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RADIO SPECTRUM POLICY GROUP REPORT ON "COGNITIVE TECHNOLOGIES"

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Executive summary

Radio applications may apply cognitive technologies, such cognitive radios have the potential to play an important role, not only in increasing the efficiency of spectrum usage by offering new sharing opportunities, but also in providing more versatility and flexibility to applications as a result of their ability to adapt their operations to external factors. In the longer term cognitive radio technologies may play a fundamental role in the shift from static spectrum management to dynamic spectrum management and access.

Many aspects of cognitive radio technologies, including the business models, are still unclear. This report has the objective to inform policy makers in Europe as early as possible of the discussions and challenges raised by cognitive technologies.

This report:

- Defines and explains the terminology used (i.e. Cognitive Radio systems, Software Defined Radio, etc);
- Provides an overview of various components of cognitive radio technologies (sensing the environment, information gathering, databases, cognitive pilot channel, learning capabilities, etc.) and a brief overview of the experiences and lessons in Europe and elsewhere with (pre-)cognitive technologies;
- Provides insight in the way in which cognitive radio technologies could operate in some models for spectrum management;
- Briefly summarises (as requested in the RSPG Work Programme) the USA framework for 'white spaces' including the differences in the USA and EU regulatory framework, and possible actions to ensure timely regulatory responses in the EU;
- Identifies the challenging issues which require further attention.

The focus of the use of cognitive radio technologies is on opportunistic spectrum access whereby Cognitive Radios (CR), for example, could identify "unused" portions of spectrum and share that spectrum without interfering with the existing users. The assumption is that a CR is aware of its environment and employs this acquired information to decide on its transmission behaviour. Ideally, the CR would learn from previous operations and would adjust its own behaviour based on this. An ideal CR will make its decisions not only based on information about the radio and geographical environment but also on other information, such as the users' needs, operational costs of the service or other criteria to be pre-defined by the spectrum band manager or licensed operator. This means that a CR has to obtain complete knowledge of the radio operational environment (including its location), decide on the gathered information and act based on this decision (dynamically and autonomously).

There are various techniques possible to obtain information about the environment: sensing, the use of a Cognitive Pilot Channel (CPC) and/or databases. All these techniques have a number of challenges that should be addressed by regulation.

Currently there are already various radio devices that incorporate some of the features of cognitive technologies such as Dynamic Frequency System (DFS) and Detect and Avoid (DAA). These technologies, originally intended as mitigation techniques, are described in section 4.3. Future CR and relevant (spectrum) regulation should capitalize on experience from the close cooperation with ETSI in the development of pre-cognitive radio systems.

CR could be foreseen in various sharing arrangements[1]. This report focuses on two models: a model based on collective use of spectrum and a model whereby the rights of use could be traded or leased. In both situations one can distinguish between vertical sharing, where the cognitive radio shares spectrum with the existing users, and horizontal sharing, where the cognitive radio technologies have the same rights to access the spectrum as the existing users. These models are described in section 5.1 and 5.2. The regulatory interventions are different according to the model.

In sections 5.4 and 5.5 a number of considerations related to methods that can be used by the cognitive radio to get information about the environment in which it operates are given.

Section 6 gives an overview of activities in CEPT ECC, ITU and the USA. Section 7 is on Research and Development (R&D) and on standardization. R&D is the initial phase in developing new technologies and covers various components (technologies, architectures, testing, etc.). Standardisation is bridging the gap between the research and the commercial implementation phase. ETSI has a major role to play in complementing the regulatory initiatives; the current ETSI initiatives should be supported.

Section 8 provides information on the economic aspects of cognitive radio systems and on the need from the industry's perspective to establish viable initial business models. It also acknowledges the need for regulators and industry to work in close cooperation to maximise the benefits of cognitive technologies whilst ensuring protection of other users.

In Section 9 a number of conclusions are drawn from the findings in the report. The overall conclusion is that there are significant benefits by adopting a harmonised approach to cognitive radio technologies. The timely availability of a regulatory response across Europe and harmonised rules for cognitive devices assist in exploiting economies of scale and encourage industry investment, thus enabling new cognitive applications that could bring significant benefits to European markets.

1 It is to be noted that this report does not deal with the specifities of spectrum management of Public Use of Spectrum (see RSPG Public Use of Spectrum - PUS).

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1 Introduction

The Radio Spectrum Policy Group (RSPG) is a high-level advisory group that assists the European Commission in the development of radio spectrum policy. The RSPG advises in a forward-looking manner on a variety of technological, market and regulatory developments relating to the use of radio spectrum.

This RSPG Report focuses on the impact and challenges of innovative cognitive technologies on access to the radio spectrum. The objective is to understand the appropriate regulatory conditions for dynamic access to spectrum and to identify issues which require further attention.

Systems and devices using cognitive radio technologies have the potential to play an important role not only in increasing the efficiency of spectrum usage by offering new sharing opportunities, but also in offering more versatility and flexibility, with their ability to adapt their operations based on external factors. From a long term evolution perspective, cognitive technologies[2] could play a role in a paradigm shift from static spectrum management to dynamic spectrum access and dynamic spectrum management. Therefore there is a need to engage as early as possible in the discussions on challenges and opportunities raised by cognitive technologies.

2 Scope of the Report

Cognitive radio technologies are expected to be a key driver of innovation, resulting in more efficient use of spectrum and having the potential to offer considerable benefits across a broad range of applications. Devices using cognitive technologies may allow for real-time spectrum management and are capable of increasing spectrum efficiency significantly. One current case study on cognitive technologies is in the use of so-called 'white spaces' in the UHF band. Europe should engage in these discussions in order to facilitate access to the spectrum and to promote innovation.

This report:

- Clarifies the basic concepts and explains the terminology used (Cognitive Radio system, Software Defined Radio, etc.);
- Provides an overview of various aspects of cognitive technologies (sensing the environment, information gathering, using databases, cognitive pilot channels, learning capabilities etc.) as well as a brief overview of the experiences and lessons in Europe and elsewhere with (pre-)cognitive technologies;
- Provides insight in the way in which cognitive technologies could operate in the various models for spectrum management;
- Briefly summarises (as requested in the RSPG Work Programme) the USA framework for 'white spaces' including the differences in the USA and EU regulatory framework, and possible actions to ensure timely regulatory responses in the EU;
- Identifies the challenging issues which require further attention.

3 Basic concepts and terminology

The term cognitive radio was first presented officially by Joseph Mitola III and Gerald Q. Maguire, Jr. in 1999[3]. They described a cognitive radio as a device that is capable of cognitive behaviour in a cognition cycle of six phases "Observe, Orient, Plan, Learn, Decide, Act".

A cognitive radio matches its internal models to external observations (in terms of available radio resources, prevailing spectrum rules, user needs and preferences, operational costs of a service etc.) and uses this knowledge to adapt itself to provide wireless services most appropriate to the user needs and preferences. The radio is capable of learning from its past actions

2 In this report, the term "cognitive radios" refers to systems or equipment based on cognitive radio technologies
3 J. Mitola III and G. Q. Maguire, Jr., "Cognitive radio: Making software radios more personal," *IEEE Personal Commun. Mag.*, vol. 6, no. 4, pp. 13-18, Aug. 1999.

and experience and incorporating this knowledge in the Decision and Act phases of the process/cycle. In the view of Mitola cognitive radio is a research goal towards which a software defined radio platform evolves. This type of Cognitive Radio is often referred to as full Cognitive Radio or Mitola radio. Due to the current state of technology, only a few elements of the Mitola concept: i.e. Observe, Decide, Act have so far been implemented.

