REGULATORY ISSUES FOR TV WHITE SPACES

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This chapter discusses current issues of spectrum regulations related to TV White Spaces, with focus on dynamic spectrum management and cognitive radio. It is based on recent studies conducted in the framework of the International Telecommunication Union (ITU). National aspects are also discussed, with a few examples from the United States and European Union.

3.1 INTRODUCTION

The ability to carry energy and messages at a distance with the speed of light, and at no cost, made the spectrum of radio waves a valuable resource from which everybody could profit. However, due to the laws of nature, various applications of radio waves can interfere with each other and - if incorrectly used - can nullify the benefits they could offer. To avoid such interference, each application requires some free amount of radio frequency spectrum, and to assure it, an appropriate spectrum management is necessary. To be effective, any spectrum management system should include sound spectrum regulation, planning, engineering, monitoring and enforcement. Three objectives shape any spectrum management system: conveying policy goals, apportioning scarcity, and avoiding conflicts, with due regard to social, political, economic, ecological, etc., aspects. The society is composed of various groups, each with its particular interests and goals. As a consequence, probably there is no spectrum management possible that could fully satisfy all those interested. Conflicts might arise between those who have access to the spectrum resource and those who have not, between competing uses of the spectrum, etc.[1]

The capacity a communication system provides is ultimately limited by the spectrum available to that system. The number of radio systems

1. R. Struzak: Introduction to International Radio Regulations; in S. Radicella (ed.): ICTP Lecture Notes No. 16, Trieste 2003, ISBN 92-95003-23-3; http://publications.ictp.it/lns/vol16.html

in operation worldwide is already enormous and continues to increase. Most of suitable frequencies have already been occupied and in some frequency bands and geographical regions there is no place for new radio systems. Cloud-based applications, which exchange data back and forth with distant datacenters instead of storing them locally, increase the spectrum occupation further. To solve spectrum problems, numerous organizations have employed thousands of experts. The International Telecommunication Union (ITU), a specialized Agency of United Nations, is one of them.

3.2 SPECTRUM REGULATIONS

ITU assembles 193 countries (grouped in three ITU Regions) to assure, among others, rational use of the spectrum/orbit resources through the consensus-based decision process, *"taking into account the special needs of developing countries"*. The ITU mission involves:

- Ensuring meeting the specific needs of countries through mechanism of the World and Regional Radio Conferences, International Conventions/Agreements, etc.
- Coordinating the efforts to eliminate and prevent harmful interference between radio stations of different countries,
- Studying and recommending technical and operational standards by Radiocommunication Study Groups and Assemblies.

Other tasks include global standardization and development. The mission is accomplished in the spirit of collaboration and mutual trust.

3.2.1 International Regulations

How the spectrum/orbit resources are used has profound impact on the society, on its prosperity, security, culture, and education. Keeping the ITU mission in mind, the ITU members have agreed upon common Radio Regulations[2] that aim at assuring inter-communication among various systems, assuring rational use of spectrum, and preventing mutual interference. Radio Regulations have the status of an International Treaty, and each government warrants they are respected under its jurisdiction. Traditionally, the use/management of the spectrum/orbit resources on the international forum bases on a few general principles:

2. Radio Regulations, International Telecommunication Union, Geneva 2012

- The spectrum/orbit resources are public. The uses of these resources are based on the common administrative regulations and allocations of frequency bands (and orbital parameters for satellite communications). These regulations and allocations are set through the mechanism of international consultations, negotiations, and consensus.

- Every country has an equitable and free access to spectrum/orbit resources: no fee mechanism has been envisaged on the international scene for the use of spectrum/orbit resources.

- National sovereignty is a "sacred" principle in the ITU. Each country decides about its uses freely, as long as it respects the international regulations and agreements in force. On that basis, many countries have introduced a national system of fees. Some countries have created an internal spectrum market, although not everywhere with success. We will come back to that in section 2.5 below.

The uses made of the spectrum/orbit resources have been based on the Table of Frequency Allocations of Radio Regulations. *Allocation* means the distribution of a frequency band to a wireless service, *allotment* - to a country or area, and *assignment* - to an individual radio station. Some allocations are worldwide, others are regional, i.e., uniform throughout a particular region. A country can make an assignment to an individual station or to a group of stations when needed. This is the so-called *ad hoc* frequency distribution method. An alternative is *a priori* frequency distribution. They differ in the time horizon taken into account. For services subject to a priori planning, an assignment in accordance with the plan receives protection from any other assignment. In the case of ad hoc managed services, the protection is given in accordance with the priority of registration dates - a system frequently described as first-come, first-served.

