COGEU

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COgnitive radio systems for efficient sharing of TV white spaces in EUropean context

D2.1
European TV White Spaces Analysis and COGEU use-cases

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Abstract:
This deliverable analyses the digital switchover roadmap in Europe and surveys the trends in the TVWS market for different European countries in order to identify technically and economically viable COGEU application scenarios. D2.1 also investigates the technology, regulation/policy and economic aspects related to the cognitive access to TVWS in Europe.

Executive Summary

Radio spectrum when used appropriately is an important catalyst for the flourishing of economic activities through broadband wireless services provision. The radio spectrum suitable for the propagation of wireless signals is a limited resource and hence requires optimal allocation as collectively dictated by regulatory, technical and market domains. The current global move to switch from analogue to digital TV has opened up an opportunity for the re-allocation of this valuable resource. In one way, spectrum bands once used for analogue TV broadcasting will be completely cleared – leaving a space for deploying new licensed wireless services, and in another way, digital television technology geographically interleaves spectrum bands to avoid interference between neighbouring stations – leaving a space for deploying new unlicensed wireless services. The focus of the COGEU project is the utilization of geographic interleaved spectrum, also known as television white spaces (TVWS), based on cognitive radio technology. Real-time spectrum trading mechanism will also be investigated to satisfy dynamic spectrum demand.

The main objective of deliverable D2.1 "European TV White Spaces Analysis and COGEU use-cases" is three-fold: analyze the digital switchover roadmap in Europe and survey the trends in the TVWS market for different European countries in order to identify technically and economically viable application scenarios; study spectrum sharing models; identify and define viable COGEU use-cases for TVWS. This deliverable is a basis for future work. It is the first step from which COGEU will provide flexible tools and solutions for using the spectrum as facilitated by cognitive technology.

Key Conclusions

- 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.
- From the description of the frequency usage in the band 470 – 790 MHz, it can be concluded that the spectrum usage is dynamically evolving and that a regular update of the channel usage is necessary. The available resource for white space usage is unknown and may differ strongly from country to country as well as locally.
- Available reports show that TVWS are present and fragmented. They are typically more abundant in rural areas, with larger contiguous blocks of unused channels available, as broadcast network planning priorities are linked to population density. Also, database coordination of white spaces combined with spectrum sensing is a most promising technique, as compared with spectrum sensing alone.
- CEPT has recently started its own program of work, laying the technical foundations for white space devices to be allowed access to spectrum. COGEU will extract relevant subsets of existing CEPT specifications in the scope of TVWS access and protection requirements.
- OFCOM proposal for TVWS devices will require either sensing or geolocation/database access unlike the FCC rules which required a combination of both protection mechanisms. The sensing levels being proposed for sensing-only devices are -120 dBm for digital TV and -126 dBm for wireless microphones. These stringent parameters have a direct impact on the QoS of cognitive devices as well as battery life and terminal complexity. COGEU will combine local sensing and geolocation database access in order to relax sensing constraints, increasing TVWS feasibility and market potential.
- The COGEU vision has no intent to reinvent the wheel. During the course of the project, the consortium will investigate and tailor available solutions for the operation in TVWS and follow current standardization activities such as IEEE P1900, IEEE 802.x and ETSI RRS.
- PMSE in Germany has not to be registered in a database, sensing of PMSE equipment might be necessary not to interfere with PMSE. Germany regulator BNetzA points out that deployment of CR must not impede the future development of incumbent services (e.g. DVB-T2). German administration refuses an international approach and reclaims that the database has to be under the responsibility of the national regulators.
• Database for wireless microphones are not available in many EU countries. Moreover, geolocation database is unlikely to be updated sufficiently rapidly for all PMSE users (e.g. Electronic Newsgathering).

• Particularly relevant for COGEU is the agenda item 1.19 of WRC-11: to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution 956 (WRC 07)

• The existing WAPECS directive, which underpins regulatory developments in the member countries for a number of sub-bands, and particularly the 470-862 MHz sub band, provides a clear framework for the development of technology and service neutral licensing of spectrum.

• European harmonization: economics of scale, particular for mass-market applications such as WLANs, some applications may also benefit from international roaming.

• Manufactures currently have little incentive to maximize the interference tolerance of DTV receivers and there is still a lack of standard for minimum interference rejection for DTV receivers.

• Furthermore, there may be legitimate concerns that the current system provides incentives to those who may suffer from interference to complain to the regulator and block the launch of the new service rather than take actions and invest in more efficient receivers. This may occur even when the cost of replacing receivers is significantly less than the benefits from the new service.

• Existing commercial users of spectrum could have small incentives to sell or lease excess or unused spectrum if potential buyers will use their acquired spectrum to provide a service competing with the sellers or if secondary user will be introduced distortion.

• The introduction of secondary use allows a portion of players who cannot afford an exclusive license or find it impractical to use to become secondary users. The necessity of secondary use of spectrum appears when there are a large number of participants. Secondary use is higher when primary users have continuous spectrum usage (such DVB-T) than intermittent spectrum usage.

• If TVWS can be exploited as tradable and flexible spectrum, then it further expands the range of spectrum available over which key services can be provided. In turn, this increases the difficulty of for large players to dominate a market or develop market-abusive strategies.

• The UK model, administered on Ofcom’s behalf by JFMG, is interesting for COGEU because PMSE users can book the capacity online, coordinated through a database. Database coordination of white space, as we shall see, is a concept which is set to be at the heart of the future exploitation of white spaces.

• Secondary markets initiatives in Europe generally lag the rest of the developed world – there has been very little progress in the development of comprehensive frameworks for secondary trading at European level.

• A different approach for compliance other than the R&TTE Directive regime should be promoted, so that the market is protected by developing responsibility sharing bylaws – and hence filling the gap that is missing in device compliance regime and providing means to protect the European TVWS market.

• COGEU envisage a business model where the Geolocation Database and the Spectrum Broker can be different business entities. Such solution may be useful to manage real-time spectrum allocation in both spectrum sharing regimes considered by COGEU: spectrum commons (database only) and secondary spectrum market (database and broker).

• COGEU user terminal: communication in white spaces complements networks that use other parts of the spectrum. Thus is likely that existing types of devices will acquire white space interfaces alongside other more established radio interfaces.

• Market Potential of COGEU use cases: WiFi with cognitive access to TVWS-very high ; UMTS and LTE extension over TVWS – high ; Public safety applications with cognitive access to TVWS – high ; DVB-H with cognitive access to TVWS – moderate ; PMSE with cognitive access to TVWS – moderate ; WiMax with cognitive access to TVWS – low.
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List of Abbreviations

ARNS  Aeronautical Radio Navigation Services
ASO   Analog Switch Off
ATSC  Advanced Television Systems Committee
3G    Third-generation
3GPP  3rd Generation Partnership Project
4G    Fourth Generation
CEPT  Conference of European Postal & Telecommunications
COMREG Commission for Telecommunications Regulation
CR    Cognitive Radio
CRD   Cognitive Radio Devices
DSM   Dynamic System Management
DSO   Digital Switch-Over
DVB-H Digital Video Broadcasting – Handheld
DVB-T Digital Video Broadcasting - Terrestrial
DTT   Digital Terrestrial Television
DTV   Digital Television
DwPTS Downlink Pilot Time Slot
ETSI  European Telecommunication Standards Institute
EU    European Union
FCC   Federal Communications Commission
GE06  Geneva 2006
GSM   Groupe Spécial Mobile (also, Global System for Mobile communication)
HNM   Hidden Node Margin
IEEE  The Institute of Electrical and Electronics Engineers
ICT   Information and Communications Technologies
IMT   International Mobile Telecommunications
ISM   Industrial Scientific and Medical (band)
ITU   International Telecommunication Union
LAN   Local Area Network
LTE   Long Term Evolution
MAC   Medium Access Control
MFN   Multiple Frequency Networks
MIMO  Multiple-Input Multiple-Output
MPEG  Moving Picture Experts Group
Ofcom Office of Communications
OFDM  Orthogonal Frequency Division Multiplexing
PMSE  Programme Making and Special Events
PWMS  Professional Wireless Microphone Systems
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
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>SDR</td>
<td>Software Defined Radio</td>
</tr>
<tr>
<td>SFN</td>
<td>Single Frequency Network</td>
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<td>TV</td>
<td>Television</td>
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<tr>
<td>TVWS</td>
<td>TV White Spaces</td>
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<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<tr>
<td>US</td>
<td>United States of America</td>
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<tr>
<td>USRP</td>
<td>Universal Software Radio Peripheral</td>
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<tr>
<td>VHF</td>
<td>Very High Frequency</td>
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<tr>
<td>WAPECS</td>
<td>Wireless Access Policy for Electronic Communications Services</td>
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<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
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<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
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<td>WiFi</td>
<td>IEEE 802.11</td>
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<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<td>WPAN</td>
<td>Wireless Personal Area Network</td>
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<td>WSD</td>
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1 Introduction

Information and Communication Technologies (ICTs) have drastically changed the world in which we live. With increased interconnections in economic activities, knowledge sharing, entertainment, socializing etc, billions of people around the world today are utilizing ICTs to function in real-time across the world without delay and with blurred distinction between physical and digital experiences. These experiences are further magnified by access to mobile broadband networks where the limitations of wire-line access are overcome by giving people the ability to communicate anytime and anywhere. From the European Union's (EU) perspective, the Lisbon Treaty envisions providing significant improvements in mobile broadband, multimedia and Internet access to European citizens. To this end, the European Commission is putting forth efforts to make a pan-European mobile broadband network become a reality through harmonizing the spectrum usage of the 27 EU Member States, especially by creating an innovation space in the digital dividend, after the re-allocation of broadcast spectrum.

The broadcast spectrum is a low frequency spectrum in the VHF and UHF portion of the radio spectrum; a portion that has traditionally been used exclusively by television broadcasters for analogue transmission. The spectrum section offers attractive features like high building penetration, wide coverage, and moreover, the wavelength of UHF bands signals is sufficiently short such that resonant antennas with sufficiently small footprint can be used which are acceptable for many portable use cases and handheld devices. However, regulatory rules don’t allow the use of unlicensed devices in the TV bands, with the exception of remote control, medical telemetry devices and wireless microphones. Currently, there is a global move to convert TV stations from analogue to digital transmission. This is called the digital switch-over (DSO) or in some cases the analogue switch-off (ASO) referring to the time when digital transmission effectively starts, or when analogue transmission effectively stops operation respectively.

Although the DSO process is underway in EU countries, the ASO process will differ from country to country depending on the market configuration. It is predictable that the European Commission’s call for the completion of the ASO process by 2012 will be difficult to achieve for some Member-States. On the other hand, however, it is expected that the experiences of countries that have completed the ASO process or undertaken extensive planning will provide useful lessons for countries only beginning the planning process.

Due to the spectrum efficiency of DTV, some of the spectrum bands used for analog TV will be cleared and made available for other usage. Moreover, DTV spectrum allocation is such that there are a number of TV frequency bands which are left unused within a given geographical location so as to avoid causing interference to co-channel or adjacent channel DTV transmitters; that is to say, the spectrum bands are geographically interleaved. The cleared bands and the unused geographically interleaved spectrum bands provide an opportunity for deploying new wireless services. These opportunities create what is called the “Digital Dividend”. For the European Commission, the Digital Dividend (cleared spectrum and geographically interleaved spectrum) constitutes a great opportunity to achieve important goals of the EU Lisbon strategy, especially in the area of providing mobile broadband Internet access.

Market analysis indicates that the digital dividend in Europe is a unique opportunity to realise economic/social benefits across Europe. This is a key to maintaining Europe’s competitiveness – especially given digital dividend advances in other regions. Secondary markets initiatives in Europe generally lag the rest of the developed world – there has been very little progress in the development of comprehensive frameworks for secondary trading at European level.

The digital dividend could be valuably employed by cognitive devices. The Cognitive Radio (CR) technology is a key enabler for both real-time spectrum markets and dynamic sharing of licensed spectrum with unlicensed devices. It performs spectrum acquisition, either through purchasing (in cleared spectrum) or sensing (in vacant bands e.g., geographic interleaved spectrum), over a range of frequency bands, dynamically acquires unused spectrum, and then operates in this spectrum at times and/or locations when/where it is able to transmit in a non-interfering basis while achieving its service’s QoS. Currently Cognitive radio is being intensively researched for proper access to the TV White Spaces (TVWS) which become available on a geographical basis after the digital switchover.

In December 2009, the RSPG published the final draft of their report on ‘Cognitive Technologies’, which makes explicit comments on the possibility of supporting trading mechanisms for CR technologies. This report describes the vertical and the horizontal models for the licensed sharing of spectrum. The vertical
model, which is most likely of more relevance, envisages the licensed user, i.e. the DTT broadcaster, allowing secondary usage of its spectrum at locations and times that it is not used. The horizontal model, on the other hand, is of less relevance to horizontal sharing because it pools all the spectrum held by a group of licenses such they can then access that spectrum according to their given demand profiles.

Globally, the active secondary trading of spectrum is still more a concept than a reality. There are a number of milestones that may mark the inception of secondary spectrum trading in the global context. Notably, New Zealand commenced trading in 1987, Guatemala in 1996, Australia commenced in 1997 and both the FCC and Ofcom adopted spectrum trading regulations in 2004. However, there has been little activity in the economic/business and regulatory development of an active secondary trading environment for micro trades of the kind that we might envisage in the TVWS context. The development of secondary trading systems in Europe is delayed when compared with the rest of the developed countries. For this case, COGEU project envisions filling this gap by investigating mechanisms for secondary spectrum trading and proposing relevant means to enable the existence of a secondary spectrum regime in the European context.

For the successful development of dynamic spectrum trading mechanisms and marketable wireless service provision models in TVWS, the COGEU project needs to first analyse the intersection of the influences form regulatory, technology, and market potential aspects. To this end, this deliverable (D2.1) aims at analysing the digital switchover roadmap in Europe and surveying the trends in the TVWS market for different European countries in order to indentify technically and economically viable COGEU application scenarios. Furthermore, D2.1 will examine the incentives for spectrum sharing and investigate under what circumstances potential secondary users for TVWS would emerge.

COGEU will move away from the binary choice of optimize current spectrum (not always possible) or buy new spectrum with exclusive rights (too costly) by including a third option which is the secondary use of TVWS: new spectrum commons and secondary spectrum market. (see Figure 1).

Figure 1: COGEU third way opportunity.

The European Commission noted that it intends to see the following key features of an EU spectrum trading framework developed: Tradability, Technology neutrality, Service neutrality, Transparency and Spectrum rights. 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 interference limits. A negotiation protocol is required for information exchange among the players and negotiation mechanisms by which users can request and acquire temporarily exclusive rights to a part of the TVWS. To this end, D2.1 will also investigate spectrum sharing models relevant for TVWS as a preliminary step leading to policy and technical realisation in later work packages.

Furthermore, the COGEU project has to achieve QoS support for TVWS cognitive systems based on the spectrum access model in the selected use-cases. The COGEU system is expected to be enabled with capabilities allowing the commons and/or real time paid usage of spectrum. To achieve this, specific technical challenges in the TVWS have to be identified. D2.1 will identify the specific technical
challenges faced in the TVWS scenario, which emanates from the hidden node problem, the protection of incumbent users, the fragmentation of TVWS and the spatial-temporal variations in spectrum availability.

Apart from regulatory and technical issues, COGEU will also address several business models or use-cases suitable for TVWS. D2.1 will address several application scenarios to play a part in achieving those goals. The scenarios at low frequencies (<1 GHz) are ideal for both rural coverage and indoor penetration. Particular importance is given to rural areas where mobile systems deployment are made to provide good coverage. Hence, reduction in the number of sites directly corresponds to a reduction in the cost of offering service. Likewise in urban areas, the lower frequency band tend to refract better around corners and can pass more easily through walls to obtain an improved indoor coverage with the ability to serve devices in the home without an external antenna. In later stage of COGEU, cognitive capabilities, for example using geo-location with database techniques to identify spectrum availability, will be considered for integration with off-the-shelf protocols and solutions based on the use-cases indentified in this deliverable.

The arrangement of this deliverable is as follows. Chapter 2 gives the overview of the digital dividend and specifically TVWS. Chapter 3 presents the three domains namely regulatory, market and technical regarding cognitive access to TVWS in Europe. Chapter 4 presents the COGEU spectrum sharing models. Chapter 5 identifies the COGEU potential application scenarios and use-cases. Chapter 6 concludes the deliverable.
2 Global perspective of the TVWS

This chapter is dedicated to describe the important resource that the COGEU project is going to exploit, that is, TVWS. First, the current situation of the digital switchover around the globe is overviewed. Second, a conceptual definition of the digital dividend is given and the TVWS is elicited. Third, a general overview of incumbent systems in TVWS is given. These incumbents are important since COGEU systems have to consider coexistence with them. Forth, the availability of TVWS in Europe is highlighted based on studies in UK, France and Italy.

2.1 Current situation of the digital switchover

The digital switchover process is underway. Around the world, countries have launched their Digital Terrestrial Television (DTT) services and begun planning to switch off their analogue networks. But analogue switch-off is not easy. Ending the transmission of analogue services can have terrible consequences if viewers were not adequately prepared. Governments will not want the risk of viewers without television and will want to ensure that proper safeguards are taken. But doing so will require careful planning and the involvement of the entire broadcast industry.

The process of analogue switch-off will differ in countries depending upon the market configuration. Countries with many households relying on the terrestrial platform will need to take different measures than countries with few terrestrially dependent households. The experiences of countries that have completed analogue switch-off or undertaken extensive planning can provide useful lessons for countries only beginning the planning process. Understanding which approaches work best, as well as pitfalls that should be avoided, can help ensure a successful process. The transition to digital television at present is largely a preoccupation of the advanced economies of the world and the major markets are the USA, Japan and Europe – and, within Western Europe, the UK, Spain, Germany, Italy and France.

2.1.1 Outside Europe

The DTT transition in the United States was the switchover from analog to exclusively digital broadcasting of free over-the-air television programming. For full-power TV stations, the transition went into effect on June 12, 2009, with stations ending regular programming on their analog signals no later than 11:59 p.m. local time that day. The transition was originally scheduled for February 17, 2009. However, since around two million families were not prepared for the transition, the switch-off of analogue was postponed.

In Japan, the switch to digital is scheduled to happen on July 24, 2011. In Canada, it is scheduled to happen on August 31, 2011. China is scheduled to switch-off in 2015. Brazil switched to digital on December 2nd of 2007 in major cities and it is estimated it will take seven years for complete signal expansion over all of the Brazilian territory.

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Figure 2 shows the status of analogue to digital transitions worldwide.

Figure 2: World map of digital television transition progress in 12 January 2009 [1]
2.1.2 **Within Europe**

The switchover from analogue to digital terrestrial TV in Europe will free up highly valuable radio frequencies due to the greater efficiency of digital broadcasting transmission. This ‘digital dividend’ has great potential for the provision of a wide range of services, as the radio signals in this range travel far and equipment can be easily used indoors. It represents a unique opportunity for Europe to meet the growing demand for radio spectrum, particularly to provide wireless broadband to rural areas, thereby bridging the digital divide, and to stimulate the take-up of new wireless services such as the next generation of mobile broadband, as well as to support the development of terrestrial broadcasting. It can therefore contribute significantly to the Lisbon Agenda goals of competitiveness and economic growth and satisfy some of the important social, cultural and economic needs of European citizens.

The digital dividend spectrum will become available throughout Europe within a relatively short space of time, as all Member States should complete the switch-off of analogue TV by 2012 at the latest. It is essential that this window of opportunity is used to ensure an appropriate level of coordination in the European Union to reap the full social and economic benefits possible from access to this spectrum, and to provide a clear EU roadmap for Member States moving ahead at different speeds as a result of differing national circumstances.

The opening of the digital dividend spectrum for different services creates an opportunity particularly for wireless broadband network operators to gain valuable radio spectrum. This would allow for more effective competition in the provision of broadband services.

As of late 2009, 10 countries had completed the process of turning off analog terrestrial broadcasting. Many other countries had plans to do so or were in the process of a staged conversion. The first country to make a wholesale switch to digital over-the-air (terrestrial) broadcasting was Luxembourg, in 2006, followed by the Netherlands later in 2006, Finland, Andorra, Sweden and Switzerland in 2007, Belgium and Germany in 2008, and the Denmark and Norway in 2009. In Table 1 we can see the digital television launch date (and the termination of analog TV).

<table>
<thead>
<tr>
<th>Country</th>
<th>Launch date</th>
<th>Compression format</th>
<th>Completion of ASO (Analog Switch Off)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>1998</td>
<td>MPEG-2</td>
<td>2012</td>
</tr>
<tr>
<td>Sweden</td>
<td>1999</td>
<td>MPEG-2</td>
<td>Completed</td>
</tr>
<tr>
<td>Spain</td>
<td>2000/2005</td>
<td>MPEG-2</td>
<td>2010</td>
</tr>
<tr>
<td>Finland</td>
<td>2001</td>
<td>MPEG-2</td>
<td>Completed</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2002</td>
<td>MPEG-2</td>
<td>Completed</td>
</tr>
<tr>
<td>Belgium (Flemish)</td>
<td>2002</td>
<td>MPEG-2</td>
<td>Completed</td>
</tr>
<tr>
<td>NL</td>
<td>2003</td>
<td>MPEG-2</td>
<td>Completed</td>
</tr>
<tr>
<td>Italy</td>
<td>2004</td>
<td>MPEG-2</td>
<td>2012</td>
</tr>
<tr>
<td>France</td>
<td>2005</td>
<td>MPEG-2/MPEG-4 AVC</td>
<td>2011</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2005</td>
<td>MPEG-2</td>
<td>2011</td>
</tr>
<tr>
<td>Denmark</td>
<td>2006</td>
<td>MPEG-2/MPEG-4 AVC</td>
<td>Completed</td>
</tr>
<tr>
<td>Estonia</td>
<td>2006</td>
<td>MPEG-4 AVC</td>
<td>2010</td>
</tr>
<tr>
<td>Austria</td>
<td>2006</td>
<td>MPEG-2</td>
<td>2010</td>
</tr>
<tr>
<td>Slovenia</td>
<td>2006</td>
<td>MPEG-4 AVC (TBC)</td>
<td>2011</td>
</tr>
<tr>
<td>Norway</td>
<td>2007</td>
<td>MPEG-4 AVC</td>
<td>Completed</td>
</tr>
<tr>
<td>Lithuania</td>
<td>2008</td>
<td>MPEG-4 AVC</td>
<td>2012</td>
</tr>
<tr>
<td>Hungary</td>
<td>2008</td>
<td>MPEG-4 AVC</td>
<td>2011</td>
</tr>
<tr>
<td>Ukraine</td>
<td>2008</td>
<td>MPEG-4 AVC</td>
<td>2014</td>
</tr>
<tr>
<td>Latvia</td>
<td>2009</td>
<td>MPEG-4 AVC</td>
<td>2010</td>
</tr>
<tr>
<td>Portugal</td>
<td>2009</td>
<td>MPEG-4 AVC</td>
<td>2012</td>
</tr>
<tr>
<td>Croatia</td>
<td>2009</td>
<td>MPEG-2</td>
<td>2011</td>
</tr>
<tr>
<td>Poland</td>
<td>2009</td>
<td>MPEG-4 AVC</td>
<td>2013</td>
</tr>
<tr>
<td>Slovakia</td>
<td>2009</td>
<td>MPEG-2</td>
<td>2012</td>
</tr>
<tr>
<td>Ireland</td>
<td>2010</td>
<td>MPEG-4 AVC</td>
<td>2012</td>
</tr>
<tr>
<td>Russia</td>
<td>to be confirmed</td>
<td>MPEG-4 AVC</td>
<td>2015</td>
</tr>
</tbody>
</table>
The Member States that launched DTT early mainly broadcast using MPEG-2 compression technology, while Member States that have recently launched, or are yet to launch (such as Ireland, Latvia, Lithuania, Romania, and Slovenia) plan to use MPEG-4 compression technology from the outset. Austria, Denmark, Finland, Germany, Italy, Luxembourg, Portugal, Sweden and the UK all consider future migration to the MPEG-4 standard to be highly likely. In particular, Sweden and Denmark intend to simulcast using both the MPEG-2 and MPEG-4 standards in the foreseeable future.

Market evidence shows that the MPEG-4 AVC compression technology is increasingly being integrated into DTT receivers. Markets that have launched DTT services since 2008 have overwhelmingly adopted MPEG-4 AVC while markets that presently use MPEG-2 will likely transition to MPEG-4 AVC. In France, and as from 2010 in Spain, all HD receivers must include an MPEG-4 AVC chipset. As a result, MPEG-4 AVC is expected to become the de-facto compression technology used in almost all DTT receivers.

The average simulcast period for analogue and digital terrestrial TV in Member States is about 5.5 years. Smaller Member States with extensive cable infrastructure/take-up, such as the Netherlands and Luxembourg, switched off their analogue TV signals nationally overnight. Germany, as a larger nation with extensive cable infrastructure, adopted a regional digital switchover plan and had a simulcast period of almost six years. In contrast, in the UK, where terrestrial TV is one of the main TV platforms, simulcast is expected to occur for a total of 14 years prior to ASO.

As we have seen, Member States have varying approaches to their Digital Switch-Over (DSO) plans. The pace at which they are being executed appears to depend on geography, the television platform landscape, policy objectives and political will, as well as the level of technological advancement. In general, Western European Member States have started, and are likely to complete, their DSO before Eastern European Member States. Indeed, five (Finland, Germany, Luxembourg, the Netherlands and Sweden) have already switched off their analogue transmissions.

The European Commission’s call for the completion of analogue switch-off by 2012 may be difficult to achieve for some Member-States. Based on currently available evidence, it can be generally assumed that the digital switchover process will take between 14 years (as in the United Kingdom) and 3 years (as in the Netherlands) from the time of the first launch of DTT services to the switch-off of the last analogue services. Factors that will influence the process include the number of viewers relying on the terrestrial television platform, spectrum availability, and the penetration of DTT services.

Countries that have already launched DTT services and begun to switch-off their analogue terrestrial platform will likely complete digital switchover by 2012. However, countries that have not yet launched their DTT platforms risk being unable to complete analogue switch-off by 2012. At this stage, all Member-States, apart from Poland, appear to have confirmed their intention to complete analogue switch-off by 2012. Already, the process have been completed by 5 Member-States (Finland, Germany, Luxembourg, the Netherlands, Sweden) while a further 8 Member-States (Austria, Belgium, Czech Republic, Estonia, France, Italy, Spain, the United Kingdom) have begun switching off analogue services in one or more areas. It is expected that these countries will be able to complete analogue switch-off by 2012, if not earlier. Member States that have not yet launched DTT services will have more difficulty in reaching a sufficiently high level of penetration to allow for analogue switch-off by 2012. [2]

2.2 What is the TVWS?

2.2.1 The Digital switch-over

Broadcast television services operate in licensed channels in the VHF and UHF portion of the radio spectrum. The spectrum section offers attractive features like high building penetration, wide coverage, and moreover, the wavelength of UHF bands signals is sufficiently short such that resonant antennas with sufficiently small footprint can be used which are acceptable for many portable use cases and handheld devices. However, regulatory rules don’t allow the use of unlicensed devices in the TV bands, with the exception of remote control, medical telemetry devices and wireless microphones. Currently, there is a global move to convert TV stations from analog to digital transmission. This is called the digital switch-over (DSO) or in some cases the analogue switch-off (ASO) referring to the time when
digital transmission effectively starts, or when analogue transmission effectively stops operation respectively [3].

2.2.2 The Digital Dividend

Due to the spectrum efficiency of DTT, some of the spectrum bands used for analog TV will be cleared and made available for other usage. Moreover, DTV spectrum allocation is such that there are a number of TV frequency bands which are left unused within a given geographical location so as to avoid causing interference to co-channel or adjacent channel DTV transmitters; that is to say, the spectrum bands are geographically interleaved. The cleared bands and the unused geographically interleaved spectrum bands provide an opportunity for deploying new wireless services. These opportunities create what is called the “Digital Dividend” in the literature [3] [4] [5] [6] [7] [8] [9]. In other words, the digital dividend refers to the “leftover” frequencies resulting from the change of TV broadcasting from analog to digital.

The UK regulator, Ofcom, has led Europe in creating a digital dividend. As illustrated in Figure 3, the UK’s digital dividend comprises [8]:

- Cleared spectrum –128 MHz that will become available for new uses primarily as a result of digital switchover;
- Geographical interleaved spectrum (or Television White Spaces - TVWS) – the capacity available within the spectrum that will be retained for digital terrestrial TV after switchover. This is known as interleaved spectrum because not all this spectrum in any particular location will be used for digital terrestrial TV and so is available for other services on a shared (or interleaved) basis. Since the COGEU project is based on TVWS, more details will be given in the next section.

Following the UK’s leadership, it is now clear that a growing number of other European countries will release a digital dividend, but within a slightly wider block of spectrum than the UK’s, at 790-862 MHz (the so-called 800 MHz band). For example:

- In Sweden, a governmental decision taken in 2007 came into force on January 1, 2009;
- In Finland, the Government allocated the band 790-862 MHz to digital broadband mobile networks; the decision came into force on July 1, 2008;
- In France, the government announced the allocation of the 790-862MHz band to digital broadband mobile networks; with auctions/beauty contest announced for 2009.

As Finland, France and Sweden have already decided to release this wider block of spectrum of 72 MHz, a number of other countries are expected to do likewise. On the other hand, the European Commission is under consultation on how to harmonize the realization of the digital dividend over the whole of Europe so as to avoid fragmentation in terms of policies among member states [3] [5] [6] [7]
As we have seen above, the Ofcom on its part is already aligning its digital dividend to the 72 MHz wider block so that devices can operate all over member states.

For the European Commission, the Digital Dividend (Cleared spectrum and geographical interleaved spectrum) constitutes a great opportunity to realize significant elements of the EU Lisbon strategy, e.g. providing significant improvements in mobile broadband, multimedia and Internet access. The COGEU project aims the efficient exploitation of the geographical interleaved spectrum (also called TVWS) that will be detailed in the next section.

2.2.3 TVWS or geographical interleaved spectrum

2.2.3.1 CEPT definition

The European Conference of Postal and Telecommunications Administrations (CEPT) identifies white space 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 [9].

The interleaved spectrum or TVWS arises because in a multiple frequency network any television channel is carried on a number of different frequency channels around the service area. On any given frequency channel there will be a geographical zone where use for high-power broadcasting is not possible because of the interference it would cause, but use for low/moderate power applications is possible, provided these are carefully designed so as to be compatible with the primary users DTV and other secondary users such as PMSE (Programme Making and Special Events).

As shown in Figure 4, the coverage area between broadcast services defines the white spaces that could be exploited by a cognitive radio network. According to the Geneva 2006 frequency plan (GE06), the majority of the European countries within CEPT obtained seven nationwide coverage for DVB-T in Bands IV/V and one DVB-T coverage in Band III. Figure 5 gives illustration of the availability of TVWS across Europe by showing the map of envisage DVB-T plan in UHF channel 21 (GE06), the white spaces are the areas without coverage and potential beneficiaries of the COGEU project results.

Figure 4: A Cognitive Radio network operating in a Television White Space (channel 40)
2.2.3.2 COGEU interpretation of CEPT definition of TVWS

The white spaces could be valuably employed by cognitive devices. COGEU assumes a regulatory scenario where part of the TVWS will be released to establish a spectrum commons and a secondary spectrum market where cognitive radios coexist with primary users and other secondary users in a non interference basis. Although the project follows CEPT definition on TVWS devices and services, in that it will play by the set rules of the game, the interpretation is the following:

2.2.3.2.1 “The non-interfering aspect”

A crucial specification of technologies is to avoid provoking harmful interference with incumbents. However, it is important that the definition of standards for primary user’s protection not to be excessively restrictive, by setting stringent and inflexible thresholds. COGEU project will investigate compatibility criteria between TVWS devices and primary users under different QoS and white space availability categories. Currently there is a lack of standard for minimum interference rejection for DTT receivers. On the other hand, currently manufactures have little incentive to maximize the interference tolerance of DTT receivers. The regulators should set policies that will give incentives to manufactures to improve interference tolerance of DTT receivers so as to increase the chances for coexistence with other technologies. That will maximize the social benefit of spectrum usage through the creation of a wider innovation space.