The focus of the Mitola radio was to deliver the service the user wants based on “a priori” knowledge and reasoning. Since then the focus of research on cognitive radio has shifted towards spectrum sensing and dynamic spectrum access. Cognitive radio has been proposed and promoted as a technology to alleviate today’s spectrum scarcity problems.

Actual usage of the spectrum varies considerably, dependent on various parameters like for example: the number of applications which are sharing the same frequency band, the number of users in a specific area and in a specific period of time, and the environment (urban versus rural with their difference in demand) (see Annex 2: Brief overview of the complexity of radio environment). Some parts of the spectrum are deliberately unused, such as guard-bands between users or within services. The main objective of spectrum sensing is to enhance spectrum usage efficiency by finding opportunities for spectrum access (in various dimensions: time, spatial and frequency) without interfering with other users of the band and adjacent bands. The issue of spectrum sensing and monitoring is discussed in more detail in section 4.2.

This report examines cognitive radio as an enabling technology providing more efficient use of spectrum and providing more dynamic access to spectrum.

In such context Software Defined Radio is widely regarded as an important enabler for Cognitive Radio. However, this is not an absolute necessity, a Cognitive Radio could be built purely based on hardware.

The following definitions have been developed and agreed by the ITU-R Study Group 1:

Software Defined radio (SDR): *A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard.*

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

It is suggested to use these definitions in the European debate.

4 Overview on Cognitive Radio technologies

The focus of the use of Cognitive Radio technology (CRT)is on opportunistic spectrum access whereby cognitive radios are able to identify “unused” portions of spectrum and share that spectrum without affecting the existing users.

The concept of “unused spectrum” is not self-evident. As indicated, spectrum may be unused although rights of use have been issued, e.g. due to the fact, that there are geographical or time differences in demand or that there are no users present in certain geographical locations. In other cases, there are guard bands needed between different users to avoid interference. Moreover, certain systems operate with guard bands within the service (network deployment/reuse patterns). One such example is terrestrial television, where Multi-Frequency Network (MFN) spectrum planning assumes that certain channels will be unused for broadcasting in certain geographical areas (“white spaces”). Nonetheless, unused by one user does not mean unusable for another user or application. On the other hand ‘no signal present’ does not necessarily mean that the frequencies are potentially available (see 4.2.1).

The assumption is that a Cognitive Radio is aware of its environment and uses this acquired information to decide on its transmission behaviour. Ideally, the CR would be capable of learning from its own behaviour and experiences in the past. An ideal CR will make its decisions not only based on information about the radio and geographical environment but also based on other information, such as the users' needs, operational costs of the service or other criteria to be pre defined by the spectrum band manager or licensed operator. Given the current focus on CRT as an enabler for more efficient spectrum use, this section will focus on obtaining information about the radio environment as well as the (geographical) location where the CR is operating.

4.1 Features of cognitive radio technologies

Cognitive radios have the ability to use spectrum which is already used by other spectrum users, i.e. they can share spectrum with other users. To do so, they need to perform three key activities: 1) obtain complete knowledge of the radio operational environment and location, 2) decide on the gathered information and 3) act based on this decision (dynamically and autonomously). These three key functions are described below.

The first key activity of cognitive radio technologies is to obtain knowledge of the radio operational environment and location information including the frequency band assignments/allocation.

This implies features such as:

- Spectrum sensing: the ability to sense radio signals from other (nearby) radio transmitters
- Location awareness: the ability of a device to determine its location and the location of other transmitters or receivers.

The CR will also need to have information about the relevant spectrum rules and use restrictions of the bands it senses. These rules and use restrictions can have various levels of complexity depending on the designation of the band and the sharing mechanisms: frequency sharing (overlay, underlay), time sharing and geographical sharing.

The CR will have to map this information with its own capabilities. The exploitation of an opportunity may require dynamic adjustment in order to transmit without causing interference to other radio transmissions. This dynamic adjustment of a cognitive radio system could encompass several actions, such as changing the active radio access technologies or changing the operating frequency.

This implies features such as:

- Frequency agility: the ability of a radio system (transmitters and receivers) to change its operating frequency.
- Transmit Power Control: software protocols which, once the device has established its transmission, reduce the power to the minimum necessary, thereby reducing the level of interference to other devices. Such features could be useful in cases where different secondary users need to coexist (collective use of spectrum).
- Adaptive antennas.
- Adaptive modulation and coding: the ability to modify transmission characteristics and waveform based on the channel conditions and/or the users' needs.
- Learn from the results obtained: the feature implies that the devices could update its internal database and maintain this knowledge and/or transfer the information to a master database.

There is no "one size fits all" for cognitive radio systems. To ensure the protection of existing users the cognitive radio needs to respect established rules and needs to use one or more of the above mentioned features.

4.2 Radio Environment

All of the cognitive radio technologies share a common approach, in that for their adequate function a depiction, or 'map', of the radio environment is needed. Such a map would generally consist of the number/type of users already present in the band, including where necessary adjacent bands, and their characteristics including other CR systems competing to access the same spectrum. Additional information on basic necessities for the usage profile of the band is also considered useful.

There are various techniques possible to get information about the radio environment. They are described below (without any ranking of appropriateness of their usage). One or a combination of these techniques can be used.

4.2.1 Sensing

As already used for pre-cognitive techniques the sensing function (e.g., performing a scan of the dedicated part of spectrum) provides a real-time 'map' of the radio environment. The main focus is on identifying unused areas in the intended frequency range that can be used by CRs.

Monitoring of spectrum usage and detection of systems present in the spectrum that are to be protected from harmful interference is a non-trivial technical problem, for reasons given below.

The "hidden node" problem is a fundamental challenge for cognitive radio technologies in cases where the cognitive radio is also responsible for monitoring and sensing other spectrum users in order to protect those users. The "hidden node" problem occurs when the cognitive device, due to a physical obstacle, cannot sense another spectrum user transmitting, and therefore assumes that the spectrum is available. In this case, it is possible that the transmission of the cognitive device interferes with the reception of the "hidden" user's signals. The situation may be more clearly illustrated by the following picture:

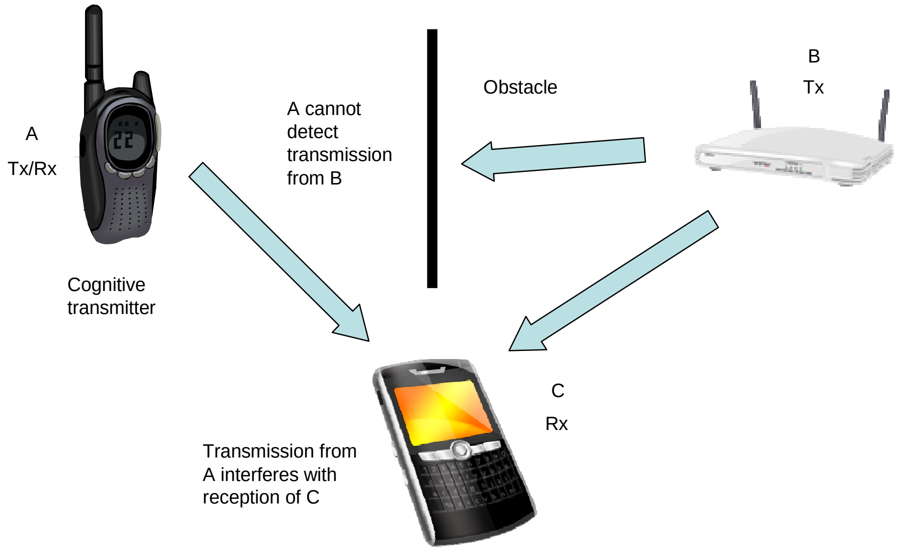

Figure 1 The hidden node problem

Another problem facing pure spectrum sensing and monitoring methods is that it is also not possible to detect receive-only users such as passive radio astronomy services and other scientific uses.

