Chapter 1
State-of-the-Art in Policy and Regulation of Radio Spectrum

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Abstract This chapter sets the stage for the rest of book by presenting the current state of affairs in the management of radio spectrum and related standardisation and regulatory initiatives pertaining to the emerging fields of CR and DSA. Section 1.1 discusses the international structure of spectrum management from the global ITU level down to the regional and national level. It also outlines how the ITU has started approaching the consideration of DSA challenges. The next Sect. 1.2 looks at how these efforts have been matched by the European regulators. Next, two Sects. 1.3 and 1.4 examine the complex issue of standardisation of CR/DSA technologies, starting from the general overview of work in global and regional standardisation bodies, followed by the analysis of drivers and obstacles. Standardisation is particularly covered because it has intrinsic interactions with regulation. For example, a well-targeted standardisation initiative involving strong industry players and perhaps an industry association can provide significant motivation for regulators to adapt regulations to support that initiative, in support of economic/industrial and national interests. The chapter is concluded by Sect. 1.5 that takes a closer look at the developments in two countries that have been particular champions of CR technologies: namely the United States and the United Kingdom. This is done with a viewpoint on the status of TV White Space access implementation—currently a key driver of DSA.

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1.1 International Regulations and DSA

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1.1.1 Introduction

Radio waves are used to deliver a broad range of services and applications, for instance, mobile telephony, radio and television broadcasting, maritime radio, research into the (birth of) the universe, and even for heating food in a microwave oven. However, it is not possible for users to use this resource without limitations. The use of radio waves at a particular frequency by one user will influence the use of the same, or nearby frequencies, by other users at the same time. Radio receivers will have difficulties to distinguish the intended signal from all other signals it receives. This phenomenon is called interference. Hence, coordination is needed in the use of radio waves between the various users to manage the problems associated with interference. As the propagation of radio waves is not hindered by national borders, this coordination will need to be performed on an international level.

Particularly for users, it is also often important that services and the related equipment are standardized, i.e. these services can operate with similar equipment in various countries in the same frequency band. As a result of this harmonisation of allocations, the spectrum can be used more efficiently and the equipment can be used over much wider geographical areas, increasing the size of the market for such equipment and reducing production costs. In the case of a number of applications, international harmonisation is even necessary owing to the nature of the application.

Historical developments have led to a situation in which governments have taken the role of 'supreme coordinator' in the use of the radio spectrum. Spectrum management has become based on the avoidance of interference and technically efficient use of spectrum. This section gives an overview of the international regulatory framework for spectrum regulations and their ability to support the introduction of CR. The section focuses thereby on the general framework for Europe. Detailed European regulations on CR and standardisation of CR are dealt with separately in other sections of this chapter.

1.1.2 Different Levels of Spectrum Management: European Case

1.1.2.1 ITU

Spectrum is globally governed by the International Telecommunications Union (ITU), a specialized agency of the United Nations. The Radiocommunication Sector of the ITU (ITU-R) develops and adopts the Radio Regulations, a binding international treaty, with a voluminous set of rules, recommendations and procedures for the regulation of radiocommunications. The Radio Regulations are based on avoidance of radio interference through the division of spectrum in bands which are allocated to one or more services out of some 40 different radio services. These radio services include services such as fixed, mobile, satellite, amateur, radio navigation and radio astronomy. Most bands are shared among primary and secondary services. Primary services have priority in case of conflicts resulting in harmful interference. Harmful interference is defined as *Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations ([1], article 1.169)

A wide range of regulatory, operational, and technical provisions ensure that radio services are compatible with one another and harmful interference among services of different countries is avoided. The Radio Regulations are regularly updated in response to changes in needs and to new demands at World Radiocommunication Conferences (WRC), which are held every three to four years [2].

The Radio Regulations are an international treaty between countries. This means that it only concerns the relations between countries. Individual countries can adopt some or all of the allocated services of each band and they are allowed to deviate from the Radio Regulations as long as no harmful interference is caused to the recognised services in other countries.

1.1.2.2 CEPT/ECC

The Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) brings together 48 countries to develop common policies and regulations in electronic communications and related applications for Europe. Its primary objective is to harmonize efficient use of the radio spectrum, satellite orbits and numbering resources across Europe. It takes an active role at the international level, preparing common European proposals to represent European interests in the ITU and other international organisations. The ECC work is carried out in partnership with all stakeholders including the EC and ETSI.

There are four different regulatory deliverables developed by the ECC:

- *ECC Decisions* are regulatory texts providing measures on significant harmonisation matters, which CEPT member administrations are strongly urged to follow. ECC Decisions are not obligatory legislative documents, as any other CEPT deliverable; however, they are normally implemented by many CEPT administrations.
- *ECC Recommendations* are measures which national administrations are encouraged to apply. They are principally intended as harmonisation measures for those matters where ECC Decisions are not yet relevant, or as guidance to CEPT member administrations.
- *ECC Reports* are the result of studies by the ECC normally in support of a harmonisation measure.
- *CEPT Reports* are the final results of studies developed in order to support responses to EC mandates. In many cases the results in the report form the basis for future EC Decisions on harmonized technical conditions of use (see the following section on the European Union).

As noted above, CEPT deliverables are non-binding. This gives the National Regulatory Authorities (NRA) a large degree of flexibility when it comes to adapting these to country specific conditions, legacy usages and circumstances.

1.1.2.3 European Union (EU)

Throughout the 1990s the EC gradually increased its involvement in spectrum issues, as the RF spectrum use started to affect the 'internal market'. The first intervention was related to the creation of a single European (internal) market for equipment. On the 9th of March 1999 the European Commission published the R&TTE Directive 1999/5/EC [3]. This Directive covers most products which use the radio frequency spectrum, including unlicensed devices. All equipment that is placed on the market must comply with a set of essential requirements, covering the protection of health and safety, electromagnetic emission and immunity of the equipment and effective use of the radio spectrum so as to avoid harmful interference.

Equipment manufactured in accordance with a "Harmonised Standard" may be placed on the market within the whole European Union (EU) (see also the following Sects. 1.3 and 1.4 on standardisation). However, certain restrictions may apply to the use of radio equipment if the frequencies are not harmonised in the European Union (EU). If a Harmonised Standard is used, the manufacturer has to perform some specific radio tests and can make its own declaration of conformity (self-declaration) which states that the product satisfies the essential requirements. There is no need for an external body to perform the testing. When a Harmonised Standard is not available or not appropriate, a manufacturer needs to demonstrate more extensively how the requirements of the Directive are being met through testing, to be documented in a 'technical construction file'. This file has to be reviewed and approved by a notified body.

Involvement of the European Union with radio spectrum management came with the introduction of the new regulatory framework. This framework was aimed at further liberalisation, harmonisation and simplification of the regulations in the telecommunications sector. The Framework Directive (2002/21/EC), *on a common regulatory framework for electronic communications networks and services*, states that the allocation and assignment of radio frequencies by national regulatory authorities are to be based on objective, transparent, non-discriminatory and proportionate criteria [4]. The related Authorisation Directive (2002/20/EC) specifies the circumstances under which the granting of an individual license is being allowed [5]. The Directive states that granting of an individual license is only allowed to ensure efficient use of radio frequencies. The Directive also limits the conditions that may be attached to the rights of use for radio frequencies. The licensing and the formulation of the conditions under which the radio frequencies may be used are left to the Member States.

Under this new regime harmonisation of spectrum is still left to CEPT. However, the associated Radio Spectrum Decision by the European Commission (2002/676/EC) created the possibility to impose technical harmonisation measures upon the Member States [6]. This Decision created a legal framework for 'the harmonised availability and efficient use of radio spectrum in the European Union (EU) for the establishment and functioning of the internal market in Community policy areas, such as electronic communications, broadcasting and transport'. In the implementation of the Decision the European Commission is assisted by the newly formed Radio Spectrum Committee (RSC). The RSC is composed of experts from the Member States.

The European Commission can issue mandates to CEPT to solicit advice on technical harmonisation measures. The RSC approves the CEPT Report and associated technical implementation measures prepared by the Commission. The implementation of these measures is mandatory for the EU Member States.

Next to the RSC, the Radio Spectrum Policy Group (RSPG) was set up to facilitate consultation and to develop and support radio spectrum policy. The Radio Spectrum Policy Group (RSPG) is a group of high-level representatives of the Member States which advises the European Commission on radio spectrum policy at a strategic level.

The revision of the regulatory framework in 2009 introduces two governing principles that will have implications on the future regulation. Firstly, general authorisation should be the general rule when authorizing access to spectrum. Individual licensing can still be used but such deviations from the general principle must be justified. Secondly, the principles of technology and service neutrality should be the general rule for both general and individual authorisation of access to spectrum. Deviations from this principle are still allowed but must be justified. As the allocation of spectrum to specific technologies or services is an exception to the principles of technology and service neutrality and reduces the freedom to choose the service provided or technology used, any proposal for such allocation should be transparent and subject to public consultation [7].

1.1.2.4 ETSI

The European Telecommunications Standards Institute (ETSI) is an independent, non-profit organisation, whose mission is to produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio and TV broadcasting, internet and several other areas. ETSI plays a major role in developing a wide range of standards and other technical documentation as Europe's contribution to world-wide ICT standardisation. This activity is supplemented by other activities such as interoperability testing services. ETSI's prime objective is to support global harmonisation by providing a forum in which all key players can contribute actively.

ETSI is recognised as an official European standards organisation by the European Commission and works under mandates from the Commission to prepare Harmonised Standards under the provisions of the R&TTE Directive. Membership is open to all interested parties. Harmonised Standards are standards adopted by the European Standards Organisations (ETSI, CEN and CENELEC), prepared in accordance with the General Guidelines agreed by them with the EC, and in response to a mandate issued by the Commission after consultation with EU Member States. The reference of a Harmonised Standard must be published in the Official Journal (OJEU) in order to give a presumption of conformity to the essential requirements of the R&TTE Directive.

ETSI is an officially recognised partner of the ECC, which is reflected in a Memorandum of Understanding (MoU). The cooperation between ETSI and the ECC plays an important role to ensure the objective of harmonised and efficient use of the radio spectrum across Europe.

1.1.2.5 National Spectrum Management Authority

Based on the international allocations and regulatory provisions the national spectrum regulator-NRA-grants access to spectrum for users. An EU Member State has the right to set conditions on the use of spectrum under the Framework Directive. These conditions can include appropriate limits that aim to avoid harmful interference to other radio services. These conditions can be harmonised on a European wide basis either through a European Commission Spectrum Decision (which is mandatory for EU Member states to implement) or by an ECC Decision or Recommendation. Alternatively, if no mandatory harmonised guidance is available, a regulatory deliverable can be developed on a national basis.

Usually a license gives an exclusive right to operate in a specific frequency range, in a specific location or geographic area and under specific technical conditions (e.g., power level, antenna height, antenna location etc.) and other conditions such as service obligations and (network) build-out requirements. The compliance of spectrum users with the license obligations is monitored and enforced by the NRAs.

