Cognitive Radio: How to Proceed?
An Actor-Centric Approach

Peter ANKER & Wolter LEMSTRA
Delft University of Technology
Faculty of Technology, Policy and Management

Abstract: This paper proposes to use an actor-centric approach to deal with the alignment between technology and the radio spectrum regulatory environment to facilitate the successful introduction of Cognitive Radio. The value of this approach is demonstrated through a review of historical cases of changes in radio spectrum regulations and the introduction of new (radio) technology. It proposes to apply this approach to explore Use Cases within a Community of Practice as the way forward for realising the necessary coordination between the actors involved to facilitate the successful deployment of cognitive radio and to realise – at the same time – the goal of improved utilisation of the radio frequency spectrum.

Key words: Cognitive radio, technology introduction, regulations, community of practice.

Already, nearly 15 years ago the concept of cognitive radio was proposed by Mitola and Maguire as a promising technology to deliver personalised services to the user through the most efficient radio resource available (MITOLA & MAGUIRE, 1999). Since then the concept of cognitive radio (CR) has been further explored and the importance of cognitive radio for efficient use of the radio spectrum has gained momentum (HAYKIN, 2005; RSPG, 2011b). Significant efforts are put into the development of various aspects of cognitive radio. Trials with the commercial use of cognitive radio are ongoing but are mainly limited to TV broadcasting bands. There is still no commercial use of cognitive radio.

One of the main reasons for the lack of practical and commercial use of CR technology is uncertainty about the regulatory model. Although there are possibilities to use cognitive radio under the current radio spectrum management regime, the current regulatory model is not conducive for dynamic access of spectrum made possible by cognitive technology. Regulatory provisions are needed to align the regulatory model with the new

capabilities of CR technology of flexible and more efficient utilisation of the radio spectrum (ANKER, 2010).

The dilemma that governments are facing since the liberalization is that prevailing policy suggests a technology neutral assignment of radio spectrum, while enabling the deployment of a specific technology, i.e. cognitive radio technology, is of public interest to achieve more efficient utilisation of the radio spectrum. It appears that in this light, regulation to allow the deployment of a specific type of CR technology in parts of the radio spectrum that would otherwise be underutilised or not used at all is justified (LEMSTRA, ANKER *et al*., 2011).

As CR encompasses a very versatile set of technologies, the subsequent challenge governments are facing is the choice among some of the more fundamental features of CR technology, such as the technology used to make a CR aware of its radio environment and the band in which the CR is allowed to operate. In making these choices there is a need to align the regulatory environment with a specific set of capabilities related to CR technology.

This paper proposes to use an actor-centric approach to deal with this issue of alignment. After all, cognitive radio is a technology to share spectrum among various users. The various users of the spectrum, the industry that has to develop the equipment and the government that has to provide the necessary regulations certainty will have to coordinate to come to a successful exploitation of CR. The actors involved in this coordination will all have their own objectives and incentives. Although this approach can be used more generally for spectrum management, this paper deals with this perspective only in the context of the alignment of technology with the regulatory environment for the introduction of Cognitive Radio technology.

This contribution is structured as follows. It starts with an explanation of the methodology to analyse the alignment between a new technology and the regulatory environment within which it will be introduced. Evidence for the relevance of this approach is found in the following section which analyses the coordination of radio spectrum use in the past and the development of radio spectrum regulations resulting from those coordination efforts. This approach is then applied to the analysis of the so far best known intended use of CR technology: white spot access in the TV bands.

Based on the results of this analysis, we propose in the final section the exploration of Use Cases within a Community of Practice as the way forward

for realising the necessary coordination between the actors involved to facilitate the successful deployment of cognitive radio and to realise – at the same time – the goal of improved utilisation of the radio frequency spectrum. This proposal is also based on experiences gained at the national level, in the Netherlands, with a Community of Practice related to cognitive radio.

The paper concludes with recommendations to implement this approach on the European level.

■ Two levels of alignment

Various contributions have been made on the need to adapt the regulatory framework to the new capabilities of cognitive radio (ANKER, 2010; RSPG, 2011a). While alignment between new technologies, such as CR, and the associated regulations is an important prerequisite, it is not enough to assure a successful introduction of CR. There are numerous examples on the introduction of new technologies were the necessary alignment between the technology and the regulations was in place but the market for the provisioning of products and services based on this new technology did not mature.

