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Abstract

In this deliverable a final assessment is provided of the regulatory feasibility of secondary spectrum access schemes for TV, Aeronautical and Radar bands, as proposed by the QUASAR project. First the emerging trends in worldwide regulation of secondary spectrum access using cognitive radio are critically reviewed. This is followed by a discussion of remaining regulatory and policy road blocks which are identified by the QUASAR project. With increased interest from the European policy makers and industry in the use of secondary spectrum sharing there is a need for a shift from the regulatory regime of "how to protect primaries" to how to enable

[1] Dissemination level codes: **PU** = Public
PP = Restricted to other programme participants (including the Commission Services)
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industry to exploit secondary spectrum opportunities in order to provide harmonized, profitable and sustainable communication services which benefit users. A number of technical and policy solutions are then proposed that address regulatory challenges of this new regime and recommendations are made for their implementation.

Keywords List:

Secondary spectrum access, spectrum sharing, cognitive radio, spectrum regulation, TV white spaces, radar bands

Executive Summary

In this deliverable a final assessment is made of the regulatory feasibility of the secondary spectrum sharing schemes proposed within the QUASAR project, and remaining regulatory obstacles are identified. Based on our analysis, and discussions with industry stakeholders and regulators, a number of recommendations on technology, policy and regulatory steps that are needed to remove these road blocks are provided. The work is put in context by providing a short overview of current and emerging regulatory trends and timelines for secondary spectrum access in Europe and elsewhere.

A regulatory framework for secondary access to TV White Spaces (TVWS) is already in place in the US, and is currently well underway in the UK. On a European level, work within CEPT is being finalized on defining technical and operational requirements for the possible operation of cognitive radio in this spectrum, with the final studies being concluded in ECC Report 159. Furthermore, regulators in a number of countries, including Canada are in the process of putting in place a regulatory framework, while Finland, Singapore and Japan have allowed testing and evaluation by industry of cognitive radio techniques, sensing and geolocation, in these TVWS bands prior to moving to regulations.

The current "first wave" of regulations has focused on how to offer maximum levels of protection to primary systems against operation of cognitive radios. This is also reflected the fact that framework is emerging for regulating the mechanisms for detection and protection of primary systems, as well as operational parameters of cognitive radios, such as transmit power and out-of-band emission limits. These are currently defined in order to offer maximum protection certainty to incumbent systems.

On the other hand, with increased interest from the industry in the use of TVWS, we are seeing first signs for a possible shift in emphasis from "the feasibility of and requirements for protection of primary systems", to the "feasibility and requirements for the provision of profitable wireless services in secondary spectrum". The regulatory issues that arise here include limits on the operational parameters of secondary systems, protection against aggregate interference of a large number of cognitive radios, and mechanisms required for sharing of secondary spectrum. The lack of a clear regulatory framework to deal with such issues is currently forming an obstacle to the development of systems capable of operating in secondary spectrum. In this deliverable a number of specific proposals to policy makers and regulators are made that should help with removing such remaining obstacles. Some of these proposals have also been put forward by QUASAR to regulatory bodies, in particular the CEPT SE43 working group and Ofcom.

Finally, regulatory feasibility of secondary access to civilian radar and aeronautical band is assessed, and some of the obstacles to the opening of these bands are identified along with possible solutions.

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1 Introduction

Secondary sharing of already licensed but underutilized spectrum has gained huge momentum in recent years as one approach to cope, in a flexible manner, with the very significant increase in demand for radio spectrum [1,2]. The global mobile data traffic grew by 280% between 2008 and 2010, and this increase is predicted to continue for several years, more than doubling every year [3]. In addition to mobile broadband a huge increase in WiFi traffic is expected, for applications such as high-definition multimedia streaming in homes. WiFi networks also provide an important mechanism for data offloading, which helps relieve mobile operators' wireless networks from congestion. Other services which are expected to derive the need for more spectrum include smart grid communications, e-health and intelligent transport systems.

The success of secondary spectrum access to address some of the future demand for spectrum relies on a combination of more flexible approaches to regulation, advances in technology and viability of business cases built on the use of secondary spectrum. The EU FP7 QUASAR project has taken a holistic approach to assessing the feasibility of secondary spectrum access. In addition to quantifying the spectrum opportunity associated with this form of access and addressing a number of associated technology challenges of cognitive radio, business viability and regulatory feasibility are also examined.

This document is one of the two final deliverables of Work Package 1 of the QUASAR project. It corresponds to task T1.3. The aim of this task has been to critically examine the current regulatory framework for secondary spectrum access in Europe and elsewhere. Subsequently, a number of outstanding regulatory issues and obstacles to future success of secondary access are identified and specific proposals to regulators and policy makers are made which we believe will help remove these road blocks. Particular focus is given to:

- *Secondary spectrum access to unused portions of Digital Terrestrial Television (DTT) broadcasting bands, the so-called TV white space: 470-790 MHz*
- *Secondary spectrum access to radar bands: 2700-3100 MHz, 5250-5850 MHz,*
- *Secondary spectrum access to aeronautical bands for DME: 960-1215 MHz*

1.1 Lay-out of the report

The rest of this report is organized as follows. To put the work presented in this deliverable within an up-to-date regulatory context, Section 2 gives an overview and critical examination of the current activities, status and trends in regulation of secondary spectrum access in Europe and elsewhere, with particular emphasis given to TVWS.

This is then followed, in section 3, by an examination, from QUASAR perspective, of some of the remaining issues and obstacles which are currently roadblocks to the success of TVWS. Subsequently, a number of specific proposals to policy makers and regulators are made that should aid the removal of such remaining obstacles. Some of these proposals have also been put forward by QUASAR to regulatory bodies, in particular the CEPT SE43 working group and Ofcom.

In Section 4 feasibility of secondary spectrum access to civilian radar and aeronautical band is assessed, and some of the obstacles to the opening of these bands are identified along with possible solutions.

This report is finalized with a summary, a set of recommendations and conclusions in Section 5.

2 Worldwide trends in regulation of secondary spectrum access using cognitive radio

In this Section we review the state-of-the-art in worldwide regulation of cognitive radio-based secondary access to radio spectrum. We review and compare emerging regulatory trends with regards to incumbent protection and detection, operation parameters of cognitive radios and secondary licencing models in the United States, UK, Europe and elsewhere. We also discuss the current status of the cognitive radio within the ITU. This section sets the scene for the rest of the report. It updates and expands the overview which was provided in QUASAR deliverable D1.2 [4] with new material which has become available since 2010, as well as a more in-depth discussion of regulations, see also [5,6].

In addition to publicly available regulatory documents, this Section draws on a wide range of other resources. These include discussions with QUSAR's regulatory partners, BNetzA (Germany), FICORA (Finland), PTS (Sweden), Ofcom (UK), as well as representatives from the FCC (USA), iDEA (Singapore) and KCC (Korea). Another source of information has been presentations and discussions at a regulatory and industry panel. This panel was held during QUASAR's public workshop in Stockholm on June 20, 2012[2].

The rest of this Section is organized as follows. In Section 2.1 some regulatory essentials on protection of incumbent systems are reviewed. This is followed in Section 2.3 with an overview of the current and emerging trends in regulation of secondary access in the United States, UK, Europe, and elsewhere.

2.1 Regulatory essentials for protection of incumbent systems

Secondary operation of cognitive radios is conditioned by regulators on the ability of these devices to avoid harmful interference to incumbents. In the case of secondary operation in TV bands, these include TV receivers as well as Program Making and Special Event (PMSE) users, such as wireless microphones. In the case of secondary operation in radar and Distance Measurement Equipment's (DMSE) bands, protection is required for radar systems. In addition to protection of incumbents, successful operation of cognitive radios relies on the ability of devices to reliably detect white spaces and successfully use them. There is often a tension in achieving these dual goals. This is best illustrated in the case of sensing-based cognitive radios where reducing the probability of miss-detection (which would offer a higher level of protection to incumbents) would at the same time result in an increase in the probability of false positives, i.e. a reduction in the white space opportunities for cognitive radio. Figure 1 illustrates, as an example, the operation of a cognitive radio in TV White Spaces, also known as White Space Device (WSD), under protection requirements of TV and PMSE.

[2] http://www.quasarspectrum.eu/latest/129-quasar-public-workshop.html.

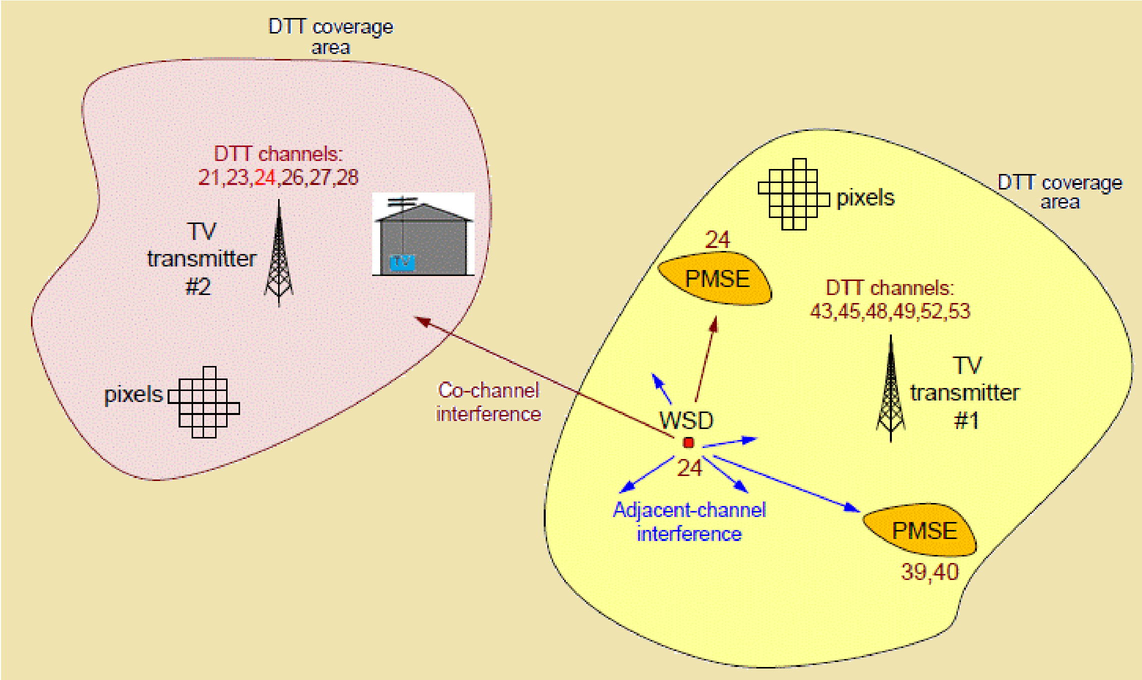

Figure 1: Illustration of secondary operation of a cognitive radio in unused TV bands [courtesy of Ofcom].

Several approaches have been proposed and investigated by the research community that aim at achieving these dual objectives. So far the following main methods have been considered and evaluated by a number of regulators: geolocation databases, spectrum sensing, and beacons. In the following we will briefly examine these methods.

2.1.1 Geolocation databases

In this approach to find out which unused frequencies are available at a given location and time, a cognitive radio queries a central database with its location and other device specifications, such as device type, antenna height and the required service area. The geolocation database then uses this information along with a database of location, transmit power, frequencies, antenna heights and radiation patterns of primary transmitters to perform a set of propagation modelling calculations, see e.g. [7]. The outcome of these calculations are a list of available channels that could be used by the requesting secondary devices, accompanied by limits on allowed transmit powers, and possibly, a time validity stamp for each channel. In the case of TV bands, some of these channels may be already in use by PMSE at that location, in which case they are excluded for use by cognitive radios.

Incumbent protection and spectrum opportunity detection via a geolocation database is mainly applicable to incumbent systems that have usage patterns which are either fixed in time (such as TV transmitters) or vary slowly, e.g. on an hourly basis, such that information stored in the database does not require frequent updating. Furthermore, devices need to know their location with a level of accuracy which is prescribed by regulators, e.g. 50-100 meters for access to TV bands. For outdoor applications Global Positioning System (GPS) could be used to support location-awareness but in the case of indoor applications the poor penetration of GPS signals into buildings is problematic. Finally, to access the database in the first place a device needs to be connected to the Internet via a wired link, or it could establish a wireless link (e.g. using WiFi or LTE) that does not require secondary access.

Partly due to the above issues the geolocation database approach is being mainly used in combination with master-slave communication architecture, as opposed to adhoc architecture. In this setting a master devices, such as a WiFi access point or a LTE eNodeB is already connected to the Internet and can also geolocate itself. The master node then uses its location to query the geolocation database about available secondary spectrum within a pre-defined service range. Based on this information it then instruct a set of slave nodes, e.g. handsets or tablets, on the frequencies they could use, see [8]. The master-slave approach, has been proposed by the QUASAR project to the CEPT SE43 working group, and has been included in ECC Report 159 [9] (see Appendix for further a reference).

