Cognitive Radio, the Market and the Regulator

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Abstract — ***At the moment in a number of countries experiments with the use of cognitive radio are performed. However, there is a considerable degree of uncertainty regarding the potential application of cognitive radio. For successful use of cognitive radio, there is a need for cooperation between the technology developers, the market players and the regulator to reduce these uncertainties. In this contribution a proposal is made to make a more congruent approach towards the implementation of cognitive radio to lower these uncertainties to an acceptable level, with a special emphasis on the role of the regulator.***

Keywords: spectrum management; dynamic spectrum access; property rights; commons

I. INTRODUCTION

Already more than 10 years ago the concept of cognitive radio was proposed by Mitola and Maguire as a promising technology to deliver personalized services to the user through the most efficient radio resource available [1-2]. Since then the concept of cognitive radio (CR) has been further explored and the importance of cognitive radio on the efficient use of spectrum has gained momentum [3]. Significant efforts are put in the development of various aspects of cognitive radio. However, the number of experiments and field trials with cognitive radio are still very limited. Experiments are done in, e.g. the United States and Ireland [4].

One of the reasons is the uncertainty around the practical use of CR technology. For instance, sensing, one of the key aspects of cognitive radios, is still under development and yet not reliable enough for commercial exploitation of applications based on CR technology. But there are also other factors that create uncertainty. For instance, spectrum users see cognitive radio as a threat to their own spectrum and regulators are still discussing the topic without a clear perspective on their role to facilitate the implementation of CR technology.

Although there are possibilities to use cognitive radio under the current radio spectrum management regime, doing nothing is not a valid option for a regulator as long as these uncertainties exist. Regulation is about giving certainty. Not only by restricting spectrum use, but also by enabling and facilitating innovative use [5]. What is needed is a more congruent approach towards the implementation of cognitive radio. There is a need for cooperation between technology developers, the market players and the regulator.

Although the regulator can't do much about technological uncertainties as such, the regulator plays a crucial role. The regulator should create a regulatory environment in which these uncertainties are lowered to an acceptable level for commercial applications to emerge. This environment should, among other things give clear directions on the expectations of CR technology. To do so, a common understanding is required regarding, firstly, the role cognitive radio can play within the current and proposed spectrum management regimes and secondly, what needs to be done to realize this role. In other words, what should we expect from cognitive radio and how can we realize this expectation?

This contribution proposes to focus the coordination between the regulator, market players and the technology developers. The emphasis is on the role of the regulator. To obtain a common understanding of the role cognitive radio can play, this contribution starts with a short summary of the problems encountered in today's spectrum management regime. Subsequently, the role cognitive radio can play in the various solutions that have been proposed is discussed.

II. TODAYS SPECTRUM MANAGEMENT PROBLEMS

An important objective of radio spectrum management is to facilitate sharing of spectrum between various users and/or services, without causing too much interference to one another. Today's spectrum management is still largely based on the same principles that were agreed upon in 1927. In that year, administrations agreed to divide the radio spectrum in different frequency bands and allocate these bands for one or more services. Nowadays, there are in total some 40 different radio services defined in the international Radio Regulations, such as various forms of mobile communications, terrestrial broadcasting, fixed satellite services and radio navigation. The Radio Regulations are developed and adopted by the Radiocommunication Sector of the ITU (ITU-R) [6].

This separation of the various services over different frequency bands, together with a large range of regulatory, technical and operational provisions, will ensure that the services are compatible with another and the interference among various users is kept below an agreed value. The national regulatory agencies assign rights to use specific frequencies within the various allocations to specific users or usage.

This traditional spectrum management method, based on the avoidance of interference and with an emphasis on technical efficient use of spectrum, leads to a number of

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limitations: 1) significant parts of the spectrum are hardly used, and 2) the method is slow in responding to changes in markets and technologies.

The first point is validated through various measurements which have shown that at particular geographical locations large portions of the spectrum are hardly used or not used at all [7-8]. Although, the qualification when spectrum is not used is debatable, the measurements clearly show that there is ample room for more efficient use of the spectrum. The second point reflects the fact that the current spectrum management regime gives preference to the existing services, whereby new technologies have to adapt to the old technologies.

In an economic sense, there appears to be a paradox. The rights to the available radio spectrum are fully assigned, but significant part of radio spectrum remains unused in practice when considered on a time or geographical basis. Under the current command and control spectrum management model it is very difficult to make this unused spectrum available. What is required is a more dynamic form of spectrum use, i.e., Dynamic Spectrum Access (DSA) and a spectrum management regime that supports it [9].

