

Information on DVB-T incumbents is stable and hence suitable for the spectrum database approach. The same is the case with registered PMSEs, usually for professional applications. COGEU assumes that a database for professional PMSE is either available or will be built up in advance of introduction of white space using equipment. However, the unpredictability of unregistered PMSE applications and Electronic News Gathering, which requires protection, is the main challenge in the design of the COGEU geo-location database.

Moreover, so far there is no clear regulatory framework regarding sensing requirements in Europe.

Because the process of switching PMSE to “safe harbor” will take years to be concluded in Europe, therefore we can assume a scenario where TVWS commons has to coexist with unpredictable PMSE trough combination of cooperative sensing and geo-location database access (master-slave topology) should be assumed for unlicensed use of TVWS. Figure 9 shows a scenario where geo-location access and sensing will be required.

The implications of the 1st Regulatory Scenario are as follows:

- In order to provide means to protect incumbent systems, combining the use of geo-location database together with autonomous sensing seems plausible. The database protects DVB-T and professional PMSE systems that can be planned in advance. The maximum allowed transmit power in a specific vacant DVB channel is computed based on co-channel and adjacent channel protection ratios. Other PMSE users (not planned, not registered) such as ENG shall be protected trough autonomous sensing.
- In this scenario, autonomous sensing should be mandatory for PMSE and optional for DVB-T signals (which are mainly protected by the geo-location database). Detection thresholds are

adopted from current regulatory framework. The system should provide a signaling channel for reporting of local sensing data and supports centralized cooperative sensing.

- **Combining the two approaches can relax the sensitivity required for sensing devices which is a major limitation of TVWS developments. Also, since local sensing is only performed in a limited number of TV channels indicated by the database, the hybrid approach will speed up the sensing process**. Moreover, cooperative sensing exploits spatial diversity of sensors located in different positions (preferentially with low correlated shadowing). COGEU will investigate cooperative sensing able to relax the sensitivity requirements of single nodes trough the reduction of the hidden terminal margin. Cooperative sensing requires protocols for sharing sensing information among TVWS devices which add extra complexity and sensing overhead to the TVWS system.

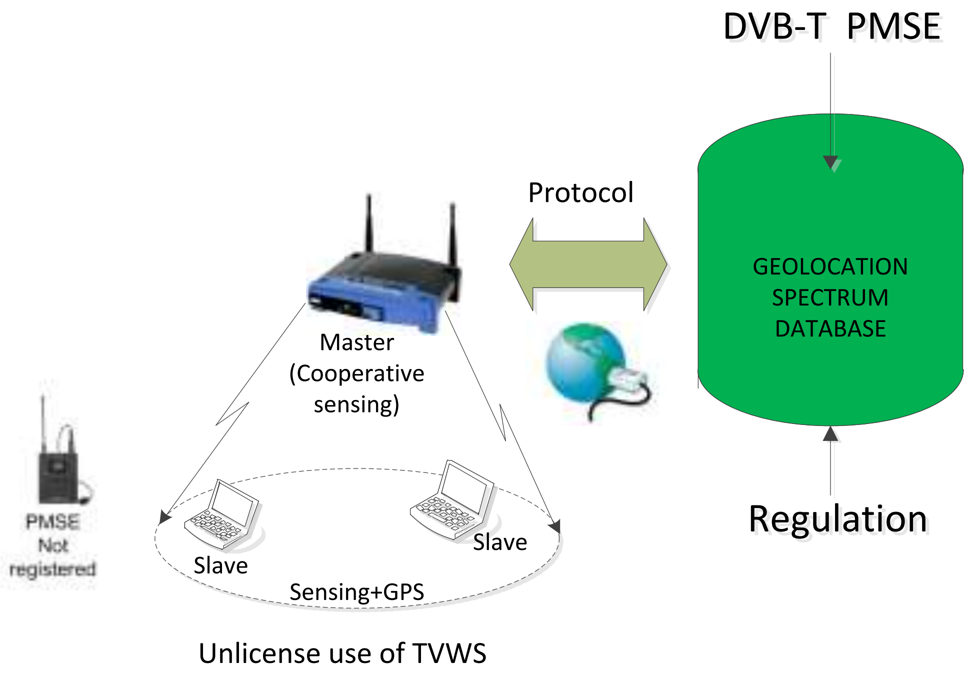

Figure 9: COGEU reference model assuming sensing requirement.

- The system should provide a means to support applications with different QoS parameters, such as transmission rate, delay and delay jitter. Thus, COGEU system should be flexible enough to satisfy different QoS requirements. Because TVWS devices have to do database access (and spectrum sensing, if necessary) and reconfiguration before transmitting, some delay sensitive services, such as voice service, should be considered when designing the RRM strategies.

Figure 10 shows the initial COGEU frame structure for the combination of geo-location data base access and sensing.

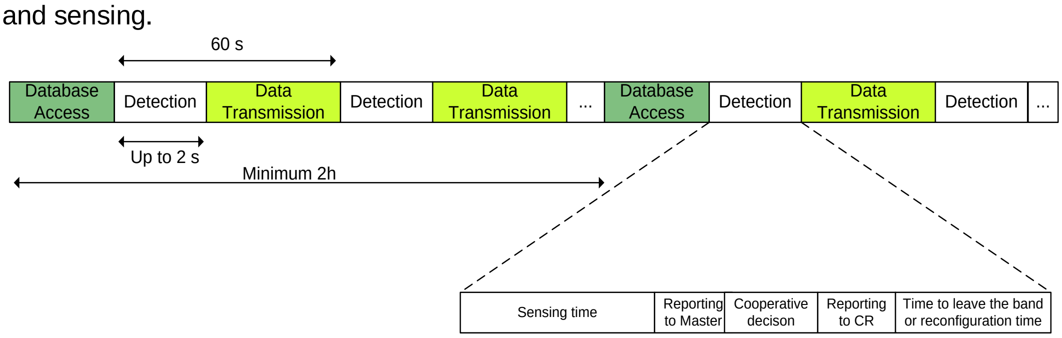

Figure 10: Initial COGEU frame structure [Source: D3.1].

However, wireless service applications in this scenario will have to deal low QoS (latency). Therefore, there is a need for a scenario where better QoS guarantee can be given. In the next section we present a scenario where sensing is not required, only geo-location database access.

3.3- Regulatory scenario 2: Commons and secondary trading, only geo-location access required

For reliable access to the TV white spaces and the guarantee of the QoS for wireless service providers, COGEU envisions a scenario where geo-location database access and “safe harbor” channels for non-registered PMSE will be required. Within this scenario we assume that sensing is not necessary. The proposed solution is to consider that Europe has implemented “safe harbor” for the exclusive PMSE usage, i.e., number of TVWS channels for reserved PMSE usage only in which no TVWS devices would be permitted. The “safe harbor” bands are flexible and it may change from country to country. These channels are excluded by the geo-location database and therefore out of the market. In this case the broker doesn’t need to consider sensing (only database access) and system doesn’t need backup channels to guarantee QoS and increasing spectrum efficiency. Hence, COGEU considers a regulatory regime that allows a fast re-assignment of spectrum ownership.

The rationale for this scenario is aligned with CEPT ECC Report 159:

> *“… it appears that the identification by national administration of at least one (or more) safe harbor channel, not used by DTT and which would be reserved for PMSE use would be helpful for the protection of PMSE, in particular for casual or unplanned usage by PMSE which would not be registered.”*

Therefore, COGEU considers this regulatory scenario assuming that the TVWS in channels 21-40 are reserved for PMSE use (here just non-predictable ENG use is relevant as the other predictable systems can be registered in a database). This is in line with COGEU assumptions where only channels 40-69 are considered. This gives a stable situation for COGEU considerations.

Reserving some channels (e.g. the available TVWS in channels below 40) for ENG would stabilize the available TVWS in the (other) channels considered by COGEU. These TVWS are for spectrum commons use and for spectrum broker as will be discussed later in the deliverable.

If there arises a situation where incumbents need more spectrum, then the spectrum available for spectrum commons and spectrum broker will be reduced by the regulator or its representative (i.e. also here the situation of less TVWS may happen). The broker will have to cope with this anticipated situation.

The safe harbor concept smoothes variation of TVWS availability and, to some extent, has impact on the cost of available TVWS for secondary use. The benefit for TVWS secondary use is that it is known which channels are reserved.

Figure 11 shows the COGEU reference model assuming scenario 2. Currently, only unlicensed access to TVWS is envisage\allowed by regulators, typically for low power applications (CEPT, OFCOM, FCC). COGEU investigates an extension of this regulatory regime and proposes a secondary spectrum market of TVWS that can leverage the value of these underutilized bands

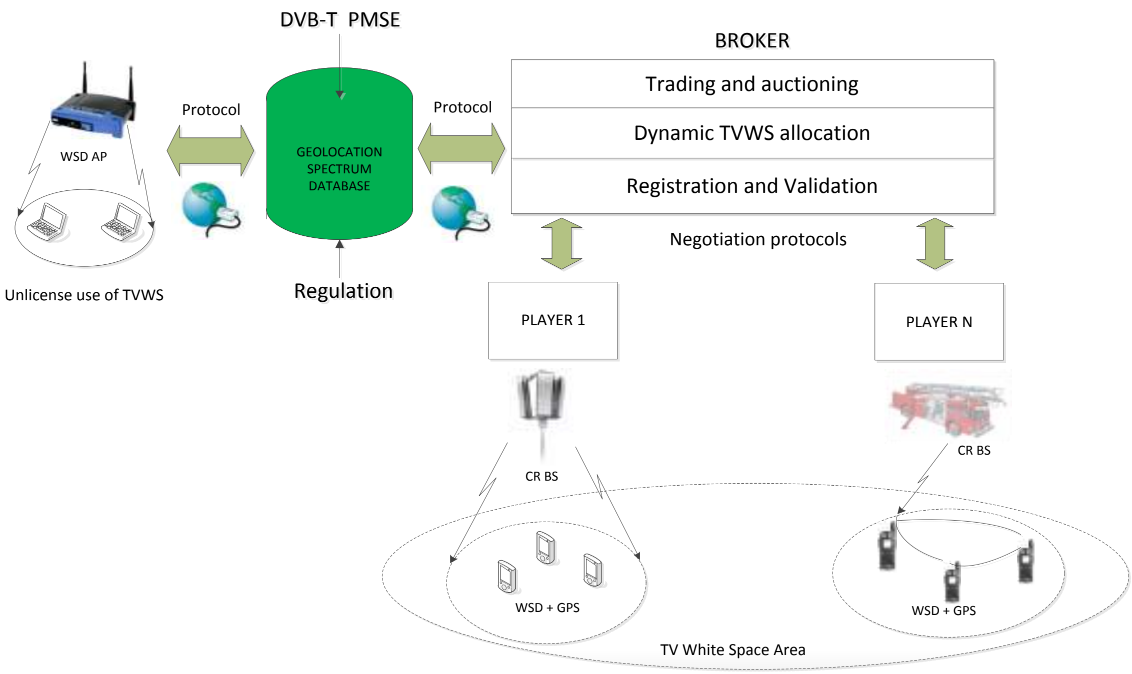

Figure 11: COGEU reference model assuming regulatory scenario 2

The implications of the 2nd Regulatory Scenario are as follows:

- The system shall be able to facilitate coexistence with other secondary systems operating in TVWS. This is done through dynamic TVWS allocation mechanisms based on protection rules specified for each combination.
- Cross-border issues have to be considered in the specification of the database. In COGEU context, assisted-GPS technology will be adopted in order to overcome problems with low signal levels, enabling also the usage of secondary systems devices in indoor environments.
- Players (spectrum holders and spectrum seekers) are subject to regulation. Regulators must determine exactly what rights can be granted to secondary users. A centralized spectrum broker manages TVWS on real-time basis subject to non interference rules. Moreover, specification of spectrum usage rights and obligations, the minimum set of information that parties to a spectrum trade must disclose, and approaches to the protection of competition needs to be investigated. **It is important to note that this model has the potential not just to open the market to new players but that it also has the potential to create new business opportunities for the spectrum broker entity be it in new public sector roles or in the commercial sector**.

The following core elements for an efficient secondary spectrum market should be taken into account in the subsequent development of the project [2][3]:

- *a large number of buyers and sellers to create competition necessary for an efficient market,*
- *clearly defined rights to the spectrum for both buyers and sellers,*
- *free entry and exit to the secondary markets,*
- *availability of relevant information to all buyers and sellers,*
- *a mechanism to bring buyers and seller together and facilitate the transaction with reasonable administrative costs and time delay,*
- *reliable procedures for payment between players, etc*.

These features will be partly addressed in the COGEU architecture and in the subsequent work packages.

4- Initial architecture for spectrum commons with sensing and geo-location access required

The main objective of this task is to derive reference architecture for the first COGEU regulatory scenario considered under the 1st Regulatory Scenario. For the COGEU TVWSDs (spectrum commons) a master-slave configuration is envisage, where the master connects to the database and the slaves are managed by the master, without necessary access to the database.

4.1- Master-slave architecture

In line with current regulatory bodies (FCC, OFCOM) device distinction, COGEU considers two types of TVWS Devices:

- "master devices" that contact a database to obtain a set of available frequencies in their area; and
- "slave devices" which obtain the relevant information from master devices but do not contact the database themselves.

For example, a master device might be a wireless router in a home – similar to a WiFi router but operating in the interleaved frequencies – while the slave devices might be other wireless devices in the home such as laptops and printers that are connected to the router. In order to be used legally within, any device that emits a radio signal must either have a licence or be exempted from licensing. In the Spectrum Commons regulatory scenario considered, it is proposed to exempt TVWSDs from the need to be licensed.

4.1.1- Master devices

Master devices are generally fixed location devices communicating with the central geolocation database. In line with OFCOM recommendations, exemption from licensing of a "master device" would be subject to the following:

i) Determining its location and assessing the accuracy of that location with 95% certainty. This location accuracy should reflect the maximum area of operation within which slave devices can be located.

ii) Consulting a list of geolocation databases and selecting one of these databases unless it has previously consulted the list within the last 24 hours.

iii) Sending its location and accuracy of that location to the selected geolocation database along with its model identification and for devices mounted on a master or similar its height above ground level.

iv) Receiving from that database a set of parameters including the frequencies of allowed operation, associated power levels, geographic validity of operation and time validity of operation. Other parameters may also be provided.

v) Operating in accordance with these parameters, ceasing transmission immediately where the time validity expires or where it moves outside of the geographic area of validity.

vi) Operating in a "fair" manner, sharing the available spectrum resource as evenly as possible across competing users.

vii) Provision from the device manufacturer as to the out-of-band performance of their device in terms of relative power levels emitted into adjacent bands up until n+/-9 or until power falls to the noise floor.

viii) Managing slave devices as required by signalling to them the parameters by which they may communicate with the master device.

ix) Maintaining a record of all active slave devices and requiring slave devices to stop transmission if the master device needs to cease transmission for any reason including an expiry of time validity or moving outside the geographical area of validity.

4.1.2- Slave devices

Slave devices must receive regular signals from master devices that provide an updated list of good-to-go channels, or they must contact the master device themselves at least once per minute. Meanwhile the master device and fixed devices must check their own locations at the same rate, except if in "sleep mode"—that is, the machines aren't transmitting data, but they aren't powered down either. Exemption from licensing of a “slave device” would be subject to the following:

i) Receiving a signal from a master device indicating that a channel is available for use along with an allowed power level.

ii) Operating in accordance with the signaling from the master device.

iii) Ceasing transmission immediately when instructed by the master device or within 5 seconds of not receiving a response from the master device to a transmission.

iv) Transmitting only to a master device (and not directly to other slave devices).

v) Provision from the device manufacturer as to the out-of-band performance of their device in terms of relative power levels emitted into adjacent bands up until n+/-9 or until power falls to the noise floor.

4.1.3- Information exchange between geo-location data base and WSD

As first requirements for TVWS Devices (in this case Master devices) information exchange with a geolocation database, we’ll stick to regulatory bodies, and in particular OFCOM that provides recommendations on that topic.

Information Provision according to OFCOM in [23]:

- Location: The device would provide its location and the accuracy of the location. Download only frequency availability relevant to its current location.
- Device type: Providing information about the type of the device, it might allow information to be returned according to device capabilities.

Information returned to the device

- Cognitive devices using geolocation will be prohibited from transmitting until they have successfully communicated with the database and determined which frequencies, if any, are available in their location.

Frequency availability

- It seems appropriate for the database to perform the computations needed to translate the known transmitted location into frequency availability. Making these calculations to the database ensures that they can be carefully verified and changes made if necessary.

Form of Information

- The simplest form of information would provide a list of frequencies that could be used within each pixel.
- In order to allow variable size bandwidths to be used using start and end frequencies seems more appropriate.
- In addition the maximum transmit power can be provided for each frequency assignment. This would allow the devices to operate accordingly in order to minimise the possible interference or to increase the flexibility of the device.

Considerations on Location

- All the terrain covered by a geo-location database is represented as “pixels” which are squares of prearranged dimensions.