2.1.2 Spectrum sensing

In the sensing method devices autonomously detect the presence (or absence) of primary system signals using a detection algorithm. Detection of primary signals could be subject to the so-called "hidden node" problem [5], which occurs when there is blockage between the secondary device and a primary transmitter resulting in a situation where a cognitive radio may not detect the presence of primary signals and starts using an occupied channel, hence causing harmful interference to primary receivers. To solve this problem cooperative sensing algorithms have been investigated within the QUASAR project where measurements performed by multiple secondary devices are combined in order achieve a higher sensing level than is possible with a single device, see [10] and references therein.

One key problem with cooperative sensing, which was also highlighted through research within QUASAR, is that the gains compared to a single sensor detection depend on location and number of cooperating sensors, which will typically be random. Thus it will be difficult to establish firm lower bounds for the gains over single sensor scenarios, which is necessary in order to take into consideration such gains when defining a regulatory framework for cooperative sensing.

2.1.3 Beacons

With the beacon method, cognitive radios only transmit if they receive an enabling beacon granting them the use of vacant channels. Alternatively, a cognitive radio may transmit in a channel as long as it has not received a disabling beacon denying it the use of the channel. One issue with the beacon approach is that it requires a beacon infrastructure to be in place which needs to be run and maintain by the regulator or a third party. In addition, beacon signals could be lost due to mechanisms similar to the aforementioned hidden node problem.

We note that in the case of geolocation databases there is also the need for an entity to run and maintain such a service. However, unlike the beacon approach the use of geolocation databases offers a higher level of protection to incumbents, as well as opening new possibilities for management of secondary spectrum. The connection to a database could further be done in an over-the-top manner through the Internet, which is not possible with the beacon approach for which new signalling needs to be standardized, and possibly also new spectrum dedicated.

2.1.4 Emission masks

Signals transmitted by a wireless device are never entirely confined within the intended bandwidth B. Out-of-band emission (OE) is the signal energy that leaks outside the allocated band B. Regulatory authorities and standardization bodies typically prescribe *spectrum masks* for any access technology in a particular band of operation. The mask specifies the rate at which the power spectral density (PSD) outside the intended band decays relative to the peak power within the band of emission. For example, the IEEE 802.11 a/g standard for WiFi specifies the PSD decay at a rate of 1.1 dB/MHz outside the main band.

In typical operation scenarios a cognitive radio would operate in a primary channel which is unoccupied at its location (at a given time). However, it is possible that a primary system is operating in a channel adjacent to the one being used by a cognitive radio. Consequently, due to imperfectness of cognitive radio's transmitter filter, energy transmitted in the unoccupied band could leak into the adjacent band, causing harmful interference to a primary receiver. Even if a cognitive radio's filter is ideal, interference could still be experienced by a primary operating in an adjacent channel because of the imperfection of the primary receiver filter.

To avoid the above problems regulators typically define guard-bands between two primary systems, e.g. LTE and DVBT, operating in adjacent frequency bands. However, such guard-bands are difficult to implement in the case of cognitive radios because the available frequencies are not fixed but change with time and location. For this reason, regulators tend to stipulated stringent emission masks on cognitive radios operating in TVWS in order to ensure protection of primary receivers against adjacent channel interference, as described above.

2.2 Regulations in the United States

In the United States the Federal Communication Commission (FCC) proposed to allow secondary access by cognitive radio devices to TV bands already in 2004. In November 2008 the FCC adopted a Second Report and Order [11] in which it allowed unlicensed operation in TV bands at locations where frequencies were not used by licensed services. The Commission permitted both fixed and personal/portable unlicensed devices to operate in TV bands. Furthermore, the FCC decided to proceed with regulation of both sensing and geolocation approaches for incumbent protection. However, it required that devices that incorporated geolocation and database access must also listen (sense) to detect the signals of TV stations and wireless microphones.

In a further ruling published in September 2010 [12], the Commission eliminated the sensing requirement for cognitive radios with geolocation capability. The FCC also issued a call for proposals for geolocation database providers in September 2010. After evaluating the responses received from industry, the FCC conditionally designated in January 2010 [14] nine commercial entities as TV band database administrators. Based on detailed information received from these entities following their filings, the FCC has granted preliminary approval for operation to two of the nine database administrators, SpectrumBridge Inc., and Telcordia (which was recently acquired by Ericsson).

The FCC has established two classes of TV band devices: those that may establish a network (called Fixed or Mode II) and those that may join a network (Mode I). Fixed devices may transmit at up to 4W (36 dBm) EIRP (Effective Isotropic Radiated Power)[3]. They are allowed to operate at any channel between 2 and 51 except channels 3, 4 and 37, and are subject to a number of other conditions such as restriction against operation in the same channel (co-channel) or on the first channel adjacent to a licensed TV station. Fixed devices must contact a geolocation database to obtain a channel list before operating and re-check the database at least once a day. Personal/portable devices may operate either in Mode I (operating only on channels available through either a fixed or Mode II device) or in Mode II when relying on internal geolocation and database access to determine channels at their locations. Mode I and II-type personal/portable devices may operate on any unoccupied channel between 21 and 51, except channel 37, and may use up to 100 mW EIRP, except that operation on the first adjacent channel to TV stations are limited to 40 mW EIRP.

Sensing-only devices are also allowed, in principle, by the FCC. However, a sensing-only device is limited to 50 mW transmit power and must be able to detect ATSC digital TV signals and NTSC analog TV signals at -114 dBm (in a 6 MHz band) and be able to cease

[3] In the FCC ruling fixed WSD may transmit at a maximum of 1 W into one or more TVWS channels with antenna gains up to 6 dBi allowed, thus permitting up to 4W EIRP.

transmission within 2s of TV signal detection. In addition a sensing-only WSD must be able to detect wireless microphone signals at -107 dBm (in a 100 KHz band). Furthermore, the developer of a sensing-only device needs to "demonstrate with an extremely high degree of confidence that they will not cause harmful interference to incumbent radio services".[4].

The FCC has stipulated strict out-of-band emission limits for WSDs, i.e. as compared to WiFi. This is to protect incumbent systems both inside and outside (e.g. LTE) TV bands from the aforementioned adjacent channel interference. The most recent ruling by the FCC [14] requires that the adjacent channel emission limit for each device category should be -72.8 dB below the maximum power permitted for that device category. The resulting out-of-band emission limits are summarized in table 1.

Table 1 : WSD adjacent channel emission limits required by the FCC [14].

Type of WSD	**Power limit**	**Adjacent channel limit(100 kHz)**
Fixed	30 dBm (1 Watt)	-42.8 dBm
Personal/Portable (adj. channel)	16 dBm (30 mW)	-56.8 dBm
Sensing only	17 dBm (40 mW)	-55.8 dBm
All other personal/portable	20 dBm (100 mW)	-52/8 dBm

We note that the FCC rules allow for transmission by a WSD on multiple white space channels. This enables bonding of several (not necessary contiguous) white space channels, which is required to support high-bandwidth applications such as HDTV streaming in home environments or ultrafast (1Gbps) wireless broadband access in TVWS.

With respect to the operation of devices requiring higher powers, e.g. for cellular applications, the FCC states that [12] "we also understand that there may be situations where radio communication facility could operate at higher power in TV white spaces without causing interference. However, we continue to conclude that because the extended range of such devices would significantly increase the potential for interference and also make it more difficult to identify sources of interference, it would not be appropriate to allow higher power for unlicensed TV devices at this time". It then concludes that "Indeed, such [higher power] operation would be more appropriate under a licensed regime of regulation".

The FCC report [12] includes a detailed discussion about whether secondary access to TVWS should be licensed, licence-exempt, or subject to light licensing. It concludes that the best way to facilitate innovative new applications is via licence-exemption and that licensing would be difficult to define and would be subject to change (e.g. if television coverage was re-planned), so the rights awarded would be rather tenuous.

2.3 Regulations in the United Kingdom

The UK regulator, Ofcom, issued a statement on 13 December 2007 [15] where it considered for the first time the use of interleaved spectrum (TV White Spaces) by licence-exempt devices. It concluded that it should allow licence-exempt access to TVWS as long as this would not cause harmful interference to licensed users. Subsequently, Ofcom published a consultation on 16 February 2009 [16]. This predominantly consulted on sensing threshold levels that would be needed for licence-exempt devices making use

[4] See FCC, TVBDs that rely on spectrum sensing, Code of Federal Regulations (US), Title 47, Section 15.717 (a), available from http://frwebgate.access.gpo.gov

of sensing only. In a follow up statement [17], Ofcom evaluated three mechanisms for incumbent protection: (1) sensing, (2) geolocation and (3) beacons. It concluded that beacon transmission was inferior to the other two approaches and therefore would not be considered further. The main reason being that this approach required the establishment of a costly infrastructure while at the same time not being able to guarantee that harmful interference could be avoided at all times (due to the possibility of beacon signals getting lost). Furthermore, Ofcom concluded that there were advantages and disadvantages to both sensing and geolocation, and decided to proceed with regulation of both approaches. However, it concluded that in the short term the most important mechanism for spectrum detection would be geolocation. The operation parameters for sensing-based and geolocation-based WSD as proposed by Ofcom are summarized in Table 2.

From this table it can be seen that Ofcom's required sensing thresholds are similar to those of the FCC. Furthermore, unlike the FCC, Ofcom has not fix the maximum transmit power of geolocation-based devices but has left this to the geolocation database, thereby allowing more flexibility. We examine this important difference between the FCC and the Ofcom approach in more details in a following section.

Following the above statement Ofcom has established a TV White Space technical Working Group in order to create a UK-specific framework for the regulation of WSD operating under geolocation databases. This work is expected to be finalized in 2012, with the first commercial applications in the UK appearing in 2013.

At the time of writing, Ofcom's work on specifying out-of-band emission limits of WSD is ongoing. It is likely that Ofcom may adopt a somewhat different approach to the FCC's approach: Instead of specifying absolute limits on adjacent channel emissions Ofcom may specify the ratio between the in-band and out-of-band emission of WSD.

Table 2: The operation parameters for sensing-based and geolocation-based cognitive radios as proposed by Ofcom [17].

Cognitive Parameter	**Value (sensing)**	**Value (geolocation)**
Signal detection sensitivity for DTT	-120 dBm (8 MHz channel)	_
Signal detection sensitivity for wireless microphones	-126 dBm (200 KHz channel)	_
Maximum transmit power	4 dBm (adjacent channel) to 17 dBm (next adjacent channel)	As specified by database
Transmit power control	Required	Required
Bandwidth	Unlimited	Unlimited
Out-of-band performance	< -46 dBm	< -46 dBm
Minimum time between sensing	< 1 second	_
Location accuracy	_	Nominally 100 metres

2.4 Regulations in Germany

BNetzA is very interested in the development of new technical possibilities which will enhance the flexible and efficient use of spectrum. In particular to investigate new sharing methods and mechanisms, new solutions have to be developed in order to deal with the increasing demand for capacity of mobile Broadband in the future.

BNezA considers that the combination of sensing and geolocation databases looks very promising. In order to protect the primary user and also to allow a certain QoS for the secondary user BNetzA is taking part in the development of the Licensed Shared Access (LSA) concept and intends to use some results of the project in the discussion of LSA.

BNetzA is currently looking into defining the licensing regime for different applications using cognitive techniques, i.e., what kind of licensing scheme should be used - licensed or license exempt.

2.5 Regulations in Finland

In Finland, the Council of State issued a statement in 2009, which states that cognitive radios are permitted to operate in the 470-790 MHz frequency band provided they do not cause harmful interference to other systems in the band. Based on this the Finish regulator, FICORA, has already granted several short term test licences and is working currently on a complete regulatory framework.

2.6 Regulations in Europe

2.6.1 The European Parliament and Council

On 14 March 2012, the European Parliament and Council approved the first Radio Spectrum Policy Programme (RSPP) establishing a multiannual radio spectrum policy programme. This decision creates a comprehensive roadmap to contribute to the functioning of the internal market for wireless technologies and services, particularly in line with the Europe 2020 initiative and the Digital Agenda for Europe. The decision sets general principles and calls for concrete actions to meet the objective of EU policies. This decision also includes a policy objective regarding the development of cognitive radio technology. Specifically in Article 4 of the decision the following statement has been made "Member states shall also foster the development of current and new technologies, for example in cognitive radio, including those using 'white spaces'."