In frequency bands used for satellite reception conventional monitoring may show no usage of the spectrum, due to the very low power levels of the satellite signal at the surface of the earth. Furthermore, sensing may be able to detect transmitting earth stations, but many do not transmit continuously.

On top of this, regional or global coverage of satellites means that even when a satellite downlink is detected it does not mean that service is actually used by receiving earth stations in that particular area.

On the other hand, sharing sensing information among cognitive radios may increase the likelihood of proper detection of all nearby spectrum usage in the band and may reduce the required sensing threshold.

Another method to increase the likelihood of proper detection is infrastructure sensing, i.e. sensing through base stations receivers which in general are placed high level on buildings or masts and thus are not as sensitive to the "hidden node" problems as mobile terminal devices.

To sense radios that are active in a given area, the sensing technology must be able to detect transmissions from a greater distance than intended receivers of that transmission. The reason for this is that cognitive radio situated further away from the transmitter than the intended receiver should not interfere with the reception of the signals by the receiver Therefore the cognitive radio must be more sensitive than the other spectrum users' receivers . In order to develop adequate sensing technologies, the receiver parameters of the existing users should be known too. This issue needs to be addressed in any future spectrum management decision.

Sensing is a technology that is still under development. Sensing becomes more challenging when a wider range of frequencies and/or a wider range of technologies need to be taken into account. Therefore it might be useful to start with the introduction of CRT in a limited frequency range in which the range of technologies used by the other existing users in the band is limited, e.g., within the UHF broadcasting bands.

Sensing is a key feature to protect the primary users but may not be sufficient in all cases.

4.2.2 4.2.2 Cognitive pilot channel (CPC)

A Cognitive Pilot Channel (CPC) is a dedicated carrier providing frequency usage information for the intended band. The CPC may be situated within the intended band or it could be on an internationally designated frequency outside the band. When only CPC is used to gather information about spectrum usage, the CPC will need to have feedback from the CR about its use.

As observed in the E2R II White Paper4 introducing the Cognitive Pilot Channel (CPC) concept, the current trend for communications systems indicates a composite radio environment, where multiple Radio Access Technologies (RATs) are used at the same time (heterogeneous radio environment) . The Cognitive Pilot Channel (CPC) concept initiated by E²R consists in conveying the necessary information to let the terminal know what the available frequency bands are, the RATs in use, the congestion in the networks, the rules applicable within the network, etc. One phase of the cognition cycle consists in observing the environment for which the CPC has been implemented. The prime incentive for the CPC is basically to overcome potentially time consuming scanning processes that would be required to obtain similar knowledge.

Various forms of CPC are foreseen by European researchers and ETSI[5]. Either an in-band CPC or out-band can provide downlink as well as uplink information transfer.

- In-Band CPC is a logical channel within the technologies of the heterogeneous radio environment using specific channels of the existing access technologies.
- Out-Band CPC is a radio channel outside the component Radio Access Technologies. It either uses a new radio interface, or alternatively uses an adaptation of legacy technology with appropriate characteristics.

Such models encompass a number of regulatory issues (such as management of the frequency usage information and regulatory environment) which needs to be carefully studied (see section 5.5).

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4 The E2R II Flexible Spectrum Management (FSM) Framework and Cognitive Pilot Channel (CPC) Concept –Technical and Business Analysis and Recommendations. See https://ict-e3.eu/project/white_papers/e2r/5.E2RII_FSM_White_Paper.pdf
5 See for instance ETSI TR 102 683 on CPC.

4.2.3 Databases

An alternative to sensing or the CPC is for a CR to have a database available of the frequencies which can be used at certain locations as well as the applicable rules. To use the database, the CR needs to know its own location. Such a concept, also known as a geo-location database, could help to overcome most of the problems associated with sensing.

Database functionality would be possible both for fixed devices and mobile devices, in case these devices have a functioning positioning capability (e.g. via satellite geo-location services or terrestrial network positioning) and connection to the database. Databases may be more practical for the case where the location of existing radio users is fixed rather than mobile. In those case there is less need for frequent updating of the database and therefore less complexity than in the mobile case.

For a CR based on the database concept to be effective it must have ready access to a live database of the spectrum environment within which the CR is operating. Such a database should contain the relevant information for each intended frequency band. Such information could be a table of users, their regulatory status, interference protection parameters and other regulatory requirements specific to that band. Section 5.4 describes some regulatory issues related to databases.

4.3 Pre-cognitive radio systems

Some radio applications currently available on the market already incorporate some of the features of cognitive technologies such as DFS[6] and DAA[7]. These technologies could be considered as early generation cognitive radio technologies or "pre-cognitive" radio technologies. These radio technologies are introduced as part of mitigation techniques to facilitate sharing in frequency bands which would otherwise not be possible.

These systems obtain knowledge of the operational and geographical environment by sensing the environment. Mechanisms to react to this radio environment are embedded in the device and refer to spectrum management policies on the assumption that they will not be modified during the device's lifetime. As explained further on, the regulation of these devices falls under vertical sharing in the CUS model (see section 5.1.1)

This experience from deployment of pre-cognitive radio systems is relevant for the future development of CRT.

The technical conditions for access to spectrum for these devices are defined by regulators based on the results of compatibility studies. The regulatory process is summarised below:

- At the European level CEPT is responsible for conducting the compatibility studies and these are conducted on a case-by-case basis according to the characteristics of the incumbent spectrum users to be protected and monitored accordingly.
- The characteristics of incumbent spectrum users to be protected needs to be agreed in the compatibility study. This tends to be complex and involves discussion with all the relevant spectrum stakeholders including governmental users of spectrum. CEPT develops relevant sharing and technical conditions to be met for the cognitive device to access spectrum.
- ETSI respects these spectrum sharing conditions and parameters in the harmonised standards (see RSPG opinion on streamlining EU regulation) and develops appropriate

6 "Where a transmission delay is unacceptable, a device may use LBT in combination with Adaptive Frequency Agility (AFA). This combination of LBT/AFA is often called Dynamic Frequency Selection (DFS). By using this method, the equipment will search for a different free channel as soon as it detects that the wanted channel is occupied. Transmission delay by this method is minimized to the listen time defined by the LBT/DFS algorithm." - Reference FM(07)141

7 Detect and Avoid (DAA) mechanisms are mechanisms which detect the presence of signals from other radio systems (such as fixed broadband wireless access and mobile services) and reduce the transmitted power of the UWB device down to a level where it does not cause interference to indoor reception of these systems." - Reference ECC Report 120

tests methods to ensure compliance with the technical conditions. CEPT and ETSI cooperate in order to ensure that test methods and suites drafted in the standardization process will comply with assessment of relevant spectrum requirements as identified in future harmonized standards.