III. THE USE OF CR IN THE REALISATION OF A PARADIGM SHIFT

In the recent past, two different approaches are already proposed to increase the flexibility and the efficiency in the use of radio spectrum. A model based on exclusive property rights and a model based on a commons for spectrum [10]. In these discussions, cognitive radio has been closely linked to the commons. Advocates of the commons see CR technology as an enabler to realize a radio spectrum commons [11]. Cognitive radio can not only play a role in the realization of a spectrum commons but also in a model based on property rights.

In this spectrum management regime with dynamic spectrum access both a spectrum commons and exclusive property rights have their place. CR technology can be used to realize this goal of dynamic spectrum access [9]. It can play an enabling role in a paradigm shift from static spectrum management to dynamic spectrum management which allows for dynamic spectrum access. However, a paradigm shift will not happen overnight. Such a shift may take 10 to 20 years. Regulators should have a clear view on how this shift towards dynamic spectrum management should be approached.

In the remaining sections of this paper a proposal is discussed to realise a dynamic spectrum management regime. It starts with a discussion of the international regulatory framework within which the introduction of more dynamic spectrum access will have to take place. The current activities at an international (regulatory) level are discussed and some proposals are made to further develop a common understanding of cognitive radio and the role cognitive radio can play for the various radio services. This contribution then follows with a step wise approach the national regulator can take to realize this goal. This step wise approach consists of three steps. Firstly, introduction of cognitive radio within the current regime, secondly, creation of a spectrum commons and thirdly, realization of a more fluid market for spectrum property rights.

IV. INTERNATIONAL SPECTRUM MANAGEMENT FRAMEWORK

The first question is if there is any international regulation in place that prohibits the use of cognitive radio. The short answer to that question is: No. Administrations that wish to implement cognitive radio have two different alternatives to do so.

Firstly, cognitive radio can be used under any service defined in the Radio Regulations, i.e., if the cognitive radio is used to deliver mobile communications, the cognitive radio can be treated in the same way as an ordinary mobile radio, and will be allowed to operate under the provisions for the mobile service. This means that the cognitive radio can use bands that are allocated to the mobile service as far as the (international) interference and sharing conditions are met.

A second option is to implement cognitive radio on a so-called non-interference basis. This means that the cognitive radio shall not cause harmful interference to, and shall not claim protection from, harmful interference caused by a station operating in accordance with the provisions of the Radio Regulations[1]. These provisions only apply for cross-border communications (and interference), since the Radio Regulations are an international treaty between countries. This means that it only concerns the relations between countries. Individual countries can adopt some or all of the allocated services of each band and they are allowed to deviate from the Radio Regulations as long as no harmful interference is caused to the services in other countries.

Although the introduction of CR technology is already possible under the current provisions of the Radio Regulations, further facilitation of the deployment of this kind of technology remains required. Some activities have already been started on a worldwide level within the ITU. On the agenda of the World Radio Conference 2012 (WRC-12) two items are related to this issue.

Agenda Item 1.2 is put on the agenda to facilitate more flexibility in the use of spectrum[2]. The objective of the agenda item is to develop concepts and procedures to enhance the Radio Regulations to meet the demands of current, emerging and future radio applications, while taking into account existing services and usage. Account should also be taken of the fact 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 [12].

The WRC-12 also has an Agenda Item (1.19) specifically on Software Defined Radio and Cognitive Radio[3]. This agenda

[1] ITU Radio Regulations, Edition of 2008, article 4.4.

[2] 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;

[3] 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.

item was a compromise, in part proposed by the European Administrations within the CEPT. The CEPT proposal was to create the possibility to designate a worldwide or regional harmonized frequency that can be used to provide local information about the use of spectrum, to inform cognitive radios, a so-called Cognitive Pilot Channel. As part of the negotiations at the World Radio Conference in 2007 this proposal led to the inclusion of agenda item 1.19 on the agenda of the WRC-2012.

ITU-R Study Group 1 (Spectrum management) is responsible for the work in preparation of both agenda items. ITU-R Study Group 1 already came to conclusion that cognitive radio systems are not a radio service as such and consequently do not need to be included in the Radio Regulations.

