

A TV WHITE-SPACES WIRELESS NETWORK ARCHITECTURE FOR EFFICIENT SPECTRUM SHARING IN EUROPE, AND ITS APPLICABILITY FOR PUBLIC SAFETY APPLICATIONS

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ABSTRACT

Growing need in wireless services consumption require more spectrum and improved utilization of existing allocations. New spectrum-use policies, as well as innovative wireless technology, have to be developed and embraced if we are to avoid a major "spectrum crisis". In this context, the digital TV switchover provides a rare opportunity for the development of innovative wireless services and the introduction of new advanced technologies into the television white spaces (TVWS). From the perspective of the EU funded COGEU project, this paper proposes several approaches to leverage the value of the TVWS namely secondary spectrum trading, and spectrum commons. Spectrum Commons generally implies unlicensed use of white spaces, while Secondary Spectrum trading denotes a mechanism whereby rights to use spectrum are transferred from one party to another. COGEU provides an alternative to spectrum commons usage by introducing managed spectrum by a broker. Information about TVWS are stored, managed and distributed by the broker based on dynamic resource allocation algorithms. A reference architecture, which consists of an intermediary broker, a geo-location database and associated protocols, is introduced and reply to both regulatory scenarios. Main capabilities, system requirements and reference model architecture are discussed leading to the introduction of WiFi-over-TVWS, LTE-over-TVWS and Public Safety systems as representative use cases. A special focus in this paper is given to the instantiation of the reference architecture for Public Safety. Indeed, highly critical systems such as Public Safety systems are about to be leveraged by spectrum access priority and policies mechanisms implemented into the spectrum management framework.

1. INTRODUCTION

This paper gives an overview of the architecture definition for a TVWS management framework under the COGEU

FP7 project. The main objective of the COGEU project is to design, implement and demonstrate enabling technologies to allow an efficient use of TVWS for mobile radio communications based on secondary spectrum market regime. In particular, COGEU intends to develop innovative mechanisms to realize the concept of TVWS cognitive systems to take advantage of the existing TV White spaces that goes beyond the immediate opportunities of the often quoted rural broadband.

2. RELATED WORK & STANDARDS

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 many applications. We are 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 brief 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, and incumbent protection. Relevant standards and related works are described in following sub-sections. Focus is on Architecture building block definition to gain access to TVWS.

2.1. ETSI RRS

ETSI RRS currently considers the usage of TVWS for adapting existing and/or evolving Radio Standards, such as 3GPP LTE (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



Figure 1: Database driven access to TVWS

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. TD-LTE) 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. TDD (Time-Division Duplexing) can be considered more suitable for a secondary spectrum access compared with FDD (Frequency Division Duplexing). 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.

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.

2.3. 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 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 has a significant 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 follows 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.

3. INITIAL ARCHITECTURE FOR SPECTRUM SHARING IN TVWS

Although there is no harmonised European regulation yet, TVWS could operate in both the commons and secondary spectrum trading model. In a common spectrum usage model, there is no spectrum manager to preside over the resource allocation. Spectrum commons regimes promote

sharing, but does not provide any QoS due to sharing of spectrum resources. However, for applications that require sporadic access to spectrum and for which QoS guarantees are important, temporary/exclusive licensed spectrum with secondary markets is 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. In this context COGEU proposes two regulation scenarios explained hereafter:

1. **Spectrum Common Only:** Both geo-location database access and spectrum sensing are required for the protection of Incumbent users.

2. **Spectrum trading AND Spectrum Common:** Only geo-location database access is required for the protection of the Incumbents.

3.1. First Regulatory Scenario: Spectrum Common only

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 (ENG), which requires protection, is one of the main challenges in the design of a geo-location database. Moreover, so far there is no clear regulatory framework regarding sensing requirements in Europe. The process of switching PMSE to “safe harbor” may take years to be concluded in Europe, therefore we can assume a scenario where TVWS Devices have to coexist with unpredictable PMSE through combination of sensing and geo-location database access (master-slave topology) should be assumed for unlicensed use of TVWS. 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 is a promising approach. The database protects DVB-T and some of the 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 through autonomous sensing.
- In this scenario, autonomous sensing for PMSE and optional for DVB-T signals (which are mainly protected by the geo-location database) should be mandatory. 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. Cooperative sensing requires protocols for sharing sensing information among TVWS devices which add extra complexity and sensing overhead to the TVWS system.