- Each pixel is associated with a list of available frequencies and other relevant data that are provided to cognitive devices querying the database.
- It should be noted that the area associated with the "location" as determined by a WSD may cover one or more pixels, depending on the location accuracy of the device.

The following technical information needs to be communicated by the WSD to the geo-location database:

- Location
- Location accuracy
- Expected area of operation (optional) – coverage area
- Device type
- In the case of a master/slave WSD configuration, the above information will be obtained by the WSD master by requesting it from its associated slaves or deriving it by other reliable means.

The following technical information will be communicated by the geo-location database to the TVWSD:

- Available frequencies (minimum requirement)
- Maximum transmit power
- The appropriate national/regional database to consult

Also, on a more generic basis, systems operating under TVWS should follow those rules:

- The TVWSD shall only transmit in the 470-790 MHz band once it has successfully communicated with the database and received the instructions regarding the frequencies available in its location and the allowed power levels.
- In the case of a master/slave WSD configuration, it can be envisaged that the master would be responsible for the query of the database and that associated slaves would be controlled by the master and would receive information on their operational parameters (channels, powers, etc) directly from the master without querying the database themselves.

4.2- Architecture for combination of geo-location database with sensing

Although the recent moves from FCC and OFCOM have removed sensing requirements, COGEU has to accommodate some level of local sensing because:

a) The protection of no registered wireless microphones (PMSE) is required.
b) The process of moving PMSEs to specific channels and store them in a database will take years to be finished.
c) Few EU countries have a database for wireless microphones.
d) PMSE usually operate indoors, implying that they are hard to geo-locate.

TVWS Devices (TVWSD) have in principle two methods to determine if a channel is occupied or not: (1) sensing, where the channel is probed to find incumbent signals at or above certain signal strength; (2) consult a geolocation database where for a certain region the attribution of the channels to primary users is presented.

Both methods have their advantages and disadvantages. For sensing, to avoid hidden-node problem, the channel must be sensed at very low levels of signal strength, e.g. -126 dBm for wireless microphones, which is less than the noise floor (-121 dBm). Sensing at this level may raise the false alarm rate. However, sensing makes devices truly cognitive and it is useful to detect signals that are not registered in databases.

The geo-location database is based on predictable models to determine the coverage in a certain region, namely its boundaries, which can be quite inaccurate. Furthermore, the device needs to provide its location, e.g. by means of GPS, and access to the database (or use a preloaded device), which may be costly. However, the channel occupancy is based on databases and is independent of channel characteristics, which can greatly reduce the false alarm rate. Databases need to be updated with correct information as time goes by, otherwise errors in the database will lead to interference in the field.

In this sense, a solution that combines sensing and geolocation databases seems to be the most reasonable solution, optimising channels occupancy and minimising the false alarm rate.

4.2.1- Methodology for combination sensing with geo-location database

In the first COGEU regulatory scenario TVWSD are capable of performing sensing and geo-location database access. The geolocation spectrum database is used to determine if the device is inside or outside a TVWS area. Let T be the threshold that the sensor uses, e.g. T = -120 dBm for DVB signals. Let S(T) be the decision based on the threshold T, and G be the decision based on the geo-location database, as presented in Table 1.

G = 0	The device is inside the TVWS map and the channel is vacant
G = 1	The device is outside the TVWS map and the channel is occupied

Table 1: Channel availability based on geolocation-only information

Following the same approach, for S(T) the information may be presented as in Table 2.

S(T) = 0	The signal is less than T and channel is vacant
S(T) = 1	The signal is higher that T and the channel is occupied

Table 2: Channel availability based on sensing-only information

When combining both sensing and geo-location information four situations may occur, as shown in Table 3.

G AND S(T)		Decision
G = 0	S(T) = 0	Channel is vacant
G = 1	S(T) = 1	Channel is occupied
G = 0	S(T) = 1	The sensing information is used for the decision as shown in 1)
G = 1	S(T) = 0	The sensing information is used for the decision as shown in 2)

Table 3: Channel availability based on geo-location and sensing information

1) In this situation the database indicates the device is inside the TVWS map and the channel is vacant but the sensing detected a signal level greater than the threshold. In this case, the threshold shall be increased by Δ_1 and the new value used as threshold, e.g. if $S(T + \Delta_1) = 1$ the channel is occupied, otherwise is vacant.

2) In this situation the database indicates the device is outside the TVWS map and channel is occupied but the sensing detected a signal level less than the threshold. In this case, the threshold shall be decreased by Δ_2 and the new value used as threshold, e.g. if $S(T\text{-}\Delta_2) = 1$ the channel is occupied, otherwise is vacant [4].

Expanding Table 3, the decision process is made as in Table 4.

G AND S(T)		G AND $S(T \pm \Delta)$		Decision
G = 0	S(T) = 0			Channel is vacant
G = 1	S(T) = 1			Channel is occupied
G = 0	S(T) = 1	G = 0	$S(T + \Delta_1) = 1$	Channel is occupied
G = 0	S(T) = 1	G = 0	$S(T + \Delta_1) = 0$	Channel is vacant
G = 1	S(T) = 0	G = 1	$S(T\text{-}\Delta_2) = 1$	Channel is occupied
G = 1	S(T) = 0	G = 1	$S(T\text{-}\Delta_2) = 0$	Channel is vacant

Table 4: Final decision process for channel availability based on geolocation and sensing information

Depending on the choices for Δ_1 and Δ_2 the following cases are possible:

1) $\Delta_1 = 0$ AND $\Delta_2 = 0$: Rely on sensing alone with threshold T.

2) $\Delta_1 = \infty$ AND $\Delta_2 = \infty$: Rely on geolocation database only.

3) $\Delta_2 = \infty$: Rely on geolocation spectrum database inside coverage area and sensing outside with threshold of $T + \Delta_1$.

4) $\Delta_1 = \infty$: Rely on geolocation spectrum database inside coverage area and sensing outside with threshold of $T\text{-}\Delta_2$.

These possibilities may be used as policies depending on the region (rely on sensing or geolocation spectrum database) to determine if the channel is occupied or vacant.

Thus, appropriate values for the threshold shall be selected. For example, in the case of wireless microphones, it is required to sense them for values of -126 dBm (and the thermal noise is -121 dBm) or for DVB signals it is required to sense them for values of -120 dBm (and the thermal noise is -105 dBm) [5]. On the first case, using T = -121 dBm, $\Delta_1 = 2$ and $\Delta_2 = 6$, means using a sensing level of -127 dBm inside the TVWS map area determined by the database and -119 dBm outside the TVWS map area. That approach makes sense because within the TVWS map area devices require extra protection than the ones outside.

In a region where both DVB and wireless microphones coexist, the lowest threshold shall be used.

4.2.2- General Architecture Description

In the next description only spectrum commons, which is the one that uses a geolocation spectrum database, is considered. Furthermore, the access to the databases is based on network protocols with reliable connections. Finally, each secondary system is a master controlling several TVWSDs (slaves) with sensing capabilities under the master's serving area.

When the TVWSD(slave) requires communication, it requests a TVWS channel from the WSD(master);or just requires a channel to start transmitting and no legacy channel is free, so a TVWS channel is required. The TVWSD(master) inquiries the geolocation spectrum database for TVWS availability in the area, providing the GPS location and cell radius[1] of the secondary system (WSD master and slave). The geolocation spectrum database transmits the list of vacant TV channels and maximum transmit power (TVWS spectrum pool) to the master.

The TVWSD (master) asks the TVWSDs (slaves) to sense locally these potential channels (only these!) in order to detect wireless microphones, DVB-T or other systems. The WSDs perform the sensing and report the information to the master plus the GPS location.

The sensing from more TVWSDs provide a more accurate information; the master combines sensing information coming from different TVWSDs, apply a fusion rule and forward the channel information to be used to TVWSD (slave). The cooperative sensing algorithm can utilize past channel histories to make predictions on future spectrum availability. This process is illustrated in Figure 12.

Under this arrangement TVWS operation is only allowed upon a double affirmative from both the geolocation spectrum database and collaborative sensing. These permits to identify any wireless microphone operations and any other protected signal that might be present at their location but do not appear in the database.

[1] This information depends how the geolocation spectrum database is implemented; the predictions of signal coverage may be based on transmitted power, antenna type and height, and theoretical transmission models, and not the cell radius itself.

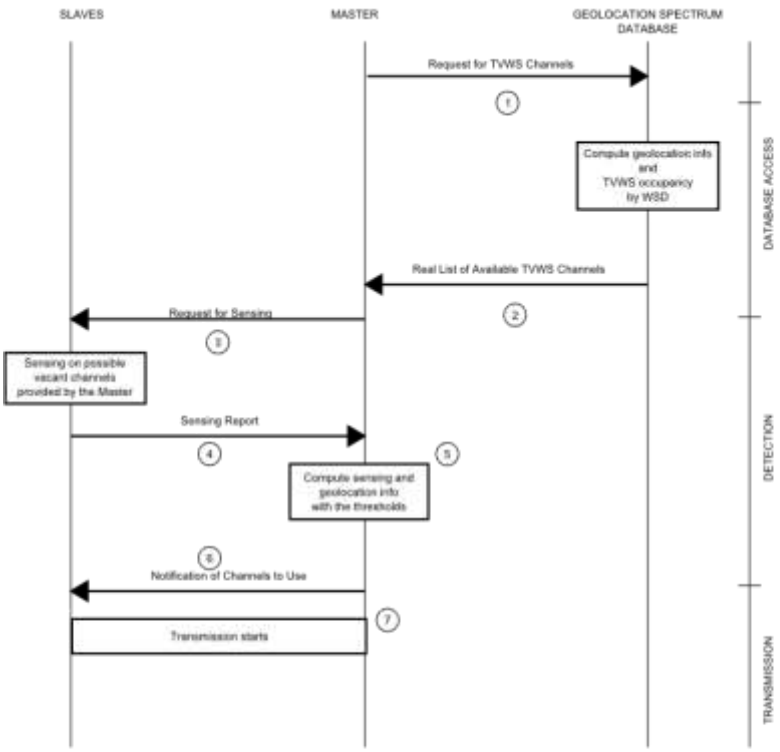

Figure 12: General architecture for combining geolocation and sensing information

The diagram presented in Figure 12 is better explained in following table.

#	Action	Required/given information	Description
1	Request for TVWS channels	GPS coordinates of devices, number of channels, occupancy time	The Master detected that needs additional frequencies according to certain location. So it forwards the request to the geolocation spectrum database.
2	Real list of available TVWS channels	GPS co-ordinates, channels, coexistence policies	List of channels per location according to location that are really vacant (from primary users) according to database
3	Request for sensing	Device_ID, channel(s)	According to the location of each WSD, the Master provides the possible vacant channels and requests sensing on those channels to detect primary users that are not registered
4	Sensing report	Device_ID, channel(s), detected signal strength	The sensing information is sent to the Master to be further processed
5	Compute sensing and geolocation information	Channels, detected signal strength, threshold T, Δ_1 , Δ_2	Detect if channels are occupied or vacant based on geolocation and sensing information. In this phase, a suitable value for threshold T must be selected
6	Notification of channels to use	Channels	The Master sends the notification to the Slaves about the channels that shall be used to transmit. There is one channel per Slave
7	Transmission start		From that moment on, the transmission may start. Periodical sensing may be required to detect primary users

Table 5: Relevant actions for combining geolocation and sensing information

Any of the previous information may be changed in order to follow the work done in other WPs.

5- Initial architecture for commons and secondary trading, only geo-location access required

COGEU will consider a centralized topology with a spectrum broker trading with players. The spectrum broker controls the amount of bandwidth and power assigned to each user in order to keep the desired QoS and interference below the regulatory limits. In the COGEU reference model, the centralised Broker is an intermediary between the geo-location database (spectrum information supplier) and players that negotiate spectrum on behalf of spectrum users.

The main innovation brought by COGEU is in the combination of unlicensed access to TV white spaces with secondary spectrum trading mechanisms.

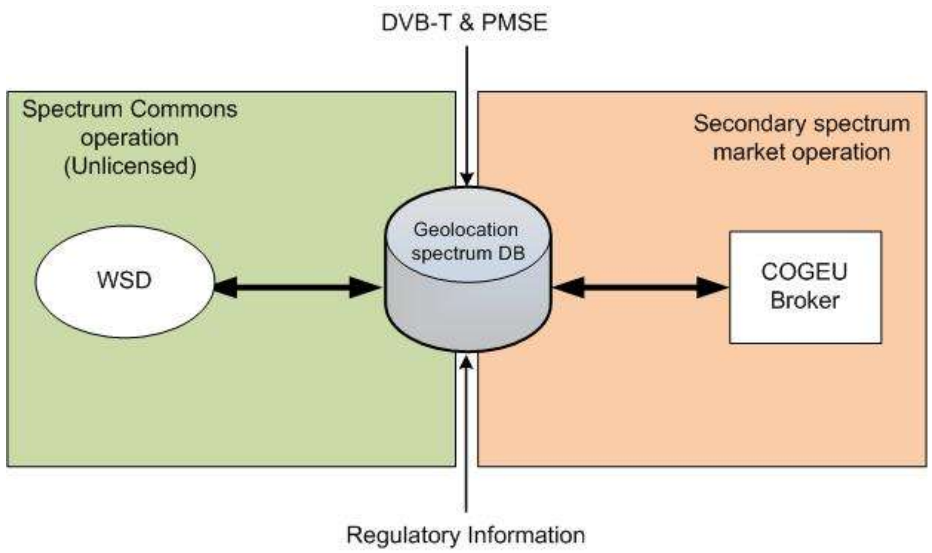

Figure 13: Geolocation database with allowing spectrum commons and secondary spectrum trading operations

In line with previous conclusion on spectrum use in section 3-, COGEU proposes to divide spectrum into Unlicensed (in green in Figure 13) and spectrum market (in orange in Figure 13). We strongly believe it is the best way to manage spectrum use, in line with current European regulators situation in early 2011. Indeed, with this assumption as the basis for our scenario, COGEU architecture will benefits from the best of both alternative (Commons and Spectrum market) while staying flexible enough to fit with any regulator decision in the future.

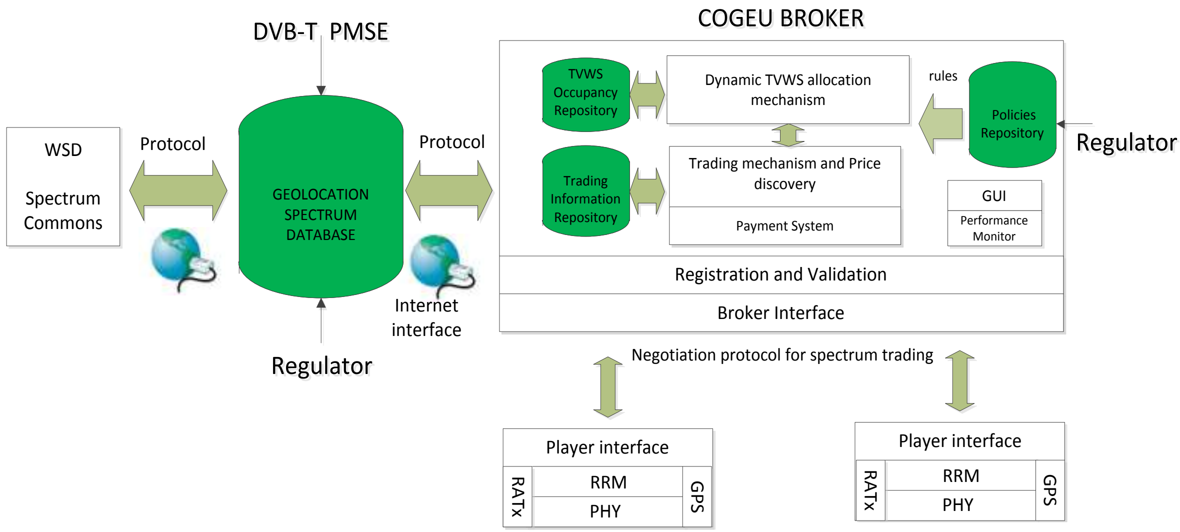

Figure 14: Initial COGEU reference architecture for commons and secondary trading, only geo-location access required.

COGEU will consider a centralized topology with a Geolocation Spectrum database dealing directly with TVWS Devices (Spectrum Commons world) or with Spectrum Broker (Secondary Spectrum Market). An overview of the spectrum broker reference architecture is presented in Figure 14. The spectrum broker controls the amount of bandwidth and power assigned to each user in order to keep the desired QoS and interference below the regulatory limits. In the COGEU reference model, the centralised Broker is an intermediary between the geolocation database (spectrum information supplier) and players that negotiate spectrum on behalf of spectrum users. The COGEU reference architecture supports both Spectrum commons and Secondary Spectrum Market, and its main elements are extensively described in the following sub-sections.

