

Does Cognitive Radio need Policy Innovation?

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5 Introduction

The growing demand for radio frequency (RF) spectrum makes the introduction of more spectrum efficient technologies and a more efficient spectrum management regime necessary. Cognitive Radio (CR) is a promising innovative technology to improve spectrum utilization. Cognitive Radio systems not only have the potential to make more efficient use of spectrum, but also offer more versatility and flexibility, with the increased ability to adapt their operations based on external factors. Cognitive Radio systems can play an important role in achieving Dynamic Spectrum Access, and thereby a paradigm shift from a static to a dynamic spectrum management model.

Rapid progress is being made in the research on Cognitive Radio technology to facilitate Dynamic Spectrum Access. However, Dynamic Spectrum Access will require changes in spectrum management to take advantage of the possibilities for more efficient spectrum usage. This contribution focuses on the implications of Dynamic Spectrum Access on the policy dimension of spectrum management.¹⁶

6 Spectrum management: the current paradigm

Today, spectrum management is still based on the same principals as agreed upon in 1927. Spectrum is globally governed by the International Telecommunications Union (ITU). The Radiocommunication Sector of the ITU (ITU-R) develops and adopts the Radio Regulations, a binding international treaty, with a voluminous set of rules. The Radio Regulations are based on avoidance of radio interference through the division of spectrum in bands which are allocated to one or more services out of some 40 different radio services¹⁷. A wide range of regulatory, operational, and technical provisions ensure that radio services are compatible with another and harmful interference among countries is avoided. The Radio Regulations are updated in response to changes in needs and demands at World Radiocommunication Conferences (WRC), which are held every three to four years.

Individual countries adopt some or all of the allocated services of each band. Nations are allowed to differentiate from the Radio Regulations as long as no harmful interference¹⁸ is caused to the services in other countries. Based on the allocations the

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¹⁶ Introduction of Cognitive Radio based on Software Defined Radio will also have regulatory implications for conformance testing and the placing of equipment on the market. This subject is dealt with in (Veenstra and Leonhard, 2008).

¹⁷ These radio services include services such as fixed, mobile, satellite, amateur, radio navigation and radio astronomy. Most bands are shared among primary and secondary services. Primary services have priority in case of conflicts resulting in harmful interference.

¹⁸ Harmful interference is defined as *Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly

national Spectrum Management Authority (SMA) assigns licenses to users. Usually a license gives an exclusive right to operate on a specific frequency in a specific location or geographic area and under specific technical conditions (power, antenna height, etc.) and other conditions such as service obligations and build-out requirements. Compliance of spectrum users with the license obligations is monitored and enforced.

Licenses are usually granted on a first come first served approach if the demand for spectrum within a particular band is considered to be far less than supply. When spectrum demand exceeds supply, the SMA has to use another mechanism to award the licenses. Increasingly, SMAs have turned to spectrum auctions, comparative hearings or “beauty contests” are occasionally used (ITU 2004).

In this model all decisions are made by the SMA. Therefore, this traditional spectrum management model is commonly referred to as Command & Control. This Command and Control model has a number of limitations: some of the portions of the spectrum are hardly used, and the method is slow in responding to changes in market and technology.

In the past, the huge inefficiencies in spectrum utilization from bureaucratic command and control were tolerable. As demand grew, advancing technology ensured that new frequency bands were available¹⁹, and there was no need to deal with economically inefficiently used spectrum. More recently, demand has grown very rapidly and technology has delivered new services and devices to serve that demand. However, the opening up of even higher frequency bands is not going in the same pace and not all frequencies are alike²⁰. This means that Spectrum Management Authorities more or less ran out of useable spectrum to identify for new services and technologies. Hence, services based on new technologies can only be introduced at the expense of existing services.

Consequently Spectrum Management Authorities all over the world are in the process of modernising their spectrum policies, and are seeking alternative spectrum management models which allow a much more efficient and flexible utilisation of the spectrum (Nekovee 2006).