3.2.2 *Frequency Planning*

International frequency plans, which are subject to a priori frequency planning, are coordinated among all those interested at competent radio conferences. A frequency plan assigns appropriate technical characteristics to radio stations in specific frequency bands, for specific applications and geographic regions. The name "frequency planning" remained from the early days of radio, when only operating frequency of radio stations was coordinated. International plans are general and contain minimal number of details. In contrast, national assignments include all the details necessary to operate the station properly. In such plans, specific frequency bands and associated service areas are reserved for particular application well in advance of their real use. Such a distribution of the spectrum resource is made on the basis of the declared needs of the parties interested. That principle was also used at the ITU Regional Radiocommunication Conference RRC Geneva 2006 in planning the digital terrestrial broadcasting service[3]. Advocates of the a priori approach indicate that an ad hoc method is not fair because it transfers the entire burden to the latecomers, which are forced to accommodate their requirements to those of the existing users. Opponents, on the other

3. Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06), International Telecommunication Union, Geneva, 2006

hand, point out that a priori planning freezes the technological progress and leads to "warehousing" the resources. Critics of a priori planning indicate that it is impossible to predict future requirements with a degree of accuracy, and that any plan based on unrealistic requirements has no practical value, blocks frequencies, and freezes the development. Indeed, the technological progress is very fast, and the plan may become outdated before is implemented. What is important is that there is no mechanism to limit the requirements, as the spectrum/orbit resource is available at no cost at international planning conferences. Although the ITU Convention calls for minimizing the use of these resources, each country has an incentive to overstate its requirements, and there are few accepted or objective criteria for evaluating each country's stated needs. Under these circumstances, it is easy to make a case that common plans are not only difficult to construct, but lead to a waste of resources as frequencies and orbit positions are "warehoused" to meet indeterminate needs. Radio Regulations differentiate between *primary* and *secondary* services. Those qualified as "primary" (or "co-primary") enjoy the full protection rights in relations to other stations. Stations of a secondary service shall not cause harmful interference to, and cannot claim protection from *stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date*. However, they can claim protection, from harmful interference from stations of the same or other secondary services [4].

4. Radio Regulations, International Telecommunication Union, Geneva 2012, RR5.28 to 5.30

3.2.3 Radio Conferences

Radio Regulations are regularly reviewed by the competent World Radio Conferences (WRCs) or Regional Radio Conferences (RRCs), in order to keep pace with technological, political, and economic changes; only these organs are authorized to make changes in the regulations. Every ITU member state is obliged to incorporate these modifications into its national regulatory legislation as soon as possible. For television, the regional conference RRC Geneva 2006 decided that all analog TV transmissions have to be replaced by digital ones [5] and this has already happened in most European countries. In 2012, the World Radio Conference[6] has opened the way for the practical use of *cognitive radio systems (CRS)*, which earlier was considered as a possibility in distant future[7], and such systems are being introduced.

The RRC GE Geneva 2006 conference was called to coordinate the transition from analog to digital television and to produce a plan satisfying more than 70 thousand broadcasting requirements throughout the planning area of the ITU Region 1 and part of Region 3. This planning area embraces all European and African countries plus some Asian ones. Most of the original requirements were mutually conflicting. To solve these conflicts, almost 1000 experts from over 100 countries came to Geneva to work together during 34 days (and late evenings). They negotiated the national proposals that had been submitted and discussed

5. Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06), International Telecommunication Union, Geneva, 2006

6. Final Acts of the World Radiocommunication Conference WRC-12, International Telecommunication Union, Geneva, 2012

7. Mitola J: Cognitive Radio: an integrated agent architecture for software defined radio, Dissertation, Doctor of Technology, Royal Institute of Technology (KTH), Sweden, 2000

during the six years of the pre-conference period. The proposals were analyzed from the viewpoint of satisfying the national needs while avoiding unacceptable interference to neighboring countries. It was an iterative approach, which required complex computer simulations after every modification. The volume of necessary computations exceeded the capacity of the ITU computer network, and computing resources of other entities in the region, such as the CERN's supercomputers, had to be employed. Finally, a common reference plan (about 2000 pages in length) was accepted that will serve as a basis for designing the national digital TV plans in the frequency bands 174-230 MHz and 470-862 MHz in the planning area. The transition from analog to digital television releases a large amount of spectrum for other uses, the so-called *digital dividend*. Advances in signal processing and single-frequency networks (SFNs) made possible the delivery of digital TV programs using only a part of the spectrum required by analog TV.