5.1- TVWS allocation and trading mechanism

The spectrum broker determines how the TV white spaces are allocated among players, and also how much each player pays for the acquired spectrum [6][7]. Therefore, TVWS allocation and trading mechanism are important functions of the COGEU broker. Figure 15, shows the cycle of allocation, trading as well as maintenance of the TVWS repository in the COGEU broker. The preparation and analysis phase allocates the TVWS based on a matching algorithm to determine the best combination of the bands and respective technical parameters such as power emission, fragmentation etc, in order to maximize the usage of the TVWS. The trading phase allocates the TVWS to the most valuable users through auction or pricing mechanism. Finally, after the trading phase, the repository is updated to reflect the current status of the TVWS availability. The TVWS allocation and Trading Mechanisms will be presented in the subsequent subsections.

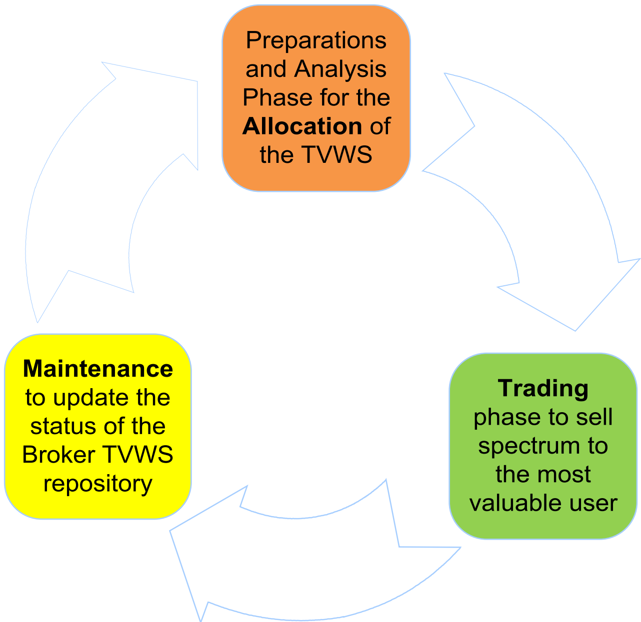

Figure 15: The three phases for the allocation and trading of the TVWS as well as the maintenance of the broker repository

5.1.1- TVWS Allocation

TVWS allocation mechanism: is an optimization problem of resources allocation designed by the technical point of view that can be solved by different optimization strategies as presented in D6.1.

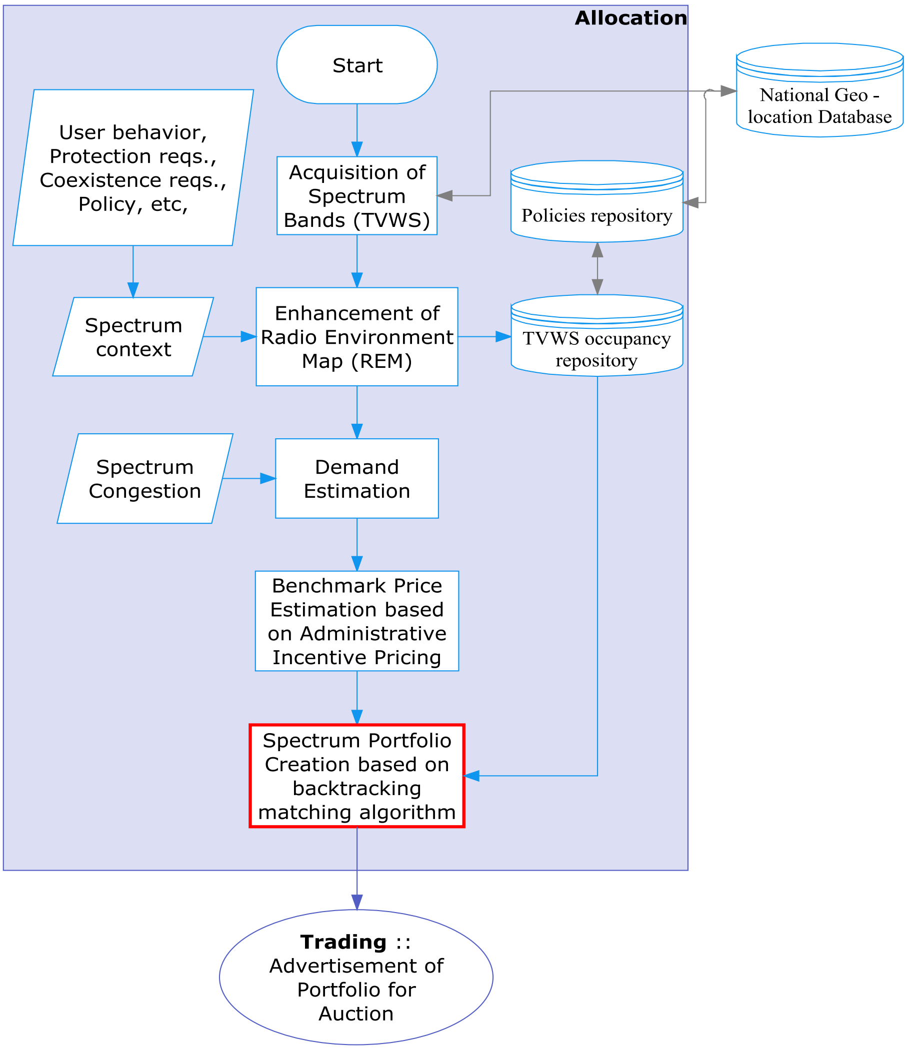

Figure 16 : TVWS allocation and trading mechanism based on D6.1

5.1.2- Trading mechanism

Several terms are important in the definition of spectrum. These include frequency, geographic location and time. Therefore, for a trade to occur, the needs of the buyer and seller must coincide across all three dimensions [9]. It is not envisioned in the TVWS that the buyer of spectrum will be used to provide DTV services, therefore, there exists incentives for license holders to sell spectrum to other usage as far as there is excess or unused bands which society would obtain more value if it was in the hands of a different user. As a result, the number of participants in a spectrum market may be very low. When the market is 'thin', the likelihood that a trade will take place decreases [9][10]. If a trade is conducted, it may occur at a price that is substantially higher (lower) than the buyer (seller) desired. A "thin" spectrum market may prevent current and prospective spectrum users from receiving the price signals they need in order to make decisions on how best to allocate their resources [4]. However, the Broker can increase market thickness by adopting appropriate trading mechanisms that create the opportunity for and enhance the willingness of spectrum users to conduct a trade.

The COGEU broker determines how the TVWS are allocated among service providers, and how much each service provider pays for each spectrum asset. The allocation method, or mechanism, must balance efficiency with complexity [7]. The trading mechanism could be realized through an auction mechanism in which the broker collects bids to buy from the service providers, bids to sell from the geolocation database, and subsequently determines the allocation along with the price for each spectrum asset. The auction would then be repeated as spectrum assets become available (i.e., as they are released by supplying players). Figure 17 illustrates the COGEU trading mechanism based on auction.

Alternatively, the COGEU Broker could announce a set of reference prices for the available TVWS, and adjust the prices based on time, location, bandwidth required and other factors to maximize expected revenue or to clear the market periodically. This approach is generally simpler, and requires less overhead (information exchange) than an auction mechanism [7]. However, a well-designed auction mechanism can achieve either a higher efficiency or more revenue depending on the intended objective.

As Figure 18 shows, the choice between these two approaches should depend on the thickness of the market. When the market is thin, that is with relatively few buyers and sellers, an auction mechanism may be preferred doe to simplicity in implementation and the chances for higher revenue. However, when the market is thick, with a large number of buyers and sellers, the pricing mechanism should be preferred due to decreased loss in terms of efficiency or revenue.

The COGEU broker provides a platform where both pricing and auction mechanisms are supported. In both approaches the algorithm for maximizing profit and the sequences of information exchange for bidding or price adjustments are done automatically. This is supported by electronic definition of spectrum rights.

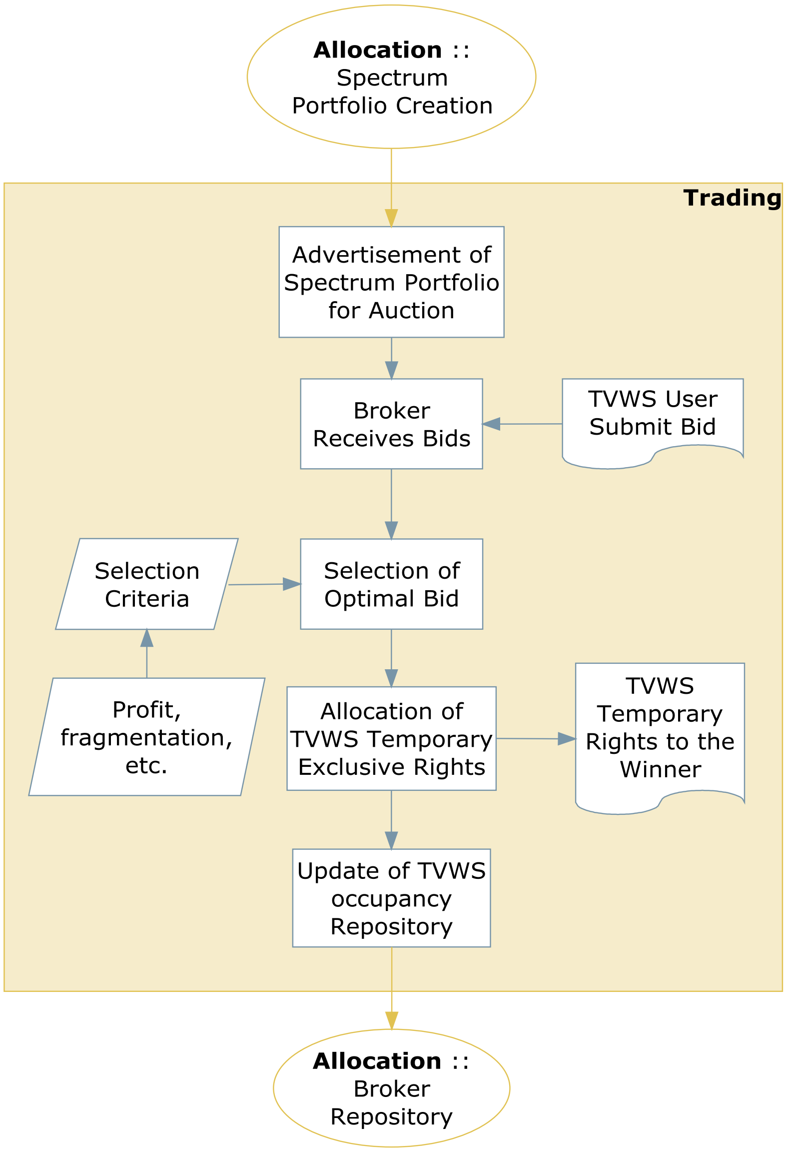

Figure 17: TVWS trading mechanism based on D6.1

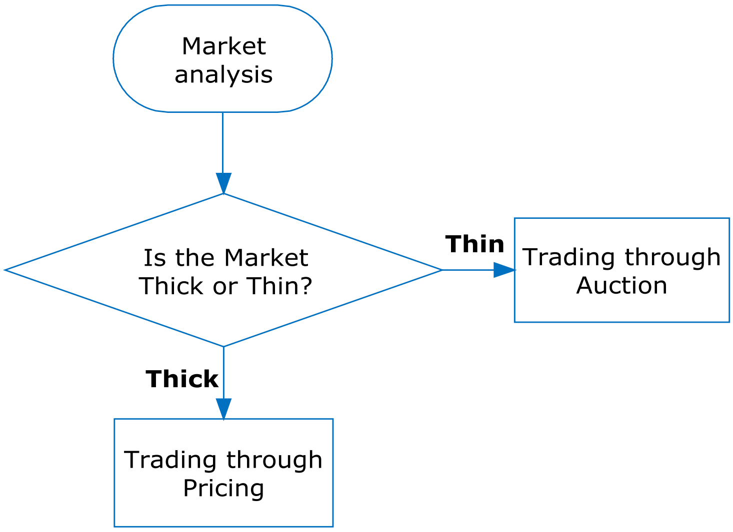

Figure 18: Thick versus thin market

5.2- Negotiation protocols for trading spectrum rights with the broker

The COGEU broker supports *pricing* mode and *auction* mode for allocating spectrum. In the *pricing* mode, the price is decided by the allocation procedure which considers various factors which influence the value of TVWS in a given place. In the *auction* mode, the auctioned band has a benchmark price, then each demand (bid) has an associated price and the winning bid decides the final price. In this section, the interfacing signalling between the broker and the spectrum user are presented. The signalling interface is the protocols that enable the transaction of spectrum between the broker and the user to take place efficiently. Through these negotiation protocols, the Broker maximizes its revenue as well as ensures fairness between players. In this case, spectrum is sold in terms of first come first serve basis in the *pricing* approach, or the most valuable bidder wins the band depending on the *auction* mechanism.

In the following subsections the negotiation sequence steps of the *pricing* and *auction* modes will be given. The modes are based on the flow charts presented in Figure 16 and Figure 17.

5.2.1- *Pricing* mode protocol

Figure 19 gives the operation sequence of the pricing mode protocol. The sequence is as follows:

(1) The broker informs the players about the available TVWS portfolio and corresponding prices,

(2) Network operators and service providers buys spectrum in first come first serve basis

(3) The broker authenticates the players

(4) The Broker process the bill for the temporary spectrum rights for the buyer.

(5) The payment systems authorizes the transaction (or payment)

(6) The Broker allocates temporary spectrum rights to the buyer

(7) The Broker updates the local TVWS repository and monitors market

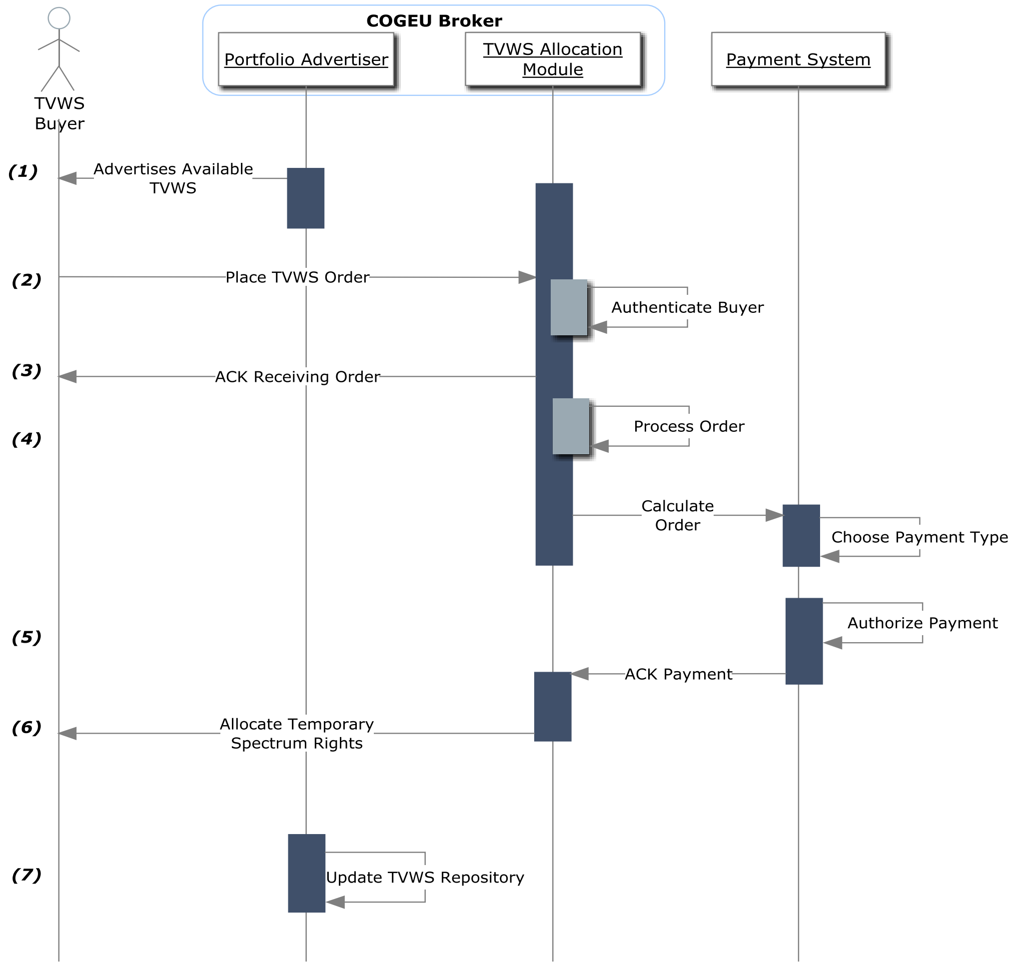

Figure 19: Pricing mode protocol sequence diagram

5.2.2- *Auction* mode protocol

The auction mode behaves differently depending on the type of auction. The following is a generic sequence of events in allocation the TVWS through the auction mode:

1. The broker informs the players about the available spectrum.
2. Network operators and service providers send their bids for the spectrum.
3. The broker authenticates the players
4. The broker solves an auction to maximize its revenue or spectrum efficiency.
5. The Broker informs the bid results.
6. Depending on the auction mechanism, an iteration (1-5) continues until the bit winner is found.
7. The broker announces the final results
8. The winner acknowledges the results
9. The Broker process the bill for the temporary spectrum rights to the bid winner.
10. The winning bidder authorizes transaction (or payment
11. The Broker allocates the temporary spectrum rights to the winner.
12. The Broker updates the local TVWS repository and monitors market
13. The player transmit their data.