The recent introduction of pre-cognitive devices has raised the issue of putting constraints on the future development of other uses of a frequency band especially when these devices are under a license-exempt approach. This is because the technical conditions can only be defined based on known protection requirements of the incumbent users. Hence, CRT devices will need to be able to adapt to new sharing conditions in line with the evolution of other radio systems

It is recognised that a harmonised solution of CRT devices at the European level could reduce complexity and reduce uncertainties and allow the CRT devices market to benefit from a larger geographical spectrum harmonisation.

As such these pre-CRT devices are authorised, under a licence-exempt approach, to operate on a non protection, non interference basis.

5 Access to spectrum by CR and implications on regulations and licensing

In theory, applications using cognitive radio technologies could be foreseen in various, but not all, frequency bands with various sharing arrangements and relevant regulatory models. Cognitive radio technologies can be allowed in spectrum covered by the collective use of spectrum (CUS)[8] approach as well as spectrum which is individually licensed if the rights of use could be traded or leased[9]. Within the latter model CR could also be introduced based on Collective Use of Spectrum.

Cognitive Radios can be used to dynamically share unused portions of licensed spectrum or they can dynamically share spectrum with other CRT. So, there are different sharing arrangements possible:

- Vertical sharing

One approach to sharing spectrum can be referred to as vertical sharing where the cognitive radio shares spectrum with the existing users. The cognitive radio is only allowed to utilize frequencies within the band as long as the existing user(s) is not affected, i.e. the cognitive radio must not cause harmful interference to the existing users. Depending on the spectrum rights of the primary user(s), the conditions under which the CR devices can operate are to be defined in advance by the regulator or could be left to the primary user.

- Horizontal sharing:

An alternative or complementary approach to vertical spectrum sharing is when cognitive radio technologies have the same rights to access the spectrum. Therefore this type of sharing is referred to as horizontal sharing. The established policies including the sharing conditions should be transparent and non discriminatory. In this model, regulatory intervention is required to define the conditions to ensure appropriate protection for other users or devices.

5.1 CR in a Collective use of spectrum model

The RSPG defined Collective Use of Spectrum (CUS) as:

8 RSPG08-244 Radio Spectrum Policy Group Opinion on aspects of a European approach to 'Collective Use of Spectrum', 19 November 2008

9 RSPG 04-54 The Radio Spectrum Policy Group Opinion on secondary trading of rights to use Radio spectrum, November 19, 2004.

"Collective Use of Spectrum allows an undetermined number of independent users and/or devices to access spectrum in the same range of frequencies at the same time and in a particular geographic area under a well-defined set of conditions."

This model includes license exempt use, light licensing and private commons. With the exception of the latter case, where the entity to which the band has been licensed sets the rules of access to the band, the regulator is responsible for defining (minimum) conditions to ensure appropriate protection for other services or devices.

5.1.1 Vertical sharing

The basis for this type of spectrum access is opportunistic spectrum access whereby cognitive radios identify unused portions of licensed spectrum, and utilize that spectrum without affecting the existing user(s).

In this model, the regulator will designate the frequency band where cognitive access could be introduced to share spectrum on an opportunistic basis with existing users and set the appropriate technical conditions of spectrum access. Such an initiative is expected to a large extent to be driven by industry's business models and the foreseen cognitive applications.

Examples: RLAN 5 GHz (using DFS), UWB DAA in 3.1 - 4.8 and current discussion on the use of white spaces in the UHF band.

5.1.2 Horizontal sharing

In this model a frequency band dedicated to collective use is identified by the regulator and has usage restrictions to ensure compatibility with existing users. The regulator may also define some conditions of access for the collective use in the band which may require the devices to have cognitive features. These usage restrictions are established policies in order to ensure that various applications could share the frequency band on a non-discriminatory basis. These cognitive features are used to dynamically share the spectrum with each other in such a way that all devices have the same rights and an equal chance to access the spectrum, i.e. the cognitive features are used to ensure a fair distribution of rights to access the spectrum.

This horizontal sharing could also form a subset of the vertical sharing in that the entity to which the band has been licensed or the regulator define the rules to share with existing users and the cognitive users share horizontally with each other.

Examples: This type of sharing can be typically used in ad hoc networks. Each device that is added to the network results in a reconfiguration of the network to fairly distribute the resources.

5.2 CR where the rights of spectrum use could be tradable or leased

Some applications may need, even temporarily and locally, access to spectrum with a guaranteed quality of service (QoS). Such applications might be better served under an individual authorisation regime.

CR can operate on a protected basis (as primary spectrum user through the authorisation granted to the network operator). A licensee may use CRT for its own services under its individual authorisation. This will be for instance the case of terminals operated in mobile networks where cognition is shared between terminals and the core network. Bi- or multilateral agreements could be established between licensees taken into account competition issues in order to use CRT for their own purposes (cf. current mobile environment). This is outside the scope of this report.

However, in order to provide additional applications in a licensed band, when a national framework defines the conditions for rights of spectrum use to be tradable or leased, cognitive radios can be used to dynamically share unused portions of licensed spectrum. In the future, a real-time secondary market for spectrum could be anticipated[10].

In such a model, the regulator does not set the technical conditions for the individual cognitive radio user beyond defining the rights of the block of spectrum in which the cognitive device will operate within as spectrum access is negotiated between cognitive users.

5.2.1 Vertical sharing

In the vertical sharing model the licensed user of the spectrum could allow secondary usage of its spectrum at the locations and for the time that it is not used. The initial investigation could be based on information gathered from spectrum monitoring activities and is expected to a large extent to be driven by industry's business models and the foreseen cognitive applications. The conditions under which a cognitive radio user may use the spectrum could be set by the licensee under a framework defined by the rights of spectrum usage granted by the regulatory body or by the spectrum regulator. Such a framework should describe conditions to use the spectrum and provide dispute resolution mechanisms.

Consequently, no regulatory intervention is required beyond having tradable or leased rights of spectrum use and flexible licence conditions.

Guaranteed access and other QoS parameters (for both the licensee and the cognitive radio user) could be part of the regulatory framework given also visibility of negotiation opportunities.

5.2.2 Horizontal sharing

In the horizontal sharing model licensed owners of spectrum form a pool of spectrum that can be used by all licensees. These licensees do not necessarily have to offer the same type of use. The framework defined by the rights of spectrum usage granted by the regulatory body shall provide mechanisms for resolution of disputes and interference cases and ensure that conditions to use spectrum are fulfilled in any case.

This form of spectrum pooling can be used to tailor the spectrum needs of the different licensees to their actual demand. It is particularly useful in situations where demand fluctuates in time and/or location.