3.3 DYNAMIC SPECTRUM ACCESS AND COGNITIVE RADIO

Until recently, the spectrum has been accessed to transmit (and/or to receive) signals in the fixed radio frequency slots dedicated to specific services in specific regions, on what is known as fixed spectrum access (FSA). The Frequency Allocation Tables in Radio Regulations set precisely such a mode of operation. In this mode, the assigned frequency band cannot be changed during the license validity (an exception is Frequency Hopping (FH) systems, where the carrier frequency varies, but only within the assigned band). Special methods have been developed to use optimally the spectrum resources in that mode[8]. The Dynamic Spectrum Access (DSA) concept frees radio systems from that restriction. It may be seen as a generalization of FH systems, in which not only the carrier frequency can vary, but also the assigned frequency band. In static conditions, where the spectrum users operate at fixed frequency bands assigned to them, Administrations can set up static coexistence (compatibility) conditions for the new systems. Such solutions have been in use for a long time e.g., in the case of earth satellite stations sharing frequencies with terrestrial radio-relay links. However, the static sharing conditions may be not applicable, and the a priori sharing conditions may be insufficient, if the signals change their power, direction of arrival, etc. In such case the Dynamic Spectrum Access concept has to be applied, which requires that existing technical, legal, and other aspects must fit the actual local conditions. The Dynamic Spectrum Access Systems can switch automatically from one band to another. In this way, the spectrum previously allocated for exclusive use can be shared - at a given time in a particular region - with a new user, under the condition that the potential interference levels are kept within acceptable limits.

8. R. Leese, S. Hurley (eds.): Methods and algorithms for Radio Channel Assignment; Oxford University Press2002, ISBN 0-19-850314-8

Such a mode of operation is also known as "Opportunistic Spectrum Access (OSA)". However, to exploit that method, advanced hardware - cognitive radio - has to be used. ITU experts have defined a Cognitive Radio System (CRS) as *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* (ITU-R Report SM.2152[9]). Cognitive Radio (CR) technology is seen as a future solution for increased radio spectrum demands. It allows increasing spectrum efficiency and increased number of radio services in operation in the same place and/or time by using Dynamic Spectrum Access (DSA) techniques, but it is complex and not cheap.

9. ITU Report SM. 2152, Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS), International Telecommunication Union, 2009

3.3.1 Decisions of WRC Geneva 2012

The agenda of World Radiocommunication Conference (WRC) Geneva 2012 included considerations of regulatory measures in order to enable the introduction of software-defined radio and cognitive radio systems (agenda item 1.19). Two major proposals were submitted in this connection. One was to keep the current Radio Regulations as they are, without change. The second proposed the preparation of a new Resolution on regulatory measures for the CRS Systems, which could delay its introduction. After discussions, the Conference decided that no change to the Radio Regulation, nor special Resolution on CRS regulatory issues are needed. The prevailing argument was that CRS is a new technology rather than a new service, and that the present Radio Regulations are adequate to assure sufficient protection of the existing radio services when the new technology is introduced. From the regulatory viewpoint it means that CRS can operate in any frequency band under the condition that they not violate the current RR in the country and in neighboring countries. It is possible to introduce CRS at any frequency band under the condition that other services already operating, or planned, are adequately protected. It implies that protection criteria are specified in the Radio Regulations, or agreed among the parties interested, which is not easily achieved. It is very difficult to establish protection criteria if the service, devices, and deployment details are unknown because both services and devices are still in the planning phase and may be produced and deployed in an unspecified future. In such a case, when a CRS device is not ready for deployment, only some general assumption can be taken into account: for example the assumed basic spectral masks, or reference deployment scheme. In such a preliminary phase usually one uses very approximate theoretical models. More exact models often require detailed experimental data, on, for instance, the degree of devices' nonlinearities. In some cases, the necessary data can be taken from other systems that employ similar components, for which the protection criteria in similar conditions have already been established and are available. Such an approach was used, for instance, during preparation of the ECC Report 159 and its amendments[10] [11] [12] where, in evaluation of 470-790 MHz TV white spaces, the protection criteria were taken from the measurements of DVB-T against LTE, in the LTE bands. At the same time the WRC12 conference admitted that CRS is a new technology, not fully established yet. It recommended Administrations to participate actively in studies on the *deployment and use of cognitive radio systems* (Recommendation 76) and invited Administrations participating in these studies to take into account that *any radio system implementing CRS technology needs to operate in accordance with the provisions of the Radio Regulations; and that the use of CRS does not exempt administrations from their obligations with regard to the protection of stations of other administrations operating in accordance with the Radio Regulations* (Resolution ITU-R 58). Along the same line, the ITU Radiocommunication Assembly (Geneva 2012, RA12) [13] resolved *to continue studies for the implementation and use of CRS in radiocommunication services; to study operational and technical requirements, characteristics, performance and possible benefits associated with the implementation and use of CRS in relevant radiocommunication services and related frequency bands; to give particular attention to enhancing coexistence and sharing among radiocommunication services; [and] to develop relevant ITU-R Recommendations and/or Reports based on the aforementioned studies, as appropriate* (Resolution ITU-R 58). It means that further studies are to be focused on the coexistence and sharing among radiocommunication services i.e., on compatibility issues and spectrum sharing criteria. Comparing the Frequency Allocation Tables with local (actual) spectrum occupancy it can be found that the dynamic/opportunistic spectrum access can be introduced not only in TV bands, but also in other bands. Indeed, any part of the spectrum (civil or military) with fixed transmissions (e.g., fixed services, broadcasting services, fixed radars etc.) can be seen as a potential region for better spectrum use via DSA and CR systems. Also mobile operators might dynamically access spectrum portions granting, buying, or borrowing them when they are not used. This would allow better spectrum utilization but also liberalization of spectrum access.