This means that the actions that may be performed in preparation of the WRC-12 are limited. Part of the original proposal is the possible designation of a harmonized Cognitive Pilot Channel (CPC). An assessment made by E2R in the 6th framework research program of the European Union revealed that there are various options foreseen for the implementation of the CPC. Such as a logical channel within an existing radio access technology (in-band CPC) or a dedicated radio channel which uses either a new radio interface or an adaptation of an existing technology (out-band CPC) [13].

There are two reasons not to take a decision about a harmonized dedicated CPC at the next WRC. First of all, industry does not have a clear view, at this point in time, on the need to designate a harmonized frequency for such purposes and the characteristics of such a frequency. Secondly, and more importantly, there is no need to harmonize a CPC through the Radio Regulations. This harmonization can be done by industry itself in the standardization arena.

However, there is another action ITU-R might perform. The ITU-R might make a detailed assessment of the introduction of CR technology in the various radio services and on the implication on the (international) interference and sharing criteria, if any. However, this will need a lot of time and effort, because it has to be dealt with on a case-by-case basis.

The reason for proposing this action is that there is still a certain reluctance by existing users of the spectrum on the use of CR technology. This kind of action, performed by the ITU-R, can help to obtain a common understanding about the possible use of this kind of technology and how to optimize the interference and sharing criteria to the latest state-of-the-art technology, if needed.

Study Group 1 already started some initial work to get a common understanding within the ITU-R by adopting a definition on Cognitive Radio Systems which is applicable for all radio services [14]:

"Cognitive radio system (CRS): 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."

The detailed studies on the possibilities for the introduction of cognitive radio technology will have to be performed by the Study Groups for the radio services under their purview.

ITU-R Study Group 5 (Terrestrial services) already started work on the possibilities for the introduction of cognitive radio in the mobile service and the operational implications of this introduction. It would be beneficial for the common understanding within the ITU-R if all Study Groups would perform such a study.

However, to realize the full potential of cognitive radio the radio will need to have dynamic access to a wide range of spectrum bands which might currently be designated for different radio services. Introduction of dynamic spectrum access is only possible if these exclusively designated frequency bands are opened up for other services and technologies. There is a need to enhance the international regulatory framework to allow for more flexibility in the use of radio spectrum. This task is performed by ITU-R Study Group 1 in the preparation of agenda item 1.2. Various options are under discussion to introduce more flexibility in the international regulatory framework.

Also within the European Union there are a number of activities to introduce more flexibility in the use of spectrum (WAPECS[4]) and to introduce secondary trading[5] of spectrum licenses. 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 (ECC) of the CEPT to perform a study on the introduction of cognitive radio in the television bands. This study has shown that the amount of white spaces in the broadcasting bands might be limited in Europe, see further section V. This study further indicates that the feasibility of the introduction of CR devices 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 for CR devices to be deployed in white space spectrum in order to facilitate the further development of CR technology in Europe. The current CEPT view is that any new white space applications should be used on a non-protected non-interfering basis [15]. The ECC has decided to investigate and define technical requirements for white spaces operation in the UHF broadcasting band (470-790 MHz).

The RSPG (Radio Spectrum Policy Group), an advisory body for the European Commission composed of experts of the member states, decided also to develop a report on cognitive radio. This Report will not give concrete proposals for the introduction of cognitive radio in the European Union. The

[4] 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 (RSPG05-102, available at http://rspg.groups.eu.int/rspg_opinions/index_en.htm).

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

Report is intended to provide an overview of the various aspects related to CR technology and to identify challenging regulatory issues which require further attention.

V. STEP 1: GAINING EXPERIENCE

As a first step towards Dynamic Spectrum Access, the introduction of cognitive radio can take place under the current regime. There are already some countries which have taken this step. The most notable example is the introduction of CR applications in the UHF broadcasting bands. This type of sharing is based on Opportunistic Spectrum Access. The cognitive radio identifies unused portions of spectrum that has been licensed to a conventional user and utilizes these so-called "white spots" without causing interference to the conventional user(s).

OSA devices will need to obtain knowledge of the radio environment. This knowledge can be obtained by sensing the radio spectrum in which it intends to operate or it can obtain this information from elsewhere, e.g., a beacon or a database. Opportunistic Spectrum Access further implies that there are strict rules defined for the use of OSA devices. These rules will have to be set by the regulator in such as way that a) the rules are strict enough to keep the interference to the conventional user(s) below an acceptable level, but b) these rules are not too tight as to enable the use of an opportunity to communicate, and c) be realistic, given the current state of technology, especially the sensing technology. These rules should also be designed in such a way that they promote fair sharing of spectrum resources among OSA devices. Finding the right balance will be extremely difficult. The regulator will have to do this in close cooperation with industry and market players.