Solutions have to address the lack of available (accessible) spectrum in the current static model. RF spectrum is divided into fixed and non-overlapping blocks, separated by so-called guard bands, and exclusively assigned to different services and wireless technologies, while a lot of spectrum usage is only local and limited in time.

In an economic sense, there appears to be a paradox whereby the rights to the RF spectrum are fully assigned, but a lot of RF spectrum remains unused in practice when considered on a time or geographical basis. Under the current command and control model it is very difficult to make the unused spectrum available. What is required is Dynamic Spectrum Access (DSA) and a dynamic spectrum management model that

interrupts a *radiocommunication service* operating in accordance with Radio Regulations (ITU Radio Regulations, edition of 2004, article 1.169).

¹⁹ In 1927 only the frequency range up to 23 MHz was allocated; in 1932 this was extended to 30 MHz, since then the upper limit was extended to 200 MHz in 1938, 10,5GHz in 1947, 40 GHz in 1959, 275 GHz in 1971 and 1000 GHz in 2000, although there are no services defined above 275 GHz.

²⁰ In the higher frequency range is more bandwidth (capacity) available but higher frequencies have a shorter range *ceteris paribus*. The ideal frequency range for e.g. mobile communications is roughly 1-3 GHz. Below this frequency range there is not enough data throughput capacity available and above this range the coverage area of the base station becomes too small.

supports it. Cognitive Radio, as a technology, is a tool to realize this goal of Dynamic Spectrum Access.

The term Cognitive Radio was first suggested by Mitola. He defines CR as a radio driven by a large store of a priori knowledge, searching out by reasoning ways to deliver the service the users want. The Cognitive Radio is reconfigurable and built on the software-defined radio (SDR) (Mitola 1999).

Nowadays, the term Cognitive Radio is mostly used in a narrower sense. Cognitive Radios have been proposed as a means to increase the efficiency of the use of already licensed spectrum. The key feature of a Cognitive Radio is its ability to recognize the unused parts of spectrum that is licensed to a primary user and adapt its communication strategy to use these parts while minimizing the interference that it generates to the primary user.

7 Dynamic Spectrum Access: what is it and what is the problem?

Dynamic Spectrum Access is based on the notion of the existence of white spots, i.e. frequencies assigned to a primary user, but, at a particular time and specific geographic location, not used by that user²¹ (Haykin 2005). The objective of DSA is to provide the means to make these white spots available for secondary users. Secondary means in this context that the white spots may be used by a secondary user as long as this usage doesn't interfere with the usage of the primary user i.e. no (harmful) interference to the primary user is allowed and a primary user has priority in access to spectrum.

The basic approach of Dynamic Spectrum Access systems is to access the spectrum based on the systems own judgment of the local use of the spectrum. This is called Opportunistic Spectrum Access (OSA). The DSA system looks for white spots in the spectrum and then transmits over sections of the spectrum that are not in use. However, it has the additional complexity that it needs to keep listening for other transmitters in order to vacate a white spot when a primary user starts accessing it.

This opportunistic behavior gives rise to a problem that is known as the hidden node problem, whereby the DSA system was inadvertently not able to detect the primary usage of a frequency channel. There are different reasons for the occurrence of the hidden node problem. One of the most eminent reasons is that a primary transmitter is not detected due to 'shadowing', e.g. due to an obstruction (like a building or a mountain) in between the primary user and the DSA system. The hidden node problem makes the detection of spectrum usage by no means an easy task. In general, the sensitivity of the DSA system will have to outperform primary user receivers by a large margin (Pawelczak, 2008).

There are at least three options to overcome this hidden node problem.

One of the options is to share sensing information among different DSA systems in an area. This is known as cooperative or collaborative detection. Cooperation can improve the probability of detection and reduce the detection time and thus increase the overall agility. The drawback is the overhead needed to exchange sensing information.

A second option is to get information about the local use of a frequency band from a database. In this case the DSA system must be aware of its geographical position, e.g.

²¹ Examples of white spots are the empty spaces (guard bands) between TV channels. The actual size and frequency range of the white spot will be different in different locations.

by incorporating radionavigation in the terminal; the DSA system will need to have access to the database on a regular basis and the database will have to be kept up-to-date. This option is especially suitable in cases where spectrum usage of the primary user does not change frequently, e.g. in a broadcasting band.