This form of sharing may be initiated by the regulator by granting relevant spectrum usage rights to a group of licensees. A central entity (a spectrum broker) could be used to facilitate this form of "flexible rights of use" or any other solutions agreed by the parties and endorsed by regulation "under the regulatory framework". In this case, the regulator will need to define the minimum technical conditions for the relevant blocks of spectrum pool within which cognitive radio users will operate.

In this model the primary user will normally have paid or still pays fees for the spectrum usage rights whatever the frequency charges/taxation model is. Therefore, it is to be expected that the primary user will seek economic benefits from sharing the band with CR (CR to pay for the use of the band). This may impact on the CR applications.

5.3 Summary of Regulatory Intervention

10 In such a context, which is largely theoretical at this stage, cognitive radio could be used to facilitate the creation of a spot market whereby rights to access the spectrum are traded instantly. Such a real-time secondary market is not addressed in this report.

The role of the spectrum manager will be different according to the model chosen. The type of regulatory intervention required is summarized in the following table.

<table>
<tr><th>Regulatory Invention</th><th>Vertical Sharing</th><th>Horizontal Sharing</th></tr>
<tr><td rowspan="2">CUS Model</td><td>Designate the frequency band where cognitive radio could share spectrum with existing users on an opportunistic basis.
Define the appropriate technical conditions for the cognitive devices.</td><td>Designate the frequency band to allow usage on a cognitive basis which does not interfere with existing users;
Define technical conditions for the block of spectrum where cognitive radio will operate within.</td></tr>
<tr><td colspan="2">CT devices will need to be able to adapt to new sharing conditions in line with evolution of other radio systems;
Sharing between cognitive radios could be set between themselves through industry standardization or negotiated access between the spectrum users;
Ensure equitable and non discriminatory access to spectrum for all the cognitive users and to ensure competition.</td></tr>
<tr><td rowspan="3">Rights of spectrum usage could be tradable or leased</td><td>Vertical Sharing</td><td>Horizontal Sharing</td></tr>
<tr><td>Define the framework for trading or leasing of rights of spectrum usage (including, where needed, QoS requirements;
Assess the results of negotiations between market parties and their effects on e.g., competition and approve them.</td><td>Define the framework for trading and leasing of rights of spectrum usage;
Provide defined mechanisms in case of disputes and interferences issues and in case of not fulfilling the conditions of use.</td></tr>
<tr><td colspan="2">Ensure that the rights of spectrum usage are tradable or could be leased and are flexible
Identification of spectrum for cognitive access lies with the existing licensed holders and not with regulators</td></tr>
</table>

When addressing the introduction of cognitive radio systems in a given band, the spectrum manager will assess the most suitable regulatory framework in accordance, amongst other criteria, technical sharing feasibility and the foreseen cognitive applications.

In the CUS model, the regulator's decision to allow cognitive access will take into consideration various factors including the potential benefits of new applications incorporating cognitive radio technologies and to facilitate innovation as well as weighing the risks of potential sterilization of spectrum and evolution of incumbent service.

The authorisation regime will depend on the established conditions to ensure coexistence between CRT applications and existing spectrum users. This would be developed on a case by case basis according to the requirements of the given frequency band. The current regulatory framework provides sufficient flexibility in terms of possible licensing regimes at national level:

from general authorisations to individual authorisations (see also ECC Report[11] on Light Licensing)[12].

It is to be expected that with a growing use of CR, refarming will become more complex where there is a large number of invisible CT devices active in spectrum bands.

5.4 Regulatory considerations of technologies related to cognitive radio

5.4.1 Databases

As described above (section 4.2.3), one way to implement cognitive technologies would be to use 'geo-location databases'. Using such databases gives rise to a number of issues of a regulatory nature. The proper instrument for the regulatory response (spectrum regulation, equipment regulation, self-regulation, etc.) is very much dependent on the issue addressed. Some of these issues can however be better dealt with on a national basis, whereas others would benefit from a European harmonisation approach.

The following issues are considered more relevant for national responses, since the solutions will vary between various countries depending on the different existing users that need to be protected from the cognitive devices.

- The cognitive device will need to know its position; the positional accuracy should be specified and agreed by the national regulator.
- The data concerning spectrum used in each location would have to be provided (e.g. either by the existing users, regulators or a specific entity). There will be associated costs in providing the information (e.g. the entity who will need to bear the costs could be the regulator, external database owners or cognitive radio users).
- There will be issues associated with access to, availability and reliability of the database (frequently of updating, accessing data, etc.).
- Operational and management issues (security, integrity, privacy, etc.) linked to the databases.

An issue where a European harmonised approach will be desirable is:

- for cognitive radio devices to have standardised protocols/languages to access the database and format of data within the database (database profile). This would allow the cognitive devices to establish connection to the database and download the rules from the database to allow correct operation in the country it's operating, even though the rules may vary between countries.

5.4.2 Cognitive Pilot Channel

The information transmitted through the CPC on the frequency usage and on the regulatory environment needs to be reliable. The issue for regulation would be how to safeguard the reliability and accuracy of this information. Furthermore, all CR systems reliant on access to a CPC need to be able to understand the CPC.

According to market needs, relevant regulatory solutions could be studied in cooperation between administrations and industry to develop the most suitable forms of CPC, particularly for the frequency to be used by the CPC. The form of regulatory intervention may differ according to the form of CPC (see also WRC 1.19 agenda item).

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[11] ECC Report 61: Review of the Current Use of electronic Processes within CEPT/ECC for Licensing and Information Purposes

[12] It has to be noted that there are a number of other ways to manage spectrum (see for example the RSPG Opinion on Public Use of Spectrum)

5.4.3 *Software Defined Radio*

Software Defined Radio (SDR) functionality may be considered as one possible enabler for Cognitive Radio Technologies (CRT). Where SDR is implemented in a CRT context, SDR functionality may extend or increase the performance of CRT. A CRT device could be able to share spectrum with other systems through a change in software, the SDR functionality can change the radio parameters. This assumes the technological capability of the CR device being able to revise its behaviour with respect to its radio environment once software altering its radio parameters has been run.

Intrinsically, CRT devices do not lead to other issues of responsibility than is the case for non-CRT devices, as long as all the sharing situations potentially resulting from cognitive capabilities have been studied and are duly taken into account. CRT functionality can even help overcome some issues regarding responsibility (e.g. location awareness may help preventing unauthorised usage; CPC could inform CR devices on the evolution of regulation). The implementation of SDR functionality may in certain situations lead to concerns for the responsibility of the radio emissions. This would be the case in particular where an alteration of radio parameters may lead to a compatibility issue where, before the reconfiguration, such issues did not exist or were duly dealt with.

The regulatory issues surrounding SDR functionality would be significantly different depending on the market approach considered

- In the case of a vertical integrated market of SDR (a single entity is in charge of the hardware and software defined radio component), the responsibility remains clearly identified with either the manufacturer or the entity responsible for the introduction of the radio equipment on the market.
- In the case of a horizontal market (an open hardware platform and software defined radio provided by different suppliers), the situation becomes more complex. A third party software provider can sell its downloadable software (e.g., over the Internet) without having “locally” any legal representative on whom the responsibility could effectively rely. Such software which alters the RF parameters of the hardware platform will raise responsibility issues.

