Advanced coexistence technologies for radio optimisation in licensed and unlicensed spectrum

(ACROPOLIS)

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Abstract:

The purpose of this deliverable is to provide an overview of the current status on regulations and standardizations across the globe on Software Defined Radio (SDR) and Cognitive Radio (CR). The report describes the main regulatory and standardization bodies and industrial associations, which are working on these technologies.

Keywords: Cognitive Radio Systems, Harmonisation, Regulation, Standardisation

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Executive Summary

Deliverable D6.2 is the second deliverable of ACROPOLIS Work Package (WP) 6. Its aim is to describe the current regulatory and standardization framework for Cognitive Radio technology and to identify potential actions to support the development and deployment of these technologies at European level.

Cognitive Radio technologies are investigated by various regulatory and standardization bodies around the world. These technologies can provide important benefits but they also present relevant challenges from the regulatory, technical and deployment points of view. Regulations should be defined to protect existing communication radio services but also to promote the market deployment of Cognitive Radio technologies.

The deliverable provides an overview of the main regulatory entities in section 2 and the main standardization entities in section 3. The relationships among regulatory and standardization entities is provided in section 4.

The relationship between regulations and market is described in section 5 for various use cases. The market potential and the role of the regulations are described for each use case. Regulations can promote the market success of CR technologies if the timing is correct and if they are not too restrictive. The mitigation of harmful interference to primary users is considered a main priority by spectrum regulators and this aspect is more relevant in specific use cases (e.g. opportunistic spectrum access) than others (e.g. dynamic flexible use of spectrum).

In section 6, the input from the previous sections is used by the authors to identify the main issues at the regulatory and standardization level and to define recommendations.

Section 7 identifies the links between the regulatory and the standardization issues, identified in section 6, and the research activities in the ACROPOLIS project. For each work package, the deliverable identifies and describes the areas where research activities could contribute to support the regulation and standardization process.

Finally Section 8 concludes the deliverable.

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1 Introduction

The purpose of this report is to provide an overview of the current status on regulations and standardizations across the globe on Software Defined Radio (SDR) and Cognitive Radio (CR). The report describes the main regulatory and standardization bodies and industrial associations that are working on these technologies. The report also identifies existing communications standards that may include SDR and CR concepts and technologies in their evolution.

Regulation activities are usually linked at regional and global level, while standardization activities are usually tightly related only within the same standardization organization (e.g. IEEE, ETSI). There are gaps among the various regulations and standardization activities across the globe. Regulations and standards activities in USA already started 5-7 years ago (i.e. FCC, IEEE), especially in the area of “white spaces”, while in Europe and other parts of the world the activity started 2-3 years ago or is starting now.

There are still many issues and challenges to be solved in the regulatory and standardization frameworks at the economical, technical and political levels. This report tries to identify the main issues to be solved and how ACROPOLIS work packages can support the resolution of these issues.

2 Regulations

This section identifies the main regulation bodies around the world and the related regulations

2.1 Regulatory bodies and regulations at international level.

The International Telecommunication Union (ITU) - Radiocommunication Sector ITU-R started activities on cognitive radio in response to a decision of the World Radiocommunication Conference 2007 (WRC-07) to put an item on the agenda for the World Radiocommunication Conference in 2011 (this has now been shifted to 2012).

Agenda item 1.19 of WRC-12 deals with regulatory measures needed for the introduction of Software Defined Radio and Cognitive Radio. ITU-R Study Group 1 came to the preliminary conclusion that Software Defined Radio (SDR) and Cognitive Radio Systems (CRS) are related technologies which can be used in any radio service within the Radio Regulations, therefore there is no need to incorporate the definitions of SDR and CRS in the Radio Regulations. The definition of SDR and CRS are captured in an ITU-R Report. It remains unclear what the potential changes to the Radio Regulations should be in addition to the need for more flexibility (which is addressed under WRC-12 agenda item 1.2).

At the recent WRC-12, the Agenda item 1.19 was resolved with the decision that no change to the regulations is needed for CR and SDR, because the current international framework was considered sufficient. In the same area, WRC-12 approved a recommendation (COM 6/1) to investigate further the implications of the introduction of CR technologies in accordance with Resolution ITU-R 58.

One important outcome for WRC-12 and CR technology is the decision to allocate the band 694-790MHz in region 1 to co-primary access by mobile services by 2015. This decision could restrict the “white spaces” that can be used by CR devices.

ITU–R has already been studying cognitive radio and software defined radio. An important outcome of its work is the report on “Software-defined radio in the land mobile and amateur satellite services”, published in February 2008. This ITU–R study has shown that SDR using cognitive control mechanisms is a valuable approach for achieving better spectrum utilization, dynamic spectrum management and flexible spectrum use.

ITU-R is also investigating future trends in software defined radio and cognitive radio as identified in [1] :

- “Discussions also focused on how much regulation is required for the new technologies. The need for regulation depends on whether a vertical model or a horizontal model is used. With a vertical model, the operation, functioning and conformity of all hardware and software components of a system are under the responsibility of only one entity. This well-defined responsibility ensures that all the devices will operate within the given regulatory limits. With a horizontal model, many different companies will operate systems using SDR and CRS. Mechanisms will need to be developed to ensure that this does not result in increased interference”.
- “Coexistence scenarios present a difficult regulatory challenge. Two aspects to be considered are the sensing levels for existing radiocommunication systems, which

may be different for each frequency segment, and the need to have prior knowledge about systems because some are receive-only. For the cognitive pilot channel, it is very important to authenticate the integrity of users and maintain privacy, in order to prevent unauthorized or malicious users from gaining knowledge of existing systems. It was also pointed out that ownership of the cognitive pilot channel manager needs to be considered carefully, so as to avoid anti-competitive aspects”.

- “Another area of discussion was the contrast between today’s context for operators, including the evolution of ways to assign spectrum, such as auctions, and future business models that will create a new environment for operators and regulators”.

In conclusion, ITU-R has identified various business use-case scenarios where CR can provide important benefits from the commercial point of view. As described in [42], ITU-R WP1B has identified four scenarios:

1. Use of CRS technology to guide reconfiguration of connections between terminals and multiple radio systems;
2. Use of CRS technology by an operator of radio communication systems to improve the management of its assigned spectrum resources;
3. Use of CRS technology as an enabler of cooperative spectrum access;
4. Use of CRS technology as an enabler of opportunistic spectrum access.

Each of these scenarios has its own benefits and challenges, which will be discussed in greater detail in section 5.

The recent WRC 2012 was a key event affecting the future trends of coexistence technologies within the scope of ACROPOLIS. The outcome of AI 1.19 was for WRC to resolve that “no change” to the regulations is necessary regarding CR and SDR. This is not necessarily a bad thing, it is simply stating that the current international framework is seen to be sufficient to handle the implications of such technologies. Moreover, WRC 2012 passed a “recommendation” COM 6/1 (as the name implies, this is less stringent that a “resolution”) for further study of the implications of CR introduction to continue, in accordance with Resolution ITU-R 58.

One highly important development was the decision to allocate the 694-790 MHz spectrum in region 1 to co-primary access by mobile services, to be put into practice after WRC 2015 (with the lower end of this allocation, and technical conditions for it, to be defined in WRC 2015). This is a result of the “second digital dividend”, as it is known in some circles. The text of the resolution is as follows (see, e.g., [50]):

1. to allocate the frequency band 694-790 MHz in Region 1 to the mobile, except aeronautical mobile, service on a co-primary basis with other services to which this band is allocated on a primary basis and to identify it for IMT;
2. that the allocation in resolves 1 is effective immediately after WRC 15;
3. that use of the allocation in resolves 1 is subject to agreement obtained under No. 9.21 with respect to the aeronautical radionavigation service in countries listed in No. 5.312;
4. that the lower edge of the allocation is subject to refinement at WRC 15, taking into account the ITU-R studies referred to in invites ITU-R below and the needs of countries in Region 1, in particular developing countries;

5. that WRC 15 will specify the technical and regulatory conditions applicable to the mobile service allocation referred to in resolves 1, taking into account the ITU-R studies referred to in invites ITU-R below.

Regarding the reallocation of spectrum to mobile services on a co-primary basis after WRC 2015, clearly such a reallocation could lead to a significant reduction in the number of secondary spectrum access opportunities in TV bands should this co-primary access be widely taken up. Hence, alternative spectrum for usage on a secondary basis is a key area of interest, as is analysis of the extent of spectrum holes after this reallocation—keeping in mind that the lower bound for this reallocation being as low as 694MHz is a worse-case scenario.

2.2 *Regulatory bodies and regulations at regional level.*

2.2.1 Regulatory bodies and regulations in Europe.

2.2.1.1 European Union

In Europe, the regulation process for the introduction of new wireless services is described in Figure 2-1, where the European Commission mandates the CEPT for a study on a new wireless service. CEPT subsequently requests a related feasibility study from ECC. CEPT can also request a study from ETSI or it can contact relevant ETSI technical committees through Liaison Statements.

For a description of the main entities involved in spectrum regulations for cognitive radio, refer to section 4.

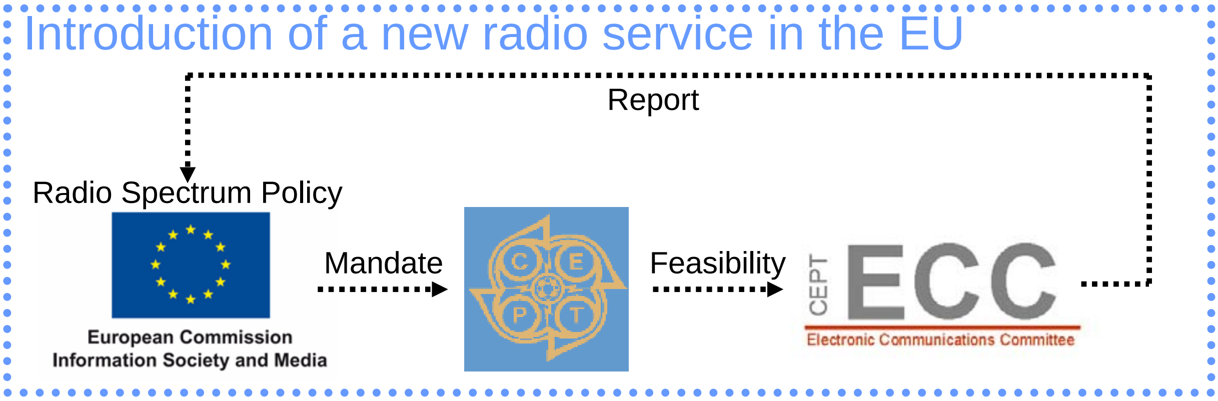

Figure 2-1 European regulatory process for the introduction of a new wireless service.