Our analysis of the underlying causes is that firms will only decide to invest in new products and/or services if they can expect a future return. These investment decisions are driven by three major considerations: (1) the prospective demand and willingness to pay for new products and/or services; (2) the magnitude of the investments required; and (3) the degree of risk or uncertainty involved.

The profile of the business case, in terms of depth of investment and the recovery period required, will influence the ability to obtain the necessary (external) funding. As such the business case is especially challenging for service provisioning that requires a huge, up front investment, e.g. an infrastructure roll-out to provide mobile telephony. In these cases the right to exploit the radio spectrum or any other infrastructure over a significant period of time and on an exclusive basis will contribute to the willingness of firms to invest as it reduces the uncertainty, which may make the business case more viable (LEMSTRA, ANKER *et al.*, 2011).

In setting up the institutional arrangements, governments will steer technology and possible business cases in a certain direction. OSTROM

(1990) showed that the specificities of the entry and authority rules will favour certain types of usage over other types of use. [1] This is also true the other way around; certain types of perceived usage will require particular entry and authority rules.

Hence, decisions made by governments on the market design and associated regulations will have an influence on the viability of possible business cases. For example, decisions made in spectrum policy on the amount of spectrum allocated, whether the spectrum is made available on a license exempt basis or not, the number of licenses issued, the roll-out and other obligations attached to the licenses and the award mechanism for the licenses (e.g. an auction or a beauty contest) will all influence the required investments and the possibilities to exploit a certain business case. This is quite well demonstrated by mobile communications (GSM) which could flourish under a strict licensing regime and Wi-Fi that could develop under a license exempt regime.

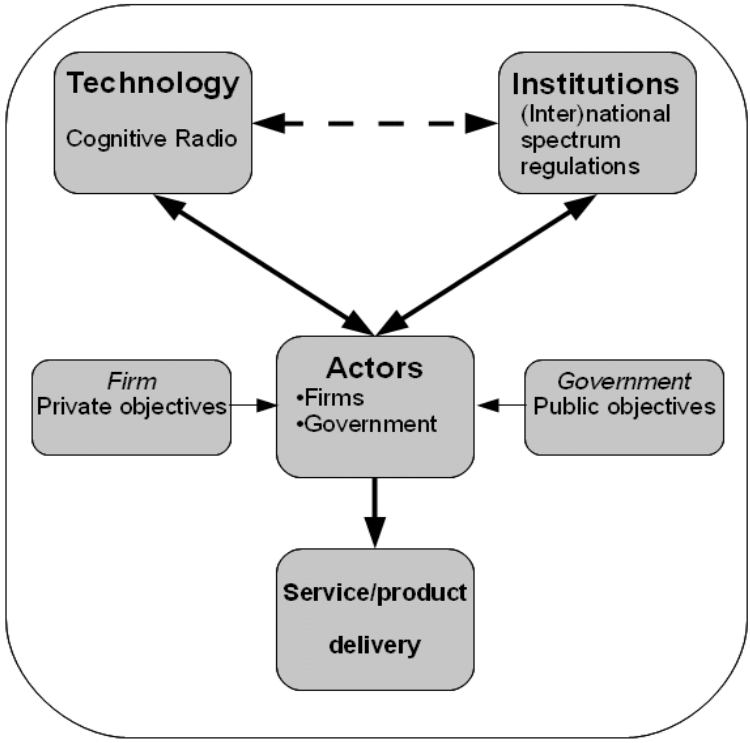
Governments will need to be very well informed to make the right decision in order to let the intended business case flourish. Lessons learned from the past seem to suggest that a too "pushy" approach from governments may be counterproductive and retard or stall technological development (HAUG, 2002). Governments will need to take decisions that are not only in line with their own goal(s), but also make it possible for entrepreneurs to realize their goals. After all, it is through the actions of the firms, individually and collectively, that the governmental goals will be realized.

This is illustrated in figure 1.

Two important actors in the case of the introduction of cognitive radio and its associated regulatory regime are the government and the entrepreneurial firm. These two actors have different objectives. In a somewhat simplistic view of the world, since the liberalization governments have, above all, an objective of economic efficient use of complex infrastructural systems.