2.2.3.2.2 “The non-protected aspect”

Although TVWS services are non-protected by interference from primary users, COGEU project will develop techniques to provide QoS for the secondary users of the spectrum, e.g., using as backup TV channels when a primary user appears and the TVWS device must leave the band. COGEU considers that QoS provision is very important for cognitive radio success in real markets.

2.3 General overview of incumbent systems in TV bands

The Band 470 – 790 MHz where potential TVWS may exist is currently used by several applications:

2.3.1 Broadcast services

The main usage is of course Digital terrestrial television based on DVB-T standard. In general, the transition to the digital terrestrial is well advanced and is completed in several countries. Three categories of countries can be defined:

- Countries which have already switched off analogue television;
- Countries which have started to switch off analogue television;
- Countries which will soon start to switch off their analogue transmissions.

In conjunction with this switch over process, there is the transition process towards the target GE06 plan. During the RRC-06 which established the GE06 plan the countries obtained 7 – 8 DVB-T so called layers. A layer is a network of frequency channels in order to obtain a nationwide coverage. From the GE06 plan one can easily estimate that an average frequency reuse factor of less than 7 characterizes...
the DVB-T usage scheme for MFN (Multiple Frequency Networks). In this configuration adjacent transmitters use different channels for broadcasting the same content. In MFN frequency reuse is restricted by large safety distances to avoid interference between the transmitters using the same frequencies. Most of European countries use MSF as their standard which, for the case of analogue transmission is the only way to build a broadcast network.

Figure 6 gives an idea on the number of multiplexes after the GE06 plan:

![Figure 6: Number of multiplexes obtained at the RRC06. (Source: EBU)](image)

For digital transmission, MFN is not the only way as the characteristics of transmission system (guard bands which help to compensate different propagation times) also allows to build up SFN (Single Frequency Networks).

Within a SFN it is possible to cover larger areas (even a whole country) with the same channel for one multiplex. SFN also require less transmit power because possible signal fading can be compensated by an adjacent transmitter in the SFN.

One limiting factor for the size of a SFN is the requirement for regional or even local TV programs. As programs are not transmitted separately but instead put together into multiplexes, SFN are limited in size by the coverage of the regional and local TV programs.

Some European countries, e.g. Germany and Italy operate Single Frequency Networks.

As an indicator, the following table gives some typical parameters of DVB-T operation:

<table>
<thead>
<tr>
<th>16 QAM 2/3, fixed reception, ITU-R P 1546-3 (different antenna heights)</th>
<th>Typical power</th>
<th>Coverage radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full power transmitter (digital TV)</td>
<td>~100 kW</td>
<td>~80 km</td>
</tr>
<tr>
<td>Low power transmitter</td>
<td>~1 kW</td>
<td>~25 km</td>
</tr>
<tr>
<td>DVB-T repeater station</td>
<td>5-20 W</td>
<td>~7 km</td>
</tr>
<tr>
<td>Single Frequency Network</td>
<td>-</td>
<td>Up to countrywide</td>
</tr>
<tr>
<td>Full power transmitter (portable indoor)</td>
<td>~100 kW</td>
<td>~20 km</td>
</tr>
</tbody>
</table>

In parallel to the digital switchover, there are replanning activities for the release of the 790 – 862 MHz spectrum which will intensify the usage of the band 470 – 790 MHz. Some countries will give up (parts of) layers while others will (try) to reconstruct the losses in the layers.

Moreover, there is an ongoing process in some countries to negotiate additional resources for DTT enhancements like HDTV, or additional services.

Additionally, it is expected that additional resources will be needed for the DVB-T2 simulcast. Another usage is the mobile television based on DVB-H. Although mobile television based on broadcast technology has not yet shown the expected success, there have been replanning activities in order to reserve resources for mobile TV. In some countries the service has started whilst in other countries, there are still several open issues pending prior to a launch of service.
2.3.2 \textit{PMSE Applications}

The band 470 – 790 MHz is further used for PMSE services on a secondary basis (non interference to and non protection against broadcast services). The PMSE services are Programmer Making and Special Events. It includes transmission of speech, music and/or pictures in the environment of news reports, productions and technical services. The transmission can be between a mobile transmitter and fixed receiver, a mobile transmitter and a mobile receiver or a fixed transmitter and a fixed receiver.

More precisely, in the band 470 – 790 MHz the following applications are in use:

- In-ear monitors;
- PWMS;
- Professional cordless camera/Mobile airborne video links;
- Engineering link/Telecommand;
- Remote control;
- Temporary point to point audio link;
- Temporary point to point video link;
- Mobile audio link;
- Mobile vehicular video link;
- Talkback.

The usage scheme and the licensing regime vary importantly across Europe. This is among others due to the following:

- Countries with the PAL B, G, H, D, K system used a 7 MHz in an 8 MHz channelization band plan, so that the 1 MHz gap became a candidate for additional PMSE usage. In these countries the usage of the TV Band developed more than in other countries with 8 MHz analogue TV standards;
- In some countries the higher frequencies were reserved for military applications (Germany e.g.), so that coexistence between Professional Wireless Microphone Systems (PWMS) and military applications became possible and the band was opened for PWMS as a general authorization. Following SE43 definition, PMSE equipment in the UHF band covers professional wireless microphone systems (PWMS), talk back systems and audio links. As Table 2 shows, in the higher bands of UHF, above 790 MHz, only PWMS is allowed. As a consequence, the band 790 – 862 MHz became intensively used by PWMS. For example, in Germany the number of PWMS operating in the band 790 – 862 MHz is estimated around 600 000;
- The licensing regime was different and the devices aren’t widely tunable.

Table 2 summarizes the usage scheme for Germany.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
Application & Frequency range & TV-channel & Max. ERP (Watt) & Max. RF-Bandwidth (kHz) \\
\hline
Temporary point to point audio link & 470 - 606 MHz & 21 – 37 (only 1 MHz-Gap) & 250 & 300 \\
\hline
Temporary point to point audio link & 614 - 790 MHz & 39 – 60 (only 1 MHz-Gap) & 250 & 300 \\
\hline
Talkback & 470 - 526 MHz & 21 – 27 (only 1 MHz-Gap) & 30 & 20 \\
\hline
Talkback & 470 - 510 MHz & 21 – 25 (only 1 MHz-Gap) & 5 & 50 \\
\hline
Talkback & 510 - 790 MHz & 26 – 60 (only 1 MHz-Gap) & 5 & 50 \\
\hline
Professional Wireless Microphones & 470 - 606 MHz & 21 – 37 & 50 x 10-3 & 200 \\
\hline
Professional Wireless Microphones & 614 - 790 MHz & 39 – 60 & 50 x 10-3 & 200 \\
\hline
Professional Wireless Microphones & 790 - 814 MHz & 61 – 63 & 50 x 10-3 & 200 \\
\hline
Professional Wireless Microphones & 838 - 862 MHz & 67 – 69 & 50 x 10-3 & 200 \\
\hline
\end{tabular}
\caption{Overview on the spectrum usage scheme for SAP/SAB applications in the band 470-862 MHz for Germany}
\end{table}
In Germany, professional wireless microphones in the band 790 – 862 MHz have a general authorization. Below 790 MHz there is always a need for a license award, so that the possible interference to DVB-T is fully controlled and limited.

In Eastern Europe (e.g. Russia, Belarus), there is an additional primary allocation for aeronautical radio navigation services (ARNS) in the band 645 – 862 MHz. During the RRC-06 negotiations, the protection of these services led to some constraints regarding DVB-T transmissions. With the introduction of mobile services in the band 790 – 862 MHz there are still negotiations and constraints in order to protect the aeronautical navigation service.

Finally, the radio astronomy on channel 38 (608 – 614 MHz) is in use in several countries or part of the countries, it has to be protected.

From the description of the frequency usage in the band 470 – 790 MHz, it can be concluded that the spectrum usage is dynamically evolving and that a regular update of the channel usage is necessary. The available resource for white space usage is unknown and may differ strongly from country to country as well as locally.

### 2.4 Overview of TVWS availability in Europe

For the COGEU project to be successful, the ability to quantify the availability of TV white spaces is important in both developing white space devices and also protecting incumbent systems. The guiding parameters in quantifying the number of available white spaces in a given location are the interference limitation thresholds set to protect incumbent system and the transmission power of cognitive radio devices. Moreover, the geographical pattern for the availability of TVWS is affected by factors like wireless signals propagation properties like shadowing, fading; as well as station/device design factors such as antenna pattern, maximum transmission power, etc.

The result of quantifying the available TVWS is information to help a secondary-market or commons spectrum user to operate without causing interference to incumbent systems. Specifically, in case where channels are available in a given geographical location, the results help the TVWS system to determine how much transmit power to use, and also what kind of modulation to use depending on the closeness or sparseness of available channels, i.e., whether contiguous or non-contiguous respectively.

Based on public reports the following subsections will give an overview of TVWS in UK, France and Italy. COGEU project in WP4 will characterize TVWS in Munich (Germany) area where COGEU system will be demonstrated.

#### 2.4.1 United Kingdom

The digital TV standard adopted in the UK is DVB-T, which uses 8 MHz wide frequency bands for its transmission. At the bottom of Figure 7 is presented the chart of the UK’s analog TV frequency bands and how these will be divided after digital switchover into cleared and interleaved spectrum. From this chart it can be seen that the total UK interleaved spectrum, which is entirely in the UHF frequency range, is 256 MHz. However, Ofcom has proposed to auction off channels 61 and 62 for licensed use, reducing the TV bandwidth available for access by cognitive devices to a total of 240 MHz. However the exact number and frequency composition of TVWS can vary from location to location and is determined by the spatial arrangement of DTV transmitters and their nationwide frequency planning.

Figure 7 shows that channel 38 is now available for shared use of wireless microphones and personal monitors, subject to specific geographic restrictions. The UHF UK Wireless Microphone License now not only includes specified Channel 69 frequencies, but it also includes access to Channel 38. It is recognized that channel 69 is of great importance to wireless-microphone users because it is available throughout the UK. This channel is therefore heavily used to support travelling theatre productions and musical concerts.
Figure 7: Changing the configuration of the UK’s digital dividend

Figure 8 summarizes in a bar chart the availability of TVWS channels for 18 major population centers in England, Wales and Scotland. The total number of channels available at each location is shown as red bar. It can be seen that there are considerable variations in the number of TVWS channels as we move from one UK location to another. For any given location, however, a minimum of 12 channels (96 MHz) is accessible to low-power cognitive devices, while the average available spectrum is just over 150 MHz. [11]

Figure 8: Variations in the availability of TV White Spaces is show for 18 UK locations. Results are shown before (red bars) and after (green bars) the exclusion of those vacant channels whose adjacent were found to be occupied by DVT transmission. [11]

Other studies conducted by Ofcom [12] suggest that over 90 per cent of the population could have access to at least 100 MHz, aggregated across the interleaved spectrum. They also estimated that around 50 per cent of the population could have access to 150 MHz or greater and some rural communities could enjoy over 200 MHz of this spare capacity.

In addition to estimating the total available TVWS, it is of importance to investigate channel composition of this spectrum. Figure 9 shows, as an example, channel composition of TVWS in 4 cities in England: Bristol, Liverpool, London and Southampton. In this figure vacant channels are shown as blue bars while occupied channels are left blank. As can be seen from the figure, the precise composition of TVWS channels varies greatly from location to location. In particular, both in Bristol and Liverpool most of the available channels are located in the lower end (470-550 MHz) of the UHF band while in the case of Southampton these channels are bunched up in the higher end of this band (836 MHz).

Furthermore, the available TVWS channels can be highly non-contiguous. In the case of London, for example, although a total of 96 MHz spectrum bandwidth is in principle available, only 16 MHz can be utilized for contiguous frequency access [11].
In conclusion the exact number and frequency composition of TVWS can vary from location to location and is determined by the spatial arrangement of DTV transmitters and their nationwide frequency planning.

2.4.2 France

The availability of TV white spaces in France is reported in the 3rd meeting of SE43 [13]. The documents provide an estimation of the spectrum potentially available as white space in 3 rural areas with different topology characteristics in France: Morbihan, Creuse and Vosges. This study is done using the sensing-only methodology, using a 35 dB hidden node margin (HNM), and the sensing and geolocation database methodology, using the cross check effect with the consultation of a database and HNM= 0 dB.

It should be noted that the PMSE were not taken into account in this study and the protection of radio astronomy is assumed by the fact that the channel 38 is not available for DTT and for WSD.

As an example, DVB stations distribution on Morbihan are represented in Figure 10 a). The 261 test points considered for the determination of the potential available spectrum for white spaces devices (WSD) are depicted in Figure 10 b). Each test point in the studied area represents the centre of the city.
Details on the DTT stations considered and the test point localization for Creuse and Vosges areas can be found in report [13].

### 2.4.2.1 Digital Terrestrial Television scenarios

According to “France Numérique 2012” plan, and especially action point n° 20, 13 multiplexes are intended to be used in France after the DSO, 11 for fixed reception and 2 for mobile outdoor reception.

The detailed characteristics of the DTT considered in this study are listed in [13]. The same report also considers that WSD are equipped with an omnidirectional antenna (0 dBi) with the following heights: 1.5 m, 3 m and 10 m.

The results of the area 1, 2 and 3 are aggregated to obtain the graphs of Figure 11 and Figure 12. The WSD maximum EIRP considered are: 10, 20, 30, 40, 50 and 60 dBm. DTT Scenario shown has 11 + 2 Multiplexes and WSD antenna height is 1.5 m. Other scenarios are described in [13]. The study gives an estimation of the probability to have a given number of 1 or 2 contiguous channels for WSD.

![Figure 11: 1 x 8 MHz channels: a) Sensing + geolocation database and; b) Sensing only](image)

![Figure 12: 2 x 8 MHz channels (two contiguous channels): a) Sensing + geolocation database; b) Sensing only](image)

As can be seen from the previous figures, TVWS are fragmented since the probability to find 2 contiguous channels are lower. Geolocation methods are more efficient for detection of TV channels than sensing-alone techniques.

The number of channels potentially available decreases as the power of the WSD increases. This is because with the increased power of the WSD lower viability will have to not interfere with primary users.

### 2.4.3 Italy

In CEPT REPORT 24 [9], an estimate of the spectrum potentially available as white space in the west of Piedmont area is provided, with a detection threshold (DT) approach. Figure 13 a) and b) show the West Piedmont area with the number of channels available for each pixel for two DT: -120 dBm and -114 dBm.
The amount of spectrum available as white space strongly depends on the detection threshold used by the WSD. As a matter of fact, with $\text{DT} = -120 \text{ dBm}$ and $h = 1.5 \text{ m}$ the percentage of pixels where there is at least one available channel is 47.19%, while raising the detection threshold to $-114 \text{ dBm}$ this percentage becomes 56.99% \[13\].

For the same region, Figure 14 and Figure 15 show the Complementary Cumulative Distribution Function (CCDF) of the estimated amount of spectrum available as white space. For example, while almost 20% of locations have more than 64 MHz available with $\text{DT} = -120 \text{ dBm}$ and $h = 10 \text{ m}$, only 2% of population is actually in these areas. [13]

These Figures confirm the point that the areas where there are more available channels are rural, as the CCDF referring to the population percentage (Figure 15) is extremely fast in going to values under 5-10%, while the one referring to the location percentage (Figure 14) has a more gradual slope.
2.4.4 Conclusions on TVWS availability

This section presented the main results of the estimation of TVWS availability in three European countries: UK, France and Italy. Results show that white spaces are present and fragmented. They are typically more abundant in rural areas, with larger contiguous blocks of unused channels available, as broadcast network planning priorities are linked to population density. Also, database coordination of white spaces combined with spectrum sensing is a most promising technique, as compared with spectrum sensing alone.

In other countries not referred in the previous sub-sections, where the use of a single frequency terrestrial network (SFN) is planned, white spaces can be found outside the boundaries of the SFN. Also, the different content requirements of regions and counties means that such networks need to be partitioned and suitable gaps left between those using the same frequency.

Even with the introduction of new services by broadcasters, TVWS will not disappear. This persistence is due to the DTV planning around relatively inflexible “high power- high tower” distribution networks. Whilst roll-out and operating costs may be lower with such sparse networks, they impose a cost in terms of spectrum efficiency that can be used as an opportunity for TVWS devices.
3 Cognitive access to TVWS in Europe: economic, regulatory and technical domains

This chapter analyses the potential of Cognitive radio access to TVWS in the European context under the regulatory, economic and technology domains as shown in Figure 16. The economic potential is presented, followed by the position of various regulators on TVWS in Europe. Technical challenges for realizing the operation of cognitive radio devices in TVWS is presented, and complimented by identifying the necessary standardization and certification issues for compliance and interoperability.

3.1 The economic potential and social value of the TVWS in Europe

The economic potential and consequent social value in Europe, arising from a wise management of the digital dividend (cleared spectrum + TVWS), has been the object of many studies in last 3 years. The major findings of most of the studies are correlated and identify the following potential uses of the digital dividend:

- DTT
- Broadcast mobile TV
- Commercial wireless broadband services (fixed and mobile),
- Wireless broadband services for public protection and disaster relief (PPDR)
- Services ancillary to broadcasting and program making (SAB/SAP)
- Cognitive technologies

Due to the differences and peculiarities of each Member State, the potential growth and demand on each of the aforementioned potential digital dividend uses may vary significantly. However, studying a representative sample from a wider categorization of all Member States, illustrated that the UHF band used for terrestrial broadcasting is estimated to generate €750bn to €850bn in Net Present Value (NPV) for the European Economy. Additionally, the excellent propagation and coverage characteristics of this band are, without doubt, of great interest for the major stakeholders and will require a common approach and harmonization of the actions, especially on behalf of neighboring countries.

In this respect, the conservative trend in Europe is to allocate a part of the UHF spectrum (ranging from 72 to 92 MHz at a first stage) to mobile operators, which is estimated to generate between €63bn to €232bn NPV, measuring the benefits for a 20 year period. A further expansion will probably be reconsidered at a second stage, after reevaluation of the market as a whole, taking into consideration updated data on demand, market growth and technological innovations.

At a broader view, the market can be analyzed under different scenarios (e.g. pessimistic, conservative, and optimistic) in which, the main key drivers are the DTT and Wireless Broadband Service growth/demand and the relation between them. These parameters are then interpreted into economic figures considering, either a very specific UHF spectrum allocation for each service (e.g. 790 MHz – 862 MHz sub-band for mobile operators) or different ranges of spectrum allocation for the each service, in order to identify the optimal distribution of the band to the different potential uses of the digital dividend.

In order to quantify the forecasting of the growth and demand of the Wireless Broadband Service and finally interpret them into direct and indirect economic benefits and externalities, the models are using
measurable key activities such as Video (streaming and downloading measured in minutes/month), Browsing (pages/month), Music (tracks per month), Email (emails/month), Mobile TV (minutes/month), and Other Business Applications, all referring to a representative “file size per use”.

Direct benefits are those arising from the direct consumption of mobile broadband services and are split into the cost/benefits (or surplus) due to the producers and those due to the consumers. For producers of mobile broadband services, direct benefits primarily accrue as a result of a reduction in network costs. If these cost savings were retained by the operators or their shareholders, this would add to the producer Surplus. However, since the specific market is considered to be highly competitive, it can be safely assumed that almost 100% of cost-savings are ultimately passed on in price changes. Reduced prices for mobile broadband will facilitate increased consumer usage of the service and the incremental benefit to consumers or consumer surplus is this additional usage, combined with lower prices for existing usage.

Indirect benefits result from indirect effects that the market for these services have on other product markets and, as a result, can further increase total consumer and producer surplus. For example, some of the incremental revenues from a mobile broadband service could be generated by advertisements or incensement of e-commerce and not only by the subscribers. However, especially for the advertising revenues, they do not represent an economic benefit but a financial flow or an expense by the advertiser as part of its marketing strategy which results in higher sales and profits for the producers in other parallel markets. Externalities are wider economic benefits to society as a whole which are not generally taken into account by the consumer or the producer when selling the product or service. These would include increased productivity of workers, since the business applications will be available easier and in more efficient ways, additional job generation, boosting of related industries etc. Moreover, as a further social add on, can be considered the improvement of QoS, as well as the enhancement of the safety and security related applications, which promote a better quality of life to the citizens.

The approach described in Figure 17 is a standard model used in many studies, including the study of Spectrum Value Partners “Getting The Most Out Of The Digital Dividend (March 2008)”, as well as in the report prepared by Analysys Mason Limited, DotEcon Limited and Hogan & Hartson LLP for the Information Society Directorate-General of the European Commission: “Exploiting the Digital Dividend - A European Approach (August 2009)”, both resulting in similar conclusions and recommendations. [14]

![Figure 17: How the economic value generated by the 470-862MHz is considered by Analysis Mason, DotEcon and Hogan & Hartson, 2009 report [3].](image)

### 3.2 The regulatory framework for the use of cognitive TVWS systems

Taking into account that the spectrum dividend will become available throughout Europe within a relatively short space of time (i.e. when all Member States have completed the analogue switch-off by 2012 at the latest), it is of major and strategic importance to ensure an appropriate level of coordination among all Member States, towards reaping the full social and economic benefits possible from access to this spectrum, and to provide a clear EU roadmap for Member States moving ahead at different speeds as a result of differing national circumstances. In this respect, this section elaborates on the actions taken up-to-now by European organizations both at technological and legalization/political
levels, including roadmaps provided by European Commission itself, individual Member States, the Radio Spectrum Policy Group (RSPG), CEPT and ITU-R.

3.2.1 Action of the European Commission in the field of cognitive TVWS

In 2005 the Commission identified the release of the digital dividend in Europe as a spectrum policy priority, in its Communication on the ITU’s Regional Radiocommunication Conference (RRC-06) [15]. The Commission later called for efforts to be made at the World Radiocommunication Conference (WRC-07) [16] to give mobile services the same status as broadcasting services, a goal that was partially achieved. In November 2007, the Commission followed up with a key Communication outlining the need for and possible approaches to, achieving appropriate EU coordination. In line with the EU’s policy framework, the Commission requested, through a formal mandate, technical input from the Member States’ experts in the CEPT [17]. In its response to the Commission, the CEPT provided the essential technical elements necessary for the coexistence of bidirectional low/medium-power networks (e.g. for wireless broadband) and traditional high-power broadcasting networks in the digital dividend spectrum. This led to further preparatory work on the technical harmonization of the 790-862 MHz sub-band.

In order to understand the social and economic impact of the potential uses that can be made of the digital dividend under different scenarios, the Commission conducted a large-scale study to analyze and evaluate the various social and economic aspects by applying appropriate economic models. The results of the study have been a key input in the development of the proposals included in this Communication.

The Commission has also consulted with a wide range of interested stakeholders in different ways, including stakeholder interviews by consultants, a formal stakeholders’ hearing, two dedicated Member State workshops, consultation of the Radio Spectrum Policy Group, and finally a public consultation on the current proposals [18].

The overall goal of the Commission is to rely on the future radio spectrum policy programmer, as set out in the draft reform of the regulatory framework for electronic communications, which is expected to be adopted in the coming months, as the means to secure endorsement by the European Parliament and the Council of the main strategic elements in the future EU roadmap concerning the digital dividend. The future use of the UHF band in third countries bordering the EU is of fundamental importance as it will influence the way the digital dividend can be used in Member States affected by cross-border interference. It will also influence other Member States through a ‘knock-on’ effect. Action by neighboring third countries will also have an impact in terms of the economies of scale and scope that can be achieved in the wider region with regard to future innovative services. The adoption of a common EU position on key aspects of the digital dividend for the WRC negotiations, supported by the European Parliament and Council, would greatly improve the EU’s effectiveness in ensuring support for its standpoint.

The Commission study analyzed how economic outcomes and costs/benefits vary under a combination of scenarios for spectrum supply and demand over a period of 15 years, starting in 2012. This showed that opening up one part of the digital dividend — the 790-862 MHz sub-band — to wireless broadband services by 2015, in all Member States and under common conditions of use, would generate an added value compared to individual national initiatives of at least EUR 17 billion and up to EUR 44 billion depending on the pace of development of wireless broadband services in this sub-band. For this reason, the study identified the opening of the 790-862 MHz sub-band, which is already under consideration in several Member States, as the most pragmatic way to gain immediate benefits from the digital dividend. It is also why the Commission is proposing to adopt an urgent technical measure on that particular sub-band. However, this technical harmonisation decision will not oblige Member States to withdraw high-power broadcasting transmitters or to open up the sub-band to electronic communications services, due to the need to take account of the differing situations regarding terrestrial broadcasting in the Member States.

Regarding TVWS the European Commission has been considering the potential of white spaces for cognitive radio access, requesting opinions from leading experts in the CEPT (the association of European spectrum regulators) and its own Radio Spectrum Policy Group (RSPG). CEPT has recently started its own program of work, laying the technical foundations for white space devices to be allowed access to spectrum.
3.2.2 *Action of CEPT in the field of cognitive TVWS*

CEPT was mandated by the EC to carry out technical activities in order to provide the EU with relevant technical information in preparation for an EU-level policy proposal on how to achieve a suitable coordination, and consistency of approaches, regarding the digital dividend, in view of maximising its overall value. This also aims at developing harmonised conditions for the availability of radio spectrum to be able to satisfy a future demand for pan-European service. **COGEU will extract relevant subsets of existing CEPT specifications in the scope of TVWS access and protection requirements.**
### CEPT REPORT

<table>
<thead>
<tr>
<th>CEPT REPORT</th>
<th>Title</th>
<th>Relevance for COGEU</th>
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<tbody>
<tr>
<td>Report 138 [19]</td>
<td>&quot;Measurements on the performance of DVB-T receivers in the presence of interference from the mobile service (especially from UMTS)&quot;, Ljubljana, September 2009</td>
<td>COGEU system requirements (WP3) COGEU coexistence evaluation, protection of DVB-T (WP4)</td>
</tr>
<tr>
<td>Report 32 [22]</td>
<td>&quot;Recommendation on the best approach to ensure the continuation of existing Program Making and Special Events (PMSE) services operating in the UHF (470-862 MHz), including the assessment of the advantage of an EU-level approach&quot;, October 2009</td>
<td>COGEU system requirements (WP3) COGEU coexistence evaluation, protection of PMSE (WP4)</td>
</tr>
<tr>
<td>Draft Report (3rd meeting SE43) [23]</td>
<td>Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the White Spaces of the frequency band 470-790 MHz, January 2010</td>
<td>COGEU system requirements (WP3)</td>
</tr>
<tr>
<td>Report (Draft) [24]</td>
<td>Draft ECC Report LTE: &quot;Measurements on the performance of DVB-T Receivers in the presence of interference from the mobile service (especially from LTE)&quot;, February 2010</td>
<td>COGEU system requirements (WP3) COGEU coexistence evaluation, protection of DVB-T (WP4)</td>
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CEPT ECC Spectrum Engineering working group 43 (SE43) is defining technical requirements for the operation of Cognitive Radio in the TVWS. An initial report is expected by mid 2010 (www.ero.dk). Two established groups are relevant for COGEU: Determination of detection thresholds and Requirement for Geolocation database. Following the aims of these groups is presented.

#### 3.2.2.1 CEPT SE43: Spectrum sensing and detection thresholds

With spectrum sensing, devices try to detect the presence of protected services in each of the potentially available channels. Spectrum sensing essentially involves conducting a measurement within a candidate channel, to determine whether any protected service is present. When a channel is determined to be vacant, sensing is typically applied to adjacent channels to determine what constraints there might be on transmission power, if any. Some channels may be excluded, because the occupying service is not amenable to protection by sensing. For example, the radio astronomy service on Channel 38.

An increasingly sophisticated array of techniques is being applied to spectrum sensing, yielding enhanced levels of sensitivity, in return for using more detailed knowledge of the signal characteristics of the services in question.

A significant advantage of spectrum sensing (stand alone) is that it does not rely on any existing local infrastructure, such as connection to a database, for example. This may be more important in remote and rural areas. However, if sensing thresholds are set very low, then increasing device cost and complexity is matched with a reduced number of available channels. This would reduce the potential value to end users, particularly in areas of higher population density, and would hinder cost reductions in the technology.
So far analyses of sensing performance assume that detection is carried out independently by each device, in ignorance of results found by other cognitive devices in the same location. The emergence of cooperative sensing in which devices share their findings, brings the potential to reduce the hidden node margin by a substantial amount.

The cooperative sensing devices could for example be on different height, or one devices controls the other. This in turn would enable more relaxed sensing thresholds to be allowed, without compromising the protection afforded to established services.

In addition to a preliminary scanning of the band when a device is installed or powered on, we anticipate that sensing devices will periodically rescan the channel. This will allow them to detect changes in the presence of protected services. For example, a protected service may have started up in a channel previously considered vacant or in one or more of the adjacent channels.

Key parameters for spectrum sensing include:

- The sensing threshold;
- Periodicity of re-sensing on channels that have been detected as vacant;
- Sampling duration.

### 3.2.2.2 CEPT SE43: Requirement for Geo-location database

Geo-location appears to be an alternative to sensing. In this approach cognitive devices measure their location and make use of a “geo-location” database to determine which channels they can use at their current location. They are unable to transmit until they have successfully determined from the database which channels, if any, are available in their location.

In this case parameters such as location accuracy and frequency of database enquiry are important. This approach would require fast update (real-time in principle needed) in order to cover/model dynamic components (time variability) in the licensed Network. Considerations need to be made on maintenance, responsibility, geographical coverage, etc.

### 3.2.3 Action of RSPG in the field of cognitive TVWS

The Radio Spectrum Policy Group (RSPG) [25] is a high-level advisory group that assists the European Commission in the development of radio spectrum policy. The RSPG advises in a forward looking manner on a variety of technological, market and regulatory developments relating to the use of radio spectrum.

RSPG focuses on the impact and challenges of innovative cognitive technologies on access to the radio spectrum. The objective is to understand the appropriate regulatory conditions for dynamic access to spectrum and to identify issues which require further attention.

CR could be foreseen in various sharing arrangements. RSPG focuses on two models: a model based on collective use of spectrum and a model whereby the rights of use could be traded or leased. In both situations one can distinguish between vertical sharing, where the cognitive radio shares spectrum with the existing users, and horizontal sharing, where the cognitive radio technologies have the same rights to access the spectrum as the existing users.

RSPG also provides information on the economic aspects of cognitive radio systems and on the need from the industry perspective to establish viable initial business models. It also acknowledges the need for regulators and industry to work in close cooperation to maximise the benefits of cognitive technologies whilst ensuring protection of other users. [5]

The RSPG report on “Cognitive Technologies” [5], identified several aspects to be taken into account when considering cognitive access of secondary systems in the UHF band. First of all, the terrestrial digital TV standards and the regulatory situation in Europe and the USA are different and hence the regulatory solution developed in Europe is also likely to differ. Industry should be kept well informed of the European requirements to ensure a clear understanding of the conditions to be met. Also, there are numerous challenges facing both regulators and industries. Regulators will need to be satisfied that they have specified appropriate conditions of access which protect incumbent users and allow feasible operation of cognitive devices and systems, including additional regulatory considerations such as management of database solutions. Industries would need to develop technological solutions to meet the regulatory requirements that will still allow for feasible business case with acceptable implementation costs. Finally, there are significant benefits in adopting a harmonised approach to this work. The timely availability of spectrum across Europe and the harmonised specification of
cognitive devices will exploit economies of scale and encourage industry investment, thus enabling new cognitive applications that could bring significant benefits to European markets by maximising the effective and efficient use of spectrum. This will only be achieved if common technical conditions can be agreed at the European level on identified frequency bands, which provide sufficient certainty and stability to industry within an appropriate timeframe.

3.2.4 European Countries

The next section elaborates on the actions that national regulators have initiated (at European level) towards TVWS exploitation. This overview is focused on the different countries of COGEU partners. Additionally the UK was included since Ofcom is one of the most active regulators in this area. Different actions that have been taken in Europe are analytically presented below.

3.2.4.1 Action of UK regulator in the field of cognitive TVWS

In Ofcom statement of 13 December 2007, Ofcom approach to awarding the digital dividend [26]. Ofcom considered the use of interleaved spectrum by license-exempt applications and concluded that should allow cognitive access as long as cognitive devices not cause harmful interference to licensed uses, including DTT and program-making and special events (PMSE). This could potentially bring substantial benefits to citizens and consumers in the form of new devices and services. Cognitive devices should detect spectrum that is otherwise unused and transmit without causing harmful interference. They have the potential to support a wide range of uses, including high-speed always-on broadband.