2.6.2 The European Commission

In preparation for an impact assessment to accompany the Commission's initiative to Shared Use of Spectrum (SMART2011/0017), the DG Information Society and Media, Electronic Communication Policy, Radio Spectrum Policy (Unit B4) has commissioned a study on "Perspectives on the value of shared spectrum access" which was released in February 2012 [1]. The study is one of several inputs supporting the European Commission's plan to publish a communication on these issues, and intended to contribute to a better understanding of the socio-economic value shared spectrum access. According to the report shared spectrum access includes "all situations in which two or more wireless applications are authorized to utilize the same span of frequencies on a non-exclusive basis in a defined sharing agreement". It therefore includes secondary opportunistic use of white spaces, as well as other approaches to sharing, such as "Authorized Shared Access" (ASA) [25] and the Soft Licensing approach proposed within the QUASAR project [26].

ASA has been proposed recently [26], with backing from industry players Nokia and Qualcomm. The EC is currently looking into regulation of a variant of this approach; the

Licensed Shared access (LSA) in order to promote further spectrum sharing and a public EU consultation is forthcoming.

2.6.3 **Activities within CEPT**

On the European level detailed technical and regulatory work on cognitive radio is being carried out in several working groups of CEPT (Conférence Européen des Administrations des Poste et des Télécommunications). At the same time the Radio Spectrum Policy Group (RSPG), which advises the European Commission on development of radio spectrum policy on a strategic level, has been addressing high level policy issues of cognitive radio.

2.6.3.1 CEPT Frequency Management (FM)

Within the FM working group responsibility for cognitive radio lies with the Corresponding Group Cognitive Radio Systems (CR-CRS), which follows up the development of cognitive radio area in general and reports back to the high level group WGFM if there are new requirements that require action by CEPT. WGFM at their 74th meeting on 23-27 April 2012 decided to establish two new work items for the creation of two new ECC Reports in relation to cognitive radio:

1. To provide master set of the overall requirements for all CEPT countries that will be needed to facilitate communication and interaction between a WSD and White Space Database;
2. To provide information on issues and requirements that needs to be addressed when setting up a geolocation database and/or the management of independent database providers.

CG CRS was also asked by WGFM to assess if these work items should be carried out independent of the frequency band considered for sharing or if they should be limited to the TV UHF band, and to provide its conclusion on this issue at the next WGFM meeting. WGFM also decided to turn the CG CRS into a WGFM Forum Group at the next WGFM meeting.

2.6.3.2 CEPT Spectrum Engineering (SE)

CEPT SE43 project team has developed a new ECC Report 159 "Technical and Operational Requirements for Possible Operation of Cognitive Radio Systems in the 'White Space' of the Frequency band 470-790 MHz" which was finalized and approved on 28th of January 2011 [19]. The SE43 draft report was developed in order to ensure protection of the incumbent radio services. While three techniques (sensing, geolocation databases and beacons) were considered at the start of the SE43 study, most of the effort was devoted to the assessment of the feasibility of and technical requirements for the sensing and geolocation techniques.

With regard to protection of the broadcasting services the sensing thresholds recommended by SE43 were derived for a number of interference scenarios taking into account a range of potential DTT receiver configurations in Europe. The values so obtained were in the range from -91 to -155 dBm, some of which are far too low to be implemented with the current sensing technology, as is also confirmed by QUASAR studies undertaken in WP2 and WP3. Moreover, the report concludes that even those low detection threshold values do not guarantee a reliable detection of presence/absence of the broadcasting signals at a distance corresponding to the interference potential of WSD. This led the SE43 working group to the conclusion that "the sensing technique investigated, if employed by a stand-alone WSD does not appear to be reliable enough to guarantee protection of nearby DTT receivers using the same channels" [CEPT-SE43-2011]. The report also concludes that "The use of geolocation databases appear to avoid possible interference to DTT receives appear to be the most feasible option. In cases where the use of geolocation database can provide sufficient protection to broadcast services, sensing is not required. There may be some potential benefits in using a combination of sensing and geolocation databases to provided adequate protection of DTT receivers but these benefits would need to be further considered" [19].

With regards to the protection of PMSE from WSD interference the report concludes that "spectrum sensing is currently considered as a problematic approach" and, therefore, "use of geolocation databases appears to be the most feasible approach considered so far". The report identifies a number of implementation issues with the use of geolocation databases to protect PMSE users, including how data on PMSE use could be communicated to and stored in the databases and how often WSD should consulate the databases in order to "check" for PMSE users. Although not considered in detail, the report also discussed the use of the disable beacon concept for the protection of PMSE, as a way to overcome some of the issues of the sensing-based approach.

Finally, the report sets up the principles and defines the requirements for the operation of WSDs under the geolocation approach. Specific requirements are provided for WSD deployment using the aforementioned master-slave architecture, as well as guidelines to national administrators on a general methodology and algorithms for the conversation of the information retained in the database, DTT transmitter location and field strength data, into a list of allowed frequencies and associated maximum transmit powers to be used by WSD.

In agreement with Ofcom's approach, the SE43 group has decided not to impose fixed transmit power limits on WSDs operating under geolocation, allowing for *location-based transmit powers* to be determined by the geolocation database. Other operational requirements for the operation of WSD, including spectrum masks, are yet to be developed.

After approving the SE43 draft report in January 2011, CEPT WG SE (the parent group of SE43) developed a new work item for SE43 and suggested the following issues to be addressed in the short term: (i) elaboration of the approaches combining the geolocation database and spectrum sensing, (ii) studies on the impact of WSD on the services adjacent to the 470-790 MHz, (ii) identification of a common set of the parameters required to calculate location specific WSD power levels. In the meantime SE43 has initiated development of two complementary ECC reports which are expected to be finalized in September 2012. One key advance provided by these reports is that protection of services in adjacent bands requires some additional limitations on WSDs which need to be implemented in the geolocation database.

2.7 **Regulations elsewhere**

In Korea, the national regulator, KCC, announced in 2011 a plan for TVWS regulation [19]. According to this plan, a technical framework for the protection of TV broadcasting against interference from WSDs will be established in 2012. Licensing schemes and other regulatory policies will also be investigated in 2012, followed by trials in restricted areas taking place in 2013. Geolocation databses are expected to be an essential component of these trials while spectrum sensing will be investigated later. Nation-wide white space services are expected by KCC to appear in Korea by 2014.

Industry Canada released in August 2011 a consultation [21] seeking comments on all aspects of policy and technology related to operation of WSD in TV bands. Industry Canada has not yet proposed detailed operational parameters for WSD. However, it is proposing to focus initially on the use of geolocation databases for incumbent protection and recommends that a Canadian database should be developed.

In the Asia Pacific region, the national regulators in Japan and Singapore have created special zones for experimentation by industry of cognitive radio technologies prior to adopting a regulatory framework. The approach of the Japanese spectrum regulator Ministry of Internal Affairs and Communications (MIC) to white spaces seems to be to focus on consensus development among traditional spectrum users before making major spectrum policy changes.

2.8 Activities within the ITU

The 2007 World Radiocommunication Conference (WRC-07) adopted Resolution 956 dealing with "Regulatory measures and their relevance to enable the introduction of software-defined radio and cognitive radio system" [22]. This resolution invited the ITU-R to study whether there is need for regulatory measures related to study "the application of cognitive radio system technologies … (and) whether there is a need for regulatory measures related to the application of software-defined radio." In addition, this resolution became Agenda Item 1.19 for WRC-12.

The 2012 WRC's Preparatory Meeting concluded that "A common concern within the ITU-R is the protection of existing services from potential interference from the services implementing CRS (Cognitive Radio System) technologies, especially from the dynamic spectrum access capabilities of CRS.

In addition, "a service using SDR and/or CRS should not adversely affect other services in the same band with the same or higher status. Thus, the introduction and operation of stations using SDR and/or CRS technologies in systems of any radio communication service should not impose any additional constraints to other services sharing the band" [23].

So far the attempt to bring cognitive radio into the ITU forum has had limited success other than recognizing cognitive radio as legitimate technology. Therefore, for the foreseeable future one may expect that the regulation of cognitive radio will be at the regional and national levels. However, if a major non-ITU international standard group adopts the technology for a specific new standard then the pace of introduction could be speed up significantly.

3 Remaining regulatory obstacles and specific proposals to address them

The "first-wave" of regulation of cognitive radio for secondary access which we reviewed in the previous Section has primarily focused on putting in place the required mechanisms and regulatory framework for protection of incumbent systems against harmful interference from cognitive radios. At least in the case of TVWS, there seems to be consensus among regulators that the geolocation database technology can offer incumbent systems a satisfactory level of protection. This has also helped create the required level of certainty for a number of industry players interested in TVWS to proceed with planning for, and investing in white space technologies. For example, BT (www.bt.com) has recently announced its intention to deploy the white space technology for the provision of wireless broadband to up to half a million of its customers in rural Britain. Also, in the UK, the company NEUL (www.neul.com) has developed a white space technology for machine-to-machine communication services, such as smart metering, and is also developing a new industry standard, Weightless, specifically geared towards M2M communication requirements.

With growing interest from the industry, we expect that the regulatory and industry focus would shift towards addressing the remaining challenges to actual exploitation of TVWS for the provision of scalable, reliable and profitable wireless to users.

Several of these challenges of TVWS which were identified within the QUSAR project will be discussed in this Section and specific proposals to address a number of these issues will be described.

3.1 International harmonization of protection rules

There are currently important differences between the CEPT's SE43 group's and FCC's approaches in implementing protection rules for secondary access to TVWS which, as we describe below, can result in very significant variations in the white spectrum opportunities, and consequently, the available capacity for services between the US and Europe. These variations are not due to differences in the operation frequencies and planning of TV transmitters between the United states and Europe but are purely the result of differences in the methodologies used to protect primary systems, i.e., applying the different rules in the same country will result in clear differences in white space availability, see below.

The SE43 project team has chosen a more flexible approach while the FCC is more prescriptive. While the FCC impose as 4W maximum transmit power on WSD, SE43 has left the maximum transmit power to be determined through a database depending on distance to the nearest TV coverage area and adjacent channel interference potential. Although the methodologies proposed by Ofcom and CEPT SE43 are very similar the following discussion and comparison is based on the SE43 methodology as described in [19].

In the SE43 method white space availability is defined indirectly via a location-dependent maximum permitted transmit power for WSD, as is depicted in Figure 2 Within a TV transmitter's coverage area, the permitted co-channel transmit power is zero. Outside the coverage area it gradually increases with increasing distance from coverage edge. If WSDs operate on frequencies adjacent to a TV transmitter's operating frequency, they are in principle allowed to transmit within the coverage area, but have to adjust their transmit power so that the interference they generate stays below the limit that TV receivers can tolerate based on their respective wanted signal level. That is, WSD located at the edges of the adjacent channel TV transmitter's coverage area will have a lower transmit power limit than the ones located in the centre of the TV coverage area. The same principle is also applied to non-adjacent channels, but due to the increase of the isolation between the respective channels, e.g., the second adjacent channel will have less stringent transmit power limits at the same location compared with the first adjacent channel. Other than these channel and distance separation based power limits there are no further limitations on transmit power.

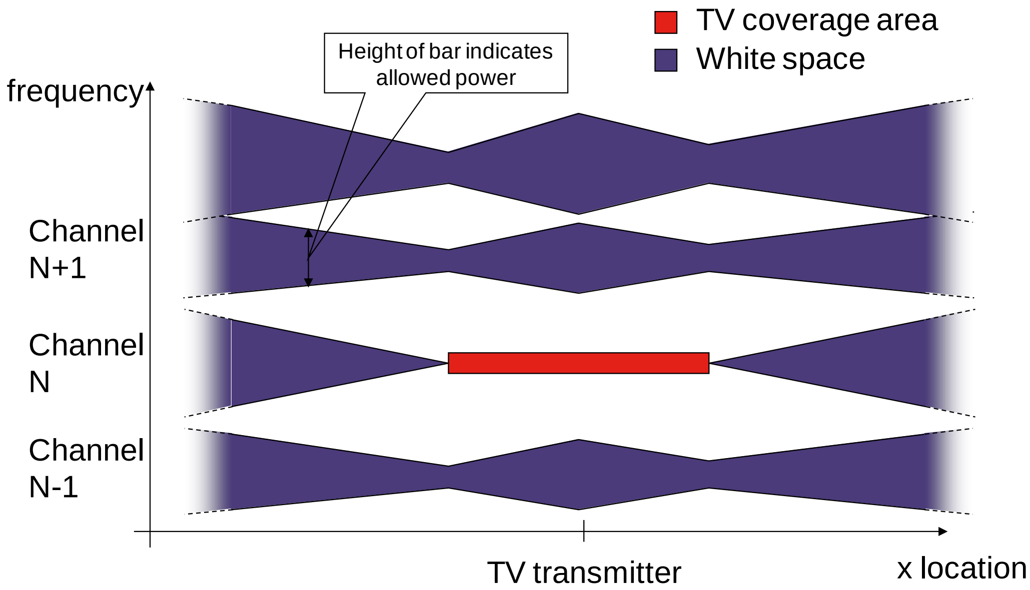

Figure 2: Schematic illustration of the basic principle of the SE43 approach to location-based maximum transmit power of WSD [6].