Certain regulatory aspects of SDR functionality may be satisfactorily handled by self-regulation or industry standardisation. However, other aspects, such as the regulatory issues raised by a horizontal market, need further attention. The upcoming review of the R&TTE Directive creates an opportunity to discuss these issues in more detail.

6 Activities in ECC, ITU and the USA

6.1 ECC correspondence group on Cognitive Radio (ECC-CG-CR)

CEPT ECC had launched a number of activities in relation to CT:

- In response to industry initiatives, CEPT ECC has developed spectrum regulation and sharing conditions for pre-cognitive technologies (UWB DFS, DAA, RLAN) in strong co-operation with ETSI,
- CEPT ECC has already published a report on ”white spaces”: CEPT Report 24 is a preliminary assessment of the feasibility of fitting new/future applications/services into non-harmonised spectrum of the digital dividend (namely the so-called "white spaces" between allotments),
- CEPT ECC is already preparing a position for WRC-12 in relation to the Agenda Item 1.19 (see section 6.3).

Following a workshop organized by CEPT in January 2009, other initiatives are highlighted as follows:

- The majority of administrations supports the view that the ECC should take a pro-active role in driving the regulatory work on CR. This approach was especially supported to facilitate the introduction of CR, to respond to requests from industry and to encourage industry investments as the industry may be waiting for some regulatory signal before investing in CR. This approach calls for active cooperation between CEPT and industry.
- A project team from the ECC Spectrum Engineering Working Group (SE43) is defining technical and operational requirements for the operation of cognitive radio systems in the “white spaces” of the UHF broadcasting band (470-790 MHz) to ensure the protection of incumbent radio users/systems and investigate the consequential amount of spectrum potentially available as “white space”. An initial report from SE 43 is expected by mid 2010.
- An ECC correspondence group comprising a large number of stakeholders is also active in identifying tasks to be undertaken by the ECC by taking into consideration feedback from initial investigations by ECC PT SE43 and the experience gained on pre-cognitive systems.
- Finally ECC also decided to task its Frequency Management Working Group (WG FM) to start to identify possible candidate bands for cognitive radio systems.

6.2 Activities in the USA

The Federal Communications Commission (FCC) of the USA set up a Spectrum Policy Task Force in 2002. Based on the SPTF Report, the FCC issued a Notice of Proposed Rule Making (NPRM – FCC 03-322 [2]) advancing CR technology in 2003 as a candidate to implement negotiated or opportunistic spectrum sharing.

The FCC published a notice of proposed rulemaking to permit unlicensed use and to request comments on their proposed rules changes for opportunistic access to “white spaces” in the TV bands in 2004 (FCC, 2004). This proposal was followed in October 2006 by a first report and order and further notice of proposed rule making in which “the Commission is taking a number of important first steps towards allowing the introduction of new low power devices in the broadcast television spectrum (TV bands) on channels/frequencies that are not being used for authorized services (also referred to as "TV band devices").” and “ask questions and set forth certain proposals with regard to the provisions necessary to implement complete and final rules.” In November 2008 the FCC released a second report and order and memorandum opinion and order which adopts rules to allow unlicensed “white space” devices to operate in the broadcast television spectrum at locations where that spectrum is not being used by licensed users (FCC, 2008). Annex 1 contains details of the situation in the USA.

6.3 Activities in the ITU

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 tackled under WRC-12 agenda item 1.2).

However, there might be a need for changes to the Radio Regulations in order to facilitate cognitive radios under a specific service. An example of the required regulatory measures on global level are those used in the deployment of RLAN in the 5 GHz bands based on DFS. These changes will have to be made on a case-by-case basis.

7 Research projects and Standardisation

CR requires a large amount of investment in R&D. The EU framework programmes and COST are two of the three pillars of joint European research initiatives. Under the 6th Framework Programme (FP6), the European Union has been funding collaborative research and development activities in the field of telecommunications with a financial allocation of over €370 million and with the objective to make significant progress towards advanced communication technologies, systems and users. One of the key challenges in the evolution of the telecommunications world will be to efficiently manage and control the optimisation of radio resource and spectrum usage. The Spectrum and Resource Management (S&RM) Cluster is addressing this. The EU also supports a number of initiatives within the 7th Framework Programme (FP7) – see http://cordis.europa.eu/fp7/ict/future-networks/projects_en.html.

One of the nine key domains of COST is Information and Communications Technologies (ICT). Cognitive Radio and Networking is one of the ICT actions (Action IC0902).

Research is the initial phase in developing new technologies and covers various components (technologies, architectures, testing, etc.). Standardisation bridges the gap between the research and the commercial implementation phase. Standardisation work and study of CR systems has been undertaken both by IEEE and ETSI in recent years.

- IEEE work is essentially based on the regulation recently adopted by the Federal Communications Commission (FCC) proposing to allow license-exempt devices to operate on a non-interfering basis within the ”white spaces” of the TV spectrum.
- The European standardisation organisation, ETSI, has already taken some initiatives on pre-cognitive radio systems by providing the relevant harmonised standards to support the market development in cooperation with CEPT. Moreover, in 2007 ETSI established a technical committee on radio reconfigurable systems (TC RRS) to study the feasibility of standardisation for cognitive technology and software defined radio and to identify in which areas ETSI could develop its own standardisation deliverables. Some deliverables are already adopted and some possible standardisation areas have been identified. ETSI has also recognised that the standardisation activity should be developed in coherence and in cooperation with the initiative launched by ECC in UHF band.

Standardisation by ETSI plays a major role in complementing the regulatory initiatives within Europe; therefore the current ETSI initiatives should be supported.

8 Economic and social impacts

This section discusses the economic aspects of CR, including the need for industry of establishing viable business models, and underlining the need for regulators and industry to work in close cooperation to maximise the benefits of CR

8.1 Industry and cognitive features: trials to explore opportunities

CR could support local/regional development and bring significant economic and social benefits. CR would, in particular provide such benefits if it becomes widely available. Regulators can contribute to the success of CR by facilitating access to spectrum and by taking away potential barriers to the introduction of CR.

Cognitive radio technologies have the potential to support new applications in several markets, including public safety and military applications. For commercial markets, CRT would need to be underpinned by a viable business model and the ability to compete with similar applications offered in other bands without cognitivity.

According to the market needs, business models and availability of technologies, CRT could provide solutions to comply with the required sharing conditions in various frequency bands, on case by case basis. However, the economic value of spectrum may differ depending on demand and characteristics of the given spectrum band and foreseen applications. For either some commercial or government applications, the value of spectrum below 1 GHz, and between 1 and 2 GHz, is likely to be valued higher than other frequency bands and, initialy, may require investigation of relevant sharing conditions between various applications (see current study on “white spaces” in UHF bands) .

Opportunities to provide additional applications through cognitive access are expected to be driven by the market. However, investments in R&D and in technology evolution would catalyze this process.

Studies have been initiated by market players (e.g. in ETSI TC RRS) to assess the energy efficiency of cognitive radio systems and the consequent economies in power consumption that cognitive technology could bring to operators.