A third option is to use a local beacon which transmits information to DSA systems nearby. The beacon transmits information about the availability of spectrum and possibly usage conditions to the DSA systems in that area.

These solutions may lead to a need for a communication link; either between DSA systems to share sensing information or between a DSA system and a central entity to get information about usage possibilities. This communication channel is called a Cognition supporting Pilot Channel or Cognitive Pilot Channel (CPC).

There are different possibilities for the implementation of a CPC. The CPC can use a new dedicated (ideally worldwide harmonized) frequency, a specific channel of existing access technology or a combination of both.

8 Implications of Dynamic Spectrum Access on spectrum management

There are no international treaties that prohibit the use of dynamic access to spectrum in general or Cognitive Radio in particular²². However, there are some barriers that prevent a successful use of more dynamic forms of spectrum access. As said, in most countries the management of spectrum is based on a static approach. Spectrum is split into fixed blocks which are assigned to a specific service or technology. There are bands designated for e.g. analogue radio broadcasting, air traffic control, emergency services, television broadcasting and mobile radio. The frequencies are exclusively assigned to licensees to offer these services.

Introduction of Dynamic Spectrum Access in these exclusively designated and assigned frequency bands is only possible if these bands are opened up for other services and technologies. Since the designation of bands to specific services and the rules under which they may be used have their origin in the international framework, there is a need to adapt both the international and national regulatory framework for the management of RF spectrum.

8.1 Adapting the international regulatory framework

There is a need to enhance the regulatory framework at an international level to allow for more flexibility in the use of RF spectrum and there is a need for harmonization activities related Dynamic Spectrum Access including cooperation between DSA systems or between DSA systems and a central entity.

There are already activities started within the ITU-R that are related to these tasks. At the World Radio Conference 2007 (WRC-07) it was decided to put two related items on the agenda for the World Radio Conference in 2011.

Agenda Item 1.2 is put on the agenda for the WRC-11 to allow more flexibility in the use of spectrum:

²² A few countries, including the United States and Ireland, have already made provision to allow the introduction of cognitive radio. See also Akalu (2008).

1.2 taking into account the ITU-R studies carried out in accordance with Resolution 951 (Rev.WRC-07), to take appropriate action with a view to enhancing the international regulatory framework;

The related Resolution 951 identifies that further studies are needed in order to develop concepts and procedures for enhancing the Radio Regulations to meet the demands of current, emerging and future radio applications, while taking into account existing services and usage. The studies should take into considering that evolving and emerging radiocommunication technologies may enable sharing possibilities and may lead to more frequency-agile and interference-tolerant equipment and consequently to more flexible use of spectrum and that these evolving and emerging technologies may not require band segmentation within the traditional spectrum allocation framework.

The WRC-11 also has an agenda item (1.19) specific on Software Defined Radio and Cognitive Radio.

1.19 to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution 956.

Study Group 1 (Spectrum management) of the ITU-R is responsible for the studies needed in preparation of the WRC-11. Within Working Party 1B of Study Group 1 work has started to develop definitions of Software Defined Radio and Cognitive Radio Systems, to discuss its related concepts such as the Cognition supporting Pilot Channel and a database, and to identify potential regulatory issues associated with SDR and Cognitive Radio Systems. A Correspondence Group has been set up to speed up the work.

It remains unclear what the potential changes to the Radio Regulations should be in addition to the need for more flexibility (which is tackled in agenda item 1.2). The only remaining issue that might have an impact on the Radio Regulations is the need for a globally harmonized Cognition supporting Pilot Channel. However, further studies are needed to prove the viability of Dynamic Spectrum Access based on a local beacon.

There might also be a need for involvement of regulators to create a database with local information on spectrum usage and standardization of the protocols needed to access this database. However, this task has no implications for the Radio Regulations.