In the FCC rules the permitted maximum transmit power of WSD's is fixed as described in Section 2.2 (see also Figure 3). Around each TV transmitter's coverage area there is an additional protection distance in which WSD's are not allowed to operate at all on a co-channel, and outside this distance the allowed transmit power immediately goes up to the maximum allowed value. This principle is also applied to the first adjacent channel, only the protection distance is smaller. Beyond the first adjacent channel there are no limitations from the view point of one particular transmitter, but of course there may be other transmitters operating on other frequencies that would result in further restriction on the use of these frequencies.

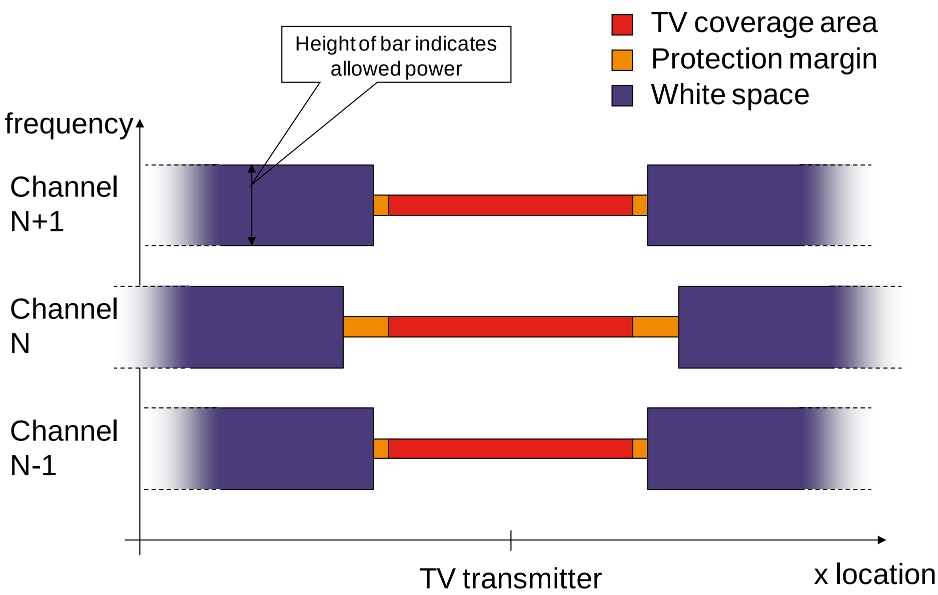

Figure 3: Schematic illustration of the basic principle of the SE43 approach to location-based maximum transmit power of WSD [6].

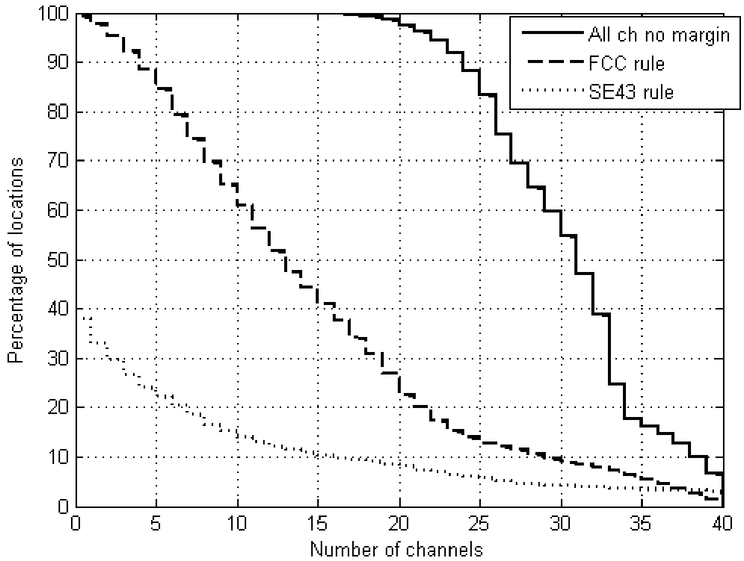

Figure 4: CDF of the number of white space channels available for usage in Sweden when using the FCC rules (dashed line) and the SE43 approach (dotted line). Also shown is the availability when no adjacent channel interference margin is applied [6].

We have found that the above differences between the SE43 approach and that of FCC can result in remarkably large differences in TV White Space availability even when the same set of TV transmitter and propagation modelling algorithms are used to compute white space channel availability.

As an example, in Figure 4 the number of available white space channels is compared (using the example of Sweden using the FCC and the SE43's approach, respectively. Since the emission masks for WSD in Europe are not yet fixed, for the SE43 approach we have assumed that WSDs use emissions masks that are similar to the current LTE equipment specification, as standardized by 3GPP which implies that adjacent channel interference is non-negligible for up to 9 adjacent channels. This leads to significantly higher probability of being limited by adjacent channel interference, for which very low minimum coupling loss (MCL) has to be assumed for calculating the maximum WSD transmit power.

As can be seen from Figure 4, there are very significant differences in the availability of TVWS channels depending on which rules are applied. This example illustrates clearly that the protection rules have a very significant impact on white space availability, and therefore care has to be taken such that, while the required protection is offered to incumbents, spectrum efficiency gains resulting from secondary use are not wasted. Furthermore, such large variations in white space spectrum opportunity resulting from different protection rules could have a significant impact on the viability of the same service depending on which rules are used in a specific country, and this may form an important obstacle in harmonization between Europe and the United Sates.

3.2 Protection from aggregate interference from secondary systems

While a single cognitive radio could be assumed to operate safely under the protection rules of the FCC, Ofcom and CEPT SE43 group, future deployment scenarios may involve large numbers of such devices, e.g. WiFi-type access points or cellular base-stations, whose aggregate emissions in white space channels could cause harmful interference to nearby TV receivers or PMSE users [8]. This problem is schematically depicted in Figure 5.

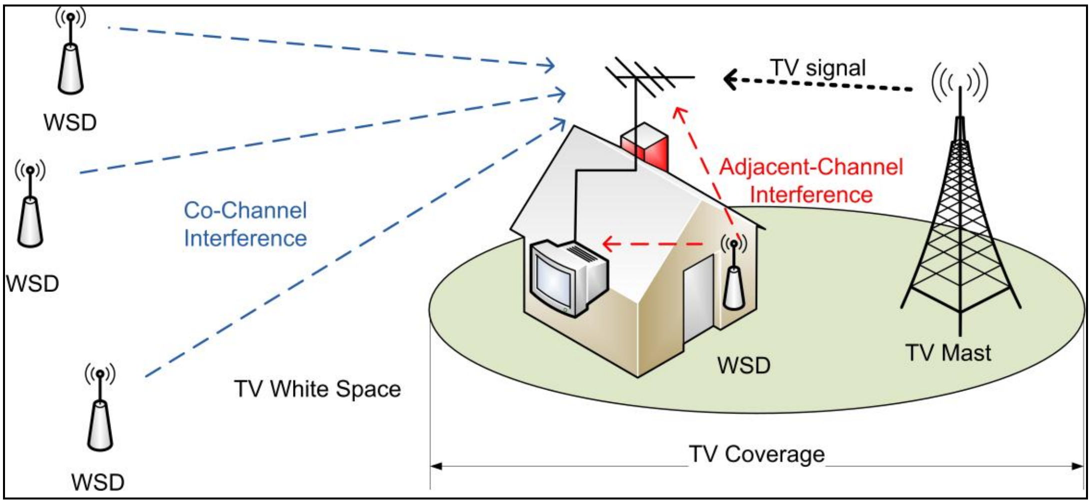

Figure 5: Aggregate interference from multiple WSD using the same white space channel may cause interference to TV receivers although transmission by each single WSD is below the harmful interference level.

FCC does not appear to have addressed the aggregate interference issue in its rulings but the problem has been considered by the CEPT SE43 group. The approach proposed by this group [19] is to introduce two additional margins to the protection ration of TV receivers when computing the permissible transmit power of WSD in a given channel. This additional margin is then assumed to offer sufficient protection against interference resulting from multiple WSD.

The main drawback of the approach adopted by CEPT SE43 is that in practice both density and transmit powers of WSD could vary depending on the service offered and deployment scenario. For example, WiFi-like use of white space may involve high deployment density of relatively low-power WSD while cellular deployment or the use of rural broadband connectivity may involve large sparsely deployed high power transmitters. Since in the SE43 approach the aggregate interference margin is a fixed value, harmful interference could result in situations where deployment of WSD is high. On the other hand, higher transmit power which could be beneficial in application such as rural broadband where deployment density is low cannot be achieved because the aggregate interference margin is far too conservative for such scenarios.

A more flexible approach to aggregate interference control would be to allow the geolocation database allocate transmit powers to WSDs not only based on their locations but also on its current estimates of the aggregate interference levels. Consequently, where WSD deployment is high, lower transmit powers are assigned by the database while where WSD deployment is sparse, higher transmit powers could be used. Such flexible approaches to aggregate interference control have been proposed by the QUSAR project to CEPT SE43 group (see Appendix). They are briefly described in the following section.

3.2.1 CEPT (SE43) approach

The ECC report 159 proposes technical and operational requirement for the possible operation of cognitive radio systems in “White Spaces” of the frequency band 470-790 MHz The report describes means to allocate power to secondary users – called White Space Devices. The WSDs can operate co-channel or adjacent channel to the TV broadcasters.

For co-channel WSD operation, the ECC report 159 considers one WSD at a time and the interference from multiple WSDs is counted for by using a multiple interference margin

(MI). The report only describes how the margin should be set if the number of interferers vary from one to four. For more interferers another safety margin (SM) can be introduced. A range of values is given in SE43 report for the SM (3, 6, 10, 19 dB).The ECC report 159 does not explicitly specify how to allocate the transmission power if more than 4 WSDs transmit simultaneously. Allocating too low value for the SM might violate the target SINR for some of the TV receivers if, for instance, the number of active secondary transmitters increases. This has been illustrated in QUASAR deliverable D5.2 [27] where the cellular capacity of TVWS in Finland is studied. The SINR distribution at the TV cell borders is illustrated in Figure 6. For a smaller cell size more secondary transmitters are simultaneously active and because of that the aggregate interference increases.

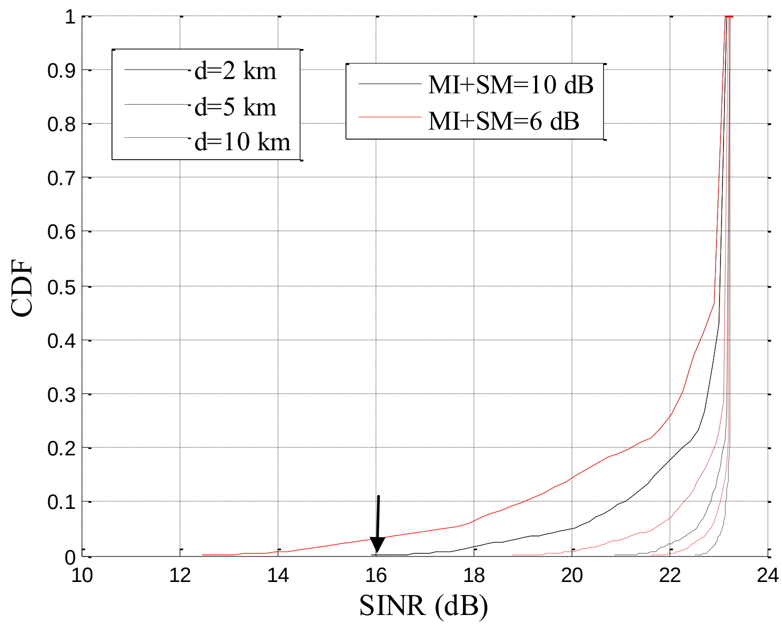

Figure 6: SINR distribution at the TV coverage boundaries computed with aggregate interference from all secondary transmitters which use the CEPT SE43 proposal to adjust their transmit power. Different secondary cell radius and interference margins MI+SM are considered. The target SINR ratio for successful reception by TV receivers is SNIR=16 dB (marked by arrow)

Also, the ECC report 159 proposes a power allocation scheme for a WSD operating inside the coverage area of adjacent TV channels. For adjacent channel operation the spatial separation between the WSD and the TV receivers is not known. Because of that a reference geometry rule is proposed for allocating the power. The reference geometry rule underestimates the permitted power level of the WSD as illustrated in QUASAR D2.4 [28]. A statistical-based power allocation method is proposed in D2.4 that allocates higher transmission power levels in comparison with the deterministic reference geometry rule without violating the protection criteria of the TV system.

