Part I

White space technology signal processing and digital design

1 White space technology, the background

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1.1 Introduction

Discovered more than 100 years ago, radio communications continue to populate everywhere, from local area computer networks, to cellular and broadcasting sectors, including wireless sensors and radio frequency identification (RFID). This imposes the existence of a crowded spectrum, Figure 1.1. As the spectrum has been loaded very fast, it is becoming a scarce resource, which is a problem for radio planning engineers and designers.

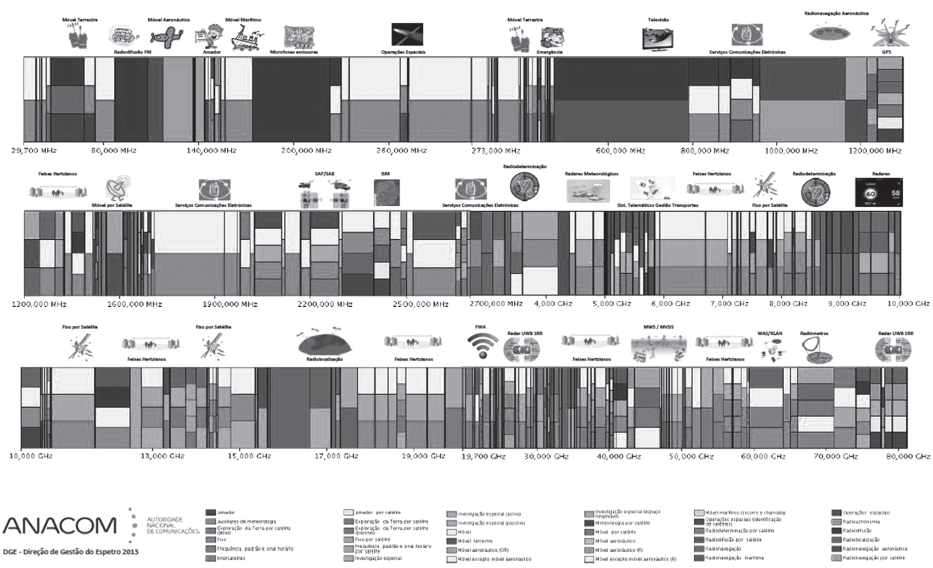

Figure 1.1 Spectrum allocation in Portugal (figure supplied by ANACOM)

Nevertheless, in recent years a spectrum paradox is been identified: many wireless technologies are experiencing spectrum congestion, yet measurement campaigns demonstrate that, as a whole, the spectrum is being under-utilized [1–3]. In fact, in some regions, at certain periods, a large amount of frequency is not being utilized at all. This gives rise to the so-called “white spaces” spectrum.

White spaces are thus spectrum holes where no signal exists despite being attributed to a specific service and to a specific company or organization. This is shown in

Figure 1.2. Since these spaces are not used at all most of the time, it would be economically and socially advantageous to change the current regulation policy of allocating spectrum to a technology, service, or company to a more flexible scheme which makes efficient use of these white spaces.

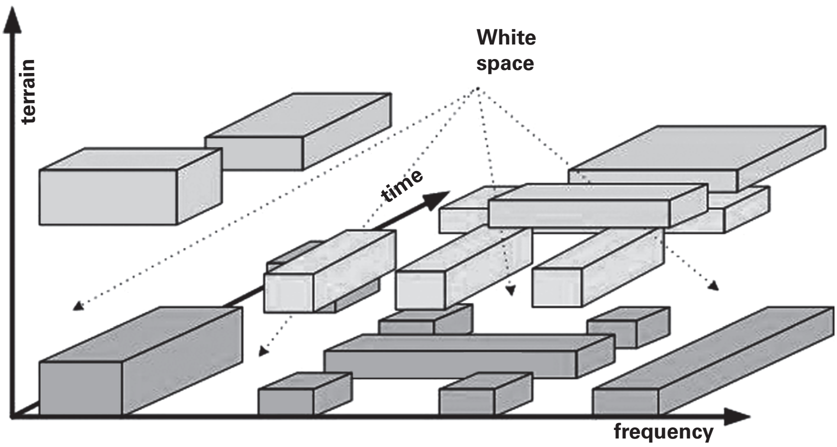

Figure 1.2 Spectrum holes

Several solutions can be identified for reusing the spectrum, most of them allowing the use of the spectrum under certain rules that can pass through spectrum re-trading, spectrum sensing for monitoring spectrum activity, and use only in quiet moments, as well as many others.