[1] Ostrom made this observation in the investigation of common pool resources. As KÜNNEKE & FINGER (2009) show the problems associated to infrastructures are quite similar. They argue that infrastructures (including energy, communication, transport, and postal services) can be perceived as common pool resources providing essential services to society.

Figure 1 - Two levels of alignment



This is accompanied by societal objectives, such as universal service delivery, and in some cases also by industry policy. Governments rely on a market design and associated regulations to serve this mixture of economic and societal objectives. In the case of mobile communications, radio spectrum policy is used to create a market for mobile telephony. Specific auction rules may be used to allow new entrants and to influence the number of players on the market. Specific obligations are attached to the licenses to serve societal objectives, e.g. a coverage obligation.

Firms, on the other hand, have a completely different objective. They want to invest in (new) technology to develop products and services with the aim to maximize profit. The government and the firm are highly interdependent in the realisation of their objectives. The institutional arrangements that are set up will have to provide the certainty to entrepreneurial firms to invest in new technology and the exploitation thereof. If, as a result of profit maximisation considerations, firms decide not to use the system as intended, the government fails in realising its governance objectives.

Use of the new technology in such a way that both the government and the entrepreneurs can realize their goals is what we call a "sweet spot". A "sweet spot" is only possible if the use of certain technology and the associated institutional arrangements are aligned in such a way that both the intended business opportunity and the public objectives can be realized.

■ Evidence from the past

Evidence for the relevance of this actor-centric approach can be found in the coordination of radio spectrum use in the past and the development of radio spectrum regulations resulting from these coordination efforts. Until now, most of the advances that have been made in the coordination of radio spectrum usage were triggered by problems with a specific service. This will be illustrated in the three cases to be discussed in the following subsections. Each case is concluded with an assessment that places the observed coordination efforts in an actor-centric perspective on alignment.

Marconi and the birth of spectrum management

At the time of Marconi, spectrum was like an open and untouched pasture. Marconi was the first to enter this pasture to exploit this common resource. He started his business by selling wireless stations for use onboard of ships. As others also started to enter the business, he changed its strategy. He decided to sell not only the equipment but also wireless telegraphy as a service. For that purpose he set up a new company, the Marconi International Marine Communications Company in 1900. He built his own land based radio stations along the sea-trade routes on the shores of Britain, Ireland, Belgium, Italy, Canada and New Foundland. He trained his own radio telegraphists and placed them on all ships he equipped with a wireless radio station. These radio telegraphists, or marconists as they were called, were only allowed to communicate with Marconi wireless stations both land based and onboard other ships (ITU, 1965). By doing so, he created a very successful private business using a public resource, radio waves.

The behaviour of the Marconi Company led to governmental involvement in the use of radio waves. In 1902, Prince Heinrich of Prussia tried to send a courtesy telegram to President Roosevelt on his way back from a visit to the

United States. However, his ship was equipped with a German make wireless station. His radio telegraphist did not succeed to get through to the land based station which was operated by Marconi (BERTHO LAVENIR, 1991).

This event probably triggered the start of the international coordination of the use of the radio spectrum. Kaiser Wilhelm of Germany convened an international conference on the use of radio telegraphy in 1903. Representatives of nine countries gathered in Berlin for the *Preliminary Conference on Wireless Telegraphy* (KIRBY, 1995). Complete agreement was not reached, but the Conference drafted a protocol that served as the basis for a future international agreement on the use of wireless telegraphy. Among the articles of the protocol was the requirement that all coastal stations were required to exchange messages with all ships without distinction as to the system of radio being used (ROBINSON, 1985).

Although interconnection was the main problem on the table for the Conference, the reasons for the German government to convene the conference was broader and had also to do with industry politics. The refusal to interconnect by the dominant player, Marconi, made it harder for competitors, such as the German company Telefunken, to enter the market.

This preliminary Conference was followed in 1906 by the first Radio Telegraph Conference of Berlin. Twenty-nine countries adopted the first *International Radiotelegraph Convention*. Two important provisions of the Convention were firstly, a requirement to accept all messages from coastal stations and ships regardless of the system used and secondly, priority for distress calls. The annex to this Convention contained the first regulations governing wireless telegraphy. It was decided to use two wavelengths corresponding to 1000 kHz and 500 kHz for public correspondence.