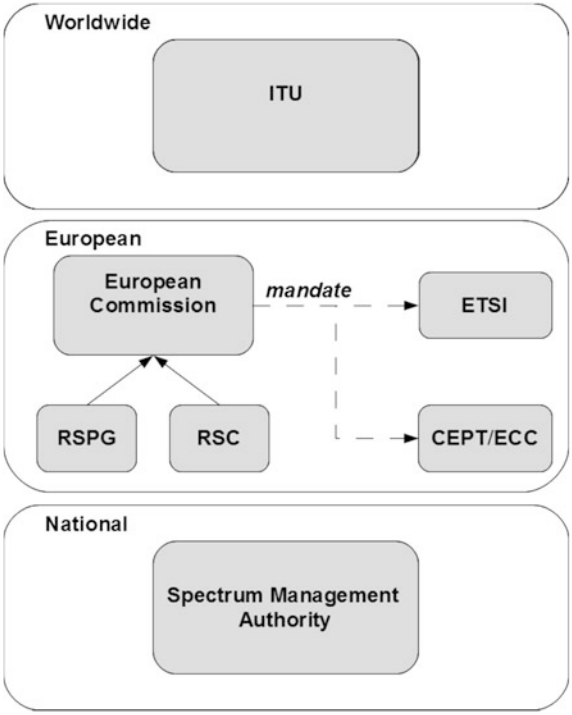

Fig. 1.1 The international and national regulatory framework for spectrum regulations in Europe

If the demand for spectrum within a particular band is considered to be significantly less than the supply, licenses are usually granted on a first come first served basis. When spectrum demand exceeds the supply, the spectrum regulator has to use another mechanism to award the licenses. Increasingly, regulators have turned to comparative hearings or "beauty contests" and more recently to spectrum auctions [8].

In summary, the current spectrum management model operates on both a national and international level as depicted in Fig. 1.1.

In the current paradigm all decisions are made by the spectrum regulator. Therefore, this traditional spectrum management model is commonly referred to as Command & Control. This Command and Control model has its limitations. The two most eminent are: all (usable) spectrum is allocated but some of the portions of the spectrum are hardly used, and the method to allocate and assign spectrum is slow in responding to changes in market and technology.

In the past, the inefficiencies in spectrum utilisation introduced by this bureaucratic command and control spectrum management model were tolerable. As demand grew, advancing technology ensured that new frequency bands were available, and there was no need to deal with inefficiently used spectrum. More recently, demand has grown very rapidly and technology has delivered new services and devices to serve that demand. However, the opening up of even higher frequency bands is not progressing at the same pace and not all frequencies are alike. More bandwidth (capacity) is available in the higher frequency range, but higher frequencies have a shorter range, ceteris paribus. To give an example, ideal frequency range for mobile communications is roughly 0.1–3 GHz. Below this frequency range there is not enough data throughput capacity available and above this range the coverage area of the base stations becomes too small.

This means that the NRAs more or less have run out of useable spectrum to assign for new services and technologies. Hence, services based on new technologies can only be introduced at the expense of existing services. Consequently, NRAs all over the world are in the process of modernising their spectrum policies, and are seeking alternative spectrum management models which allow a much more efficient and flexible utilisation of the spectrum [8, 9].

1.1.3 Lessons from the Past

This subsection will offer a few example case studies of the coordination of radio spectrum use in the past and the development of radio spectrum regulations resulting from these coordination efforts. Besides offering very revealing lessons from the past, this historic discourse will provide the foundation for proposing an actor-centric approach to analyse the links between different stake-holders involved in coordination of spectrum use. It may be seen that until now, most of the advances that have been made in the coordination of radio spectrum usage were triggered by problems with a specific service. This will be illustrated in the three cases to be discussed in the rest of this subsection. Each case is concluded with an assessment that places the observed coordination efforts in an actor-centric perspective on alignment. This discussion will be then continued in Sect. 5.2 of this book.

1.1.3.1 Marconi and the Birth of Spectrum Management

At the time of Marconi, spectrum was like an open and untouched pasture. Marconi was the first to enter this pasture to exploit this common resource. He started his business by selling wireless stations for use on-board ships. As others also started to enter the business, he changed his strategy. He decided to sell not only the equipment but also wireless telegraphy as a service. For that purpose he set up a new company, the Marconi International Marine Communications Company in 1900. He built his own land based radio stations along the sea-trade routes on the shores of Britain, Ireland, Belgium, Italy, Canada and New Foundland. He trained his own radio telegraphists and placed them on all ships he equipped with a wireless radio station. These radio telegraphists, or marconists as they were called, were only allowed to communicate with Marconi wireless stations both land based and onboard other ships [10]. By doing so, he created a very successful private business using a public resource, radio waves.

The behavior of the Marconi Company led to governmental involvement in the use of radio waves. Kaiser Wilhelm of Germany convened an international conference on the use of radio telegraphy in 1903. Representatives of nine countries gathered in Berlin for the *Preliminary Conference on Wireless Telegraphy* [11]. Complete agreement was not reached, but the Conference drafted a protocol that served as the basis for a future international agreement on the use of wireless telegraphy. Among the articles of the protocol was the requirement that all coastal stations were required to exchange messages with all ships without distinction as to the radio system being used [12].

This preliminary Conference was followed in 1906 by the first Radio Telegraph Conference of Berlin. Twenty-nine countries adopted the first *International Radiotelegraph Convention*. Two important provisions of the Convention were firstly, a requirement to accept all messages from coastal stations and ships regardless of the system used and secondly, priority for distress calls. The annex to this Convention contained the first regulations governing wireless telegraphy. It was decided to use two wavelengths corresponding to 1000 kHz and 500 kHz for public correspondence.

The interconnection among radio operators was considered to be of public interest to support the safety of the man at sea, and the continuous availability of the service should be assured at all times. This need for rules of engagement and international coordination was strengthened at the next Radio Telegraph Conference which took place in London, shortly after the Titanic disaster in 1912 [10, 13].

To conclude, it was not the introduction of new technology—radio—as such that made it necessary to coordinate the use of the radio frequency spectrum and design new regulations. It was the use of this new technology by Marconi which triggered it. Marconi used this new technology in such a way that a conflict became apparent between his efforts of realizing private objectives and the realization of the newly identified public objectives.

Regulations were put in place to safeguard the public interests in the use of maritime communications. The regulations allowed for as much (business case) freedom as possible for the maritime service with the exception of a few standardized channels for the exchange of public messages and as an emergency signalling frequency. The outcome of the coordination efforts provided the support for a public service using a commercial incentive scheme, i.e. combining the public and private interests in a creative new combination.

1.1.3.2 Spectrum Auctions

In 1959 economist Ronald Coase posed that the allocation of spectrum should be determined by the forces of the market rather than as a result of government decisions. Radio licenses should be bought and sold like any other scarce resource in our economy, such as land or labour. Rights should be assigned to individual users via an auction with the provision that these rights can subsequently be traded in an open market. The market should not only decide who will own the license, but also what services will be provided. If a business model would fail, the right to use the radio spectrum could be bought by another operator with a different, more successful, business model or by a new entrant. The problem of interference could be solved by delimiting the rights. These delimitations should not only come from strict regulations, but also as a result of transactions on the market [14].[1]

At that time, Coase's idea was taken as a big joke by the FCC [16]. Nonetheless, the idea of a model based on trading of the property rights has since been discussed among economists,[2] but a property rights model was only considered seriously by spectrum management authorities in the early 1990s. At that time a broad consensus in political thinking had emerged in support of deregulation; the introduction of market forces was considered for a number of infrastructures that had been heavily regulated in the past, including mobile telephony [16].

Deregulation changed the set of objectives pursued by the government. One of the new objectives pertaining to mobile communications became the creation of a market for radio spectrum usage rights for mobile communications. The institutional change that was already proposed in the late 1950s by Coase perfectly fitted the newly defined objectives. Hence, various countries chose to auction the spectrum rights for mobile telephony [18].[3]

1.1.3.3 Wi-Fi and License Exempt Use of Spectrum

In 1985 the FCC decided—for the purpose of deregulation—to allow the use of spread spectrum for communication purposes in three bands designated for Industrial, Scientific and Medical (ISM) applications (900 MHz, 2.4 GHz and 5.8 GHz). These where bands that could be used without the need for a license but applications had to be limited in output power and had to tolerate interference from other users, including other ISM applications.

The new (for civil applications) technology of spread spectrum and the introduction of regulations to support it, triggered NCR Corporation to use spread spectrum for a nagging issue from their sales force: the lack of 'mobility' in their cash register product portfolio. Through their involvement in IEEE, as a leading standards developing organization, NCR became the de facto leader in the IEEE 802.11 Working Group resulting in a highly successful Wireless-LAN standard [20].

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[1] Coase generalized this idea in his Noble prize winning essay "The Problem of Social Cost" [15].

[2] See note 6 of Baumol and Robyn for an overview of references [17].

[3] New Zealand was probably the first country that experimented with the definition of long-term, tradable property rights to radio channels, and the first country to auction these rights to the highest bidder [19].

This case shows that the introduction of new technology will also need associated institutional arrangements supportive of this technology. Before 1985, the institutional arrangements were based on exclusive rights. In such a setting there was no need to use a new technology (spread spectrum) that facilitated shared access.

It further shows that alignment between technology and the institutional arrangements is necessary but is by itself not enough for successful introduction of this new technology. In the institutional arrangements that were set up by the FCC, it is up to the radio equipment manufacturers to coordinate the efficient use of the radio spectrum, including graceful degradation of service levels under increasing load conditions and avoiding interference. The coordination activities necessary to develop new technology to achieve alignment between this new institutional arrangement and technology were only realized after a private actor (NCR) had a private objective that materialized in a compelling business case. This private objective of NCR was compatible with the public objectives of the FCC.

1.1.3.4 Conclusions

This review of historical cases has provided evidence of the value in applying an actor-centric approach to the process of alignment. Each of the cases described above were triggered by problems related to private actors on the one hand and public actors on the other hand pursuing the realization of their private, respectively public objectives. A successful outcome can be concluded when private and public actors can realize their objectives simultaneously, by designing a business opportunity in theory and allowing it to be transformed into a viable business case in practice.

1.1.4 The New Regulatory Paradigm of DSA

DSA solutions have to address the lack of available (accessible) spectrum in the current static model. In the current spectrum management model, radio spectrum is divided into fixed and non-overlapping blocks, sometimes separated by so-called guard bands, and exclusively assigned to different services and wireless technologies, while a lot of spectrum usage is only local and limited in time. In an economic sense, there appears to be a paradox whereby the rights to the radio spectrum are fully assigned, but a lot of radio spectrum remains unused in practice when considered on a time or geographical basis. Under the current command and control model it is very difficult to make this unused spectrum available.

There are two basic alternative regimes considered, a regime based on exclusive property rights and a regime based on spectrum commons with strict general rules on the use of spectrum without the need for individual licenses [8, 21]. In these discussions, CR has been closely linked to the commons. Advocates of the commons see CR technology as an enabler to realise true radio spectrum commons

[22]. However, technologies such as CR do not favour one regime over another. CR can be used in both spectrum management regimes, as it can also be used to facilitate an efficient market-based regime based on property rights [8]. CR, as a technology, is an enabling tool to realise this goal of increased flexibility in access to spectrum.

The key feature of such a CR is its ability to recognise unused parts of spectrum that are assigned to conventional users and adapt its communication strategy to use these parts while minimising the interference that it causes to the conventional users. An important consequence is that CR can be an enabling technology to facilitate a paradigm shift for spectrum management from a regime based on static spectrum assignments to a regime based on more dynamic forms of spectrum access [8, 23].

1.1.4.1 Adapting the Regulatory Framework for DSA

The first question is if there is any international regulation in place that prohibits DSA through the use of CR. The short answer to that question is: No. Administrations that wish to implement CR have two different alternatives to do so [24].

Firstly, CR can be used under any service defined in the Radio Regulations, i.e., if the CR is used to deliver mobile communications, the CR can be treated in the same way as an ordinary mobile radio, and will be allowed to operate under the provisions for the mobile service. This means that the CR can use bands that are allocated to the mobile service as far as the (international) regulations on interference and sharing conditions are met.