Meanwhile, Ofcom, made a significant progress in developing regulations for the TVWS with a first consultation released on February 2009, and a further statement in July 2009 [12]. The detailed rules have yet to be released but a first indication is that TVWS devices will require either sensing or geolocation/database access unlike the FCC rules which required a combination of both protection mechanisms. The sensing levels being proposed for sensing-only devices are -120 dBm for digital TV and -126 dBm for wireless microphones.

In November 2009, Ofcom released a consultation on geolocation for cognitive access to the interleaved spectrum [27], the closing date for responses was 9 February 2010. In this consultation document Ofcom claims that the most promising alternative to sensing is geolocation, where cognitive devices measure their location and make use of a “geolocation” database to determine which frequencies they can use at their current location. Following a list of relevant Ofcom reports for COGEU is showed.

<table>
<thead>
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<tr>
<td>Ofcom, Digital dividend: cognitive access</td>
<td>Statement on license-exempting cognitive devices using interleaved spectrum, July 2009</td>
<td>Provide key parameters for sending (thresholds) and geolocation. Relevant for COGEU system requirements (WP3).</td>
</tr>
<tr>
<td>Ofcom, Digital dividend: cognitive access</td>
<td>A discussion on using geolocation to enable license exempt access to the interleaved spectrum, November 2009</td>
<td>Important for COGEU anti-interference spectrum database specification (T4.2)</td>
</tr>
</tbody>
</table>

3.2.4.2 Action of German regulators in the field of cognitive TVWS

The German regulator BNetzA considered the usage of white Spaces as one option in order to provide broadband in rural areas in 2007. Following the digital dividend discussion which resulted in clearing of the 790 – 862 MHz band from broadcast and PMSE applications until 2015, as a compromise, it was decided that the band 470 – 790 MHz should be shared exclusively among PMSE (Special Events and Program Making) and broadcast services.
As it is expected that the usage of cognitive technologies could partly alleviate the spectrum shortage for PMSE with peak usage like for important events, the German regulator actively participates to studies on white spaces and cognitive radio like for example, in the SE43. Besides this, there is also the idea that cognitive technologies will ease the deployment and frequency assignment procedures.

SE43 identified several fields for the TVWS usage by cognitive devices. Among them are:

- Sensing: Detection Threshold / Hidden Node Margin;
- Geolocation + Database;
- Emission limits;
- Program Making and Special Events.

First results of SE43, gathered until February 2010 enabled BNetzA to fix a German position:

- Sensing

Different works on hidden node margin (HNM) show the HNM margin to be in the range of -40 ... -50 dB, therefore protection of incumbent services requires a detection threshold well below -120 dBm. Following this results, German regulator BNetzA believes that autonomous sensing seems not to be feasible for the near future. Anyhow, sensing should be considered further as combined sensing by multiple user terminals as well as combined operation of database plus sensing could overcome some problems. In addition, as PMSE in Germany has not to be registered in a database, sensing of PMSE equipment might be necessary not to interfere with PMSE.

Even with reduced hidden node margin will sensing only be possible if features of the DTT are known to the TVWS device. New or modified DTT systems (e.g. DVB-T2) need at least a software update, but could also require new sensing hardware.

- Future development of broadcast transmission systems and PMSE systems

In accordance to CEPT SE43 which states that CR must work on an non interfering non protected basis BNetzA points out that deployment of CR must not impede the future development of incumbent services (e.g. DVB-T2).

- Geolocation Database

In accordance to some other European regulation authorities, German administration refuses an international approach and reclaims that the database has to be under the responsibility of the national regulators. In case of database usage or combined sensing communication between CR equipment has to be initiated by one terminal (either user terminal or base station). If communication is initiated by a device which has not yet been assigned a free channel, this communication channel (at least for the first contact) must not lie within broadcast bands.

A Master-slave scenario with a base station, where the base station is connected to the internet via a wire seems to be feasible.

- Interference Margin

In the context of SE43 and being aware that introduction of any additional service in the TV bands will cause additional interference, BNetzA demands that the additional interference has to be limited to 20 dB below noise.

BNetzA also decides that technical parameters like protection ratio (PR) should protect 90% of the DTT receivers (+PMSE…) in the market.

- Status of spectrum trading; business models for Germany

According to German legislation, UHF band is exclusively reserved for broadcast use. As most of the PMSE use is under the control of the broadcasters and broadcasters are interested to avoid interference with their broadcast transmission, this secondary use is accepted. Enabling spectrum trading in the UHF band would require the laws to be changed.

3.2.4.3 Action of Portuguese regulator in the field of cognitive TVWS

The Portuguese regulator, ANACOM released a public consultation process on the “Potential uses of the digital dividend” that ended in May 2009. Most of the issues were related with the allocation of the 800 MHz cleared spectrum, however there was a specific question regarding the cognitive access to TVWS. The majority of answers considered that cognitive radio technologies are not mature enough to
be allowed by the Portuguese and European regulatory bodies. There is a consensus regarding the need of further studies on the coexistence with European incumbent services. Some support the idea of a special pilot band of the digital dividend for trials of innovative technologies such as cognitive radio. There is a common understanding that a harmonization approach between European countries regarding the digital dividend potentiating economy of scale is especially important for small European countries. Moreover in the consultation report [28] ANACOM highlighted that the secondary spectrum regime, allowing reassignment of spectrum usage rights, is already possible by the Portuguese national law since 2004 (Lei n.º 5/2004) and its implementation mechanisms will be soon subject of a specific national consultation process.

3.2.4.4 Action of Irish regulator in the field of cognitive TVWS

The Irish regulator, the Commission for Telecommunications Regulation (Comreg), is in the early stages of developing its position on the future uses of the reformed TV spectrum. In March 2009, Comreg initiated a debate on the DTV transition by publishing a consultation document [29]. This consultation document was quite open in its scope, seeking the responses of interested parties on both the Cleared spectrum and the interleaved spectrum (TVWS). Comreg’s stance in this consultation was neutral, except that it noted that it “considers that rights of use to spectrum comprising Ireland’s digital dividend should in the interest of promoting market mechanisms and lighter touch regulation generally be made available on a technology and service neutral basis.” The responses to this consultation, published in January 2010, revealed that there is industrial interest in Ireland in exploring the use of TVWS by cognitive technologies. Whilst Comreg did not state its vision for TVWS in that consultation, its response to the European Commission consultation [30] in August 2009, revealed that Comreg “strongly supports an EC-led investigation into the feasibility of adopting a common European position on the use of white spaces by cognitive radio technologies. To this end Comreg encourages the EC to invest funding in this area in order to stimulate further research and speed up delivery of mass market consumer devices using cognitive technology to maximise the use of the ‘White Space’”. Additionally, Comreg are supportive of the WAPECS directive, and whilst this directive does not specifically address cognitive technologies, it does recommend a technology and service neutral approach which would facilitate cognitive TVWS. Furthermore, in March 2010, Comreg will host a cognitive technology workshop which will involve academia and industry. As such, it can seen that Comreg is supportive of research into the exploitation of TVWS, but as yet has no fixed position on how such uses should be regulated.

3.2.4.5 Action of Greek regulator in the field of cognitive TVWS

The final phase of digital TV switchover is based on a finalized technical study covering nationwide. The broadcasting plan, derived from the aforementioned study, has been based on the frequencies granted to Greece in the 2006 Geneva plan for the digital terrestrial TV. The broadcasting technical characteristics are determined among a number of standardized parameters depending on each provider’s network settings. The complimentary legal framework for the full transition is still under preparation. The digital broadcasting plan for the digital television service (full implementation) includes the network broadcasting sites for each Single Frequency Network (SFN) of the 11 service regions. The corresponding frequency channels for each SFN are defined therein.

As the Greek DSO is in its infancy, only a few actions have been taken for exploiting and regulating the TVWS. Among them is a recently published “Call for Interest” by the Ministry of Transport and Communications, in August 2009, concerning scientific research in the fields Spectrum exploitation and usage of radio frequencies”. The Call targets research institutes and academia with expertise in radio communication and spectrum exploitation technologies, by funding (after an evaluation procedure) state-of-the-art approaches, implementations and results. However, due to governmental restructuring processes, there is no actual implementation for these actions.

3.2.4.6 Action of Cyprus regulator in the field of cognitive TVWS

The digital TV switchover in Cyprus will happen on 1st July 2011. On this date the analogue transmission will be terminated and the digital TV platforms will be the sole TV signal transmitters. The regulator in Cyprus has provisioned for two digital TV platforms that they will use the frequencies agreed during the regional agreement relating to the planning of the digital terrestrial broadcasting services (GE06). In order for the entire vicinity of the republic of Cyprus to be covered, two frequencies are needed for Single Frequency Network (SFN) for each platform and additional pairs for future use.
Regarding the use of TVWS in Cyprus in the zone of UHF (470-860 MHz) it hasn’t yet been decided how the remaining spectrum will be used. This is mainly because of the current status of the European scene on the matter. Various options are being considered in the framework of the use of the spectrum. The current status suggests that TVWS in Cyprus can be exploited in many ways in order to provide novel and complementary to the existing services in urban and rural environments.

3.2.4.7 Action of Polish regulator in the field of cognitive TVWS

Digital broadcasting will be gradually introduced in Poland, according to the schedule determined by the President of UKE. It is predicted that national coverage with digital signal within MUX-1 will take place no later than by 31 July 2011. Complete switch-off of analogue television should take place in Poland no later than by 31 July 2013.

Due to procedural reasons, implementation of MUX-1 has been delayed. The first four transmitters have been working since September 2009 on a temporary basis and the date of connecting new ones set for the end of March 2010 is uncertain. According to the President of UKE, the delay in full implementation of MUX-1 may amount to even one year.

So far, Polish communications administration bodies (the minister competent for communications, currently the Minister of Infrastructure, and the President of UKE) have not undertaken any initiatives concerning TVWS, in particular the use of cognitive radio technology. These bodies avidly observe works which analyze the possibilities of using UHF band also in other systems on the basis of interleaved spectrum or white spaces that are underway in Europe (ECC TG4) and the USA (FCC). In the report of the Institute of Telecommunications (Warsaw) a remark was made that it is possible in the future that the use of TVWS systems will be planned with consideration of the fact that these systems may use a band as secondary importance one (lack of protection and elimination of interference to other systems) and, thus, do not have to be subject to direct (licensed) division of frequencies.

Due to the works that are underway, this report includes summary of the basic issues of electromagnetic compatibility of various radio systems which are candidates for UHF band sharing on the basis of the current state of works at the European level and of own works and measurements. One of the suggestions included in the report is allocation of the whole UHF band as secondary importance one to broadband access cognitive systems (IEEE 802.22 etc.). However, actual use of that band in the future will depend on the decision of administration bodies of European countries and activities undertaken in Poland.

3.2.4.8 Action of France regulator in the field of cognitive TVWS

The plan of the regulator stipulates that the analogue broadcasting signal will be switched off by 30 November 2011 at the latest, to be replaced by a digital signal which consumes six times less spectrum. This switch-off will therefore free up a substantial quantity of frequencies below 1 GHz. The roadmap also stipulates that the majority of this newly available spectrum will be assigned to audiovisual services, to enable the deployment of new solutions such as high definition (HDTV) and personal mobile TV. It does, however, also provide for the possibility of assigning a portion of these frequencies to electronic communications. This opportunity, to be correlated with the need for low frequencies to deliver ultra high-speed mobile services in the next decade, is an economic and societal issue that will shape the market in the coming years.

The decision to assign the 790-862 MHz sub-band to ultra high-speed mobile was announced by the government on 20 October 2008 when unveiling the “France numérique 2012” (Digital France 2012) plan. This was followed soon thereafter by an updated national frequency allocation table: ARCEP becomes the sole entity responsible for allocating the sub-band, the assignment of the 790-830MHz and 830-862MHz segments to broadcasting and Ministry of Defense, respectively. Moreover, French broadcasting authority, CSA, is requested not to use this spectrum in the sub-band when planning for digital TV after the analogue switch-off. Exceptions to this last point, which could prove necessary for coordinating spectrum use with neighboring countries, will only be allowed by the government on a temporary basis. Based on the context information given above, scenarios called "Opportunistic Mobile Network" are enabled where unused spectrum is intending to be used by an "opportunistic mobile operator".
3.2.5 **International level**

### 3.2.5.1 Action of ITU-R in the field of cognitive TVWS

The International Telecommunication Union is a UN agency with a membership of 191 countries. ITU-R co-ordinates and organises work at the World Radiocommunication Conferences (WRC), where the decisions are taken collectively on how to avoid interference in Radio Spectrum between countries, by updating, amending and adding to the global agreements.

The use of analogue TV frequencies in Europe was regulated by the ITU 1961 Stockholm Plan. At the latest Regional Radiocommunications Conference (RCC) in 2006, a new frequency agreement was adopted, replacing the analogue broadcasting plan. The ITU Geneva 2006 frequency plan (GE06) defines the use of the broadcasting bands III (VHF – 174-230 MHz) and bands IV/V (UHF – 470-862 MHz) for digital terrestrial broadcasting (T-DAB and DVB-T digital services) for the next decades over a large area including 118 countries. In practice, the Geneva Plan is an all-digital plan for use after the analogue TV services have been closed. Indeed, it makes clear that analogue TV services in UHF Bands IV & V will not be protected against interference after 17 June 2015. Interference is a crucial issue and does not stop at borders. This is why it is the biggest issue at the ITU planning conferences. Therefore the Geneva Agreement must be respected.

The World Radiocommunication Conference 2007 (WRC-07) allocated the upper part of the UHF band (790–862 MHz) to the mobile service in Region 1 as from 2015, and allowed some countries of this region to use this allocation immediately, under certain conditions. These conditions include protection of the GE06 Agreement and all its future developments.

The agenda for WRC-11 was agreed at the previous WRC (WRC-07 Resolution 805) and was formally established by the ITU council with the concurrence of a majority of the Member States. Particularly relevant for COGEU is the agenda item 1.19: to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution 956 (WRC 07) [32].

<table>
<thead>
<tr>
<th>Topic</th>
<th>Responsible Group</th>
<th>Action to be taken by the Group</th>
<th>Concerned Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution [COM6/18] (WRC-07)</td>
<td>WP 1B resolves to invite ITU-R 1 to study whether there is a need for regulatory measures related to application of cognitive radio system technologies; 2 to study whether there is a need for regulatory measures related to the application of software-defined radio,</td>
<td>SG 3, SG 4, SG 5, SG 6, SG 7</td>
</tr>
</tbody>
</table>

### 3.2.5.2 Action of the USA regulator in the field of cognitive TVWS

On February 17, 2009, the FCC released the final rules for “Unlicensed Operation in the TV Broadcast Bands” [33]. This was the culmination of many years of deliberations on the subject, starting with the first NPRM in May 2004 [34] and followed by laboratory and field testing of sensing devices through 2007 [35] and 2008 [36]. The main features of the rules as set forth in this order are as follows:

TV Band Devices (TVBDs) are divided into two categories: fixed and personal/portable. Fixed TVBDs operate from a known, fixed location and can use a transmit power of up to 4 W EIRP. They are required to have a geolocation capability, capability to retrieve list of available channels from an authorized database, and a spectrum sensing capability. TVBDs can only operate on channels that are not adjacent to an incumbent TV signal in any channel between 2 and 51 except channels 3, 4, and Personal/portable devices are restricted to channels 21 – 51 (except Channel 37) and are allowed a maximum EIRP of 100 mW on non-adjacent channels and 40 mW on adjacent channels and are further
divided into 2 types: Mode I and Mode II. Mode I devices do not need geolocation capability or access to a database but must have sensing capability. Mode II devices, like fixed devices, must have geolocation, database access and sensing.

**Sensing is a mandatory function that all TVBDs must implement.** ATSC, NTSC and wireless microphone signals have to be detected at a level of -114 dBm. A channel must be sensed for 30 seconds before determining if it is available for use by a TVBD. If a wireless microphone is not detected during this time and the database indicates that there is no TV signal present, then the channel is available for use. In the event that the sensing indicates the presence of a TV signal, but the database indicates otherwise, the sensing result must be communicated to the user who has the option of removing this channel from the available channels list. Once operation has started on a channel, sensing must be done at least once every 60 seconds and if a wireless microphone is detected the channel must be vacated within 2 seconds.

Geolocation means must be present in all fixed and Mode II devices, with an accuracy of +/- 50 meters. This position information is used to query a database for a list of available channels that can be used for TVBD operation. The database will include information on all TV signals and may also have information on wireless microphone usage.

Safe harbour channels for wireless microphone usage are defined in the 13 major metropolitan markets to be the first available channel on either side of Channel 37. TVBDs cannot operate on these channels.

On November 25, 2009 FCC released a public notice inviting proposals from entities seeking to be designated TV band device database managers [37]. FCC is currently in the evaluation process.

### 3.3 The secondary spectrum market initiatives

#### 3.3.1 Global trends on secondary spectrum trading

Globally, the active secondary trading of spectrum is still more a concept than a reality.

There a number of milestones that may mark the inception of secondary spectrum trading in the global context. Notably, New Zealand commenced trading in 1987, Guatemala in 1996, Australia commenced in 1997 and both the FCC and Ofcom adopted spectrum trading regulations in 2004. However, in spite of these actions there has been little activity in the economic/business and regulatory development of an active secondary trading environment for micro trades of the kind that we might envisage in the TVWS context. The development of secondary trading systems in Europe lags that of the rest of the developed world. Discussion of European secondary trading trends, such as they are, is covered in Section 3.1.4.

The essence of most schemes in existence can be explained as follows: spectrum licenses are issued in the form of enumerated spectrum rights: in terms of geographic scope, bandwidth, time and power. These licenses are partitionable or fragmentable in space, frequency and time. In many cases change of use is allowed so long as it does not cause interference to the existing neighboring licenses. Where, heretofore the only way that licenses could be traded was if the company owning the license was itself bought by another company, now the licenses are tradable assets in and of themselves. The mechanisms by which this trading takes place have slowly moved from paper-based filing, notification and registration to e-filing and e-registration.

However, while it may be acknowledged that these initiatives mark a step change in the way in which spectrum is traded from the preceding 80 years of command and control style regulation, these initiatives still fall well short of what can be considered an active or liquid market for spectrum.

To date, despite the provision of private market-based exchanges, such as Cantor Fitzgerald and Spectrum Bridge [38], secondary spectrum trading in the US has been confined to non-real time, bilateral trades, i.e. it is not traded and used instantly. The FCC does offer next-day license transfer, which it deems to be ‘immediate’. In the case of Spectrum Bridge, although this company quotes a real-time price for spectrum, the price being quoted is a proxy measure as it values the composite value of all traded spectrum together with ancillary valuations. The Spectrum Index measure is generated by looking at the market capitalizations of major companies with spectrum holdings, e.g. Verizon, AT&T, the market capitalizations of major equipment vendors and, finally, past prices paid in the secondary market or at FCC auctions. In truth, this is a far cry from giving any real estimate of the spot price of spectrum at any given location/frequency/time or the spot price of spectrum suitable for a given service/technology at a given location/time. It is this price which a trading system must reveal to interested buyers/sellers/traders.
In a sense, it may be considered that the approach of the United States was to run before it could walk when it comes to spectrum trading. Australia, on the other hand, has been a leader in liberalization of spectrum regulation and the promotion of market-based systems for assignment of spectrum licenses. To date, the Australian secondary market has manifested itself as an after-market that allows for the correction of initial offerings of spectrum. Thus, economic efficiencies can be realized when unused or under-used spectrum is made available to other users and uses without regulatory intervention. This market is very much based on bilateral trading – as many nascent and illiquid markets will be. It is also still very much paper based at the Australian Communications and Media Authority (ACMA). Intermediary companies do offer electronically based services through which buyers and sellers can find each other, but the final legal trading process is still resolved at the ACMA on paper.

Table 3: Trading in Australian spectrum licenses between 1998 and 2007

<table>
<thead>
<tr>
<th>Financial year</th>
<th>Mhz traded</th>
<th>Number of licences traded</th>
<th>Percentage turnover rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 - 1999</td>
<td>136</td>
<td>50</td>
<td>13.8</td>
</tr>
<tr>
<td>1999 - 2000</td>
<td>85</td>
<td>22</td>
<td>5.4</td>
</tr>
<tr>
<td>2000 - 2001</td>
<td>879</td>
<td>47</td>
<td>7.7</td>
</tr>
<tr>
<td>2001 - 2002</td>
<td>598</td>
<td>51</td>
<td>8.4</td>
</tr>
<tr>
<td>2002 - 2003</td>
<td>24</td>
<td>34</td>
<td>8.6</td>
</tr>
<tr>
<td>2003 - 2004</td>
<td>1315</td>
<td>24</td>
<td>3.6</td>
</tr>
<tr>
<td>2004 - 2005</td>
<td>50</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>2005 - 2006</td>
<td>5534</td>
<td>119</td>
<td>18.7</td>
</tr>
<tr>
<td>2006 - 2007</td>
<td>120</td>
<td>24</td>
<td>3.5</td>
</tr>
<tr>
<td>2007 - 2008</td>
<td>130</td>
<td>28</td>
<td>4.1</td>
</tr>
<tr>
<td>Total trades</td>
<td></td>
<td></td>
<td>425</td>
</tr>
</tbody>
</table>

Notes:

a. Some of these trading figures may represent license transfers between related companies, for example AAPT LMDS Pty Ltd to AAPT Ltd.
b. Partial trading results in untraded residual spectrum space lot(s) (geographic or frequency). A new license is generated for the residual lot even though it is owned by the same licensee. This is not counted as a trade.
c. The turnover rate is the number of licences traded each year compared to the total number of spectrum licences on issue. This can change as licences are disaggregated or aggregated, even if there is no change in the amount of spectrum licensed.

Table 3, taken from [39], illustrates the level of secondary trading of licenses in Australia over a 10 year period from 1998 to 2007. The authors note that the level of license turnover averages 5%, which is broadly equivalent to the turnover in the Australian housing market. However, from year to year it can be seen that the market can become very illiquid (or thin) as seen in the 2004-2005 financial year. On the other hand, years that show high level of trading 2002-2003 are attributable to a single event; the bankruptcy of an operator and subsequent sale its assets.

The Australian regulators conducted a consultation [39] on improving the performance of this regime after more than 10 years of experience. They noted that the secondary market had not yet developed to any significant extent in Australia. But now that the players in the market are more experienced with the concept of trading spectrum, the regulators seek to promote more activity in the spectrum market by encouraging the following developments:

- Standardization of third party authorizations, i.e. standardization of the procedures/forms used for this process. (Australian TPAs are akin to what is termed spectrum leasing in other jurisdictions);
- Increasing certainty of license tenure: greater regulatory certainty on the part of the primary/initial licensees regarding the renewal of the original license. (Most licenses had a 10 year life);
- Traded price information: the collection and publication of traded prices and general market activity;
- Minimizing transaction costs: modification of stamp duty rates, i.e. the tax imposed on each trade, allowing online trading mechanisms, clarification/simplification of rules;
- Accommodating frequency/technically agile equipment;
- Increasing the flexibility of license conditions.
These proposed changes are very much in line with the view of COGEU. We noted in COGEU original proposal document, that for all possible gains to be achieved from trade (e.g. gains such as spectral and/or economic efficiency), mechanisms must be introduced that will allow spectrum users to interact with each other on a multilateral basis with low transaction costs. Attempting to answer this question, at least in part, in May 2007 Google proposed to FCC what it called a "real-time airwaves auction model," which would allow a spectrum license holder to auction off unused spectrum to bidders on a wholesale basis. This model is based on Google online advertising auction in which companies bid on the placement of their ads on Google’s search engine based on how much they're willing to pay per user click through to their websites. A real-time auction model will allow small companies enter in spectrum market, have access to TVWS and be charged based on spectrum utilization [40].

In terms of the trading process, transaction costs have been identified under the following headings:

- Search: each party needs to find the other party;
- Convey: each party needs to inform the other as the presence of an exchange opportunity;
- Decision: if it is a multilateral process, i.e. several agents on each side, then several extra layers of decision-making have to take place;
- Policy & Monitoring: the terms of the bargain are enforced.

In terms of current trends in spectrum trading, the Cantor Fitzgerald- and Spectrum Bridge-type companies are the closest we have to exchanges, which offer these facilities for macro trades. In Section 3.1.3 the UK’s Ofcom’s concept of a band manager which has some of these responsibilities is discussed. However, as yet, we are unaware of any real-time systems, which accommodate the micro trades, i.e. trades of licenses that cover small geographical areas such as a TVWS area or which cover durations of less than a day.

A competitive secondary market enables participants to discover the price of spectrum at the required grade or QoS. However, within each spectrum holding or unit, acquired on such a market, i.e. how well it can mine its resource, and the consumer demand for its offering. Solutions have been offered for the dynamic internal pricing of bands of spectrum, such that the use of that particular band of spectrum is maximized with regard to the demand placed on it by its end-users [41]. The notion of a spectrum broker, which manages the allocation of spectrum according to price in cellular networks, has been presented as a model, which can maximize the value extracted from a licensed band of spectrum [42]. The QinetiQ Sky DustTM [41] system enables a licensee to manage the internal trading of its spectrum holding according to the varying demand of its customers. Unlike the system described in [42], the QinetiQ framework offers a solution for such internal price discovery in peer-to-peer network architectures.

Presently, as was noted, the secondary market is one that consists of notification to the regulators, approval or denial of requests to trade and the transfer of ownership of physical assets (e.g. network infrastructure) when a trade occurs. However, with cognitive networks, the rate of change of ownership of rights will continually increase, demanding a more nimble rights management system. Mechanisms for searching, conveying, deciding and then enforcing and monitoring policy have already received much attention and many are suited to the application for the modalities of a trading scheme.

There is a wealth of research in the area of distributed, pervasive, mobile, and wireless computing which has yielded any number of possible solutions to issues such as dynamic policy enforcement, dynamic authorization, dynamic authentication and trust schemes [43], [44], [45], [46], [47], [48], general security services, dynamic payment and settlement techniques [49], [50], among others

3.3.2 Secondary markets initiatives in Europe

Secondary markets initiatives in Europe generally lag the rest of the developed world – there has been very little progress in the development of comprehensive frameworks for secondary trading at European level. There does not appear to be any active industrial engagement with secondary markets. However, the EU, through its various agencies and arms, has made some basic progress in laying the initial regulatory groundwork for secondary markets in the Member States. The RSPG has also begun to address the concept of spectrum trading for cognitive radios. This section examines the current state of secondary spectrum markets in Europe, particularly within the EU.
As noted in the proposal document one of the leading goals of the EU and its Member States is to provide ubiquitous, affordable Internet access for all. In September 2005, the EU Commission issued a communication to the Council and Parliament [51], referring to the aims of the revised Lisbon agenda, namely that the vision of the community is one a “common and coordinated removal of restrictions” which would help to promote an “open and competitive digital economy”. The broad framework for the secondary trading of licensed spectrum, which falls along the lines depicted in Figure 18, mirroring the implementations of the FCC, would generally allow for the re-sale or lease of licenses, in whole or in part, subject to certain provisos.

![Figure 18: Secondary Trading Possibilities](image)

In particular, the Commission stated that it wants:
- The right to trade individual rights to use frequencies in a selection of spectrum bands for terrestrial electronic communications services;
- The right to use the frequencies in a flexible manner put into practice at EU level.

However, of more particular interest to project is the Commission’s reference to low frequencies. The communication from the Commission notes that “the low frequency parts of the spectrum continue to be occupied by older, less efficient technologies while new technologies can only get access to higher frequencies with limited propagation and higher roll-out costs”. The Commission recommends the embrace of technology and service neutrality, noting that the definition of tradable rights should be combined with flexibility which they define as, “the right of a spectrum holder to use it [the spectrum] for any service as long as the technical requirements are fulfilled. Noting the there are broad categories defined at the ITU level where rules on cross-border interference are imposed, the Commission believes that in the field of terrestrial electronic communications that these categorizations are becoming rapidly obsolete. In summary, the Commission noted that it intends to see the following key features of an EU spectrum trading framework developed:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tradability</td>
<td>The right to trade, the definition of a trading process</td>
</tr>
<tr>
<td>Technology neutrality</td>
<td>Establishing the least restrictive limitations possible</td>
</tr>
<tr>
<td>Service neutrality</td>
<td>Establishing the least restrictive limitations possible</td>
</tr>
<tr>
<td>Transparency</td>
<td>Access to information for spectrum markets</td>
</tr>
<tr>
<td>Spectrum rights</td>
<td>Common formats for the rights that define the freedom to use</td>
</tr>
</tbody>
</table>

However, there has been little progress since the publication of the RSPG Opinion on secondary trading in 2004 [52]. The RSPG is of the opinion that European harmonization of spectrum trading rules should not be introduced until the Member States have greater experience of secondary trading. These experiences should be notified to, and shared with, the community. In essence, the RPSG call for more local experimentation and trialling of market-based initiatives before there is any attempt at full European harmonization. To date, the UK’s Ofcom has been to the fore in leading the development and trialling of trading initiatives which generally mirror the e-filing, e-registration approach undertaken by the FCC. Recent data released by Ofcom shows that between 2007 and Q2 of 2009 the number of trades had risen from near-zero to over 600, whilst the number of tradable licenses had risen from near-zero also to just over 200 [53]. In this latest consultation document, Ofcom has begun to explore regulatory changes that will be necessary to facilitate a more nimble and liquid spectrum market. Specifically, it explores the concepts of spectrum leases, akin to the leases already introduced by the FCC, and band managers. It should be noted that spectrum leases are generally given by a license to a sub-license for a limited period after which the rights revert to the original license. As it is a lease and not a license transfer, Ofcom is considering eliminating the need for the formal, and onerous,
license transfer process. In essence, it is reducing the transaction costs for the traders. The band manager concept may also have applicability to the project. Whilst still at an early stage of consultation, Ofcom foresee the possibility of entities, called band managers, which would allow a license to commercially exploit its spectrum holding through spectrum trading. As such, the responsibilities of the band manager could include: planning the use of the licensed spectrum (or the TVWS), packaging the spectrum for disposal through trading, engaging with the market to trade the spectrum and acting at the first point of contact for dispute and interference resolution.

The implications of trading are now also pervading discussions of emerging technologies such as cognitive radio. In December 2009, the RSPG published the final draft of their report on ‘Cognitive Technologies’ [25] which makes explicit comment on the possibility of supporting trading mechanisms for cognitive technologies. This report describes two models for the licensed sharing of spectrum; vertical and horizontal (Figure 19).

The vertical model, which is most likely of more relevance to COGEU, envisages the licensed user, i.e. the DTV broadcaster, allowing secondary usage of its spectrum at locations and times that it is not used. This description closely corresponds to TVWS. The RPSG does not foresee the need for any significant regulatory intervention supporting a vertical sharing regime beyond actually making the spectrum tradable and making the usage conditions flexible, such that they allow uses not necessarily covered by the primary license. More specifically, the report considers that the important aspects of any negotiations, for both the primary licensee and the cognitive radio, are issues of guaranteed access and QoS parameters for both parties.

The horizontal model, on the other hand, is of less relevance to the project. Horizontal sharing involves the pooling all of the spectrum held by a group of licenses such they can then access that spectrum according to their given demand profiles. This type of trading regime allows primary licenses to release spectrum that is underused to others for a payment, or to top up on their existing holding when experiencing excess demand. This model would only seem to be of interest in areas in which the primary licensee experiences fluctuations in demand for its spectrum/services which is not the case in DTV broadcasting. DTV broadcasting is a very static service that does not generally respond to demand side issues. The exception to this may occur under mobile broadcasting scenarios, i.e. DVB-H broadcasts, when a broadcaster is catering for a large irregular event, such as a major sporting event, and requires extra spectrum to deliver more temporary channels.