The interconnection among radio operators was considered to be of public interest to support the safety of the man at sea, and the continuous availability of the service should be assured at all times. This need for rules of engagement and international coordination was strengthened at the next Radio Telegraph Conference which took place in London, shortly after the Titanic disaster in 1912 (CODDING, 1952; ITU, 1965).

Case assessment

To conclude, it was not the introduction of new technology – radio– as such that made it necessary to coordinate the use of the radio frequency spectrum and design new regulations. It was the use of this new technology by Marconi which triggered it. Marconi used this new technology in such a way that a conflict became apparent between his efforts of realising private objectives and the realisation of the newly identified public objectives.

Regulations were used as the institutional arrangement of choice to safeguard the public interests in the use of maritime communications. The regulations allowed for as much (business case) freedom as possible for the maritime service with the exception of a few standardised channels for the exchange of public messages and as an emergency signalling frequency. The outcome of the coordination efforts provided the support for a public service using a commercial incentive scheme, i.e. combining the public and private interests in a creative new combination.

Spectrum auctions

In 1959 economist Ronald Coase posed that the allocation of spectrum should be determined by the forces of the market rather than as a result of government decisions. Radio licenses should be bought and sold like any other scarce resource in our economy, such as land or labour. Rights should be assigned to individual users via an auction with the provision that these rights can subsequently be traded in an open market. The market should not only decide who will own the licence, but also what services will be provided. If a business model would fail, the right to use the radio spectrum could be bought by another operator with a different, more successful, business model or by a new entrant. The problem of interference could be solved by delimiting the rights. These delimitations should not only come from strict regulations but also as a result of transactions on the market (COASE, 1959). [2]

[2] Coase generalized this idea in his Noble prize winning easy "The Problem of Social Cost" (COASE, 1960).

Case assessment

At that time, Coase's idea was taken as a big joke by the FCC (HAZLETT, 2001). Nonetheless, the idea of a model based on trading of the property rights has since been discussed among economists [3], but a property rights model was only considered seriously by spectrum management authorities in the early 1990s. At that time a broad consensus in political thinking had emerged in support of deregulation; the introduction of market forces was considered for a number of infrastructures that had been heavily regulated in the past, including mobile telephony (HAZLETT, 2001).

Deregulation changed the set of objectives pursued by the government. One of the new objectives pertaining to mobile communications became the creation of a market for radio spectrum usage rights for mobile communications. The institutional change that was already proposed in the late 1950's by Coase perfectly fitted the newly defined objectives. Hence, various countries chose to auction the spectrum rights for mobile telephony (CAVE, DOYLE *et al*., 2007). [4]

Wi-Fi and license exempt use of spectrum

In 1942 a new technology was invented: spread spectrum. [5] Spread spectrum is a technology whereby the signal is intentionally spread over a much wider bandwidth than strictly necessary. Spreading makes the signal inherently more resistant to interference. Until 1981 this technique remained classified as military technology because a spread spectrum signal is also difficult to intercept and hard to jam. It was not allowed to be used in civil applications (ANKER & LEMSTRA, 2011). On the other hand, there was also no reason to use it. The institutional setting for the use of spectrum was based on exclusive rights. There was no need to use a technology that

[3] See note 6 of Baumol and Robyn for an overview of references (BAUMOL & ROBYN, 2006).

[4] New Zealand was probably the first country that experimented with the definition of long-term, tradeable property rights to Radio channels, and the first country to auction these rights to the highest bidder (MUELLER, 1993).

[5] In that year, a patent was granted to the actress Hedy Lamarr and composer George Antheil on a "secret communication system" through the use of a spread spectrum technology called Frequency Hopping. See e.g. LEMSTRA, HAYES *et al*., 2011, and the references therein for more information on the history of spread spectrum.

made communications more robust to interference at the expense of the use of a wider range of frequencies.

This changed in 1985. In that year, the FCC decided – for the purpose of deregulation – to allow the use of spread spectrum for communication purposes in three bands designated for Industrial, Scientific and Medical (ISM) applications (900 MHz, 2.4 GHz and 5.8 GHz) (FCC, 1985). These where bands that could be used without the need for a license but applications had to be limited in output power and had to tolerate interference from other users, as well as from ISM applications.