10. ECC Report 159, "Technical and operational requirements for the possible operation of cognitive radio systems in the 'white spaces' of the frequency band 470-790 MHz" Cardiff, January 2011

11. ECC Report 185, "Complementary Report to ECC Report 159. Further definition of technical and operational requirements for the operation of white space devices in the band 470-790 MHz", 2013

12. ECC Report 186 "Technical and operational requirements for the operation of white space devices under geo-location approach", 2013

13. Book of ITU-R Resolutions, Radiocommunication Assembly RA-12, Edition of 2012, Geneva 2012

3.4 WHITE SPACES IDENTIFICATION AND INTERFERENCE AVOIDANCE

TVWS, or Television White Space, refers to frequencies allocated to a TV broadcasting service but not used locally. TV White Space Spectrum Systems (TVWSSS) are seen nowadays as one of promising solutions for realizing the Dynamic Spectrum Access concept in practice. White spaces can be identified using three methods: spectrum sensing, pilot channel (beacon) and geolocation database, which can be used independently or in combination. Such kind of operation may be considered as "third-rate" status (after the primary and secondary services) of the CRS opportunistic services. The CRS have to protect other radio services working in the same geographic and adjacent areas, in the same and adjacent frequency bands, etc. This implies establishing criteria and mechanisms allowing full protection of all incumbents. The protection mechanism can be derived when compatibility criteria are known, and current and planned spectrum usage is controlled.

Spectrum sensing. Spectrum sensing by the CRS devices was found as a natural solution for learning about the existence of other incumbent radio services and controlling the device emission parameters. It means that the CRS devices continuously detects current spectrum usage and learn from it about the current spectrum situation. However such solution is still under research. First of all there is "hidden node" problem - where the sensing device is hidden and cannot sense primary signals, for example, due to obstruction (hills, buildings, trees, etc.) on the receiving path. In such situation it can declare "free spectrum" when in reality it is occupied. Trying to increase the accuracy of the sensing and solving the hidden node problem with a single device could lead to the situation where the required sensing level is very low and practically impossible to implement in some frequency bands (as it is in case of TV UHF band). Also in case of very short time transmissions (burst, PMSE, M2M etc.) where the device is only active in very short time period, it is very difficult to detect the transmission and avoid interference. Some improvement is offered by Cooperative Sensing (CS), where many devices together are sensing the spectrum and exchanging the information that they collect. This may solve the problem of the hidden node, however, it is more complicated solution which cannot be used without recurring to additional protection mechanism, when, for instance, some channels have been previously allocated by administrative decisions but are not currently in use. Furthermore, this does not work in protecting the receive-only services, such as radioastronomy.

Pilot channel (beacon). One of possible solutions for protection of the incumbents is the pilot channel (beacon). Here a dedicated channel is used to inform every WS device about the current spectrum usage and free channels available. However, it could be difficult to find a common world-wide (or regional-wide) frequency allocation for such special pilot channel due to different frequency allocations in different countries. In fact such channel could be allocated for each country separately but in that case many frequency pilot bands around the World can complicate the wireless mass market. Also different interference problems between stations transmitted beacons in different regions have to be mitigated. Such solution has met with limited success so far, since alternatives (especially geolocation databases) seem to be more promising. However if some operators may use their own transmission channels (e.g. GSM or Wireless Internet operators) - the information on the available spectrum can be sent via a conventional GSM/UMTS/LTE channel or via ISM/RLAN band.

Geolocation Databases. Geolocation database is now considered as the most promising solution because it can be used as one simple solution solving all problems (protection of reception-only devices, hidden node problem, sensing level etc.) for all types of transmissions and frequency ranges. It stems from the fact that every regulatory provision for any radio systems can be registered in a controlled database, along with rules that will determine the White Space Spectrum availability. The WS device has only to determine its location (using e.g., GPS), send its geographical coordinates to the database and asks it (directly or via a Master device) which channels are available under specific conditions (transmit power, antenna heigth, mode of operation, etc.). Data in the database can be easily changed, which offers additional flexibility of spectrum usage and protection of incumbents. The database can also include "safe harbor" channels for special applications, e.g. Program Making and Special Events (PMSE) channels, which may be reserved for local PMSE and be forbidden for CRS. Additional spectrum-related operations can be performed with on-line real-time access to the database. Such operation is necessary to assure, for instance, protection of the WS CR devices that just have channels access for a limited time. Other possible applications are discussed in the section below.