Figure 20 shows an example of the English auction protocol message sequence.

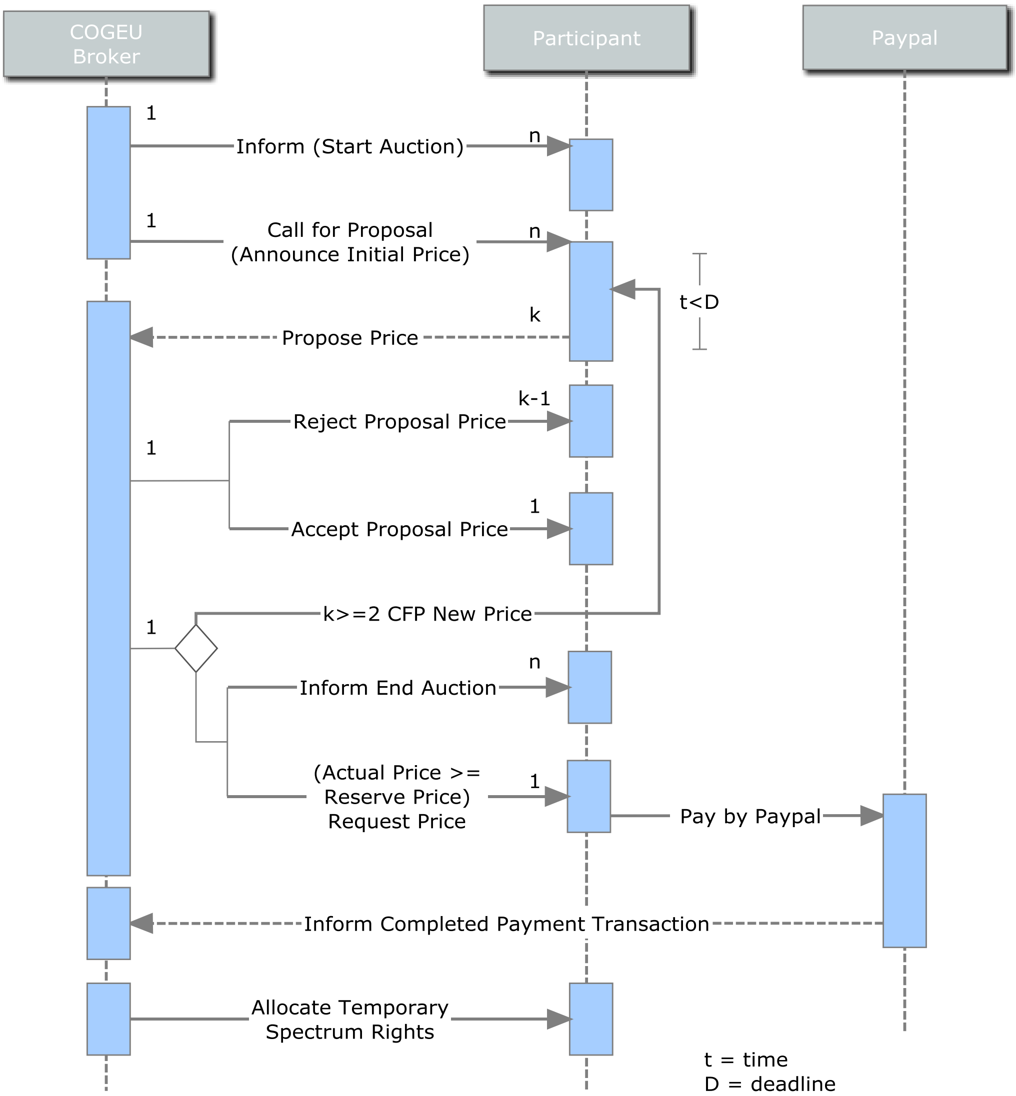

Figure 20: English Auction Protocol

5.3- Payment System

Provides the facility that from the spectrum broker side allows to deliver and check out bills (either repeatedly or only once) from the TVWS users to pay them. In the TV white space context information provision service, the payment system provider plays an important role since the TV white space user is paying every time it wants to acquire reliable TV white space availability information, and hence its functioning should be reliable to avoid being a single point of failure for the model. Assuming a web interface for COGEU Broker TVWS transactions, Figure 21 give an example of payment with an electronic payment system, Paypal. In the figure, the buyer represents the Spectrum Buyer, the Merchants represent the COGEU Broker and Paypal is the payment system.

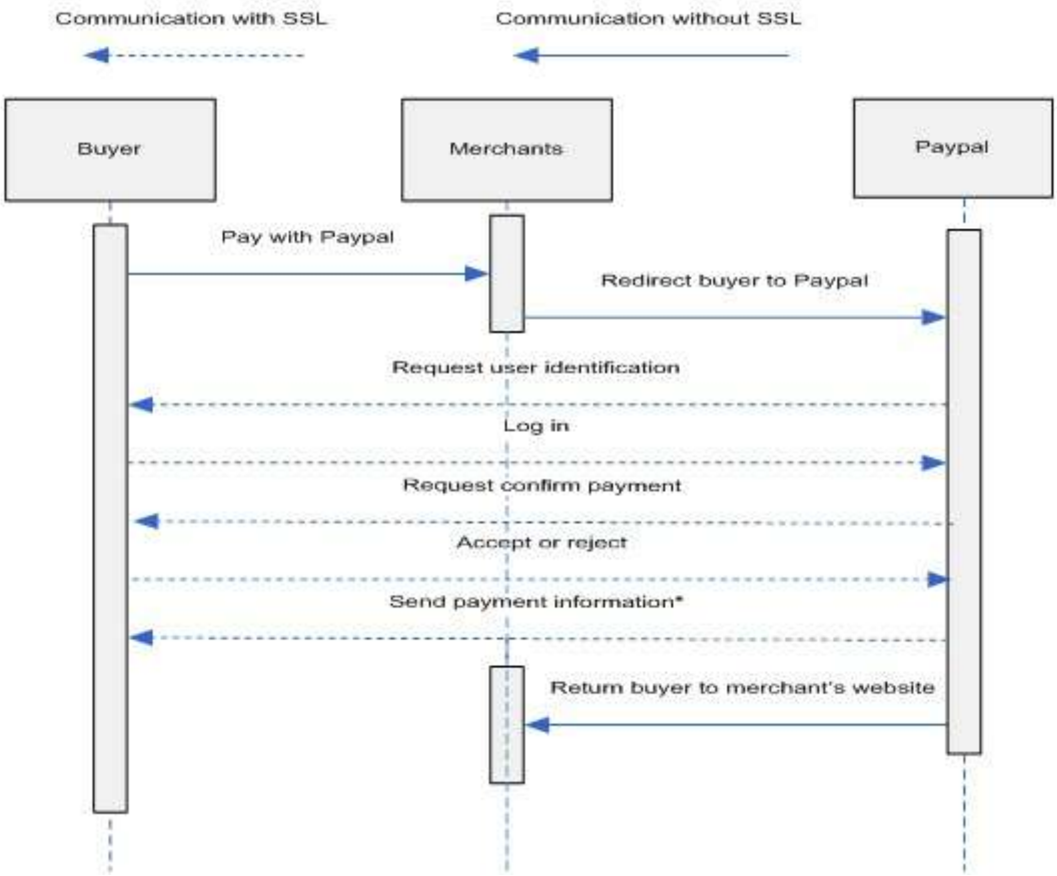

Figure 21: Paypal transaction protocol (Paypal) (* Note that before send payment information, Paypal will adjust the buyer and merchant's Paypal account) (source [11])

5.4- External geo-location spectrum database

In COGEU model, the regulatory bodies assign TVWS for spectrum commons (free access) in given areas. The remaining TVWS can be traded in a secondary spectrum market. The design of COGEU geo-location database has to deal with these two operation models. The COGEU geo-location database receives enquires from both, unlicensed WSD's and from entities running spectrum brokers. [D4.1]

Each pixel has associated an operation "Mode" field, in order to make clear if a specific entry will be used by the Broker or by the spectrum of commons model. [D4.1]

The main purpose of the COGEU geo-location database is to enable the protection of the incumbent systems from harmful interference. Interference can be caused by white space devices when operated in the same or adjacent channels with the incumbent systems. In order to be able to offer sufficient protection, various parameters need to be specified that will enable and help the protection process in conjunction with the overall anti-interference database design.

The design of COGEU geo-location database has to deal with these two operation models. The COGEU geo-location database receives enquires from both, unlicensed WSD's and from entities running spectrum brokers. In particular, when the available TVWS are calculated, according to the regulator's policies a percentage of these available TVWS are marked for spectrum commons access, and the remaining for spectrum market. When this distinction is made, COGEU geo-location database model can operate both spectrum sharing regimes. The spectrum of commons model will operate in the bands marked for unlicensed use TVWS, and the (COGEU) broker will trade the spectrum that is marked for secondary trading. An entity called spectrum commons manager will make sure that the enquiries of WSD are served from the already divided spectrum for the specific use, and an entity called Broker manager will deal with enquiries coming from the Brokers. The difference is that the Broker will request and receive batch data concerning the availability for all spectrums that is available for trading, and then the broker will use the available spectrum information efficiently through trading.

Besides the information on the incumbent systems that a database will hold, it will also include the geo-location information per geographic pixel for a specific region and records of the WSD that operate in the specific region. This will lead to database information explosion. Due to the vast amount of information that the database is expected to store, a hybrid approach for the database topology design is required. Therefore, for efficiency and better performance, COGEU geo-location database will adapt a two level database topology. The first level will contain the regulator's controlled information, which includes the incumbent system's parameters. This information can be contained in one database that holds information per country. The second level of information will hold the calculated geo-location information and the operating WSD devices per specified region of control. This design also offers the flexibility of the deployment of more than one database for one region and thus allows competitive operation of database administrators.

Details on the interfaces for the geolocation database are given in section 5.7.1-.

5.5- COGEU broker internal repositories

The COGEU spectrum broker role is to determine how spectrum is allocated among secondary users, and also how much each player pays for the acquired spectrum. To do so, it has to maintain internal repositories dealing with secondary users co-existence, spectrum policies implementation, and trading information.

5.5.1- TVWS occupancy repository

In general TVWS occupancy repository holds TVWS channels occupied by other TVWS networks before the actual allocation process, current status of secondary networks and real-time spectrum occupancy of TVWS.

As Figure 22 shows, the TVWS occupancy repository is designed to keep a track of the allocated TVWS spectrum for trading by the broker. In D4.1 has been described that the available spectrum that the geo-location database manages will be divided in two categories. The one category is for unlicensed use, in spectrum of commons, and the second category for trading on the secondary market, which is managed by the broker entity. The contents and operations of TVWS occupancy repository are designed to enable and help the provision of QoS to the secondary players in the TVWS bands.

The TVWS occupancy repository is the unit that contains all the information where TVWS devices may transmit and also contains information on active TVWS devices and their operational parameters. The repository carries all the information required to estimate mutual interference between TVWS systems. One of the fundamental parameter in this database is the spatial resolution (the cell size). It is defined once at the introduction of the system and then kept fix. However, a change to another resolution may not be excluded, even use of different resolutions may be reasonable.

The first step is to make sure that correct information is included in the repository. In order for the TVWS occupancy repository to provide updated information to the broker modules for trading, the interface that was described in D4.1 between the geo-location database and the broker is used. The aforementioned interface is designed for exchanging information between the geo-location database and the TVWS occupancy repository.

The TVWS occupancy repository not only contains the data, it as well hosts the methods to manage the TVWS systems and generate events or reacts on external events relevant for the management of TVWS systems, e.g:

a. Data
   - TVWS (channels unused by incumbent services: DVB-T, PMSE…), supplied by the external database.
   - All TVWS devices in use in the considered area with its describing parameters
b. Methods
   - How to fill the database / updating the database (TVWS)
   - Management of database (add/modify/remove TVWS service)
   - Perform interference calculations / calculate coverage of TVWS devices…{using the methods of the spectrum policy database }
   - Handle prioritized services
c. Events
   - Trigger TVWS Update (periodically / on external trigger)
   - Start prioritized service

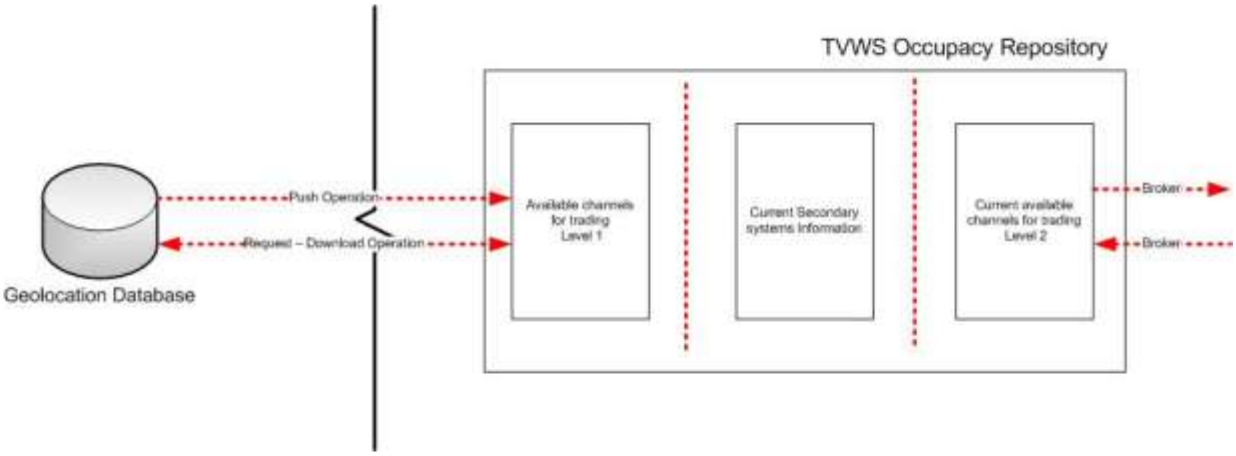

Figure 22: TVWS Occupancy Repository

There are two different methods for this communication. On a specified interval, for instance once a day, the TVWS occupancy repository downloads the available channels for trading. As an alternative the geo-location database can push these information when and if there is a change in the geo-location database data that affect the current broker trading area. When the information are available at the TVWS occupancy repository, stores them for trading reference, compares the information with the previous and if there are any conflicts regarding the allocated bands, actions are initiated in order to resolve the conflict, based on the predefined policies . The communicated information includes the available channels and the maximum transmit power per geographical pixel that has been marked for trading by the geo-location database entity.

The two different types of communication between the TVWS occupancy repository and geo-location database, are necessary due to the variability of the operation areas and in order to accomplish the validity and uniformity of data between the two databases for optimal protection of the primary users and optimal allocation of bands to the secondary users.

When the information for the band availability is in the repository, the broker can use the information for evaluating the secondary player's requests for usage. During this process when a request is made for usage from a secondary player, an evaluation process is taking place that the current request will not cause to the already allocated spectrum interference. This is important, since the secondary players, request a band and if it is allocated to them, it needs to be guaranteed, under conditions, for optimum availability and interference from other secondary systems.

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.

Due to the fact that the broker is solely dealing with the secondary spectrum market, it will only take into consideration the secondary systems that operate in the TVWS bands that the broker controls. In order to enable the broker to manage the spectrum, TVWS repository needs to include the following information.

As aforementioned, TVWS repository needs to hold information that will ensure the seamless operation of the entity and the broker overall. The available channels with the maximum transmit powers will be in the repository after the processing and inclusion of the current operated secondary systems. The characteristics of the already deployed secondary systems that have been allocated spectrum will also be stored in the repository. Connecting information and expiration dates for the band in use also will be in the repository.

These information entities will be needed in order to evaluate current and feature requests from secondary users regarding an available band for usage by a secondary player.

Other information that needs to be present in the repository is the specification for the secondary systems that already occupy and operate networks in the TVWS bands. This information will help in the evaluation of the potential interference from proposed system during the allocation process for a specific TVWS band.

5.5.2- Trading Information Repository

The trading information repository stores trading information to maximize auction revenue, spectrum utilization and fairness such as reserve price and transaction costs. Information about local spectrum demand is important to adapt the trading behaviour in the future. TVWS occupancy repository is designed to keep a track of past auctions managed by the broker. It will then interact with the allocation mechanisms in order to maximise the revenue it can obtain.

5.5.3- Polices Repository

In order to facilitate trading of radio spectrum, participants (both buyers and sellers) require legal certainty over the rights and obligations that will be transferred. There are a number of basic steps in establishing a framework for trading spectrum:

- *Creating the tradable usage rights and defining associated rights and obligations.*
- *Permitting various forms of trading of these rights.*
- *Establishing rights to protection from and obligations to not create harmful interference in relation to liberalisation of use.*
- *Clarifying rules on the expiry of usage rights and regulatory powers to reclaim them.*
- *Developing clear rules to ensure effective enforcement of rights and obligations*.