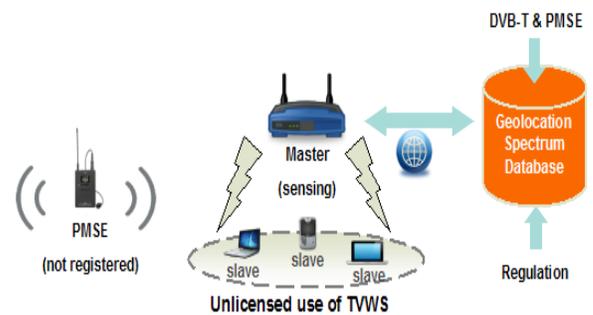


Figure 2 : Spectrum Common under 1st GOGEU Regulatory

As illustrated in Figure 2 two types of TV White Spaces Devices (TVWSD) are considered:

- “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 that 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

3.2. Second Regulatory Scenario : Spectrum Common AND Spectrum trading

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 it is assumed 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). 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 [4]:

“... 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. 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. In this sense, COGEU framework propose to enhance the database concept by supporting both Spectrum Common and Secondary exclusive rights under secondary spectrum trading. Division of spectrum into Unlicensed (in green in Figure 3) and spectrum market (in orange in Figure 3) is illustrated in Figure 3.

We strongly believe it is the best way to manage spectrum use, in line with current European regulators

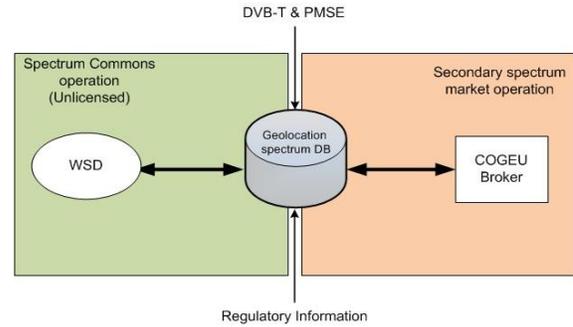


Figure 3: Geolocation database with allowing spectrum commons and secondary spectrum trading operations

situation in early 2011. Indeed, with this assumption as the basis for our scenarios, 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. Thus, 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 4. 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 described in the following sub-sections.

3.2.1 TVWS Allocation mechanisms

The spectrum broker determines how the TV white spaces are allocated among players, and also how much each player pays for the acquired spectrum [2][3]. Therefore, TVWS allocation and trading mechanism are important functions of the COGEU broker. There exists a cognitive 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. In order to implement this cycle and the functions required for allocation and trading, a framework is defined and illustrated in Figure 4.