The (for civil applications) new technology of spread spectrum and the introduction of regulations to support it triggered NCR Corporation to use spread spectrum for a nagging issue from their sales force; the lack of 'mobility' in their cash register product portfolio. Through their involvement in IEEE, as a leading standards developing organization, NCR became the de facto leader in the IEEE 802.11 Working Group resulting in a highly successful Wireless-LAN standard (LEMSTRA, ANKER *et al*., 2011).

Case assessment

Since then, specific frequency bands are assigned on a license-exempt basis for specific types of communication equipment. These bands can be used as long as some specific rules (e.g. maximum power level and usage restrictions) are obeyed. These unlicensed bands have attracted new types of applications where the communication is generally short range and the devices are numerous. The spectrum commons provides the lowest possible barriers to the use of the radio spectrum. However, not all types of services (e.g. long-distance communication, broadcasting) and applications fit the operating conditions in a commons. Nonetheless, it is great example of shared use of the radio spectrum. It is up to the radio equipment manufacturers to optimise the business case. The Wi-Fi case shows the power of industry actors effectively aligning their objectives with the public objective of efficient use of the radio spectrum, including graceful degradation of service levels under increasing load conditions and avoiding interference. This alignment was triggered by an industry actor with a compelling business case.

Conclusions

The review of the historical cases has provided evidence of the value in applying an actor-centric approach to the process of alignment. Each of the cases described above were triggered by problems related to private actors on the one hand and public actors on the other hand pursuing the realisation of their private, respectively public objectives.

A successful outcome can be concluded when private and public actors can realise their objectives simultaneously, by designing a business opportunity in theory and allowing it to be transformed into a viable business case in practice.

Having established this actor-centric perspective as a valuable instrument in achieving alignment between technology and institutions in the past, we will now apply this perspective to a case of which its resolution lies in the future. It concerns the introduction of cognitive radio technology. First we will analyse the intended application of CR in the so-called white spots in TV-bands. By applying an actor-centric approach, we will conclude a misalignment between technology and institutions and hence predict a failure of policy. Secondly, we propose and discuss an alternative approach to achieve alignment, using the actor-centric perspective in a community-of-practice environment.

■ Analysing the case of white spot access in the television broadcasting band

The first application for CR that was put forward was the use of white spots in the TV broadcasting bands. The US Federal Communication Commission (FCC) made these white spots available for unlicensed broadband Internet. Its intended use is, above all, to provide more affordable broadband deployment in rural areas (FCC, 2010).

In this case CR technology is intended to share the TV-band with the legitimate primary users, the TV broadcasting stations and low power auxiliary service stations (notably wireless microphones). Given the latter, it is understandable that the FCC removed sensing from the original requirements and took alternative measures to guarantee access to spectrum for wireless microphones and to prevent wireless microphones from being subjected to interference from CR devices. First of all, at the

current state of technology sensing is not sufficiently reliable. More importantly, to prevent interference to the primary user, the output power of the CR device should be low relative to the primary users. These primary users are not only TV broadcasting stations but also these low power wireless microphones. Restriction of the output power of CR devices to a level that is low compared to the wireless microphones would have been detrimental for the business case of rural broadband access.

In taking the perspective of the private actor, the first question to be asked is: Why is there no service provided at the moment? There certainly is no scarcity of radio spectrum; the 2G/3G bands are under-utilised in these rural areas. The main reason appears to be that the costs to provide the service are too high in relation to the willingness to pay for the provided service.

The second question to be asked is: How will the business case for CR improve the situation? For the business case to become viable either the willingness to pay for the CR enabled services has to become higher or the cost reduction needs to be greater than the additional costs associated with the new (more capable and sophisticated) cognitive technology. Combined they need to bridge the gap between the provision of services based on the current technology and the current willingness to pay.

Under the FCC white spot ruling, rural broadband access is made more feasible due to the fact that a lower frequency range is made available, which extends the coverage area of a base station, compared to the existing alternatives to provide the service. However, existing mobile networks operate at frequencies that are just above the television band. This means that the gains of using a lower frequency are very limited. [6] Therefore the business case for deployment of a wide area network in rural areas based on white spot access remains highly questionable. It is much more likely that white spot access will be used to provide localised access to the Internet at specific backbone nodes. This is a business case that is comparable to Wi-Fi hot spot access, although over larger distances.