A second option is to implement CR on a so-called non-interference basis ([1]: article 4.4). This means that the CR is allowed to operate as long as it doesn't cause harmful interference to, and shall not claim protection from, harmful interference caused by a station operating in accordance with the provisions of the Radio Regulations. These provisions only apply for cross-border communications (and interference), since the Radio Regulations are an international treaty between countries. Hence, individual countries are allowed to deviate from the Radio Regulations as long as no harmful interference is caused to the services in other countries.

However, to realise the full potential of CR, the radio will need to have dynamic access to a wide range of spectrum bands, which might currently be divided in a number of frequency bands designated for different radio services. Introduction of DSA is only possible if these exclusively designated frequency bands are opened up for other services and technologies. Hence, there is a need to enhance the regulatory framework to allow for more flexibility in the use of radio spectrum.

1.1.4.2 Activities Within the ITU

At the World Radio Conference 2007 (WRC-07) it was decided to put Software Defined Radio and CR on the agenda for the World Radio Conference of 2012 under agenda item 1.19. Study Group 1 (Spectrum management) of the ITU-R was responsible for the studies needed in preparation of this agenda item of the WRC-12. As part of these studies, the following definition was developed [25]:

> Cognitive Radio System: A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.

The World Radio Conference of 2012 (WRC-12) came to the conclusion that SDR and CR are related technologies which can be used in any radio service within the Radio Regulations. There is no need to incorporate the definitions of SDR and CR in the Radio Regulations. However, WRC-12 reiterated that any radio system implementing CR technology needs to operate in accordance with the provisions of the Radio Regulations.

In other words, WRC-12 confirmed that CR can be used under any of the services defined in the Radio Regulations. Administrations that wish to implement CR already can do so. However, it was also noted that there remain questions around the deployment and use of CR. A common concern was expressed within the ITU-R about how the protection of existing services from potential interference from the services implementing CR technology, especially from the DSA capability of CR, could be realised. ITU-R and the WRC-12 came to the conclusion that there is need for further studies within ITU-R on the implementation of CR technologies within a radiocommunication service and on sharing among different radiocommunication services with regard to the capabilities of CR, in particular dynamic access to frequency bands.

ITU-R came to aforementioned conclusion that there is a need for further studies on CR during the discussions on the future work programme of the ITU-R at the Radiocommunications Assembly (RA). This need for further studies is expressed in ITU-R Resolution 58. The RA was held in January 2012, in the week prior to the WRC-12. The WRC-12 confirmed this need for further studies in WRC-12 Recommendation 76.

ITU-R Study Group 5 (Terrestrial services) already started work on the possibilities for the introduction of CR in the mobile service and the operational implications of this introduction. ITU-R Report M.2225 provides a general description of CR systems and describes a set of deployment scenarios for the introduction of CR systems in the land mobile service (excluding international mobile telecommunications (IMT)). ITU-R Report M.2242 describes how introduction of CR in the IMT systems may be used for more dynamic and flexible radio resource management and optimisation.

Working Party 5A of Study Group 5 is now working on a second report on CR systems in the land mobile service (excluding IMT). This report aims to present existing, emerging and potential applications of CR systems in the land mobile service from a technical perspective, including the impact on the use of spectrum.

It is now up to the other study groups to study possibilities for the introduction of CR technology for the radio services under their purview.

1.2 European Regulatory Developments Related to CR

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1.2.1 Introduction

This section will review the European regulatory developments pertinent to CR. However it must be clarified from the beginning that the current state of thinking in European regulatory circles does not really consider the CR as the subject of regulatory policy, but rather as pure technological innovation phenomenon that should find its way to fit into the existing regulatory service definitions and spectrum access rules. Moreover, the CR term is generally understood in current European (and elsewhere) regulatory context as a moniker for DSA-enabling solution, and in that sense the White Space Devices (WSD), as may be deployed in the traditional TV Bands, are seen as proxy CR systems to be encountered in the near future. Thus in the rest of this section the terms WSD and CR are used interchangeably and should be seen as being synonymous.[4]

1.2.2 Historical Background

As was presented in Sect. 1.1, the Europeans firmly believe that management of radio spectrum should follow the road of broadest possible international harmonisation and therefore all European regulations in the area of spectrum management are initiated on the international (regional) level through co-operation arrangements between CEPT and EU. So also the formal consideration of the subject of CR, first embodied as WSDs in the TV Bands, started when the European Commission issued to CEPT in 2007 a Mandate on the "Technical considerations regarding harmonisation options for the Digital Dividend". The principal goal of this mandate was the most flexible spectrum usage in the band 470–862 MHz while allowing the widest possible range of uses and technologies.

[4] The author would like to acknowledge assistance of Dr. Alexandre Kholod, the chairman of CEPT PTSE43, in compiling the material for this section.

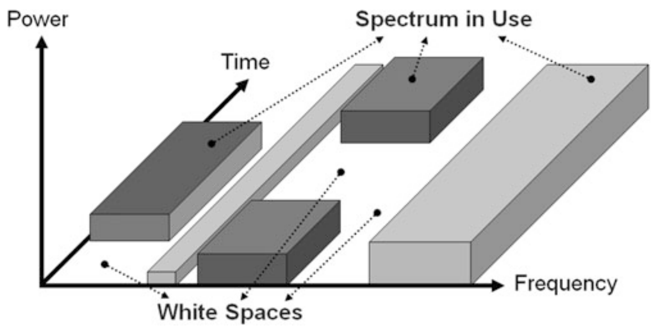

Fig. 1.2 Illustration of the concept of white spaces

As far as the practicability of implementation of new/future applications within the white space spectrum in the band 470–862 MHz is concerned, the CEPT provided its preliminary review in CEPT Report 24 [26]. This seminal high level policy document was important as it set the ground for all further European developments in this field. Most notably, it formalised the concept of White Spaces, see Fig. 1.2, as "*a part of the spectrum, which is available for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering/non-protected basis with regard to primary services and other services with a higher priority on a national basis* [26]".

Note the two critical points that were laid solid into the definition of WS and, accordingly, became the ground rules for authorising access to them (i.e. the DSA):

- the WSDs would be operated on a strictly non-protected non-interfering basis, and
- the incumbent would always retain higher priority.

These principles were clearly well intentioned and aimed at protecting the safe operation of incumbent services, which was especially critical in the case of high political importance of TV broadcasting deployed within the initial candidate band of 470–862 MHz. They also contributed to shaping the following considerations of WSDs in order to establish their operational requirements so as to ensure strict compliance with the above principles.

The main burden of establishing those technical conditions for co-existence was entrusted to a specially created Project Team Spectrum Engineering #43 (PT SE43), which was active from 2009 until January 2013. The PT SE43 was heavily attended by national regulators and industry alike, and over its lifetime produced three important technical reports, that form the basis of current European regulatory regime for deployment of WSD/DSA systems:

- ECC Report 159 establishing key technical principles for possible operation of CR in WS of the frequency band 470–790 MHz [27];

- ECC Report 185 that further defined the technical and operational requirements for the operation of WSDs in 470–790 MHz [28], and
- ECC Report 186 describing requirements for WSD operation under the concept of Geo-location Database (GDB) managed operation [29].

First of all it should be noted that the reports focused only on the portion of the TV Bands IV&V, namely 470–790 MHz. The remaining band 790–862 MHz (800 MHz band) was earmarked as “Digital Dividend” to be freed from TV Broadcasting owing to switch-over from analogue transmission to more spectrally efficient digital transmission based on DVB-T standard. That Digital Dividend band would be licensed to broadband IMT systems, such as implemented by the LTE standard. Ironically, by the time of completion of PTSE43 work, after the World Radiocommunications Conference that took place in 2012, it was already becoming obvious that the TV operations might be soon squeezed further due to the extension of the mobile allocation into the 700 MHz band (694–790 MHz). The important corollary of this is that the reduction of band available to TV means increasing density of TV transmitters, which in turn minimizes the potential availability of WS.

Secondly, it is important to note that ECC Report 185 was developed as complementary to ECC Report 159, whereas ECC Report 186, though complementing the discussions in ECC Report 159, may be also considered on its own, as the principles set in this report could be easily extended to other frequency bands.

The Report 159 reviewed various possible mechanisms for ensuring coexistence (sensing, GDB and beacons) and essentially concluded that in terms of practical feasibility for ensuring protection of incumbent users from WSDs interference, the GDB approach would be the prime (and only) solution. This led to re-focusing the bulk of subsequent CEPT work towards consideration of that approach. Nevertheless, the Report 185 still provided certain consideration of sensing, especially cooperative sensing, as well as beacons, e.g. for protection of radio microphones. This report also presented further additional studies for co-existence and established more explicit conditions for WSDs such as transmit power limits.

Then the Report 186 is solely focusing on practical implementation of GDB approach, such as requirements for database operation, its interfacing with master and slave WSDs as well as what type of data should be stored in the GDB. More detailed analysis of European GDB approach is presented in Sect. 3.1.

By the time PTSE43 was finishing its work, in September 2012 CEPT has kicked-off a complementary regulatory analysis by creating a new Project Team Frequency Management #53. Its mandate was to review the technical reports produced by PTSE43 and based on them to formulate the overall regulatory framework for WSDs under GDB approach, including guidelines for national implementation. By that time also another concept for DSA was starting to emerge under the name of Licensed Shared Access, which was also added to the PTFM53 mandate. The target dates for completion of PTFM53 considerations were set to

2014/2015, which means that by the time of writing this book it was too early to sum up conclusions of this project team.

Another important element of the European regulatory landscape is the standardisation aspect which is being addressed through the work of ETSI. The CR-related aspects are being addressed in its Technical Committees on Reconfigurable Radio Systems (TC RRS) and on Electromagnetic compatibility and Radio Matters (TC ERM). Their key objective is the development of the standards for WSD operation. Please refer to Sects. 1.3 and 1.4 for more detailed analysis of standardisation activities.

1.2.3 *Current State-of-the-Art of European CR/WSD Regulatory Policies*

With departure in above described historical background, the current European philosophy that will define the CR/WSD regulatory policies may be summarised by the following key points:

- Spectrum sensing alone is not feasible approach [27], however collaborative sensing may provide certain added value as complementary feature to GDB approach [28];
- Geo-location database (also in combination with sensing) is the only viable option for controlled deployment of WSDs [29], as further discussed in Sect. 3.1;
- The WSD deployment is expected to cover three typical use cases, see Fig. 1.3 [28]:
  - Indoor wireless access;
  - Outdoor wireless access;
  - Machine-to-Machine connectivity;
- The WSD maximum transmit powers for all above use cases can be set either by the geo-location database or at the hardware level by WSD manufacturers, or by an algorithm implemented in the firmware [28];
- Protection of different services/systems remains of paramount importance. As far as the band 470–790 MHz is concerned, this covers such incumbent services and systems as Broadcasting Service, wireless microphones (aka Programme Making Special Events—PMSE applications), Radio Astronomy Service, Aeronautical Radionavigation Service as well as Mobile Services in adjacent bands [27, 28]. This might even include the need to protect operation of cable TV head-ends, which was left to be considered as mostly national issue [28]. Different incumbent users of the band 470–790 MHz are schematically shown in Fig. 1.4.