The ECC WGSE (Spectrum Engineering) established the special project SE43 dealing with cognitive radio matters in May 2009. The objective of SE43 is to complete the ECC Report "Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'White Spaces' of the Frequency Band 470-790 MHz" [2]. The report was completed in January 2011.

The main focus of the report is on coexistence with incumbent or primary systems. The report defines different scenarios for CR operation in terms of WSD types (personal/portable, home/office and public access points) and also discusses the three well known types of cognitive techniques: spectrum sensing, geo-location and beacons.

The report is focussed on the protection of various incumbent systems:

- Protection of the broadcasting service;
- Protection of (Programme Making and Special Events) PMSE services;
- Protection of Radio Astronomy (RAS) in the 608-614 MHz band;
- Protection of aeronautical radio navigation (ARNS) in the 645-790 MHz band;
- Protection of Mobile/Fixed services in bands adjacent to the band 470-790 MHz;
- Definition of the requirements for the geo-location database approach;
- Assessment of the spectrum potentially available for WSD.

For each incumbent system, the report provides coexistence studies and recommendations for the coexistence of the radio services.

In February 2010, the DG INFSO Radio Spectrum Policy Group (RSPG) published a first report on cognitive technologies. The report had the objective of informing policy makers in Europe as early as possible of the discussions and challenges raised by cognitive technologies. The report provided an overview of cognitive radio technologies, described new spectrum management approaches based on cognitive radio and identified challenging issues that require further attention. The use of cognitive radio technologies is seen as an enabler providing more efficient spectrum sharing and providing more dynamic access to spectrum.

In October 2010, RSPG published a new document “RSPG Opinion on Cognitive Technologies” RSPG10-348 [44] to identify benefits and challenges for implementing CR at the European Community level. In particular, the opinion investigates the need for coordination at EU level on cognitive radio technologies.

In particular, the scope of this opinion includes (from [44]):

- high-level approach at each cognitive feature studied within a common European framework;
- considerations on the possible merits of taking further regulatory steps;
- near-term regulatory action that needs to be taken to enable any cognitive technology;
- necessity of establishing a harmonised basis and if so the actions necessary.

An important aspect is also the revision of the Radio and Telecommunications Terminal Equipment Directive (R&TTE) Directive for SDR and CR technologies.

In Europe, certification of wireless equipment is driven by the R&TTE, which came into force in April 2000 in Europe. With the exception of a few categories of equipment, the Directive covers all equipment that uses the radio frequency spectrum. A basic requirement is that radio equipment shall be so constructed to effectively use the spectrum allocated to terrestrial/space radio communication and orbital resources so as to avoid harmful interference. The adoption of the R&TTE for SDR technology has been investigated by the Telecommunications Conformity Assessment and Market Surveillance Committee (TCAM), which is the standing Committee assisting the European Commission in the management of the R&TTE Directive 99/5/EC. In TCAM, the specific sub-group TGS (TCAM Group on SDR) was created to investigate SDR regulation with respect to the R&TTE Directive. Based on a TGS report provided to TCAM in 2006 ("Conclusions concerning the regulatory aspects of SDR with respect to the R&TTE Directive"), and on discussion in TCAM, the European Commission drew some conclusions on particular discussion points, but the discussion was not finalized.

Two deployment models for SDR technology are considered:

- Vertical mode, where the terminal reconfiguration can only be done (and authorised) through the equipment manufacturer (who also takes the responsibility).
- Horizontal model, where the reconfigurations can be authorised by different actors.

The software only needs a declaration of standard compliance, (responsibility can be taken by different actors).

The following conclusions were presented:

- For downloaded SW a digital marking (e.g. CE marking) is recommended;
- It is recommended to maintain a history of software changes in devices;
- SDR equipment would be considered as a "relevant component", in the meaning of article 2 of the R&TTE Directive;
- Harmonised standards covering SDR devices should contain countermeasures against illegal programming and hacks for equipment that is at risk.

Future versions of the R&TTE Directive may incorporate additional elements for SDR certification.

In conclusion, the European Commission is investigating both Software Defined Radio and Cognitive Radio with multiple activities. The two main regulatory activities are for the business case of "white spaces" (e.g. CEPT SE43) and to investigate the deployment of new reconfigurable mobile devices on the market (e.g. R&TTE).

A recent workshop was organized by DG INFSO "Towards an EU policy Dynamic Spectrum Access" on 7th March 2012 (http://www.eu-ems.com/agenda.asp?event_id=109&page_id=825), where other spectrum access models were also addressed for potential business cases including Licensed Shared Access (LSA).

2.2.1.2 UK – Ofcom

In the UK, spectrum regulator Ofcom has also permitted cognitive access to TV spectrum bands as long as they would not cause harmful interference to licensed users [4].

Ofcom has published a report drafted together with QinetiQ on these technologies. The report describes the background of Cognitive Radio technologies and the main issues and challenges.

The report provides a number of recommendations, which includes (from [3]):

- A key driver for CR systems and technologies will be spectrum demand and spectrum congestion. Ofcom believes that a study of estimates of the spectrum demand for various applications is needed to asses the technical requirements for cognitive radio systems.
- The identification of a CR dedicated test band, potentially in collaboration with the Irish spectrum regulator or the FCC.
- Subject to drivers from standards bodies and potential CR vendors, there may be a need to characterise (in terms of bandwidth, national or local channels) dedicated spectrum for a CR control channel, initially for R&D applications and then for future CR deployments.
- Security aspects, the format of the exchange data and policy languages are particularly important and they are not yet defined, even if some standardization bodies (e.g. IEEE) have made proposal in this area.

The report recommends that the CR simulator developed through the study should be made available to those organisations actively developing CR products.

In a recent (September 2011) communication [43], Ofcom has described plans for the introduction of White Space technology in the UK. From the communication, it is clear that Ofcom is driving the regulation of “white spaces” because they have identified a clear business cases related to rural areas, machine to machine (M2M) and other sensors applications.

2.2.1.3 Germany

In [31], the National Regulatory Authorities for Private Broadcasting in Germany (DLM) provided various comments to the draft RSPG opinion on Cognitive Technologies:

- DLM shares the RSPG’s view that - in principle – cognitive technologies can be used in broadcasting bands and that they may in the long term provide means for a more efficient spectrum usage.
- DLM however is concerned that the use of cognitive radio systems in White Spaces will cause harmful interference to broadcasting services and that no proper solutions are at hand for the time being to ensure protection against this interference.
- It is DLM’s view that an implementation of CR technologies in the national frequency management will take time.

2.2.1.4 Finland

The government of Finland started to investigate cognitive radio technology in 2010. In accordance with the government’s new frequency allocation plan, the frequency range of

470-790 MHz will be allocated for cognitive radio systems. Cognitive radio systems can use the spectrum as long as they do not interfere with other communication networks.

The government of Finland advocates a future-oriented “active communications policy” and strongly supports new product development and testing [26].

2.2.2 Regulatory bodies and regulations in USA

In USA, the main regulatory body is the Federal Communications Commission (FCC), which regulates interstate and international communications by radio, television, wire, satellite and cable in all 50 states, the District of Columbia and U.S. territories. In its work, the agency seeks to capitalize on its competencies in (from www.fcc.gov):

- “Promoting competition, innovation, and investment in broadband services and facilities;
- Supporting the nation’s economy by ensuring an appropriate competitive framework for the unfolding of the communications revolution;
- Encouraging the highest and best use of spectrum domestically and internationally;
- Revising media regulations so that new technologies flourish alongside diversity and localism;
- Providing leadership in strengthening the defence of the nation’s communications infrastructure”.

The FCC issued a docket [7] to permit unlicensed opportunistic access to “white spaces” in the TV bands by CR secondary devices. In parallel, the FCC sent requests for opinion to representatives from industry and research organizations on a more efficient use of spectrum. On November 4th 2008, the FCC adopted a Second Report and Order [9]. This document establishes the rules that will allow new, CR wireless devices to operate, as secondary users, in the broadcast television spectrum. To avoid harmful interference to primary users, FCC suggested the implementation of spectrum databases where the operational parameters, range and location of primary users can be registered.

In September 2010, the Second Memorandum Opinion and Order [10] eliminated the sensing requirement for Television Band Devices that include geo-location/database functions, as petitioners argued that sensing technology was not sufficiently mature for consumer devices and would delay market entry. The FCC has recently issued a call for administrators of the TV white spaces spectrum database.

The certification of CR devices and SDR devices was also investigated by FCC. In [5], it adopted rule changes to address the certification of SDR and CR equipment, which are considered a new class of equipment with streamlined equipment authorization. FCC amended the equipment authorization rules to permit equipment manufacturers to make changes in the frequency, power and modulation parameters without the need to file a new equipment authorization application with the Commission. The certification rules were updated in [8] to eliminate the rule for a manufacturer to supply radio software to the Commission upon request because this may become an unnecessary barrier to entry.

One of the main recommendations of the National Broadband Plan (NBP) is to free up 500 MHz of spectrum for broadband use in the next 10 years with 300 MHz being made available for mobile use in the next five years. The NBP urges the FCC to initiate further proceedings on OPA beyond the already completed TVWS proceedings.

In June 2002, FCC Chairman Michael Powell commissioned a task force to perform a comprehensive review of FCC spectrum management practices. This task force created a report to describe changes from traditional spectrum management towards an increased reliance on market-based mechanisms.