A spectrum usage right is related with the availability of the spectrum (in terms of bands or channels) and ensures that all entities that want to compete for the spectrum usage are able to do it in the same conditions. Obligations specify conditions that users must fulfil in order to maintain their rights.

For example, when a specific channel in the secondary spectrum market is attributed to a certain entity, that entity has the right of exclusive use, but obligation to protect primary users and limit the interference with other secondary users.

5.5.3.1 Policies Management

A Policies Repository (see Figure 23) secure the policy management and distribution mechanisms in order to prevent malicious users from altering loaded policies as well as from inserting additional policies and thus causing harmful interference.

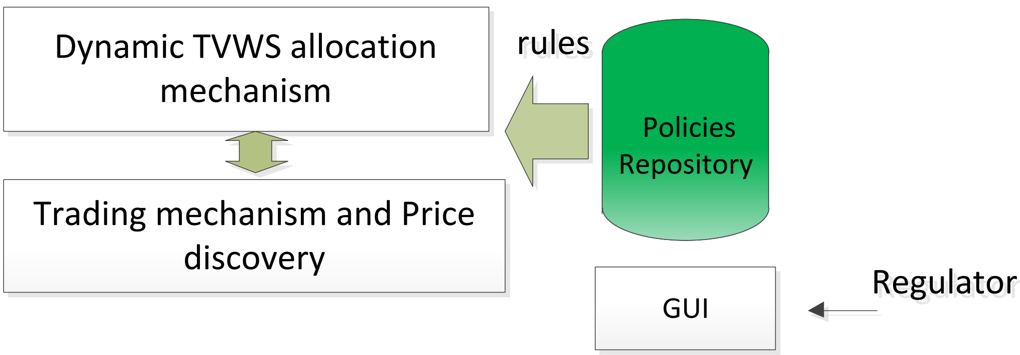

Figure 23: Policies Repository functional block

Authenticated and authorized stakeholders create and modify policy documents using the Policy Authoring Tool. The policy management tool (See Figure 24) is used to input active policies. This tool takes high-level policy information and constructs a more detailed, low-level policy description that can be applied to various devices in the network. This should be implemented as an intuitive graphical user interface (GUI) and can be either a standalone application or a component of a mission / network planning system. The resulting detailed policy description is stored in the policy repository (see Figure 23).

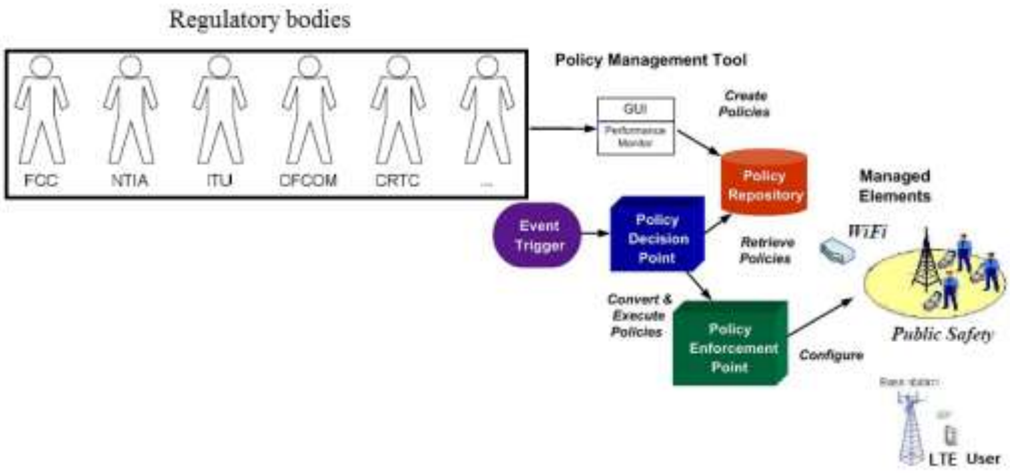

Figure 24: Policy management tool

The policy repository is most commonly a database, files or directory service. When persisted in a directory service, policy distribution becomes a part of the overall directory replication mechanism. This enables the policy descriptions to be automatically distributed throughout the network and aids in the synchronization of policies between the creation points and the enforcement and decision points.

Policy enforcement points (PEP) enforce and execute different policies, and can use intermediary policy decision points (PDP) instead of communicating directly with the repository.

Policies are used to describe the constraints on using the spectrum, such as for how long the spectrum can be used, what level of interference is allowed and what power level is allowed to transmit. The policies may vary depending on geographic region and time; therefore the systems must be able to load new policies at runtime.

5.5.3.2 Regulatory Policies for the Specification of Spectrum Usage Rights and Obligations

Rights to transmit or receive signals over spectrum can be defined in relation to four generic parameters:

- *Geographical area* e.g. an entire country, a region or a defined area around a base station.
- *Duration and time* of access, e.g., unlimited or defined length of licences, gain access to spectrum throughout the entire day, or at a specific time of day only.
- *Spectrum endowment*– the frequency bandwidth to which access is granted.
- *Protection from interference*– the right to receive signals without harmful interference from other spectrum users, and the obligation not to cause such interference.

All existing spectrum rights, whether distributed under a command-and-control approach or the market model, can be defined in terms of these generic parameters. In relation to the basic spectrum endowment, geographical area and duration/time, it should be quite straightforward to extend these concepts to tradable rights. The spectrum endowment can be specified as a start frequency and end frequency. Geographical boundaries are generally specified as vertical planes between two grid references, where TVWS users can change spectrum use interference needs to be regulated (e.g. one which limits emissions at the boundary) to protect other users from higher priority on a national basis. Duration and time of access are relevant where the right to access spectrum is being transferred between users for defined periods of time (e.g. as it is the case of special events broadcasting) and/or shared between users.

Existing licences, when converted to liberalised spectrum usage rights, should retain a definition of the current deployment. If required, such restrictions can be relaxed or removed through negotiation with neighbouring spectrum users. New licences can start with or without a definition of deployment and the rights may depend on the approach that is chosen. While systems using highly directional antennas could be accommodated within a general technology-neutral spectrum framework, it is considered that this would likely result in gross inefficiencies. Centralised planning is required for this and it may be appropriate to define a different style of licence.

The rights and obligations of tradable licence must be sufficiently clear: duration, area and interference restrictions. Obligations for the owner of the spectrum or broker have the following points:

- Coverage requirements;
- Quality of service requirements;
- Interoperability requirements (e.g. handover, roaming);
- Minimum service offering (e.g. location-based services, high speed data transfer, video telephony);
- Social aspects and universal service obligations, for instance special services for the disabled.
- The licensee's obligation not to interfere with other spectrum user's rights.
- The licensee's degree of protection from other users;
- The band which is available for use;
- The geographical area in which it can be used;
- The period for which the licence is entitled.

Procedures for scrutiny and reaction by the Broker responses must be in place to prevent or avert the consequences of trades which confer high levels of market power on firms acquiring licenses. Where existing licences become tradable and subject to change of use, rights should be established consistent with current uses; this will avoid conflicts of rights and permit parties to renegotiate rights when circumstances change.

5.5.3.3 Rules for Dynamic TVWS Allocation

To improve the utilisation of the spectrum, more dynamic access schemes are now being considered by regulators, in particular the FCC in the USA and the UK's Office of Communication (OFCOM). This consideration is supported with advances in the development of agile radio technologies. The central idea of dynamic spectrum access is not just that it leads to a great innovation in radio technology, such as cognitive radio, but that such innovation is linked to innovation in the use of the spectrum to meet commercial and social goals. As such, it should not be the aim of regulators to set the rules that are directly enforced in cognitive radio implementation. Instead, regulators shall provide a framework of rules that later are translated to concrete implementations according to cognitive radio systems.

In order to maximise the opportunity of innovation in the combination of software radio technology and dynamic spectrum access policies, a highly disaggregated approach to the delegation of policy-making authority should be encouraged. For example, policy-making authority could be delegated to municipal authorities to best meet local social conditions or different spectrum trading commodity markets could be established in different bands or regions to allow parallel experimentation with market rules. A regulatory database with policies (rights and obligations) is therefore required to ensure high level of radio quality for consumers.

5.5.3.4 Prioritization of TVWS Access

The hierarchy of polices is very important to define prioritization of policies for TVWS. Figure 25, below, represents a possible policy hierarchy and accessing spectrum. Once the TVWSD learns the static policies that apply in any location, it can dynamically resolve user's requests for spectrum based on more situational policies, dependent on factors such as the application, the user's role in the incident or the developing incident command system as an incident grows and wanes [12].

Some spectrum access policies may be static, some may be universal, and some may be dynamic or regional. Some policies may only be invoked in certain circumstances, and at certain locations. Some static policies may be hard-coded into the TVWSDs when they are manufactured, while others may be downloaded periodically from a database. We envision a hierarchy of spectrum pool policies, which will guide the user to the best choice for the channel based on its ability to resolve available options within a structure of rules.

The type of used antennas, like directional, creates space for other links, so could acquire spectrum at cheaper prices. During disaster, all systems should be in emergency mode, so no charges at that time – hence the adjustment factor adds some degree of manipulation to the spectrum band – which could increase spectrum efficiency by attracting or repelling services in certain bands or regions.

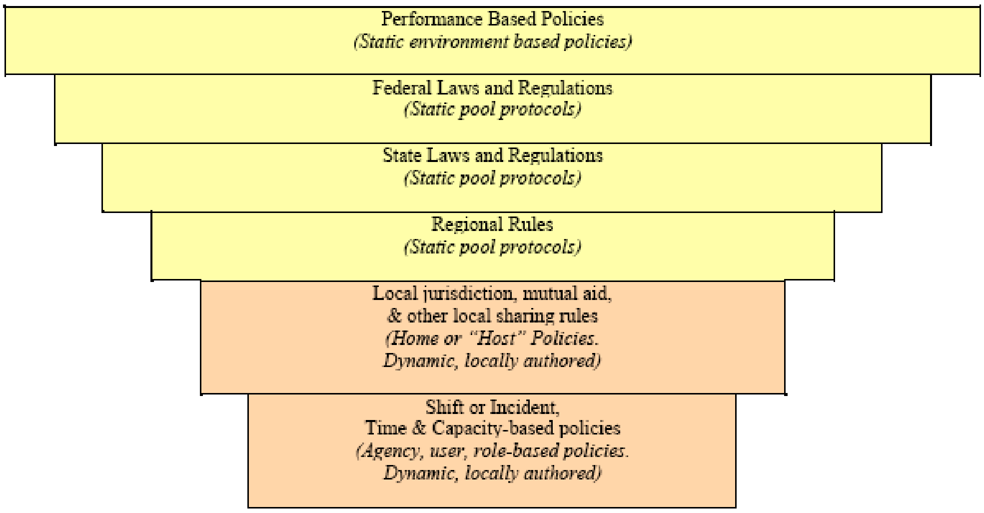

Figure 25: Hierarchy of polices

5.5.3.5 Protection of Competition

Regulatory bodies are designed to make decisions in a slow and methodical process that is transparent to everyone, and to promote compromise among competing interests. Such processes are great at avoiding corruption and favouritism, but not well suited to reacting quickly to exploit a new technology, or to repair newly visible interference problem or security vulnerability. Thus, where a regulator is in charge, all else being equal, there are more reasons to select a secondary spectrum sharing model based on coexistence.

Spectrum trading allows the assignment of spectrum to respond to changing circumstances and so use spectrum more efficiently [25]. Whilst the provider of a spectrum-derived service might be able to make up for a shortage of spectrum by additional expenditure on infrastructure, however a minimum amount of spectrum is still required. Therefore, if a rival purchases the entirety of this provider's spectrum, it might be able to eliminate its competitor, reducing competition in the downstream market for services and rising prices. Whether such exclusionary strategy succeeds and has an appreciable effect on competition will depend on the entry barriers to the downstream market.

Consider the following simple example. Suppose that there were a monopoly service provider earning a profit of, say, 10, absent any payments for spectrum. If, in contrast, there were a duopoly, with the market equally shared between two providers, their total profits would be less than 10 as competition would erode supernormal profits resulting from market power. For the sake of argument, suppose that each duopolist earned profits of 4, again absent any payments for spectrum. Now suppose that we were to start from a situation where there are two providers, and then introduce spectrum trading. If one operator offers to buy the other's spectrum, the seller will accept if the offer is above 4 (the duopoly profit lost). However, this leads to monopoly and the buyer will be prepared to pay up to 6 (the increase in its profits in moving from a duopoly to a monopoly situation). Therefore, we would expect a transaction to occur at some price between 4 and 6 and the market to be monopolised.

Providing competition is effective; there should be close accordance between the willingness of spectrum users to pay for spectrum and the benefits they generate for end users. One provider will be prepared to pay more for spectrum than another either because it can provide a superior service or because it can reduce other costs. However, if competition is not effective, then it does not automatically follow the statement that the entity prepared to pay more for spectrum is the one that can generate greater benefits for consumers. Some of the willingness to pay for spectrum may derive either from existing market power or from the anticipation of gaining market power.

Competition is guaranteed through quantitative limits on spectrum holdings applied at the time of primary assignment. Given that, the secondary trading or liberalisation restricts the limits applied at the time of a possible second assignment, and this limitation shall be forward over the lifetime of the licence, unless further spectrum becomes available.

In order to protect competition the following rules must apply:

- The regulatory authority establishes rules that specify how spectrum trading should take place.
- Trades or transfers of spectrum are subject to approval by the regulatory authority.
- Spectrum owned by one company cannot be used by another.
- The spectrum charge should be calculated fairly, i.e. if two users are using the same amount of spectrum in the same way, both should pay the same charge.
- The pricing structure should be clear, transparent and comprehensive, without unnecessarily lengthening the licensing process.

In conclusion [24], "*concerns that spectrum trading could lead to hoarding of spectrum are not well grounded. In fact, there are a number of ways in which spectrum trading may actually reduce incentives to hoard spectrum. First, liberalisation can relieve spectrum scarcity and may increase competition in downstream service markets. This reduces the need for associated obligations (such as roll-out conditions) to ensure services are delivered to customers. Second, spectrum trading (even without liberalisation) leads to greater transparency of the opportunity costs of leaving spectrum unused. Even if spectrum is unused, such behaviour is not necessarily anti-competitive per se and clearly needs case by case analysis. Such problems appear to be ideal candidates for treatment through standard competition law*."

5.5.3.6 Possible Implementation

The operation of the market according to the open-cry auction model establishes that initially the spectrum seller need to define a policy statement that specifies which banks they trust to provide micropayment tokens and have an account with. Figure 26 [14] presents an example that defines a contract between buyers and banks (public keys and signatures are truncated for readability). A spectrum buyer needs to have a contract with a bank that allows them to spend micropayment tokens.

```
local-constants:
    buyer = "rsa-hex:3048024100aa88..."
    bank_1 = "rsa-hex:3048024100bf78.."
authorizer: bank_1
licensees: buyer
conditions: app_domain == "spectrum market" &&
    @date <= 20070912 &&
    amount == "0.1" && @number <= 100 -> "true";
signature: "sig-rsa-sha1-hex:26d7da6725..."
```

Figure 26: Definition of the contract between buyers and banks

The spectrum seller specifies in a signed policy statement an offer which is sent to the clearing house. The statement specifies the terms of the offer and the signature binds the seller to these terms. Figure 27 [14] is a keynote credentials the details of the offered spectrum usage rights, the expiration date of the offer, and that a bid should be greater or equal to 3.0 monetary units.

```
local-constants: seller = "rsa-hex:3048024100cc02..."
authorizer: seller
conditions: app_domain == "spectrum market" &&
    &frequency <= 236.0 && &frequency >= 232.0 &&
    frequency_unit = "MHz" &&
    channel_bw == "1.75" && channel_bw_unit == "MHz" &&
    &transmit_power <= 1.0 && power_unit == "W" &&
    &latitude <= 51.15656 && &latitude >= 51.14949 &&
    &longitude >= 2.99228 && &longitude <= 3.01011 &&
    @date >= 20070417 && @date <= 20070418 &&
    @time >= 100000 && @time <= 220000 &&
    &amount * &number >= 3.0 -> "true";
signature: "sig-rsa-sha1-hex:81a0e2520f..."
```

Figure 27: Definition of the parameters to seller

When a seller finds a bid they first need to verify that the buyer can indeed deliver the payment and that all market / context / technical terms are satisfied by the given bid. If the buyer has a valid contract with a bank that the seller trusts and the offer terms are met by the proposed bid then their PDP authorizes the transaction (Figure 28 [14]). Therefore, the seller is sure that they are going to be paid for the provided spectrum usage rights.

```
local-constants: buyer = "rsa-hex:3048024100aa88..."
      seller = "rsa-hex:3048024100cc02..."
authorizer: buyer
licensees: seller
conditions: app_domain == "spectrum market" &&
      &frequency <= 236.0 && &frequency >= 232.0 &&
      frequency_unit = "MHz" &&
      channel_bw == "1.75" && channel_bw_unit == "MHz" &&
      &transmit_power <= 1.0 && power_unit == "W" &&
      &latitude <= 51.15656 && &latitude >= 51.14949 &&
      &longitude >= 2.99228 && &longitude <= 3.01011 &&
      @date >= 20070417 && @date <= 20070418 &&
      @time >= 100000 && @time <= 220000 &&
      commitment == "b80e336f22b733e4692e270" &&
      amount == "0.1" && number == "30" -> "true";
signature: "sig-rsa-sha1-hex:59295c356d..."
```

Figure 28: Definition of the parameters to buyer

When the seller informs the buyer that they accept the bid the latter releases the required number, in the above case 30, of tokens to the former. At that point, the seller issues a signed keynote policy statement to the buyer that includes the purchased spectrum usage rights as specified in the initial offer. We call this the spectrum use credential. It can be used by the buyer as a proof of the spectrum assignment facilitating the operation of policy schemes. The seller collects tokens and periodically contacts the issuing bank to translate them into monetary units and deposit them to their account.