On the other hand, the need to have cognitive features is likely to increase the costs of CR compared to conventional radio. Hence, the volume of terminal and infrastructure equipment will be a driver for additional cost reduction opportunities. Harmonisation of technical parameters would provide economies of scale through standardisation

Moreover, shifting features from hardware to software is becoming a major driver of industry innovation. In such a context, competition implies faster sequences of updates and improvement of operating behaviour of CR. Software defined radio may be an additional attractive component to CRT and could improve the economic benefits for industry or the consumers by reducing the equipment implementation costs. The initial standardisation effort at European level (see ETSI TC RRS) needs to be pursued and further developed. Initiatives to support European research in identified cognitive features and technological challenges (such as sensing) would be most beneficial to the Community

Furthermore, trials combining various industry partners could provide opportunities to explore new applications and business models. This should be encouraged at national level with also opportunities to exchange results and views between administrations and between Member States and Commission.

8.2 Regulatory framework and (initial) business plans

Benefits from the introduction of CR appear in several areas. The main benefits are the improved efficiency in the overall spectrum use and facilitating access to "new” spectrum. Detection of unused spectrum (spectrum sensing), utilization of free spectrum slots (spectrum management within the scope of spectrum usage rights), dynamic selection of frequencies when the presence of other users is detected (spectrum mobility), coordination & sharing of spectral resources among users (spectrum sharing) may provide new opportunities for industry and operators. Nevertheless, the benefit of CR could be reduced by additional costs of the equipment complexity and possible deployment restrictions on devices using cognitive features and incumbents applications. Harmonisation of CRT capabilities and spectrum usage should therefore be further studied in order to reduce the risk of additional costs due to equipment complexity.

For spectrum regulators, it would be highly beneficial to understand the relevant (business) requirements, industrial costs, potential size of the market and investment profitability, in order to be able to advice on effective regulation.

Any major changes in the frequency usage are expected to meet some resistance from present users. Consultation between spectrum managers and these users will be part of a process of giving the confidence that they need in the regulatory framework of CR. A related issue that may need to addressed is the different levels of quality of service that need to be guaranteed.

Industry is therefore invited to provide such information, where considered appropriate. At this stage, there is a common European interest in establishing some form of partnership between European standardisation bodies and spectrum regulators (e.g. through CEPT), where possible, on the basis of initial business plans from industry.

9 Conclusions

On the basis of the foregoing analysis of the current state of development of CR and the issues which need to be addressed in order to facilitate a successful development of CR the following conclusions can be drawn:

- Cognitive radio technologies are expected to be a key driver of innovation, resulting in significant increase of overall spectrum efficiency, by increasing sharing opportunities between applications, to solve at least part of the spectrum shortage problem in the future.
- Cognitive radio has the potential to offer increased spectrum access for a broad range of (new) applications. But, many aspects of cognitive radio technologies, including the business models, are still unclear.
- The concept of 'unused spectrum' should be managed carefully taking into consideration the relevant radio spectrum usage of a given frequency band. Assessment of the availability of 'unused spectrum' needs to take into account the various spectrum usages in a given band, particularly when receive-only or passive equipment is using the band.
- Sensing is a key feature to protect the primary users but may not be sufficient in all cases. A case by case approach is required which takes into consideration the current usage and expected applications. Obtaining knowledge of this environment may require a combination of the cognitive features.
- Purely passive usage is impossible to detect. To ensure future development of CRT, such issues need to be addressed in any future spectrum management regime.
- Receiver parameters have to be known in order to be able to protect existing users.
- Infrastructure sensing or cooperation between sensing devices may ease the challenges associated with sensing.
- Future CR systems and relevant spectrum regulation should use experience from deployment of pre-cognitive radio systems.
- Introduction of CT devices should be studied, at least initially, on a case by case basis taking into account the incumbent users to be protected.
- For the database, it will be desirable to have European standardised protocols/languages to access the database and format of data within the database (database profile). This would allow the cognitive devices to establish connection to the database and download the rules from the database to allow correct operation in the country within which it is operating, even though the rules may vary between countries
- The information transmitted through the databases and the cognitive pilot channel (CPC) on the frequency usage and on the regulatory environment needs to be reliable. The issue for regulation would be how to ensure the reliability and accuracy of this information.
- According to market needs, relevant regulatory solutions could be studied in cooperation between administrations and industry to develop the most suitable forms of CPC, particularly for the frequency to be used by the CPC. The form of regulatory intervention may differ according to the form of CPC (see WRC 1.19 agenda item).
- In theory, applications using cognitive radio technologies could be foreseen in various frequency bands, but different sharing arrangements are possible. A distinction could be made between a CUS model and a model where rights of spectrum usage could be traded or leased.
- Introduction of CRT by a licensee for its own purpose under an individual authorisation regime does not require regulatory intervention and is managed at standardisation level.
- It might be useful to start with the introduction of CR in a limited frequency range in which the range of technologies used by the other users in the band is limited, e.g., within the UHF broadcasting bands.
- Standardisation by ETSI plays a major role in complementing the regulatory initiatives launched by CEPT ECC; the current ETSI initiatives should be supported.
- Trials combining various industry partners could provide opportunities to explore new applications and business models. This should be encouraged at national level. The results

could be exchanged between Administrations and between Member States and Commission.

- In order to be proactive and to support / promote European Research & Development initiatives in the sector, a strict interaction and consultation with industry is strongly suggested (e.g. through CEPT and ETSI).
- For spectrum regulators, it would be highly beneficial to understand the relevant (business) requirements, industrial costs, potential size of the market and investment profitability, in order to be able to introduce effective regulation.

For cognitive access in the UHF band, the following can be noted:

- The terrestrial digital TV standards and the regulatory situation in Europe and the USA (as described in Annex 1) are different and hence the regulatory solution developed in Europe is also likely to differ. Industry should be kept well informed of the European requirements to ensure a clear understanding of the conditions to be met.
- There are numerous challenges facing both regulators and industries. Regulators will need to be satisfied that they have specified appropriate conditions of access which protect incumbent users and allow feasible operation of cognitive devices and systems, including additional regulatory considerations such as management of database solutions. Industries would need to develop technological solutions to meet the regulatory requirements that will still allow for feasible business case with acceptable implementation costs.
- There are significant benefits in adopting a harmonised approach to this work. The timely availability of spectrum across Europe and the harmonised specification of cognitive devices will exploit economies of scale and encourage industry investment, thus enabling new cognitive applications that could bring significant benefits to European markets by maximising the effective and efficient use of spectrum. This will only be achieved if common technical conditions can be agreed at the European level on identified frequency bands, which provide sufficient certainty and stability to industry within an appropriate timeframe.