The SPTF report characterized spectrum management approaches as falling into three categories:

- "Exclusive use" model. A licensing model in which a licensee has exclusive and transferable flexible use rights for specified spectrum within a defined geographic area, with flexible use rights that are governed primarily by technical rules to protect spectrum users against interference.
- "Commons" model. Allows unlimited numbers of unlicensed users to share frequencies, with usage rights that are governed by technical standards or etiquettes, but with no right to protection from interference.
- "Command-and-control" model. The traditional process of spectrum management in the United States, currently used for most spectrum within the Commission's jurisdiction, in which allowable spectrum uses are limited, based on regulatory judgments.

The SPTF report advocated increased reliance on the use of the commons model, and reduced use of traditional allocation mechanisms (command and control).

In 2003, the FCC created the framework for the secondary markets in 2003 [34]. The regulatory permission for secondary markets in exclusive spectrum licenses led to the creation of public-facing markets, like Spectrum Bridge's SpecEx.com and Cantor Fitzgerald's Cantor Spectrum Exchange.

Recently, the FCC has supported the concept of “Incentive Auctions”, which are defined as (from [49]):

“An incentive auction is a voluntary, market-based tool to compensate existing spectrum licensees for returning their licenses to make spectrum available for innovative new uses like mobile broadband”.

2.2.3 Regulatory bodies and regulations in Asia.

2.2.3.1 Japan

The spectrum regulator in Japan is the Ministry of Public Management, Home Affairs, Posts and Telecommunications.

From the policy point of view, the first radio policy related to a concept of “cognitive radio” was mentioned in the “e-Japan” policy. In September 2000, the Japanese government announced the “e-Japan” policy and according to this policy, the “e-Japan strategy and program” were drafted in 2001. The main target of the e-Japan program was to deploy high speed communication environments and make Japan the most advanced country in the world by the end of 2005.

The e-Japan policy was followed by the u-Japan policy in 2006, whose main target was to realize a “ubiquitous network society” based on broadband networks. In ubiquitous networks, a seamless ubiquitous network environment should be created in which people can use services without acting on wired or wireless networks. From a technical point of view, this concept was supposed to be realized by cognitive radio networks.

On December 2, 2009, the first meeting of a “Study group for Future vision of new radio utilizations” was held. The main mission was to discuss how to use and how to promote “white space” radio resources. The report reached similar conclusions to similar studies in Europe and the USA:

- new services and systems using white spaces could bring social and economical effects, therefore it is important to invest in this technology.
- the introduction of new services using white spaces may require pre-commercial experiments before institutionalized systems and services. The areas where these pre-commercial experiments are carried out are called “Special zone”.

Also, the study group concluded that Japan should actively contribute to standardization organizations such as IEEE, ETSI and the ITU and research activities should be strengthened.

From the research point of view, reference [12] provides an extensive overview of cognitive radio technologies in Japan.

The project MASCOT (Mobile Access Signaling Card On Telecommunication systems) was the first R&D project related to the present cognitive radio systems.

The key point of MASCOT was to propose a novel basic mobile access system, which may realize personal mobility in mobile communications independent of services and frequencies.

As part of the e-japan program, the MIRAI project (Multimedia Integrated network by Radio Access Innovation) was the follower of the MASCOT project with the objective to develop new technologies like 4G to enable seamless integration of various wireless access systems and make the existence of heterogeneous networks transparent to users. To fulfil this objective, the MIRAI project defined requirements which are also valid for SDR and CR technologies including Multi-service user terminal (MUT), Wireless system detection, Wireless system selection and Mobility management.

The National Institute of Information and Communications Technology (NICT) is the main Japanese research institution for ICT. NICT has carried out research on cognitive wireless systems since the MIRAI project with a new project called CWC (Cognitive Wireless Cloud).

In CWC, a NRM (Network Reconfiguration Manager) installed in networks collects measured data from each terminal such as data speed, delay time, throughputs and signal strength. The NRM will analyse collected data and feedback the optimized information to the terminal to make it access the most appropriate wireless system in a more efficient and effective manner.

2.2.3.2 China

Cognitive Radio technology is still being discussed by spectrum regulators in China. An overview of the contributions of the Chinese activities in CR standardization is presented in [40], where it is indicated that China has contributed to knowledge learning and decision making design in the context of the National Basic Research Program, Key Project of National Natural Science Foundation, and National Key Technology RD Program, etc. The standard organization in China is the China Communications Standards Association (CCSA).

UWB regulations and standards have received more attention. An UWB radio transmit device is defined as a device that can transmit with a bandwidth (-10dB) of (at least) 500 Mhz.

The UWB EIRP spectrum requirements in China are described in tables Table 2-2:

Freq(GHz)	Max EIRP(dBm/MHz)	Detection system
<1.6GHz	-90	Effective value(RMS)
1.6-3.6GHz	-85	
3.6-6.0GHz (note 1)	-70	
6.0-9.0	-41	
9.0-10.6	-70	
>10.6GHz	-85	

Table 2-2 UWB EIRP requirements in China

Note: In 4.2-4.8GHz, the max EIRP can be restricted to -41dBm/MHz by the date of 31st Dec, 2010. After that, the UWB devices shall adopt the Interference Mitigation Technology. The effectiveness of this technology shall be identified by the State Radio Administrations (SRRC).

Transmitter Mode	48.5-72.5MHz 76-108MHz 167-223MHz 470-798MHz (test bandwidth 100kHz)	Other frequency band in 30MHz-1GHz (test bandwidth 100kHz)	1—40GHz (test bandwidth 1MHz)
work	-54dBm	-36dBm	-30dBm
standby	-57dBm	-57dBm	-47dBm

Figure 2-3 Narrowband Spurious emissions requirement of UWB radio transmitting devices

The following regulations also apply:

- UWB devices are prohibited to be used in aircraft.

- UWB radio devices are prohibited to be used within1 Km of Radio Astronomy Stations, which is provided in the footnote CHN12 of Regulation on Allocation of Radio Frequency of the People's Republic of China
- UWB radio transmit devices are regulated by the same standard as the micro-power (short range) radio transmit devices. Prior to commercial use, the devices should get Equipment Type Approval by the Ministry of Industrialization and Information Technology.
- UWB radio transmitting devices shall not cause radio interference to other radio stations, and shall not request interference protection from other radio stations.

2.2.3.3 Korea

As described in [32], the Korean Korea Communications Commission (KCC) has studied new regulations based on the application of cognitive radio technology to the UWB and RFID technologies.

Korea has created a task force team to define a UWB specification based on the FCC spectrum emission mask. The team concluded that a Detect and Avoid mechanism must be mandated in the band between 3.1 and 4.2 GHz. UWB devices operating in the frequency range 7.2 - 10.6 GHz don't need a DAA mechanism.

There are two specifications for RFID in Korea: one of them is FHSS (frequency hopping spread spectrum) and the other is LBT, where the sensing threshold is -65 dBm and the RFID reader should sense more than 5 ms before using the channel.

The Korean government has also been developing the core technologies of CR and seeking the application of these technologies, especially personal/portable devices. ETRI and Samsung have developed PHY and MAC technologies for IEEE 802.22 WRAN and ECMA-392 standard.

2.2.3.4 Singapore

The spectrum regulatory body in Singapore is the Info-Communications Development Authority (IDA). The IDA defined the possible TV white spaces in the VHF (174-230 MHz) and UHF bands (470-806MHz). The predominant users of the bands are television broadcasters, with the only exception being Channel 7 (188-195MHz), which is occupied by digital radio broadcasting services. In the VHF bands, each channel occupies 7 MHz bandwidth while in the UHF bands, each channel occupies 8 MHz bandwidth. In the UHF bands, currently there are three channels (29, 37, and 38) for digital broadcasting using the DVB-T standard, while other spectrum is used for analog TV using the PAL-G standard.

In the 407-806 MHz bands, wireless microphones operate on a secondary basis without causing interference to, nor seeking protection from, the broadcast services. Professional wireless microphone systems use either analog or digital technology.

Analog devices occupy 200 kHz channels, while digital devices occupy 200, 400, or 600 kHz channels.

In 2007, I2R and IDA jointly conducted a spectrum measurement campaign (as described in [30]) to investigate the 24-hour spectrum usage pattern in Singapore in the frequency bands ranging from 80 MHz to 5850 MHz. Its objectives were to find how the spectrum was used in Singapore and identify the bands that could be utilized for future opportunistic access like cognitive radio. The measurements lasted for 12 working days. The measurement results showed that, apart from the frequency bands allocated for cell phones and broadcasters, most of the allocated frequencies are heavily under-utilized (average occupancy rate was 4.54%). The occupancy is quantified as the amount of spectrum detected above a certain received power threshold.

2.2.4 Regulatory bodies and regulations in the rest of the world.

2.2.4.1 Canada

Canada is a country of large size and low population density and there are many vacant (unassigned and non-allotted) TV channels, especially in rural areas. Canada is very interested in the cognitive usage of the TV spectrum. It has taken steps to open a subset of TV channels for broadband access in remote rural areas in the UHF band under licensed operation [24], [25]. In March 2007, the government agency, Industry Canada, announced license based interim guidelines to deliver Remote Rural Broadband Services (RRBS) in TV bands [24].

Canada has adopted a high-power licensed approach to serve larger areas. In Canada the frequencies are assigned by Industry Canada on a case by- case basis to avoid interference.

2.2.4.2 Australia

The Australian Communications and Media Authority (ACMA) has been investigating the applications of cognitive radio since 2008. The ACMA has investigated the availability of “white spaces” in Australia and has also defined the concept of Protection Factors for Auxiliary Access (PFAA) to introduce cognitive radio concepts.

Spectrum trading is carried out directly between buyers and sellers, but any trades have to be registered with the Australian Communications Authority.

The ACA publishes this information on its website. It has recorded a total of 246 trades since 1998. However this figure substantially overstates the volume of trading as it counts each spectrum trading unit as a separate trade, and includes the re-assignment of spectrum between related companies in the same group of companies.

In reality about 21 separate exchanges of spectrum have taken place, and only 12 of these have been between unrelated entities (representing about 140 spectrum trading units).

3 Standardization bodies and standards

This section discusses the identification of standardization bodies around the world that are directly addressing cognitive radio technology or the evolution of existing standards that may use cognitive radio technology.