3.2.1 QUASAR's proposals

In case of TV, the primary system protection constraint can be expressed in terms of the *area location probability* – that is, the probability that in a randomly selected location at the coverage area of the TV system, the Signal-to-Interference+Noise Ratio (SINR) is above the minimum requirement for quasi-error free reception. Given the deployment area of the WSD network, we can determine critical points (pixels) on the primary protection zone (coverage area) that set a limit for the WSD interference. See Figure 7. A straightforward but computationally very heavy approach is to determine the power of a new WSD by performing Monte Carlo simulations to determine the area location probabilities at the critical points. It turns out that we can find close form approximation for the interference and SINR distributions and thus greatly simplify the computations.

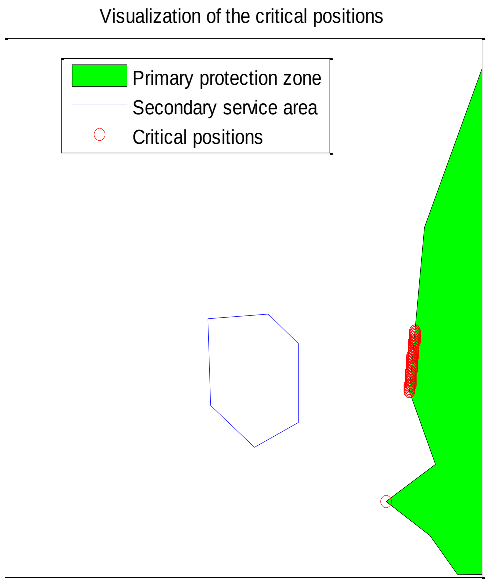

Figure 7: An example illustrating a set of critical points located along the TV coverage edge for a secondary service area.

Shadow fading is typically modelled using log-normal random variables. Hence the TV signal strength and the interference power from a single WSD can be assumed to follow the log-normal distribution. It turns out, that the computations can be greatly simplified by modelling the shadow fading using log-normal distribution and applying the Fenton-Wilkinson (FW) approximation [29] to model the sum of many – possibly correlated - log-normal random variables as a single log-normal random variable. With this type of approximation, if both signal power and interference power modelled as log-normal random variables also SINR becomes log-normal.

The FW approximation is particularly interesting to use in the context of interference modelling for secondary usage of spectrum for several reasons. First, it is efficiently computed in closed-form. This is highly important, e.g., when computing the aggregate interference or SINR to a large set of points (e.g., when computing the probabilities of harmful aggregate interference or area location probability for an area). Second, perhaps even more importantly, the FW approximation is known to provide good approximations for the upper tails of the probability distribution. This is highly relevant when modelling secondary interference to primary users since one typically then looks at a situation for which the probability of harmful interference must not exceed a low number (e.g., 0.5% or similar). For such a case it is of little importance if the approximation precision is lower towards the middle or lower parts of the probability distribution function. This behaviour is illustrated in Figure 8. For SINR computations the log-normal approximation becomes accurate towards the lower end corresponding to high (e.g. 90%) area location probability.

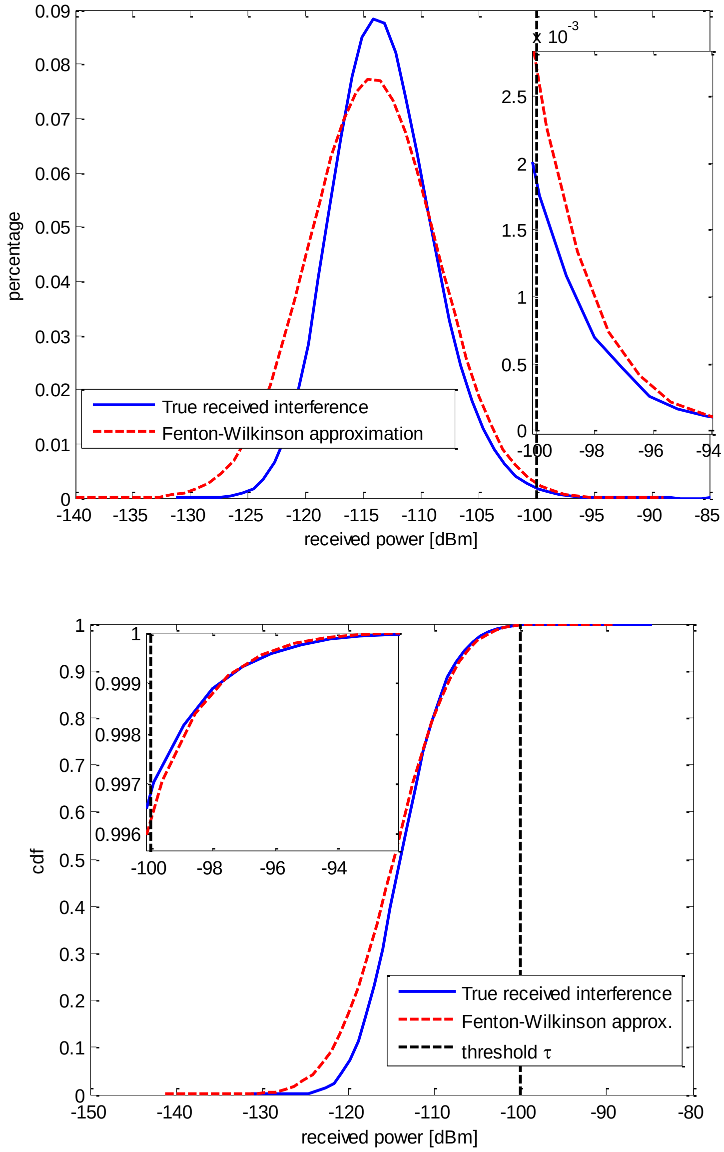

Figure 8: Comparison between the Fenton-Wilkinson approximation and the true distribution, calculated using Monte Carlo simulations, of the aggregate interference generated from five secondary transmitters, each experiencing log-normal fading.

For each critical point we can easily determine the area location probability for given interference statistics (mean and variance). Alternatively, we can determine the amount of tolerable interference – interference margin – in each point. It turns out, that we can determine a conservative bound $I_{\Delta,p}(q)$ for the mean aggregate interference I_p (in Watts) for each point p such that as long as $I_p \leq I_{\Delta,p}(q)$ the primary system area location probability is guaranteed to exceed q. This interference margin can be treated as a resource and shared among multiple systems. For instance, the database can delegate the interference control to different areas simply by allocating in each area a fraction of the interference margin I_{Δ_k} (See Figure 9). In that case the sum of allocated interference margins to the areas should not exceed the entire interference margin:

$$\sum_{k=1}^{K} I_{\Delta_k} \leq I_{\Delta}.$$

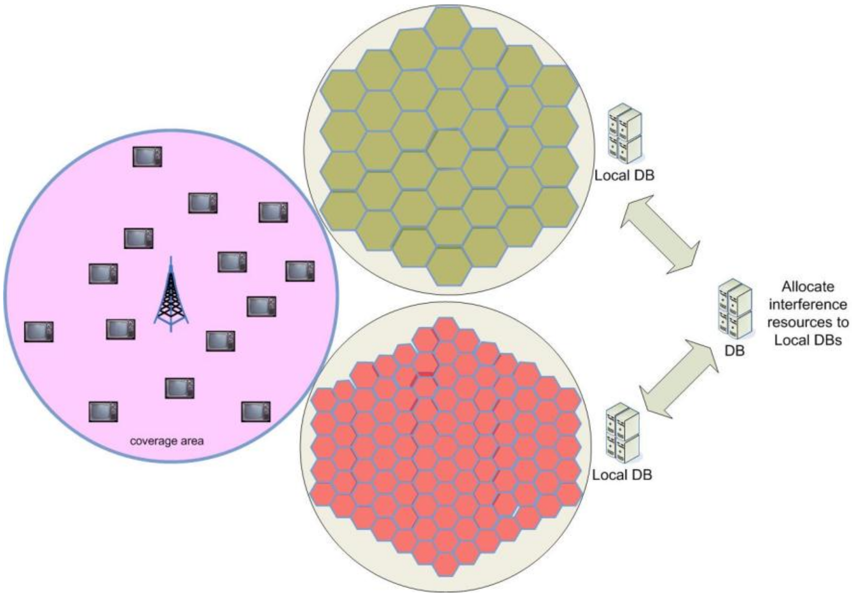

Figure 9: Two databases allocate the transmission power to white space devices in each area. The aggregate interference margin for each area is negotiated between the two databases.

The required area location probability was 90%, which translates to 10% outage probability in Figure 11 for a SNIR target of 16.3 dBm. As can be seen from the Figure, the aggregate interference from the WSD system does not violate the TV system area location probability (outage) bound. For more details see D2.4 [28] and the references therein.

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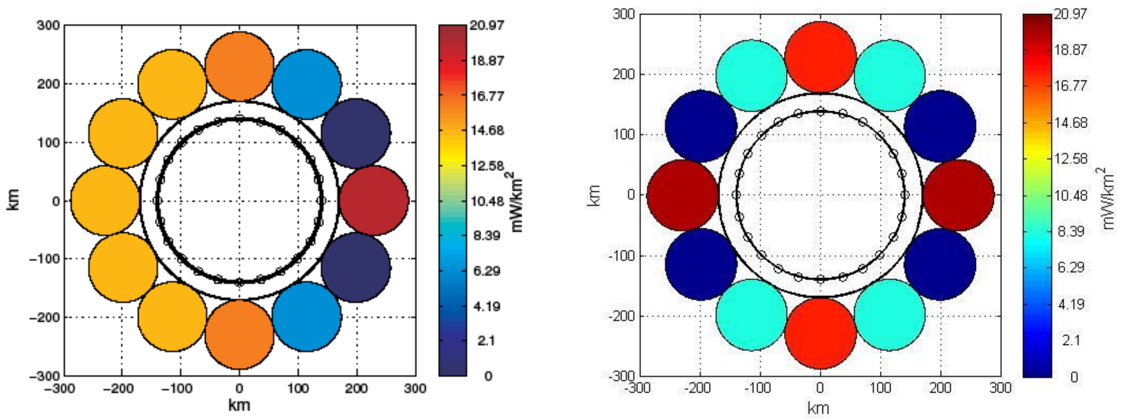

Figure 10: Power density allocation for twelve cellular secondary base stations deployed outside the protection area of a TV transmitter using flexible aggregate interference control.

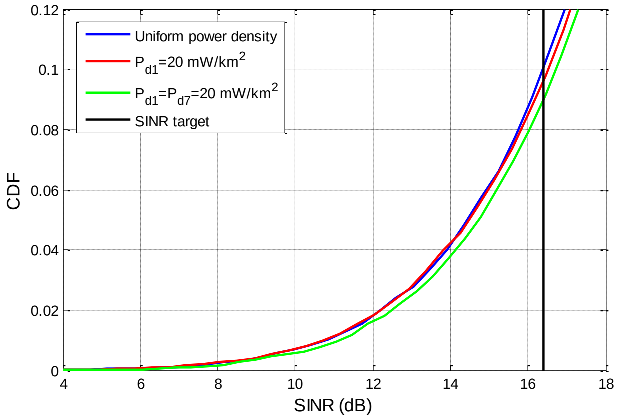

Figure 11: Distribution of aggregate interference at the TV receiver test points using a location and density-dependent transmit power allocation.

Another approach to control the aggregated interference which is applicable to the situation where the primary receiver density is very low with known locations (as is the case in e.g. the aeronautical bands) is using the in D4.3 [30] proposed model for aggregated interference that is based on introducing an exclusion region around the primary receivers.

Having a valid model for the aggregated interference allows a database to control the secondary usage to adequately protect the primary receiver. The application of the exclusion region model is outlined below.

Based on the location of each secondary user, it makes an estimate of the interference that it will generate towards a primary receiver. Note that the locations of the primary receivers may be available via a geo-location database. The database is also assumed to provide a threshold on the allowed interference a single secondary device is allowed to cause to the primary receiver. If the estimated interference is below the threshold the secondary user may transmit using the secondary opportunity. If the secondary devices provide the database with information on their locations the database may adjust the allowed interference threshold based on the geographical distribution of the secondary users. This will in effect adjust the exclusion region. If no information is passed from the secondary users the database must resort to a more conservative setting for the interference threshold.

Yet another method for controlling the aggregated interference has been proposed in QUASAR deliverable D4.3 [30] and in a contribution to CEPT (SE43) [31], which is based on using a power density model for aggregated interference. The model is in particular applicable to scenarios where there are a lot of secondary transmitters and primary receivers with unknown locations. This model is readily applicable to TVWS scenarios and offers a computationally efficient way of finding the aggregated interference.