5.5.3.7 Conclusion

The exclusive right to operate a transmitter within a given frequency range in a given geographic area is only part of the definition of a flexible spectrum license and once the authorization process is underway the role of the regulator is to ensure non-discriminatory treatment of all players in the liberalized market. For COGEU the right and obligations should be clear and additional obligations on the licensee must be specified to limit interference.

In addition to the rights of transmission, the repository also stores the rights and obligations of user of communications services. The user has a right to have access to communications services (e.g. voice, data, etc) at reasonable prices. The user have a right to receive a service with a quality that reflects the cost of the service (Value for money) and also the user have a right to receive the level of quality of service that is quoted or stated by the service provider/operator in the Service Level Agreement(SLA). In conclusion, the user has a right to complain about quality, delay, quantity and tariff with regard to the nature of the communication service provided.

The temporary owner of spectrum may issue Spectrum Usage Rights as they see fit so long as the conditions of the Spectrum Management Rights are met. Otherwise it would be necessary for the Spectrum Management Rights owner to negotiate a change of its Spectrum Management Rights (SMR) parameters with any affected neighbours. It is proposed that use of spectrum by an SMR holder should be registered through issuing itself with Spectrum Usage Rights (SURs), so as to reduce transaction costs and improve spectrum efficiency.

Buyers and seller require clarity over the expiry of usage right. If the duration of a usage right is uncertain, or approaching its end date, this will depress the value of the licence in a secondary market.

Ofcom distinguish between the four following types of transfer for spectrum use [16]:

- *Outright total transfer*: An outright transfer of all the right and obligations arising under a licence to a third party.

- *Concurrent total transfer*: A transfer of all the rights and obligations to a third party which results in a concurrent holding of those rights and obligations by the transferor and the transferee(s).

- *Outright partial transfer*: An outright transfer of some of the right and obligations arising under a license to a third party.

- *Concurrent partial transfer*: A transfer of some of the rights and obligations to a third party which results in a concurrent holding of those partial rights and obligations by the transferor and the transferee(s).

The traditional framework is highly prescriptive and often requires very detailed regulatory oversight. For example, it may prescribe the applications that can use spectrum (e.g., mobile services, terrestrial point-to-point links, etc.), the technology to be used, power levels, localization and height of the transmission masts, as well as bandwidth.

Liberalization means removing, or at least reducing, these restrictions. Introducing liberalization and spectrum trading in parallel would facilitate the migration of spectrum usage rights to more efficient uses. This boosts efficiency, furthers innovation and makes competition more intense. However, in so doing, it must be considered that specific restrictions are necessary to avoid harmful interference, while other requirements are necessary to satisfy international agreements.

If a country decides to introduce spectrum trading, it must:

- Establish clear legal titles to spectrum rights so that buyers and sellers have certainty about what it being traded, and these should enable leasing (both short term and long term) as well as the complete transfer of rights;
- Publish information about what spectrum has been allocated on a public register, and what transfers have taken place;
- Establish a quick and simple process that enables the regulator to prevent undesirable trades.

Beyond the rights and obligations, the COGEU policies repository also includes different priorities. The prioritization mechanisms for public safety is set to be the highest priority in case of disaster. Under such conditions; all systems should be in emergency mode, to guarantee QoS for the Public safety workers. However, we will take into account the fact that polices of prioritization for public safety is different from country to country. COGEU TVWS policies to enable efficient spectrum sharing will be detailed by T2.1 and reported in D22.

5.6- Graphical User Interface

The purpose of the Graphical User Interfaces is for the communication and interaction with the secondary players. In order for a secondary player to communicate with the broker, a graphical user interface is needed that will ensure the information passing between them are verified and valid. There are three main steps in the interaction process. The first step is for the broker to advertise and make public to the potential players that a spectrum or a specific band is available. This can be done by using RSS feeds technology or by email technology. This can be accommodated in a user graphical interface by providing an RSS feed or an internal email client. The proposed method has the characteristic that only the registered players can view some of the advertisings and some can made public through a web interface that a public access is in place.

The second step is for a player to put its interest forward. In order for a player to clearly define what and where wants a network to be deployed a map of functionality and system characteristics input will also be available in the graphical user interface. The system will need to input with very high accuracy in order to be able to evaluate the request for usage in a specific location.

The third step is the answer from the broker system. When a player indicated where and what exactly wants to deploy in the available band, a validation and allocation process will be held in the broker and the player will be able to observe and inform regarding the outcome of its request using the graphical user interface.

For a successful usage and communication between the broker and the players the graphical user interface need to stay simple and intuitive and also hold help functionality and troubleshooting capabilities.

5.7- Interfaces for geo-location database access and regulatory enforcement

5.7.1- Interfaces and Protocols for Geo-location database access

As reported in D4.1, the COGEU geo-location database will be accessible by the following interfaces as shown in Figure 29.

- **Interface A** is to provide communication with the WSD repository that operates under the spectrum of commons operations;
- **Interface B**, is to give access to the COGEU Broker entity that will handle the secondary spectrum market;
- **Interface C** is connected to a regulation and policies repository for the current area that the database is operating;
- **Interface D** will be by the Incumbent systems repository which will provide information for the protected incumbent systems;
- **Interface E** is public access interface that would enable anyone to search the Database's non-confidential publicly available information.
- **Interface F** connects the local database with the central database in order to retrieve updates on policies and information regarding the close border areas. Each of interfaces will use IP security.

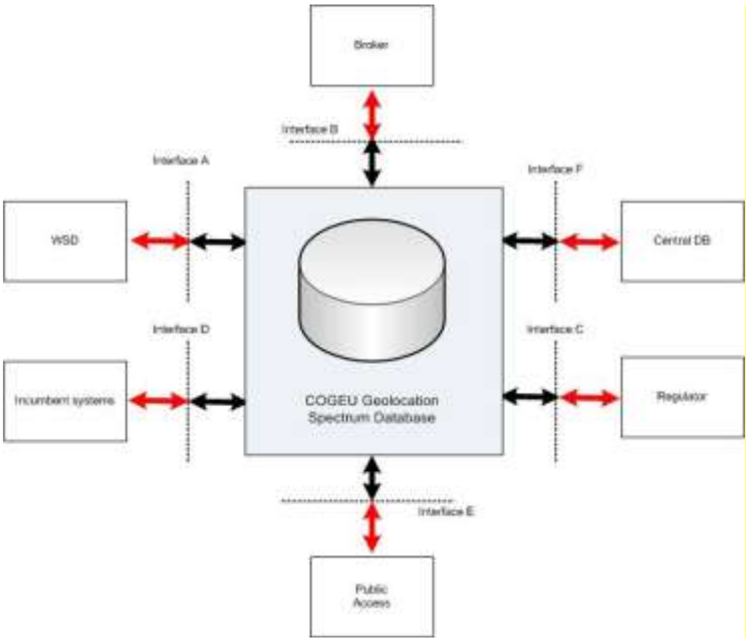

Figure 29: COGEU interfaces with the geo-location database [Source: D4.1]

5.7.2- Interfaces and Protocols for Geo-location database access

The interface for database access is the Interface A for the WSD devices which operate under the spectrum of commons and the Interface B for communication with the Brokers under the secondary spectrum market. Database enquires and downloads use appropriate protocols. COGEU will adopt Internet-based protocols and standard enquiry languages. The proposed database access procedure includes XML through web services. In more detail the database will expose web services though the appropriate interfaces. The transported data will include XML formatted data and by using SOAP encapsulation will be transported through HTTP. Using the above methodology, the architecture has the benefit that the access to the database is controlled, and secure, since the queries that an entity will be able to perform are predefined and preformatted. Through this process the entity that accesses the database can be authenticated and authorised according to the policies that are in place at the current time in the specific database. Also the benefit of well formatted data that can be easier to manipulate and validated is inherited through the use of XML. The database is protected to the boundaries of the exposed interfaces, simply put no entity can directly access the database and alter stored information.

An entity will be able to use the services of the database, by connecting to the appropriate exposed port of the database and using the available queries. On the other hand the respond from the database will bear the same characteristics, which will provide well formatted and easier to manipulate data to the entities. That will add the benefit of faster processing of the transported data between the databases and the querying entities. In general faster processing of the exchanged information will be possible using the proposed process.

Channel	EIRP (dBm)	Validity period
41	30	1 hr
43	33	1 day
45	15	1 day
55	30	2 hr

Figure 30: Example of list of available channels format reported by the geo-location database for a specific location

5.7.3- Interface for populating the geo-location database

In order to populate the geo-location information in the geo-location database, the operation need to use the Interfaces C, D and F. Interface C is for retrieving regulatory information, Interface D is to retrieve the incumbent system characteristics and Interface F is to compliment the process if needed with information held in the central database. COGEU assume a realistic scenario where the regulators will not supply the sensitive data concerning broadcast transmitter parameters. Therefore, the regulator would convert the incumbent's data (confidential raw data) into a list of allowed frequencies and associated transmit powers by performing TVWS calculations. As a result of these calculations, regulators may use a map with a grid size of e.g. 200 m x 200 m ('pixel'). For each pixel and each channel the acceptable transmit power is contained in the database as shown in Figure 31.

In COGEU, these TVWS calculation for the Munich area will be performed based on the data given by Germany's broadcasters and German regulator BNetzA. For the considered Munich area and a pixel size of 200 m, for each channel arrays of approximately 2000 x 2000 items will be supplied e.g. as ACSII files (in this case the whole federal state of Bavaria is covered). COGEU database will be populated by inputting these data. COGEU assumes that a database for PMSE is either available or will be built up in advance of introduction of white space using equipment. However, PMSE use in Germany is not registered. To get a realistic scenario for COGEU demonstration in Munich some assumptions have to be made on distribution of PMSE equipment. For example, it can be assumed that broadcast production companies, Theatres, Stadiums and Universities use such PMSE systems. By estimating the number of devices used at these facilities some channels may be excluded for these locations.

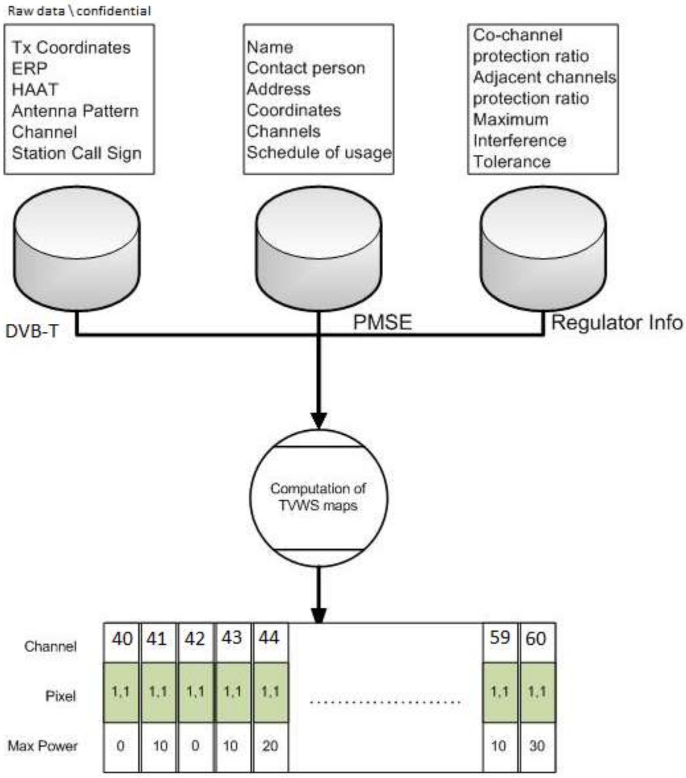

Figure 31: The process of TVWS computation.

5.8- Interface between the COGEU broker and players

The need for the TVWSD or operators control centre to exchange information with the database before being allowed to use any frequency in the 470-790 MHz would imply the need to have a communication channel between both. This communication channel might be realized wirelessly using frequencies outside the band 470-790 MHz, or via some wired connection in case of non-portable TVWSDs (see Figure 32). Indeed, we made the choice not to rely on a logical Cognitive Pilot Channel to support the user terminal for discovery of available radio access and reconfiguration (as introduced in ETSI TC RRS WG3). The advantages of using the geolocation spectrum allocation via the broker and communicating with it are mainly its simplicity of implementation compared to a full-CPC oriented approach.

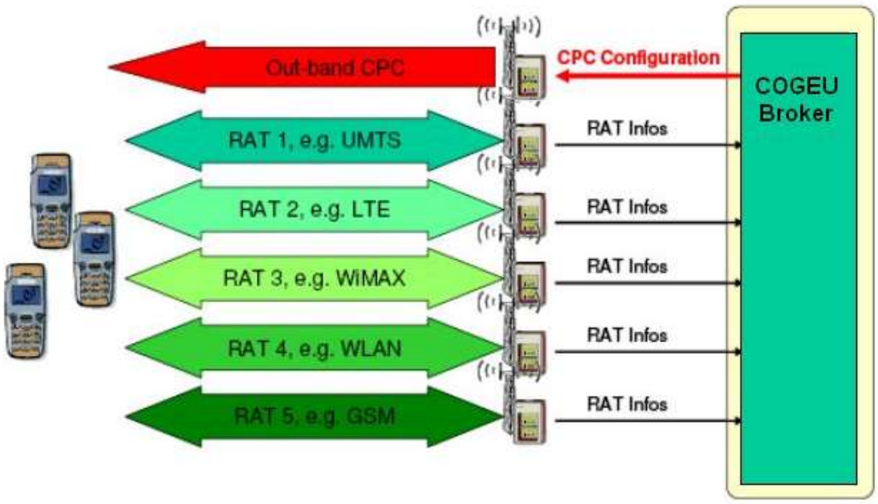

Figure 32: Physical Out-band CPC

On this communication channel, COGEU will adopt a "Service Oriented Architecture" (SOA) communication pattern in order to provide flexibility and standardised interfaces.
The main technologies to be used are based on the Web-Services standards:

- XML (Extensible Mark-up Language) for data encapsulation
- SOAP (Simple Object Access Protocol) to transfer the data
- WSDL (Web Services Description Language) described how to interface with a given web service

The nature of messages, and parameters to be exchanged for allocation are described in section 5.1.1-

5.9- Registration and validation in the COGEU broker

In the secondary spectrum market implemented by COGEU, a security mechanism is necessary to protect messages transmitted between each player and COGEU broker. These messages are control messages to request or assign TVWS carriers, update information about the market, etc. Security issues between COGEU broker and geo-location database will not be treated here, however a security channel may be assumed.

The importance of security may be seen at least in three approaches: 1) since the COGEU system assigns TVWS channels and the spectrum is a scarce resource, security attacks may lead to occupancy of the spectrum from those that do not have the right to do it; 2) in the secondary spectrum market, fake entities would request more TVWS carriers and possibly resealing them, building a parallel market; 3) fake entities would notify players has being the COGEU broker, and then collect money from the spectrum and spectrum rights that they do not own.

As previously mentioned, the information exchange between the COGEU system and players is highly sensible. However, simple and standardised mechanisms are proposed: the asymmetric cryptographic or public-key cryptography. One of the strong benefits of this method is that it allows the transmission of sensible data through Internet in a secure way without establishing a security channel.

It is assumed that each player and COGEU broker has a public/private key pair. It is also assumed that only the owner of the private key knows its private key, while the COGEU broker public key can be broadcasted in the network through a security channel (or other security mechanism).

When players establish a contract with COGEU allowing then to request TVWS carriers and participate in the market, their names or IDs and corresponding public key are stored in a certificate, which can be signed by the COGEU broker. In other words, the COGEU broker may be the one that generates valid certificates for the players; information about player's public key, its ID, key usage, that may be delivered by the player to COGEU system when the contract is established, is later included in the certificate. Other important information that is in the certificate is the issuer (the entity that generated the certificate), the validity (valid from and valid to) and serial number (that is used to uniquely identify the certificate).

It is not necessary to store the certificate inside the broker, because its validity can be checked. The COGEU broker signs the certificate directly (as explained before), or a certification authority (CA) (more complex with probably no extra benefit) signs the certificate, establishing trust over the public key. For this purpose it seems sufficient that only the broker signs the certificate, since it then can revoke it when needed, and assert more control and trust over what players get signed certificates. If a CA is used, IDs and certificates must be stored inside the broker.