One of the zones of spectrum, where holes are easily identified, is the old analog television band, which most of the time is completely free, taking into account the geo-location of a specific device. This happens because TV broadcasting technology is changing, with analog TV transmissions gradually being shut down and being replaced by their digital counterparts almost all over the world.

Digital terrestrial TV (DTT) with its better spectral efficiency demands spectrum intervention regulators to decide how to use the released spectrum. This opens a window of opportunity to change spectrum regulation policies. Regulators are working to provide new rules that allow unlicensed use of "white spaces" while assuring that licensed spectrum owners will not be hassled. This is quite important and decisive, since the pressure from mobile operators is tailoring the future of these spectra.

In this chapter, we will first discuss regulatory approaches to the use of the television "white space" in several parts of the world, then focus on technical solutions for the use of "white spectra," and finally discuss the technical challenges to implement these technological solutions.

1.2 TV white spaces regulatory approach

Since the early 1920s, TV development has occurred in parallel in the USA, Europe, and Japan. In Japan and Europe, the focus until the middle 1990s was on improving analog systems before reaching high-definition TV (HDTV) systems. In the USA, the same thing was happening, but in 1990 FCC asked for a HDTV system using the same 6 MHz channel used by standard definition analog TV. This challenge was met through compression techniques and by migration-to-digital technology. Japan and Europe were also working on digital TV, but until the middle 1990s only for satellite and cable segments.

Digital terrestrial TV systems have been proposed since the early 1990s, with the first technical standards approved in 1995 (USA). In Europe and Japan, the standardization produced the first standard in the late 1990s, and the first emissions began in 1998 and 2003, respectively. Since then, analog has coexisted with digital, but is being gradually replaced almost all over the world. Examples of some countries that have switched off analog transmissions are: Luxembourg (2006), Netherlands (2006), Finland (2007), Sweden (2007), Germany (2008), USA (2009), Portugal (2013), and most of the European Union (EU) countries (2012).

This digital switchover has led to a significant amount of free spectra, which, as previously said, could be used efficiently by cognitive radio transceivers, thus optimizing the use of spectra.

In this specific case, the digital switchover may free up considerable amounts of spectrum in VHF and UHF bands, as can be seen in Figure 1.3. A smaller amount of the spectrum should be allocated to the more spectral efficient digital TV. The free TV channels, some MHz wide, would be adequate for both supplanting spectrum congestion and would allow the florescence of new broadband services.

The VHF and UHF bands are also attractive because of their better propagation characteristics (e.g. a range about three times higher than in the ISM band) and better propagation through walls.

Regulators must decide if they should license the white spaces or allow their unlicensed use. Licensed use would make difficult the licensing process (auction) and license supervision. Moreover, the necessity to avoid interference to broadcasting systems imposes additional technological difficulties and costs that could prevent interest on a licensed basis.

Unlicensed use of white spaces seems to be preferable as it will make white space use cheaper, allowing a greater number of companies to propose innovative uses of the spectrum, and lead to a faster adoption rate. It seems there is a place for innovation, which could provide economic benefits for those showing interest.

Instructed by respective governments, regulators started to work on regulations on the use of TV white spaces several years ago. Among them, proposals from the USA and the EU are those already finished [4]–[7], [9], [10], [12]–[17].