Abbreviations

AFA	Adaptive Frequency Agility
ARPU	Average Revenue Per User
BEM	Block Edge Mask
ATSC	Advanced Television Systems Committee
CAPEX	Capital expenditures
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CMOS	Complementary Metal Oxide Semiconductor
CPC	Cognitive Pilot Channel
CRS	Cognitive Radio Systems
CT	Cognitive Technologies
CUS	Collective Use of Spectrum
DAA	Detect and Avoid
DFS	Dynamic Frequency Selection
DVB-T	Digital Video Broadcasting Terrestrial
DSL	Digital Subscriber Line
DTT	Digital Terrestrial Television
E2R	End-To-End Reconfigurability
E^3	End-to-End Efficiency - Research Project under FP7
ECN&S	Electronic Communications Networks and Services
EESS	Earth Exploration-Satellite Service
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
EU	European Union
FSS	Fixed-Satellite Service
FTTx	Fiber to the ”x”
GMDSS	Global Maritime Distress and Safety System (Maritime)
GSM	Global System for Mobile communications (originally Groupe Spécial Mobile)
IEEE	Institute of Electrical & Electronics Engineers
ITU	International Telecommunication Union
LAN	Local Area Network
LBT	Listen Before Transmit
MFN	Multi Frequency Network
MIPS	Microprocessor without interlocked pipeline stages
MSS	Mobile-Satellite Service
NGA	Next Generation Access
NFTA	Network File Transfer Authority
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational expenditure
OSA	Open Systems Architecture
PMSE	Programme Making and Special Event
PRF	Pulse Repetition Frequency
PUS	Public Use of Spectrum
QoS	Quality of Service

RLAN	Radio Local Area Network
R&TTE	Radio and Telecommunications Terminal Equipment
RAS	Radioastronomy Service
RATs	Radio Access Technologies
RNSS	Radio Navigation-Satellite Service
RSPG	Radio Spectrum Policy Group
SDR	Software defined Radio
SFN	Single Frequency Network
SWOT	Analysis of Strengths, Weaknesses, Opportunities, and Threats
T-DAB	Terrestrial Digital Audio Broadcasting
TVWS	Television White Space
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
WAPECS	Wireless Access Policy for Electronic Communications Services
WRC	World Radiocommunication Conference

Annex 1: Feedback from TV White Spaces in USA

In order to introduce unlicensed devices in TV White spaces in the USA, the FCC, the US spectrum and equipment regulator, combined various rigorous regulatory conditions:

- a mandatory geo-location system and rigid requirements to protect incumbent spectrum users, in particular broadcasting reception, cable TV head ends and PMSE. The radio regulatory requirements differ according to the foreseen applications: fixed or personal/portable.
- a database (see detail below) under a pay access mechanism should be also established; this still raises a number of issues : business model, specifications, confidence for current spectrum users.
- a mandatory sensing feature to detect PMSE. Sensing feature shall also be available for detecting TV signals.

In addition, the regulatory framework on radio equipment in the USA is different than in Europe. In particular, type approval of all radio devices (FCC equipment certification) is mandatory. This is considered a key element in the FCC decision to envisage the possibility of sensing-only TV white space device.

These regulatory conditions and framework reveal the complexity of devices entering the TV white spaces. EU Member States and the European Commission should carefully take this complexity into consideration. Due to the fact that key elements of the EU regulations for equipment and use of spectrum are significantly different from those of the USA, the European regulatory solution will be different.

The analysis of the FCC approach identifies a number of differences with regard to the European situation:

- Terrestrial TV coverage in the USA leaves a number of TV channels available. The USA is “cable TV and satellite TV centric” in a competitive environment with other emerging solutions such as TV DSL and optic fibre. There is more uncertainty on the availability of white spaces in Europe (see CEPT report 24).
    - Terrestrial TV is still the main TV distribution system in a number of European countries.
    - Available channels are already used by PMSE equipment although the number of available channels used by PMSE will vary significantly between different countries (and even between different locations in the same country);
    - FCC regulations provide strong protection from adjacent channel interference: no emissions are allowed in the adjacent channel of fixed Television White Space (TVWS) devices, reduction of the maximum e.i.r.p. for portable equipment which implies that large amount of free spectrum is available.
    - In addition to the channels used for local TV coverage and possibly the adjacent channels, also the channels used in neighbouring areas for TV coverage may be unavailable in particular in the case of fixed TVWS applications where stations are placed on roofs.
- Broadband requires spectrum bandwidth:
    - Lack of “available channels” could drastically reduce broadband perspective, in particular for fixed TVWS applications.
    - A large amount of spectrum (83,5MHz + more than 400MHz) is already available for Wifi applications in 2,4 GHz and 5GHz bands respectively. However the UHF TV broadcasting band offers different and better characteristics.
- Terrestrial Digital TV standards differ in USA (ATSC) and in Europe (DVB-T):
    - Detection thresholds are extremely low (below noise level) and require specific detection techniques based on an assumed structure of the TV signal which is different in

USA and Europe. For ATSC, detection would be based on the presence of a residual carrier, for DVB-T on the cyclic prefix of the OFDM signal.

- USA operates a national type approval regime for radio equipment
  - The R&TTE Directive regime in force in Europe is based on manufacturer's self-certification (declaration of conformity) and does not require either type approval or registration of the equipment. Moreover modification of assumptions are difficult to revise in case of interference and the RSPG identified some recommendations to improve the current European regulatory process (see RSPG Opinion on streamlining the regulatory environment.
  - FCC also considered the possibility to allow for equipment relying purely on sensing of TV and PMSE signal (i.e. without the requirement for geo-location and connection to a database). However, in this case, the manufacturer would have to apply to the FCC. In such a case the FCC lab will carry out testing of the equipment and the FCC will then carry out a public consultation with the final decision being taken by the full Commission. This approach with obligatory testing by the regulator would also be precluded in the EU due to the R&TTE Directive.
- The national database will be managed by a third party on pay-access mechanism
  - A database raises a number of issues which need to be carefully studied due to their regulatory, policy and economic implications: management of a database with accurate and reliable data, specification of the database, initial founding and opex (business model), privacy issues, competition issues, relationships with spectrum management policies, management of devices operating in geographical areas outside the database service areas. Such issues should be addressed further to compatibility studies if they are still relevant. The current situation in the USA is that a mandatory technical standard has yet to be approved. The business model to operate the database is also not well known. The implications of geo-localisation and database approaches need to be further investigated.
  - A national approach is not suitable due to free circulation of radio devices in Europe. The spectrum environment in Europe is larger than in individual EU countries.
  - National spectrum conditions vary from country to country due to historical reasons, broadcasting and PMSE usages and will add a degree of complexity to updating a database and maintaining accurate data to prevent interference.

Annex 2: Brief overview of the complexity of the radio environment

Various users and applications coexist in the spectrum environment: Fixed Service (FS), Mobile-Satellite Services (MSS), Earth Exploration-Satellite Service (EESS), Radio Astronomy Service (RAS), DVB-T, T-DAB, Bluetooth, RLAN in the 5 GHz range (RLAN), IMT-2000, Radio Navigation-Satellite Service (RNSS), Fixed-Satellite Service (FSS), Amateur/Amateur-Satellite Service (Amateur), Maritime Mobile Service including Global Maritime Distress and Safety System (Maritime), Aeronautical Mobile Service and radio determination service (Aeronautical), and Meteorological Radar, (see EFIS www.efis.org to obtain more services and applications). Each service/application has its own technical and operational characteristics. In this context, it is obvious that the radio environment is far from being homogeneous and could evolve in space and in time. For example, reconfiguration of infrastructures (new emission sites), increasing of spectrum use by an incumbent operator, increasing of spectrum use by CT equipment, variation of traffic according to location and time, evolution of transmitters versus receiver's characteristics, predictability/ unpredictability of the usage are various factors impacting the radio environment.

Compatibility studies focusing on victim users operating in dedicated frequency bands need to anticipate such technical and operational conditions to prevent interference. The relevant results and solutions are closely tied to a given frequency bands and victim users and should not be generalized to other frequency bands.