The next question is whether the capacity that can be supported by white spot access is high enough to support the demand of the users. In areas

[6] As the use of white spots is considered to be free of charge, this represents a benefit compared to the business case for existing 2G/3G deployments, which may be subject to the recovery of a hefty auction fee. However, in serving the rural areas, economists will consider the auction fee as sunk costs and will calculate the business case on marginal costs.

where the required demand for capacity is bigger, the coverage area of the base station may have to be made smaller. This conflicts with the reasoning to make these lower frequencies available. This means that the business case will be restricted to areas with a population density below a certain limit. This limit will be lower if the demand per customer is higher. It remains to be seen whether the assigned band will have enough white spot capacity available for the intended application – broadband Internet access – to support a successful business case.

Studies performed on the use of the UHF broadcasting bands for cognitive radio in Europe showed that the amount of white space is limited, because of the tight digital broadcast planning. Moreover, the TV band is already heavily used "opportunistically" for Programme Making and Special Event services, especially wireless microphones. Furthermore, the upper part of the band has been made available as a harmonised subband for mobile use(ECC, 2008). Hence, the amount of available spectrum for white space devices is far less than in the United States (ECC, 2008; BEEK & RIIHIJARVI, 2011). This amount may be even further reduced in Europe through the decision of the World Radio Conference 2012 to extend the possibility of the use of the TV band for mobile services to the 694-790 MHz band.

To conclude, the white spot access regulations appear to be a technological fit instead of a BuC fit, driven by the regulator to realise a social goal. Whether the BuC is viable remains highly questionable. It would explain why the intended service providers are relatively absent in the standardisation activities and other discussions around white spot access in the TV band. Moreover, it may explain why there is, as yet, no viable business model for the commercial operation of a database in support of sharing the spectrum with wireless microphones.

■ Next steps: finding a sweet spot for Cognitive Radio

Although there are possibilities to use cognitive radio under the current radio spectrum management regime, there is still no compelling business case apparent. When governments want to enable the use of Cognitive Radio, they will have to make certain choices on the specific CR technology and the regulatory environment. The choices will have an influence on the business opportunities for CR. The specific CR technology and the

regulatory environment that is chosen should match. The business opportunities that are enabled by the specific choices should serve the objectives of both the firm and the government.

To assure development and deployment of CR technologies, it is worthwhile to review potential product-market combinations where CR functionality provides a 'value add' and determine whether these cases are attractive enough to be taken up by the industry as first applications of CR, as first steps on the road toward broader deployment of CR technologies.

The government can facilitate this process through the initiation of a platform in which the equipment industry, the service providers and the government itself closely cooperate with the aim to find a "sweet spot". This sweet spot serves as a catalyst to both the private sector and the government; for the private sector to develop products and services based on cognitive technology and for the government to realise the ultimate goal of more efficient use of spectrum.

The RSPG (Radio Spectrum Policy Group) have already recommended creating a platform to allow researchers, academia, manufacturers, operators, service providers and regulators to coordinate research activities. According to the RSPG, this platform could build upon already existing platforms with comparable purposes, notably COST-TERRA (RSPG, 2011a). This notion of the RSPG on COST-TERRA is quite relevant. The discussions within COST-TERRA are very fruitful, but are rather academic in nature.

COST-TERRA proposes a new licensing concept to promote spectrum sharing between licensed primary users and unlicensed secondary users. This pluralistic licensing model encompasses the award of licenses under the assumption that opportunistic secondary spectrum access will be allowed, and that interference may be caused to the primary user with parameters and rules that are known to the primary user at the point of obtaining the license. Pluralistic licensing has the benefit that the primary user can be given an incentive to accept sharing with other users (HOLLAND, DE NARDIS *et al*., 2012).

Although the concept is very promising, it needs further study in a number of areas. Among these are firstly, pricing schemes and other incentives for the primary user to make unused spectrum available and secondly, combinations of primary and secondary services that can benefit from this licensing model.

As the discussion within COST-TERRA is too academic, discussions will benefit from an extension of the platform to a Community of Practice that involves all stakeholders. In order to do so, the participation should be widened in two directions. Firstly, participation should be extended to service providers and users of spectrum. This may strengthen the discussions on the incentives for primary users and possible business cases for the primary and secondary users. Secondly, participation should be widened to industry players to incorporate the ideas and solutions in the development of new technology and technology standards.