As sensing is a technology that is still under development, the OSA devices may need to use other sources of information on spectrum usage, such as a database. Especially in spectrum bands were the use of the conventional user is rather static, a database can be of great help.

Given the fact that the current state of sensing technology is not sensitive and reliable enough, the best way forward might be to start experimenting with CR technology in a not too wide band with rather static users. This band could be selected by the regulator in close cooperation with industry. This cooperation will need to continue to keep the rules up to date. To obtain the required economies of scale, the best way forward might be to select a band on a regional basis, e.g., for the whole of Europe. The conditions are met in e.g. broadcasting bands but also in fixed satellite bands.

The United States has chosen the UHF broadcasting band as a first band to introduce OSA devices. It remains to be seen whether this band will have enough capacity for the application - broadband internet access - to be successful. A preliminary study performed in Europe, by CEPT on the use of the UHF broadcasting bands for Cognitive Radio based on spectrum sensing showed that the amount of white space is limited in Europe, because of the tight digital broadcast planning. Moreover, the TV band is already heavily used "opportunistically" for Program Making and Special Event services [15]. Hence the amount of available spectrum for white space devices is most probably less than in the U.S.

The use of the UHF broadcasting band for program making and special events, especially wireless microphones, poses a serious problem for OSA devices, which have great difficulty in sensing wireless microphones. A better alternative might be to start the introduction of Cognitive Radio in the UHF broadcasting band, whereby the wireless microphones themselves are OSA devices. Now already, the professional program maker will need to tune its wireless microphones manually to an available channel at the specific location where it is used. CR technology can be used to automate this tuning.

Another possibility is to take the fixed satellite band in the 3.4 – 3.8 GHz range to gain experience with CR technology. This band is recently opened for mobile communications with an emphasis on Broadband Wireless Access. However the BWA systems will have to take account of the satellite earth stations. The location of these fixed satellite stations could be put in a database to be referenced by the BWA systems. A big advantage of this band is that the use of the CR devices can be introduced in a more controlled situation whereby the device is under control of a licensed operator.

Nonetheless, no matter how good the sensing technology is, there will always be a likelihood of interference and there are no guarantees that the OSA device will be able to find a spectrum hole and obtain spectrum access for communication purposes. This implies that the services that can be offered by OSA are limited. Hence, OSA is expected to be limited to low power applications. Notwithstanding, opportunistic spectrum access can be used to share bands between licensed users and unlicensed short range devices in bands that were difficult in the classic scenario. A good example of this is the 5 GHz RLANs which share the bands with various radar systems.

The military also have shown great interest in opportunistic spectrum access but for a completely different reason. A true OSA device can use any given opportunity without the need for cooperation with the outside world. This makes it possible to communicate wherever they are without the need to disclose their location.

VI. STEP 2: CR AS ENABLER FOR A COMMONS

The second step in the use of cognitive radio could be the use of CR as enabler for a true spectrum commons. A spectrum commons is a dedicated spectrum band that can be used by everybody for any kind of application as long as some basic rules are followed. These rules are often referred to as radio etiquettes. These etiquettes consist of rules to reduce the interference among the users. These etiquettes include e.g. reduction of the power level to just the level needed, listen-before-talk, selection of a free channel and the use of modulation types that are robust to interference.

These etiquettes can be developed by the users themselves or by the manufacturers of the devices through standardization bodies. The task of the regulator will be limited. The main purpose of the regulator will be to assign a band for the realization of a commons. To reach economies of scale, the band could be harmonized on a regional basis. In the case of opportunistic access in the current regime these etiquettes will have to be developed to a large extend by the regulator in order to keep the interference to licensed users of the band beneath

an acceptable level; there is no need to do so in a spectrum commons.

Just as in the case of opportunistic spectrum access under the current regime, the spectrum commons is best suited for low power applications. The main reason is that every application should have fair access to the spectrum. Promising applications for a commons is for instance *ad hoc* networking, especially for in-house networking. The network topology of an *ad hoc* network will be highly dynamic. The dynamic character of cognitive radio gives a perfect match. OSA can be considered the radio counterpart of the computer notion of 'plug-and-play'. Once a radio is turned on, it senses its environment and attaches to the network nearby and communicates over any channel available.

This kind of sharing is not completely new. Various cordless telephones already sense the available channels to find a free channel. However, in that case there is only one application active in the band.