3.1 Institute of Electrical and Electronics Engineers (IEEE)

3.1.1 IEEE 802.22

The IEEE 802.22 standards working group on “Wireless Regional Area Networks” (WRANs) aims to use CR technology (or, more appropriately worded, opportunistic secondary spectrum access) over TV Whitespaces to provide broadband service to rural areas or other remote areas where the TV spectrum is not heavily used. This standard is facilitated greatly in countries where there is an allowance of “fallow” bands in the VHF and UHF TV frequency range and the necessity to provide broadband connectivity in rural areas presents significant economical and technical challenges. In these contexts, the IEEE 802.22 standards have a good economic justification. In particular, the FCC has supported IEEE 802.22 with its regulations on “white spaces” [5].

The definition of the standard started in 2004 and it was finally published in July 2011. Each WRAN will deliver up to 22 Mbps per channel without interfering with reception of the TV broadcast signal. The standard is available at [14].

The core topology in IEEE 802.22 is point-to-multipoint, with fixed base stations that provide access to a number of clients (Customer Premises Equipment—CPE), mounted, for example, on the home of the 802.22 broadband customer. Details on the core IEEE 802.22 standard can be obtained from [13].

Two other standards under 802.22 have been initiated: IEEE 802.22.1, and IEEE 802.22.2. IEEE 802.22.1, “Standard for the Enhanced Interference Protection of the Licensed Devices,” defines a method to protect difficult-to-detect low power transmitters in the TV bands such as wireless microphones, specifying a pseudo-noise low-bandwidth but relatively high power beacon through adding hardware to such devices. There are various design criteria of this beacon, which is also called protective disabling beacon system. It must occupy a relatively narrow portion of the TV channel, be detectable during short quiet periods offered by proposed unlicensed devices meant for the detection of incumbents, convey geographic and other operational information, mitigate multipath and channel imperfections, and offer security thereby insuring that only legitimate, authorized users will have access to beaconing devices [45].

This IEEE 802.22.1 standard was initiated in March 2006 and completed in November 2010. The usefulness of such a standard has, however, been somewhat reduced given the FCC’s decision in September 2010 to reserve channels for such low-power devices [10]. The IEEE 802.22.2 work is a “Recommended Practice for the Installation and Deployment of IEEE 802.22 Systems”, whereby a recommended practice is the least “normative” form of IEEE standard merely conveying recommendations not requirements. Work on this standard is still under progress.

The history of IEEE 802.22.1 shows that a regulatory action has basically removed the need to define a technical solution like the protective disabling beacon system. Nevertheless, the technical solutions created and described in IEEE 802.22.1 can be used in future contexts with similar requirements.

3.1.2 IEEE DySPAN Standards Committee (DySPAN-SC)

The IEEE DySPAN Standards Committee (DySPAN-SC) [15], in its original formulation, was established in the first quarter of 2005 under the sponsorship of the IEEE Communications Society (ComSoc) and the IEEE Electromagnetic Compatibility (EMC) Society as the IEEE 1900 committee responsible for 1900 standards. However, in March 2007, the IEEE Standards Board approved the reorganization of the IEEE 1900 Committee as Standards Coordinating Committee 41 (SCC41), "Dynamic Spectrum Access Networks" (DySPAN). The IEEE Communications Society and EMC Society were still the supporting societies. More recently, SCC41 was approached by ComSoc in late 2010 as ComSoc showed an interest in SCC41 being brought back under its sponsorship. SCC41 voted to be back under ComSoc in December 2010. Under this new arrangement, the intention is for the structure to remain the same as in IEEE SCC41, where the effort has been renamed as "IEEE DySPAN-SC". IEEE DySPAN-SC therefore manages the 1900 series standards on the topic of DSA and DySPAN.

The current working groups in IEEE 1900:

- IEEE 1900.1: "Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management" [15],
- IEEE 1900.2: "Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems" [16],
- IEEE 1900.3: "Recommended Practice for Conformance Evaluation of Software Defined Radio (SDR) Software Modules" (disbanded) [17],
- IEEE 1900.4: "Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks" [18],
- IEEE 1900.5: "Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications" [19],
- IEEE 1900.6: "Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems" [20].

IEEE 1900.1 was instantiated in March 2005 under the realisation that many of the terms used in the fields of spectrum management, policy-defined radio, adaptive radio, software-defined radio, reconfigurable radio and networks, and related technologies, do not have precise definitions or have multiple definitions. IEEE 1900.1 facilitates development of such technologies by clarifying the terminology and how these technologies relate to each other. The original standard was published in 2008, although the standards work has recently been reinitiated to incorporate new terms that have emerged since the publication of the original standard.

The IEEE 1900.2 standards work was initiated in March 2005 and the standard was published July 2008. IEEE 1900.2 provides technical guidelines for analyzing the potential for coexistence or interference between radio systems operating in the same frequency band or between different frequency bands. In that sense, IEEE 1900.2 facilitates a range of spectrum coexistence technologies, assisting assessment of their potential for realisation in a viable way.

The IEEE 1900.3 standards work was initiated in May 2005, but the working group was disbanded in late 2008. The standard was to provide guidance on how to estimate the conformance with relevant specifications of software intended for deployment into a SDR terminal. Concepts and methods to be used in these analyses were to be detailed, and the standard was intended to support quality control and testing. Given a range of issues that could be caused by SDR devices being hacked and misbehaving, for example, although this group is disbanded such work is still extremely relevant to assuring the correctness of the SDR modules.

The IEEE 1900.4 standards work was initiated in February 2007, and the standard was published in February 2009. IEEE 1900.4 aims to improve overall composite capacity and quality of service of wireless systems in multiple radio access technology environments by defining an appropriate system architecture and protocols to facilitate the optimization of radio resource usage. It specifies a three-level resource management hierarchy: the network or inter-network level, RAN level, and terminal level. These levels are managed by two key components: the Network Reconfiguration Manager (NRM) and Terminal Reconfiguration Manager (TRM), in conjunction with other functions such as the Operator Spectrum Management (OSM) entity. IEEE 1900.4 is currently continuing with an amendment in 1900.4a, "Architecture and Interfaces for Dynamic Spectrum Access Networks in White Space Frequency Bands", and an additional standard in the working group, 1900.4.1, "Interfaces and Protocols Enabling Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Networks". At the time of writing 1900.4a is in the sponsor ballot stage, close to publication, and 1900.4.1 has work ongoing. It is noted that IEEE 1900.4 facilitates a range of spectrum coexistence technologies of interest to ACROPOLIS, although it particularly emphasises those that are network driven, as might be managed by an operator, for example, with a range of spectrum bands and radio access technologies available which can adapt to operation in different bands.

The IEEE 1900.5 standards work was initiated in 2008, with the scope being adjusted in June 2010. At the time of writing, the standard is currently being finalised and is close to progressing to the stage of sponsor ballot then publication. IEEE 1900.5 defines a policy language (or a set of policy languages or dialects) to specify interoperable, vendor-independent control of CR functionality and behaviour for DSA resources and services. The appropriate definition of such policies is an essential step in the facilitation of autonomous spectrum coexistence of devices and systems, both in primary-secondary and in other contexts.

The IEEE 1900.6 standards work was initiated in September 2008, and was published in late April 2011. IEEE 1900.6 defines the information exchange between spectrum sensors and their clients in radiocommunication systems; this might be applicable in both the cooperative/collaborative sensing scenarios and in other scenarios where the intelligence that makes spectrum access and other decisions in the network and spectrum sensors are at different locations in the network. The logical interface and supporting data structures are defined abstractly without constraining the sensing technology, client design, or data link between sensor and client. Of course, the facilitation of sensing technologies through standards such as IEEE 1900.6 assists many spectral coexistence techniques that utilise locally-obtained spectrum information, such as CR.

Finally, it is noted that at the time of writing the IEEE DySPAN-SC is considering initiating a project on a PHY/MAC for white space access. The aim is for the PHY/MAC to be generic, applicable to a range of spectrum bands and use cases. If this work is initiated, it is currently anticipated to form a new IEEE 1900.7 working group.

3.1.3 IEEE 802.11af

The IEEE 802.11af standard is similar to the traditional IEEE 802.11 standard, also known as WiFi. It is considered an extension of IEEE 802.11 to exploit “White Spaces”. The standard will be based on an incumbent database that maintains data about used frequencies in the TV band. A white space map (WSM), which is similar to the concept of Radio Environment Map (REM), describes the available channels in the area and the respective maximum transmit power that is allowed. The WSM will be distributed to the 802.11af terminals by any available means (e.g. an internet connection). Terminals must perform spectrum sensing to detect primary services for a certain period of time before they are allowed to access the channels and they can report this information to the main stations (also called enabling stations). IEEE 802.11af will also implement cognitive functions using Channel Power Management (CPM) and dynamic STA enablement (DSE). The standard will support 5, 10, 20 and 40 MHz bandwidth in the TVWS. The report messages can be based on existing 802.11 standards.

The IEEE 802.11af has the advantage to be an evolution of an existing and widely deployed standard (IEEE 802.11). This can become a competitive benefit because the cost of the design changes is minor in comparison to other Cognitive radio standards.

3.1.4 IEEE 802.15.4m

This amendment specifies a physical layer for 802.15.4 meeting TV white space regulatory requirements and also any necessary MAC changes needed to support this physical layer.

The IEEE 802.15 Task Group 4m (TG4m) is contracted to specify a physical layer for 802.15.4 and to enhance and add functionality to the existing standard 802.15.4-2006 MAC meeting TV white space regulatory requirements. The amendment enables operation in the available TV white space, supporting typical data rates in the 40 kbits per second to 2000 kbits per second range, to realize optimal and power efficient device command and control applications. It also supports accepted methods of TV White Space coexistence in existence at the time of development.

As in the case of IEEE 802.11af, IEEE 802.15.4m is an evolution of an existing standard and this could be a competitive advantage.

3.2 European Telecommunications Standards Institute (ETSI) Reconfigurable Radio System Technical Committee (RRS TC)

The European Telecommunications Standards Institute (ETSI) Reconfigurable Radio System Technical Committee (RRS TC) [21], [22], which was created in January 2008, comprises four working groups, namely:

- WG1 System Aspects,
- WG2 Equipment Architecture,
- WG3 Cognitive Management and Control, and
- WG4 Public Safety.