1.2.1 European approach

Telecommunication industry activities, excluding military operations, within the EU are governed by the Regulatory Framework for Electronic Communications, which covers fixed and wireless telecoms, internet, broadcasting, and transmission services. The framework intends to be simple, technology and service neutral, legally predictable to foster investment, and sufficiently flexible to deal with the fast evolving market

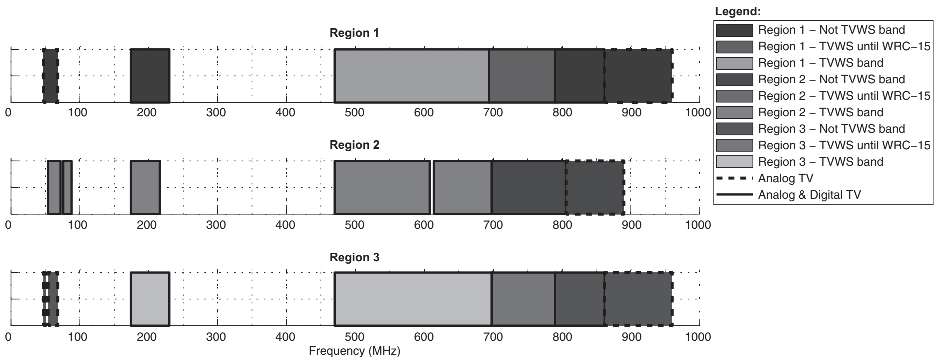

Figure 1.3 ITU-R television broadcasting allocations, after WRC-12

conditions. In the longer term, it intends to lead to deregulation, as a means to increase the competition in the internal market.

Within this framework, spectrum issues are dealt by the "Framework Directive" and the "Authorisation Directive" [18]–[20], which promote spectrum management efficiency (e.g. through competitive spectrum trading in authorized bands or light licensing regimes) and coordination of spectrum policies within the EU in order to obtain fair and predictable harmonized spectrum utilization conditions.

The Radio Spectrum Policy Programme [21], [22], proposed in 2010 and approved in 2012, complements this legal framework by setting the spectrum policy and harmonization objectives in the near future, in accordance with the Europe 2020 [23] Initiative and the Digital Agenda [24], [25]. The programme goals are:

- identify, at least, 1200 MHz for wireless data communications by 2015;
- make the bands 800 MHz (digital dividend), 900/1800 MHz, 2.5–2.69 GHz, 3.4–3.8 GHz available to high-speed electronic communications;
- provide wireless internet connections not less than 30 Mbps for all citizens by 2020;
- construct a spectrum inventory, describing all spectrum allocations, which facilitates harmonization activities, re-allocates frequency bands, improves spectrum sharing, and analyzes future spectrum needs, etc;
- harmonize frequency bands;
- allow spectrum trading in harmonized bands where flexible use was already introduced, as long as this does not distort competition;[1]
- promote spectrum sharing as much as possible, using different options for improved efficiency and innovative applications;
- promote research and development of new technologies such as cognitive radio, white space communications, and geo-location databases;
- promote research of new services – if necessary, allocate spectrum for new services with major economic impact;

[1] Such bands are: 790–862 MHz, 880–915 MHz, 925–960 MHz, 1710–1785 MHz, 1805–1880 MHz, 1900–1980 MHz, 2010–2025 MHz, 2110–2170 MHz, 2.5–2.69 GHz and 3.4–3.8 GHz.

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Excerpt
More information

- guarantee spectrum for RFID and other technologies associated with the "Internet of Things" (M2M communications);
- study the possibility of providing pico and femto-cells, possibly organized under a mesh-network topology accessing unlicensed spectrum as a means to avoid the digital divide;
- increase the adoption of wireless technologies to improve efficiency in energy production and distribution (smart grids and smart metering);
- identify spectrum for wireless microphones and cameras (PMSE);
- protect frequencies used for meteorological surveillance, space communications, satellite navigation (Galileo navigation system), and transportation systems.

Spectrum management in Europe is migrating from rigid command-and-control policies to flexible strategies focusing on spectrum sharing [18], [19], [22], [26].

Spectrum use will be allowed to any company through general authorization grants, the terms of which will be regulated. National administrations may impose additional constraints in spectrum utilization when this is justified as increasing the social and economical benefits of spectrum utilization (article 5 of [18]).