The Radiocommunication Assembly prior to the WRC-07 decided to put QUESTION ITU-R 241-1/5 *Cognitive radio systems in the mobile service* on the agenda of Study Group 5 (Terrestrial services) for the forthcoming study period. The Question ITU-R 241-1/5 lists the following issues to be studied (ITU 2007):

- 1 What is the ITU definition of cognitive radio systems?
- 2 What are the closely related radio technologies (e.g. smart radio, reconfigurable radio, policy-defined adaptive radio and their associated control mechanisms) and their functionalities that may be a part of cognitive radio systems?
- 3 What key technical characteristics, requirements, performance and benefits are associated with the implementation of cognitive radio systems?
- 4 What are the potential applications of cognitive radio systems and their impact on spectrum management?

- 5 What are the operational implications (including privacy and authentication) of cognitive radio systems?
- 6 What are the cognitive capabilities that could facilitate coexistence with existing systems in the mobile service and in other radiocommunication services, such as broadcast, mobile satellite or fixed?
- 7 What spectrum-sharing techniques can be used to implement cognitive radio systems to ensure coexistence with other users?
- 8 How can cognitive radio systems promote the efficient use of radio resources?

Study Group 5 is expected to deliver a response to this question in the form of a Report or possibly Recommendations by the year 2010. Study Group 5 is already working on a Report on *Cognitive radio systems in the land mobile service*.

Within the European Union there are a number of activities to introduce more flexibility in the use of spectrum (WAPECS²³) and to introduce secondary trading²⁴. Both issues are included in the European Commissions proposals for the EU Telecoms Review 2007. A detailed assessment of these activities falls outside the scope of this paper.

The European Commission also mandated the European Communications Committee to perform a study on the introduction of Cognitive Radio's in the television bands. This report indicates that the feasibility of the introduction of Cognitive Radio systems has not yet been conclusively demonstrated. Since the CR technology is at a very early stage, the CEPT recommends to look further into the requirements within the European environment for CR devices to be deployed in white space spectrum in order to facilitate the further development of CR technology. The current CEPT view is that any new white space applications should be used on a non-protected non-interfering basis (CEPT 2008).

8.2 Adapting the national regulatory framework

The National Spectrum Management authority will have to adapt the national regulatory framework in order to improve the efficiency and flexibility in the use of spectrum. From a regulatory perspective there are two different models considered to improve the efficiency and flexibility, a model based on tradable property rights and a model based on open access (Faulhaber, 2006). These models need to be linked to the new technological capabilities of Cognitive Radio's and dynamic spectrum access.

Dynamic Spectrum Access in an open access regime

An open access regime is a regime in which a user can have access to spectrum without the need for a license. In this case it means that a DSA system can have access to white spots on a secondary basis without the need to have an individual license. There are only general conditions imposed to the secondary use of the band. Access to white spots

²³ WAPECS is a framework for the provision of electronic communications services within a set of frequency bands to be identified and agreed between European Union Member States in which a range of electronic communications networks and electronic communications services may be offered on a technology and service neutral basis, provided that certain technical requirements to avoid interference are met, to ensure the effective and efficient use of the spectrum, and the authorisation conditions do not distort competition.

²⁴ EC Communication COM(2005)400 "A market-based approach to spectrum management in the European Union".

can be facilitated in an open access regime if strict rules are defined to keep the interference to the Primary Users at an acceptable level.

This level will have to be clearly defined by the regulator. The definition of an appropriate level is not an easy task. If the level is too restrictive the potential gains of Opportunistic Spectrum Access (OSA) are marginal, while a level that is too loose may affect the Quality of Service of the primary user. The regulator will have to cooperate with industry to set a realistic level which is based on the state of the art of technology.

No matter what interference level is defined, there will always remain a likelihood of interference, and there are no guarantees for an OSA system to have access to spectrum. This sets limitations to the use of opportunistic spectrum access and on the types of applications it can support in an open access regime. Opportunistic spectrum access is expected to be restricted to low-end applications, involving low power devices. OSA is also of interest to military users to set up ad-hoc networks without the need for central coordination.