Additionally, the RSPG and their colleagues in the European Regulators Group (ERG) have undertaken a study on possible competition issues that may arise in a liberalized spectrum regime which allowed for more trading [54]. Whilst it is felt that in the near-term, demand is likely to exceed supply in the key bands, the report considers it likely that when spectrum markets are more fully liberalized, the prospect of success for anti-competitive action is diminished. Basically, the more spectrum that is made tradable and flexible, the more expensive it is for any individual or group of companies to hoard spectrum such that they can skew or dominate the price of spectrum and range of services on offer. TVWS offers another avenue by which anti-competitive trends can be thwarted. If TVWS can be exploited as tradable and flexible spectrum, then it further expands the range of spectrum available over which key services can be provided. In turn, this increases the difficulty of for large players to dominate a market or develop market-abusive strategies.
In spite of the lack of specific regulatory clarity surrounding the development of trading initiatives in the TVWS, the existing WAPECS directive, which underpins regulatory developments in the member countries for a number of sub-bands, and particularly the 470-862 MHz sub band, provides a clear framework for the development of technology and service neutral licensing of spectrum. Such licensing is a fundamental building block for any trading system on which a secondary market will be developed. In particular, the RSPG advice underpinning WAPECS [55], [56] states that “For each WAPECS frequency band, provided that the associated electronic communications network complies with the relevant spectrum technical requirements, technological neutrality and flexibility in future use of the spectrum should be ensured” and that “Any electronic communications service (ECS) may be provided in any WAPECS band over any type of electronic communications network. No frequency band should be reserved for the exclusive use of a particular ECS.”

In [57], the authors have explored some of the key concepts that enable flexibility, and hence tradability. One of the WAPECS proposals is for the use of Block-Edge Masks (BEM) for the definition of transmission rights of networks so that they do not interfere with adjacent blocks of spectrum. These BEM rights can be calculated using a variety of techniques and allow a basis for negotiation between adjacent channel neighbors. They explore the idea of developing spectrum transmission masks that respect adjacent channel interference considerations whilst maximizing the spectral efficiency of the bands to which the masks apply. This is particularly crucial to the trade of rights in the TVWS setting as the masks governing the TVWS must maximize the potential to use that spectrum, but also protect the DTV signals. CR devices in TVWS must be enabled to trade rights which have very clear. Indeed, the UK’s Ofcom is using the WAPECS approach to derive BEMs for its 2.6GHz FDD/TDD allocation of spectrum, the rights to which will become tradable on the secondary market after

3.3.3 **Implications from the current state of secondary trading to COGEU**

There are a number of implications arising from the current state of secondary trading to COGEU project as given in the following:

- **Low transaction costs**
  A key requirement of any system that supports a market is the ability to trade with low transaction costs. As noted, there are many kinds of transaction costs. For example, search and information costs arise in determining that the required good is available on the market, and who has the lowest price, etc. Or, trading costs are the costs that are incurred when coming to an acceptable agreement with the other party to the transaction, drawing up an appropriate contract and so on. The technology involved in these costs will play a role as the ease and the speed at which these transactions can occur will influence the dynamics of the market as well as the size of the trading units.

- **Avoidance of thin markets and market failure**
  It is clear that for the secondary spectrum trading model to be successful in TVWS, applications and business scenarios must be identified which will attract many players and hence, competition. Without competitive interest in the TVWS spectrum and the services that can be provided in it, we risk the possibility of market failure.

- **Clear spectrum usage rights and responsibilities**
  Following on from the WAPECS directive, which will have a bearing on any regulations developed for TVWS, it is clear that a WAPECS-compliant proposal must define spectrum rights using service and technology neutral means. The RSPG draft report on cognitive technologies [25] draws attention to the necessity for regulatory intervention in the vertical sharing model at the point where the rights of the primary (DTV broadcaster) and CR are to be negotiated such that they each know what the other is guaranteeing them in terms of access and QoS. The WAPECS directive provides some direction on mechanisms which can be used to maximize the spectral efficiency of neighboring spectrum users whilst protecting the services they provide from harmful interference.

- **Regulatory certainty**
  Regulatory certainty will be key to the success of any market. Markets can thrive under the uncertainty of supply and demand of the good being traded – however, they strongly dislike any regulatory uncertainty as it is something over which they have no control and cannot hedge against. Therefore, clarity of definition of spectrum rights within the TVWS or the tradable spectrum access mechanism will be a key requisite for a successful trading system. One of the (then) FCC Commissioners, Harold W.
Furchtgott-Roth, who ruled on the FCC’s Second Report on Secondary Trading [58] noted in his personal remarks at the time of passing the report that: “The solutions to this problem, I believe, lie in three areas:

- We must make clear our rules, on the exclusionary and permissive authority to use spectrum rights;
- We must make clear our liability rules for interference, interference that is ... , interference on background and ambient noise, and;
- We must make clear the license transfer rules. They must be simple, transparent, and nondiscriminatory.

Until we do these things, until we make the bundle of rights that exist with spectrum, clear and predictable, less a pig-in-a-poke and more a bundle of rights that can be traded in markets throughout America, we will not have solved the problem of secondary markets for spectrum.”

So for, the objective will be to provide clear guidance to the European regulators on how to regulate trade in the TVWS context such that industry has the confidence to develop consumer systems that can exploit that market.

**Dissemination**

Regarding the last implication, it is important that COGEU makes efforts to disseminate the concept of traded TVWS. Most existing discussion regarding access to TVWS revolves around sharing, open-access, commons-like models. COGEU needs to make a concerted effort in creating a more high-profile discussion about the following:

- Traded spectrum allows industry to identify the optimal use and optimal users of any particular spectrum band in any given area.;
- Trading can be expected to benefit the economy, improve welfare and yield greater value from the available spectrum;
- Traded spectrum easily accommodates innovation and shifts in market demand. Such changes can be accommodated by changes in uses or users.

Increased transparency of opportunity costs of spectrum, which is possible through trade, increases industries understanding of the value of spectrum and raises awareness of entry opportunities for new entrants.
3.4 Technical challenges for the cognitive access to the TVWS in Europe

This section describes some of the challenging issues that cognitive radios have to face to access TV white spaces. These challenges result from TVWS characteristics and are common to all COGEU application scenarios. The technical challenges have direct impact of TVWS devices complexity, price and COGEU market potential.

3.4.1 High sensitive sensing mechanisms

Cognitive radios will typically need to detect DVB signals at ground level (1.5 m) with low gain antennas. DVB reception is normally planned on the basis of directional high-gain antennas at 10 m. The signal strength difference between the two antennas is referred to as the hidden terminal margin. This margin determines the Cognitive Radios detection sensitivity and imposes an additional burden on the CR devices. This margin differs in different application setting as shown in Table 4.

Figure 20 illustrates the hidden terminal problems. A house receives a DTT signal using a rooftop directional aerial mounted clear of surrounding buildings (path 1). Nearby is a mobile cognitive device attempting to detect the same signal at street level, but it is blocked by surrounding buildings (path 2) and therefore much reduced in strength. The cognitive device might erroneously conclude that there are no transmissions and hence no active nearby receivers, transmit and cause harmful interference to the rooftop aerial (path 3). A similar situation can be envisaged with respect to PMSE applications, including wireless microphones.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Hidden node margin (dB) for 90% of locations</th>
<th>Hidden node margin (dB) for 95% of locations</th>
<th>Hidden node margin (dB) for 99% of locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Densely urban</td>
<td>18.5</td>
<td>22.4</td>
<td>29.2</td>
</tr>
<tr>
<td>Urban</td>
<td>28.1</td>
<td>30.2</td>
<td>32.5</td>
</tr>
<tr>
<td>Suburban</td>
<td>30.5</td>
<td>31.4</td>
<td>32.9</td>
</tr>
<tr>
<td>Rural</td>
<td>14.9</td>
<td>15.6</td>
<td>16.6</td>
</tr>
</tbody>
</table>

Table 4: Summary of hidden node margins for different area types [12]
Table 5 shows a set of sensitivity levels that cognitive devices must be able to achieve to ensure that harmful interference does not occur. This sensitivity needs to be achieved in “real-world” scenarios. In particular, the devices must be able to sense the presence of strong signals in adjacent channels (or they must choose not to use channels where strong signals are present in adjacent channels). They must also be able to sense adequately in the presence of other cognitive devices using nearby channels.

<table>
<thead>
<tr>
<th>Cognitive parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity assuming a OdBi antenna</td>
<td>-120 dBm in 8 MHz channel (DTT)</td>
</tr>
<tr>
<td></td>
<td>-126 dBm in 200 kHz channel (wireless microphones)</td>
</tr>
<tr>
<td>Transmit power</td>
<td>4 dBm (adjacent channels) to 17 dBm</td>
</tr>
<tr>
<td>Transmit-power control</td>
<td>Required</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Out-of-band performance</td>
<td>&lt; -46 dBm</td>
</tr>
<tr>
<td>Time between sensing</td>
<td>&lt; 1 second</td>
</tr>
</tbody>
</table>

The key point of the difference between OFCOM approach and the FCC’s is that OFCOM suggest that sensing alone could be allowed without detailed device tests (although devices would have to operate in conformity with the Radio and Telecommunications Terminal Equipment Directive).

With these levels for sensitivity and additional margin, cognitive devices will need to detect a transmission at very low levels, all in the presence of signals in adjacent channels and fluctuating signal levels. This is an extremely challenging task and will likely require the cognitive device to process repetitive elements of the signals in order to recover them from below the noise. More work need to be done in enabling sensing under stringent regulatory threshold, otherwise alternative approaches need to be considered.

### 3.4.2 Geolocation database

An alternative to sensing is for a CR to have a database available of the frequencies that can be used at certain locations as well as the applicable rules (transmit power). The CR could also send back sensing measurements and several device parameters. To use the database, the CR needs to know its own location. Such a concept, also known as a geolocation database, could help to overcome most of the problems associated with sensing.

In discussion document [27], OFCOM suggests that there are five key issues to be addressed in developing a geolocation database:

- The information to be provided by the device to the database;
• The information returned from the database to the device. An intelligent database could return to the CR device not only the spectrum but also the transmit powers that could be used in each channel, decreasing complexity on the CR terminal side;
• The frequency of update of the database and hence the periodicity with which devices will need to update from the database;
• The modeling algorithms and device parameters to be used to fill the database;
• The maintenance of the database.

Table 6 sets out the key parameters for geo-location that are recommended by the regulatory bodies.

<table>
<thead>
<tr>
<th>Cognitive parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location accuracy</td>
<td>Nominally 100 metres</td>
</tr>
<tr>
<td>Transmit power</td>
<td>As specified by the database</td>
</tr>
<tr>
<td>Transmit-power control</td>
<td>Required</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Out-of-band performance</td>
<td>&lt; -46 dBm</td>
</tr>
</tbody>
</table>

Table 6: Key parameters for geo-location [12]

Database for wireless microphones are not available in many EU countries. Moreover, geolocation database is unlikely to be updated sufficiently rapidly for all PMSE users (e.g. Electronic Newsgathering).

3.4.3 Co-channel and adjacent interference

Co-channel interference refers to a situation where interference from the transmitter of the secondary system is experienced by the receiver of the primary system. For instance, within a given area, license-exempt white space devices may use the same channels as the cable TV service. This could cause co-channel interference to the cable TV service, as suggested by the FCC tests on the susceptibility of cable TV reception to interference from devices that might operate within the white space spectrum [64].

Adjacent channel interference is caused when a receiver (DVB-T) tuned to the wanted service is subject to interference in the wanted channel from another service operating in an adjacent channel (CR). If the two services are transmitted from different locations and/or at significantly different power levels, difficulties arise to specify how to protect the wanted service across its entire coverage area.

![Adjacent channel interference from CR broadcasting network into DVB-T service](image)

Figure 22: Adjacent channel interference from CR broadcasting network into DVB-T service

In addition, some DVB-T receivers are susceptible to interference from transmissions nine 8 MHz spectrum channels above the intended spectrum channel. This is often referred to as the ‘image channel’ or the ‘n+9 channel’. This means that, for a particular channel, if a transmitter site (for DVB-T or any other service, including TVWS services) were deployed in the n+9 channel, there may be an area around the transmitter site where that DVB-T signal could not be received.

3.4.4 Lack of standard for minimum interference rejection of DVB receivers

Digital and analogue TV interference are different. Most DTV sets go from perfect picture and sound to no picture or sound in 1 dB (Nevertheless, hierarchical modulation of DVB can switch to a lower resolution before this occurs). Moreover, currently manufactures currently have little incentive to maximize the interference tolerance of DTV receivers and there is still a lack of standard for minimum interference rejection for DTV receivers.
3.4.5 **Reconfigurable TVWS radio transceiver**

For cognitive radio transmission, orthogonal frequency division multiplexing (OFDM) modulation scheme is a natural approach that might satisfy desired properties. However, conventional OFDM scheme does not provide truly band-limited signals due to spectral leakage caused by sinc-pulsed shaped transmission resulted from the IFFT operation. Furthermore, Peak-to-average Power Ratio (PAPR) in non-contiguous OFDM signals (because of the fragmented spectrum available for TVWS) can force the receiver into non-linear operation, resulting in Inter-modulation distortion (IMD). IMD causes spectrum broadening that can interfere with adjacent DVB-T channels.

Another challenge for TVWS radio transceiver is the choice of the best digital hardware to meet the requirements. Features likes flexibility, performance and power consumption are key factors for cognitive radios.

3.4.6 **QoS in TVWS cognitive access**

One of the challenging features of the TVWS is its variation across space and time. More specifically the available channels are not contiguous and vary from one location to another (see Section 2.4). In addition the white space available in a given location can vary with time if one or more of the TV band primary users start/stop operation.

Opportunistic access to TVWS is interruptible in the sense that CR has to cease transmission immediately and relocate to a new band as soon as the DVB-T or PMSE appears. The delay associated with such relocations may face cognitive users with abrupt QoS degradation as communication peers need to coordinate the frequency transition, and many parameters across the protocol stack have to be reset to match the characteristics of the new frequency band. Therefore, cognitive radio links built on TVWS are inherently unreliable. The issue is on how to provide the best quality TVWS for secondary usage to maximize persistence of allocations while avoiding interference with primary users.

3.4.7 **Stringent constraints set by regulators**

Table 7 provides a comparison of some of the key parameters determined by Ofcom and those put forward by the FCC for cognitive access in TVWS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UK value</th>
<th>US value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTT sensing</td>
<td>-120 dBM</td>
<td>-114 dBM</td>
</tr>
<tr>
<td>Wireless-microphone sensing</td>
<td>-126 dBM</td>
<td>-114 dBM</td>
</tr>
<tr>
<td>Location accuracy</td>
<td>100 metres</td>
<td>50 metres</td>
</tr>
<tr>
<td>Transmit power – adjacent channels</td>
<td>2.5 mW</td>
<td>40 mW</td>
</tr>
<tr>
<td>Transmit power – non-adjacent channels</td>
<td>50 mW</td>
<td>100 mW</td>
</tr>
<tr>
<td>Out-of-band powers</td>
<td>&lt; -46 dBM</td>
<td>55 dBC</td>
</tr>
<tr>
<td>Time between sensing</td>
<td>1 second</td>
<td>1 minute</td>
</tr>
</tbody>
</table>

It is obvious that considering sensing alone under such stringent conditions, effective data transmission by cognitive devices in TVWS is a big challenge. These parameters have a direct impact on the QoS cognitive devices as well as battery life and terminal complexity. COGEU will combine local sensing and geolocation database access in order to relax sensing constraints, increasing TVWS feasibility and market potential.
3.5 Standardization and certification activities related to the TVWS

3.5.1 Standardization activities related to the TVWS

The opening of TVWS promises a whole new set of possible applications. The first step towards realizing these applications is the creation and adoption of industry standards. These standards have a role in facilitating the deployment of cognitive based technologies through multiple stakeholders while guaranteeing interoperability among peer technologies, and coexistence with other technologies. In the following subsections, standardization efforts of different organization will be shortlisted.

3.5.1.1 European Telecommunications Standards Institute (ETSI) activities on TVWS

The European Telecommunications Standards Institute (ETSI) regards cognitive radio and software defined radio related technologies as Reconfigurable Radio Systems (RRS) exploiting reconfigurable radio/networks and self-adaptation to a dynamically changing environment, with the aim of ensuring end-to-end connectivity. ETSI recently established a technical committee on RRS with the following responsibilities:

- Study the feasibility of standardization activities related to Reconfigurable Radio Systems encompassing radio solutions related to Software Defined Radio (SDR) and Cognitive Radio (CR) research topics;
- Collect and define the related Reconfigurable Radio Systems requirements from relevant stakeholders;
- Deliver its findings in the form of Technical Reports and/or ETSI Guides.

The Reconfigurable Radio System technical committee is addressing topics in standardization such as improved spectral utilization and inter-operator coexistence, using flexible usage modes and a variety of different Radio Access Technologies (RATs). The ETSI RRS technical committee has currently 4 sub-working groups (WG) as Table 8 shows.

<table>
<thead>
<tr>
<th>Work Group</th>
<th>Task</th>
<th>Technical Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>WG1</td>
<td>System Aspects</td>
<td>DTR/RRS-01002: Cognitive Radio system concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTR/RRS-01003: Spectrum Aspects of Cognitive Radio and Software Defined Radio Systems</td>
</tr>
<tr>
<td>WG2</td>
<td>Radio Equipment Architecture</td>
<td>TR 102 680 V1.1.1: SDR Reference Architecture for Mobile Device</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTR/RRS-02003: Radio Base Station (RBS) Software Defined Radio status, implementations and costs aspects, including future possibilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTR/RRS-02004: Multiradio interface for Software Defined Radio Mobile Device Architecture and Services</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTR/RRS-03007: Cognitive Pilot Channel (CPC) design</td>
</tr>
<tr>
<td>WG4</td>
<td>Public Safety</td>
<td>DTR/RRS-04005: System Aspects for Public Safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTR/RRS-04006: User Requirements for Public Safety</td>
</tr>
</tbody>
</table>

The new wireless microphone initiative STF386 is a ETSI special task force that will propose methods, parameters and test procedures for cognitive interference mitigation techniques for use by PMSE devices.

3.5.1.2 IEEE activities on TVWS

The Institute of Electrical and Electronics Engineers (IEEE) is in the forefront of cognitive radio standardization. The industrial relevance of cognitive radio in the US is the result of regulation authorities that, for many years, advocated the liberalization of spectrum regulation. This resulted in the necessary required industrial momentum for the development and commercial realization of cognitive radio in the US [59]. Many IEEE standardization bodies are working on incremental steps toward the vision of cognitive radio as summarized in Table 9.
### Table 9: overview of standardization activities towards cognitive radio within the IEEE

<table>
<thead>
<tr>
<th>IEEE Standardization Body</th>
<th>Cognitive Radio Feature/Building Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC 41/P1900</td>
<td>Series of general standards on cognitive radio</td>
</tr>
<tr>
<td>802.11h</td>
<td>Enhances network management, dynamical spectrum management and TPC of 5 GHz band, and improves such mechanisms as channel energy detection and report mechanism, channel coverage, Dynamic Frequency Selection (DFS) and TPC mechanisms in several regulatory domains.</td>
</tr>
<tr>
<td>802.11k</td>
<td>Measurement, reporting, estimation and identification of characteristics of spectrum usage</td>
</tr>
<tr>
<td>802.11y</td>
<td>High power contention based medium access and flexible spectrum management framework</td>
</tr>
<tr>
<td>802.16h</td>
<td>Coexistence among license-exempt systems based on IEEE 802.16</td>
</tr>
<tr>
<td>802.19</td>
<td>Coexistence technical advisory group</td>
</tr>
<tr>
<td>802.22</td>
<td>Wireless rural access network for the (re-) use of TV bands with a radio technology similar to IEEE802.16/WiMAX</td>
</tr>
</tbody>
</table>

Many of the wireless communication systems standardized by the IEEE are operating in unlicensed spectrum. Within unlicensed frequency bands, radio systems coordinate the usage of radio resources autonomously while operating. These are of interest to the COGEU project since some of the standardized technologies will be examined and improved to fit in TVWS under the commons or secondary spectrum trading models. In the next paragraphs we give a short overview of the enlisted standards.

#### 3.5.1.2.1 IEEE SCC41/IEEE P1900

The IEEE Standards Coordinating Committee (SCC) 41 has initiated a series of standards, the IEEE P1900 series on next generation radio and advanced spectrum management, to stimulate research and development of cognitive radio. The SCC 41 formed in April 2007 was an advancement of the IEEE P1900 Standards Committee that started in 2005. The scope of SCC 41 includes improvement of spectrum usage, new techniques and methods of dynamic spectrum access, interference management, coordination of wireless technologies, network management and information sharing. The SCC 41 is currently divided into six Working Groups namely: IEEE 1900.1-6 which work in different categories. Table 10 gives a summary of these WGs and their respective tasks.

#### Table 10: IEEE SCC 41/P1900 work groups and their respective tasks

<table>
<thead>
<tr>
<th>IEEE SCC 41/P1900 Work Group</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1900.2</td>
<td>Recommended Practice for Interference and Coexistence Analysis</td>
</tr>
<tr>
<td>P1900.3</td>
<td>Recommended Practice for Conformance Evaluation of Software Defined Radio (SDR) Software Modules</td>
</tr>
<tr>
<td>P1900.4</td>
<td>Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks,</td>
</tr>
<tr>
<td>P1900.5</td>
<td>Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications</td>
</tr>
<tr>
<td>P1900.6</td>
<td>Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems</td>
</tr>
</tbody>
</table>

#### 3.5.1.2.2 IEEE 802.11h

IEEE 802.11h standard was originally designed to comply with European regulations on spectrum management and Transmit Power Control (TPC) protocol for 5 GHz band. In Europe, there are other devices (e.g. radar) operating in the 5 GHz band that is used in European High Performance Radio LAN (HIPERLAN) and IEEE 802.11a standards, and it is difficult to prevent WLAN from interference with such devices. To enable IEEE 802.11a radio system to detect the signals of these devices (e.g. radar) and avoid their interference, IEEE 802.11 Working Group developed and released IEEE 802.11h standard as an extension to IEEE802.11 MAC and physical layer specifications. Already applied in many countries, IEEE 802.11h modifies IEEE 802.11a physical layer standard, enhances network management, dynamical spectrum management and TPC of 5 GHz band, and improves such
mechanisms as channel energy detection and report mechanism, channel coverage, Dynamic Frequency Selection (DFS) and TPC mechanisms in several regulatory domains.

3.5.1.2.3 **IEEE 802.11k**

IEEE 802.11k is an amendment to the IEEE 802.11 base standard for radio resource measurements and was approved in May 2008. Various types of measurements are defined that enable wireless LAN stations to request measurement from other stations, for example, in order to measure how occupied a frequency channel is. The measurement results are reported back to the requesting station in standardized frames. It provides means for measurement, reporting, estimation and identification of characteristics of spectrum usage. IEEE 802.11k improves spectrum opportunity identification in unlicensed bands in unpredictable environments and is able to characterize the interference on different frequency channels.

3.5.1.2.4 **IEEE 802.11y**

In July 2005, FCC opened 3.65-3.7 GHz band for public use, which was originally reserved for fixed satellite service networks. Developed for this band, IEEE 802.11y standard specifies the mechanism of WLAN communications in this band for the purpose of avoiding interference with other communication users. It defines such contents as transmission initialization process, channel status detection method and retransmission mechanism when a channel is found busy, and adopts several bandwidths and OFDM technology. With subcarrier assignment function of OFDM, IEEE 802.11y can achieve quick adjustment and flexible switch among several bandwidths, thus allowing CRs to avoid using LUs’ working bands, reducing the interference with LUs and improving the system’s robustness and flexibility.

3.5.1.2.5 **IEEE 802.16h**

In December 2004, IEEE 802.16h Working Group was set up to improve coexistence mechanisms for license-exempt operation. The main idea of IEEE 802.16h standard is to use intelligent technology to let several systems share resources, thus enabling coexistence among license-exempt systems based on IEEE 802.16 to satisfy QoS requirements of IEEE 802.16 standard.

3.5.1.2.6 **IEEE 802.19**

The IEEE 802.19 working group calls itself Coexistence Technical Advisory Group 802.19 and it aims at the development and maintenance of policies defining the responsibilities of IEEE standardization efforts to consider coexistence with existing standards and other standards under development. If required, 802.19 evaluate the conformity of the developed standard to coexistence policies and offers documentation of coexistence capabilities to the public.

3.5.1.2.7 **IEEE 802.22**

IEEE 802.22 is the first standard to fully incorporate the concept of CR as well as the first CR-related air interface standard. It has played an important role in evolution and development of CR technology. IEEE 802.22, also called standard for Wireless Regional Area Networks (WRANs), uses available Ultra High Frequency (UHF)/Very High Frequency (VHF) TV bands between 54 and 862 MHz (scalable to 41-910 MHz), but only frequencies below 698 MHz will be allowed by the FCC regulations in the US. It focuses on how to make effective use of these bands for wireless communications without interfering with existing TV bands and to develop a standard for physical/MAC layer air interface. To be compatible with various TV standards, its channel bandwidths include 6 MHz, 7 MHz and 8 MHz.

IEEE 802.22 system defines an air interface for fixed point-to-multipoint topology, which must consist of a Base Station (BS) and at least a RU. In addition to traditional BS functions, the BS in IEEE 802.22 system must have distributed cognition capability, guiding Customer Premises Equipment (CPE) to perform a distributed measurement of signals on different channels. Then, based on received feedback information and cognized information, the BS decides its next step, for instance, changing transmit frequency or transmit power, to avoid interference with licensed services in TV bands. Among IEEE 802 standards, IEEE 802.22, which is developed specifically for WRANs, has the largest coverage area because TV bands less than 900 MHz are of good propagation characteristics. If the BS’s power is unlimited, its coverage can reach 100 km. Even with Effective Isotropic Radiated Power (EIRP) of 4 W, which is specified in the standard, the coverage range can reach 33 km. The spectral efficiency of 802.22 systems ranges from 0.5 to 5 bit/s/Hz. At an average value of 3 bit/s/Hz, the capacity of a 6 MHz channel can reach 18 Mbit/s.
3.5.1.3 **Ecma-392 standard**

In December 2008, a new group called the Cognitive Networking Alliance (CogNeA) was initiated. This group is composed of Philips, Samsung, HP, ETRI, GeorgiaTech and Motorola. CogNea aims to help drive the definition and adoption of industry-wide standards for low-power personal and portable wireless devices to operate over the TV white spaces. In this regard, a new standard was created in the framework of ECMA in December 2009. This standard (ECMA 392) covers “PHY and MAC for operation in TV white space”. The standard target applications are high speed video streaming and internet access on personal/portable electronics, home electronics equipment, and computers and peripherals \[60\].

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. This Standard specifies a number of incumbent protection mechanisms which may be used to meet regulatory requirements, which themselves are outside of the scope of this Standard.

The standard will employ cognitive radio technology to avoid interference with licensed services and other incumbent users in compliance with the Federal Communication Commission (FCC) regulatory rules.

### 3.5.2 Certification and compliance in TVWS

#### 3.5.2.1.1 The FCC Approach

In order to introduce unlicensed devices in TV White spaces in the USA, the FCC combined various rigorous regulatory conditions, to mitigate the potential interference and to help remedy potential interference should it occur. For example:

- All fixed devices must register their locations in the database. In addition, fixed devices must transmit identifying information to make it easier to identify them if they are found to interfere. Furthermore, fixed and personal/portable devices operating independently must provide identifying information to the TV bands database;
- All devices must include adaptable power control so that they use the minimum power necessary to accomplish communications;
- All white space devices are subject to equipment certification by the FCC Laboratory. The (FCC) Laboratory will request samples of the devices for testing to ensure that they meet all the pertinent requirements;
- The FCC will permit applications for certification of devices that do not include the geolocation and database access capabilities, and instead rely on spectrum sensing to avoid causing harmful interference, subject to a much more rigorous set of tests by FCC Laboratory in a process that will be open to the public. These tests will include both laboratory and field tests to fully ensure that such devices meet a “Proof of Performance” standard that they will not cause harmful interference. Under this procedure the FCC will issue a Public Notice seeking comment on the application, as well as test procedures and methodologies. The FCC will also issue a Public Notice seeking comment on its recommendations. The decision to grant such an application will then be made at the Commission level;
- FCC will act promptly to remove any equipment found to be causing harmful interference from the market and will require the responsible parties to take appropriate actions to remedy any interference that may occur.

In addition, the regulatory framework on radio equipment in the USA is different than in Europe. In particular, type approval of all radio devices (FCC equipment certification) is mandatory. This is considered a key element in the FCC decision to envisage the possibility of sensing-only TV white space device. One of the COGEU project objectives is to develop a set of compliance procedures for cognitive devices in TVWS.

#### 3.5.2.1.2 The European approach

The directive Radio and Telecommunications Terminal Equipment (R&TTE), in force in Europe, is based on manufacturer self-certification (declaration of conformity) and does not require either type approval or registration of the equipment. This unique situation where there is no certification regime is not appropriate to the operation of cognitive devices in Europe. This is more complicated when there is
responsibility to be shared. Under the R&TTE Directive, the manufacturer is responsible, but the matter is complicated by the fact that: in the IT industry, the licenses are made available to potential users with terms which often exclude any kind of responsibility of the manufacturer/software provider. Therefore, the way in which responsibilities should be shared, in the case of cognitive devices in TVWS, have to given special attention when defining compliance standards in the COGEU project.

On the network side, under the R&TTE Directive Regime, control of the terminal connected to a network would remain within the responsibility of the operator, in accordance of Article 7 of the R&TTE Directive. Robust protection of the equipment should be ensured in order to avoid the occurrence of virus and malwares which could impact the network. However, without requirements for devices identity, it will be difficult to monitor Cognitive Radio Systems, or to identify, and determine, when necessary, a source of interference. Therefore, this can pose security issues in the cognitive radio systems. For example, relationship between sensor input, beliefs, and behavior in a cognitive engine, showing how an adversary manipulating sensory input can change the beliefs and behavior of a cognitive radio. Though the COGEU project does not specifically address the security issue, compliance procedures that will be investigated will provide a reasonable or basic degree of security for operation in TVWSs.

3.5.3 Implications of standardization and certification aspects to COGEU

The technical challenges, standardization and compliance status in TVWS as discussed in preceding subsections have diverse implications to the COGEU project. The technical challenges outline the scope of solutions that are expected to be delivered by the project. The current standardization status implies that the COGEU project can leverage existing technical solutions by adopting them in the scenarios that will be investigated. On the compliance aspect, the COGEU project will contribute by developing compliance procedures for cognitive devices operating in TVWS. The following are the details of the implications.

3.5.3.1 Implication of standardization

The COGEU vision has no intent to reinvent the wheel. During the course of the project, the consortium will investigate and tailor available solutions for the operation in TVWS and follow current standardization activities such as IEEE P1900 and ETSI RRS.

3.5.3.2 Implication of compliance status

The regulatory conditions and framework reveal the complexity of devices entering the TVWS. EU Member States and the European Commission should carefully take this complexity into consideration. Due to the fact that key elements of the EU regulations for equipment and use of spectrum are significantly different from those of the USA, the European regulatory solution will be different. The COGEU project has to take into considerations these differences and address them within a practical scope.

- Terrestrial digital TV standards differ in US (ATSC) and in Europe (DVB-T). This implies specific detection techniques and protection rules to avoid harmful interference;
- COGEU WP4 will contribute to the development of equipment certification recommendations to be adopted by the RSPG (through CEPT) at a European level. A different approach for compliance other than the R&TTE Directive regime should be promoted as well, so that the market is protected by developing responsibility sharing bylaws – and hence filling the gap that is missing in device compliance regime and providing means to protect the European TVWS market;
- In case of a spectrum white space availability database, the COGEU project will address some of the challenges including the database access model (whether free or paid); complexity issues (how many times should the database be accessed per unit time?); and also the scope of the database, i.e., whether each nation should have a separate database or there should be a pan-European white space database to be shared among member states.

In the lifetime of the COGEU project, there has to be constant monitoring of the regulatory compliance status. Concurrently, the consortium has to develop dynamic technologies for operation in TV white spaces assuming diversity in regulatory requirements, that is, both in interference avoidance thresholds and spectrum usage models.
4 COGEU spectrum sharing models

This chapter is dedicated to the description of two spectrum sharing approaches that will be investigated within the COGEU project:

- **The Spectrum Commons** representing an extreme point of view, in which the relationship with DVB-T is assured by controlling levels of interference, instead of fixed spectrum allocation, promoting spectrum efficiency without QoS guarantees;
- **The Secondary Spectrum Market** which involves the sale of spectrum for applications that require sporadic access, establishing a secondary market for the lease and auction of spectrum.