3.5 NATIONAL REGULATIONS AND TV WHITE SPACES

National regulations can add specific requirements to those internationally agreed as long as they do not violate the international treaties in force. On that basis, for instance, national spectrum licensing fees have been obligatory in most countries, and only a minuscule portion of the spectrum is open for license-free operation. This is in spite of the fact that no country pays any spectrum fees and the radio spectrum is considered as a *common heritage of humanity*. The current spectrum management practices are inherited from the times when radio was mainly under the state monopoly and the governments agreed that access to the spectrum resources should be at no cost for them. Within a country, the government can control strictly who, how, where and when, uses the spectrum by issuing licenses. This is done by three different mechanism: administrative adjudication where licenses have been awarded (almost) for free, on the basis of the "first come - first served" rule; by lottery; or by comparative hearings (called sometimes "beauty contests"). However, the world has changed. The state monopoly has been abandoned in most countries; the importance of private sector and international corporations is growing. Some economists have put forward the concept of spectrum management through market forces. It is based on the idea of replacing the administrative licensing system by a competitive market mechanism. The full control by the government (and parliament) is replaced by the supply-demand-price game with minimal governmental intervention, if any. The licenses are granted to the highest bidders. It is based on the theory that the spectrum does not differ from other natural resources that have been managed in such a way since a long time, like coal or oil. For the time being, that approach has been limited to selected frequency bands, services, and countries, and has found as many supporters as opponents. The main declared benefits of that approach is that (1) the market mechanism tends to match automatically the demand to the available resource capacity, as it does in other sectors, and (2) the market-based spectrum management is inexpensive. With an unregulated market, there will be no spectrum scarcity (for those who are rich enough to buy it). In addition, selling the spectrum is an easy way to feed the government's budget, a very tempting proposition for some politicians. In 1995, for instance, two pairs of 15-MHz bands aimed at providing personal communication services in the 1900 MHz region, for were auctioned in the USA for a total of 7.74 thousand millions of USD. But not all auctions were so successful. The opponents to spectrum market say that the spectrum differs significantly from other resources and privatizing it would be a serious mistake leading to irreparable losses in the future. There are numerous examples where the unregulated market approach has led to irreversible environmental disasters, not mentioning global crises. Auctions do not stimulate the use of the most efficient technology for the use of frequency. They only let a successful bidder push smaller operators out of the market, and build a monopoly. Note that on top of the mentioned amount paid in the USA, the successful bidders had to pay all the expenses for relocating thousands of microwave transmission facilities that were already using that spectrum. But the total expense has always been put on the shoulders of the final users. Market forces ignore social aspects and - as Garrett Hardin noted - add the PP-CC (privatize profits and "commonize" costs) game to the price-supply-demand interplay. A sound alternative to spectrum market is spectrum sharing in the license-exempted frequency bands like ISM/WiFi/RLAN at 2.4 and 5 GHz. It has resulted in the decades-long growth of various applications and services, with minimal management costs. The license-exemption approach could easily be applied in the TVWS spectrum; indeed it is not restricted to any specific frequency, and could be applied in any band (with appropriate technology).

Possible uses of TVWS are being intensively studied in several countries (e.g., USA [14] [15] [16], UK [17] [18]) and discussed at international forums (e.g. ITU and CEPT) and standardization groups (e.g. IEEE 1900.x, 802.22, 802.11af, and ETSI RRS).

In some countries preliminary regulatory provisions have already been proposed. This is because of the good propagation characteristics in the UHF TV frequency bands, which is important for business

14. FCC 10-174 Second Memorandum Opinion And Order Adopted: September 23, 2010

15. FCC 12-36 Third Memorandum Opinion And Order Adopted: April 4, 2012

16. FCC 12-118 Notice Of Proposed Rulemaking Adopted: September 28, 2012

17. OFCOM, Implementing geolocation, Consultation, Publication date 9 November 2010

18. OFCOM, Implementing Geolocation Summary of consultation responses and next steps Statement Publication date: 1 September 2011