Individual rights of spectrum utilization should only be granted when this is absolutely necessary to provide the required quality of service and to increase spectrum utilization efficiency. In practice, due to technological difficulties, this licensing option is the most used.

The licensing process foresees individual licenses, light-licensing, and license-exempt regimes [27] (Table 1.1).

The institutions involved in radio regulation are the National Regulatory Administrations, the European Commission (EC), and the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT).

Spectrum management is performed by each country in accordance with ITU guidelines and EU policies. The EU policies take into account strategic opinion from the

Table 1.1 Regulatory regimes of radio services (according to the ECC [27])

Individual authorization (exclusive rights of use)		General authorization (no individual rights of use)	
Individual license	Light-license		License exempt
– Individual frequency planning	– Individual frequency planning	– No individual frequency planning	– No individual frequency planning
– Traditional procedure to issue licenses	– Simplified procedure to issue licenses	– Registration and/or notification required	– No registration nor notification required
	– Limits the number of users (first-come-first-served)	– No limitations in the number of users	– No limitation in the number of users
		– Coordination not mandatory	– No coordination

Radio Spectrum Policy Group (RSPG) and technical decisions from the Radio Spectrum Committee (RSC).

CEPT is responsible for making technical studies concerning spectrum allocation and spectrum use. It also coordinates EU viewpoints expressed in ITU World Radio Conferences (WRC) and manages the European Common Allocation (ECA) table.

White space operation in Europe has been under consideration since 2005, fueled mainly by the UK National Regulatory Agency (OFCOM) and the ECC/CEPT.

At the beginning of 2007, the EC asked CEPT for technical advice regarding allowing new applications into nonharmonized "white spots" between TV broadcasting frequency allotments [28]. In response, CEPT issued a report [29] suggesting potential candidates for white space use such as PMSE (Programme Making and Special Events) devices, other portable devices with output powers up to 100 mW (Wi-Fi cards, smart phones, media players), and fixed devices with output powers up to 1W (broadband wireless access points). Due to the high heterogeneity of scenarios possible when using white spaces, a new technology – cognitive radio – seemed specially suited to make useful use of this spectrum [29].

According to [29], white space devices (WSD) should not be protected from interference among them. However, they must not interfere with licensed primary users, and move to other white space channels whenever necessary. Among services to protect in the 470–862 MHz band are digital television broadcasting (according to the Geneva 2006 Plan, there will be seven or eight multiplexes in most European countries), aeronautical radio navigation, military applications (channel 36), radio astronomy (channel 38), program making, and special events services (channel 69).

The document ended with CEPT acknowledging the need for further studies on 470–862 MHz band white space use by cognitive radio devices before deciding to proceed to a European recommendation on the matter. Such studies would only be treated in 2009 [29].

Some years before, in 2005, OFCOM started consultations with market players about possible applications of the spectrum that would be free after the digital switchover. In 2007, there was a decision to support opportunistic radio applications [10] in those frequencies. Therefore, OFCOM started to work on the technical details with the market players. Several proposals on operational parameters were made between 2007 and 2009. The first proposal relied both on autonomous spectrum sensing and geo-location databases [10], [11], but autonomous spectrum sensing was abandoned due to reliability concerns [12]–[14].

In 2009, the Electronic Communications Committees (ECC) Working Group on Spectrum Engineering (WG-SE) formed the project team SE43, which was in charge of defining technical and operational requirements for the operation of cognitive radio systems in the white spaces of the UHF broadcasting band in order to ensure the protection of incumbent radio services. The team was also to investigate the expected amount of spectrum potentially available as white space [7].