The scope of this technical committee is on standardization activities related to Reconfigurable Radio Systems encompassing system solutions related to Software Defined Radio (SDR) and Cognitive Radio (CR); the committee's activities include the definition of RRS requirements, identifying gaps where existing standards do not fulfil those requirements and proposing solutions to fill those gaps.

The activity of each working group will be defined in detail in each subsection.

3.2.1 WG1 - System Aspects

WG1 is the main working group in ETSI TC RRS. WG1 has the responsibility to develop and maintain a common technical framework for SDR and CR systems standardization in TC RRS regarding system level aspects, to collect and define requirements on Reconfigurable Radio Systems from relevant stakeholders.

A number of Technical Reports have already been produced by ETSI TC RRS WG1. The current focus of WG1 is the definition of Technical Specifications for the exploitation of the "white spaces".

The current work items are active or just completed:

- TS 102 946 "System requirements for Operation in UHF TV Band White Spaces"
- TS 102 908 "Coexistence Architecture for Cognitive Radio Networks on UHF White Space Frequency Bands"
- TS 102 968 "System requirements for Reconfigurable Radio Systems operating in IMT-Bands and GSM-Bands for intra-operator scenarios"
- TR 102 907 "Use Cases for Operation in White Space Frequency Bands"
- TR 103 067 "Feasibility study on for Radio Frequency (RF) performances for Cognitive Radio Systems operating in UHF TV band WS"
- TR 102 947 "Use Cases for building and exploitation of Radio Environment Maps for intra-operator scenarios"

Recently, ETSI TC RRS has approved a new work item for the use of "White spaces" for the M2M application domain.

WG1 also addresses security aspects in SDR and CR. ETSI TR 103 087 is being drafted to identify the potential security threats in various CR use cases, including the ones already defined in previous technical reports.

The main challenge of the standardization activity in WG1 is to define standards, that are conformant with spectrum regulations and still cost-effective for consumer market deployment.

3.2.2 WG2 - Equipment architecture

The main focus of WG2 is to define a mobile device architecture that can be used to support various radio communication interfaces. While some concepts of SCA can be re-used, the standardization efforts are finalized in(?) the design of a hardware/firmware architecture that can be used for the mass market.

As described in [46], the design of the mobile device architecture is based on a Unified Radio Application Interface (URAI) between the Unified Radio Application (URA) and the Reconfigurable Radio Frequency Interface (RRFI).

3.2.3 WG3 - Cognitive Management and Control

The main focus of WG3 is on the functional architecture and particularly the Control Channels for Cognitive Radio Systems. This is investigated in ETSI TR 102 684, which is near completion. The TR identified a set of challenges for the design and deployment of Control Channels (from [46]):

- Discovery and identification of neighbouring devices could be a complex operation;
- The management of advanced Multi-RATs in heterogeneous networks will require the definition of various standards and interfaces.
- The retrieval of information on available White Spaces from a geo-location database needs to be investigated.
- The management of operator-governed opportunistic networks in terms of creation, maintenance and termination is a new area, which needs further investigation.
- The investigation of implementation options is a crucial step towards the realisation of the Control Channels and the deployment of Cognitive Radio Systems. The implementation options for Control Channels for Cognitive Radio Systems, take into account previous work on in-band-Cognitive Pilot Channel (CPC) and Cognitive Control Channel (CCC).

Some of the issues described above are relevant to ACROPOLIS activities and can be investigated in specific work packages (see section 7).

3.2.4 WG4 – Public Safety

The main focus of WG4 is the application of Software Defined Radio and Cognitive Radio to the Public Safety domain.

WG4 has already produced a number of Technical Reports:

- ETSI TR 102 745 V1.1.1 (2009-10). Technical Report. Reconfigurable Radio Systems (RRS); User Requirements for Public Safety.
- ETSI TR 102 733 V1.1.1 (2010-03). Technical Report. Reconfigurable Radio Systems (RRS); System Aspects for Public Safety.
- ETSI TR 103 064 V1.1.1 (2011-04). Business and Cost considerations of Software Defined Radio (SDR) and Cognitive Radio (CR) in the Public Safety domain.

WG4 has also collaborated with ETSI TC TETRA for the drafting of ETSI TR 102 628 V1.1.1 (2010-08). "System reference document; Land Mobile Service; Additional spectrum requirements for future Public Safety and Security (PSS) wireless communication systems in the UHF frequency range".

The current focus of WG4 is on the application of spectrum sharing approaches like dynamic flexible spectrum management where spectral bands can be reassigned dynamically for crisis resolutions or disaster relief.

3.3 ECMA- 392

ECMA-392 is a standard recently defined by the Cognitive Radio Alliance (CogNeA) [47] to manage the cognitive radio network (CRN) for the context of the TV white spaces. The ECMA-392 standard defines two basic network formation modes: a) master-slave network and b) peer-to-peer (P2P) network. The P2P network mode is based on the concept of the logical beacon group (BG), which is formed around each individual device.

ECMA-392 is targeted towards various applications: a) multimedia video applications for home environment, b) enhanced range for public services in rural areas, c) enhanced range for RFID and remote machine-to-machine (M2M) and d) interactive applications for TV broadcasters, such as weather and news updates.

The physical layer (PHY) of ECMA-392 is based on a 128-fft orthogonal frequency division multiplexing (OFDM). Each physical protocol data unit (PPDU) consists of a PLCP 1 preamble, header and payload. The preamble is mainly used for synchronization and channel estimation purposes. The header is encoded with an outer encoder Reed-Solomon (RS), with an inner convolutional encoder having rate 1/2 and modulated using quadrature phase shift key (QPSK).

While ECMA-392 is a consolidated standard, it can be used as a base for future extensions and evolutions to improve specific aspects or to adapt it to specific contexts. One example of these extensions is provided in [48].

3.4 International Telecommunication Union (ITU)

ITU-R Study Group 8 (SG8) [27] has published two reports [28][29] on SDR, which provide basic information on SDR technology and present the application of SDR to IMT-2000 (International Mobile Telecommunication-2000) and to other land mobile systems. SG8 recently also approved a Study Question on “Cognitive Radio Systems in the Mobile Service”.

3.5 *Industrial associations and fora*

3.5.1 Wireless Innovation Forum

The Wireless Innovation Forum (WInnF) established in 1996, is a non-profit mutual benefit corporation dedicated to driving technology innovation in commercial, civil, and defence communications worldwide. Members bring a broad base of experience in Software Defined Radio (SDR), Cognitive Radio(CR) and Dynamic Spectrum Access (DSA) technologies in diverse markets and at all levels of the wireless value chain to address emerging wireless communications requirements.

WInnF has already published a number of reports on SDR and CR technologies even if the focus is mostly in the military domain.

WInnF has produced various reports, which include:

- Quantifying the Benefits of Cognitive Radio, WINNF-09-P-0012-V1.0.0. The report has reviewed hundreds of reference papers to identify the potential benefits of cognitive radio in commercial, public safety and military domains.
- Securing Software Reconfigurable Communications Devices, WINNF-08-P-0013-V1.0.0. The report aims to present an approach for the development of SDR security architecture and processes that address the threats and security issues, SDR devices are likely to face in its development, manufacturing and operational environments
- Commercial Baseband Technology Overview, WINNF-09-P-0009-V1.0.0. This report discusses both programming environments and hardware platforms for Software Defined Radio (SDR). It is not intended to provide a generic description of programmable baseband technologies. Rather it focuses on a few specific technologies as representative examples.
- Use Cases for Cognitive Applications in Public Safety Communications Systems - Volume 1: Review of the 7 July Bombing of the London Underground - SDRF-07-P-0019-V1.0.0. The report aims to develop and convey concepts for the application of cognitive radio technology to enhance the communications capabilities of public safety first responders.

Historically, WInnF was mostly focused on the defence domain and the SCA architecture, but some areas like security are of direct interest to ACROPOLIS work packages.

3.5.2 Wireless Innovation Alliance (WIA)

From [23]: “The Wireless Innovation Alliance (WIA) is a broad-based group of innovators, providers, consumer groups, think tanks and education organizations that believe that more efficient use and expanded access to the nation’s spectrum resources are fundamental to the future of U.S. economic policy and global competitiveness. One of the driving forces is the potential spectrum scarcity in both licensed and unlicensed bands that must be addressed in order for innovation and investment to move forward. WIA members are committed to working with policymakers to ensure the most efficient, effective and flexible use of spectrum - including “innovation bands” like the newly-authorized Super WiFi to fuel growing demand and new technologies. A balanced, flexible, market-driven policy framework, incorporating licensed and unlicensed allocations alike, offers the best path to accommodate legitimate interests in promoting spectrum efficiency and innovation”.

WIA supports new approaches for spectrum management with greater flexibility than the current “command and control”. In particular, WIA is active in the following areas: a) spectrum inventory, b) incentive auctions, c) advantages/disadvantages of licensed vs unlicensed spectrum management and d) “variable power” where the defined limits by spectrum regulators could be changed depending on the context.

The scope of WIA is quite wide and it can be related to various activities of ACROPOLIS. In particular the area of “variable power” presents important research challenges to design a system that can dynamically adapt the power emissions for opportunistic spectrum access.

3.6 Other standards related to SDR and CR

The possibility of using Software Defined Radio and Cognitive Radio has been investigated in various standards. Note the existing IEEE standards are addressed in section 3.1.

3.6.1 TETRA

A pre-emptive mechanism to implement spectrum sharing between public safety, commercial and military users has been investigated in ETSI TR 102 628 V1.1.1 (2010-08) “Technical Report Electromagnetic compatibility and Radio spectrum Matters (ERM); System reference document; Land Mobile Service; Additional spectrum requirements for future Public Safety and Security (PSS) wireless communication systems n the UHF frequency range”. The first objective of the report is to identify the spectral requirements for TETRA technology to provide wideband and broadband connectivity. A secondary objective of the report is to present the possibility of share the spectral bands in case of an emergency crisis.