Regardless of these well matured and solidified European views on the WSD regulation, the practical enactment of these policies had been somewhat lagging, with obvious reason that national administrations did not (and still often do not)

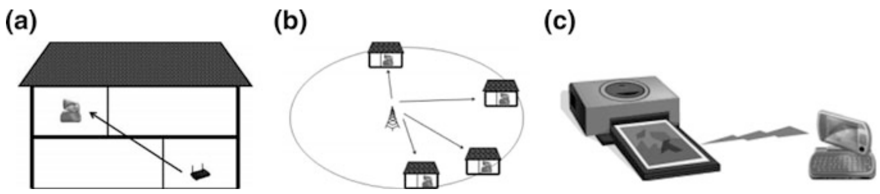

Fig. 1.3 Three classes of WSDs considered in current European regulations: **a** indoor, **b** outdoor, **c** Machine-to-Machine [28]

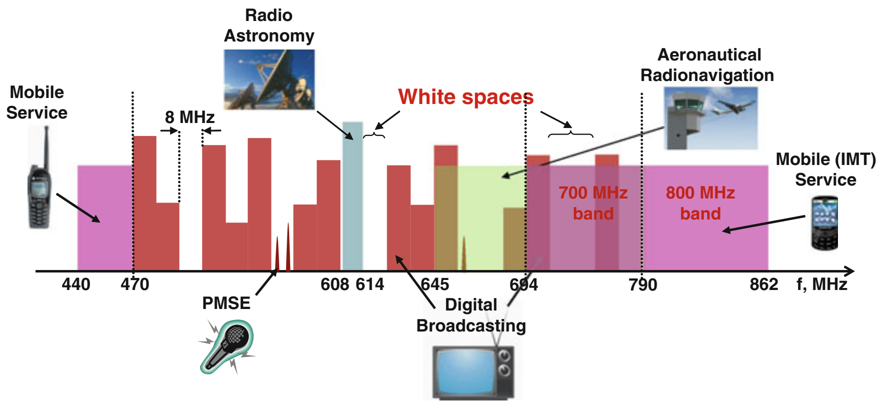

Fig. 1.4 Incumbent users of the band 470–790 MHz to be protected from WSD interference

perceive the market demand for such applications. One European administration that was steadily progressing with the practical implementation of WSD regulation is the United Kingdom. Its case study is offered in separate Sect. 1.5.2 later in this chapter.

1.2.4 The Emerging Value of CR as Part of Spectrum Sharing Paradigm

As was discussed above, up to now the European regulatory focus was mostly on allowing the deployment of WSDs in TV Bands as a certain niche application. However as of lately, the CR started gaining wider recognition as important element of regulatory toolbox for enabling the further growth of spectrum sharing as dominant means for radio spectrum access. This development may be linked to the political push by the EU, which in March 2012 approved the Radio Spectrum Policy Programme (RSPP) [30].

The key objectives and concrete envisioned actions of the RSPP may be summarised as follows:

- providing at least 1200 MHz of total spectrum to accommodate the growth of wireless data traffic;
- assessing the need for harmonised bands as part of the above spectrum portfolio;
- authorising spectrum trading in all harmonised bands that allow flexible use;
- fostering different modes of spectrum sharing in Europe, with the aim of ensuring its most efficient use and allowing access for innovative products.

This high-level political programme will definitely set a renewed focus on possibilities for shared spectrum use, including DSA option. The first obvious implementation, designed to address the spectrum need of mobile operators and hence adding to the balance of those 1200 MHz of spectrum, would be the Licensed Shared Access mechanism (see discussion in Sects. 2.5 and 2.6). But also other interesting and more general approaches are appearing, such as the concept of Beneficial Sharing Opportunity (BSO) [31].

BSO is a concept that allows judging whether sharing is appropriate and desirable for a given band:

- the BSO may exist in both licensed and licence-exempt frequency bands;
- the BSO condition is deemed fulfilled if the net benefit of application A (incumbent) is less than the combined net benefit of applications (A + B + C − (cost of sharing)).

So in effect the EC is seeing the BSO as a twofold concept: one being the most efficient use of licence-exempt bands (commons, such as 2.4 GHz ISM band), the other being the licensed sharing, namely the LSA concept.

What is however most important with new approach, compared with the original European focus on WSDs in TV bands, is the emergence of recognition of the general value of DSA in fostering spectrum sharing, and its corollary that identification of white spaces may be pertaining to any band, where the radio spectrum usage can be reliably identified in geographic and time domains. In that sense also the value of GDB was re-affirmed as the key infrastructure for enabling dynamic spectrum management.

1.3 An Overview on CR Standardisation

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It may be noted that the strength and breadth of standardisation efforts and interest in TV White Space and related areas has helped to drive forward the regulatory case for CR. Moreover, standardisation of new technologies provides a level of stability that can assist regulators in planning for the allowance of them, and can yield dependable and consistent results. Therefore, this section provides a summary overview of standardisation activities in various standardisation bodies pertaining to the field of CR.

1.3.1 IEEE

The IEEE has developed one of the first CR Standards (IEEE 802.22 for wireless regional area network (WRAN) on secondary usage of TVWS) and currently has a number of projects ongoing for short-term (e.g., IEEE 802.11af enabling Wi-Fi in TVWS) and longer-term (e.g., IEEE DySPAN-SC developing solutions for DSA) requirements.

IEEE standards for secondary usage of TVWS include in particular:

- **IEEE 802.22** [32]: This standard was aimed at bringing broadband access to hard-to-reach, low population density areas, typical of rural environments and developing countries, and is based on a point to multi-point network topology. It provides a solution for a CR-based PHY/MAC air interface for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service.
- **IEEE 802.11af** [33]: This standard provides modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC), to meet the legal requirements for channel access and coexistence in the TV White Space. It is based on Wi-Fi technology, appropriately modified to meet the regulatory requirements, database access, out of band emissions and channel bandwidths.
- **IEEE 802.19** [34]: The IEEE 802.19 Wireless Coexistence Working Group (WG) develops standards for coexistence between wireless standards of unlicensed devices. IEEE 802.19 Task Group 1 develops corresponding solutions for Wireless Coexistence in the TV White Space.

The IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC) is developing standards in the areas of DSA, CR, interference management, coordination of wireless systems, advanced spectrum management, and policy languages for next generation radio systems [35]:

- **IEEE 1900.1 Working Group on Definitions and Concepts for Dynamic Spectrum Access : Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management**: This standard provides terms and definitions in the field of DSA and related technologies;
- **IEEE 1900.2 Working Group on Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio System**: This standard provides guidance for the analysis of coexistence and interference between various radio services in the specific context of spectrum management, policy-defined radio, adaptive radio, and software-defined radio;

- **IEEE 1900.3 Working Group on Recommended Practice for Conformance Evaluation of Software Defined Radio (SDR) Software Modules**: IEEE 1900.3 WG has been disbanded;
- **IEEE 1900.4 Working Group on Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks**: This standard provides solutions for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks; IEEE 1900.4a is an amendment providing an architecture and interfaces for DSA in White Space Frequency bands; IEEE 1900.4.1 is a Standard for Interfaces and Protocols Enabling Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Networks;
- **IEEE 1900.5 Working Group (WG) on Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications**: This standard defines a vendor-independent set of policy-based control architectures and corresponding policy language requirements for managing the functionality and behaviour of DSA networks;
- **IEEE 1900.6 Working Group on Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems**: This standard defines the interfaces and data structures required to exchange sensing-related information in order to increase interoperability between sensors and their clients developed by different manufacturers; 1900.6a is an amendment providing procedures, protocols and message format specifications for the exchange of sensing related data, control data and configuration data between spectrum sensors and their clients. In addition, it adds specifications for the exchange of sensing related and other relevant data and specifies related interfaces between the data archive and other data sources;
- **IEEE 1900.7 White Space Radio Working Group**: This standard project develops solutions for Radio Interface for White Space DSA Radio Systems Supporting Fixed and Mobile Operation.

1.3.2 ETSI

ETSI focuses its work on CR solutions in the Reconfigurable Radio Systems Technical Committee (ETSI RRS). They are closely related to the current EC Mandate M/512 on Reconfigurable Radio System standardisation [36]. Current key activities relate to:

- **Licensed Shared Access (LSA)**: In alignment to the European Commission’s Radio Spectrum Policy Group (RSPG) definitions on LSA [37], ETSI has issued a System Reference document (SRdoc) [38] and develops solutions for LSA usage in the 2.3–2.4 GHz band in close cooperation with National Regulation Authorities in Europe in ETSI RRS;

- **Secondary usage of (TV) white spaces**: ETSI is in the process of finalizing a Harmonized Standard for enabling the introduction of TVWS systems into the European market [39]. Besides this rather regulation focused document, a number of technical documents are under development related to inter-database-exchange and coordinated/uncoordinated access to TVWS [40–43];
- **Mobile Device Architectures for enabling a Heterogeneous Networks approach**: This activity is performed in alignment to the current revision of the basic regulatory framework in Europe given by the Radio Equipment and Telecommunications Terminal Equipment Directive (R&TTE Directive) [44]. The new Directive is indeed expected to allow for Software reconfiguration of Mobile Devices. ETSI develops corresponding solutions for Mobile Device architectures and Interfaces [45–47] as well as novel Certification approaches [48] in support of simultaneous usage of multiple RATs.

1.3.3 ECMA

The European Computer Manufacturers Association (ECMA) has developed a standard for secondary usage of TVWS with a specific focus, among others, on home electronics equipment:

- **Secondary usage of TVWS**: ECMA has issued the standard 392 [49], which specifies a physical layer and a medium access sub-layer for wireless devices to operate in the TV frequency bands.

1.3.4 IETF

The Internet Engineering Task Force (IETF) is in the process of developing a protocol on how to access (TV) White Space databases:

- **Accessing (TV) White Space databases**: The Protocol to Access White Space database (PAWS) [50] is intended to enable a radio device to determine, in a specific location and at specific time, if any white space is available for secondary use.

The above had depicted the complex picture of global standardisation efforts in support of development of CR technologies.

1.4 Standardisation as Enabler of CR Developments

Vladislav V. Fomin[1], Gintare Sukareviciene[1] and Heejin Lee[2]

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1.4.1 Introduction

Standardisation plays important role in the technology innovation and the associated economic development of industries and nation-states [51–53]. However, predicting how standardisation process must unfold to maximize the chance of successful innovation is hardly possible due to the complexity of both standardisation and innovation processes, and their inter-dependencies [54–58].

The growing complexity of Information and Communication Technologies (ICT) in general [59] and ICT standards in particular [54], contribute to the development of "blurred ICT standardisation landscape" [60, 61]. With the "blurred landscape" scholars and politicians refer to the situation when there are several standards development organizations (SDOs) and/or consortia active in a particular field, and some areas of standardisation activities are overlapping [62]. Such situation makes it difficult to efficiently steer the overall innovation process (as it is critically dependent on the availability of technology standards). CR innovation process is not an exception here.

Recognizing the importance of the wireless communications in general, and CR-enabled technologies in particular, many (if not all) major SDOs and relevant regulatory organizations have embarked on developing standards or defining norms and regulation for one or another aspect of CR-related telecommunications, as may be seen in the previous Sect. 1.3. Those efforts, in one or another way, are aimed at developing a new generation of telecommunications services, a "more dynamic" one than the current telecommunications paradigm. "More dynamic" spectrum management here is understood as not being bound by rigid spectrum allocations with regard to particular technologies and services.

The switch from the current "command-and-control" spectrum management principle to the one based on dynamic spectrum allocation and spectrum sharing is not likely to happen overnight. As commented by Intel Corp.'s Markus Mueck [63], we are likely to see "islands of CR" within the existing telecommunications domain at first, with the presence of CR-enabled services growing gradually, as more stakeholders realize the advantages of the new paradigm and as the number of CR-related technology standards grows:

> I think that the more dynamic the system is—the more spectrum opportunities you will have. So actually it makes sense in the first step to look at something that is really just a

> little bit dynamic and you will get some more spectrum. Then once you run out of that, probably you will have to increase the level of dynamicity a little bit in order to free new resources. And so my expectations is that little by little we will move from LSA [Licensed Spectrum Access] to DSA [Dynamic Spectrum Access] depending, actually, on how fast we run out of spectrum availability [63].

This cumulative, versatile pattern of CR standardisation has sparked many different research threads. In this section we review some recent works on CR standardisation. In doing so, we aim to demonstrate the complexity of the CR development process, highlighting the major drivers and barriers in the development of this novel paradigm in the history of radio communications.