4.1 Incentives for spectrum sharing

This section will examine the incentives for spectrum sharing and investigate under what circumstances potential secondary users of TVWS would emerge. This answer, it turns out, depends in large measure on the application that the secondary users have in mind and regulatory/technical restrictions.

COGEU will move away from the binary choice of optimize current spectrum or buy new spectrum with exclusive rights by including a third option which is the secondary use of TVWS (see Figure 23).

![Figure 23: COGEU third way opportunity.](image)

When extra spectrum is required to support a specific service with multidimensional requirements (including coverage, bandwidth, QoS, access duration, price), the operator has several options to get in:

- **Optimize current own spectrum** for the efficient use of spectrum which may be achieved in the way of better frequency planning, creating better coexistence strategies or re-assign own spectrum. This option is not always possible since current wireless networks are usually spectral efficient;
- **Buy new spectrum with exclusive rights**, e.g., the new released TV spectrum (790-862 MHz). It means that, if the operator wants a nationwide development with market dimension for economy of scale and international harmonization is more likely to buy new spectrum with exclusive rights, e.g., the cleared spectrum that will be released after ASO (790-862 MHz). However, this solution may be too costly for entrants;
- **COGEU approach**: temporarily exclusive rights obtained in the secondary market or new unlicensed bands within TVWS.

COGEU approach is an attractive alternative and advantages of secondary trading might be easy to perceive. In general, secondary spectrum markets help to promote efficient allocation, assignment and use of spectrum. They offer opportunities for licence holders to trade licences or lease spectrum when demand and supply conditions change. As a result of changes in technology, business strategy and/or
market share, some licensees may hold spectrum they no longer need. They can on-sell or lease their surplus spectrum to users, including other licensees who desire access to that spectrum. Secondary markets also allow the emergence of intermediaries that may trade in spectrum or lease it to third parties. In case of TVWS, these spectrum bands on a specific area are simply wasted if not used by the secondary users either as spectrum commons or temporarily licences obtained on secondary spectrum market.

Spectrum trading and liberalisation will benefit spectrum users of various types [61]:

- Large users of spectrum, such as telecommunications companies, will benefit from a greater certainty over the term of their rights to use spectrum and the potential to access more spectrum for expanding technologies;
- Small users of spectrum, such as private business radio users, will benefit from the opportunity to profit from investing in new equipment and selling any spectrum that is released as a result, or to purchase more spectrum for to the expansion of their business;
- Firms will have more opportunity to compete for spectrum for new technologies or services with incumbents. Spectrum trading and opportunities to change the use of spectrum will also remove barriers to entry in markets where lack of access to spectrum previously restricted entry by new players.

Another notable benefit of spectrum trading is that it enhances the prospect of greater wireless deployment in underserved areas e.g. rural areas. Spectrum trading can thus help to provide the flexibility needed for the development of additional and innovative services in rural areas. However, there is concern that spectrum trading activity may remain low in rural areas where the scarcity of frequency is low, compared with demand [61].

The crucial goal is to assess under which conditions secondary markets in spectrum work as efficiently as possible, generate the largest total welfare in the long run. The aim is to remove any unnecessary restrictions that may hamper increasing efficiency as long as the cost of removing them or implementing reforms does not outweigh its benefits.

The review [62] shows that allowing licensee to trade and modify the term of their licences is only the initial, though crucial, step in allowing spectrum markets to operate as any other market. Ensuring that procedures are lean and simple, there is sufficient information to provide confidence to buyers and sellers, anticompetitive behaviour is kept at bay and that “property rights” are designed to provide incentives for efficient outcomes are all very important to ensure that consumers take advantage of spectrum reforms.

Efficient markets are those that generate the largest total welfare for consumers and producers and where trades (or changes in use) that increase social welfare should not be impeded and, conversely, those that do not should be prevented.

Given an initial allocation of the existing finite spectrum resources to a number of exclusive users, trades occur if an entrant (or another incumbent) values an existing portion of spectrum more than the incumbent user and if the difference between the two is larger than the transaction costs. This may involve the entrant providing the same service as the incumbent or changing the use of spectrum to provide a different service.

Buyers and sellers may need to learn to be confident about the real value of spectrum in order to venture into trades. Second, spectrum is a heterogeneous input and there may be many secondary spectrum markets. Hence, information on the price paid for a specific frequency may not be indicative of the value of another frequency. Third, in most cases in order to launch services operators would need to sink costs. This could be seen as a transaction costs and could limit gains from trade.

Property rights are well-defined and transferable, in the absence of transaction costs. The importance of having low transaction costs in ensuring efficient markets in spectrum. Property rights need to be enforceable. This means that the licensees must be able to enforce their rights, if, for example, they suffer from interference.

The fact that there are many buyers and sellers increases the transaction costs of reaching an agreement. The availability of a spectrum register will facilitate the identification of relevant parties to the transaction, but this may not be sufficient and there may be scope for having third parties acting as
The most important piece of information for buyers and sellers to obtain a better understanding of the value of the spectrum they are either buying or selling is the price paid in similar transactions.

The potential for most anticompetitive concerns is heightened when the spectrum available to the market is limited, there is limited liquidity and applications are frequency specific. Hence, one could expect concerns about potential anticompetitive behaviour to be alleviated by releasing more spectrum to the market and providing stronger incentives for the Government bodies that hold spectrum to participate in the market. There appear to be no strong reason to conclude that the above risks may be larger than in any other sector of the economy.

The presence of (negative) externalities in the form of interference was the main reason behind the adoption of a “command and control” approach to spectrum. Interference can generally be controlled via well-defined property rights.

The technical parameters will be set at a level to keep the risk of interference low. However, in some circumstances it may be more efficient to allow some interference (with compensation). It is unclear whether this is possible under a licence exempt approach (other than by the regulator changing the technical parameters on request). More importantly, third parties could perhaps more quickly adjust the technical parameters and the type of services they provide if other more valuable services emerged. They will have stronger incentives to do so than a regulator.

The current rules do not provide strong incentives for licensees to invest in receiving equipment that minimises interference. Furthermore, there may be legitimate concerns that the current system provides incentives to those who may suffer from interference to complain to the regulator and block the launch of the new service rather than take actions and invest in more efficient receivers. This may occur even when the cost of replacing receivers is significantly less than the benefits from the new service.

There have been a number of attempts to quantify the benefits and costs of spectrum trading. For instance, a consultancy report produced for the European Commission [14] estimates that the annual benefits to the European Union of introducing liberalisation and spectrum trading would amount to around EUR 9 billion whereas the benefits from trading alone would be just 10% of that amount. The study also estimates that the additional costs of liberalisation, for example in terms of additional interference co-ordination, would amount to less than EUR 100 million a year across the EU and so would be small relative to the potential benefits.

4.1.1 Primary users’ incentives to share portions of spectrum for secondary use

For spectrum sharing to take place, current spectrum incumbents need to have some incentives to sell or lease their own spectrum. From economic and financial standpoints we can demonstrate that primary users have a financial incentive to lease spectrum. However, the interest of trading the spectrum for secondary use largely depends on the classification of primary users. Existing commercial users of spectrum could have small incentives to sell or lease excess or unused spectrum if potential buyers will use their acquired spectrum to provide a service competing with the sellers or if secondary user will be introduced distortion [63].

In terms of technical issues, spectrum has multiple access dimensions. Regardless of the dimensions of sharing, a lessee's bid and a licensee's offer must match in all dimensions for trading to occur. This could imply that the number of participants in the spectrum market may be low. This lack of liquidity decreases the likelihood that a trade takes place, leading to the need to develop policies, incentives, and market mechanisms that increase market liquidity and enhance the willingness of spectrum users to conduct a trade. The transaction costs of secondary use are still unclear. It is likely to be related to the negotiation process, which in turns depends on types of spectrum use and dimensions of sharing [64].

There are a number of basic steps to encourage primary users to share portions of his/her spectrum for secondary use:

- Establish a framework for secondary markets;
- Define and create the tradable usage rights and obligations;
- Permit various forms of trading of these rights;
• Establish rights to protection from interference and obligations not to create harmful interference in relation to liberalisation of use;
• Clarify rules on the expiry of usage rights and regulatory powers to reclaim them;
• Develop clear rules to ensure effective enforcement of rights and obligations;
• Establish and clarify enforcement mechanisms, whether regulatory or through private rights of action in courts.

4.1.2 \textbf{Spectrum users’ incentives to become a secondary user}

Secondary users hold a risky position in their service operations since they may not have direct control over the availability of radio spectrum, quality of service, and coverage expectation. This may make it difficult for the secondary users to control the quality of service they provide to their clients, so it is important to guaranteed by the regulatory and technical restrictions.

Depending on the type of sharing, demand and supply could become very specific in each of the sharing dimensions, such in time, geographical location, frequency, and so forth. This may result in more complicated matching and negotiation mechanisms, especially when the markets progress towards real-time markets.

The trading of secondary use may occur through intermediaries such as bandwidth brokers or distributed market makers or through the process of online-automated spectrum sharing and trading in a real-time fashion. In general, the mechanisms of searching for a match between the primary and the secondary users largely rely on types of services, access characteristics, and service levels requested by secondary users. The access types could consist of a long-term lease, a scheduled lease, and a short-term lease or spot markets. Each type requires different discovery mechanisms and applies with different levels of service agreements.

Summarizing, the introduction of secondary use allows a portion of players who cannot afford an exclusive license or find it impractical to use to become secondary users. The necessity of secondary use of spectrum appears when there are a large number of participants. Secondary use is higher when primary users have continuous spectrum usage (such DVB-T) than intermittent spectrum usage. This condition creates a competitive market force to drive secondary use transactions and suppresses opportunistic behaviors of the secondary use participants. The expansion of unlicensed spectrum is useful for both spectrum users with small and large coverage requirements. The users with smaller coverage, however, can derive greater benefits from an additional spectrum in the unlicensed band, as showed in [63].

4.2 \textbf{Spectrum management options}

In [65], Pogorel presents comprehensive analysis of wide range choices available to regulators and industry in establishing a radio spectrum management policy by expanding beyond the standard options: Command and Control, Market and Commons. The Pogorel’s paper is based on the research being carried out within the EC Specific Support Action SPORT VIEWS (Spectrum Policies and Radio Technologies for Viable Wireless Services, Contract No. 027297) [66]. A spectrum management regime comprises four dimensions that are deeply analyzed [67] of which last two are most important from COGEU point of view:

• Allocation: service harmonization or service flexibility;
• Technology: standardization or technology flexibility;
• Usage rights definition: alternative regimes;
• Assignment modes of spectrum usage rights.

The following categories of usage rights can be defined:

• Property rights, including exclusive property rights and property rights with easements: they make provisions for sharing, overlay, underlay, and Dynamic Frequency Selection (DFS). DFS can be intended as the possibility of shifting between a set of predetermined harmonised bands, or as the possibility of shifting across large areas of the spectrum. It is compatible with all non-exclusive property based regimes. The SPORT VIEWS project has examined the potential interest of introducing reasoned easements. This perspective of disaggregating property rights to benefit from technology evolution has been extensively explored by Cave [68];
• Collective use or “commons” since nineties is promoted as a far-reaching, future-oriented model. The possible extent of collective uses, and conversely, of property rights, was extensively explored in a EU Study [69].

Assignment modes have been the subject of numerous studies (eg. [68], [70]). There are two main categories of usage right assignment modes:
• Comparative administrative procedures, which include pure administrative procedures and hybrid modes, such as administrative procedures with a bidding price as part of a weighted multi-criterion formula. There is a price component, but the license remains under administrative control and administered incentive pricing, which also remains within the category of administrative control;
• Auctions resulting in exclusive property rights, which represent the quintessential market solution for the assignment of spectrum usage rights. Trading is a complement to this approach for secondary markets.

Table 11 summarises the overall alternatives arranged in a 4-step decision tree designing nine spectrum management regimes. The standard solutions are present in this table. The traditional Command and Control model can be recognized as regime 1a. Regime 7b qualifies as a full property-based market regime. Regime 6 is the commons model. This table illustrates a diversity of regimes broader that usually exposed. However, not all regimes are representative of realistic alternatives, but homage should be paid to regime 9 California Dream, which embodies the vision of a vast radio spectrum commons, supposing that the technologies exist to support it. This shows that flexibility and efficiency in spectrum management has to be considered at various levels and can be combined in a variety of ways [65].

Under the European Regulatory Framework, a distinction is made between two different models of spectrum authorizations: individual authorizations and general authorizations. Individual authorizations are usually associated with both administrative and market based approaches to spectrum management while general authorizations are associated with the Common Use of Spectrum (CUS) model [71].

This legal differentiation basically reflects the obligation or not for the user to be granted individual rights of use before transmitting. It should however be emphasized that this first level differentiation should not prejudge the various spectrum management practices that can be developed to optimize the use of the spectrum. Nor should it be assumed that this split matches with distinctions between e.g. protected / unprotected use or exclusive / collective use of the spectrum [72].

Table 11: Spectrum management regimes: a decision guide Source: [65]

<table>
<thead>
<tr>
<th>STEP 1</th>
<th>STEP 2</th>
<th>STEP 3</th>
<th>STEP 4</th>
<th>Spectrum Management Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Allocation: Harmonization or Not</td>
<td>Technologies Standardization or Not</td>
<td>Usage rights</td>
<td>Spectrum assignment mode</td>
<td></td>
</tr>
<tr>
<td>Harmonized spectrum (no service flexibility)</td>
<td>Standardization</td>
<td>Property rights: Exclusive</td>
<td>a) Administrative Assignment Procedure/Hybrid</td>
<td>1a) Standard Command and Control (CC)</td>
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<tr>
<td></td>
<td>(no technology flexibility)</td>
<td></td>
<td></td>
<td>1b) Technology Control/Property rights (PR) Market</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>b) Auctions/Trading</td>
<td>2a) Mitigated CC with easements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2b) Technical CC+ Mitigated Market</td>
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<tr>
<td></td>
<td></td>
<td>Collective use</td>
<td>License-exempt</td>
<td>3) CC Collective</td>
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<tr>
<td>Techno Flexibility NO Standardization</td>
<td>Property rights: Exclusive</td>
<td>a) Administrative Assignment Procedure/Hybrid</td>
<td>4a) Technology flexibility in CC context</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with Easements</td>
<td></td>
<td>4b) Harmonized flexibility</td>
<td></td>
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<tr>
<td></td>
<td>Collective use</td>
<td>b) Auctions/Trading</td>
<td>5a) Controlled flexibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>License-exempt</td>
<td>5b) Harmonized flexibility Plus</td>
<td>6 Standard “Commons” Regime</td>
<td></td>
</tr>
<tr>
<td>Service Flexibility NO Harmonization</td>
<td>Property rights: Exclusive</td>
<td>a) Administrative Assignment Procedure/Hybrid</td>
<td>7a) Administered Flexibility</td>
<td></td>
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<tr>
<td></td>
<td>with Easements</td>
<td></td>
<td>7b) Pure market regime: libertarian</td>
<td></td>
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<tr>
<td></td>
<td>Collective use</td>
<td>b) Auctions/Trading</td>
<td>8a) Technology Flexibility/Administered semi-PR Market</td>
<td></td>
</tr>
<tr>
<td></td>
<td>License-exempt</td>
<td></td>
<td>8b) Mitigated Market regime: semilibertarian</td>
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<tr>
<td></td>
<td>9) California Dream</td>
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As a second level differentiation factor, it is proposed to retain the possible obligation or not for registration or notification. An obligation for registration or notification is of administrative nature and necessitates - as a prerequisite for use - that the user contacts the Spectrum Management Authority to meet its obligation. Such provisions, often associated with the concept of "light-licensing", would remain in the field of "general authorization" as long as they are only meant to allow controlling the deployment and use of the application so as to avoid harmful interferences on radio services, but not to restrict it. Conversely, these provisions would fall under the "individual authorization" umbrella if associated with possible limitation of the number of users or some kind of coordination prior to use. The answer from an administration resulting e.g. from such coordination process would from a regulatory perspective be equivalent to an "individual authorization".

The CEPT ECC Report 132 [72] reviews the various terminologies that are commonly used to qualify the type of "regulatory regime" or "licensing regime" that is applied when regulating the use of a radio application. It shows in particular that practices in various European countries reflect different interpretation of the terminologies "license-exempt" and "light licensing".

In order to capture some fundamental differences between various regulatory options, the Table 12 presenting main characteristics of different "licensing regimes" as proposed [72]. This Report concludes that the use of the terminologies like "license-exempt", "light licensing" and "individual license" is quite convenient as a way to better qualify the "licensing regime" and associated spectrum management approach and to reflect various levels of control of the deployment and/or use of transmitters by the administration that may be needed in order to meet the market demand.

<table>
<thead>
<tr>
<th>Table 12: Key characteristics of different “licensing regimes” Source: [72]</th>
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<tbody>
<tr>
<td>Individual authorization</td>
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<tr>
<td>(Individual rights of use)</td>
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<tr>
<td>Individual license</td>
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<tr>
<td>(traditional licensing)</td>
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<tr>
<td>Individual frequency planning / coordination</td>
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<tr>
<td>Traditional procedure for issuing licenses</td>
</tr>
<tr>
<td>With limitations in the number of users</td>
</tr>
</tbody>
</table>

Figure 24: Place of CUS in models of spectrum management [73]
The development of wireless communication networks for the new released TVWS, will significantly differ from the classical development of systems for a licensed band. Although it is clear that the current paradigm of TV licensing has to be changed to provide flexibility and efficiency, as mentioned above, there are several options or philosophies to consider. Of these possibilities two approaches will be investigated in the scope of COGEU project: spectrum commons and real-time secondary spectrum market. The following sections will address these two spectrum sharing regimes.

4.3 COGEU spectrum commons in TVWS

The spectrum commons or unlicensed regime represents an extreme point of view where coexistence with incumbent DVB-T channels is assured via control of interference levels (spectral mask) rather than by fixed spectrum assignment. In a commons spectrum usage model there is no spectrum manager to preside over the resource allocation. It means that, there is no centralized coordination to control the resource allocation. This solution is most suitable for low power short range systems.

The experience of the recent past in the wireless ISM bands has shown that innovation and openness to new entrants is facilitated when these have to fulfill the technical rules ensuring good coexistence but do not need to negotiate with existing players. However, despite the fact that unlicensed spectrum promotes efficiency through sharing, QoS cannot be guaranteed. This is a serious problem for some applications. Sensing techniques for reliable detection of TVWS and coexistence mechanisms for interference avoidance are the main technical challenge. Defining spectrum policies and etiquette rules to promote fairness and avoid the “tragedy of the commons” are key challenges.

Collective use refers to access to license-exempt bands. In principle the benefits of collective use include: low entry barriers, quickly addressed niche applications, certainty of obtaining access, lower demand for licensed spectrum, innovation (anti-monopoly), public infrastructure, freedom of speech/cultural diversity, light licensing, possibility of private commons or experimental commons [65].

4.3.1 Collective use of spectrum

The RSPG issued an opinion on “Aspects of a European Approach to the «Collective Use of Spectrum's»” [73]. This opinion does offer insight into the consideration of the RSPG regarding the future of unlicensed devices. The RSPG defines Collective Use of Spectrum, what is more popularly referred to in the literature as a commons, in the following way: “Collective Use of Spectrum allows an undetermined number of independent users and/or devices to access spectrum in the same range of frequencies at the same time and in a particular geographic area under a well-defined set of conditions.”

RSPG are of the opinion that spectrum managed under the commons model has the potential to stimulate service innovation by offering a long term perspective and a wide range of potential users. But they also note that this model should be considered as one part of a mix of spectrum management approaches along with market mechanisms and administrative means.

The commons models can vary in their form, and their implementation will vary the experience of the users. The commons model is proposed for devices beyond the low-power, short-range category, then it may be necessary to consider light-licensing or private commons. Light-licensing can help higher power devices to co-ordinate and co-exist as it provides some means of tracking the users of the spectrum. Private commons on the other hand involves handing over responsibility for planning to a private band manager appointed by, or responsive to, the needs to the users of the spectrum [73].

Three levels of responsibility should be considered under the commons model: user, manufacturer and the regulator. The user is responsible for applying the conditions imposed by general authorization. The manufacturer ensures the conformity of the equipment with the necessary spectrum and equipment regulations and the regulator sets minimum conditions which protect other services. They also believe that regulators should try to explore the removal of existing constraints and to continually question whether constraints are justified. This approach reduces the risk of regulatory distortions [73].

In Microsoft’s response to that Opinion, which was largely in agreement with the RSPG’s recommendations, i.e. commons use across all bands, application and technical neutrality and global harmonization of commons bands. Microsoft also single out the potential of “mesh networking where lower frequencies can enable a mesh network to operate with a sparser penetration than would be possible at the frequencies typically allocated for wireless broadband using license-exempt equipment”.

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From other hand, PWMS Manufacturer Group, a representative group for European Professional Wireless Microphone Systems manufacturer's claims in their response, noting that PMSE equipment is extensively using the UHF band 470-862 MHz and that their devices cannot accept any degradation of signals. As such, they remind that any commons models that do operate in this spectrum will have to be able to prove themselves capable of detecting and protecting incumbent users which are offered interference protection by the national regulators.

Generic use models of CUS provide greatest scope for innovation by opening the band for a broad range of applications. The generic approach relies extensively on adequate ‘politeness rules’ and ‘polite protocols’. The alternative approach is to designate spectrum for a specific application. This limits entry to the band, meaning that the number of devices may be better estimated and interference scenarios may be more reliably predicted, but risks inefficient use of spectrum if the specific applications are not taken up as expected [73].

Under the CUS model QoS cannot be guaranteed at all times as the responsibility for interference management is delegated to the manufacturer and, to a lesser extent, the end user. In this case it is the manufacturer and/or user that takes responsibility for congestion management – in other words how users behave as the spectrum becomes more heavily used or how the equipment mitigates against other users.

While individually licensed users, through the regulator, have means to deal with harmful interference, the individual CUS user is unlikely to have any such recourse, neither through the manufacturer nor the regulator (unless it is caused by illegal transmissions). Nevertheless, under CUS, quality can and should be high and, for many users, CUS is likely to provide a perfectly acceptable level of service. QoS is dependent upon the level of congestion within the band and coexistence between the different technologies and services deployed. CUS requires agreement on the level of politeness that must be achieved. This means two things:

- Politeness rules (e.g. restrictions on power, duty cycle...) - generally imposed by the regulator;
- Polite protocols (technological requirements) - generally defined through voluntary standards.

Different management approaches under the CUS model (generic uses, specific uses, light licensing...) result in market players having different levels of control over the radio environment. This impacts on the QoS that can be offered by radio systems operating under a CUS model [73]. Achieving high QoS is an important issue to be addressed by COGEU project where coexistence of licensed primary users (broadcasters) and those who operates under CUS model may considered. Two model approaches can solve this problem: private commons and/or light licensing.

### 4.3.2 Private commons

Under a private commons model, an individual right of use is required but access to spectrum may be “sub-let” to third parties on a license-exempt basis without the need for co-ordination, so long as pre-defined regulatory conditions are adhered to. Responsibility for avoiding interference with users outside the spectrum band rests with the right of use holder [71].

Not all types of private commons could be considered CUS. This depends on license holder behaviour which may determine the conditions of access to the band with by setting limit the number of users that have access to the band on a license-exempt basis (not CUS model by definition - the number of users may not be “undetermined”) or may open the band to any number of license-exempt users (CUS model).

Private commons may be also associated with a market based approach to spectrum management as it is most probable that the license holder will have obtained their rights of use through a competitive process. Given that CUS may also overlap with some approaches based on administrative assignments, it can be concluded that CUS potentially cuts across all three approaches to spectrum management: license-exemption, administrative assignments and market mechanisms [71].

Under private commons model, the regulator give the role of managing interference to a private entity. The rules that determine access to the band are set by the entity to which the band has been licensed. The users are dependent on the licensed entity, as well as other users, to manage the risk of interference within the private commons band. The regulator has very little need for intervention [73].
Many applications which use spectrum under the CUS model are technologically very basic (low cost, mass market products with minimum technical complexity). This can potentially result in less efficient use of spectrum if there is insufficient incentive on manufacturers to develop innovative products which would improve sharing capabilities either between CUS applications or between CUS and licensed users. In purpose to try to optimize use of spectrum, the R&TTE Directive oblige manufacturers to minimize the risk of harmful interference by deploying ‘state-of-art’ technology, but the effectiveness of such incentives is a little unclear.

The private commons concept provides a cooperative mechanism for licensees (or lessees) to make licensed spectrum available to users employing these advanced technologies in a manner similar to that by which unlicensed users gain access to spectrum to suit their particular needs, and to do so without the necessity of entering into individual spectrum leasing arrangements under existing rules [74].

The private commons option provides a potentially complementary access model, in which licensees (or spectrum lessees) would determine to make access available to a similar class of users, and would do so under technical requirements for sharing use of the licensed band established and managed by the licensee (or lessee).

The nature of these types of users’ access to spectrum under this private commons option thus differs qualitatively from the nature of access provided to spectrum lessees under the Commission’s spectrum leasing policies and procedures. In the private commons, the licensee (or lessee) authorizes users of devices operating at particular technical parameters specified by the licensee (or lessee) to operate on the licensed frequencies, consistent with the applicable technical requirements and use restrictions under the license authorization, using peer-to-peer (device-to-device) technologies.

The users’ devices may be used to engage in peer-to-peer (device-to-device) communications, such as by becoming part of compatible ad hoc or “mesh” wireless networks. Such users may need access to a particular licensed spectrum band in lieu of (or perhaps in addition to) gaining access to other bands that may be more heavily used or that do not allow for the quality of service necessary for a particular application. This type of private commons might be particularly valuable to users that find existing bands that provide for unlicensed operations to be crowded or otherwise less desirable.

4.3.3 Light licensing

Many license-exempt allocations do not regulate the number of users and hence the potential level of congestion within the band, which is influencing QoS. In certain cases, and typically where higher power levels than those typically employed for license-exempt applications are required, congestion may not be manageable without limiting the number of users in the band. Through a light licensing model the regulator may achieve this, thus enabling market players to manage the interference environment better. In general, light licensing may be used to authorize typically greater power than license-exempt regimes.

Generally speaking, light licensing regimes may be based around: notification, registration, coordination with incumbent users, etc.

Light licensing regimes can be described in many different manners. For instance, ECC Report 80 [75] provides the following definition: “A ‘light licensing regime’ is a combination of license-exempt use and protection of users of spectrum. This model has a “first come first served” feature where the user notifies the regulator with the position and characteristics of the stations. The database of installed stations containing appropriate technical parameters (location, frequency, power, antenna etc.) is publicly available and should thus be consulted before installing new stations. If the transmitter can be installed without affecting stations already registered (i.e. not exceeding a pre-defined interference criteria), the new station can be recorded in the database. A mechanism remains necessary to enable a new entrant to challenge whether a station already recorded is really used or not. New entrants should be able to find an agreement with existing users in case interference criteria are exceeded”.

The possible limitation in the number of users that is suggested above implies that such approach falls under the “individual authorization” umbrella. It should however be recognized that effective regulatory regimes may combine various regulatory features pending e.g. the geographical area of operation (e.g. “general authorization” throughout most of a national territory while some coordination zones may be subject to “individual right of use”).
Another proposal to define light licensing is as follows “the issuing of licenses for radio transmitters using IT for applications and the processing of applications”. Under this approach, “light licensing” falls precisely under the “individual authorization” umbrella but is rather considered as a tool for national authorities to utilize IT systems and the Internet to simplify the licensing process for enterprises and other radio users. It was also argued that “light licensing” should be envisaged only if individual frequency planning is necessary and should imply a real simplification of procedure comparing with typical procedure of authorization (issuing of license) [72].

In Ofcom consultation document [76], light licensing was defined as follows: “Light-licensing is a mechanism whereby the users of a band are awarded non-exclusive licenses which are typically available to all, and are either free or only have a nominal fee attached to them. There may be further obligations associated with the provision of a license such as the need to register the location of any transmitters and possibly to coordinate their deployment with other registered users”. Under this approach, “light licensing” seem to reside somewhere between the licensing and license-exempt models [72].

It seems that there are two opposite trends:

- Light licensing is a form of individual authorization characterized by individual frequency planning/coordination and simplified procedure comparing with typical procedure of individual authorization;
- Light-licensing regime is a form of general authorization characterized by no individual frequency planning/coordination and a requirement for registration and/or notification that allows controlling the deployment and use of the application, but does not restrict it [72].

Noting that such provisions for registration/notification are intended to be implemented on a national basis, the above concern should in any a case encourage administrations to regularly review that status of operational light-licensed regimes with a view to conversion to license-exemption when appropriate.

This Section provides comprehensive classification of possible unlicensed access to spectrum including common use of spectrum model with undetermined number of users/devices, private commons model where access to the spectrum may be granted to the third parties outside owner of the individual right of use and light licencing model connected with easy procedures of notification or registering.

From COGEU point of view, the two last options (Private Commons and Light Licensing) seem to be most suitable and should be developed. In the Private Commons model, the right of use holders (broadcasters) can offer access to the spectrum in TVWS to secondary users keeping responsibility. In the Light Licensing model, regulator as the government entity responsible for frequency management at national level may allow to use TVWS at strictly determined conditions with as most simplified procedures as possible. In both cases, an intermediate entity (broker) may be responsible for procedures granting access to the desired spectrum band.

### 4.4 COGEU secondary spectrum trading in TVWS

Spectrum commons regimes promote sharing, but do not provide adequate quality of service for some applications. For COGEU applications that require sporadic access to spectrum and for which QoS guarantees are important, 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. This model has the potential to enable small companies to enter the spectrum market, have access to TVWS and be charged based on spectrum utilization, thus boosting competition and innovation in the telecommunications sector.

Unlike today’s unlicensed bands, primary and secondary users would coordinate directly, making it possible to protect QoS for both primary and secondary users. In this explicit coordination, the license holder runs an admission control algorithm, which only allows secondary users access to spectrum when QoS of both primary and secondary are adequate. The license-holder also uses an intelligent frequency assignment algorithm for determining the frequency at which a secondary user should be allowed to operate and the economics of such transactions which provides incentives to maximize spectrum utilization. Secondary users dynamically request access to spectrum when and only when spectrum is needed.
The trading of secondary use may occur through intermediaries such as a spectrum broker. In general, the mechanisms of searching for a match between the primary and the secondary users largely rely on types of services, access characteristics, and service levels requested by secondary users. The access types could consist of a long-term lease, a scheduled lease, and a short-term lease or spot markets. Each type requires different discovery mechanisms and applies with different levels of service agreements.

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 interference limits. A negotiation protocol is required for information exchange among the players and negotiation mechanisms by which users can request and acquire communication rights to a part of the TVWS. The spectrum market model with a centralized broker is shown in Figure 25.

Players are spectrum holders and spectrum seekers subject to regulation. Regulators must determine exactly what rights can be granted to secondary users. A centralized spectrum broker manages TVWS on real-time regime 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 that in new public sector roles or in the commercial sector.

COGEU will take into account the following core elements for an efficient secondary spectrum market:

- 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.
4.5 Business models for the secondary spectrum market

This section starts presenting two case studies relevant for COGEU: the Spectrum Bridge Inc. in the US and the PMSE band manager JFMG in the UK. After that the COGEU initial business model for secondary TVWS trading is presented.

4.5.1 The case study of Spectrum Bridge Inc. in US

The United States has led the way in opening up TVWS. The beginning of this millennium, white space started to attract attention from the PC and Internet industry sector of US industry.

With respect to the use of geo-located spectrum databases, in February 2009 it was announced that seven of the key supporters of TVWS devices in US are working together to accelerate the creation of an anti-interference database to assist the detection of available channels in a given U.S. location. Founding members of the White Spaces Database Group include Comsearch, Dell, Google, HP, Microsoft, Motorola and NeuStar. The group intends to establish data formats and protocols that are open and non-proprietary and will advocate that database administration be open and non-exclusive [77].

In November 2009, the FCC starts looking for someone to manage the database that will identify unused TV spectrum for use by unlicensed devices. In the notice, the FCC gave potential database managers to outline proposals for the database, which will have to contain the information, a process for incumbents to register, and a way for devices to query it.