The preliminary results were presented in the ECC Report 159 [7] at the beginning of 2011. The report identified autonomous spectrum sensing, geo-location databases and radio beacons as possible solutions to identifying the unused frequencies, and recommended:

- Geo-location is the most appropriate method to protect incumbent services, since autonomous sensing has very demanding requirements that could not be met with current technology, and radio beacons do not attract interested investors.
- White space devices are classified as personal/portable devices, home/office devices, and private/public access points.
- Instead of fixing a maximum WSD output power and defining the correspondent regions where WSD operation is allowed, such as in the FCC regulation, in European regulation the WSD maximum allowed power should be location specific. This requires additional computations compared with the FCC proposal, but it is expected to improve the number of white space devices that could be used, especially in the European territory, which, on average, has a higher population density than the USA.
- The metric used to protect TV broadcasting should be location probability.
- There should be definition of safe harbor channels for PMSE protection, where WSD are not allowed.
- Exclusion zones around radio astronomy facilities should be defined.
- Additional studies concerning aeronautical navigation protection should be undertaken.
- Mobile/fixed services operating in bands adjacent to 470–790 MHz also required further compatibility studies.
- There should be a methodology to estimate white space availability; further improvements are necessary.
- Additional studies on several topics should be performed.

Regarding the database implementation, the report also suggested:

- the adoption of master–slave architecture to support devices without geo-location capabilities;
- the WSD sends information to the database, which would use it to determine the list of unused frequencies and the correspondent allowed equivalent isotropic radiated power (EIRP);
- an algorithm to calculate the maximum transmit power allowed to a WSD operating in a vacant channel;

Meanwhile, subband 790–862 MHz was allocated for mobile communications and the European white spaces band became the one spanning 470–790 MHz.

SE43 studies concluded at the beginning of 2013 with the approval of ECC Reports 185 [8] and 186 [9], the former being a complement to Report 159, contained the required additional studies related with operation of white space devices in the band 470–790 MHz, while the latter concentrated specifically on the geo-location database method.

As can be seen in Table 1.2, studies conducted by SE43 considered three WSD groups, all of them using OFDM modulation: personal/portable devices, home/office devices, and private/public access points. The first two groups represent low-power,

Table 1.2 WSD characteristics considered in the European interference studies [7]

Device category	Power category	Antenna height	Mobility
Personal/portable	Low (10–50 mW)	Low (1.5 m)	Low
Home/office	Low (10–50 mW)	Low (1.5 m)	Static
Access points	High (1–10 W)	High (10 m or 30 m)	Static

small-sized devices with low antenna height. The distinction between them is that portable devices can be moving, while home/office devices are static. Private/public access points are static devices, internet connected, eventually operating with high power and high antenna heights. All of them can have additional transceivers capable of communicating using bands outside 470–790 MHz.

These three types of devices can operate in several scenarios concerning indoor/outdoor communication, fixed/moving radios, and high/low antennas.

SE43 considered scenarios are:

- Infrastructure scenarios (i.e. at least one of the communicating devices is a static access point):
  - outdoor, one access point, both antennas with low height;
  - indoor, one access point, both antennas with low height;
  - outdoor, one access point, one high antenna and one low antenna;
  - outdoor, two access points, both antennas with high height;
- Ad hoc scenarios (i.e. no device is a static access point)
  - outdoor, both antennas with low height

Although not mandatory, in the studies conducted by SE43 it was considered that WSD should use OFDM modulation, as this was the most flexible, efficient, and reliable modulation at the time. Duplex mode can be TDD or FDD, and channel aggregation should be possible to increase throughput. Transmit powers in the order of 10 mW to 50 mW are envisioned for short-range communications, while powers between 1 W and 10 W could be allowed for long-range transmissions. These signal characteristics should be adapted according to the licensed users that must be protected in a given region. WSD devices may operate taking a collaborative or noncollaborative approach to obtain information about the most appropriate channel to use. With a noncollaborative strategy, information on the white space channels can be obtained through spectrum sensing, geo-location plus database enquiry, or accessing local beacon information.

The regulatory aspects related with database and device certification are being dealt with by the Working Group of Regulatory Affairs (WG-RA) of the ECC. The licensing regime is also being revisited, as some industry players are arguing that the white space devices should operate under a licensed shared access regime.

1.2.2 USA approach

In the 1990s, the US military recognized the need for a multi-band, multi-mode radio capable of communicating with the several radio technologies in the battlefield. This