1.4.2 Assessing Standardisation Arena for the CR Infrastructure

Information and communication technologies have been among the fastest growing and innovating technologies in both production and use during the four past decades. The ever growing demand for wireless services, however, has one negative effect—the shortage of the "enabling resource"—the radio spectrum. In part, the deficit of the radio spectrum is due to lack of flexibility in the operational principles of the extant radio telecommunications paradigm. Until today, each communication system has always had an exclusively assigned frequency band, and each wireless device must have dedicated hardware for each wireless communication system being supported [64, p. 4].

This very principle of the telecommunications services/market has one important implication for the standardisation. Namely, development of novel technologies has usually been seen from the perspective of single standard development initiative. For example, the 2nd generation (2G) mobile telephony system GSM—likely the most often quoted success story of the European telecommunications policy and market developments—is a story of the (single) GSM standard development [65, 66]. Similarly, the 1G and the 3G telephony systems were studied and referred to as single standard initiatives [67–69]. With the development of the 3G mobile telecommunications services, however, we have seen a substantial diversification of standardisation efforts, with different technologies-as-standards being accepted under the umbrella of the Universal Mobile Telecommunications Services (UMTS) tag.

CR-related standardisation seems to have surpassed the previous generations of wireless communications in terms of the scope and complexity of the on-going efforts. Two main factors contributing to the complex setup are, first, the ambiguity with regard to what exactly consumers and markets will be served by CR standards, and, second, the fact that CR application requires horizontal interoperability between (and harmonization of) different technology standards, business practices, and regulatory policies [54]. The commentary by Markus Mueck [63] points sharply at this problem:

> …The thing in standards is that it doesn't make sense to standardize, for example, a black box that one vendor sells. I mean one vendor can do whatever he wants within this black box. Standardisation is really about …interfaces and building blocks that need to interoperate between different entities… So the problem with cognitive radio is to identify which is the black box that is done by the company on the custom basis, and which are the interfaces (or the components) to be defined [in a standard], because they are required to make different vendors interoperate [63].

The multi-threaded nature of CR standardisation implies there will be a much larger amount of coordination required, as compared to the previous generations of telecommunications systems [54, p. 2], [70, p. 108]. The need for (more) coordination is particularly true in the light of convergence of previously distinct markets with one another, such as e.g., telephony, Internet, and TV broadcasting as a result of or the precondition for the introduction of CR. This convergence is not just convergence of markets (business) or technologies. Delaere and Ballon [54, p. 3] identify four inter-related domains in the development of CR-enabled markets: institutional, technological, functional, and infrastructural. A comment by Rudi Bekkers [63] shows how these multi-domain specifics of CR may look from a standardisation perspective:

> I recently was in ITU meeting, global symposium for regulators in Poland, in Warsaw, and what I noticed there was that there were several sessions on [White Space] WS and in the end it was like a very big confusion among many of the participants: many people actually were talking about different things (all called them WS) but you could see that someone was just talking specifically about the area of bands; other people were talking about … current digital dividend and …how they can use the spectrum… and then in the end people's [discussions] started to [encompass] everything, because they actually were talking about totally different things. The worst is, actually, if a lawyer starts to talk about [WS]. I can tell you—then it is getting very tricky [63].

Given the variety of perspectives on what CR is (see Sect. 2.8), and multitude of opinions on what [parts of CR] must be standardized, identification of the main stakeholders and their interests in CR may shed some light on who will be driving the innovation process in general and standardisation process in particular. Fomin et al. [71] have mapped the main stakeholders in the CR development, identifying both drivers and barriers in the CR innovation, as well as associated variables in dependent (co-evolving) domains (see Tables 1.1, 1.2, 1.3).

Complimentary to the aforementioned research on co-evolutionary forces in CR development, Fomin et al. [73] looked at the variety of threads in the CR innovation process from a different angle. They collected and content-analysed 68 documents originated by COST Action IC0905 "TERRA". Within a two-year activity of this predominantly European think-tank, a diversity of directions, institutions, and technological concepts were covered (see Fig. 1.5), thus seconding experts' opinion on the need for substantial coordination efforts in the development and standardisation of CR [54, 70].

Some authors attempted to show the complexity of the CR standardisation by enlisting different workgroups (WGs) and SDOs in charge of one or another

Table 1.1 Inter-dependencies between drivers and barriers in the market domain of CR

Original domain: market		Co-evolutionary factors	
Drivers	Barriers	Technology	Policy
Consumer demand for lower price broadband wireless services	The strong position of 3G/4G mobile telephony services in case of eventual price wars	SW-based R&D drives prices down	Increasing competition lowers prices
Demand for broader supply and diversity of RATs	Uncertain business model for provision of innovative CR-based services	SW-base allows myriad variations and on-demand adaptability	Flexible/neutral regulations promote experimentation
Demand for license-exempt home devices	Interference concerns	Innovative solutions: sensing, geolocation, pilot channel	Regulations for license-exempt use with interference safeguards

Source [72]

Table 1.2 Inter-dependencies between drivers and barriers in the technology domain of CR

Original domain: technology		Co-evolutionary factors	
Drivers	Barriers	Market	Policy
Shift from HW to SW paradigm implies faster R&D cycles and time-to-market	Initial resistance to disruptive change of technological & manufacturing base	Strong demand for new/diverse RATs	Access to "new" spectrum implies wireless market growth
Cognitive features open up opportunistic spectrum access	Interference and CR type approval concerns	Formation of new market players to service CR users, i.e. GDB operators	Suitable "fail-proof" regulations to re-assure incumbents

Source [72]

CR-related standard [74], see also Sect. 1.3. Baldini et al. [62] developed an impressively long list of SDOs—their analysis re-mapped to better demonstrate the SDO involvement in a later work by Sukarevičienė and Fomin [75] (see Table 1.4).

Specifically, Sukarevičienė and Fomin [75] extended the earlier works of Baldini et al. [62] and Fomin et al. [71] by enlisting key stakeholders and naming specific CR services and standards associated with the stakeholders or the services in the context of Lithuanian DSA development (see Fig. 1.6).

Table 1.3 Inter-dependencies between drivers and barriers in the policy domain of CR

Original domain: policy		Co-evolutionary factors	
Drivers	Barriers	Market	Technology
Shift from administrative to market-based frequency allocation to ease growing pressure for new assignments	Institutional inertia and lack of confidence in as-yet unproven dynamic spectrum assignment processes	Strong demand for new/diverse RATs; state's obligation to aid consumers	Innovative solutions: sensing, geolocation, pilot channel
Addressing demand for flexible *ad hoc* emergency frequencies	Fragmentation and sovereignty concerns for control of emergency services	Demand for cost savings by using off-the-shelf equipment	CR easily re-configurable
Making use (and generating income) from swathes of seldom used spectrum such as in military bands	Reluctance of governmental spectrum owners to relinquish control of "their" spectrum	Meeting market demand for new spectrum while generating new income to the state/ spectrum owners	Technological solutions that allow prompt vacating of bands by re-configurable CR

Source [73]

Fig. 1.5 Keywords by frequency of appearance (font size proportional to the frequency of its appearance): analysis of 68 documents originated by COST Action IC0905 "TERRA" [73]

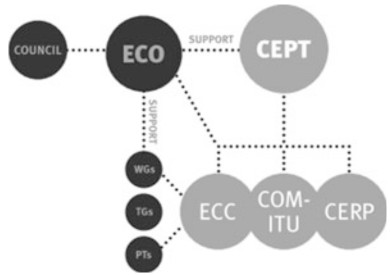
1.4.3 Conclusions

The advent of CR-enabled telecommunications services, more than the previous generations of telecommunications, will integrate and embed significant technological innovations [55, p. 3]. Even when a single standard is considered, anticipatory technology standards are very challenging to formulate and enforce as they do not just record existing practices (e.g., quality standards), or establish some new practices that need just to be coordinated (e.g., measures) [55, p. 3].

Table 1.4 Main regulatory and standardization bodies for CR and DSA, which participate in spectrum regulation and related standardization processes in Europe. Adapted from [62]

CEPT: The European Conference of Postal and Telecommunications
ECO: The European Communication Office

Purpose and members	Relationships	Structure
CEPT: harmonization of the regulatory requirements 48 countries across Europe	ECO, ECC, ITU, WRC-2012	Committees: • ECC • Com-ITU • CERP
ECO: advice and support to the CEPT 32 CEPT countries	Secretariat of the CEPT	A team of 13 people



Related standards, regulations, and projects:
Technical conditions for the use of the bands 821–832 MHz and 1785–1805 MHz for wireless radio microphones in the EU

Abbreviations used:
ECC: The Electronic Communications Committee
Com-ITU: The Committee for ITU Policy
CERP: The Committee for Postal Regulation

ETSI: The European Telecommunications Standards Institute

Purpose and Members	Relationships	Structural entities related to CR/DSA
Responsible for most of the European telecommunication standardization activities 62 countries on 5 continents, large number of industry members	Together with CEN and CENELEC	ETSI TC: • ETSI-RRS • ETSI-ERM

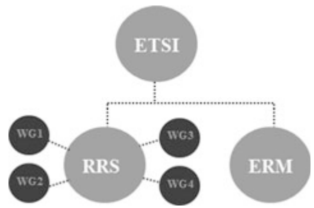


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Table 1.4 (continued)

Related standards, regulations, and projects:	Abbreviations used:
ETSI TC RRS, ETSI Specialist Task Force (STF) 386, e.g.: ETSI TR 102 799, ETSI TS 102 800	**CEN:** The European Committee for Standardization **CENELEC:** The European Committee for Electrotechnical Standardization **ETSI TC:** The European Telecommunications Standards Institute Technical Committee **ETSI-RRS:** The European Telecommunications Standards Institute Technical Committee on Reconfigurable Radio Systems **ETSI-ERM:** The European Telecommunications Standards Institute Technical Committee on Electromagnetic Radio Matters

EC: The European Commission
RSPG: The Radio Spectrum Policy Group
TCAM: The Telecommunications Conformity Assessment and market Surveillance

Purpose and members	Relationships	Structure
EC: implementation of regulatory environment EU Member States	Mandates from CEPT and ETSI	32 DGs, e.g.: • INFSO • ENTR
RSPG: development of radio spectrum policy EU Member States	Assists the EC (DG INFSO)	
TCAM: development of conformity assess and market surveillance policy EU Member States	Assists the EC (DG INFSO)	
	Assists the EC (DG ENTR). TCAM also collaborate with both CEPT and ETSI TCs	

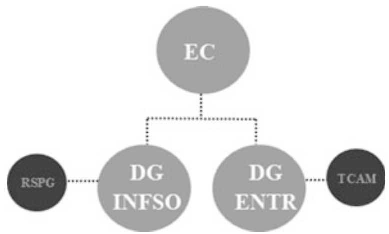

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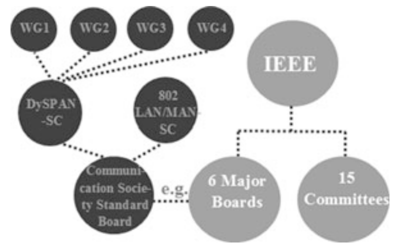
Table 1.4 (continued)

Related standards, regulations, and projects:	Abbreviations used:
Examples of EU-funded research projects: • E^3 • The FARAMIR project • The CROWN project • COGEU project	**DG:** Directorate General **INFSO:** Directorate General of the Information Society **ENTR:** Directorate General of the Enterprise and Industry