In January 2010, Google had submitted a proposal to the FCC to be designated one of the administrators of a geo-location database. Google is proposing to provide all of the database architecture, from storage to search, for what should be multiple managers, and says it is in the best position to provide an open, publicly accessible, secure system, which it will commit to paying for five years, per FCC requirements. It does not anticipate charging a per-inquiry fee -- though the FCC permits the database administrator to do so -- though it did not rule them out either. Google can also charge for registering spectrum users. The company envisions a clearinghouse model where a number of database service providers would be able to cooperate to form voluntary arrangements to share commission data [78].

One of most advanced, practical technology for accessing TVWS is offered in US by Spectrum Bridge Inc. (SBI) [79]. This technology is part of a complete spectrum access solution called Universal Spectrum Access (USA). The creation of a TVWS Database, allowing anyone to locate available TVWS, not only offers the opportunity to provide much needed access to spectrum, but also introduces a new concept in how spectrum can be allocated and accessed automatically.

Unlike the static command and control scheme in practice today, USA makes all types of available spectrum visible and dynamically accessible to all potential users. It maximizes the bandwidth available to wireless devices and applications within and across users, enterprises and networks. By making more spectrum more available, perceived scarcity can be cost-effectively addressed and alleviated using currently available spectrum allocations.

Universal Spectrum Acess is a multi-layered approach to spectrum allocation. It consist of:

- The Database Layer -- a Database Driven Architecture (DDA) for wireless networks;
- The Information Layer -- leveraging multiple resources to determine the attributes and availability of spectrum. SBI’s proprietary suite of spectrum intelligence tools including: SpecEx, ShowMyWhitespace and SmartWaves, provide this information;
- The Transaction Layer -- matching spectrum availability with dynamic network information via Dynamic Spectrum Allocation (DSA).

SpecEx.com, the online marketplace for spectrum is the place where leading wireless companies go to buy, sell and lease licensed spectrum. SpecEx contains the industry’s largest inventory of available spectrum. By providing an easy to use web-based platform, a fixed set of trading rules and standardized agreements, SpecEx makes purchasing and selling spectrum straight forward, transparent, and cost effective.
The database driving Universal Spectrum Access contains more than just a list of available spectrum channels from the FCC’s Universal Licensing System (ULS). In order to support a network-centric, rather than a spectrum-centric view, data contained in the ULS is supplemented with additional information such as:

- Secondary Market Spectrum availability, location, bandwidth and pricing;
- Geographic Information Systems - including spectrum license boundaries, census block size, tower locations, protected incumbent zones, etc;
- Census and market population data - including density and growth trends, economic indexes and business metrics;
- Spectrum service rules - including limitations and allocations.

The database must also maintain relationships between this information and create metadata on demand at the request of the Dynamic Spectrum Allocation Engine.

SBI first demonstrated a Beta version of a TVWS Database to the FCC in January 2009. By June 2009, SBI demonstrated a complete online TVWS solution, and subsequently deployed (probably) the world’s first TV White Spaces network solution in Claudville (Virginia) in September 2009 [80].

In the City of Wilmington and New Hanover County (North Carolina) SBI together with TV Band Service LLC deploy a trial network using TVWS to wireless extended the reach of the City's and County's broadband communications system. TVWS wireless transmitter hubs were installed in three locations that offered high speed internet connectivity provided by local businesses and the city/county fiber optics network. Additional transmitters were connected to a wide range of remote devices so that TV white spaces frequencies could be used to communicate back to the hubs. Some of the remote devices using the white spaces network e.g. for: video security cameras in public/county parks, video traffic and security cameras at major thoroughfares, WiFi access in county parks for the public and city/county workers. To ensure protection, the TVWS are under the control of SBI’s TVWS database solution. This database assigns available TV white spaces channels to the radios and ensures that they do not create any interference for these protected, incumbent users [81].

4.5.2 The case study of JFMG band manager in UK

The UK has taken the opportunity afforded by the digital transition to radically alter the way that it provides spectrum for PMSE users. Ofcom are moving from the provision of free non-protected services for PMSE users in Channel 69 to market and fee-based licencing of Channel 38 spectrum for PMSE users. This process is being phased in from now, through 2012 and the completion of the DSO, to 2018 when Ofcom envisages that PMSE users will be using a fully market-based method to acquire licenses. However, this process being undertaken by Ofcom has met with opposition from industry players as it had sought to completely relocate PMSE users from Channel 69 to Channel 38 and it also seeks to introduce a completely new business model for these users. Ofcom, under industry pressure, now intend to offer Channel 69 spectrum to PMSE users under the same new terms being applied to Channel 38. It should be noted that Ofcom’s proposals are still quite fluid and the definite form in which PMSE spectrum is managed has not been crystallized yet.

The current UK model for PMSE management, administered on Ofcom’s behalf by JFMG, is interesting because PMSE users can book licenses online, coordinated through a database. Database coordination of white space, as we shall see, is a concept which is set to be at the heart of the future exploitation of white spaces. The Joint Frequency Management Group (JFMG) was established after a 1985 agreement by the UK government that TV broadcasters could self manage the frequency spectrum allocated to them for broadcast ancillary services, i.e. PMSE services [82]. Owing to the complexity of the task of managing spectrum in the range of 50MHz to 12GHz for a variety of users with a variety of uses, the JFMG commissioned a database system to aid it in completing the following tasks:

- Maintain a frequency record for each assignee, i.e. each TV operator;
- Issue a temporary license to independent production companies commissioned by broadcasters;
- To be able to determine rapidly whether a sharing situation is possible and thereby to reduce the risk of mutual interference between users.

This database has now been extended to allow for the control of access to Channel 38. The database shows the availability of wireless microphones and personal monitor frequencies in Channels 38, 39, 40 and/or 69 for UHF UK Wireless Microphone use (10mW hand-held or 50 mW body-worn) in the UK.
Channels 39 and 40 are temporarily available for PMSE use as there are restrictions on the use of Channel 38 in certain areas. The functionality of this database is quite simple: a potential licensee inputs their location coordinates and receives a response indicating which of the four channels are available at that location. It may then apply online for a license at that location.

Figure 26 JFMG Channel 38 Look-up Tool Query returns for Cambridge, UK (left) and Oxford, UK (right)

Figure 26 illustrates the use of the database to determine which channels may be used under license in a given location. The query result on the left of Figure 26 is for a location in the town of Cambridge. As may be seen, Channel 38 may not be used owing to the fact that certain radioastronomy sites in Cambridgeshire are protected. In this case, Channel 39 and Channel 69 may be licensed. In the town of Oxford, where no radioastronomy sites are located, Channel 38 is available for licensing to PMSE users.

Under this transitional model, which will be phased out, PMSE users do not pay for their licenses and are not offered a protected service. These PMSE licenses are offered on a shared, non-priority basis with other licensed users. It is only though PMSE users use of the JFMG licensing service that mutual interference is avoided.

When the transition is complete Channel 38 and 69 will not be solely reserved for PMSE use and users. It is Ofcom’s intent that these frequencies be opened to competition with other users and other services eventually — fulfilling Ofcom’s targets to have more spectrum managed by market-oriented mechanisms. In order to facilitate this, Ofcom are in the process of awarding a contract to a Band Manager to license users of this spectrum [3]. The role out of the Band Manager will itself be phased as Ofcom will be using management techniques that are new to this industry segment and to the regulator itself. To help PMSE users make the transition to a market-based approach to spectrum access, Ofcom intends to use criteria designed to ensure the Band Manager’s interests are aligned with those of PMSE users. The Band Manager will itself pay a charge for the spectrum, i.e. Channels 38 and 69, to reflect the opportunity cost of these channels and the Band Manager will then be able to earn revenue by charging its customers for access under a market-oriented Alternative Incentive Pricing (AIP) system. In this way, Ofcom feel that that prices charged to end users should signal to them the value of the spectrum that they are using. According to Ofcom, over time, this may enable PMSE users to make decisions about their spectrum and equipment requirements that are likely to lead to the best use being made of spectrum. This could lead, in time, to PMSE users choosing to pay market rates for spectrum which sits outside of the Band Manager’s award, i.e. PMSE users might migrate from Channels 38 and 69.

Whilst wanting to open this spectrum up to market competition, Ofcom are mindful of the fact that this is a new model for PMSE users. Initially, PMSE users will be charged fees on a fair, reasonable and non-discriminatory (FRND) price basis. The exact nature of how FRND prices are benchmarked is still undergoing debate and consultation. The introduction of initial fees is to accustom PMSE users to the notion of paying for licenses. The fees will be changed over time to reflect the opportunity cost of this spectrum. However, at the moment, the sticking point for Ofcom is deciding on the process by which they will determine what the opportunity cost of that spectrum is.

This model, whilst still in development, illustrates a number of points. Firstly, it shows that databases are used to manage whitespace spectrum, albeit presently without the use of market-based techniques. It also shows that regulators are moving forward with the introduction of new management systems in this spectrum which has a complex system of small and diverse users. Whilst the exact form of the Band Manager’s AIP pricing scheme has not yet been finalised by Ofcom, it would indicate that PMSE license management can be brought under the market-based spectrum management umbrella.
4.5.3 The COGEU vision

The case studies of Spectrum Bridge Inc and JFMG band manager described in the previous section can inspire COGEU model of secondary spectrum market.

The COGEU vision is presented in Figure 27. COGEU envisage a business model where the Geolocation Database and the Broker can be different business entities. Such solution may be useful to manage real-time spectrum allocation in both spectrum sharing regimes considered by COGEU: spectrum commons (database only) and secondary spectrum market (database and broker).

The role of regulator to create secondary spectrum market within TVWS is crucial for COGEU. Substantial modification of regulation is needed to secure harmonized approach to the secondary use of TVWS. To achieve economic efficiency, property usage rights should be determined in the right way. Spectrum can be traded, leased, aggregated and disaggregated. The regulator shall make efforts to reduce anti-competitive conduct such spectrum hoarding, etc. General conditions to create properly functioning secondary spectrum market and precautions to avoid failures on it are described in Section 4.1.

![Figure 27: COGEU business models for spectrum trading](image)

Figure 27 shows spectrum rights, information and cash flows in COGEU model as well. TVWS spectrum is (will be after completion of DSO) well defined by the frequency band (470-790 MHz), spectrum assignments to broadcasters (geographically dependent). The information of TVWS will be stored, managed and distributed by the Geolocation Database Manager. The Broker shall obtain information on TVWS spectrum availability on certain area against payment based on fixed fees or negotiated on marked-based rules. Another possibility is free access to such information representing advertising Google-like model, which may be an attractive option for users using TVWS spectrum on commons base. Mixture of both approaches may be considered as well.

Secondary Users may be divided into two groups:
- Buyers – which need spectrum for own services;
- Sellers – which can offer excess of temporarily unused spectrum.

The Broker shall be able to manage the secondary spectrum market to maximize profit and potentially meet the goals set by regulators (e.g. optimising TVWS usage avoiding fragmentation). Financial
results of his activity may be in favour of broadcasters directly (if they will be entities offered spectrum within TVWS by the regulator’s permission) or indirectly (if financial settlements will be done in relation the Broker – regulator and broadcasters will enjoy of reduction their fees for occupied frequency bands).

Detailed COGEU business models for spectrum trading will developed later in the project (WP2 task T2.3).
5 COGEU potential application scenarios

To set the context in which the new technologies of the COGEU proposal will function, it is important to focus on prospective application areas. With this in mind a number of specific scenarios with good business potential have been envisaged and presented in this chapter.

5.1 UMTS and LTE extension over TVWS

5.1.1 Motivation

The ability to take advantage of new spectrum allocations and the opportunity to potentially reform existing GSM spectrum are two key areas that will enable LTE deployments. Enhancing network capabilities presents new deployment opportunities, economies of scale and opens up markets that were previously inaccessible.

The transition from analog to digital terrestrial television will release large amounts of spectrum potentially for mobile broadband deployments – the so-called Digital Dividend (DD). Some countries have now confirmed the availability of the 790-862 MHz band (subject to allocation processes i.e. auction), including Denmark, Finland, France, Germany, Sweden and Switzerland. Germany plans to auction a package of spectrum including 3 x 20 MHz DD spectrum in Q2 2010. Other governments in Europe are expected to follow in 2010 and later. Also many operators will deploy LTE in this band.

Over the next several years the spectrum landscape will change significantly (Figure 28). The oncoming spectrum auctions in the (700 MHz and 2.5-2.6 GHz bands) will have a direct influence on the LTE ecosystem and in which band LTE will be deployed. Furthermore, the identification of new IMT mobile bands at WRC-07 (450-470 MHz, 2300-2400 MHz, 698-862 MHz and 3400-3600 MHz) will help fulfill the projected need for future bandwidth as well as facilitate global roaming.

A key characteristic of LTE technology is its suitability for deployment in scalable bandwidths ranging from 1.4 MHz to 20 MHz. What is more, it can operate in all 3GPP frequency bands in paired and unpaired spectrum allocations. In practical terms, the actual performance achievable with LTE depends on the bandwidth allocated for services, and not the choice of spectrum band itself. This gives operators considerable flexibility in their commercial and technical strategies. Deployed at higher frequencies, LTE is attractive for strategies focused on network capacity, whereas at lower frequencies it can provide ubiquitous cost-effective coverage.

LTE's flexibility to operate at a scalable bandwidth also allows operators to deploy LTE in their existing spectrum allocations. This could be achieved via re-farming, considered by many parties in the mobile telecommunications value chain as a cost-efficient option to address increasing traffic demands.

5.1.2 Scenario characteristics and Technical viability

5.1.2.1 User Terminals

The LTE, 2G/3G and TVWS equipment can be the same but the equipment compliance with TVWS and a cognitive capability that allows minimizing the interference with DVB-T should be guaranteed through a certification process. There are significant technological challenges to address ranging from the device level to the network architecture. The interruptible nature of the shared spectrum raises new
technical challenges to provide QoS and mobility in demanding user applications. COGEU will define new methodologies for TVWS equipment certification and compliance while addressing coexistence with the DVB-T.

5.1.2.2 Coverage area

The scenarios at low frequencies (<1 GHz) are ideal for rural coverage (Figure 29) and indoor penetration (Figure 30). Particular importance is given to rural areas where mobile systems deployment are made to provide good coverage. Hence, reduction in the number of sites directly corresponds to a reduction in the cost of offering service.

Likewise in urban areas, the lower frequency band tend to refract better around corners and can pass more easily through walls to obtain an improved indoor coverage with the ability to serve devices in the home without an external antenna. TVWS could be also used for traffic peaking support. Schemes for obtaining and sharing channels on a temporary basis (short or medium term leasing) to provide relief for crowded networks experiencing peak loads will be investigated by COGEU.

Figure 29: Coverage of rural area

![Coverage of rural area](image)

Figure 30: Coverage of urban area (indoor)

5.1.2.3 Operating Frequencies

Shown in Figure 31 for the same coverage requirement, terrain, transmit power and bandwidth, if the frequency used is doubled, the associated radio path loss increases and number of sites that need to be installed almost doubled. In other words, the number of Base Stations required at 700 MHz or 900 MHz compared 2 GHz is reduced by almost 65% for the same data rate and the same coverage.
The Digital Dividend needs to be considered in the wider scope of spectrum for new mobile applications. Mobile broadband consumers could use either of the UMTS/HSPA or LTE technologies (depending on successive releases and timing) according to operators needs, using the flexibility of multi-standard base stations (SDR BS).

Licensing processes could bundle UHF bands with higher band allocations (most likely the 2.5 GHz/ 3.5 GHz) providing capacity in high traffic areas (urban/suburban zones).

LTE offers a choice of carrier bandwidths; 1.4, 3, 5, 10, 15, 20 MHz; the widest bandwidth will be needed for the highest speeds. An operator may introduce LTE in “new” bands where it is easier to deploy, e.g., 5 MHz carriers in an idle DVB-T channel (8MHz).

Currently no cellular network has the flexibility of frequency, waveform and protocol to accommodate varying spectral assignment. In fact, there are a number of challenges in efficiently using the TVWS for cellular extension. For example, the available TVWS will be fragmented, especially in the metropolitan areas. The availability of white spaces is temporal and depends on the geographic location of the radio (mobility issues). Thus, a key challenge in the design of mobile cognitive radios is the dynamic allocation of white spaces to different radios in the network. The efficiency of the spectrum allocation determines both the cellular networks QoS as well as the overall spectrum utilization. Secondary spectrum market is a suitable regime to guarantee QoS. An interesting research topic, unexplored in previous work, and that will be investigated by COGEU is to evaluate the impact of cellular extension over TVWS on overall cell planning for 3G and LTE systems.

5.1.2.4 Technical Feasibility

DVB-T systems is used the Coded Orthogonal Frequency Division Multiplexing (COFDM) and LTE is used the Orthogonal Frequency Division Multiplexing (OFDM) both with the spreading of information on a large number of orthogonal carriers. In Table 13 we can see some comparisons between the two technologies.

<table>
<thead>
<tr>
<th>System</th>
<th>DVB-T</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Between 470 and 790 MHz</td>
<td>Between 450 MHz and 2.6 GHz</td>
</tr>
<tr>
<td>Range</td>
<td>67 Km</td>
<td>5 – 100km with slight degradation after 30km</td>
</tr>
<tr>
<td>Channel spacing</td>
<td>8 MHz</td>
<td>1.4, 3, 5, 10, 15, 20 MHz</td>
</tr>
<tr>
<td>Max gross data rates</td>
<td>5 to 31.7 mbps</td>
<td>10 to 300 mbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK 16 QAM 64 QAM</td>
<td>QPSK 16 QAM 64 QAM</td>
</tr>
</tbody>
</table>

With the features of DVB-T and LTE in the previous table we can draw some advantages to using LTE in TVWS, for example: access to medium uses a similar technology and LTE supports same frequency of DVB-T.
Some of the characteristics of LTE as described below shows that this system can be deployed easily and with significant gains on the TVWS bands:

- Increased downlink and uplink peak data rates;
- Scalable channel bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz in both the uplink and the downlink;
- Spectral efficiency improvements for downlink and uplink;
- Sub-5 ms latency for small internet protocol (IP) packets;
- Performance optimized for low mobile speeds from 0 to 15 km/h, supported with high performance from 15 to 120 km/h; functional support from 120 to 350 km/h, under consideration for 350 to 500 km/h;
- Co-existence with legacy standards while evolving toward an all-IP network;
- Frequency spectrum choice and flexibility of deployment in GSM, CDMA, UMTS bands (450, 700, 850, 900, 1700, 1800, 1900, 2100, 2500 MHz) means that global roaming will be possible;
- Coverage (Cell sizes) 5 – 100 km with slight degradation after 30 km.

The combination of LTE's increased spectral efficiency and flexibility, added capacity and simpler network architecture offers a very cost effective value proposition. Combined with TVWS in low frequency bands and using advanced antenna systems, LTE networks will provide to the service providers a significant improvement on cost per bit delivered.

5.1.3 Market Potential

The world is becoming increasingly mobile, which is driving the demand for easier access to content and services from any location, with any device, at any time. Broadband subscriptions are expected to reach 1.8 billion by 2012 (Figure 32). Around two-thirds of these consumers will use mobile broadband. Mobile data traffic is expected to overtake voice traffic in 2010, which will place high requirements on mobile networks today and in the future.

COGEU can alleviate the strong growing demand for new-spectrum exploiting local available TVWS, in addition, LTE technology allows for significantly higher capacity at a lower cost per bit, leading to improved commercial viability services.

![Figure 32: Broadband growth 2005–2012 [source: Ericsson]](image)

Several European countries have already taken some steps towards the use of broadband in frequency bands TV:

- Denmark, Finland, France, Germany, Sweden and Switzerland have confirmed they will allocate 790–862 MHz for mobile broadband services;
- The UK government proposes ring-fencing of some Digital Dividend spectrum so that operators can push 3G beyond their license obligation of 80% population. In return, operators would receive an indefinite extension to their 3G licenses;
- In Germany, trials are underway with some local authorities in Mecklenburg-Vorpommern to use digital dividend frequencies to provide HSPA or LTE broadband services to communities without broadband possibilities. An auction of 790-862 MHz spectrum will be held soon;
• In Italy, Communications Undersecretary, announced that frequencies vacated during the analogue switch off will be auctioned;
• Norway recently announced that 790-862MHz will be allocated to mobile broadband;
• In Spain, the Industry Ministry recently issued a press release indicating digital dividend spectrum would likely be reserved for cellular, especially for mobile Internet broadband, from January 2015.

According to the Global Mobile Suppliers Association (GSA), 26 network operators have committed to deploy 3GPP Long-Term Evolution (LTE) systems (Table 14). In fact, the GSA says that up to 7 operators European are expected to launch commercial LTE services in 2010. Nokia, the world’s largest handset vendor, has committed to LTE as its preferred network for devices and plans to launch data-intensive devices for those networks in 2010.

Table 14: LTE operator commitments [Source: GSA Information Paper “Evolution to LTE” – December 10, 2009]

<table>
<thead>
<tr>
<th>Country</th>
<th>Operator</th>
<th>Anticipated LTE service launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armenia</td>
<td>Vivacell-MTS</td>
<td>2010</td>
</tr>
<tr>
<td>Finland</td>
<td>TeliaSonera</td>
<td>2010</td>
</tr>
<tr>
<td>Norway</td>
<td>TeliaSonera</td>
<td>2010</td>
</tr>
<tr>
<td>Sweden</td>
<td>TeliaSonera</td>
<td>2010</td>
</tr>
<tr>
<td>Sweden</td>
<td>TeleNor Sweden</td>
<td>2010</td>
</tr>
<tr>
<td>Sweden</td>
<td>Tele2 Sweden</td>
<td>2010</td>
</tr>
<tr>
<td>Germany</td>
<td>Vodafone</td>
<td>2010-11</td>
</tr>
<tr>
<td>Germany</td>
<td>T-Mobile</td>
<td>2011</td>
</tr>
<tr>
<td>Ireland</td>
<td>Hutchison 3</td>
<td>2011</td>
</tr>
<tr>
<td>Austria</td>
<td>T Mobile</td>
<td>2011-12</td>
</tr>
<tr>
<td>Austria</td>
<td>Mobilkom Austria</td>
<td>2011-12</td>
</tr>
<tr>
<td>Austria</td>
<td>Hutchison 3</td>
<td>2011-12</td>
</tr>
<tr>
<td>Austria</td>
<td>Orange</td>
<td>2011-12</td>
</tr>
<tr>
<td>France</td>
<td>Orange</td>
<td>2011-12</td>
</tr>
<tr>
<td>Europe</td>
<td>Telefonica</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Finland</td>
<td>Elisa</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Finland</td>
<td>DNA</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Italy</td>
<td>Telecom Italia</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Norway</td>
<td>TeleNor</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Portugal</td>
<td>TMN</td>
<td>To be confirmed</td>
</tr>
</tbody>
</table>

LTE will be fully endorsed by ITU and will be deployed in ITU recognised frequency bands allowing global roaming capabilities similar to today’s GSM/UMTS networks. Because LTE devices will be backward compatible with GSM and UMTS, even at early stage of LTE deployment, LTE subscribers will be able to roam worldwide irrespective of the country they are in. Today’s 3GPP network technologies carry over 85% of mobile subscribers, it is expected that LTE will benefit from similar volume price effect to drive in momentum and benefit from numerous and affordable devices suitable for both developed and emerging markets and secondary markets in areas such as:

5.1.3.1 Urban Areas

On urban areas where the indoor radio signal penetration is difficult particularly in concrete made buildings the wireless broadband access hardly is available at home. The LTE on TVWS can provide good indoor coverage due to the more easy building penetration at this frequencies, is well suited to this kind of environment. The services on TVWS could be provided by two means on the spectrum commons and spectrum secondary market depending of QoS that the user wants. For example : for internet access can used the spectrum commons, the more less expensive spectrum, but for real time services like voice or video calls a particular minimal QoS is need therefore will be used the spectrum secondary market in order to guarantee the service quality.
5.1.3.2 Rural Areas

As explained on Section 5.1.2.3 for the same coverage requirement, terrain, transmit power and bandwidth, if the frequency used is doubled, the associated radio path loss increases and the number of sites that need to be installed almost doubled. In other words, the number of Base Stations required at 700 MHz or 900 MHz compared 2 GHz is reduced by almost 65% for the same data rate and the same coverage. On rural areas where the user density is low the BS's deployed intend only to provide coverage at low bitrates. Using the TVWS bands and the COGEU approach it is feasible to reduce the number of BS's providing the same or even higher throughputs what is very important for the network operator because decreases the CAPEX (Capital Expenditures) and OPEX (Operational Expenditures) and for the user that can experience better services.

The wireless broadband access in rural and remote areas, with performance comparable to those of existing fixed broadband access technologies (e.g., DSL and cable modems) can be developed by COGEU.

5.1.4 Regulatory feasibility

Availability of new spectrum, particularly in Digital Dividend bands, is a crucial factor for LTE deployments in many countries, as are regulatory conditions, and will directly determine deployment and launch dates in those markets. There is also high interest in opportunities for LTE deployments using frequencies released by spectrum re-farming, e.g. in the GSM 900 MHz band which is now being relaxed by regulators (e.g. in Europe) to enable mobile broadband services using technologies such as LTE. There are high expectations in Europe and elsewhere to access additional UHF bands from the Digital Dividend to enable LTE to be globally deployed efficiently over large geographical rural areas, and improve in-building coverage and traffic peak support over suburban areas. Despite de benefits that clearly come from extending the LTE\UMTS use to the TVWS bands (e.g increased radio coverage and system capacity) there is constraints imposed by the SLA (Service Level Agreement) between the network operators\service providers and the user, which defines the minimum QoS that should be provided. In this sense the management of the spectrum should guarantee the exclusivity of the spectrum use and the interference level in order guarantee the QoS to be provided to the user. Regarding this, the Secondary spectrum market proposed by COGEU is a suitable regime to guarantee QoS.
5.2 WiFi with cognitive access to TVWS

5.2.1 Motivation

Conventional WiFi is operating in the unlicensed 2.4GHz ISM band (802.11b, g). Although its range is short, it has been a very successful technology in delivering cost effective wireless internet access both in homes, offices and public areas [85]. The enormous success of WiFi has inspired many researchers and engineers to try to extend its range, to cover a wider area, reaching more users while increasing revenue to the investor [86] [87] [88]. Different ways have been or are being used to stretch the reach of current WiFi systems, some of which includes MIMO technologies, usage of high gain antenna, etc.

Increasing the range of WiFi in the 2.4 GHz ISM band is faced with several challenges. First, in order to successfully use WiFi over long distances line-of-sight conditions are normally required between the endpoints; therefore its performance is subject to the negative impact of surrounding environment on microwave signals. For example, trees and vegetation as well as high rise buildings and hills may block the line of light (LOS). Obstructions and environmental features (walls etc) also reflect and absorb the radio signals, leading to reduced received power and in many case the propagated radio signal may be lost completely. Second, the 2.4 GHZ ISM band is crowded with a lot of devices which cause interference to WiFi signals. These devices include microwave ovens, baby monitors, wireless cameras, remote car starters, Bluetooth, DECT and residential wireless phones etc. The first limitation can be overcome by taking advantage of terrain elevation, or by using towers to overcome obstacles and provide Fresnel zone clearance. The second limitation is less effective in sparsely populated areas, and may be mitigated by shifting to the less crowded 5 GHz band.

Table 15: Summary of conventional methods for extending the range of WiFi [86] [87] [88].

<table>
<thead>
<tr>
<th>Setback</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement for line-of-sight between endpoints</td>
<td>• Take advantage of terrain elevation</td>
</tr>
<tr>
<td></td>
<td>• Avoid areas with obstacles</td>
</tr>
<tr>
<td></td>
<td>• Use high towers to provide Fresnel clearance</td>
</tr>
<tr>
<td>Vulnerability to interference in the unlicensed band</td>
<td>• Operate in rural areas</td>
</tr>
<tr>
<td></td>
<td>• Migrate to the less crowded 5 GHz band</td>
</tr>
<tr>
<td>Power budget limitation</td>
<td>• Use high-gain directional antennas</td>
</tr>
<tr>
<td>Timing limitation</td>
<td>• Modify the medium access control (MAC) mechanism</td>
</tr>
<tr>
<td>Cost and usability</td>
<td>• Use cheap antennas</td>
</tr>
<tr>
<td></td>
<td>• Employ technology which is affordable and</td>
</tr>
<tr>
<td></td>
<td>easier to use by people with limited training</td>
</tr>
</tbody>
</table>

Having seen the success of the traditional WiFi and some of the setbacks, it can be seen that there is still a need for a simpler and cheaper way to stretch the range of wireless internet connectivity. Compared to the higher frequency ISM bands, the lower frequency TV white spaces have inherent RF propagation properties, such as, longer range, better penetration [89] [90], lower interference, and the possibility to build small antennas for hand held devices; that make them extremely desirable for long range high speed wireless internet connectivity in various areas, including homes, offices, public places, roads, rails, etc., at a cheaper cost.

Long range WiFi over TVWS use case is motivated by the inherent RF propagation characteristics presented above. In many cases a ‘less lossy’ radio propagation environment also suggests higher received signals and thus higher sustainable throughputs. Moreover, Wi-Fi is a mature, well-understood technology that is inexpensive and easily available. In fact, there are several wireless card vendors considering pushing some version of Wi-Fi to the IEEE standards body for white space networking [91]. So far, there are standardisation initiatives to amend the IEEE 802.11 standard for operation in TVWS [92]. Therefore, high speed and long range wireless connectivity systems can be built in the TV white spaces by using off-the-shelf components, and coupling them with cognitive capabilities to allow a smarter way to access the spectrum while causing negligible interference to incumbent devices.
5.2.2 **Scenario characteristics and Technical viability**

5.2.2.1 **User terminals**

The terminals will mainly have the same form factors as the ones used for WiFi today, i.e. stationary PCs, laptops, PDAs, and mobile phones. **Communication in white spaces complements networks that use other parts of the spectrum.** Thus is likely that existing types of devices will acquire white space interfaces alongside other more established radio interfaces as shown in Figure 33. Moreover, user terminals may include spectrum sensing capabilities, or geo-location database access, or a combination of both depending on the intended way to obtain spectrum resource for data transmission. Furthermore, user terminals would need to be standardized and required to satisfy some compliance requirements, across different EU countries. They also have to be affordable so that they may benefit from economies of scale. However, in order to successfully achieve this scope, there has to be harmonization of the standardization and compliance efforts.

![Figure 33: Mobile Communication device adding TVWS interface to the already existing radio access technology (RAT)](image)

5.2.2.2 **Coverage area**

WiFi over TVWS is expected to extend the range from the conventional 30 meter to about 300 meters as shown in Figure 34. This range will be viable for urban, suburban and rural areas.

![Figure 34: Indicative comparisons of Wi-Fi range using 2.4GHz and white space spectrum in indoor (left) and outdoor (right) settings](image)

5.2.2.3 **Service and capacity**

The main benefit from using the white spaces will be the availability of frequency spectrum at significantly lower frequencies, expected to lead to high speed data connectivity and throughput. The addition of the white spaces spectrum will increase the amount of unlicensed spectrum available for
high data rate Wi-Fi communication by around 9 – 22 percent in a typical location in the US, and a similar amount in other parts of the world [85].

5.2.2.4 Operating frequencies

The targeted operating frequencies are the TVWS and, as said before, their characteristics include:
- Spatial and temporal variation;
- Spectrum fragmentation.

The next two subsections give the details of the special characteristics of the geographic interleaved spectrum bands in relation to their usage in providing wireless internet access connectivity.

5.2.2.4.1 Spatial and temporal variation

Television stations represent the largest incumbent use of the UHF spectrum. Across a wide area, the set of occupied TV channels depend on the location of TV transmitters as well as the number of stations operating in the area. Spatial variations may exist on smaller scales and depend on physical obstructions and their construction materials. For example, wireless microphones, can operate in locally idle TV channels as secondary users, in environments ranging from small-scale lecture rooms to large-scale music and sporting events with typical ranges of a few hundred meters. For these reasons we expect spatial and temporal variation in spectrum availability for long distance Wi-Fi over TVWS especially in densely populated areas. In [91] measurements of UHF spectrum were performed in two settings: the campus setting and a University dormitory setting, over several days, to determining incumbents. In both cases, they detected the use of wireless microphones at different times of day and for different durations.