The application of cognitive radio concepts in the public safety domain present specific research challenges to support the critical requirements of setup time, security and Quality of Service. Current research activities in ACROPOLIS based on the contexts of the commercial domain can be extended to support emergency networks.

3.6.2 WiMAX

IEEE 802.16h develops coexistence mechanisms for license-exempt operations of WiMAX at 2.4GHz and 5GHz, and supports the coexistence of such systems with primary users. Through reducing the potential interference caused by such systems sharing the same frequency bands, it targets improved user service experience and increased robustness and efficiency of the spectrum use. A mechanism called Cognitive Radio signalling is introduced to help co-channel 802.16 base stations to mitigate interference.

3.6.3 3GPP- LTE

Cognitive Radio functionalities are investigated in 3GPP-LTE in the femtocell design. Femtocells must be able to search the radio channel and estimate which resources are free among the available ones in order to avoid cross-layer and co-layer interference. Another area where cognitive radio concepts are utilized is the self-organizing network (SON) concept. The main self configuration concept of LTE includes self-configuration, self optimization and self-healing. LTE SON can be considered an approach of cognitive radio from the cellular networks perspective.

The design of LTE SON presents important research challenges in the area of Learning Mechanisms and Knowledge Management.

3.6.4 Ultra Wide-Band

Ultra Wide-Band (UWB) technology can have many applications in various domains: home entertainment, automotive, public transport, and mobile communications. This high data rate, low power and short range technology enables devices to operate in frequency range from 3158 MHz to 10560 MHz. In this frequency span, UWB devices can interfere with other wireless communications technologies like WiMAX. In order to avoid harmful interference to primary users (PU) a Detect and Avoid (DAA) can be implemented in UWB devices, where the UWB devices execute spectrum sensing (i.e. Detect) and transmit in another band (i.e. Avoid) if a primary user is detected. From this point of view, DAA can be considered a simple form of cognitive radio. UWB DAA devices based on Multiband orthogonal frequency division modulation (MB-OFDM) as specified by WiMEDIA standards, which are already available.

One the main research challenges in DAA UWB is to design spectrum sensing algorithms that are able to investigate large portions of the radio frequency spectrum in a short time and with minimal circuit complexity.

4 Relationships between regulations and standardizations

The purpose of this section is to describe the relationship between regulations and standardizations frameworks. For example, between CEPT, DG INFSO and ETSI in Europe.

In Europe, the relationships between the standardization and regulation bodies are described in Figure 4-1:

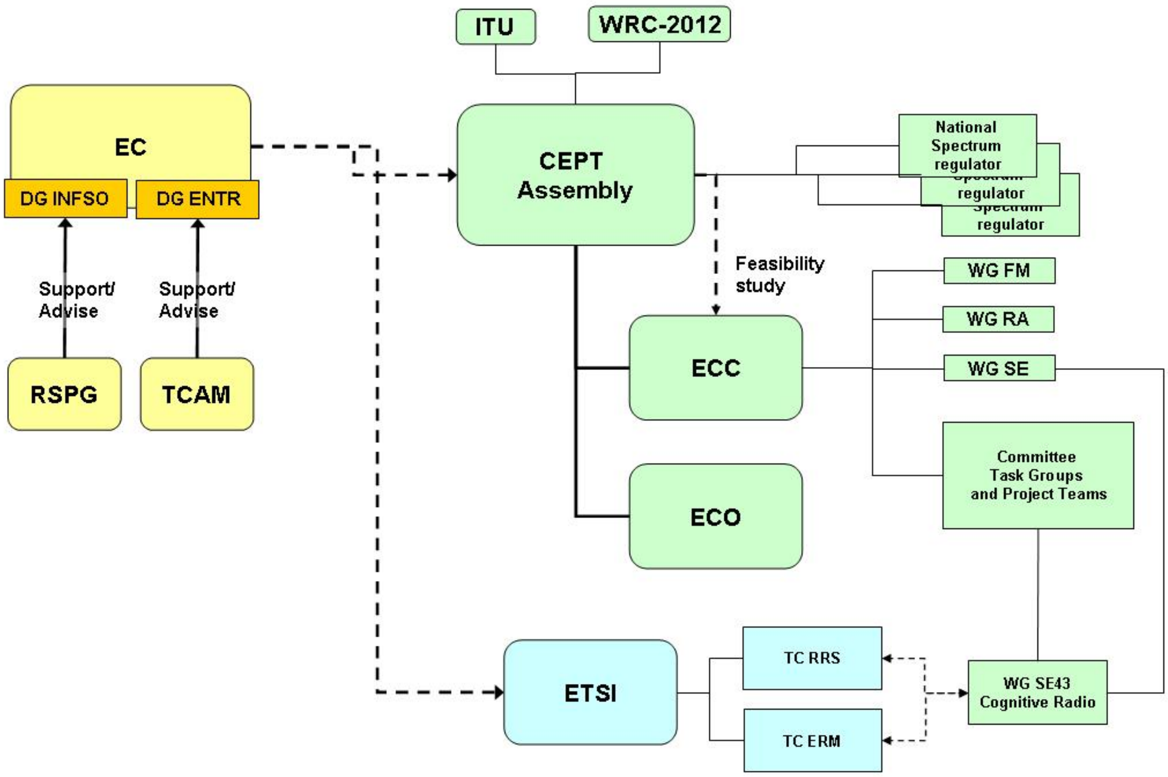

Figure 4-1 Relationships among stakeholders for spectrum regulations in Europe.

The following main entities are identified:

- The European Conference of Postal and Telecommunications Administrations (CEPT), within which policy makers and regulators from 48 countries across Europe collaborate to harmonize telecommunication, radio spectrum and postal regulations.
- The European Communications Office (ECO), which is the Secretariat of the CEPT. The ECO provides advice and support to the CEPT to help it develop and deliver its policies and decisions in an effective and transparent way.
- The European Telecommunications Standards Institute (ETSI), which is responsible for most of the European telecommunication standardization activities together with CEN and CENELEC. Within ETSI, the ETSI Technical Committee (TC) on Reconfigurable Radio Systems (ETSI-RRS) is working on the standardization of SDR and CR technologies, while the ETSI TC on Electro-Magnetic Radio Matters (ETSI-ERM) is working on radio-frequency and spectrum-related issues.

- The European Commission (EC), which is the Executive Body of the European Union. The Commission is composed of various departments or directorates general (DG). One of the objectives of the DG of the Information Society (INFSO) is to define and implement a regulatory environment that enables rapid development of ICT services. DG Enterprise (ENTR) is responsible for standardization and certification of communication devices.
- The Radio Spectrum Policy Group (RSPG), which is a high-level advisory group that assists the European Commission (i.e., DG INFSO) in the development of radio spectrum policy.
- The Telecommunications Conformity Assessment and Market Surveillance (TCAM), which is an advisory and regulatory committee that assists the European Commission in matters regarding conformity assessment and market surveillance including the Radio and Telecommunications Terminal Equipment Directive (R&TTE Directive), which is currently (i.e., October 2011) under revision. The revision of the R&TTE directive should also include SDR and CR devices.

As indicated in Figure 4-1, the CEPT can request feasibility studies from ECC, which is composed of working groups (WG), task groups and project teams. In particular WG SE43 has the responsibility to define technical and operational requirements for the operation of CR systems in the white spaces of the UHF broadcasting band (470-790 MHz).

EC can request specific mandates from CEPT and/or ETSI on specific technologies, but no mandate has been currently issued on SDR or CR technologies.

In USA, the relationships between FCC, NTIA and ITU are described in Figure (from [33]):

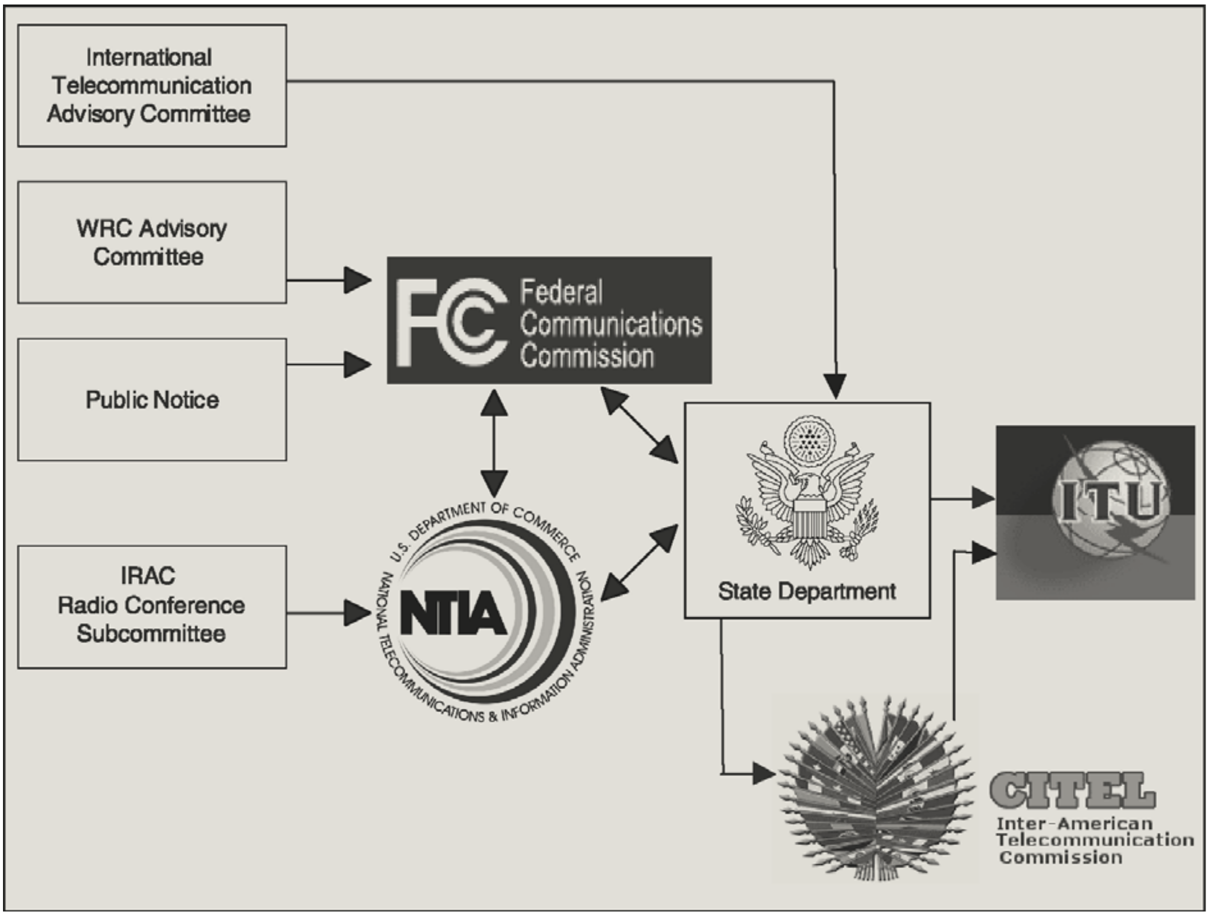

Figure 4-2 Relationships among stakeholders for spectrum regulations in USA (from [33])