opportunities: the UHF bands are called the *"gold spectrum resource"*. TV signals to be protected are (almost) stationary. Due to the fixed characteristics of the broadcasting stations (under control by the Administrations) they do not change frequency, direction-of-arrival, etc. Therefore, it is possible to estimate spectrum availability in any given location (e.g., pixel-square 100 x 100 m) under a specified transmission scheme, and such estimation can be reliable and valid for a relatively long time. Such estimations of spectrum availability have been calculated in several countries [19] [20], an example is discussed in section 3.6 below. The amount of TV WS spectrum availability depends on the methodology, propagation models, and the data used that may differ from country to country. Introducing Dynamic Signal Access systems in a country requires changes in national regulatory procedures in the licensed frequency bands. Currently, in each country there exist only fixed frequency assignments. DSA requires a new kind of license that allows for dynamic change of the frequency band in short time period (possibly even in the bands allocated to primary services) that could be shared by a number of users simultaneously in a dynamic way. Such "new vision" in spectrum management requires advanced radio technologies. *Cognitive radio* technology may need to be applied and the whole regulatory regime reviewed. For example real-time access to databases controlled by the Administration or by *"spectrum brokers"* may be needed. The databases would include the geographical locations, frequency channels, radiated power, etc. of the existing or future (licensed) users. Legal consequences of possible errors in these databases would have to be taken into account. Precise technical coexistence conditions have to be defined and relevant requirements established and enforced by the Administrations. The non-interference requirements may have to be determined in real-time and signal parameters changed automatically. In this connection, it might be necessary for Administrations to prepare and publish detailed databases of the licensed users (see below for more details). In the current regulatory framework, all primary services are protected and any transmission that could interfere (harmfully) with primary users is not allowed. If a new service is to be introduced in the country (or in neighboring countries), detailed protection conditions of the existing primary services have to be established to assure their adequate protection and keep interference levels safely below harmful limits. Currently it can take months (or even in some cases years) to negotiate and agree detailed technical conditions of such spectrum sharing issues with all neighboring countries. However this was aimed to situation where new (non-CRS) services have fixed frequency range and near-fixed technical characteristics. In the case of CRS, however, that case is more complicated and can change dynamically on both sides of the border. It could lead to the situation where it is difficult to coordinate different CRS standards and systems implemented by the Administrations. In such cases common technical CRS standards or common coexistence technical standards (or at least common database

19. D.Więcek, Methodology of White Space estimation in TV bands based on the ITU GE06 technical conditions, COST IC0905 TERRA 3rd Workshop, Brussels, 21st June 2011

20. J. Zender, K. Ruttik, QUASAR - TVWS Assessment in Europe, COST TERRA 2nd Workshop - Lisbon January 19-21 2011

settings) could help the Administrations involved.

3.5.1 Use of Geolocation Databases

If an Administration wishes to use a geolocation database only as a protection mechanism of the incumbents, the coordination process with neighbors may be limited to the technical details of the database only. In such a case databases for neighboring areas may have special conditions, or may even be compiled by the neighbors. They can offer additional "safe margin" solutions: their data can be easily modified, if needed and as needed, without changing the implementation requirements (hardware and software) of the terminals. For instance, the data on maximum permissible powers, antenna heights etc. can be adjusted/modified in the database at the operational phase, in order to modify the interference scenario. It gives the same effect as modifying directly the protection requirements depending on the current contents of the database. Reaching technical agreements with neighbors may base on common technical protection requirements but can also involve different solutions for both border sides. In such coordination, using general CRS data (e.g., mode of operation, spectrum masks, technical standards) is more practical than using specific device data because it eliminates the need for additional coordination when the device data change. The Cognitive Radio Systems can be incorporated as additional (primary or secondary) services, provided that they protect all incumbent services (and also secondary in many places) working in the country and in its neighbors. A CRS device can operate in any type of service i.e., mobile, fixed, broadcasting, satellite etc., for which appropriate frequency ranges are allocated. As the WRC12 decided, for regulatory purposes, there is no need to define an additional "service" dealing with Software-Defined Radios, or Cognitive Radios. These technologies can be seen as an alternative to OFDM, CDMA etc. However, due to the capability of dynamically accessing different parts of spectrum allocated to different radio services in different countries, special attention to the CRS implementation is necessary in the national regulatory framework. Preparation of national databases requires first deciding which technical data are needed for CRS to operate. The basic data include at least spectrum masks, but more details may be needed, such as e.g. full technical specifications/ standards. Because of the nature of CRS and mandatory protection of all other existing services, technical data in the databases cannot be "agnostic" i.e., technically neutral due to the fact that protection of incumbents depends on detailed technical data of the CRS used. Some administrations may wish to implement only selected/accepted (by them) technical CRS standards/solutions in specific regions, and may not wish to implement others because, for instance, not all transmission types may be allowed in a specific country. Other administrations may wish to accept all CRS devices that fit the spectrum mask and other general parameters, to assure flexibility or technological neutrality. Those might be the type of transmission, maximum antenna height or accuracy of geographical location, etc. However, allowing different types of radio transmission means that special attention has to be given to the adjacent frequency bands, or that larger separations of the CRS devices might be necessary, thus decreasing the number of devices allowed to operate in the protected area. But from the market point of view such neutrality solution opens markets for many possible solutions. Implementations fitting only the spectrum mask and general technical requirements allows increased competition and is more open to future (different) standards.