The temporal variations in UHF white spaces due to the intermittent operation of wireless microphones pronounce a need for a protocol that can signal the presence of a wireless microphone to the network without interfering with the microphone. Since both the WiFi over TVWS and the PMSE are secondary spectrum users, it will be a win-win strategy if there will be harmonization between the two together with other cognition based technologies operating in TVWS to solve the problem of unpredictable transmission which cause spatial and temporal variations.

A white space WiFi network (a home wireless router for example) must not naively select channel(s) to operate on based solely on its own local observation of spectrum availability. The AP must take into account the availability of spectrum at its clients as well.

5.2.2.4.2 Spectrum fragmentation

While the ISM bands are a contiguous chunk of spectrum, e.g. an IEEE 802.11b/g channel needs 22 MHz bandwidth, UHF white spaces are fragmented due to the presence of incumbents. The size of each fragment can vary from 1 channel (8 MHz for DVB-T) to several channels. The amount of fragmentation in the UHF bands depends to a large extent on the density of TV stations, which varies considerably with population density. Rural (and suburban) areas are likely to have larger chunks of available UHF spectrum than urban areas.

In case of such a possible fragmentation the radios will need to tune the spectrum that they occupy to fit within available fragments. This implies the need for radios to use variable channel widths [93] or channel bonding. Compared to conventional WiFi, the user of variable channel widths introduces two new challenges. First, it makes channel assignment more challenging, since APs now occupy a range of channels, rather than just one. Second, it increases the time taken for nodes to discover APs. This is due to a limitation of techniques that can achieve variable channel widths on Wi-Fi cards [93]. Using this technique a radio can only decode packets that are sent at the same channel width and same center frequency. An expensive switch of the PLL clock frequency is required to decode packets at other channel widths [91]. Otherwise, innovative methods beyond the state of the art have to be used; these could be spectrum shaping methods, multichannel transmission etc.

5.2.2.4.3 Sensing in WiFi over TVWS

Sensing in WiFi over TVWS can take advantage of existing IEEE 802.11 base standards, and IEEE 802.11k in particular. In 802.11k, various types of measurements are defined that enable wireless LAN stations to request measurement from other stations, for example, in order to measure how occupied a frequency channel is. The measurement results are reported back to the requesting station in
standardized frames. It provides means for measurement, reporting, estimation and identification of characteristics of spectrum usage. IEEE 802.11k improves spectrum opportunity identification in unlicensed bands in unpredictable environments and is able to characterize the interference on different frequency channels. Moreover, in COGEU, cognitive capabilities, for example using geo-location with database techniques to identify spectrum availability, will be considered for integration with off-the-shelf protocols and solutions.

5.2.2.4 Spectrum masks

To reach the market WiFi devices over TVWS need a certification process, based on clear methodologies to measure the effect of interference on the DVB-T sets and PMSE, for equipment compliance (guard bands, spectrum masks, protection ratio, etc). The current spectrum masks for WiFi operation in ISM bands cannot be simply down-converted to TV bands. Specific masks for co-existence with DVB-T and PMSEs in a common spectrum usage model have to be applied.

In the US, some guidelines have been defined for coexistence with the ATSC standard such as the TVWS spectral masks proposed by [94], as shown in Figure 35. At the European level the definition of power restrictions for WiFi operation over TVWS is still an open issue.

![Figure 35: Spectral mask for coexistence with ATSC [94]](image)

5.2.2.5 Technical feasibility

Despite the inherent good RF propagation qualities, WiFi over TVWS still faces technological challenges originating from co-existence constraints, which requires it to cause insignificant interference to incumbent devices.

WLAN has already much of the functionality that is associated with cognitive radio (e.g. sense before transmitting). Therefore, WiFi with cognitive features of TV white spaces is like a natural extension of WLANs.

Moreover, in IEEE there is a standardization initiative for “an amendment that defines standardized modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC), to enable operation in the TV White Spaces (the unused channels in the TV bands)” [92]. ECMA already has a standard for using cognitive devices over TV white spaces [91].

Leading technology companies like Microsoft [14] [95], Motorola [96], Phillips [97] etc, already have prototypes which showcase some aspects of the technical viability of WiFi over TV white spaces.

The presence of the above mentioned standardization activities going on and existing prototypes proves the rationality of believing the technical feasibility of developing long range WiFi over TV white spaces. Nevertheless all these activities have been developed under the FCC regulatory framework and considering coexistence issues with the US DTV standard (ATSC). Therefore, in Europe, there is still a need to investigate the issue of coexistence between WiFi over TVWS under the European DVB-T standard, while taking into consideration a more complex regulatory framework.
5.2.3 Market Potential

The enormous success of WiFi has allowed for economies of scale that will be hard to be surpassed by alternative technologies like WiMAX. Perspective [85] estimates the economic value that might be generated from existing Wi-Fi applications improved through using the white spaces to be in the range of $3.9 – 7.3 billion a year over the next 15 years for the US market. Ofcom believes that the net benefits to consumers could be worth £2-3 billion over twenty years for UK. Therefore, more success should be expected from delivering longer range WiFi-like internet connectivity services across Member States. Moreover, the ability to provide long range wireless access technology has further market potential in other areas like:

5.2.3.1 Business

- Provide coverage to a large office or business complex or campus;
- Establish point-to-point link between large skyscrapers or other office buildings;
- Bring Internet to remote construction sites or research labs;
- Provide cheap internet in road, sea and air transport systems.

5.2.3.2 Residential

- Bring Internet to a home if regular cable/DSL cannot be hooked up at the location;
- Bring Internet to a vacation home or cottage on a remote mountain or on a lake;
- Bring Internet to a yacht or large seafaring vessel;
- Share a neighbourhood Wi-Fi network.

5.2.3.3 Disaster areas

- Bring quick, agile and cheap internet connections in areas devastated by disaster and;
- Provide additional support in co-ordination of relief efforts.

5.2.3.4 Hospital applications

- Access to patient records;
- A rapid voice over Wi-Fi communication system.

Therefore, the market potential for WiFi in TVWS is very large, and can revolutionise the wireless industry through convergence with other technologies and services. Figure 36 shows the development trend for WiFi chipset sales.

Furthermore, in the US for example, there has been some initiatives by leading technology companies such as Google, Microsoft, and Motorola which are motivated by the fact that these frequencies are particularly well suited for providing rural areas with high-speed Internet service, as well as for short- or medium-range networking applications that might provide data transfer rates of gigabits per second, as opposed to the roughly 54 megabits per second of today's 802.11g-based Wi-Fi networks [98]. This has led to the emergence of the term WiFi 2.0. Wi-Fi 2.0 is a concept for implementing wireless broadband networks by utilizing bandwidth within the range of traditional broadcast television stations and some other consumer devices.

Figure 36: Sales of WiFi chipsets by device, 2004, 2008, 2012 [85]
The substantial number of initiatives for using cognitive technology in TVWS in the industry, academia and regulatory bodies, is further evidence for the viability of the market potential of long range WiFi over TVWS.

5.2.4 **Regulatory feasibility**

5.2.4.1 **The unlicensed spectrum sharing regime**

Basically, WiFi is a broadband wireless connectivity application which is deployed in unlicensed spectrum. The absence of the spectrum license requirement to provide wireless access service is the key factor which has promoted the success of WiFi. The spectrum commons or unlicensed regime represents a point of view where coexistence with incumbent systems (DVB-T, PMSE) is assured via control of interference levels rather than by fixed spectrum assignment and coordination. In a commons spectrum usage model there is no spectrum manager to preside over the spectrum resource allocation. The experience of the recent past in the wireless ISM bands has shown that innovation and openness to new entrants is facilitated when these have to fulfil the technical rules ensuring good coexistence but do not need to negotiate with existing players. However, despite the fact that unlicensed spectrum promotes efficiency through sharing, QoS cannot be guaranteed. This is a serious problem for some applications. Defining spectrum policies and etiquette rules to promote fairness and avoid the “tragedy of the commons” as well as guarantee QoS in the long range WiFi over TVWS use case will be given high priority.

5.2.4.2 **Regulators position on WiFi over TVWS**

Regulators in the European context, as seen in the RSPG report [25], do understand the benefits of introducing cognitive technology in spectrum usage. These include the improved efficiency in the overall spectrum use and facilitating access to “new spectrum”. Detection of unused spectrum (spectrum sensing), utilization of free spectrum slots (spectrum management within the scope of spectrum usage rights), dynamic selection of frequencies when the presence of other users is detected (spectrum mobility), coordination & sharing of spectral resources among users (spectrum sharing) may provide new opportunities for industry and operators. Specific for this use case, the RSPG asserts that: “a large amount of spectrum (83.5MHz plus more than 400MHz) is already available for WiFi applications in 2.4 GHz and 5GHz bands respectively. However the UHF TV broadcasting band offers different and better characteristics.” [25]

In its statement on license-excepting cognitive devices using interleaves spectrum the Ofcom asserts that: “the white space appears to be a substantial amount of spectrum which is unused and could be valuably employed by cognitive devices. It is effectively set aside from high power broadcast use to avoid interference with other nearby transmitters using the same frequencies. It is therefore only available for low power usage otherwise harmful interference will result” Furthermore, in Ofcom’s statement on awarding the digital dividend, it said: “we would allow license-exempt cognitive access to interleaved spectrum (then excluding channels 61 and 62) provided this would not result in harmful interference to licensed users.” [12]
5.3 WiMAX with cognitive access to TVWS

5.3.1 Motivation

As in the case of all other technology options discussed in this section, TVWS offers the potential to open up new spectrum bands at frequencies that are particularly suited to travelling long distances and penetrating buildings. These characteristics have lead to the suggestion that TVWS may be well-suited to providing rural broadband services. WiMAX as a wireless regional area network (WRAN) technology, that already targets rural broadband (among other areas) seems like a natural fit to these conditions. Hence the motivation for exploring this topic is quite obvious. Figure 37 is reproduced from a document from Tellamut Wireless Solutions, www.tellamut.com, and shows the benefit of using lower frequencies, especially in rural areas (as in the case shown).

![Figure 37: The Difference in Numbers of Base stations Needed for Coverage at 450 MHz and 3.5 GHz.](image)

However, it is not just the fact that WiMAX is suited to rural broadband that motivates the exploration of this topic. More broadly, WiMAX technologies of one flavour or another are widely associated with the term 4G (without committing to any one specific definition). As TVWS usage becomes more of a reality it is natural to ask whether WiMAX will have a significant role and in what way.

5.3.2 Scenario Characteristics and Technical Viability

We now turn to look at the technical feasibility of using WiMAX in the TVWS. There are number of key points that should be made.

- **Point 1: WiMAX Products for 450 MHz already exist**
  The 410 – 470 MHz band lies in the middle of the TVWS. WiMAX products targeted typically at rural areas already exist. It would not be fair to say that the products are not widespread but they do none-the-less prove the technical viability of the approach.
  A strong example is the Starmax-450-MHz product from Aviat Networks [99]. The reach of this product is 50 Km. Aviat Networks point out that compared to typical 3.5 GHz-based systems, a sub-1 GHz network may require five to 10 times less infrastructure—including towers, power generators and shelters. The end user uses a rooftop antenna for this product and hence we can consider this to be portable or nomadic use of the TVWS.
  There are also products for the 700 MHz bands. This is outside the TVWS but near enough to be a second useful indicator that the technology is viable. The WiMAX forum has in fact officially added a 700 MHz profile to the list of profiles supported.
  Note - There are no examples of existing products targeted to mobile WiMAX scenarios.

- **Point 2: WiMAX or 802.16 lends itself well to being extended for cognitive functionality**
  As is evident from the COGEU proposal, cognitive radio is seen as an essential technology for making use of TVWS, whatever the exact waveforms in use or application of interest. On reading the 802.16

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specification documents it becomes clear that the standard contains many features that lend themselves well to cognitive radio operation. Table 16 shows detailing technologies that illustrate this point.

**Table 16: Technologies in the WiMAX specs that mitigate interference potentially enabling successful use of unlicensed spectrum.**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthogonal Frequency Division Multiplexing (OFDM)/Multiple Access (OFDMA)</td>
<td>Breaks the signal into multiple subcarriers; up to 2048 smaller signals. If some signals are negated due to interference, other signals get through such that interference may not be discernible to end user</td>
</tr>
<tr>
<td>Dynamic Frequency Selection</td>
<td>If interference is occurring on one frequency the transmission dynamically shifts to a different frequency to avoid the interference</td>
</tr>
<tr>
<td>Dynamic Bandwidth Allocation</td>
<td>If interference is detected, more bandwidth is allocated to the transmission to strengthen the link budget and overcome the interference</td>
</tr>
<tr>
<td>Adaptive Antenna Systems (beam forming/steering)</td>
<td>Rather than broadcast over a wide geographic range, a narrow beam is formed between base station and subscriber unit, thus avoiding interference via a strong beam.</td>
</tr>
<tr>
<td>Multiple In/Multiple Out (MIMO) Antennas</td>
<td>Use multiple antennas at both base station and subscriber unit such that as interference is detected at one frequency, bulk of transmission can shift to another frequency; also boosts throughput via multiple antennas overcoming limitations of a single antenna to overcome interference</td>
</tr>
<tr>
<td>Software Defined Radios (SDR)</td>
<td>Also known as &quot;smart antennas&quot;, computer associated with the antennas dynamically reads the electromagnetic atmosphere and transmit on best available frequency</td>
</tr>
</tbody>
</table>

In much of the literature OFDM is a technology of choice for cognitive radio and the many “hooks” in the WiMAX specifications, such as those listed above, support the kind of flexibility that is characteristic of cognitive radio.

- **Point 3: The only standard which has been developed to date for TVWS is based on 802.16**

IEEE 802.22 is a standard that has been created specifically for cognitive radio use of TV white spaces. A very good overview of the standard has been written by Carlos Cordeiro, Kiran Challapalli, Dagnachew Birru and Sai Shankar N. The paper, IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios, appeared in the JOURNAL OF COMMUNICATIONS, VOL. 1, NO. 1, APRIL 2006. The network architecture, MAC and PHY are derived from 802.16 (WiMAX). The standard includes mechanisms for sensing of TV white spaces as well as for connecting to a database. It is designed to operate with one 6, 7 or 8 MHz channel in TDD mode. Multiple 802.22 systems can co-exist in the same region as long as they transmit a “co-existence” beacon to identify each other. There are working prototypes in existence from Philips and Motorola for example, which illustrate some of the key features of the standard.

**The standard has not made as much progress or impact as its originators hoped.** In fact because of impatience with progress the CogNeA alliance was created to find a faster means for making progress. While there are issues with IEEE 802.22, the key point here is the fact that it is derived from 802.16, again underpinning the technical feasibility of using WiMAX in the TV bands.

The conclusion that we can easily make is that WiMax is a viable technology for use in nomadic and portable applications in the TVWS.
5.3.3 Market Potential

To answer the question of what exactly the market potential may be for WiMAX in the TVWS bands is more difficult. On one hand it may be possible to address this by looking in general at the market potential for WiMAX. WiMAX has never been quite as successful as hoped. However it has contributed to making OFDM the dominant wireless technology. The move to LTE will mean that the vast majority of wireless and mobile communication systems will be OFDM based. Indeed, the emergence of LTE is a big threat to the growth of the WiMAX market. As discussed in Section 5.1, LTE is already being embraced by 26 cellular operators. As the overlap in the typical service available over WiMAX or LTE is quite large, this move to LTE by the operators captures a lot of the data-intensive market that WiMAX operators would otherwise be competing for. Thus, the growing support for LTE by incumbent network operators who have generally ignored the potential of WiMAX, lowers the market potential of WiMAX in the coming decade.

In spite of this negative outlook, there are some indications that the WiMAX market is picking up, albeit for services in the higher frequency ranges, i.e above 2GHz. The following extract is taken from a document written in November 2009 by Dr. Philip Marshall, Senior Research Fellow of Yankee Group Research:

“Our forecast predicts that WiMAX’s strongest adoption will occur in emerging markets in EMEA, particularly in Central and Eastern Europe and in Africa. Investments in Africa are accelerating, particularly with the implementation of several undersea cables and the freeing up of capital markets. We see slow progress for WiMAX in Western Europe, however, because most of the service providers are subscale with networks operating in the 3.5-3.8 GHz bands. We believe that this will remain the case until significant 2.6 GHz frequency bands are auctioned and future acquirers of TDD licenses in Western Europe are required to embrace WiMAX. Taking these factors into consideration, Yankee Group projects WiMAX subscriptions in EMEA to increase from 2.1 million to 33.9 million between 2009 and 2015, at a CAGR of 59 percent (see Exhibit 4)".

We can also look to individual companies for progress. Clearwire in the USA presents an interesting example. Clearwire is increasing the availability of wireless capacity and services in the US in a very different way, using its huge store of licensed 2.5GHz spectrum and its WiMAX network. It says it will hit its target of going live in 25 markets by year end (most are new and in major metros, some are upgrades from its proprietary wireless deployments in suburban or rural areas). Other companies such as Open Range Open also use WiMAX technology to deliver wireless broadband to un-served and underserved rural American communities. Open Range plans to deliver portable and eventually mobile voice and Internet services to customers. Within the next five years, Open Range intends to serve 546 communities, making its services initially available to approximately six million people. Open Range’s wireless broadband network solution will connect customers through licensed spectrum. From analyses such as this, there is a future market for WiMAX. However these analyses do not specifically consider WiMAX operating in the TVWS. Moreover, there is an increased interest in Mobile WiMAX which may or may not be suited to the TVWS. However the Yankee Group does maintain that the lion's share of the growth in WiMAX will be in the portable/nomadic sector.

One issue which is somewhat problematic and could potentially shed light on the market potential is the difference between the deployment of licensed and unlicensed WiMAX solutions. The latter tend to be significantly less popular. Whether there is something to be learned from this for unlicensed use of the TV white spaces is not yet clear. It may be the case that the COGEU focus on exclusive usage mechanisms for the TV white spaces may open up the market for WiMAX in the TV bands.

Overall, it would seem that WiMAX has a lower market potential than LTE and LTE Advanced has. The lack of appetite for WiMAX has been quite evident. Market projections that indicate that WiMAX will take off in the next 5 years are made without any significant changes in the economic or regulatory environment that has existed for the last 5 years when WiMAX growth has been very sluggish. Contrarily, as a technology promoted by network operators, rather than simply network device manufacturers, LTE would seem to have the advantage in gaining market share for wide area data intensive wireless networking.

5.3.4 Regulatory Feasibility

It could be argued that coping with WiMAX extensions in the TV white space is highly feasible from a regulatory perspective. In fact WiMAX could very quickly be deployed, on an unlicensed basis, in TVWS bands provided that power levels and the out-of-band emissions were set in accordance with
regulations. And of course the systems in use would have to be capable of accessing the spectrum availability database.

Spectrum Bridge (see Section 4.5.1) claims to have an operating TVWS network in Wilmington in North Carolina. Though technical details are not provided and it is difficult to establish the extent of the network and its performance metrics, it is likely that this has some kind of WiMAX flavour. And as mentioned already there are WiMAX products in the 450 MHz band. Hence to a certain extend we already have proof of some activity.

It is clear that using WiMAX solutions in the TVWS on an unlicensed basis could be achieved with little effort. Since WiMAX is already licensed for use in the 450 MHz and 700 MHz range, there are no foreseen hurdles to its regulatory feasibility in the frequency ranges being considered by COGEU.
5.4 DVB-H with cognitive access to TVWS

5.4.1 Motivation

Broadcast mobile TV is a service that allows users to receive and watch multiple TV channels using mobile devices (such as a mobile phone or a PDA/handheld device). Similar to DTT (Digital Terrestrial TV), this is a linear, multicast service (i.e. delivery to multiple mobile devices), which is a much more efficient way of sending TV signals than unicast mobile TV, which is streamed (sent to one device) over a mobile operator’s UMTS or HSPA network. This service requires dedicated mobile broadcast networks, which are currently available in only a few Member States, including Austria, Finland, Italy and the Netherlands. Broadcast mobile TV could potentially be provided using a number of technologies including DVB-T, Digital Video Broadcasting for Handhelds (DVB-H), Digital Multimedia Broadcast (DMB) and MediaFLO. However, the majority of existing and planned broadcast mobile TV networks in Europe use DVB-H [100].

In order to support simultaneous use of broadcast mobile TV and GSM/3G, mobile TV providers typically prefer frequencies in the low to middle part of the 470–862MHz band (below 750MHz). Unlike DTT, it would be feasible to provide mobile TV using alternative frequencies, such as 174–230MHz and 1452–1492MHz. However, 470–862MHz is regarded as the most suitable frequency range for mobile TV, as it provides a balance between range of coverage and antenna size. The potential alternative uses of TVWS spectrum, includes mobile TV, high definition digital terrestrial television (HDTV), and more digital broadcasting services, including regional and local developments. In particular, an interactive Mobile TV system is an example of convergence between mobile and broadcasting services, that currently gives rise to a great interest. Simultaneously, mobile and broadcasting operators are looking for a new intermediate common market which is not fully identified but which could combine features of their present offers.

Until now, the introduction and take-up of mobile TV in the EU has been slow while Europe's competitors have progressed significantly. Unless Europe takes concrete action immediately, it risks losing its competitive edge. To help achieve mass-market deployment in Europe, from March 2008, DVB-H (Digital Video Broadcasting for Handhelds) is officially endorsed by the EU as the “preferred technology for terrestrial mobile broadcasting” [101]. In addition, the unavailability of spectrum is the largest barrier to the launch of more mobile TV services and the Commission calls upon Member States to make spectrum available for mobile broadcasting as quickly as possible, including in the UHF band (470-862 MHz) as it becomes available. In this context, this section below investigates a use-case scenario, where cognitive radio mechanisms could be integrated within an interactive Mobile TV network, in order to exploit TVWS under spectrum sharing business models. This use-case scenario will enable for the provision of additional multimedia mobile services in Europe utilizing the TVWS spectrum resources released after digital switchover with cognitive aware features.

The proposed mobile TV networking architecture is based on a DVB-H system, which is able to operate as a secondary cognitive radio network, sense the TV spectrum in order to avoid possible interference caused to other systems and negotiate via a spectrum broker with primary networks that operate under a licensed spectrum basis in UHF band. In this framework, the next section presents the characteristics of the proposed use-case scenario regarding mobile TV cognitive radio system, its technical viability, possible market potential and regulator feasibility.

5.4.2 Scenario characteristics and Technical viability

This section elaborates on the technical characteristics of the proposed use case scenario regarding mobile TV services provision utilizing TVWS. The proposed configuration is based on DVB-H standard (Digital Video Broadcasting – Handheld). DVB-H standard defines physical and link layer specifications, for the delivery of mobile multimedia services into handheld devices by terrestrial networks. The system includes features, which will reduce battery consumption. DVB-H services can use more efficient video compression systems such as MPEG-4 AVC (Advanced Video Coding), able to be provided by transmitters on UHF band. The next section below first reviews on DVB-H standard features which can be utilized by COGEU for the provision of mobile TV services in TVWS.

5.4.2.1 DVB-Handheld characteristics

The goal, when developing DVB-H [102], was to select a technology that could promise 100 mW or less of power consumption of the complete front-end, including the RF parts, while providing 15 Mbit/s bit
rates, operating in a large Single Frequency Network (SFN) at high driving speeds and with only one antenna. To fulfill all these requirements the chosen technology extends the DVB-T standard as is depicted in Figure 38 with the following additions:

- **Time Slicing**, in order to reduce the average power consumption of the terminal and to make possible smooth handovers. The time-slicing technique, enables considerable battery power-saving. Additionally, time-slicing allows soft handover if the receiver moves from network cell to network cell;
- **MPE-FEC (Multi Protocol Encapsulation – Forward Error Correction)**, for improving C/N-Doppler performance in mobile channels and tolerance to impulse interferences. For reliable transmission under poor signal reception conditions, DVB-H introduces an enhanced error protection scheme on the link layer. This scheme is called MPE-FEC. MPE-FEC performs additional coding on top of the channel coding included in the DVB-T specification in order to increase reception robustness for indoor and mobile contexts;
- **Extended Transmission Parameter Signaling (TPS)**, for allowing transmission of enough information about the services carried by the multiplex, thus enhancing and speeding up service discovery;
- **4 k-modes DVB-H** defines this additional mode to the DVB-T standard for improving single antenna reception. The resulting three modes available (2K, 4K and 8K) provide more flexibility to network designers;
- **In-depth symbol interleaver**, for further improvement of the transmitted signal robustness in mobile environment and impulse noise conditions;
- **5 MHz channel bandwidth operation**. DVB-H standard provides the transmission parameters to operate outside of the traditional broadcasting bands in 5 MHz channel bandwidth.

Finally, the new standard recommends to use H.264 (MPEG-4 Part 10: Advanced Video Codec) and CIF resolution for video streaming [103]; while DVB-T uses MPEG-2 and PAL resolution. Video streams coded with H.264 only require a maximum bit rate of 384 kbit/s. Thus, multiple television programs can be allocated into the same multiplex.

### 5.4.2.2 Mobile TV use-case scenario configuration

The proposed use-case scenario is based on a DVB-H system, able to operate in TVWS, enhanced with cognitive radio features. This DVB-H system could be utilized as an unlicensed secondary network together with licensed primary systems, operating in UHF band.

The overall concept for the proposed use-case scenario is depicted in Figure 39 below, indicating a secondary user (DVB-H provider) exploiting the available TVWS via a Spectrum Broker. In this figure, the light blue and yellow footprints represent DVB-T broadcasting coverage areas, i.e. primary systems that operate as licensed spectrum holders in areas A and B respectively. The white footprint represents the coverage area that the secondary broadcasting system “wishes” to establish, by exploiting any...
available TVWS, for delivering linear and/or interactive mobile TV services. This secondary system is utilizing a DVB-H platform able to negotiate via a spectrum broker with a primary system, operating as a cognitive radio broadcasting network. The proposed configuration of the DVB-H network in Figure 39 below is able to operate as a cognitive radio network, negotiating via a spectrum broker with a primary licensed spectrum holder. In this configuration the mobile TV terminals are able to communicate with DVB-H platform via the appropriate return channels, requesting interactive multimedia content.

In the proposed configuration, the primary system runs an admission control algorithm, which only allows secondary systems (i.e. DVB-H system), to access spectrum when QoS of both primary and secondary ones are adequate. The license spectrum holder also uses an intelligent frequency assignment algorithm for determining the frequency at which the secondary system should be allowed to operate and the economics of such transactions, which provides incentives to maximize spectrum utilization. Secondary system dynamically request access to spectrum when and only when spectrum is needed.

The secondary spectrum trading in this case can occur through intermediaries such as the spectrum broker. In general, the mechanisms of searching for a match between the primary and the secondary systems largely rely on types of services, access characteristics, and service levels requested by secondary systems. The access types could consist of a long-term lease, a scheduled lease, and a short-term lease or spot markets. Each type requires different discovery mechanisms and applies with different levels of service agreements.

In this proposed network configuration, the primary system is able to trade with the secondary system (i.e. DVB-H system) so that the secondary system operating in the TVWS can provide interactive mobile TV services to a number of mobile users.

According to the proposed approach of Figure 39 the following cases could be considered for further study and research:

- Spectrum broker in Figure 39 is able to communicate with a Geolocation Spectrum Database, in order to trade TVWS spectrum between the primary system and the secondary unlicensed system. After the spectrum broker assigns spectrum resources, the secondary system is able to utilize this spectrum for the provision of TV services to mobile users;
• The return channel may be able to operate in the TVWS spectrum opportunistically utilizing sensing mechanisms integrated both the access network and the mobile terminals. In this case, the operation of the return channel is based on spectrum of commons regime;
• The return channel may be able to operate in the TVWS spectrum utilizing an additional spectrum broker set between the return channel network and the DVB-H platform. This spectrum broker should be able to assign the available spectrum resources of the return channel according to spectrum of markets regime.

5.4.2.3 Terminal categories
This scenario considers three different terminal categories:
• Integrated Car Terminals: This category covers DVB-H terminals installed in a car, where the antenna is integral within the car;
• Portable Digital TV Sets: This category includes terminals, which are intended for receiving digital TV services indoors and outdoors with terminal attached antennas. It is divided into two sub-categories;
  • The receiver screen size is typically greater than 25 cm and the receiver may be battery or mains powered. Typically the terminal is stationary during the reception. An example of the antenna construction may be an adjustable telescope or wide-band design, either active or passive, attached to the receiver;
  • Pocketable digital TV-receiver. The terminal is battery operated and can be moved during use. Usually the antenna is integral with the terminal;
• Handheld Portable Convergence Terminals: This category covers small battery powered handheld convergence terminals with built-in cellular radio like GSM, GPRS or UMTS. The terminals have the functionality of a mobile phone and can receive IP-based services using DVB-H. The DVB-H antenna and the cellular antenna are both integral with the terminal. Moreover, user terminals may include spectrum sensing capabilities, or geo-location database access, or a combination of both depending on the intended way to obtain spectrum resource for data transmission;
• All these kinds of devices have a number of features in common: small dimensions, light weight, and battery operation. These properties are a precondition for mobile usage but also imply several severe restrictions on the transmission system. The terminal devices lack an external power supply in most cases and have to be operated with a limited power budget. Low power consumption is necessary to obtain reasonable usage and standby cycles.

5.4.2.4 Environment - Coverage area
DVB-H over TVWS is able to provide mobile TV services in a transmission area that covers tens of kilometers. However, when nationwide coverage is required, over distances of hundreds of kilometers, several radio frequency channels will be needed. The availability of channels differs very much from one country to another. In theory, three channels should be sufficient to provide continuous coverage with any area. However, practical network planning shows that 5-6 channels are actually needed. By using different channels in neighboring areas gives the possibility also to run local content in each area. This may be important with DVB-H where local content is expected to have an important role. Commercial DVB-H pilots have shown that viewers are watching their mobile television services indoors, making it essential that services allow for portable indoor coverage. However, allowing for portable indoor coverage can be quite expensive.

Mobility is an additional requirement, meaning that access to services shall be possible not only at almost all indoor and outdoor locations but also while moving in a vehicle at high speed. Also, the handover between adjacent DVB-H radio cells shall happen seamlessly when moving over larger distances. However, fast varying channels are very error-prone. The situation is worsened by the fact that antennas built into handheld devices have limited dimensions and cannot be pointed at the transmitter if the terminal is in motion. A multi-antenna diversity approach is mostly impossible because of space limitations. Moreover, interference can be resulted from GSM mobile radio signals transmitted and received within the same device. As a result, accessing a downstream of several Mbit/s with handheld terminals is a very demanding task. Finally, DVB-H is viable for urban, suburban and rural areas.
5.4.2.5 Operating frequencies
DVB-H in TVWS shall offer broadcast services for portable and mobile usage, including audio and video streaming with acceptable quality. The data-rates feasible in practice have to be sufficient for this purpose. For the DVB-H system, a useful data-rate of up to 10 Mbit/s per channel is envisaged. Transmission channels will be allocated in the regular UHF broadcasting band. GOG EU targets on operating frequencies that are in the geographic interleaved spectrum in UHF band, which will be used by digital TV after the analogue turn-off. As a technical requirement, in a given geographical area, a number of TV channels are not to be used by DTV stations so as to avoid causing interference to co-channel or adjacent channel stations. These unused bands are called TV white spaces.

5.4.2.6 Technical Advantages/ Technical Feasibility
The proposed scenario could be partially implemented utilizing state of the art technologies. DVB-H broadcasting systems operate in the frequency band of 470–862MHz and can be used in a similar way like DVB-T broadcasting systems. Beyond state of the art, the proposed scenario needs to adopt cognitive aware features such as:

- A geolocation spectrum database: the database collects information for the coverage area in order to update/inform the spectrum broker for the field strength contributions of all transmitters in the area and the adjacent neighbors for all channels (470-790 MHz). All field strength values are summed up and define the interference level at the selected location. A Protection Ratio is added to this interference level to find the minimum required field strength for a TVWS service;
- A spectrum broker: the spectrum broker gets updates from the geolocated spectrum database in order to control the amount of bandwidth and to allocate the unused frequencies to secondary systems. Finally spectrum broker keeps the desired QoS and interference below the interference limits;
- Negotiation protocol: a negotiation protocol is required for information exchange among the players and negotiation mechanisms by which systems can request and acquire communication rights to a part of the TVWS;
- Sensing mechanism: the sensing mechanism detects weak primary user’s channels (DVB-T, wireless microphones, etc) in order to avoid the interference from a neighboring device. Moreover the user’s terminals need this additional feature in order to inform the DVB-H platform for the channel conditionals.