The following main entities are identified:

- (from http://www.state.gov/e/eb/adcom/acicip/index.htm) "International Telecommunication Advisory Committee. The Advisory Committee on International Communications and Information Policy (ACICIP) serves the Department of State in an advisory capacity concerning major economic, social and legal issues and problems in international communications and information policy. These issues and problems involve users and providers of information and communication services, technology research and development, foreign industrial and regulatory policy, the activities of international organizations in communications and information, and developing country interests. The Committee is comprised of senior-level officers of a broad range of companies and institutions that represent the communications and information technology industries, including manufacturers, service providers, software developers, trade associations, and academic institutions.
- WRC Advisory Committee. The advisory committee is chartered under the Federal Advisory Committee Act (FACA) to provide to the Federal Communications

Commission (FCC) public views and recommendations in preparation for the 2012 World Radiocommunication Conference (WRC-12).

- Interdepartment Radio Advisory Committee (IRAC). The function of IRAC is to support the Assistant Secretary in assigning frequencies to U.S. Government radio stations and in developing and executing policies, procedures, and technical criteria for the allocation, management, and use of the spectrum. The IRAC consists of a main committee, 6 subcommittees, and several ad hoc working groups that consider various aspects of spectrum management policy.
- NTIA. The National Telecommunications and Information Administration (NTIA), in the US Department of Commerce, is the Executive Branch agency that is principally responsible by law for advising the President on telecommunications and information policy issues. NTIA's programs and policymaking focus largely on expanding broadband Internet access and adoption in America and expand the use of radio frequency spectrum.
- CITEL: The Inter-American Telecommunication Commission was established under the auspices of the Organization of American States. It has 35 Member States and over 200 Associate Members. It is entrusted by the Heads of State at the Summits of the Americas with specific mandates. Its objectives include facilitating and promoting the continuous development of telecommunications.

5 Market and regulations

5.1 Introduction

The purpose of this section is to briefly describe the regulatory and market aspects that could influence the commercial success of a specific spectrum management approach.

Various studies have explored the potential of Cognitive Radio or different spectrum management approaches in comparison to the conventional "command and control" approach.

A recent study [41], has found that increasing shared access for wireless broadband could provide a significant economic stimulus to the EU economy and bring additional social benefits to Europe's citizens. The study used various scenarios, combined with economic modelling. The scenarios are not predictions but are plausible projections of possible futures. The assumption made here is that shared access is equivalent to extra spectrum and it is through exploiting this "new" spectrum that the major economic benefits of shared spectrum access accrue.

The study also mentions the potential impact to regulators. The new models of spectrum management or spectrum sharing would require new tools to be implemented: geo-location databases, spectrum monitoring networks, licensing databases. The new tools have an associated cost, both economical (the cost of implementing the spectrum monitoring or database) and administrative (new organizational structures, new procedures).

Depending on the type of scenarios, these tools and the associated costs can be shifted to other stakeholders in the new "context". For example, the implementation of policy enforcement frameworks in CR mobile devices and networks may obviate the need for the spectrum monitoring network.

In most cases, this is "uncharted" territory where political, regulatory and market driven forces are different players, with different point of views.

The final solution may not necessarily exclude specific spectrum management approaches. We can envision a future where different spectrum management approaches or spectrum access models coexist in different frequency bands and traffic can be "offloaded" from one network/spectrum access model to another depending on the context.

5.2 Opportunistic spectrum access

Opportunistic spectrum access includes various scenarios where CR devices can access the spectrum licensed to a primary radio service in an opportunistic way: the secondary user can transmit only if it does not generate harmful interference to the primary radio service. The question is how to ensure that harmful interference is not generated. One approach is to define restrictive spectrum emission masks upfront. This approach can be safe for primary radio services, but it can effectively "kill" the business case of secondary CR networks. For example, current spectrum regulations for TV white spaces are so restrictive that a market may never emerge.

The WiFi Alliance and other white-space advocates have issued a Petition for Reconsideration with the FCC over the strict emission rules, which were put in place to placate the broadcast television industry, which has long been concerned about potential interference from white space devices.

Another problem is the business cases of “white spaces” themselves. The only places where meaningful amounts of white space spectrum are available are rural areas where the population is small. This means sales volumes will be small and prices will be high - not exactly a formula for commercial success.

That said, an extension of WiFi, which uses white spaces, could be used to improve upon the commercial success of WiFi and extend the WiFi network. This is the work carried out in 802.11af standardization committee.

A specific case of opportunistic spectrum access or underlying cognitive radio technology is Ultra Wideband. Various references highlight that UWB was not commercial successful in the consumer market because of both regulatory and technical reasons: regulatory because the emission masks were too restrictive to provide the requested services (e.g. local broadband connectivity) and technical because of the degree of complexity to implement standards like WiMedia within the price constraints imposed by the main business cases. UWB can still have commercial success in specific use cases, where its unique characteristics (e.g. good propagation, tolerance to interference) make it a more well adapted technology than others.

Another approach in opportunistic spectrum access is to implement mechanisms to provide knowledge to the secondary CR device on the presence of the primary radio service. This capability has been proposed for “white spaces” CR devices, UWB devices or even other short range devices. It can be based on geo-location databases, which store the information on the presence of the primary devices in the area, or spectrum sensing capabilities like the Detect and Avoid of UWB.

These capabilities come with a cost:

1. Networks and standards for geo-location databases must be defined, implemented and deployed with specific costs, which may be anyway minor in comparison to the economical benefits.
2. Spectrum sensing creates an additional economical burden on manufacturers of mobile devices. In this case, regulators can play an important role, if the required sensitivity is too high, the implementation of the spectrum sensing capability could be too expensive for manufacturers and this would effectively “kill” the CR business case.

Many business cases for opportunistic spectrum access have not been investigated in detail from the market point of view. For example, opportunistic spectrum access in the same bands for Fixed Satellite Systems or other fixed infrastructure like railways or the future ITS.

In all these cases, specific communication radio services are used only in specific and fixed areas.

The conclusion is that further study and economic models are needed, which are coupled to the regulations and standardization studies.

5.3 Dynamic exchange of spectrum rights

Dynamic exchange of spectrum rights allows holders of spectrum licenses fluidly to reassign their rights to others who have higher-value uses for the spectrum. They are sometimes called secondary market in spectrum.

Secondary markets in spectrum have not completely failed but they have not been successful either even if the regulatory bodies were quite fast in the regulatory process as FCC defined the rules in 2003.

Reference [35] indicated the following obstacles for the “not success” of white spaces:

- Lack of education. Even today people question whether our secondary market is legal and even if it is, if they are able to participate.
- Technology fear, Interference and availability. There is the fear by stakeholders that sharing spectrum will lead to interference. There is also the fear that spectrum that they can use today won’t be available tomorrow.
- Hording of spectrum. There is the need to identify “carrots” and “sticks” approaches to stop spectrum holders (e.g. telecom operators) from simply hording spectrum and blocking smaller operators or smaller companies by entering the spectrum market. A “carrot” approach is where an incentive is create by regulators to re-allocate the spectrum, while the “stick” is a punitive approach.
- The current licensing system is geared towards multi million dollar transactions, which foster big spectrum holders and telecom operators.

A potential challenge for the commercial success of dynamic exchange of spectrum rights is that spectrum has been conventionally associated to a specific communication technology. Communication devices are designed and manufactured to work on specific frequencies. Therefore, changes in spectrum rights may not be easily “used” or adopted by the communication devices because they would lack the capability of using the spectrum.

This situation may change in the future with communications technologies, which are rather “agnostic” to the spectrum like Long Term Evolution (LTE) and Cognitive Radio, where networks and devices can transmit and received in different frequency bands. The only limitation would be the front-end, which must still be designed to operate in a “range” of frequency bands.

These new technologies may provide the key elements to make dynamic exchange of spectrum rights a commercial success.

In this specific case, it is very important that spectrum regulatory bodies start to create the regulatory framework to allow dynamic exchange of spectrum rights. In most cases, this regulatory framework does already exist both in USA and Europe (see EC Report 159 on spectrum sharing), but it is not fully adopted or it should be harmonized among member states like in Europe.

We should also investigate if the current regulatory approach is still valid from an economic point of view and that it does not create inefficiencies. As described in [39], “Carriers utilizing the existing commercial wireless business model – based on exclusive licensing, high-power transmission, very limited spectrum re-use, hub/spoke channelization, centralized infrastructure and metered billing – will continue to need more exclusive-use spectrum in the short-run to meet this demand. However, it should be equally clear that this model is not sustainable longer term".

5.4 Commons approach

Reference [38] highlights that the commons approach could be related to the use of any "common" resources like water, land or food" "Many natural resources characterised by unrestricted access are considered 'commons' and subject to the tragedy of the commons critique: without property rights or government intervention, the resource is over-consumed and eventually depleted. Increased demand and inefficient supply have recently made spectrum vulnerable to this critique (through congestion rather than depletion) and various policy propositions currently debated among communications regulators urge reform of spectrum management practice by considering alternative visions of the spectrum as an economic resource".