Dynamic Spectrum Access in a market based approach

A market based approach to RF spectrum management is based on the introduction of property rights. This approach is characterized by three elements, adapted from (Baumol and Robyn 2006):

1. Well-defined exclusive rights to the use of spectrum;
2. A market-type mechanism such as an auction for an initial allocation of spectrum rights;
3. A secondary market in which these rights can be sold or leased.

In this case the SMA will have to assume the responsibility to set well defined usage rights in the market, with as few usage restrictions as possible.

A number of countries already introduced the possibility of secondary trading. However, in most cases there is an approval mechanism from the authorities before trading may take place. These kind of barriers make instant trading impossible and, hence, will have to be removed to exploit the full potential of Dynamic Spectrum Access.

A market based approach is expected to provide the possibility for active coordination between the primary user and the secondary (cognitive) user about the likelihood of interference, and on guarantees about access to spectrum. If the barriers to instant trading are removed, the opportunity to buy and sell rights to access spectrum can be based on the actual demand for spectrum. This creates the opportunity to use DSA systems for higher valued services, such as mobile telephony, and for a spot market to be introduced. A spot market is a perfect means to acquire and sell rights to spectrum access based on the actual demand at any given moment in time.

Information about the actual ownership of RF spectrum rights will have to be readily available to facilitate trading. The SMA is ideally positioned to perform the task to keep record of these ownership rights to the use of spectrum. Inclusion of monitoring information about the actual usage of spectrum by the primary users can further facilitate trading by giving more insights in the possibilities for secondary usage.

If the spectrum market is introduced in a region, e.g., the European Union, trading can also be used to ease the problem of cross-border coordination. Nowadays the use of spectrum in border areas is based on an equal split of the use of spectrum between

neighbouring countries through the definition of preferential rights. However, there is no relationship with the actual demand for spectrum at either side of the border. If instant trading is allowed the usage rights can be tuned to the actual demand.

9 First applications

Digital Enhanced Cordless Telecommunications (DECT) can be regarded as a first implementation of spectrum sensing. A DECT telephone selects a frequency channel based on sensing of the channels available for DECT. However, DECT uses an exclusively assigned frequency band; sensing is only used to determine the best available channel within the band.

The first application that senses the available channels to detect and avoid other users is Unlicensed Radio LAN in the 5 GHz band. The Radio LAN uses a subset of OSA, which is called Dynamic Channel Selection (DFS). DFS is used to prevent a device from accessing a specific frequency channel if it is in use by a primary user, notably radar systems. The difference between OSA and DFS is that DFS is not used to seek spectrum access, but to prevent spectrum access if co-channel interference might occur. Close cooperation between regulators and industry was needed to define and standardize DFS in such a way that it can detect all different radar systems that are active in the bands involved.

The first application of Cognitive Radio is foreseen in the “white spots” of the TV-bands based on opportunistic spectrum access. The Federal Communications Commission (FCC) of the USA has already published a notice of proposed rulemaking to permit unlicensed opportunistic access to white spaces in the TV bands (FCC 2004). In response to this notice the IEEE has created a working group (IEEE 802.22) which aims to develop a standard based on opportunistic spectrum access of the television bands to provide fixed wireless broadband access in rural and remote areas.

10 Conclusions

Today’s spectrum management is still based on the same principles as set out at the time of the crystal radio. This results in highly ineffective use of spectrum. New innovative technologies, such as Cognitive Radio systems offer a huge potential to increase spectrum efficiency thereby facilitating Dynamic Spectrum Access. To make Dynamic Spectrum Access possible RF spectrum regulations will need to be adapted. A prerequisite for DSA is the need for more flexibility in the use of RF spectrum.

The Spectrum Management Authority and the industry will have to work in close cooperation to realize the goal of Dynamic Spectrum Access. One of the fields of cooperation is to define the requirements for spectrum sensing and the associated interference limits to primary users.

A too narrow focus on an open access regime to realise Dynamic Spectrum Access will limit the possibilities for new emerging technologies, e.g., Cognitive Radio. A market based approach can be a good addition to reach the goal of more efficient spectrum usage whereby access to spectrum is based on actual demand.

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