The application of the power density model rely on a database allocating transmit powers to secondary users in various regions depending on the location (see Figure 12).

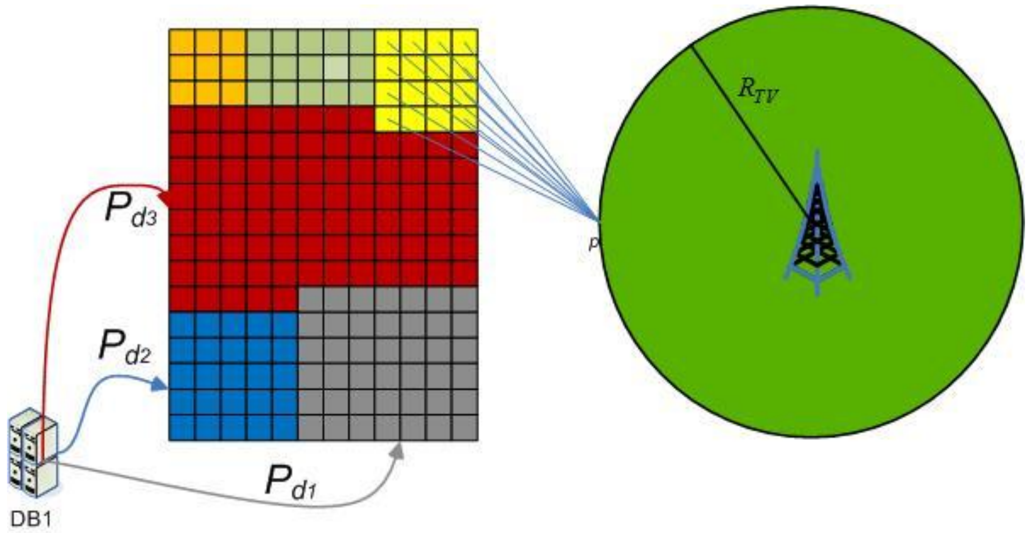

Figure 12: Area-based allocation of transmit power by a geolocation database. The database allocates a separate power density budget to multiple regions such that the interference margin at TV test points resulting from aggregate interference are not violated.

Some benefits of the flexible aggregate interference control methods proposed by QUASAR are:

- They allow flexible allocation of transmit power to WSD based not only on location but also deployment density. Therefore, higher transmit powers could be allocated in areas where deployment of WSD is sparse but larger cells are required, e.g. for rural broadband, while lower transmit powers are allocated in areas where deployment is dense, e.g. white space access point or femtocells but small cell sizes are used. This maximizes the available power to WSD for each scenario while also offering guaranteed protection to TV receivers.
- Permissible aggregate interference margin can be treated as a new resource that could be shared among multiple systems and databases. The regulator, for example, could allocate to each database provider a share of this resource. In turn database can allocate power to secondary users based not only on channel availability but also on the available interference margin. If a database runs out off of its allocated interference margin it could either deny a requesting WSD a channel, in order to avoid exceeding the margin, or acquire additional margin through negotiation with other databases.

3.3 Alternative to the licence-exempt model

A key issue of the licence-exempt model is that fair spectrum sharing can effectively only be achieved when all devices are using the same set of sharing protocols, as well as having similar service requirements. However, since there are several, possibly competing technologies under development for white spaces, including the emerging IEEE standards IEEE 802.22 and IEEE 802.11af, ECMA-392 and Weightless, as well as variants of LTE. It is unlikely that these can share the spectrum among each other in an equitable manner. This means that regulator either has to leave the fairness problem for industry to solve (which may be in conflict with the principle of technology neutrality since it implicitly favours the first white space technology that comes to the market) or they have to specify a set of sharing protocols (also known as politeness rules or spectrum etiquettes) themselves. Since regulators are typically lacking both the resources and the experience required for standardization of such rules, it appears questionable if this latter approach would be successful in practice. In this context, one important industry initiative that is worth mentioning is the IEEE 802.19 standardization project [31] which is aiming to specify radio-technology-independent methods for coexistence among dissimilar or independently operate wireless devices and networks in order to enable a better sharing of spectrum and a better quality of service in TVWS.

In addition to fairness, quality of service provision in TVWS is highly desirable for important applications of the technology, including broadband wireless access for rural communities and smart grid communications, but is difficult to achieve without coordination. Such services in TVWS (and other examples of secondary spectrum) would require access to spectrum which is predictable, measurable and offer a higher degree of certainty currently difficult under the license-exempt model.

In particular, service providers planning to deploy the certain long-range services in license-exempt (LE) TVWS require sustained access to spectrum which is predictable and measurable. This is essential to offer certainty of the offered service with respect to service availability and quality. With the emergence of geolocation databases as the regulators' preferred approach to incumbent protection, mechanisms to ascertain the availability and quality of the TVWS spectrum are becoming available. This approach can largely eliminate the fundamental uncertainty associated with a sensing-based approach to TVWS access. However, under the license-exempt spectrum management model currently adopted by both the FCC and Ofcom, there is nothing that prevents secondary white space infrastructure being deployed by different operators in same location and same channel. For example, for a long-range service that typically has a larger coverage range the probability of capturing contending users and interference goes up as a function of coverage area unlike the typical short-range conventional WiFi systems. This is illustrated in Figure 14 where a rural broadband service is deployed in a region based on White Spaces and provides a service to tens of houses over a range of few kilometres. If within this coverage area any other secondary service is operating on the same channel, it would significantly affect the performance of the service. At best, the license-exempt mode in this case would guarantee everyone a share of the available bandwidth, but there is no guarantee of how much each will receive. The license-exempt model may become increasingly problematic as usage volumes increase because the associated delay variability would eventually become unacceptable for typical rural broadband usage.

To address the service protection problem for long-range services in license-exempt white spaces, we introduce a novel light-touch regulatory model called "Soft-Licence". A summary is provided here as illustrated with Figure 15. Full details of the proposal are available from [26].

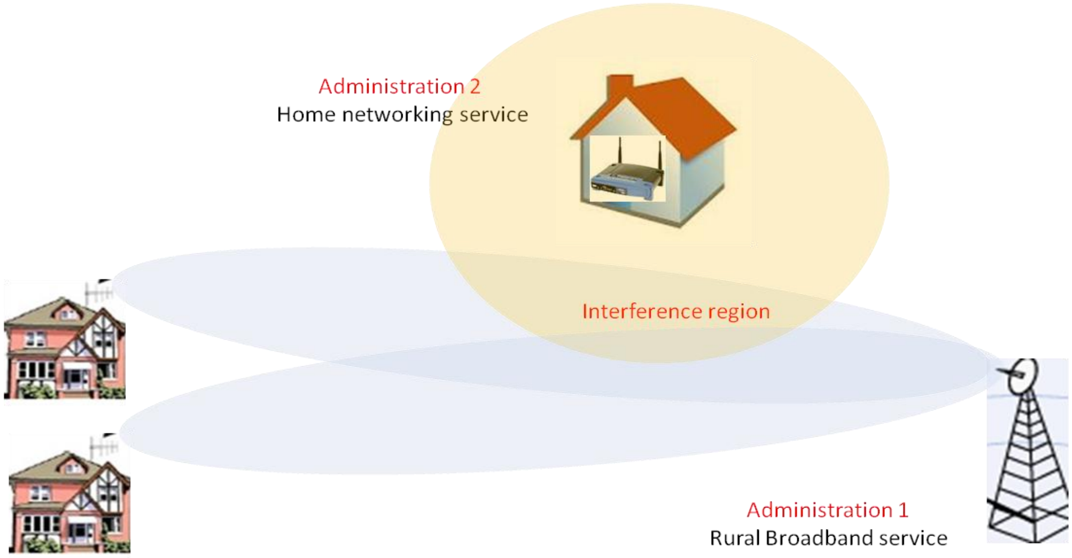

Figure 13: Two co-located systems belonging to different administrations sharing license-exempt White Space channel.

In current TVWS regulation there are two service categories identified, the 'Primary Service' category which comprises the DTT and wireless microphone service and the 'License-Exempt service' category. A new intermediate service category called 'Protected Secondary service' category is proposed as shown in Figure 15. A service such as rural broadband could be tagged as a Protected Secondary service by the regulator and protection can be granted with a Soft-Licence concept. The geolocation white space spectrum access control functionality can be extended to ensure both the Primary and Protected Secondary services are protected from the license-exempt service category i.e., all license-exempt services in the coverage area of a Protected Secondary service would have to operate at a power level determined by certain interference protection ratio, i.e., no higher than some specified value below that used by the Protected Secondary service. The spectrum access functionality in the geolocation white space database is implemented in following control flow:

1. Primary service(s) – these are licensed users of the spectrum and will be given exclusive access to the spectrum and full transmission rights. No conditions or checks applied. Examples - DTT, Wireless microphone
2. Protected Secondary Service(s) – these are Soft-Licence users, protect the Primary service and are granted restricted spectrum usage rights under the rules defined by the Soft-Licence. Examples –rural broadband, delay-sensitive telemetry service, etc.
3. Unprotected Secondary Services(s) - these are licence-exempt users and are not provided any service guarantees but only connectivity, all conditions and checks applied for protecting primary and protected service category. Example –Home networking WiFi.

Services that need protection are identified by the regulators for a Soft-Licence. Soft-Licence is a novel flexible licensing mode that sits between the exclusive license and license-exempt model. It is a pseudo-license category i.e., when viewed by license-exempt service it makes the Protected Service appear as a Primary service while when viewed from a Primary service perspective it makes the Protected service appear as any license-exempt system. It should be noted that the Primary service could cause service disruption to the Protected Secondary service as protection is offered only from license-exempt users. This constraint would change on relatively slow time-scales due to changing Primary user requirements / usage. Further there is an element of statistics regarding spectrum availability as to whether or not a Protected Service Category can be accommodated in the same coverage area. Consequently, it follows that obtaining a

Soft-Licence will probably require the Protected Secondary provider to enter into negotiations with the regulators. Examples of how the constraints would shape the Soft-Licence would be –

- it is not a national or 24x7 service, but a limited one - specified for certain regions or specified for certain times of the day only (temporal basis).
- there may be different frequency channels reserved in different regions/different times due to the constraints of the primary systems
- a certain amount of channel bandwidth would be reserved for the protected secondary service category
- duration of a Soft-Licence would be shorter than that of an exclusive licence.

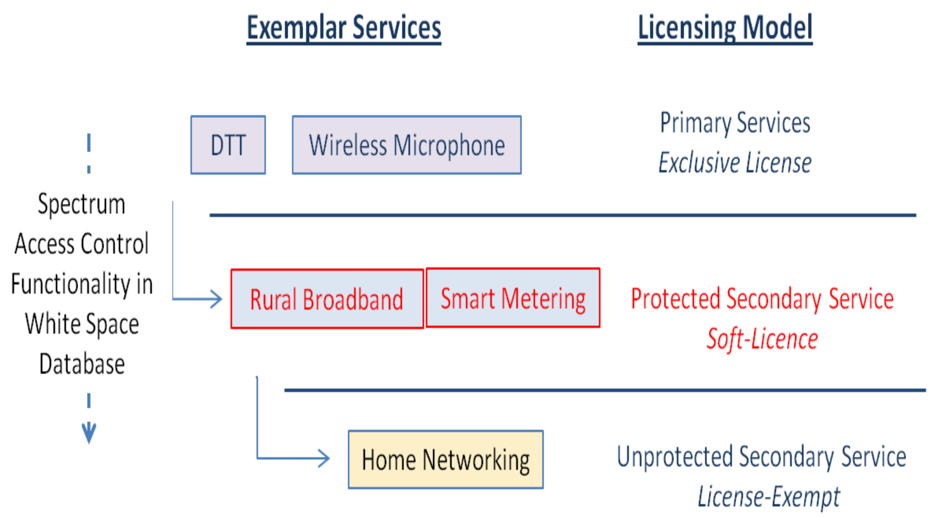

Figure 14: Example of protection of rural broadband service with Soft-Licence & Protected Service Category.

Overall the Soft-License concept provides a fine balance between how best to enable efficient use of spectrum while at the same time encourage service providers to deploy infrastructure based on spectrum shared amongst multiple systems.