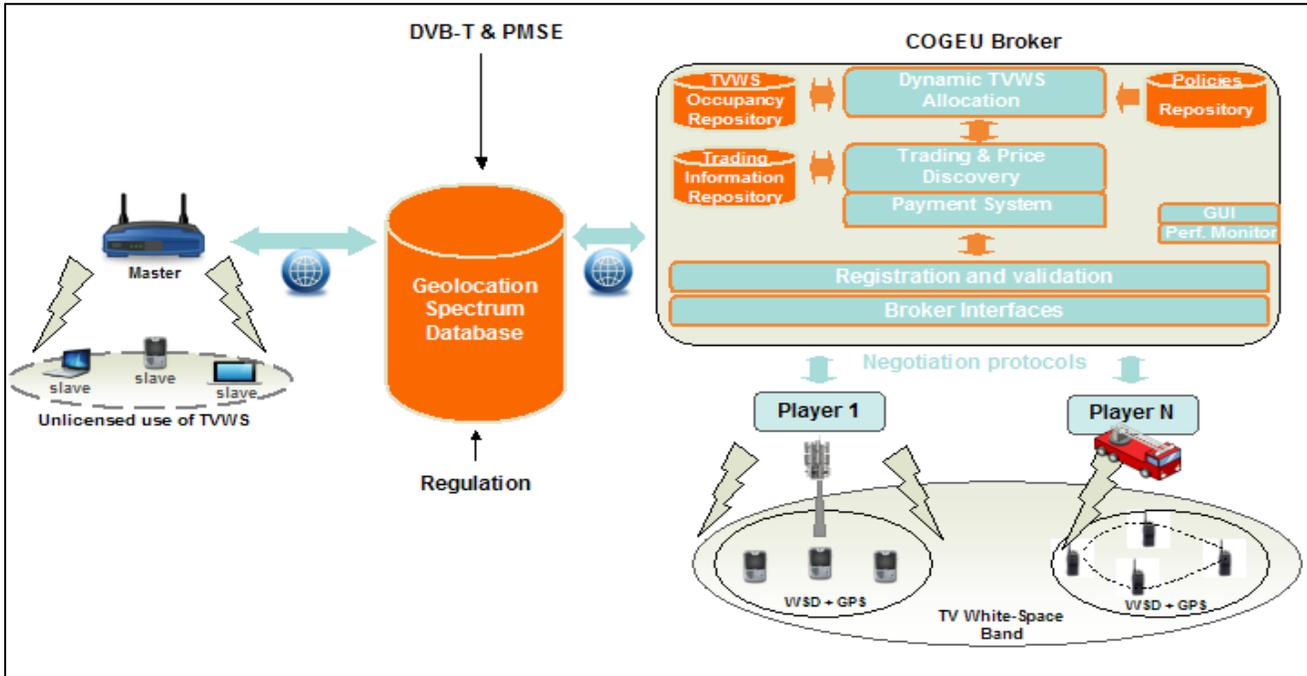


Figure 4: Initial COGEU reference architecture for commons and secondary trading, only geo-location access required.

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 are introduced 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.

Signaling between the broker and the spectrum user are introduced. The signaling 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 introduced, 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 standard overview analysis. It has to deal with two operational 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;

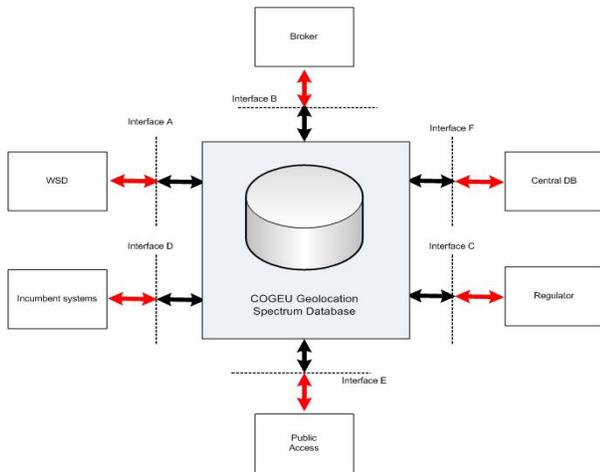


Figure 5: Geolocation database interfaces

- 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.

4. PUBLIC SAFETY SYSTEMS IN TVWS

Use of Dynamic Spectrum Access Radios by the Public Safety Community is very promising. There exists considerable opportunity for dynamic spectrum access radios to be used by the public safety community and within public safety and TVWS frequency bands. We also note the potential for reconfigurable radios to alleviate many of the interoperability issues associated with public safety spectrum use.

4.1. Manage interoperability via the broker

Public Safety domain is characterized by many different wireless heterogeneous networks like TETRA, TETRAPOL, Professional Mobile Radio (PMR) and satellite communications. In some cases, commercial systems like GSM/GPRS are also 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 band, 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.

4.2. Access priority for Public Safety Networks

Service priority is 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 trading mechanisms. In this manner, secondary TVWS systems will avoid selecting channels that are already in use by other secondary systems, enforcing coexistence.

5. CONCLUSION

From the perspective of the EU funded COGEU project, this paper proposes several approaches to leverage the value of the TVWS namely secondary spectrum trading, and spectrum commons. COGEU provides an alternative to spectrum commons-only usage by introducing managed spectrum by a broker. Information about TVWS are stored, managed and distributed by the broker based on dynamic resource allocation algorithms. A reference architecture, which consists of an intermediary broker, a geo-location database and associated protocols, is introduced and reply to both regulatory scenarios.

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