VII. STEP 3: A MORE FLUID MARKET FOR SPECTRUM

As part of the liberalization process of radio spectrum regulations, attention has been focused on a regime based on exclusive property rights. Property rights are considered to give much more flexibility to the owner in the use of the spectrum then the licenses of today. These property rights may also be traded. This market-based approach is built on the belief that spectrum is scarce and trading will ensure that the spectrum is used in the economic most efficient way. Trading is expected to occur if the spectrum right can be used more profitable by another user [16]. In order to facilitate trading, the regulator will have to set well defined usage rights in the market, with as few usage restrictions as possible.

Although secondary trading is allowed in a number of countries, in most countries the amount of trades is rather low. There appears to be a need to give the rightful owners of the spectrum incentives to start trading. There are two possible incentives that could be used to induce trading that involve the use of CR technology: real-time markets and easements.

First, cognitive radio can be used to enable involved parties to negotiate for spectrum on a real-time basis. At the moment spectrum is only traded for long periods of time. Trading based on a much shorter time basis may make the market for spectrum more fluid. In order to make this kind of trading possible, all barriers to instant trading will have to be removed. In most cases trading requires prior approval from the authorities before trading may take place, e.g., in the Netherlands every trade requires permission by the Minister. This 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 CR 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.

A real-time spectrum market can also be used to pool spectrum among various users. In this model every user of the pool makes use of CR technology. The various users can buy spectrum out of the pool for a short period of time, based on their actual demand for spectrum. This kind of set up guarantees that the spectrum will be used by the party that needs it the most, i.e. the party that offers the most attractive service to the end user [17-18].

If spectrum trading is introduced in a region, such as the European Union, such a spectrum pool can be used to ease border coordination. At the moment border coordination is based on equitable access to spectrum at both sides of the border. A spectrum pool can be used to divide the spectrum based on actual demand at both sides of the border.

A spectrum market can only function if information about the actual ownership of the spectrum property rights is readily available to facilitate trading. The regulator is ideally positioned to perform the task to keep a record of the ownership of these rights. Inclusion of monitoring information about actual usage of spectrum can further facilitate trading by giving more insights in the possibilities for secondary usage.

A second incentive might be to introduce easements in spectrum property rights. In other words, if a spectrum owner is in possession of spectrum that (s)he actually does not use, everybody is entitled to use this spectrum in an opportunistic way as long as the transmissions of the rightful owner are not subject to interference from this opportunistic spectrum access. This is an incentive which might prevent market players from hoarding spectrum.

VIII. NON SPECTRUM ACCESS ISSUES

To successfully introduce cognitive radio, there must be some assurance for the existing users of the spectrum that their usage will not be subject to (harmful) interference. This means that there is a need for a dispute resolution mechanism. To ease the settlement of disputes, it may be necessary to introduce a unique identifier for all cognitive radios that is send alongside with the message with all radio transmissions. This will require that regulators are actively involved in the development and/or standardization of CR technology [19].

A related point is that regulators will have to be very active in enforcement, especially in the start up phase of the use of CR technology. This will provide the necessary confidence to existing users of the band that all efforts are taken to prevent cognitive radios from inducing harmful interference and at the same time it will provide useful information to the industry to further develop their product.

IX. CONCLUSIONS

There is a huge potential for increased efficiency in the use of radio spectrum. Cognitive radio can be an enabler to improve efficiency following a step wise introduction towards

a dynamic spectrum management regime. The introduction of CR to realize a more flexible spectrum management regime based on a mixture of a spectrum commons and exclusive property rights may unlock the full potential of CR technology.

Opportunistic Spectrum Access is a good first step to gain experience with CR technology. Regulators should focus these experiments by selecting a band in close cooperation with industry. To reach economies of scale, this band could be selected on a regional basis, such as the European Union. Moreover, regulators could be involved in the standardization of OSA devices, to set realistic limits on CR technology that on the one hand protect existing usage but on the other hand are not too tight to hamper the introduction of cognitive radio. Regulators can also help by providing reliable and trustworthy information about the use of spectrum.

As a second step CR can help to create a spectrum commons in which the use of spectrum is fairly distributed among all devices. The regulator may need to cooperate with industry to select a spectrum band and a generic type of application to focus the standardization. It is proposed to start the introduction of CR technology in devices for ad-hoc networks, such as in-house networks.

As a third and final step, CR can be used to make the market for spectrum more fluid by the creation of a spot market and by creating an incentive to sell unused spectrum.

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