IEEE: Institute of Electrical and Electronics Engineers

Purpose and members	Relationships	Structure
Foster technological innovation, excellence for the benefit of humanity Industry and institutions from more than 160 countries	IEC, ETSI, COM/SDB, DySPAN, and many others	6 subordinate boards, 15 committees (each board also consists of several committees)



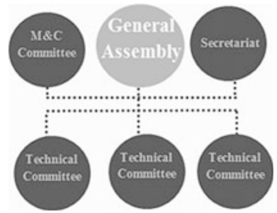
Related standards, regulations, and projects:	Abbreviations used:
Series: 802.22 (e.g. 802.11af), DySPAN-SC/P1900, 1900.1-1900.7, 802.16, 802.19, 802.18	**IEC:** International Electrotechnical Commission **ETSI:** The European Telecommunications Standards Institute **COM/SDB:** The IEEE Sommunications Society (ComSoc) Standards Development Board **DySPAN:** The IEEE Dynamic Spectrum Access Networks standards committee

(continued)

Table 1.4 (continued)

ECMA: The European association for standardizing information and communication systems

Purpose and members	Relationships	Structure
Standardization of information and communication systems Company members from Asia, Australia, Europe, N. America	Liaisons: ETSI, ITU-T, CEN, JTC1, CENELEC, IEC, ISO	Two decision levels: managerial and technical



Related standards, regulations, and projects:
ECMA-392

Abbreviations used:
CEN: The European Committee for Standardization
CENELEC: The European Committee for Electrotechnical Standardization
ETSI: The European Telecommunications Standards Institute
IEC: International Electrotechnical Commission
ISO: International Organization for Standardization
ITU-T: Telecommunication Standardization Sector of the International Telecommunications Union
JTC1: ISO/IEC Joint Technical Committee 1-Information technology

IETF: The Internet Engineering Task Force

Purpose and members	Relationships	Structure
Mission: to make the Internet work better Open to any interested individual	ITU-T SG and WP Liaisons	Working Groups (short-lived in nature)

Related standards, regulations, and projects:
RFC 5378 (BCP 78), RFC 3979 (BCP 79)

Abbreviations used:
ITU-T: Telecommunication Standardization Sector of the International Telecommunications Union
ITU-T SG: ITU-T Study Group
ITU-T WP: ITU-T Work Programme

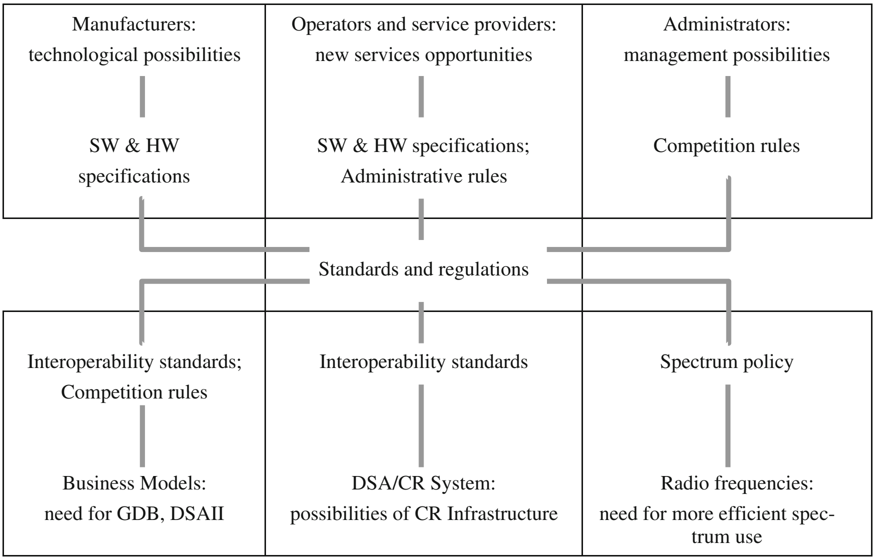


Fig. 1.6 Key elements of DSA infrastructure, adapted from [75]

Given the ambiguity surrounding the nature of future CR services, and potentially big stakes involved in developing CR-based markets, one may assume standardisation and regulatory efforts will be more and more directed towards interface standardisation. In this light, as commented by Intel Corp.'s Markus Mueck [63], "DSA standardisation is really about interface standardisation", and not about DSA-as-a-system. "The interesting thing here is that standardisation does not focus so much on DSA as such, but it focuses on the tools that are needed to implement DSA" [63].

However, standardisation focused (solely) on interfaces is not likely to give sufficient impetus to the CR innovation. Not only novel tools are needed for the paradigm-changing CR services. Orchestration of regulatory action (see Sects. 1.1 and 1.2), development of business models (see Chap. 4) and other similar measures are equally important to create basis for new CR-based communications solutions and new services. Ahead of time, very little is known about the possible market impacts of design choices made today, in the many threads of the CR standardisation efforts. In this regard, research reported in this section helps stakeholders participating in the standardisation process better estimate what choices would serve their interest best.

1.5 National Champions of CR Policy

1.5.1 US Regulatory Policy Developments and Visions

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FCC regulators first contemplated the idea of TVWS in 2004, in a Notice of Proposed Rule Making titled "Unlicensed Operation in the TV Broadcast Bands". Through much debate and contentious discussion within industry, the FCC published rules, that four years later made VHF and UHF spectrum available for "*new and innovative broadband products and services*" [76]. Since that time, further refinements and tangible progress have been made by industry (see Fig. 1.7). The FCC rules specify the use of a geo-location database that resides in the "cloud" which facilitates channel allocations without interference to incumbents. Incumbents are users of television broadcasting, land mobile radio, wireless microphones and radio astronomy. Establishing an ecosystem that would have a profound influence on future of CR technology may not have been the FCC's objective, but that was exactly the result. When CR was envisioned as a nascent technology, it was as an exotic technology that incorporated components of sensing, waveform synthesis and MAC layer adaptation and often referred to as Software Defined Radio (SDR). For various reasons, this form of SDR has not seen significant adoption, except in military and laboratory applications. This is partially due to complex and expensive radio requirements and a lack of regulatory policy to facilitate its use. However, the FCC's rules—elegant in their simplicity, changed the trend of CR. The confluence of this new regulatory landscape, widespread internet availability, cloud based computing resources and low cost radios have permanently shifted the CR paradigm from a self-intelligence to a shared-intelligence schema.

The basis of the FCC's TVWS rules is straightforward. They track geographic areas of incumbent operations, specify buffer requirements, determine channel adjacency constraints and utilize a geo-location database to allocate leftover or white space spectrum in terms of time, frequency and geography. White Space Devices (WSDs) report their location to the database, and spectrum is allocated in real-time.

Despite the appearance of simplicity, there are aspects that have caused debate, such as the path loss models to be used to determine protection and interference, how much noise margin should be allowed to ensure reliable operation and how portable devices will be managed. Fortunately, these parameters can be quickly adapted or modified, through the flexibility of a cloud based database. There is no need to re-program millions of individual devices with new operational parameters. The conservative nature of these rules has allowed industry to trudge forward without detriment to the incumbent ecosystems. As growth continues and the

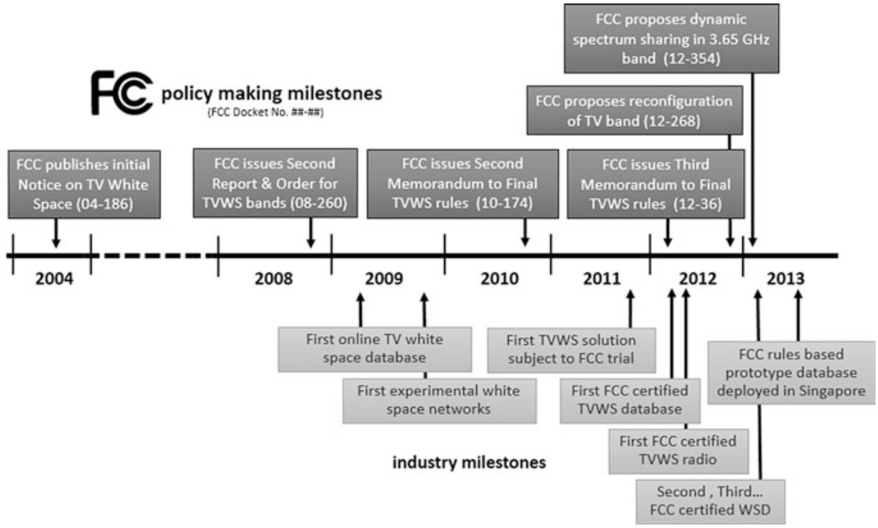

Fig. 1.7 TV white space: FCC policy making and industry progression timeline

effects of the incumbent and white space on one another is better quantified, it is expected that the FCC will consider changes to these rules.

The merits and acceptance of CR when coupled with geo-location database technology have been recognized as a positive development and served as an exemplary model for spectrum sharing. This has been affirmed through the continued development of TVWS radios and geo-location database technology in the US and unabated discussions on how this technology can be applied in other bands. In fact, the US rules have been adopted as a baseline for discussion in countries such as Canada and Singapore and several additional proceedings have been opened in the US to consider this model in other bands.

Unfortunately, widespread deployment of TVWS in the US has been lethargic and limited to a few applications in which it is currently well suited. Most applications have been targeted at smart agriculture, industrial telemetry and some rural broadband applications. Suitability of TVWS spectrum for these applications is driven by the unique combination of availability (in rural areas), excellent propagation characteristics (in harsh environments) and marginal broadband data rates.

Narrow adoption is ultimately the consequence of several policy based impediments: inflexible and particularly harsh out of band emissions requirements and the uncertainty surrounding re-allocation of UHF frequencies to accommodate changing television technology and growing demand for broadband spectrum. The out of band emissions requirements specified by the FCC for WSDs do not allow emissions to exceed -55 dB at the band edge, see Fig. 1.8. Unfortunately this is not congruent with standards based technology and every radio certified to date has required extensive filtering mechanisms.

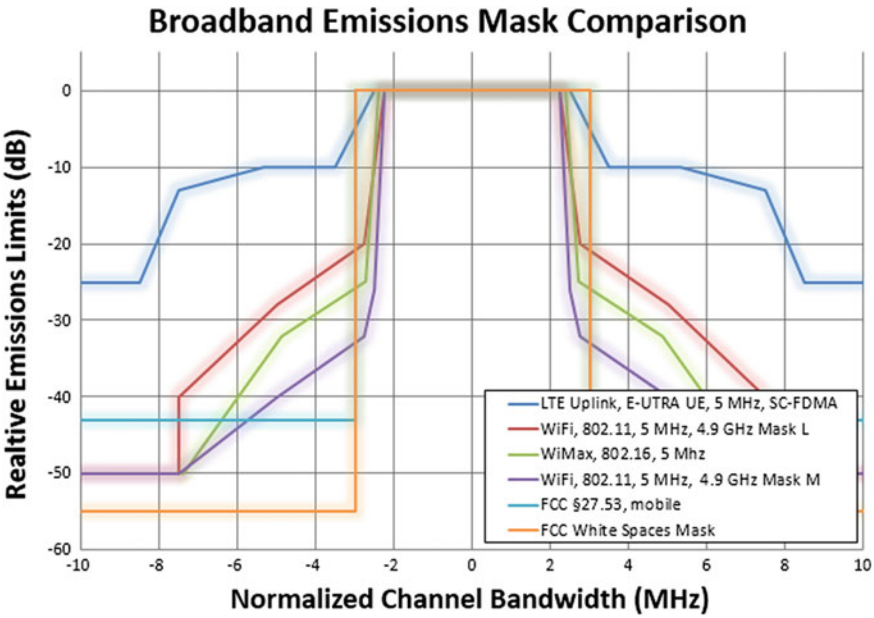

Fig. 1.8 Emissions mask comparisons: FCC TVWS and common broad band technologies

Specifically, the consequences of this limit are lower throughput (bits/Hz) and less transmit power resulting in a diminished link budget. This singular emissions limit is in contrast to the more flexible ETSI emissions device class model described in EN 301 598. Although the ETSI model is more complicated by virtue of variable transmit power limits and additional calculation requirements, it can be easily implemented within a geo-location database. The ETSI limits also permit the use of standards based technologies such as 802.11 Wi-Fi, with a bit of filtering. The only negative (albeit necessary) is the trade-off between undesired emissions and available TVWS, but it is better to have options! The second major inhibitor to TVWS adoption in the US is the uncertainty surrounding the potential repurposing of TV broadcast spectrum for licensed broadband use. In some locations within the US, there exists miniscule amounts of TVWS, especially near metropolitan areas. The risk to network operators is that when TVWS is reduced to a few channels, a real possibility exists that it may disappear altogether—after considerable capital investment and commitments to customers are made. Although the FCC has stated, "*In the white space … we propose measures that…would make a substantial amount of spectrum available for unlicensed uses, including a significant portion that would be available on a uniform nationwide basis…Television white spaces will continue to be available for unlicensed use in the repacked television band*" [77] it does not appear that this issue will be resolved soon, as illustrated in Fig. 1.9.