Players obtain the certificate of the COGEU broker through some off band/secure mechanism. Alternatively, if received through a public channel, it can verify the signature, provided that the certificate is signed by a trusted authority (CA), or the by the provider (for which the player should have the public key – this can be distributed with the device, or by off line/band mechanisms).

In Figure 33 the Authentication and Authorization architecture is presented. The Authentication Server (AS) is in charge of generating the certificates for the players and broker, verify the authenticity of the requests, and sign/encrypt the response. The players that may request TVWS channels from the broker are stored in the Policies Repository, when a CA is used.

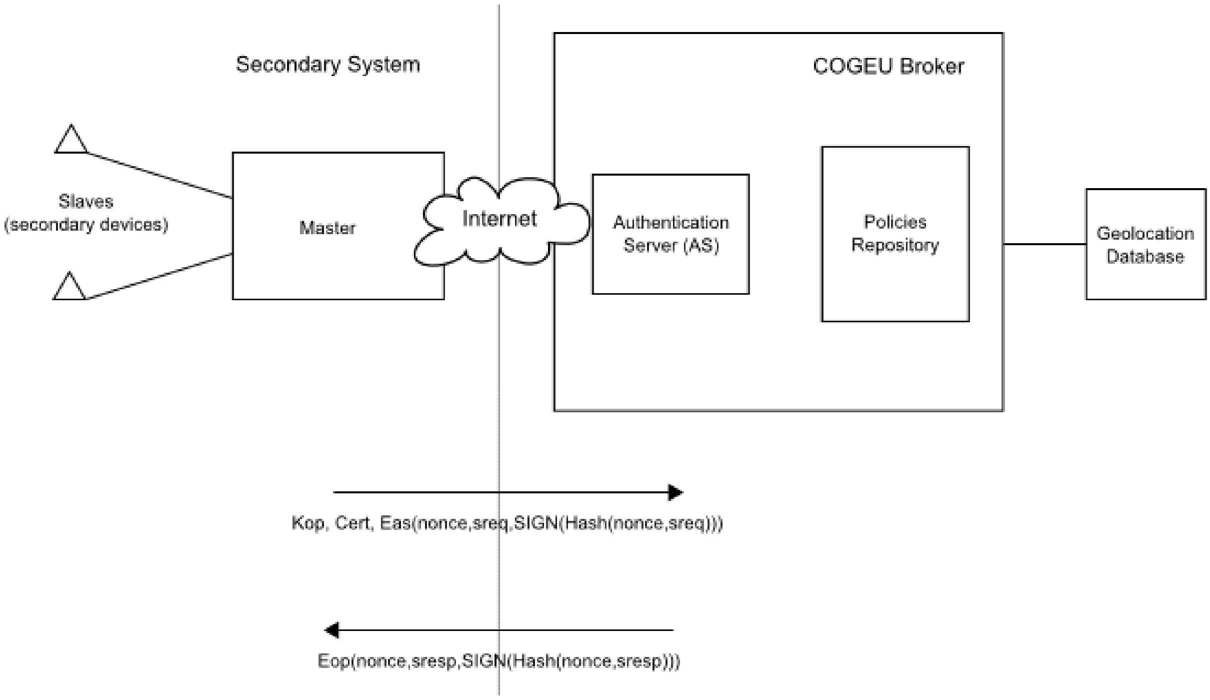

Figure 33: Authentication and Authorization Entities in COGEU system

To actually perform a request the player first generates a request and a nonce (a large pseudo-randomly generated number), to assure the freshness of the request. The player then generates a hash of the concatenation of nonce with request. The hash is then signed with the player's private key, so to assure the origin of the request. The player then takes the nonce, request and signed hash, encrypts the package with the broker's public key, thus forming the encrypted request (Eas).

The player then transmits the encrypted request along with his public key, to verify the signature, and with the public key certificate, so that the broker can verify the identity of the sender.

Kop, Cert, Eas (nonce, sreq, SIGN(Hash(nonce, sreq))) ->

The sreq message is constituted by the following parameters:

- Bandwidth
- Location of secondary devices (e.g. GPS coordinates)
- Maximal transmit power
- Occupancy duration

When the broker receives the request, it simply decrypts the request with his private key, thus obtaining the nonce, request and hash. To verify the validity of the request, the broker first verifies the public key certificate, assuring the senders identity, generates the Hash(nonce, sreq) and compares the obtained hash with the signed hash. If there is a match, the request is valid, and was signed by the true holder of the private key, corresponding to the received public key (verified through the certificate), see Figure 34.

<- Eop(nonce, sresp, SIGN(Hash(nonce, sresp))

To issue a response, the broker does a similar process, but using his private key and the public key of the player. The broker computes the hash of the response plus a fresh nonce, and signs the results with his private key. It then sends the encrypted response to the player, which is the nonce, response and signed hash, encrypted with the player's public key, thus assuring that only the player is able to open the response (Eop).

To validate the response, given that the player already possesses the verified public key of the COGEU broker, it simply decrypts the response with its private key, calculates the hash, and verifies the signature, thus confirming the validity and freshness of the response.

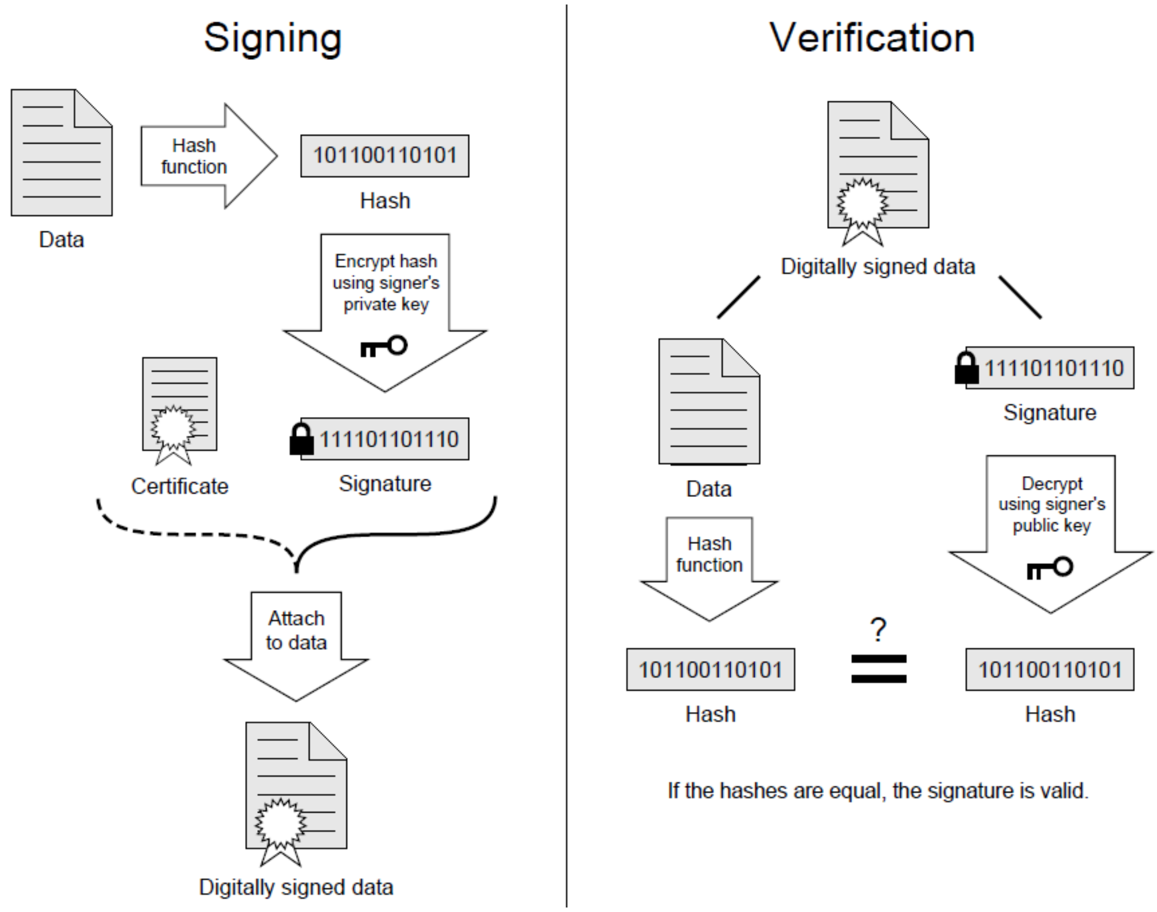

Figure 34: Example of signing a message

The response (sresp) will be later defined. However it shall contain if the request is denied or accepted and, in the latter case, the number of channel(s), frequencies, policies, duration, and other information that is necessary.

6- Instantiation of the COGEU reference architecture

COGEU three key application scenarios: WiFi with cognitive access to TVWS-spectrum commons; LTE extension over TVWS – secondary market; Public safety applications with cognitive access to TVWS – prioritization [D2.1]

6.1- LTE over TVWS

Up to now there are very few networks based on LTE. However, in the very near future this technology will be widely adopted. When it starts to being deployed as a commercial network the used frequency will be 2.6GHz in most European countries [17]. This high frequency can limit LTE and it is possible that in some areas the LTE's coverage may be only characterised by some spots, not achieving the expected performance, and being capacity limited.

As presented in [17], the excellent propagation characteristics of COGEU operation band, that starts from channel 40 to channel 60 (622MHz-790MHz),allows operators to cover higher geographical areas with less base stations (BSs), notably for a region of 624km2, LTE@700MHz only requires 4 BSs while LTE@2.6GHz requires 80 BSs to cover the same area; which is less costs for operators. Furthermore, with a better signal-to-noise ratio (SNR), which is achieved with better propagation conditions in lower frequencies, the use of higher modulation schemes, that increases the system's capacity, is possible. Thus, the temporary use of TVWS bands for LTE when extra capacity or higher coverage are required seems to be an efficient solution, namely on the real-time secondary spectrum market model.

However, the use of LTE in TVWS shall fulfil some logical steps. As in any cellular network, operator does measurements regarding the network performance. This monitoring is done in order to assess the quality of the network (mostly, in terms of quality of service (QoS) and quality of experience (QoE)). The selected key performance indicators (KPIs), e.g., drop call rate, are useful to detect possible alarms in the network and trigger an action. For COGEU, this action is to perform a carrier request for a lower frequency (TVWS channels) to the COGEU Broker.

Based on the same KPIs that triggered the carrier request or other parameters and taking into account the type of service, the number of carriers that are needed to resolve that particular situation is assessed. Along with the number of requested carriers, the operator's network sends to the COGEU Broker at least the information for desired bandwidth, location for LTE BS and associated coverage and the estimation for service's duration.

With the received request, the broker uses the GPS address of the location or its coordinates to inquire the Geolocation Spectrum Database in order to check if in that location there are free TVWS bands that may provide the requested carriers and desired bandwidth. Moreover, the broker also needs to check inside its modules the following parameters: if in that location the possible free bands are already occupied with secondary users – TVWS Occupancy Repository –, the trading information for the leasing of the spectrum and coexistence policy information with other bands / cells / technologies – in Trading Information Repository and Policies Repository, respectively. If everything was ok, the final consumer (which in cellular networks is the operator), shall be informed about the available carriers and bandwidth, time availability, leasing price, maximum allowed transmit power (see D6.1 for more details).

Finally, the operator's network shall inform the broker if it accepts or rejects the offer. In case of rejection, the process shall restart. In case of acceptation, and depending on leasing contract, the bands are delivered to the operator (that later will be assigned to users) and the TVWS Occupancy Repository is updated.

On Table 6 the previous process is summarised. The number of phases depends on the granularity for the whole process.

Phase	Logical steps
Network monitoring	Normal process in any cellular network Detection of a high variation in a defined KPI (lack of coverage or capacity) Send a request for TVWS carriers
Carrier request	Use of technology particularities, e.g., for LTE: time x frequency grid, AMC according

	to SNR, different bandwidths, fixed RRB size (12 sub-carriers, 15 kHz each and 0.5 ms of a slot duration), and Estimation of number of carriers, necessary bandwidth and duration is performed Information send to COGEU Broker
COGEU Broker inquiry	Inquiries in primary and secondary users allocation databases, and if no user is found Checks trading information and coexistence policy Information send to network operator
Carrier allocation	Requires acceptance from the operator, otherwise the process shall restart Update of TVWS Occupancy Repository

Table 6: Generic phases for requesting and acquiring TVWS carriers

With LTE, new demands on the Operation and Maintenance (O & M) of the network are foreseeable. Therefore, in addition to evolving existing management solutions, E-UTRAN/EPC also encompasses some new Self-Organized Network (SON) functionalities such as Auto-Configuration, Auto-Optimization and Self-Healing:

- Self-Configuration of Base Stations (BSs) will reduce the amount of manual processes involved in the planning, integration and configuration of new Base Station. This will result in a faster network deployment and reduced costs for the operator in addition to a more integral inventory management system that is less prone to human error.

- The Auto-Optimization has as objective to maximize network performance, optimizing the configuration while taking into account regional characteristics of radio propagation, traffic and UE mobility in the service area is effective.

- For Self-healing has as its objective when some nodes in the network becomes in operations, self-healing mechanisms aims at reducing the impacts from the failure, for example by adjusting parameters and algorithms in adjacent cells so that other nodes can support the users that were supported by the failing node.

In COGEU the introduction of SON can minimize the operation costs of running a network by reducing and eliminating manual configuration of network operational parameters at the time of network planning, network deployment, network operations, and network optimization while fitting into the existing operational processes and procedures that are currently in place today. The previously described process is illustrated for the LTE case in Figure 35 **Erro! A origem da referência não foi encontrada.**.

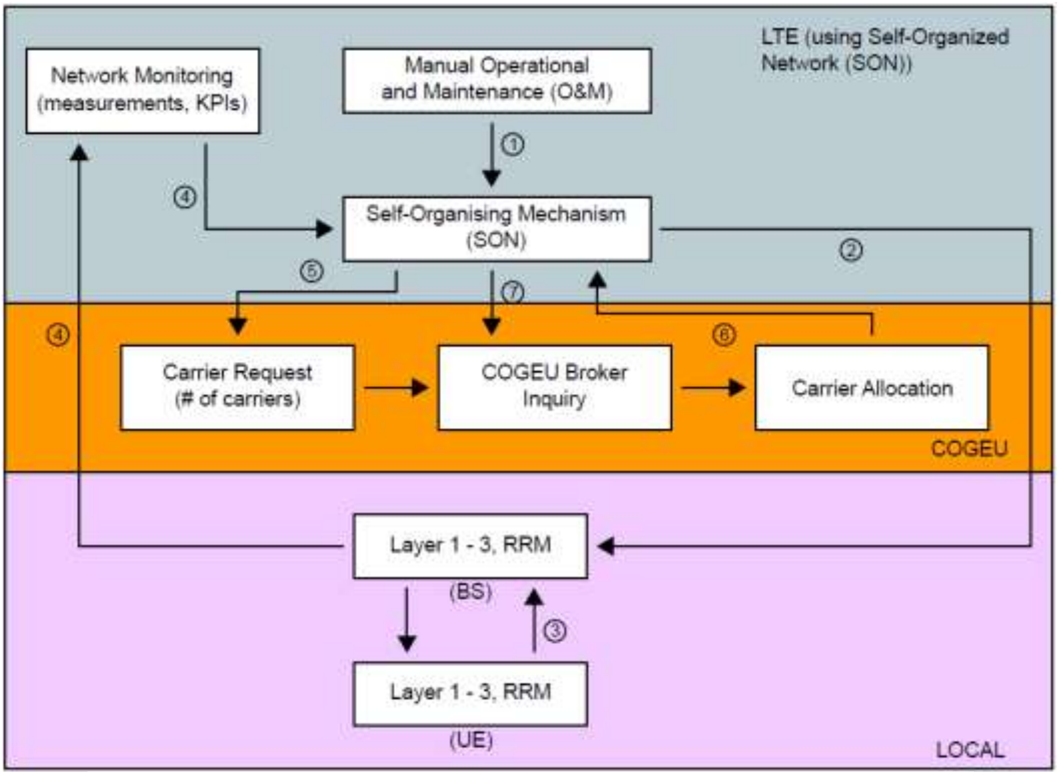

Figure 35 : Possible process to request and acquire TVWS carriers for LTE

The previous process, i.e. the process to request and acquire a TVWS carrier, can be described as follows:

1) Manual configuration and carrier allocation is done during the planning phase.
2) The information about the carrier that was allocated is sent to the specific Base Station (BS).
3) Normal communication process between BS and User Equipment (UE) is done and also the information about the carrier.
4) The UE and BS measurements are sent to Core Network (CN).
5) In order to optimise the network (i.e. interference, capacity or coverage), new carriers are requested to COGEU system; the location, required bandwidth, and duration is also sent.
6) The CN is informed about the allocated carriers, and that information is also sent to BS (2).
7) The TVWS Occupancy Repository is updated with the channels that were accepted by the operator and became in use.

Through the solution's ability to configure, optimize and recover automatically, the LTE SON will offer operators operational cost savings associated with network planning, network deployment and network optimization.