4 Opportunities and regulatory challenges in secondary sharing of aeronautical and radar bands

Substantial amount of useful spectrum, i.e. lower than 6 GHz, is allocated to radar and aeronautical navigation systems. Some of these frequency bands and their primary usage are listed below:

- 960-1215 MHz – aeronautical navigation [33]
- 2700-2900 MHz – air traffic control, meteorological aids [34]
- 2900-3100 MHz – maritime navigation, radiolocation [35]
- 5150-5800 MHz – meteorological aids, air traffic control [36]

Although the above-listed spectrum allocations are globally coordinated in a large sense, the detailed frequency assignments and operational facts on these bands are specific to each country. For example, the 2.7-2.9 GHz band is heavily occupied by air traffic control (ATC) radars in the UK (about 80 radars all over the UK [37]), but mostly empty in Sweden. Some countries allocate other bands to the radars for their specific needs, e.g. the USA employs 3500-3650 MHz for ship-borne navigation radars [38].

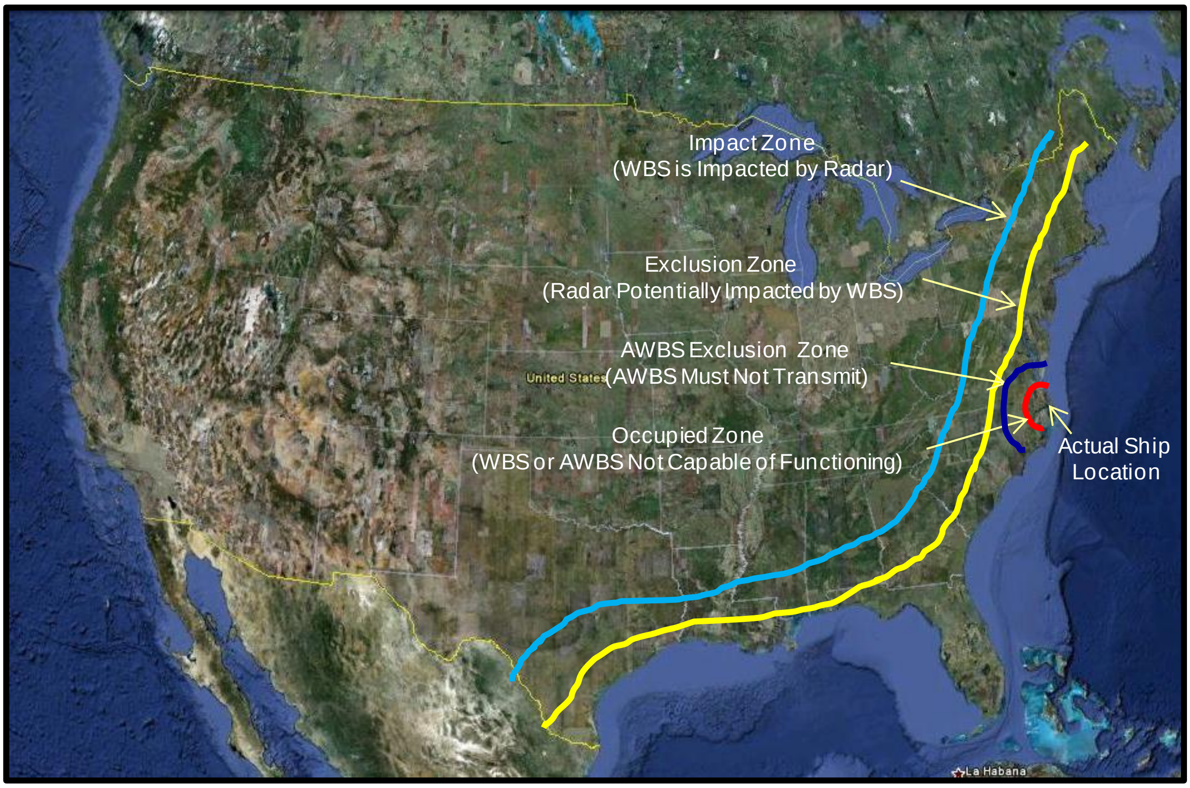

Figure 15: An example of secondary use of spectrum used by ship-borne radars, as being discussed in the United States [44].

The above-mentioned frequency bands have diverse regulatory status. It is noteworthy that 5 GHz spectrum (5150-5250 MHz, 5250-5350 MHz, and 5470-5725 MHz) has already been open to secondary use of RLAN system since 2003. ETSI standard EN 301 893 specifies a technical means by which the secondary devices have access to the spectrum [39]. This is called dynamic frequency selection (DFS), which relies on spectrum sensing by an individual RLAN network to decide whether it can use a particular channel or not. In short, a RLAN network is entitled to access a channel if the received radar pulse power is less than of fixed threshold, e.g. -62dBm or -64dBm depending on the RLAN transmission power.

We also mention that the USA, 3500-3650 MHz is considered to be a "fast track" for mobile broadband service provision. A geographically-limited licensing scheme to protect the ship-borne radars was examined in [39]. The US Government is also considering secondary access to other bands, including the Federal spectrum, in particular for mobile broadband. For example, the FCC has released a Notice of Inquiry on "Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies" [15], which is soliciting comments on how to create incentive to facilitate dynamic spectrum use in such bands.

Secondary access to aeronautical spectrum has not been seriously discussed by the regulatory bodies thus far. The ATC radars and aeronautical navigation aids have stringent protection requirements because they perform operations regarding safety-of-life. In the QUASAR project, we carried out an in-depth study about the feasibility of secondary access to this spectrum [41-42]. The results will be discussed in the subsequent sections.

4.1 Detection and protection mechanisms for radars

In this section our discussion will focus on ground-based ATC radars operating in 2.7-2.9 GHz band whose technical characteristics are described in [36]. Note that most of these radars operate under the same working principles, and thus the discussions here are widely applicable to many other types of radars, e.g. weather forecast and shipborne navigation radars. Aeronautical equipment such as distance measuring equipment shares the basic principles with the radar, but technical details differ from it. Nevertheless, it was found that the high-level conclusions about the DME are quite similar to those of the ATC radar [42].

4.1.1 Detection

4.1.1.1 Sensing-only detection of radar signals

A radar emits strong pulses, and receives the reflected rays to locate or identify the target objects. It means that the radar transmitter and the receiver operate on the same frequency at the same location. This fact makes spectrum-sensing a feasible and favourable option to detect radar. Unlike the digital TV broadcasting, you can find where the primary receiver is by sensing the primary transmitter. The sensing-only detection method has already been adopted by the DFS implemented in RLANs in 5 GHz band.

Despite the fact that it is feasible and already in use, the sensing-only method is not a desirable method of opportunity detection. First, it is difficult to prevent a wrongful transmission nearby the radar. Since the radar pulses are short and bursty, there is always a risk that the pulses are not detected by the secondary users even with high signal strength. Second, aggregate interference is not properly controlled by imposing a fixed sensing threshold to individual secondary devices. It could be possible to prevent excess aggregate interference by setting an extremely conservative margin, but it will severely reduce the secondary access opportunities.

4.1.1.2 Geolocation database approach for radars

The geo-location database is the most feasible form of opportunity detection in TVWS. Similar type of database can be constructed in radar and aeronautical spectrum. The database will be effective in regulating the wrongful transmissions by nearby secondary users and controlling the aggregate interference.

4.1.1.3 Sensing + database detection

With this method, secondary users are assumed to be attached to a geolocation database and fed information about the radar, e.g. location, centre frequency, maximum pulse power, pulse shape, antenna gain, and rotating pattern. Then, the secondary users will be able to make an accurate estimation of propagation loss in slow time scale, i.e. distance-based path loss and shadow fading via spectrum sensing. The database finally decides whether the secondary users can use the frequency band with a certain transmission power. It is shown in [41] that the combination of sensing and database can significantly improve the opportunity of secondary users compared to the pure database method.

4.1.2 Protection of radar operations from aggregate interference

The primary protection rule makes an enormous impact on the performance of the secondary access. However, the rule for the radar spectrum has not been well discussed. Therefore, we have proposed a simple protection rule that was motivated by the DFS mechanism [41-42]. We target a scenario where many low-power secondary users such as Wi-Fi access points, femtocells, and mobile phones are simultaneously accessing the spectrum over a large geographical area. The sensing + database detection method is assumed to be employed by the secondary users.

The basic rule is that the radar should be protected from the harmful interference that could potentially be generated by the aggregation of interference from multiple secondary users. Due to the random nature of the radio propagation, we proposed a rule based on the probability of interference violation:

$$\Pr\left(I_{su}^{agg} \geq THR_{rad}\right) \leq \beta_{rad} . \quad (5\text{-}1)$$

Notations used above are:

I_{su}^{agg} : aggregate interference power received at the radar from the secondary users,

THR_{rad} : interference threshold value for the radar,

β_{rad} : maximum allowable probability of interference violation.

The value of THR_{rad} is determined by the required interference to noise ratio (INR). This corresponds to approximately -110dBm for typical ATC radars [M1464]. In addition to the required INR, protective margins such as apportionment margin and fast fading margin can be applied.

Although the proposed protection rule is based on a probabilistic approach, the allowed interference violation β_{rad} should be sufficiently low to ensure the proper protection of the radar because ATC radar performs a function concerning safety-of-life. A reasonable value of β_{rad} has not been fully investigated in the literature. In [41,42], we used β_{rad}=0.001% as used in [42], though it may result in a pessimistic result. It means almost zero violation from a practical point of view. Moreover, β_{rad} does not necessarily represent the event of radar failure. It rather means the probability that I_{su}^{agg} exceeds THR_{rad}, which is already conservative due to the protective margins.

The aggregate interference I_{su}^{agg} depends on the decisions of secondary users on the transmit powers. Here, we employ an assumption that that every secondary transmitter uses the same power $P_{tx,su}$, and then it makes an individual ON/OFF decision based on its estimation of propagation. Let us consider an arbitrary secondary user j. We define ξ_j as the interference power that the radar would receive from the user j if it were to transmit. Also, let $\overline{\xi_j}$ be the estimate of ξ_j which is measured by j. The decision of j relies on the individual interference threshold I_{thr}, which is given to every secondary user in the system by the central database. A proper value of I_{thr} should be determined depending on radar protection parameters (THR_{rad} , β_{rad}) and the aggregate interference caused by the secondary users. As a result of the decision, the actual interference from the SU j to the radar is given by

$$I_j = \begin{cases} \xi_j, & \text{if } \overline{\xi_j} \le I_{thr}, \\ 0, & \text{otherwise.} \end{cases} \quad (5\text{-}2)$$

Then, the aggregate interference can be expressed by

$$I_{su}^{agg} = \sum_{j=1}^{N} I_j , \quad (5\text{-}3)$$

where N denotes the total number of the SUs in the investigated area.

As mentioned earlier, the above protection rule resembles the DFS which is specified in ETSI standard EN 301 893 [40]. However, our scheme differs from the DFS in the sense that we consider adaptive adjustment of I_{thr} depending on the intensity of secondary traffic in order to ensure the protection or the radar and to maximize the opportunity to the secondary users.

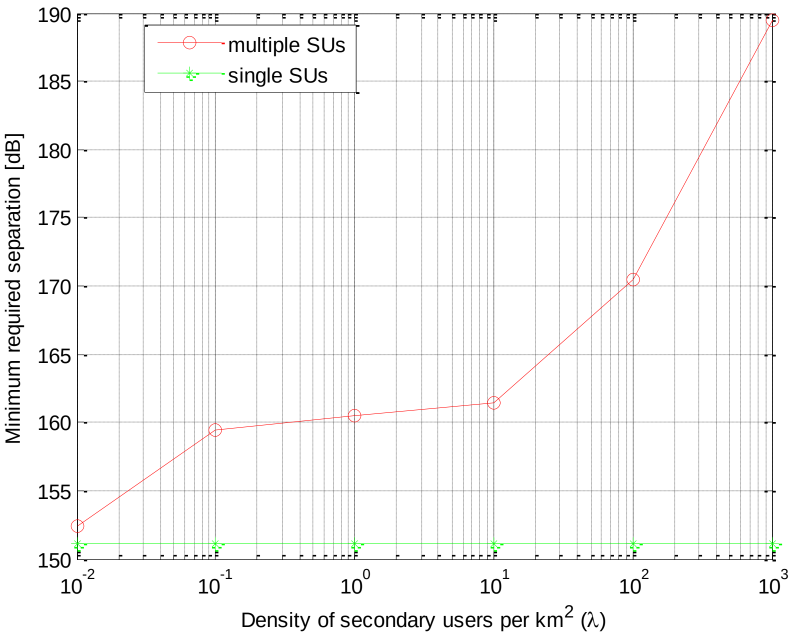

Figure 16: Minimum required separation between radar and secondary users as a function of secondary user density; Transmit power of the secondary users is 10 dBm; The height of the secondary users is 1.5m [42].