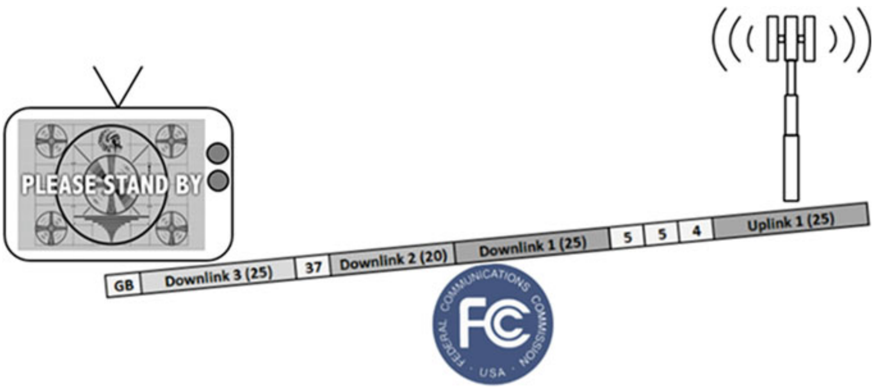

Fig. 1.9 The delicate balancing act the Federal Communication Commission facilitates between large wireless industry contingents

Fig. 1.10 The distinction between white and grey space

One advantage of this proposal is that a critical mass of TVWS might be dedicated to permanent unlicensed use through the designation of guard bands which would separate TV broadcast spectrum from licensed broadband spectrum. What remains unclear is what new constraints might appear. For example, what will the maximum allowable transmit power be in the guard band? And will portable devices be permitted to operate in a guard band? It is also unclear how long this protracted process will take.

There are other issues impeding the adoption of TVWS, but they are more technical than regulatory. A prime example is the unintended consequence of mixing high power television technology with low power broadband technology. The effects of this problem are illustrated in Fig. 1.10.

Because the FCC's primary goal in defining rules for TVWS operation is to protect incumbents, it has been left to industry to develop innovative solutions to deal with this challenge. Fortunately a geo-location database can be very effective

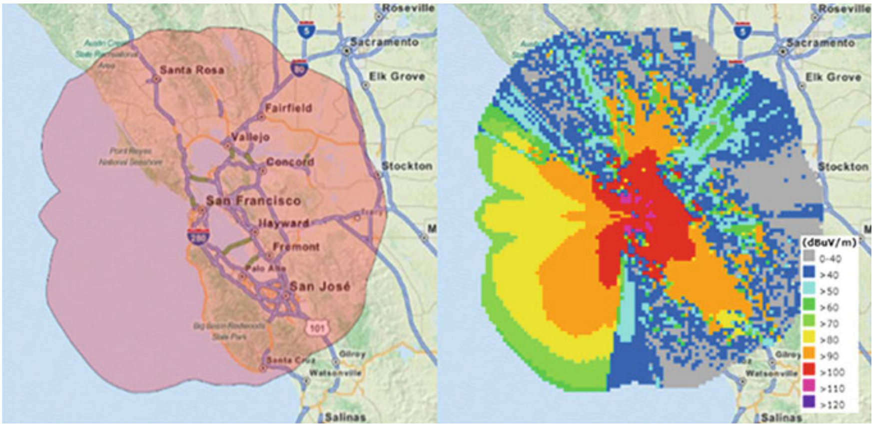

Fig. 1.11 Comparison between F-curve (R6602) and Longley-Rice contours near San Francisco, CA

in predicting and mitigating the interference between dissimilar ecosystems. This can be improved even more through crowdsourcing and feedback of interference data, in a way similar to how our smartphones forewarn us of traffic congestion on the roads we travel.

Another area in which the US model can be optimized is through the use of more accurate and comprehensive path loss and coverage models. The FCC currently utilizes the R 6602 [78] model for TV coverage, commonly referred to as the F-curve model. Although this model is fairly simple to implement and provides a more than adequate service contour prediction for television, it does not yield the resolution provided by other models such as Longley-Rice [79] or ITU-R P.1546. This is not to say that the R 6602 model is inadequate for its intended purpose, which is to define incumbent protection, but it is not well suited for optimizing the amount of TVWS available. This is illustrated in Fig. 1.11, where large areas are blocked by mountains and protected, but have no real opportunity for television coverage. One reason for the difference is that the Longley-Rice model makes significantly better use of terrain data. The Longley-Rice model also yields high resolution signal and coverage data which is compatible with the EN 301 598 pixel based methodology for defining incumbent protection. The pixel based approach is more complex in terms of computing available TVWS and data storage, but presents a trade-off that is feasible when considering the low cost of cloud based computational availability.

Although the growth of TVWS adoption and evolution of policy remains slow in the US, the promise of geo-location database technology remains positive. In fact the FCC should be affirmatively recognized as creating the first working set of TVWS rules and certifying the first TVWS radios and database platforms. Other implications of these rule making efforts have given rise to a new trend in CR. Nevertheless, it is expected that practical experience and regulatory efforts worldwide will have the biggest influence on US policy evolution.

1.5.2 UK Framework for Access to TV White Spaces

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1.5.2.1 Introduction

In this section we describe the framework for database-assisted access to TV white spaces in the UK, with special emphasis on the elements of the framework most relevant to the issue of coexistence with existing users of the spectrum inside and outside the UHF TV band (470–790 MHz). Note that at the time of writing, the final regulatory rules for access to TV white spaces in the UK are subject to public consultation.

1.5.2.2 Database-Assisted Access to TV White Spaces

White space devices (WSDs) operating in the UHF TV band in the UK will be licence exempt equipment that share the spectrum with the Digital Terrestrial TV (DTT) and Programme Making and Special Events (PMSE) services. These two licensed services are the primary users of the band, and as such, Ofcom must ensure a low probability of harmful interference to these services.

The requirement for a low probability of harmful interference also extends to services outside the UHF TV band. These include mobile networks above the band (791–862 MHz), and a range of uses such as emergency services, PMSE, scanning telemetry, short range devices, business radio, and maritime radio below the band (450–470 MHz).

The frequency allocations for the above services are illustrated below (see Fig. 1.12). Note that channels 31 to 37 are currently cleared of DTT transmissions, but are in use by PMSE, with plans for use by high definition DTT broadcasts in the near future.

By itself, a WSD does not have access to the requisite information about DTT and PMSE usage of the band to be able to transmit without there being a substantial risk of causing harmful interference to existing users. Therefore, a WSD must contact an appropriate repository—a white space database (WSDB)—and communicate information about itself and its geographic location. The WSDB will respond to the WSD with a set of Operational Parameters including the frequencies and maximum powers at which the WSD can transmit in order to ensure a low probability of harmful interference to the primary users.

The following are some of the key elements of the UK's proposed regulatory framework (see Fig. 1.13):

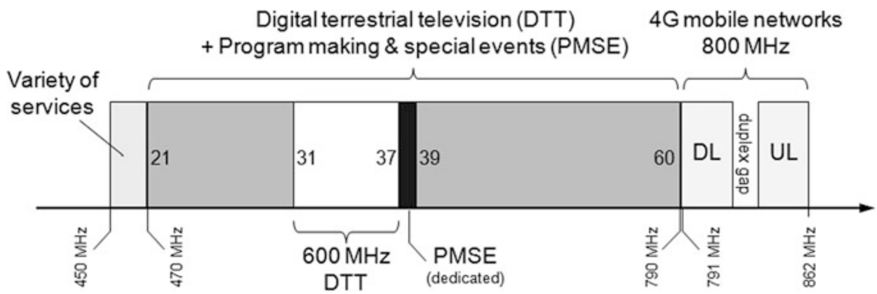

Fig. 1.12 The UHF TV band (470–790 MHz) and its users

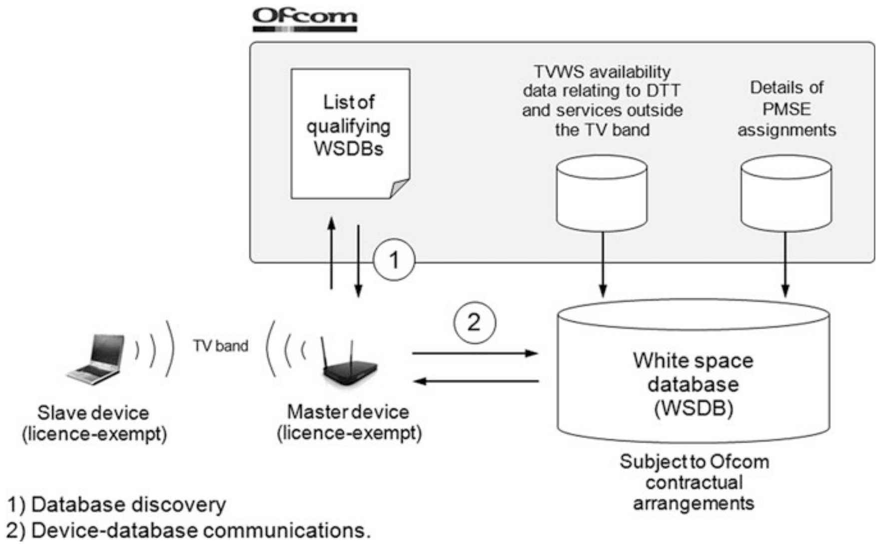

Fig. 1.13 Proposed framework for authorising the use of TV white spaces

- WSDs will be permitted to transmit in the UHF TV band provided that there is a low probability that they will cause harmful interference to existing licensed users within the band (DTT and PMSE) as well as users outside the band;
- Compliance with the licence exemption regulations will require that WSDs operate according to the frequency/power parameters (restrictions) that they receive from a WSDB. They will be required to obtain such parameters from a qualifying WSDB. The qualifying WSDB will generate the frequency/power parameters for WSDs on the basis of information relating to the existing users that Ofcom will regularly make available;
- WSDs will be able to identify qualifying WSDBs by consulting a list on a website maintained by Ofcom, and selecting a preferred WSDB from that list. This is the so-called “database discovery”. The choice of preferred WSDB will be for the master WSD to determine itself;

- WSDs are categorised as masters or slaves. A master WSD is required to have a communications link to access Ofcom's list of qualifying WSDBs, and a communications link to query one of the qualifying WSDBs. A slave WSD, on the other hand, does not have a direct connection to Ofcom or a WSDB; it will obtain its frequency/power parameters from a WSDB through a master WSD;
- Ofcom will calculate the frequency/power restrictions which apply in relation to interference from WSDs to DTT (both in the UK and across borders). The results of these calculations will be communicated to the WSDBs. These will also include any additional *location agnostic* frequency/power restrictions that may apply in relation to interference to services inside or outside the UHF TV band. Ofcom will provide scheduled updates to the above data whenever there is a relevant change to the planning of DTT or other services. It is expected that these updates will occur once or twice a year. On certain occasions, there may be unscheduled updates to the above data. These may be triggered by an interference management process or by the fine-tuning of Ofcom's coexistence modelling parameters;
- Ofcom will also provide to WSDBs information on geolocated PMSE assignments throughout the UK. This information will be updated on a scheduled three-hourly basis. WSDBs will use this information to calculate frequency/power restrictions in relation to interference from WSDs to PMSE. On certain occasions, there may be unscheduled updates to the above information. These may be triggered by an interference management process;
- The WSDBs will combine the frequency/power restrictions calculated by Ofcom with those they calculate themselves in relation to PMSE, and convey these to the relevant WSDs.