3.6 EXAMPLES

Figure 3.1 is an example of a map showing the availability of TVWS spectrum in a country. It is a graphical presentation of simulation calculations and analysis of the signals' strength, at UHF frequency range (470 - 790 MHz, UHF TV channels nos. 21 to 60). The analysis was done for some 600,000 points (raster of 1km x 1km) of Polish territory using the PIAST system [21]. Terrain irregularities were taken into account, but not buildings, trees, etc. A generic fixed-type WS device of 30 dBm EIRP power with omnidirectional antenna at 10 m above ground level was assumed, as well as standard outdoor fixed TV reception conditions. Protection of all relevant TV transmitters was taken into account[22]. The colors of individual pixels in the figure indicate the number of TV channels that a generic WS device can use without causing unacceptable interference. The average number of TV channels available in this example amounts to 14.5. With 8 MHz per channel it gives more than 100 MHz. Note that amount could be higher or lower depending on the assumed antenna height or the degree of protection.

The first national regulatory provisions introduced in the USA and UK set up only some basic technical data to be coordinated. For instance, the FCC (USA) rules define only a fixed maximum EIRP at fixed distance from the border of TV service area. The work performed in the UK (OFCOM) and other regulatory bodies shows that more complex regulations could be needed. Because of the varying number of active CRS devices, dynamic change of frequency band, and other variables, it is difficult to coordinate with neighboring countries such systems on the basis of the existing regulatory procedures. For example it is difficult to estimate (and coordinate) such "traditional" and conventional variables used in frequency coordination as "maximum permissible interference levels" or "required protection ratios" or "maximum transmitted powers". This is because of dynamic location of the CRS devices, dynamic transmission scheme (usage of current frequency during short period time) or difficulties in estimating the cumulative effect of many interferers operating simultaneously.

The protection requirements may differ among countries for various reasons, e.g., because of different technical standards. For instance, in

21. Platform IT for Analysis of Systems in Telecommunications (PIAST); National Institute of Telecommunication, Wroclaw Branch, Poland: http://www.piast.edu.pl

22. D.Więcek, Methodology of White Space estimation in TV bands based on the ITU GE06 technical conditions, COST IC0905 TERRA 3rd Workshop, Brussels, 21st June 2011

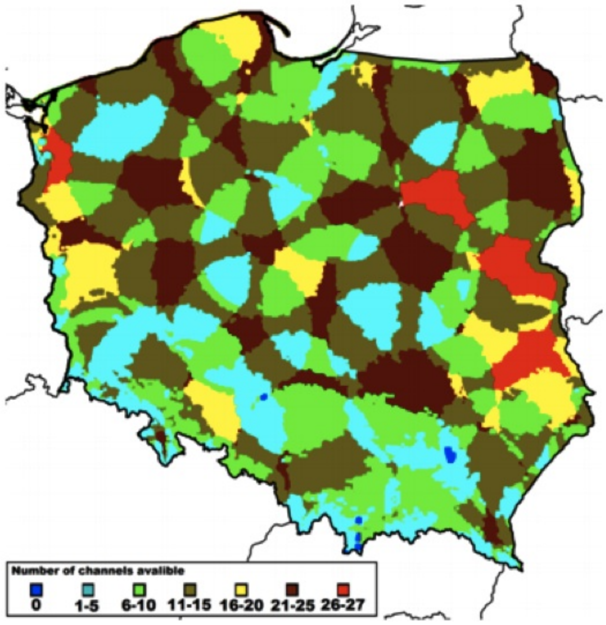

Figure 3.1: Result of the analysis of TV White Spaces availability in Poland. Source: ECC Report 185

the USA the broadcasting standard ATSC uses 6 MHz channels, while the European DVB-T/T2 system uses 8 MHz; there are also other technical details. For example the minimum protected field strength (which depends on the reception mode: roof or street, fixed or portable, indoor or outdoor), minimum required separation distance, or "percent of location probability degradation" (ECC Report 159[23]). In some countries investigations were performed, looking for the "real conditions" protection and "interference limited coverage" or "interference limited service area", taking into account also interference coming from other broadcasting stations. Results obtained with a geolocation database data depend also on the propagation models used. Different propagation models [24] [25] [26] [27] may give different estimations of spectrum availability. No agreement exists over which model should be used. In some countries different propagation model are used for the wanted signal and for the interfering signals: signal coverage from broadcasting stations is calculated differently that of WS devices. This may give different results, even if the countries use the same data and methodology in other applications. Furthermore, the technical standards used for the calculation (802.22, 802.11af, LTE, etc.), the Spectrum Masks, Adjacent Channel Leakage Ratios (ACLRs) and Spurious Emission Limits, have strong influence on spectrum availability estimations, especially in the case of adjacent channels, where different protection ratios exist depending on specific EMC systems characteristics. It means that there is no single view of the protection requirements of the TV services - even in the case of using the same system (e.g., DVB-T/T2 in Europe), the same ITU