The risk is that the commons approach is not scalable. If it is used for wide scale networks with a large number of users, eventually the quality of the communication service will be degraded to the point that it may become unusable, unless some spectrum etiquette may be implemented that regulates access to the common spectrum among users. But then, the commons may start to resemble other spectrum management approaches like the dynamic exchange of spectrum rights .

Because of scalability issues, the commons models could be utilized just in the cases where both the number of users and the emission power can be limited: for example Wireless Local Area Networks. In fact, WiFi is the most successful market case study for the commons approach.

6 Issues from regulations and standards

This section identifies the main issues and challenges with current regulations and standards, described in the previous sections that need to be addressed by the regulatory, industries and research communities.

6.1 Regulations

The following regulatory issues are identified:

1. *Regulatory framework for dynamic exchange of spectrum rights:* A comprehensive regulatory framework for the dynamic exchange of spectrum rights is still missing. Some industry stakeholders have made proposals on this type of spectrum access model but the regulatory and standardization framework is still missing.
2. *Spectrum sandbox*: Cognitive radio technologies are still not a mature technology, where some unknowns do still exist especially for deployment in the market. The allocation of specific spectrum bands for cognitive radio prototyping (i.e. “sandbox”) would be useful to test and validate cognitive radio technology.
3. *Fixed primary systems:* There are many cases where radio communications services are limited in space: radars, fixed satellite systems, transportation wireless networks and so on. There is a lack of regulations for opportunistic spectrum access where the position of the radio communication devices is clearly defined and does not change (i.e. the receivers of the primary radio communication service are not mobile or limited in space).
4. *Taxonomy of spectrum access models:* There are many types of spectrum management approach. A comprehensive taxonomy has not been clearly defined by spectrum regulators or the taxonomy is defined in different ways by different organizations and stakeholders.
5. *Economic models:* New spectrum management models may also require new economic models. Regulatory bodies and governments have not investigated these models sufficiently.
6. *Models of wireless interference:* New spectrum management models may also require new wireless interference models. Regulatory bodies have not investigated these models sufficiently. For example: models of aggregate interference are still not frequently used to assess the impact of wireless interference from secondary devices to primary radio communication services.
7. *Measurement Campaigns:* In many cases, spectrum regulators do not have a clear idea of the available spectrum in their region of responsibility. In some cases, extensive studies have been conducted but with different procedures and different outcomes. There is a need for a single set of guidelines for measurement campaigns.
8. *Validation and certification.* Validation and certification procedures for cognitive radio networks are still not defined in a complete way. Testing of cognitive radio technology presents new challenges like accurate detection of power levels, timing and validation of mitigation techniques.

6.2 Standards

The following standardization issues are identified:

1. *Standards for dynamic exchange of spectrum rights.* Standards or standardization initiatives on the dynamic exchange of spectrum rights are still missing.
2. *Security aspects:* Security aspects are not fully addressed in the standardization activities on cognitive radio. While some standards like IEEE 802.22 have included security sublayers, other standardization activities do not deal with security requirements.
3. *Link between regulations and standards:* Cognitive radio standardization is closely linked to the spectrum regulatory process. In some cases, this link is not fully established and the two areas are not(?) completely synchronized.
4. *Mitigation techniques for wireless interference*. The risk of wireless interference is perceived as one of the greatest challenges by spectrum regulators and “incumbents” (e.g. digital broadcasters, telecom operators). Mitigation techniques for wireless interference are not fully explored by cognitive radio standardization activities.
5. *Standardization board for cognitive radio.* Cognitive radio is a technology that could be applied to various application domains. As a consequence, there are various standardization activities on cognitive radio-like technologies. There is a potential to find synergies across different standardization activities. A standardization “board” could help the harmonization of the different technologies.
6. *Efficient spectrum sensing in a wide range of frequencies.* Cognitive Radio devices may need to sense a wide range of frequencies with high precision in a short time. These technical requirements are quite challenging but they are even more difficult to implement in mass market receivers at low cost.
7. *Policy framework to ensure conformance to regulations.* Spectrum regulations can be enforced dynamically through the distribution and implementation of policies. The policy framework can also be used to prevent security threats.
8. *Design linked to the level of generated interference.* The MAC and Network layers of Cognitive Radio Networks can be optimized on the basis of the generated interference to primary users or among secondary users.
9. *Use of location.* Location can be used to improve the efficiency and battery consumption of collaborative CR networks.

7 Regulations/standards and ACROPOLIS work packages

This section identifies the relationships between the gaps and challenges identified in the previous sections and the ACROPOLIS activities in the various work packages.

The objective of this section is different from D17, which describes the impact of ACROPOLIS activities to current regulatory and standardization activities.

The following tables provide the potential activities where ACROPOLIS partners could address regulatory and standardization issues:

Table 7-1 Relationships among Regulatory challenges

	Regulatory framework for dynamic exchange of spectrum rights	***Spectrum sandbox***	***Fixed primary systems***	***Taxonomy of spectrum access models***	***Economical models***	***Models of wireless interference***	***Measurement Campaigns***	***Validation and certification***
WP6	WP6 could investigate what regulatory actions are needed to foster dynamic exchange of spectrum rights.		WP6 could investigate what regulatory actions are needed to foster regulation for operational scenarios dealing with fixed primary systems.	WP6 could identify the main spectrum access models and the related advantages/disadvantages.	WP6 could investigate and define economical models for different spectrum access models.			
WP7		WP7 could identify the initial technical enablers to test the concept of cognitive radio in spectrum sandboxes across Europe.						
WP8	Game-theory could be used to model various conflict situations among main stakeholders for this specific spectrum access model.				Game-theory could be used to investigate various spectrum access models.			
WP9							WP9 could identify what spectrum sensing algorithm could be appropriate for spectrum measurement campaigns.	
WP10								
WP11								
WP12	WP12 could identify the main metrics,							

	utility functions, policies and constraints for this specific spectrum access model.							
WP13			WP13 could investigate what policy frameworks could be defined for this specific CR operational scenario.					
WP14						WP14 could investigate and identify model of wireless interference to be applied to different spectrum access models.		WP14 could investigate validation and certification procedures for CR equipment.

Table 7-2 Standardization challenges

	Standards for dynamic exchange of spectrum rights	***Security aspects***	***Link between regulations and standards***	***Mitigation techniques for wireless interference***	***Standardization board for cognitive radio***	***Efficient spectrum sensing in a wide range of frequencies***	***Policy framework to ensure conformance to regulations***	***Design linked to the level of generated interference***	***Use of location***
WP6			WP7 could investigate how to improve links between regulations and standards.						
WP7						WP7 could investigate what platforms could be used to implement efficient spectrum sensing.			
WP8	WP8 can investigate how game theory can improve the exchange of spectrum rights.								
WP9		WP9 could investigate spectrum sensing techniques to identify "spoofing" attacks.				WP9 could investigate efficient spectrum sensing in a wide range of frequencies.		WP9 could design algorithms of Interference Prediction.	
WP10		WP9 could investigate collaborative spectrum sensing techniques to identify "spoofing" attacks.				WP10 could investigate efficient collaborative spectrum sensing in a wide range of frequencies.			

WP11									WP11 could investigate how then knowledge of generated wireless interference can be used in the cognitive cycle	WP11 could investigate how location can be used in the cognitive cycle.
WP12	WP12 could define the main metrics, utility functions, and constraints and apply them to the design of CR networks.			WP12 could investigate the trade-off between centralized and distributed mitigation techniques.						
WP13	WP13 could investigate a policy framework for this specific spectrum access model.	WP13 could investigate how policy frameworks can be used to mitigate security threats to CR networks.	WP13 could investigate how regulations can be translated into a policy language.				WP13 could define policy frameworks to ensure conformance of CR equipment to spectrum regulations.			
WP14		WP14 could investigate security threats and related mitigation techniques.		WP14 could identify mitigation techniques for wireless interference.					WP14 could investigate how locations can be used to detect security threats to CR networks.
WP17					Acropolis partners of WP17 could participate to a standardization board.					

8 Conclusions

Cognitive Radio technology has the potential to improve spectrum utilization and create new value for citizens and industry.

The evidence from the “open” business model of the Internet can be replicated in the wireless communication market, where “open” wireless technologies like cognitive radio and dynamic spectrum access can drive innovation faster than the highly-engineered models of the telecom operators and licensed spectrum.

The experience of the past two decades in Internet technology also suggests that, however technological innovations may seem uncertain and not remunerative at first, innovative business cases and companies quickly appear and overcome competitors in the more “traditional” business industry (e.g., Google has a higher market cap than many telecom operators). This makes a compelling case for innovative approaches in the wireless telecom market.

The deployment of new spectrum management models requires significant changes at the regulatory level and it must be supported by associated standardization and research activities. Beyond the specific regulatory and technical challenges, the most critical issue is the timely cooperation among government, market, industry and research. This is particularly difficult in Europe, because of the geopolitical fragmentation and the large number of relevant stakeholders. Nevertheless, the evolution of wireless communications is an important element of the Digital Agenda for Europe, (one of the flagship initiatives of the Europe 2020 Strategy) and it deserves special focus by the European governments.

Glossary and Definitions

Acronym	Meaning
ACMA	Australian Communications and Media Authority
ARNS	Aeronautical Radio Navigation
CCM	Configuration Control Module
CEPT	European Conference of Postal and Telecommunications Administrations
CPC	Cognitive Pilot Channel
CR	Cognitive Radio
CRS	Cognitive Radio Systems
DSM	Dynamic Spectrum Management
DSONPM	Dynamic, Self-Organising Planning and Management
EIRP	Equivalent isotropically radiated power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
KCC	Korea Communications Commission
MAC	Medium Access Control
NBP	National Broadband Plan
PMSE	Programme Making and Special Events
R&TTE	Radio and telecommunications terminal equipment
RRS	Reconfigurable Radio Systems
RSPG	Radio Spectrum Policy Group
SDR	Software-Defined Radio
SE43	CEPT System Engineering 43
SW	Software
TC	Technical Committee
TCAM	Telecommunications Conformity Assessment and Market Surveillance Committee
TR	Technical Report
UWB	UltraWideBand
WSD	White Spaces Devices

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