5.4.3 Market Potential
The concept of providing television services on a mobile device has generated much enthusiasm among the wireless industry, thereby driving the growth of digital video broadcasting-handheld (DVB-H) technology. Many participants in the wireless industry support DVB-H technology as it is an open industry standard and this non-proprietary feature of the standards is expected to vastly assist its growth in the wireless market. Moreover, DVB-H delivers an improved end-user experience over current video streaming services that utilize cellular networks, while also providing, broadcasters, cellular operators, handset manufacturers, and silicon providers with tremendous growth opportunities. In short, DVB-H could well become a global standard similar to Global System for Mobile communication (GSM).

However, one of the biggest challenges to adoption of DVB-H by mobile operators is the issue of business and revenue models. With DVB-H, mobile operators are expected to prefer to continue operating in their area of domain expertise such as service provisioning, billing, and customer care and therefore, broadcasters would have ownership of the content and the overall visual experience. Hence, mobile operators would need to differentiate their offerings and provide value to ensure customer loyalty and remain profitable. Moreover, DVB-H operates in the Ultra High Frequency (UHF) spectrum and the availability of this spectrum has been an issue in certain parts of Europe and other regions, especially where there is still a high penetration of analog television (TV). This unavailability of spectrum in certain regions has to an extent delayed the penetration of the DVB-H standard.

Among the geographic markets, Europe is expected to by far generate the maximum revenues followed by Asia and North America. This is mainly due to the reason that DVB-H is more of a Europe-centric technology at present with deployments having already begun in a few European countries. Also DVB-H services over mobile phones are expected to trigger new television viewing behavior patterns among consumer and create a new market for television viewership. However, spectrum allocation by national agencies could remain a critical barrier to the adoption of DVB-H mobile TV services. In this context,
TVWS could be utilized as the spectrum where DVB-H systems may operate. The opportunistic and secondary usage of such systems as it is proposed in this use-case scenario will enable for further technology exploitation, mobile TV services penetration and revenue increase.

The DVB-H standard has by far the most widespread acceptance across the various sectors involved in bringing Mobile TV to market, including operators, broadcasters, broadcast network operators and content providers. This can be seen by the large number of consumer DVB-H trials that have, or are currently, taking place across the globe. In Europe, trials have so far taken place in Germany, Finland, the UK, Spain, Switzerland, France and the Netherlands. The results from completed trials are very encouraging. In the Finnish trial, over half (58%) thought that Mobile TV services would be popular and exactly half of those involved thought that €10 per month was a reasonable price to pay for such services. Local programs available through Finnish national television proved to be the most popular content alongside sporting events such as the Monaco Grand Prix.

5.4.4 Regulatory feasibility

The proposed scenario above is based on a DVB-H network that operates in UHF band as a secondary system able to access TVWS. In March 2008, the European Commission adopted a strategy favoring the take up of mobile TV services across all Member States. This strategy is based on DVB-H as a common EU standard for the provision of mobile TV services. DVB-H networks have already been deployed in the 470–862MHz band in a number of Member States, including Austria, Finland, Italy and the Netherlands. In this context, the proposed use-case scenario is based on a standard that is already adopted by EU and the proposed system will enable for the provision of additional mobile TV services if utilized as a secondary network accessing TVWS. This use-case scenario could be based either on the spectrum of commons regime or on the spectrum of markets regime in case a spectrum broker is utilized. In spectrum of commons model the absence of a spectrum manager to preside over the resource allocation and the need for sensing techniques for reliable detection of TVWS as well as coexistence mechanisms for interference avoidance, are the main technical challenges. Also in case that a spectrum broker is used in this use-case scenario, obtaining spectrum through the markets regime may be the best solution. Trading will enable primary and secondary systems to directly trade spectrum usage rights, thereby establishing a secondary market for spectrum leasing and spectrum auction. This model has the potential to enable small companies to enter the spectrum market, have access to TVWS and be charged based on spectrum utilization, thus boosting competition and innovation in the telecommunications sector. Also no major regulation change is necessary since DVB-H systems are already allowed to operate in the UHF band.
5.5 Public Safety with cognitive access to TVWS

Public safety has a very limited frequency allocation: the only harmonized public safety band in Europe (380-385 MHz/390-395 MHz) is heavily congested. The application of cognitive technologies to address TVWS could definitely help mitigate the problem.

Cognitive radio and TVWS can facilitate multi-organizational interventions which would not be based on the need for dedicated and harmonized spectrum assignment to Public Safety.

5.5.1 Motivation

Earthquake, tsunami, flooding, forest fires, hurricanes: natural disasters are, unfortunately, a part of life. And it is necessary to add disasters due to human activities, such as terrorist attacks or industrial accidents, the examples are numerous. The efficiency of public protection agencies depend of their means. The radio-communication system is a critical component of the operated means. Having noticed that each entity (Police, Firemen,) have their own radio-communication system, the problem of interoperability of the all entities of Public Protection and Disaster Relief (PPDR) was found. This problem was investigated by the ITU-R and at the World radio-communication conference in 2003 (WRC03) in its resolution 646, an important agreement was reached about the harmonisation of frequency band of PPDR. The WRC03 could not identify a common global band but bands for the three ITU regions:

- Region 1 (Europe and Africa): 380-470 MHz with 380-385/390-395 MHz is a preferred core harmonized band;
- Region 2 (The Americas): 746-806 MHZ ; 806-869 MHZ ; 4940-4990 MHZ;
- Region 3 (Asia and Australasia): 406.1-430 MHZ ; 440-470 MHZ ; 806-824/851-869 MHZ ; 4940-4990 MHZ ; 5850-5925 MHZ.

Wireless broadband for public protection and disaster relief (PPDR) users includes services of police, ambulance, fire, and security services, such as custom & border control and the Lifeboat services. Those existing Public safety systems are largely based on one of the two standards – TETRA and TETRAPOL – users frequencies harmonized for public safety use in the 380-400 Mhz band. However those networks only provide voice and narrowband data services. There is an increasing need for PPDR users to access broadband data applications while on the move.

In [104], the core concepts in public safety communications are elucidating. These concepts are the following: i) operability: communications are able to support the emergency responder, ii) interoperability: operability of disparate systems with each other, iii) reliability: operability is robust, iv) resiliency: a system that supports dynamicity and fast recovery, v) redundancy: information duplication, vi) scalability: large network deployment, vii) security: to avoid attacks or jamming, viii) efficiency: optimize the resource use, ix) interdependence: to enable co-existence of various information systems.

Supporting and ensuring those core concepts are challenging and above all crucial to enhance of public safety operations when lives are involved. Cognitive Radio networks and Software Defined Radio can unquestionably overcome main public safety precepts by providing assured, secure and seamless communications accessible anytime and anywhere.

5.5.2 Scenario characteristics and Technical viability

5.5.2.1 Deploying ad hoc networks and organizing the control of the zone and the management of a crisis

This corresponds to the first deployment of communications network to secure the crisis zone (as most as possible) to facilitate and secure the operations of safety teams, to establish a first “local control command center”, and even to replace at very short term the possible destroyed networks. This may require the emergency deployment of communication infrastructures, even airborne based, for establishing a previous ad-hoc communication network. Regarding spectrum management, several options should be taken into account:

- Complete destruction of the regular local communications infrastructures: in this case, only a ad-hoc deployed networks is effective at the precise location of the crisis zone, if this ad-hoc network reuses existing frequency plans, only “side damage” have to be limited, for example by a dynamic reallocation of the spectrum for the communications services out of the border of the crisis zone;
• Prohibition from using of the remaining local communication network: in this case, authorities want to keep the full control of the use of the remaining communications networks. A "natural" option is the local jamming of the remaining infrastructures and the jamming of dedicated communication services (mobile satcom for example). As before, the key point is the limitation of "side damages" by a dynamic reallocation of the spectrum for the communications services out of the border of the crisis zone;

• Building the ad-hoc network by the reuse and the replacement of the remaining local communication networks (for example: providing mobile radio-cellular transmitters with a satellite relay towards a external switch): in this case, authorities have to perform an efficient and very short term network engineering. A "natural" option is the use of "empty frequency ranges" after a short spectrum analysis of the local zone. Here again, there is a risk of "side damages" (interferences) with the existing networks in the neighborhood that can be solved thanks to a dynamic reallocation of the spectrum for the communications services out of the border of the crisis zone.

In all these very short-term actions, the role of the dynamic spectrum management would be to assure and secure an emergency communication service, even at low data rate, with a strong priority to link reliability. This may imply intensive use of external communication effectors and sensors, with high transmitting powers, even eventual jamming actions, and serious damage risk for regular communication systems. In these sense, the dynamic spectrum management has to be applied not only to warranty the efficiency of the emergency actions, but to limit their “border effects”.

5.5.2.2 Middle term actions regarding telecommunications (first days of a crisis)

These actions should occur during the first days after the start of the crisis. Their purpose look quite similar as short term actions, but they are more dedicated:

• To security purposes (police surveillance of the crisis zone for example, limitation of criminality, etc.);
• To investigation;
• To public information (call centers, radio and video broadcast).

For urban metropolitan zones, the intensive “middle term use” of external intrusive effectors should probably be avoided. A “softer” long-term management of radio-communications at the crisis zone appears as more suitable:

• Reparations of some parts of existing networks, local replace or densification of existing infrastructures
• Deployment of ad-hoc communication and broadcast infrastructures after a "professional" engineering phase (i.e. performed by the operators).

In this case, the main role of the dynamic spectrum management should be the organization of the cohabitation between:

• The existing communication networks in the neighbourhood of the crisis zone,
• The remaining available infrastructures within the crisis zone,
• The dedicated ad-hoc networks deployed for control, investigation and general command operations.

5.5.2.3 Possible track for this scenario

Here are possible tracks to implement parts of this scenarios:

• Possibilities of band sharing of PPDR used systems with radioastronomy, 406 – 408 MHz, in delimited geographical areas. As radioastronomy is a particular service which requires specific protection, but is usually located far from big cities, it could be possible to share an additional capacity with PPDR networks, when a crisis occurs in an urban region. This can be extended to:
  o Any area based on specific protection criteria for radioastronomy, if the considered area is “close enough” to radioastronomy equipment. The criterion could be adapted depending on the seriousness of the crisis, and the distance from Radioastronomy equipment;
  o Other frequency bands, still to be identified, the use of which is reduced or negligible in dense area.
• Introduction of video surveillance equipment, connected to an existing WIMAX or WIFI network, in nomadic or ad-hoc modes, with pre-emption of the resources which are
allocated to non professional users. Here, the issues are related to the capacity to deploy quickly such equipment, using a network a priori unknown by PPDR. Local authorities could play a significant role at this point, managing the information of existing networks to handle it to PPDR representatives, and reserving an acceptable QoS level for users (non PPDR).

SDR Forum report on “Use cases of Cognitive Radios for Public Safety agencies” outlines significant capabilities that can enhance the ability of public safety agencies to communicate, particularly under the challenging conditions of a major event or incident. Potential use of cognitive capabilities have been identified to:

- Extend existing network coverage when individual radios move outside the coverage footprint of the communications system;
- Dynamically allocate spectrum to provide greater capacity for overloaded networks;
- Dynamically prioritize communications to better manage load; and dynamically reconfigure networks.

5.5.3 Market Potential

Spectrum above 350 MHz and below 1 GHz is the most attractive for any wireless broadband network, and Public Safety network is no exception. The excellent propagation characteristics of these low frequencies means that fewer base stations are required, enabling a more cost-effective network rollout, while also enabling wide-area, good in-building coverage and non line-of-sight operation that Public Safety networks users require. As an example, good in-building coverage is one essential requirement for fire-fighting. Wireless broadband networks for Public Safety Networks users are mainly operated with medium-power, two-way transmission. Typical power levels for a wide area radio system are similar to those of a cellular network.

There is ongoing debate concerning the future technologies for Public safety users, in particular whether they should use overlays to existing systems, such as TETRA enhanced data Services, or commercially available wireless broadband technologies (e.g. WiMAX or LTE). The latter could offer economies of scale, and superior handset availability but may not be sufficiently reliable as they are optimized for different objectives than Public safety networks. A further debate is whether, and to what extent it is valuable to, identify a common band for Public Safety networks across the EU, which may facilitate the development of systems that are interoperable across Member States. The cognitive access to TVWS can be a viable alternative of a common band for Public Safety. The COGEU spectrum broker can easily integrate a prioritizing mechanism that assigns extra spectrum (TVWS) for a specific disaster area based on spectrum availability information provided by the geolocation database.

5.5.4 Regulatory feasibility

Recent work has just been started with CEPT to consider future spectrum requirements for Public Safety Networks. A number of potential alternative frequency bands are under consideration, including not only the digital dividend but also spectrum for the 300-400 MHz range, 872-876MHz paired with 917-921MHz, the 5GHz band and (S-Band) and the 5GHz band.
5.6 PMSE with cognitive access to TVWS

5.6.1 Motivation

PMSE applications have already been using the white spaces on a secondary basis for some decades. Depending on the country and on the applications, there exist different usage schemes across the 470 – 790 MHz band. This is due to the fact the frequency band management evolved differently in different countries. (see Section 2.3 for more details).

As a result of the digital switch over and of the digital dividend, the potential spectrum resources for PMSE were reduced. At the same time, it was recognized within the CEPT [22] that there is an increasing demand for spectrum for PMSE. This is especially true when a major event occurs where then is a general lack of spectrum.

In these cases, the spectrum has to be very carefully planned and channels may also be used which do not fully avoid interference. The major event can either be planned (concert, theater, convention, elections) but it can also be unplanned (accident, breaking news…). In this latter case, the timing for coordinating “on the fly” while guaranteeing an interference free frequency usage is a difficult challenge.

As it is almost impossible to find exclusive spectrum which can be harmonized for these types of applications, the usage of spectrum must occur in coexistence with other services and applications. But these applications are low powered and are used generally on a very local basis and for short distances.

As described above, the PMSE services already use white spaces, but the “cognitive part” was realized by human resources which generally involved the broadcasters, that means the “victim” services themselves are the users of the white spaces. For that reason, it was unlikely that interference would occur, and enough protection margins were included to ensure this. With additional information on the real usage situation (by real-time measurements for example) it becomes possible to reduce the margin for statistical propagation paths and the potential available spectrum would be increased and the spectrum shortage would be, at least partially, compensated. The use of cognitive technologies would therefore improve the spectrum efficiency for the current applications in the band 470 – 790 MHz.

The usage of PWMS in the band 790 – 862 MHz includes non professional usage, which may be operated without any coordination. If the interference avoidance is sufficiently reliable, one can envisage that these applications in the band 790 – 862 MHz can operate on the base of cognitive configuration. In this case, it is expected that it leads to optimal frequency usage schemes and therefore to a better spectral efficiency.

In any case, the administrative procedures and coordination would be substantially diminished if an automated process could attribute the frequency slots.

The use case for ENG (Electronic News Gathering) of white spaces cognitive technology would therefore not be a new application or a new service but the improvement in terms of reliability, spectrum efficiency, and productivity of existing applications.

It can be expected that the PMSE devices will continue to use analogue transmissions because of the lack of digital equipment. Therefore it can be reasonably envisaged that the “White space cognitive” module will be rather an add-on and not necessarily be a fully integrated product at short to middle term. At long term, when progress will have been achieved regarding real time digital transmissions, fully integrated products can be envisaged. Therefore, it is judicious to consider the characteristics of current analogue equipment for calculations.

5.6.2 Scenario characteristics and Technical viability

5.6.2.1 QOS requirements

Basically, PMSE services can be classified in two categories regarding their QOS requirements:
5.6.2.1 High QOS

These equipments need a high reliable radio link since interference would have consequences in the quality of the production. These include professional wireless microphones and remote controls (e.g. for fireworks). In the planning of PMSE it is common to use frequencies which are free of interference for more than 99 % of the time. For frequency modulation equipment such as PWMS, there is also a need to take into account the intermodulation products which additionally limit the number of usable channels. Regarding the maximum tolerated delay, it should be in the order of 1 ms. The required bandwidth for one device is in the order of several 100 KHz.

5.6.2.2 Middle QOS

These devices can suffer a certain probability of interference. In general, these devices are used for speech which is not intended for (broadcast) transmission. Therefore, it is legitimate to assume that they can tolerate the same order of interference than mobile speech services. The required bandwidth for one device is in the order of 20 – 50 KHz. Regarding the maximum tolerated delay, it should be in the order of 1 ms.

It should be noted that the required maximum tolerated delay is not relevant if existing analogue devices are considered.

5.6.2.2 Technical characteristics

Table 17 techniques characteristics of PMSE in various applications:

<table>
<thead>
<tr>
<th>Application</th>
<th>Max. ERP (Watt)</th>
<th>Max. RF-Bandwidth (kHz)</th>
<th>Transmission height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary point to point audio link</td>
<td>250</td>
<td>300</td>
<td>2 – 4m</td>
</tr>
<tr>
<td>Talkback</td>
<td>30</td>
<td>20 - 50</td>
<td>1.5 – 10 m</td>
</tr>
<tr>
<td>Professional Wireless Microphones</td>
<td>50 x 10^-3</td>
<td>200</td>
<td>1.5 – 10 m</td>
</tr>
</tbody>
</table>

The portable devices are expected to have a slow mobility (dancing, walking) while the bulky equipment (e.g. transmission vehicles with receiving equipment) is expected to be fixed when in operation.

5.6.2.3 Typical scenarios

In this section, some typical scenarios for PMSE are presented:

5.6.2.3.1 Large Event

One of the most challenging use case is a large event, where many production teams are operating. They do not necessarily arrive at one time, so that interference is dealt with progressively. It is now common that the used resources are planned ahead of the event and that there are not sufficient resources available to guarantee a 100 % interference free operation. Since these events are generally concentrated in one location which is generally not immediately near (close) to DVB-T households, there is little likelihood to interfere with DVB-T reception. The key characteristics for the scenario “large event” are the high number of devices to accommodate while guaranteeing interference free transmission.

Table 18 summarizes the resources for a selection of events in Germany:

<table>
<thead>
<tr>
<th>Event</th>
<th>Number of required frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elections (Landtagswahl) Hessen</td>
<td>298</td>
</tr>
<tr>
<td>Elections (Bürgerschaftswahlen) Hamburg</td>
<td>348</td>
</tr>
<tr>
<td>Parliament Elections (Bundestagswahl) 05</td>
<td>850</td>
</tr>
<tr>
<td>Visit of the Pope in Cologne</td>
<td>1,200</td>
</tr>
<tr>
<td>European Football Championship 2008 (Basel)</td>
<td>481</td>
</tr>
<tr>
<td>European Football Championship 2008 (Zürich)</td>
<td>343</td>
</tr>
<tr>
<td>European Football Championship 2008 (Bern)</td>
<td>328</td>
</tr>
<tr>
<td>European Football Championship 2008 (Geneva)</td>
<td>274</td>
</tr>
</tbody>
</table>
Figure 40 shows a simplified scenario with ENG: Different reporters use equipment sometimes separated by walls which causes more or less decoupling; the reporter may as well be outdoor. With a PMSE transmitter being outside, interference into a DVB-T receiving antenna in the vicinity may be possible whereas different PMSE equipment may be decoupled.

Figure 40: A simplified scenario for ENG

5.6.2.3.2 “Breaking News“

One of the crucial cases for Electronic News Gathering is the case of “breaking news“. Following on non planning events (accident, political event …), a high number of reporters are concentrated at one site within a short period time of (minutes to hour). There is in general very little time to coordinate and to plan any frequency usage scheme. Additionally due to the “random” arrival timing of the different teams, it is not practical to define a coordinated plan. Furthermore, reporters would like to limit their efforts regarding technical means and focus on the content. This trend is amplified by the fact that more and more reporter teams are reduced to one or two persons which achieve several different tasks (including technical). The key characteristics of this use case is the short timing to operation.

The objectives are self organizing networks which are easy to use, react dynamically and guarantee the avoidance of interference.

5.6.2.3.3 Everyday Report

To the difference of the “Breaking Scenario”, the use case of everyday report does not assume a high concentration of users (reporters) at one locations but a sporadic usage with limited means (one reporter who is also in charge of technical means). In this case, the self organizing character is of crucial importance. As the operation of devices can occur near households, the interference avoidance to DVB-T services has to be guaranteed.

In fact, other representative use cases are TV studio productions and movie studios or concerts and theater. However, they can be considered as covered by the three use cases above.

5.6.3 Market Potential

The number of users is estimated to 4-5 million across Europe according to the PMSE industry [22]. According to the German industry, the number of PWMS is estimated at 600 000 to 700 000. Microphones in Germany operate on the basis on general authorization in the band 790 – 862 MHz. More generally, potentially each reporter, each broadcast companies, each theater, event company could be addressed with cognitive technology for PMSE services which represents a substantial market potential in Europe. Since outside Europe, PMSE also coexists with broadcast services in the band 470 – 862 MHz, there exists market potential worldwide for cognitive technology based PMSE services.

5.6.4 Regulatory feasibility

No regulation change is necessary since PMSE services are already allowed to operate in the band 470 – 790 MHz. A priori, a commons spectrum regime can be envisaged. If other applications were to be introduced in the band 470 – 790 MHz, PMSE protection should be guarantee. ETSI has recently created a Special Task Force STF386 on “Methods, parameters and test procedures for cognitive interference mitigation techniques for use by PMSE devices.”
### 5.7 Summary of COGEU application scenarios

<table>
<thead>
<tr>
<th>Scenario key characteristics</th>
<th>RF bandwidth required</th>
<th>Spectrum sharing regime over TVWS</th>
<th>Market Potential</th>
</tr>
</thead>
</table>
| **UMTS and LTE extension over TVWS** | High mobility, Coverage extension for rural broadband; Traffic peak support for urban scenarios. | 2x5MHz (UMTS) LTE scalable bandwidths ranging from 1.4 MHz to 20 MHz; paired and unpaired spectrum allocations. | Secondary spectrum market | High  
- European rural broadband initiatives (EU Lisbon strategy)  
- LTE has been largely adopted by European operators |
| **WiFi with cognitive access to TVWS** | Nomadic, WLAN coverage extension up to 300m, Indoors and outdoors; Long range WiFi access technology: Business, Residential, Disaster areas, Hospital applications. | 22 MHz per channel | Spectrum commons with cognitive functionality | Very High  
- US developments  
- Minor changes of mature technology (WiFi over ISM) |
| **WiMax with cognitive access to TVWS** | Nomadic and portable applications Coverage extension for Rural broadband | 3MHz, 3.5MHz, 5MHz, 7MHz, 8.75MHz and 10MHz. | Secondary spectrum market | Low  
- WiMax legacy system has low market potential in Europe (competition with LTE) |
| **DVB-H with cognitive access to TVWS** | High mobility; Support Portable indoor coverage. Interactive mobile TV broadcast including local contents Urban, sub urban and rural. | 5 MHz (DVB-H) | Secondary spectrum market | Moderate  
- DVB-H systems are already allowed to operate in the UHF TV bands.  
- Business models not yet clear identified |
| **Public safety applications with cognitive access to TVWS** | Mandatory mobility support, important coverage for large scale deployment, Low bandwidth for legacy voice communications, High reliability, had doc network. | Heterogeneous RF bandwidth requirements depending on communication systems to be used. (25KHz for TETRA-like system) | Secondary spectrum market with prioritization mechanisms. | High  
- Public safety has a very limited frequency allocation in Europe  
- Extra spectrum (TWWS) can be made available through COGEU geolocation database access |
| **PMSE with cognitive access to TVWS** | Nomadic, Wireless microphones with cognitive features; Large events, Breaking News, Everyday report Mainly indoors. | 200 KHz (for High QoS) | Spectrum commons with cognitive functionality | Moderate  
- PMSE services already use TVWS on secondary basis  
- Increasing demand for PMSE services  
- Viable but small market dimension |
Currently, there is a global move to convert TV stations from analogue to digital transmission. Due to the spectrum efficiency of DTV, some of the spectrum bands used for analog TV will be cleared and made available for other usage. The COGEU project capitalizes on the fact that: the switch-over from analogue to digital terrestrial TV in Europe will free up highly valuable radio frequencies due to the greater efficiency of digital broadcasting transmission. This ‘digital dividend’ has great potential for the provision of a wide range of services, as the radio signals in this range travel far and equipment can be easily used indoors. It represents a unique opportunity for Europe to meet the growing demand for radio spectrum, particularly to provide wireless broadband to rural areas, thereby bridging the digital divide, and to facilitate the creation of new wireless services such as the next generation of mobile broadband, as well as to support the development of terrestrial broadcasting. It can therefore contribute significantly to the Lisbon goals of competitiveness and economic growth and satisfy some of the important social, cultural and economic needs of European citizens.

Taking into account that the spectrum dividend will become available throughout Europe within a relatively short space of time (i.e., when all Member States have completed the analogue switch-off by 2012 at the latest), it is of major and strategic importance to ensure an appropriate level of coordination among all Member States, towards reaping the full social and economic benefits possible from access to this spectrum, and to provide a clear EU roadmap for Member States moving ahead at different speeds as a result of differing national circumstances. In this respect, D2.1 has elaborated the timeliness of the COGEU project taking into account the regulatory feasibility, market potentials of COGEU use-cases, and technical feasibility of providing diverse wireless services in TVWS.

In the regulatory aspect, it has been shown that: Spectrum regulators in most European countries (with the exception of the UK), are still in an exploring stage. They need to understand the relevant (business) requirements, industrial costs, potential size of the market and investment profitability, in order to be able to advise on effective regulation. At this stage, there is a common European interest in establishing some form of partnership between European standardisation bodies and spectrum regulators (e.g. through CEPT), where possible, on the basis of initial business plans from industry. The European Conference of Postal and Telecommunications Administrations (CEPT), for example, has formed a new working group, SE43, with the mandate to work on a pan-European specification for cognitive devices. This work is currently at an early stage. It is not clear how any results will be promulgated. Nevertheless, as the RSPG report advocates the harmonisation of regulatory efforts, it is predictable that most European countries will follow the trend of the US and the UK and try to harmonize their policies with the rest of the World within an appropriate timeframe.

Therefore, from the European perspective, for cognitive access in the UHF band, we can see that there are numerous challenges facing both regulators and industries. Regulators will need to be satisfied that they have specified appropriate conditions of access which protect incumbent users and allow feasible operation of cognitive devices and systems, including additional regulatory considerations such as management of database solutions.

Figure 41: The iterative process between technology, regulatory and market entities in achieving the usage of cognitive technologies in TV white spaces
As illustrated in it can be seen that reaping the benefits of cognitive technologies in TV white spaces in the European context is an iterative process between technology feasibility, market potential and regulatory feasibility. In the light of market potential, technical feasibility and regulatory policies in the US and the UK, it follows that, the COGEU project is timely and feasible in regulatory and market as well as technical aspects.

Furthermore, it has been indicated that the report of consulting agencies to the European commission; the statement of the RSPG; as well as the progress made by individual regulatory bodies in some European countries like the UK’s Ofcom; provide ample support to believe that favorable policies for COGEU use cases will be available within the lifetime of the project. Moreover, as a contribution to the ongoing consultation, COGEU use cases will bring the technological feasibility and market potential insights to the industry and regulators so that they may harmonize guidelines and policies which will allow cost effective cognitive devices to operate in TVWS and co-exist in a non interfering basis with incumbent devices.

On market prospects, the COGEU project has the potential of creating diverse opportunities from spectrum market trading mechanisms to wireless services provision by extending their operations in TV white spaces. The realization of these potentials will impact the society positively as it has been identified in the deliverable. Apart from being the context of this deliverable, the presented models are a basis for other work packages as well. Table 19 gives the summary of potential COGEU business models and related WPs.

Table 19: A summary of COGEU potential business models and use-cases in TV white spaces and their related WPs

<table>
<thead>
<tr>
<th>Number</th>
<th>Business model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spectrum Broker</td>
<td>Provide spectrum trading platform to satisfy the demand of spectrum resources by various technologies and services.</td>
</tr>
<tr>
<td>2</td>
<td>Spectrum sensing</td>
<td>Provide spectrum availability information to the communication protocol. The sensor maybe used in conjunction with geo-location database.</td>
</tr>
<tr>
<td>3</td>
<td>Geo-location database</td>
<td>Provide spectrum availability information based on geographic location and time. The geo-location database maybe used together with spectrum sensing.</td>
</tr>
<tr>
<td>4</td>
<td>UMTS\LTE</td>
<td>Extending the service over TVWS especially during moments of peak traffic with mobility aspects.</td>
</tr>
<tr>
<td>5</td>
<td>UMTS\LTE</td>
<td>Provide broadband wireless access with QoS guarantee through spectrum trading.</td>
</tr>
<tr>
<td>6</td>
<td>WiFi</td>
<td>Provide nomadic and semi-nomadic broadband wireless services and extending the range of traditional WiFi through TVWS (spectrum commons)</td>
</tr>
<tr>
<td>7</td>
<td>WiMAX</td>
<td>Exploit WiMAX co-existence technologies to provide broadband wireless access in low density areas.</td>
</tr>
<tr>
<td>8</td>
<td>DVB-H</td>
<td>Provide interactive TV services by way of portable and mobile devices through TVWS.</td>
</tr>
<tr>
<td>9</td>
<td>Public safety</td>
<td>Providing first responder services during disaster through TVWS.</td>
</tr>
<tr>
<td>10</td>
<td>Cognitive PMSE</td>
<td>PMSE applications are natives in TVWS, however, with DSO, their potential spectrum resources are reduced so they need implement cognitive features to exploit more resource and co-exist with other white space devices.</td>
</tr>
</tbody>
</table>
Technically, the Spectrum Broker is one of the key aspects of the COGEU project to enable the exploration of TV white spaces, which are arranged on a geographic interleaving basis so as to protect broadcast television services from interfering with each other. The Spectrum Broker will facilitate the development of a new regulatory framework that continues the protection but allows flexibility for new applications to emerge and flourish. However, apart from regulatory flexibility, technical feasibility is important for the success of new applications. This is in part the technical feasibility of realizing the spectrum broker and also the deploying wireless services in TVWS. The COGEU vision has no intent to ‘reinvent the wheel’. Therefore, during the course of the project, the project will investigate and tailor available solutions for the operation in TVWS and follow current standardization activities such as IEEE P1900 and ETSI RRS, as well as directives from spectrum regulatory bodies, so as to operate within allowed thresholds.

The specific technical challenges faced in the TVWS scenario emanates from the hidden node problem, the protection of incumbent users, the fragmentation of TVWS and the spatial-temporal variations in spectrum availability. Therefore, the COGEU project has to achieve QoS support for TVWS cognitive systems based on the spectrum access model in the selected use-case. The COGEU system is expected to guarantee some level of QoS, protection to incumbents and at the same time affordable TVWS devices. Moreover, the price of the TVWS devices must be affordable to potentiante the market entrance, therefore COGEU will take into account the complexity and implementation challenges of the solutions investigated. The deliverable has asserted the technical feasibility of overcoming these challenges.

The purpose of this deliverable D2.1 "European TV White Spaces market analysis and COGEU use-cases" was to analyse the European market with respect to the TVWS opportunities, study spectrum sharing models and define a set of scenarios for TVWS deployment. Therefore, the output of this deliverable is a basis for other technical work packages. Immediate future work is related to WP3, T3.1, where the objectives are to extract from the COGEU use-cases the set of system level requirements that are necessary to design future cognitive radio systems. These system level requirements will be analysed and classified depending on the spectrum commons or the secondary spectrum market models. Furthermore, the task will define the COGEU reference architecture by the definition of functional building blocks and their interfaces based on the system level requirements for the spectrum commons and the secondary spectrum market models. This will then link to other WPs in a progressive manner.

D2.1 is the first step from which COGEU will provide flexible tools and solutions for using the spectrum rather than the traditional static approach. To set the context in which the new technologies of the COGEU proposal will function, it is important to focus on prospective applications areas as identified in D2.1, while providing viable interfaces for further extensions in regulatory, market and technical domains in the future.
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