23. ECC Report 185, "Complementary Report to ECC Report 159. Further definition of technical and operational requirements for the operation of white space devices in the band 470-790 MHz", 2013

24. ITU-R, Recommendation P.1546-4 "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 300 MHz," International Telecommunication Union, Geneva, Oct 2009

25. ITU-R, Recommendation P.1812-2: A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands, International Telecommunication Union, Geneva Feb. 2012

26. ITU Report ITU-R SM.2028-1 Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems, International Telecommunication Union, Geneva 2002

27. G. Hufford et al., U. S. N. Telecommunications, and I. Administration, A guide to the use of the ITS irregular terrain model in the area prediction mode . US Dept. of Commerce, National Telecommunications and Information Administration, 1982

Region, and with the same calculation methodology for the TV White Space availability estimation. This can cause different estimations and different regulatory decisions among countries. Each Administration is sovereign in setting its own regulations following its national policy of spectrum usage, type and level of protection, as well as in deciding about the WS devices and standards to be used under its jurisdiction. It means that every Administration may wish to develop its own methodology and establish its own geolocation databases. All these facts mean that spectrum availability evaluations, spectrum maps, and geolocation databases can differ from country to country. This is also because of differences in the TV reception modes and spectrum occupation, as well as in the protection requirements. As a consequence, there may be more TV channels available for CRS in one country than in others, even in the same geographical ITU Region and the same WS device. Such a situation exists now in Digital Terrestrial Television (DTT): in some countries many multiplexes exists but in some others only a few. One foresees (e.g., in ECC Report 185) that every country will prepare its requirements and databases of available TVWS spectrum, using its specific methodology. In bordering areas these have to be coordinated and accepted by the National Regulators of the neighboring countries. It may be needed to exchange data from the databases to get acceptation of other Administrations. In some cases different methodology and different spectrum availability need to be established for the bordering areas if the Administrations have different views of the situation. Such different approaches in different countries can cause also situation where in some of them market for new TV WS systems and applications (e.g. M2M, "super WiFi" etc.) will grow while in others might wither for lack of business interest. Administrations wishing to increase deployment of radio systems in rural areas have to be careful about estimating available TVWS spectrum, because even small differences in these details can produce different results. Consequently, different estimates of the potential CRS market can be obtained. As in many other cases, where Administrations stimulated market growth, an involvement of the Administration is needed, especially in an early stage of CRS implementation. If a national spectrum market exists and license-paid scheme of TVWS could be accepted, the national regulations would need on-line electronic licensing procedures in which paper documents would be unnecessary in the process of spectrum assigning. Granting licenses via on-line spectrum auctions could be arranged, where the pieces of White Space spectrum could be sold to the highest bidder automatically (if the spectrum market is accepted). Using Internet real-time access to databases, licensing system, and paying system, would lead to a fully electronic form of future frequency assignments procedures. That would certainly require regulatory amendments.

3.7 FINAL REMARKS

It is generally accepted that improved spectrum availability benefits the society at large, as do advances in hardware and software. These directions have to complement each other and match local conditions. Even the best technology is useless if the regulations curtail its operation, or the devices are inappropriately deployed. This chapter has presented a flexible approach to spectrum access that could be widely implemented in future. However, further studies, political support, and adequate financing are necessary for that to happen. For practical reasons, countries are starting with the new approach to national radio regulations in the "license exempted" frequency bands. After such "experimenting" with geolocation databases and other new elements, it might be easier to extend it over the UHF TV band. That part of spectrum is especially attractive because of its inherently better propagation conditions at long distances. Combined with high-gain antennas it could offer an inexpensive solution for the long-distance broadband access problem in many developing regions. Eventually, technology could remove the need for many spectrum management functions. Numerous functions could be automated to free the management process from the "human factor" and make it more objective and neutral. Future wireless devices would "negotiate" among themselves how to "best" use the available resources. Principles, criteria, and algorithms to be embedded in such automates would be mediated at conferences. However, in view of enormous investments in the existing (old) equipment still usable, it would not happen soon and everywhere. The Dynamic Spectrum Access and Cognitive Radio discussed above are the first steps in that direction. Setting national radio regulations in an uncoordinated way may lead to national differences. Harmonization of national rules, geo-databases, and propagation models used is necessary to avoid a regulatory patchwork that would fragment the wireless TVWS market and make the international commercial success much harder to achieve. Without such a harmonization, national decisions about channel availability may be inconsistent, which would make it impossible, even for the same WSDs, to operate across the border, as it was the case at the beginning of wireless services some hundred years ago. It would also nullify the Internet Engineering Task Force's work in ensuring that the protocol for accessing geo-databases is globally uniform, like HTML.

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