For the purposes of this section, we use the terms frequency/power restrictions, WSD emission limits, and TVWS availability data interchangeably.

1.5.2.3 Interactions Between Databases and Devices

In November 2012 Ofcom published "A consultation on white space device requirements" where it outlined proposals for the operation of WSDs and the nature of the data exchanged between WSDs and WSDBs. These proposals (among others) were subsequently incorporated into the draft European harmonised standard EN 301 598 which is currently subject to public consultation.[5] Details of EN 301 598 are presented in Sect. 2.7 of this book. Here we summarise some of the key elements of the WSDB-WSD interactions implied by EN 301 598.

As noted earlier, the first operation of a master WSD is database discovery. This is where the device consults a web listing of qualifying WSDBs. Ofcom may

[5] Draft ETSI EN 301 598 V1.0.0 (2013-07), "White space devices (WSD); Wireless access systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

occasionally update this list. For this reason, master WSDs must repeat database discovery with a minimum regularity as specified by Ofcom.

Having selected a WSDB from the web list, the master WSD may then initiate communications with that WSDB. WSDBs and WSDs are required to exchange the following parameters:

Device Parameters—These are communicated from a WSD to a WSDB, and identify specific characteristics of the WSD (including its location).

Operational Parameters—These are generated by a WSDB and communicated to WSDs. They specify the frequency/power restrictions (and other instructions) which WSDs must comply with when transmitting in the UHF TV band. There are two types of Operational Parameters:

(a) Specific Operational Parameters account for the Device Parameters of a specific WSD. In this way, for example, a WSD with a lower antenna height, a more stringent emission mask, and a more benign signal structure, would benefit from greater TVWS availability.
(b) Generic Operational Parameters are intended for slave WSDs whose Device Parameters are not known. A WSDB will communicate Generic Operational Parameters to a master WSD, which in turn will broadcast these to all slave WSDs in its coverage area. Generic Operational Parameters account for certain characteristics of the serving master WSD (e.g., location, power, and hence coverage area), but are based on assumed default values for the Device Parameters of the slave WSDs.

Channel Usage Parameters—These are reported by a WSD to inform a WSDB of the *actual* radio resources (channels and powers) that will be used by the WSDs.

The interactions between master WSDs, slave WSDs and WSDBs are described in more detail in Sect. 2.7 of this book in the context of the ETSI EN 301 598 harmonized standard.

1.5.2.4 Emission Limits for Coexistence with Existing Services

Here we describe the UK's proposed approach for the calculation of WSD emission limits to ensure a low probability of harmful interference to existing users of the radio spectrum.

Emission limits in relation to DTT use in the UK. In relation to DTT, the derivation of location-specific TVWS availability is formulated as the following problem: Calculate the maximum permitted WSD in-block EIRP, $P_{\text{WSD-DTT}}(i, F_{\text{WSD}})$ in dBm/(8 MHz), for a WSD located in a geographic pixel indexed as i, and radiating in channel F_{WSD}, subject to a target reduction in DTT signal-to-interference-plus-noise ratio in any channel $F_{\text{DTT}} = 21$ to 60. For a UK-wide picture, the above would need to be performed for each pixel in the UK and for each WSD channel ($F_{\text{WSD}} = 21$ to 60), accounting for the nationwide quality of DTT. The result can be interpreted as 40 maps of the UK with the maximum permitted WSD

EIRP depicted in each pixel. Ofcom will be responsible for generating UK-wide TVWS availability datasets in relation to DTT.

In the approach adopted by the FCC, WSDs are permitted to radiate at up to a fixed maximum power so long as they are located outside pre-defined geographic exclusion zones surrounding TV transmitters. The exclusion zones correspond to areas where the received DTT field strength exceeds FCC-defined thresholds based on FCC-defined propagation models.

In the approach proposed by Ofcom, there are no explicit exclusion zones. Here, it is the in-block EIRP of the WSDs (rather than their geographic location) that is explicitly restricted. The approach permits WSDs to communicate at greater EIRPs in areas where DTT field strength is greater; i.e., where DTT is more robust to interference. Furthermore, it is proposed to cap the maximum in-block EIRP of all WSDs at 36 dBm/(8 MHz). It is considered that such a cap on the maximum permitted power is important in avoiding the overloading of nearby DTT receivers. This value is also in line with the FCC limit for fixed devices, and is a sensible value which caters for most of the envisaged TVWS use cases.

Emission limits in relation to PMSE. In relation to PMSE, the derivation of location-specific TVWS availability is formulated as the following problem: Calculate the maximum permitted WSD in-block EIRP, $P_{\text{WSD-PMSE}}(j, F_{\text{WSD}})$ in dBm/(100 kHz), for a WSD located in a geographic location indexed as j, and radiating in channel F_{WSD}, subject to a given PMSE wanted-to-unwanted power ratio in any channel $F_{\text{DTT}} = 21$ to 60. For a UK-wide picture, the above would need to be repeated for each WSD location in the UK and for each WSD channel ($F_{\text{WSD}} = 21$ to 60), accounting for each licensed PMSE assignment.

WSDBs will be responsible for performing the above calculations. The WSDBs will need to account for WSD spectrum emission class, reported WSD antenna height, and WSD type (fixed or portable/mobile) in performing the calculations. In practice, WSDBs do not need to develop a UK-wide picture, as the calculations can be performed in real time in response to queries by individual WSDs.

Emission limits in relation to cross border DTT. In relation to cross border DTT, the derivation of location-specific TVWS availability is formulated as the following problem: Calculate the maximum permitted WSD in-block EIRP, $P_{\text{WSD-XB}}(i, F_{\text{WSD}})$ in dBm/(8 MHz), for a WSD located in a geographic pixel indexed as i, and radiating in channel F_{WSD}, subject to the received field strength in neighbouring countries not exceeding relevant international coordination trigger thresholds in channel F_{WSD}. For a UK-wide picture, the above would need to be performed for each WSD pixel in the UK and for each WSD channel ($F_{\text{WSD}} = 21$ to 60). In practice, only WSD pixels near the UK coastlines or land borders need to be examined since pixels in-land are unlikely to be subject to any cross-border restrictions. Ofcom will be responsible for generating UK-wide TVWS availability datasets in relation to cross border DTT.

Calculation of location-agnostic emission limits. Location-agnostic WSD emission limits will apply in the context of seeking to ensure a low probability of harmful interference to uses above and below the UHF TV band, as well as PMSE usage in channel 38 (the latter use is UK-wide and non-geolocated). These limits are not location-specific because information on the locations of the above uses is not readily available and therefore cannot be exploited in the database-assisted framework for access to TV white spaces. As a result, the WSD emission limits are simply specified by Ofcom as location-agnostic limits, $P_{LA}(F_{WSD})$ in dBm/(8 MHz), in each channel $F_{WSD} = 21 \ldots 60$.

Combining of emission limits by Ofcom. As explained above, Ofcom will be responsible for calculating the individual limits $P_{WSD\text{-}DTT}(i, F_{WSD})$, $P_{WSD\text{-}XB}(i, F_{WSD})$, and $P_{WSD\text{-}LA}(F_{WSD})$ across the UK. For a WSD located in geographic pixel i, and radiating in channel F_{WSD}, Ofcom will then calculate the overall EIRP limit, $P_1(i, F_{WSD})$ in dBm/(8 MHz), as the minimum of the above individual limits. Ofcom will then communicate the UK-wide values of $P_1(i, F_{WSD})$ to the WSDBs. Ofcom proposes to generate a unique set of individual limits for each combination of five WSD spectrum emission classes, three WSD technology (protection ratio) categories, and a number of representative WSD antenna heights, all for fixed WSDs. Limits for portable/mobile WSDs will be inferred by WSDBs from the limits provided for fixed WSDs.

Combining of emission limits by databases. As well as receiving the limits $P_1(i, F_{WSD})$ in dBm/(8 MHz) from Ofcom, WSDBs will calculate the limits $P_{WSD\text{-}PMSE}(j, F_{WSD})$ in dBm/(100 kHz) in relation to PMSE. Then, for a WSD at geographic location j (which falls within pixel i), and radiating in channel F_{WSD}, a WSDB will calculate the overall EIRP spectral density limit, $P_0(j, F_{WSD})$ dBm/(100 MHz), as the minimum of $P_1(i, F_{WSD}) - 10\log_{10}(80)$ and $P_{WSD\text{-}PMSE}(j, F_{WSD})$. The values $P_0(j, F_{WSD})$ dBm/(100 kHz) and $P_1(i, F_{WSD})$ dBm/(8 MHz) form the basis of the Operational Parameters which WSDBs communicate to WSDs.

Power adjustments by Ofcom (volume dial). It may be necessary for Ofcom to adjust the emission limits $P_1(i, F_{WSD})$ and $P_0(j, F_{WSD})$. Such adjustments, $\Delta(i, F_{WSD})$, will be communicated by Ofcom to the WSDBs. These might be on a location-specific and/or channel-specific basis, and may be triggered by an interference management process or by a fine tuning of Ofcom's coexistence modelling parameters.

Multiple devices and interference aggregation. In the framework presented above, it is implicitly assumed that at any one time only one WSD radiates per pixel/location and per DTT channel. In practice, one or more WSDBs may serve multiple WSDs in the same geographic area, and this may result in an aggregation of interferer signal powers.

It is believed that such aggregation of interference is unlikely to be problematic in the short term, since (a) the calculated WSD emission limits are cautious, (b) interference tends to be dominated by the nearest interferer, (c) many WSDs will implement polite protocols and are not likely to transmit simultaneously and/or congregate in the same DTT channels when in close geographic proximity, (d) even if WSDs did transmit simultaneously and in the same DTT channels, the composite signal would increasingly appear noise-like and would render the time–frequency structure of the aggregate signal more benign in the context of interference to existing services.

In the longer term, there are three high-level mitigation options in the event that interference aggregation were to become a problem:

(1) Direct reductions in WSD emission limits to incorporate fixed added margins for interference aggregation.
(2) Rule-based reductions in WSD emission limits as a function of the number of WSDs which a WSDB already serves at any given location.
(3) Rule-based reductions in WSD emission limits informed by inter-WSDB communications.

1.5.2.5 Conclusions

We have described the UK framework for database-assisted access to TV white spaces, and presented some of the key components of the data exchanged between WSDBs and WSDs, as specified in the ETSI harmonised standard EN 301 598.

We have also summarised at a high level the approach proposed by Ofcom for calculating the WSD emission limits in relation to the various existing uses of the spectrum inside and outside the UHF TV band. We have explained how the various emission limits must be combined to derive location-specific and frequency-specific limits P_0 dBm/(100 kHz) and P_1 dBm/(8 MHz) which form the basis of Operational Parameters that WSDBs communicate to WSDs.

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