6.2- WIFI over TVWS

The wide spread of Wi-Fi technology is apparent in all environments. Extremely high numbers of domestic and private networks exist in all possible locations, especially in dense populated areas. The affordability and ease of deployment of a Wi-Fi network it made it also an attractive option for larger public networks known as hotspots. Furthermore a number of operators use Wi-Fi for blanket coverage of large areas and offer their customers Wi-Fi connectivity and mobility in large areas where they operate in. Under these developments the use of Wi-Fi in the COGEU regulatory scenarios, can vary. The attractive characteristics of TVWS bands in conjunction with the characteristics of Wi-Fi technology can be a powerful enabling technology for the commercial success of TVWS usage.

According to the section 2.5-, the IEEE 802.11af TG is working towards the proposal and standardization of an 802.11 variation for use in the TVWS bands. The characteristics of the technology, which will be able to exploit the lower bands, will include the support of single or multiple usages of channels if available. The data rate of the devices will depend on the availability of the channels in the specified areas. Also the devices will be able to operate in contiguous and non-contiguous channels in order to be able to utilise the empty spaces on TVWS. 802.11af will be able to operate in 5, 10 and 20 MHz channel width. OFDM will be used and fixed subcarrier spacing is recommended in order to limit complexity.

In the case where the Wi-Fi is operated under the first regulatory scenario (see Figure 36) where the operation is under the spectrum commons with sensing and geo-location access, Wi-Fi technology can be deployed and an access point is required. This access point can be the gateway for the access to the geo-location database and also as a sensing point, the difference with the already existing APs is that is must be capable of controlling the devices using parameters of operation that the geo-location database offered after the AP contacted the database. The access point can limit the range of the coverage and also is able to control whether a client can transmit or not. The model of master-slave can be applied on the Wi-Fi operation; in this case the master is the access point and the slaves are the devices that are attached to the access point.

The operation of the Wi-Fi AP in the spectrum commons with sensing capabilities can be as follow:

- AP power on
- Location determination
- Contact DB providing location
- Receive operation instructions for available channels and maximum power
- AP Configures slave devices
- Start sensing operation
- If all OK start transmission to slave devices
- Slave devices start transmitting using the provided frequencies
- Periodic sensing operation takes place

In the case of second regulatory scenario (see Figure 36), where spectrum commons and secondary spectrum market operates with only the geo-location database access is required, Wi-Fi can be an option for both operation modes. It can also be used as a deployment of a network by acquiring a frequency band from the broker. The difficulty on this case is that because Wi-Fi need almost three channels to operate as it does in the 2.4 GHz bands it will be more expensive to operate. The 802.11af TG can be used and operate using smaller bandwidth There are currently devices that can operate in shorter bandwidths and if this can be applied it can be a viable and attractive option a deployment of Wi-Fi in TVWS band with stable frequencies. In this scenario Wi-Fi can also operate in the spectrum commons case with similar configuration with the first regulatory scenario. The difference is that it will not need to have sensing capabilities, which it makes it easier and with less overhead to process.

The operation of the access point in the spectrum commons for the second regulatory scenario, without sensing capabilities are identical to the AP with sensing capabilities but without the sensing parts.

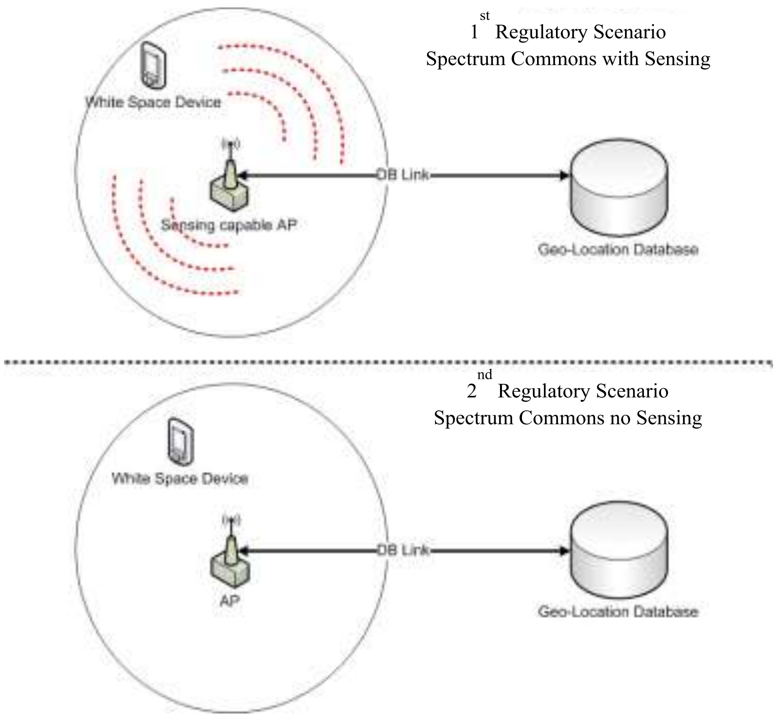

Figure 36: Wi-Fi over TVWS in the Spectrum Commons mode in both regulatory scenarios

6.3- Public safety over TVWS

As introduced in previous tasks T3.1 we consider Use of Dynamic Spectrum Access Radios by the Public Safety Community. There may be considerable opportunity for dynamic spectrum access radios to be used by the public safety community and within public safety frequency bands. We also note the potential for reconfigurable radios to alleviate many of the interoperability issues associated with public safety spectrum use.

Manage interoperability via the broker

Public Safety domain is characterized by many different wireless heterogeneous networks like TETRA, TETRAPOL, Analogy Professional Mobile Radio (PMR) and satellite communications. In some cases, commercial systems like GSM/GPRS are used. In large disasters, military entities might operate together with Public Safety organizations. As a consequence, there is an issue of interoperability when an emergency crisis is to be resolved by different public safety organizations equipped with different communication systems. Coupled with cognitive radio systems operating in the TVWS, centralised spectrum management with geolocation as in COGEU, can be a technology enabler to resolve the interoperability barriers at technical level by activating the needed waveforms on the cognitive radio platform. The spectrum regime considered could be spectrum common, or secondary spectrum trading. In this later case Public Safety agencies might enter the market as secondary spectrum players.

Nevertheless, operational requirements for communication systems in the Public Safety domain are usually different from the Commercial domain especially in terms of reliability, availability, responsiveness and security. Those specific requirements could be addressed through differentiated spectrum access where Public Safety systems could be given better priority.

Access priority for Public Safety Networks

Service priority can be introduced into the COGEU broker, with each secondary system having an assigned priority level. In general, channel availability for equal priority services is determined on based on the trading mechanisms described in section 5.1.2-. In this manner, secondary TVWS systems will avoid selecting channels that are already in use by other secondary systems, enforcing coexistence.
The concept of service priority can be a complementary solution to allow some systems (e.g., emergency public safety systems) to operate with higher priority over other services.

For example, the database can provide differing channel lists (and/or other radio operating parameters, such as maximum allowed transmit power levels) based on service priority. In order to react to an emergency incident, the broker may allocate channels to public safety systems that were previously allocated to other lower priority services or simply prioritize access to them during the allocation of frequencies. When the public safety systems arrive on a scene, it would access the broker, and the broker would have the option of assigning channels that are currently utilized by lower priority systems. The lower priority systems would also receive a new set of channels/radio operating parameters for the new spectrum usage scenario. While priority based broker should preferably be operated on a near real-time basis, even hourly broker updates could potentially provide much more efficient usage of available spectrum. Another possibility is to re-open the market (and related auction and trading mechanism) when a major crisis happens. All players re-enter the auction game but Public Safety systems have a better chance to win due to higher priority.

7- Conclusions and future work

The state of the art analysis has highlighted that there is a clear need to adapt the existing technologies and concepts in order to fully satisfy COGEU requirements as defined in previous work-packages and tasks. One of the outcomes of the document is the identification of needs for standards adaptation. The main needed adaptations have been identified in the area of Spectrum trading techniques, where there is no current architecture proposed by standardization bodies for secondary spectrum trading, indeed all of them assume unlicensed access (spectrum commons regime). Another adaptation of interest concerns the future studies around mobility management. Indeed, IEEE 802.19.1 have been identified in section 2.3- as a mean to insure co-existence between IEEE 802 family standards, but it also provides a clear mapping with IEEE 802.21 function. Integration with the media independent handover function in IEEE 802.21 standard is envisaged, extending the traditional mobility concept.

The other main outcome of the document is the initial specification of the Initial COGEU architecture. This initial version will be use as a basis for cross-work-package discussions during the lifetime of the project. The current initial architecture will then evolve in order to reach a stable version for D3.3 taking into account the possible rules announcements of European regulatory bodies. In the forthcoming final architecture, we will finalize the work begun in this deliverable by following our top-down approach and digging a bit deeper into the interfaces definition, protocol proposals and functional modules introduction. It is expected, then, to use the outcomes of this work-package to drive the implementation work. Figure 37 shows the interconnection between the work presented in this deliverable and further COGEU tasks.

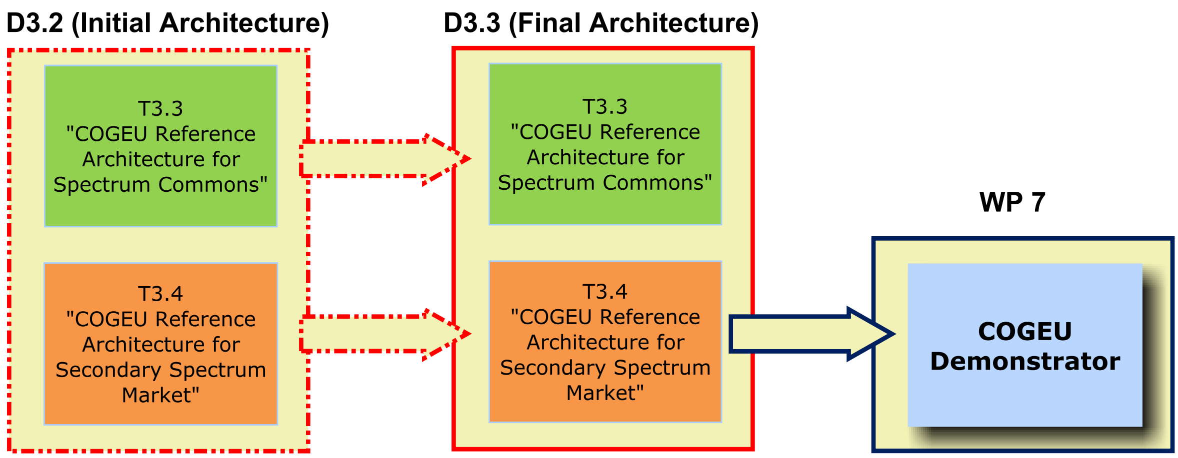

Figure 37: Main interconnections between D3.2 and further tasks of the project

8- References

[1] M. Mueck, K. Sithamparanathan, et. al., *"ETSI RRS - The Standardization Path to Next Generation Cognitive Radio Systems"*, CogCloud wokshop, collocated with the IEEE Personal Indoor and Mobile Radio Communications (PIMRC) 2010, Istambul, Turkey, September 2010.

[2] OECD (2005), "*Secondary Markets for Spectrum: Policy Issues*," OECD Digital Economy Papers, No. 95, OECD Publishing. doi: 10.1787/232354100386

[3] Patrick Xavier, Dimitri Ypsilanti, "*Policy issues in spectrum trading*," Info, Vol. 8, No. 2, pp. 34 – 61, 2006

[4] Monisha Ghosh, Vasanth Gaddam and Kiran Challapali.*"Proposed modification to Section 8.4 of Draft ECC Report,"* Philips Research North America. New York

[5] FP7 ICT-2009.1.1 COGEU. D3.1 *"Use-cases Analysis and TVWS System Requirements,"* August 2010

[6] Junjik Bae; Beigman, E.; Berry, R.; Honig, M.L.; Hongxia Shen; Vohra, R.; Hang Zhou; , *"Spectrum Markets for Wireless Services," .* 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks*, 2008. DySPAN 2008*, vol., no., pp.1-10, Oct. 2008

[7] Berry, R.; Honig, M.L.; Vohra, R.; *"Spectrum markets: motivation, challenges, and implications,"* IEEE Communications Magazine*,* vol.48, no.11, pp.146-155, November 2010

[8] D. Ardagna, C. Batini, M. Comerio, Marco Comuzzi, F. De Paoli, S. Graga, B. Pernici, "*Negotiation Protocols Definition," Multichannel Adaptive Information Systems (MAIS),* Nov, 2004

[9] Mark Bykowsky, *A secondary market for the trading of spectrum: promoting market liquidity*, Telecommunications Policy, Volume 27, Issue 7, Practical Steps to Spectrum Markets, Pages 533-541, August 2003

[10] John W. Mayo, Scott Wallsten, *Enabling efficient wireless communications: The role of secondary spectrum markets*, Information Economics and Policy, Volume 22, Issue 1, Wireless Technologies, March 2010, Pages 61-72

[11] Nguyen Hoang, Thuan. *Types of electronic payment system: The requirements from different actors' perspective (Part 2)* [Internet]. Version 5. *Knol*. April 2009 2. Available from: http://knol.google.com/k/thuan-nguyen-hoang/types-of-electronic-payment-system-the/25lgke3rt3f2g/7.

[12] Lehr, W. and N. Jesuale (2008) *"Public Safety Radios Need to Pool Spectrum,"* IEEE Communications Magazine, March 2009.

[13] Michael J. Barclay 1, Terrence Hendershott *,"A comparison of trading and non-trading mechanisms for price discovery"*, 18 March 2008, pp 846

[14] Patroklos Argyroudis, Timothy Forde, Linda Doyle and Dona lO'Mahony, "*A policy-driven trading framework for market-based spectrum assignment*", 2007

[15] M. Kumar and S. I. Feldman. "*Internet Auctions*", in Proceedings of the 3rd USENIX Workshop on Electronic Commerce, Pages 49-60, August 1998.

[16] *A Statement on Spectrum Trading: Implementation in 2004 and beyond*, Ofcom, (2004)

[17] Everything Everywhere Limited, Response to the Ofcom consultation. *"Reserving the band 2500-2690MHz for the London 2012 Games*". 17 September 2010. Source: http://stakeholders.ofcom.org.uk/binaries/consultations/band-2500-2690-london-2012-

games/responses/Everything_Everywhere.pdf

[18] COGEU FP7 ICT-2009.1.1. D3.1 "*Use-cases Analysis and TVWS Systems Requirements*". 2 August 2010

[19] ETSI TR 102 683 : *Reconfigurable Radio Systems (RRS) ; Cognitive Pilot Channel (CPC)*

[20] White Space Database Group ex parte submission(ET Docket No 04-186)

[21] IEEE 802.22 WRAN (doc IEEE 802.22-10/0073r03)

[22] Baykas, T. et al., *Developing a Standard for TV White Space Coexistence: Technical Challenges and Solution Approaches*

[23] OFCOM : *Implementing geolocation*: Publication date 9 November 2010. Available at http://stakeholders.ofcom.org.uk/binaries/consultations/geolocation/summary/geolocation.pdf

[24] Analysys, DotEcon, H&H, *Study on conditions and options in introducing secondary trading of radio spectrum in the European Community*, final report for the European Commission, Available Online:http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/studies/secondary_trading/secontrad_final.pdf, 2004

[25] Jon M. Peha, *"Sharing Spectrum through Spectrum Policy Reform and Cognitive Radio,"* Proceedings of the IEEE, 2008

List of Figures

List of Abbreviations

ATSC	Advanced Television Systems Committee
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
CEPT	Conference of European Postal & Telecommunications
CR	Cognitive Radio
DSM	Dynamic System Management
DVB-H	Digital Video Broadcasting – Handheld
DVB-T	Digital Video Broadcasting - Terrestrial
DTV	Digital Television
DwPTS	Downlink Pilot Time Slot
ETSI	European Telecommunication Standards Institute
EU	European Union
ENG	Electronic News Gathering
FCC	Federal Communications Commission
FPGA	Field-Programmable Gate Arrays
GSM	Groupe Spécial Mobile (also, Global System for Mobile communication)
IEEE	The Institute of Electrical and Electronics Engineers
ICT	Information and Communications Technologies
IMT	International Mobile Telecommunications
IPR	Intellectual Property Rights
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
OFCOM	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
PMSE	Programme Making and Special Events
PWMS	Professional Wireless Microphone Systems
PU	Primary User
QoS	Quality of Service
R&D	Research and Development
RF	Radio Frequency
RRC	Regional Radiocommunication Conference
RRM	Radio Resource Management
RSPG	Radio Spectrum Policy Group
SAP	Services Ancillary to Programme making
SDR	Software Defined Radio
TV	Television
TVWS	TV White Spaces
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
US	Unites States of America

USRP	Universal Software Radio Peripheral
VHF	Very High Frequency
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WiFi	IEEE 802.11
WLAN	Wireless Local Area Network
WP	Work Package
WPAN	Wireless Personal Area Network
WWRF	Wireless World Research Forum