The protection mechanism we proposed results in a propagation-dependent exclusion region within which the secondary use of spectrum is prohibited. The feasibility of secondary access can be evaluated in terms of minimum required exclusion region for massive deployment of the secondary users. Figure 17 illustrates the minimum required separation between the radar and the secondary users in dB scale as a function of the traffic intensity of the secondary users. In this figure, the secondary users are assumed to be uniformly distributed over a large area, and all of them want to have access to a frequency channel overlapping the radar operation. It is observed that the separation of around 170 dB is required to accommodate 100 simultaneous secondary transmissions per square kilometre. This corresponds to a physical exclusion distance of a few kilometres when the secondary users are located below the rooftop level. Considering the ATC radars are usually located near airports that are at least a few kilometres away from downtown, it suggests that the massive use of low-power secondary systems in downtown is feasible on the same frequency of radar operation.

In summary, large scale deployment of low-power secondary users requires an exclusion distance of only a few kilometres under the assumption that all the secondary users employ the sensing + database detection scheme and the protection rule described in the previous section. The feasibility can further increase significantly if the secondary systems utilize the portions of spectrum that do not overlap the radar operation frequencies.

5 Summary and recommendations

5.1 Summary

In this deliverable we critically reviewed and examined the current status and emerging trends in regulation of secondary access to radio spectrum in the United Sates, UK, Europe and elsewhere. A regulatory framework for secondary access to unused portions of TV broadcasting bands, the so-called TV White Spaces, has been finalized in the United States, is near completion in the United Kingdom, and is also under way on a European level within CEPT and in Finland. Regulatory activity has also been initiated in a number of other countries, including Canada, Singapore and Korea and Japan. The "first-wave" of regulation has primarily focused on putting in place the required mechanisms and regulatory framework for geolocation and sensing that ensure protection of primary systems against harmful interference from a "single" secondary user. The regulatory aspects of multiple secondary users using secondary spectrum, such as aggregate interference and sharing, has so far only being partially addressed in the current regulatory frameworks.

With growing interest from the industry in exploiting white spaces for a range of applications, and the emergence of geolocation databases as the regulators' preferred approach to protection, we believe the focus for the "second wave" of regulatory work should shift to addressing challenges in the use of white spaces by large numbers of WSDs. These may use a range of radio technologies to access white spaces and would potentially compete in sharing the spectrum, if the corresponding regulation chooses to allow that. We also believe that more discussion is needed on the authorization schemes and the associated rights of secondary users in order to find solutions that support public policy and a range of industry objectives.

Key remaining challenges that were identified and discussed in this deliverable included

- how to protect primary systems from aggregate interference from many cognitive radios
- how to share white space spectrum, in particular between high and low power communication services.

A number of proposals were then put forward to deal with these challenges and their applicability was demonstrated using concrete scenarios drawn from QUASAR use case scenarios, including cellular use of white spaces and rural broadband provision in white spaces.

With the prospect of an imminent "spectrum crunch" resulting from a very large growth in wireless data, there is currently great interest in the use of secondary spectrum sharing from regulators, as well as industry. Therefore, in the scope of the discussion around of secondary access to TV bands important lessons have been learned that will facilitate and stimulate secondary sharing in other bands.

Aeronautical navigation bands (960-1215 MHz), and the civilian radar band in the 2700-2900 MHz and 2900-3100 MHz appear to be promising candidates for secondary use. In particular in many cases the locations of radars are static and public knowledge, making a geolocation databases approach to incumbent protection and protection possible. Furthermore, since for most radars receiver and transmitter antennas are co-located the hidden node problem which plagues sensing-based access to TVWS is not a major problem in the case of secondary use of radar bands, and this opens up new opportunities for temporal use of radar spectrum, in particular when a radar has predictable sweep patterns. There are, however, legitimate concerns regarding the potential risks for safety (and national security in case of military radars) which may results from opening these bands for secondary use. In addition, accurate and comprehensive information on the capabilities of radar and other incumbent systems is often missing, which represents an obstacle towards identifying and opening up the actually existing opportunities in those bands. Here, regulators will play an important role in facilitating more efficient spectrum usage by actively working towards a more detailed understanding of incumbent system's behaviour and characteristics.

5.2 Recommendations to regulators

5.2.1 Clarifying differences between the CEPT (SE43) and the FCC approach to protection

In this report, and through extensive quantitative studies in the QUSAR project, it has been shown that there are important differences between the CEPT (SE43) and FCC approaches in implementing protections for geolocation-based access to TV white spaces, and we recommend that they should be further clarified among regulators. The regulator's primary aim is understandably to protect primary systems. However, over-conservative protection rules may result in considerable wastage in the efficiency gained from secondary use of white spaces and curtails important applications by the industry. The QUASAR project has developed some of the required tools that could assist regulators in addressing this dual objective and assessing pros and cons of protection rules quantitatively.

5.2.2 Implementing flexible approaches to aggregate interference control

If successful, future scenarios for exploitation of secondary spectrum access by industry be it in TV bands or other bands, will inevitably involve not one or a few secondary devices but potentially tens of thousands or millions of cognitive radios that emit signals in secondary spectrum. In worse-case scenarios the resulting aggregate interference can add-up causing harmful interference.

So far the standard regulatory approach to deal with the aggregate interference issue has been to include an extra protection margin when fixing the permissible transmit power of devices in a given channel. In dealing with aggregate interference of multiple white space devices, both Ofcom and the CEPT (SE43) have adopted this approach in defining location-based transmit powers of WSD.

This additional margin however is (at its best) an "educated" guess as it is hard for regulators, or anyone, to make predictions about future proliferation of secondary devices. However, as is shown in this report and QUASAR's WP2 and WP4, a conservatively chosen margin could severely and unnecessarily limit the maximum transmit power available to cognitive radios, thereby curtailing promising use cases of the technology. On the other hand choosing the margin too low increases the risk of harmful aggregate interference.

While in the case of sensing-based cognitive radio there may be no satisfactory technical solution for the above problem, in the case of geolocation-based systems more flexible approaches to aggregate interference control could be implemented. Simply put, instead of apriori "speculating" about aggregate interference levels, these could be dynamically computed by geolocation databases, and transmit powers allocated to devices such that interference is kept below harmful levels at all times. This means that higher transmit power could be allocated where deployment density is low, e.g. in rural environments, while lower power levels are allocated for dense deployment. Several approaches for a more flexible aggregate interference control have been proposed, implemented and demonstrated by QUASAR, as well as being proposed to CEPT (SE43), which are both to TV and other bands.

We recommend that the use of such flexible approaches to aggregate interference should be considered by regulators, in order to promote flexibility and maximizes the benefits of geolocation-based white spaces access.

5.2.3 **Not one licensing type fits all!**

The geolocation database technology is not only in the short-term the best approach to protection of primary systems in TV bands but it also offers regulators a new tool for managing spectrum dynamically. In particular, alternatives to the licence-exempt model for secondary sharing of white spaces, including the soft-licensing approach described here or spectrum reservation in a given region could be implemented in geolocation databases.

Such alternatives are important to enable a certain QoS for the secondary user[5]. We recommend that the regulatory implementation options for implementing such innovative uses of geolocation databases should be further evaluated in order to provide the industry with a range of licensing options for commercial exploitation of TVWS, in particular for applications such as rural broadband and cellular systems. The use of geolocation-based licensing approaches should be also considered in the context of the Licensed Shared Access concept which is currently being investigated by the European Commission, as a means to enhance the level of flexibility offered by LSA.

5.2.1 **Opening other bands for secondary sharing**

Work carried out within the QUASAR projects has shown that there are significant opportunities for secondary sharing in aeronautical navigation and radar bands *in addition and beyond* the 5150-5350 MHz and 5470-5725 MHz radar bands which are already to secondary access for WLAN through dynamic frequency selection (DFS). In many cases the location of radars are static and (in some cases) publicly available, making a geolocation database approach to protection highly feasible. On the other hand, since radar receiver and transmitter antennas are co-located, the hidden node issue which plagues sensing-based access to TVWS is not a major issue and this opens up the possibility to exploit both spatial (through geolocation databases) and temporal (thorough geolocation-assisted sensing) sharing opportunities.

Regarding potential uses of radar bands, the 960-1215 MHz band is of great interest because of its excellent propagation and range characteristics for application which require good range and penetration through buildings and walls such as telemetry and medical monitoring. The 2700-2900 MHz and 2900-3100 MHz bands are close to the operation frequencies of WiFi and LTE which means that new devices could be manufactured with minimum change to existing systems hence reducing deployment costs.

There are legitimate concerns regarding the potential risks of opening radar bands for secondary access to safety-of-life and security of EU citizens which need to be carefully considered and investigated in close collaboration with primary users of these bands.

Also, we recommend that opening of these bands to secondary sharing should be done in a more controlled and gradual manner than is the case of TV bands. For example instead of opening these bands for “free-for-all” sharing, secondary operations could be permitted for a certain class of applications, e.g., mobile broadband with controlled

[5] It is also important to consider what proportion of channels might be reserved for non-exclusive use to promote innovation and consumer use – much as we reserve space for parks even in crowded city centres, where property developers are ever hungry for more building land.

deployments (e.g., through LSA), the health or energy sector, or a certain set of authorized systems, e.g. indoor use by operators for data offload. Also, exclusion zones could be created around radar transmitters where no secondary operations are permitted.

5.3 Conclusion

This deliverable concludes work carried out within the QUASAR project's WP1 on an assessment of regulatory and business feasibility of secondary access to already licenced but unused spectrum. As part of this assessment, an extensive review and analysis was carried out of the emerging worldwide regulations of secondary access to TVWS and other spectrum bands, as well as business feasibility aspects service provision in secondary spectrum. Based on these investigations we identified a number of remaining obstacles to the success of secondary spectrum access. A set of specific recommendations to regulators and policy makers are made that, from the QUASAR perspective, should help overcome these obstacles. Specific contributions, drawn from this work, to the regulatory work of CEPT (SE43) and Ofcom on TVWS have submitted and follow-up contributions are planned.

Acronyms

3G	3rd generation cellular wireless standards, IMT-2000
3GPP	3rd Generation Partnership Project
4G	4th generation of cellular wireless standards
ASA	Authorized Shared Access
BNetzA	Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen
BS	Base Station
CEPT	Conférence Européenne des administrations des Postes et des Télécommunications
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DAA	Detect And Avoid
DFS	Dynamic Frequency Selection
DL	Down Link
DME	Distance Measuring Equipment
DSA	Dynamic Spectrum Access
DTV	Digital Television
ECO	European Communication Office
ENG	Electronic News Gathering
ETSI	European Telecommunications Standards Institute
FICORA	Finnish Communications Regulatory Agency
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FSS	Fixed Service Satellite
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICAO	International Civil Aviation Organization
IDA	The Infocomm Development Authority of Singapore
IMT	International Mobile Telecommunications
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union Radiocommunication Sector
KCC	Korea Communications Commission
LAN	Local Area Network
LSA	Licensed Shared Access
LTE	3GPP Long Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control
MSS	Mobile Satellite Services

PMSE	Programme Making Special Events
PTS	The Swedish Post and Telecom Agency
QoS	Quality of Service
RF	Radio Frequency
RR	Radio Regulations
RTS/CTS	Request to Send / Clear to Send
SNR	Signal to Noise Ratio
SNIR	Signal to Interference and Noise Ratio
TDD	Time Division Duplex
TV	Television
TVWS	TV White Spaces
UE	User Equipment
UL	Up Link
WLAN	Wireless Local Area Network
WSD	White Space Device

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Appendix: QUASAR contributions to regulation of secondary access to white spaces

During the course of the project QUASAR partners has contributed actively to the work of the ECC CEPT Spectrum Engineering Project Team 43 (SE43). QUASAR partners has disseminated results by providing information input but also by using obtained insight to highlight potential problems and propose corresponding solutions in the current proposed regulatory framework for secondary access to the TV bands.

List of contributions to CEPT SE43 (available online: www.ecodocdb.dk)

1. QUASAR WP1, SE43(10)12 "QUSAR deliverable 1.2", information input, CEPT SE43 meeting, Copenhagen, April 2011.
2. Ericsson AB, "SE43(10)87: Managed geo-location database queries." Accepted for inclusion in the working version of the CEPT ECC report 159. Document number: SE43(10)87
3. Ericsson AB, "SE43(10)118: Master/slave configuration - clarification and implementation examples." Accepted for inclusion in the working version of the CEPT ECC report 159. Document number: SE43(10)118
4. Aalto University and BT Research, "SE43(11)23 Control of Aggregate Interference from WSDs." Document number: SE43(11)23
5. KTH and Ericsson AB, "'SE43(11)52: On the permissible transmit power for WSDs in TV White Space." Document number: SE43(11)52
6. Aalto University and BT Research, "SE43(11)97 Control of Aggregate Interference from WSDs." The follow-up contribution to SE43(11)23. Document number: SE43(11)97