In this platform all participants should work together with the national spectrum regulators to find and enable a sweet spot. A sweet spot needs a fit between a specific CR technology, an initial business opportunity and an associated regulatory regime. The regulators can enable this sweet spot on a European level by specifying the necessary and specific regulatory regime in a European decision and/or European recommendation.

This requires participation at the working level. Intended participation is largely the same as those of the workshops that were organised by ERO, the national spectrum regulators as organised within the ECC, in association with COST-TERRA and the industry actors as organised within ETSI.

There is already some experience with a Community of Practice (CoP) related to CR in the Netherlands (CRplatform.NL). This CoP aims to identify the uncertainties surrounding potential deployment areas of CR and through discussion among stakeholders to find ways and means of addressing and reducing these uncertainties; thereby facilitating the successful deployment of CR-based products and services. This initiative evolved from the regular interaction between representatives of the Ministry of Economic Affairs, responsible for radio spectrum policy and the industry.

In addressing uncertainties and finding ways towards resolution, the CoP organizes workshops to explore potential application areas of CR, the so-called Use Cases. The following application areas have been the topic of a Use Case Workshop during the past two years: Container Terminals in the Rotterdam harbour; Special Events captured by broadcasting organisations; Public safety communications by the police force; High intensity communications at airports; and CR facilitating Domotica. Each Workshop brought together potential users, potential suppliers, policy makers and regulators, as well as academic researchers.

In these explorations, one of the first questions to be asked is: what are the gains from the use of this new technology, and are these gains high enough to cover the increased cost of the use of this technology compared to the alternatives? The Use Cases as discussed suggest that CR functionality adds most value in situations that are typically niche applications or are a small segment of the overall market for wireless technologies. One of the reasons is the fact that CR technology is basically a technology to (more efficiently) share the radio spectrum. As CR provides additional functionality compared to current radio technology this will come at increased costs, at least initially. Situations of high intensity demand are expected to provide the highest willingness-to-pay by the end-users.

Each Use Case discussed so far addressed a specific market segment, or even a market niche. Hence, potential market volumes are (relatively) low to moderate, which impacts the viability of the CR business case. Nonetheless, the Use Cases also show similarities, in particular if CR-based solutions are considered as variants of a more generic CR-platform solution. Especially the combined business case of the communication needs of the public safety services in case of an emergency and the registration of this emergency by news gathering organisations seems to be logical and promising. This became apparent during the Use Case Workshop on Special Events, as during (ad-hoc) events the needs of public safety and broadcasting converge at the same place and time. The type of communication needs show a strong parallel. Hence, pursuing solutions for one group of actors (broadcasters) should best be done cognisant of the needs of the other group of actors (public safety).

This example shows that finding a sweet spot for CR might be easier if the solutions for one group are similar to the solutions for the other group, at least on the platform level. This increases the addressable market and hence the viability of the business case.

Investigations on the possibilities for a combined platform are ongoing. The unresolved issue is the very localized capacity needs during (ad-hoc) events. What remains to be better understood is the capacity issue and a perspective whether under these circumstances there are enough 'white spots' that may be exploited. The use of a hybrid or reconfigurable radio that can use multiple communication platforms is expected to provide some relief.

Exploration of Use Cases further disclosed hybrid radio as a logical first step towards full cognition in the roll-out of new products and services.

Experimentation with hybrid radio in the Rotterdam harbour area revealed that a hybrid radio that senses which mobile networks have coverage at the specific location and automatically selects an available network can greatly increase the availability of mobile services. The experiment revealed that the availability of mobile services can be increased to 99% as opposed to an availability of only 85% if a single mobile network is used. The availability can reach virtually 100% if the hybrid radio also includes satellite radio for locations where no mobile network has coverage.

The Use Cases further show that a viable business case for CR will require economies of scale. This extends the need for coordination to the European level, if not at the global level. Such coordination may still be left to be organized by the industry actors. However, the use case experience suggests that lacking a very compelling business case the likelihood that industry actors will take the lead is expected to be low. The discussions within the CoP confirmed the role of the regulator to facilitate this search for a sweet spot.

■ Conclusions and recommendations

For successful introduction of cognitive radio, it is not enough to align the specific CR technology with the regulatory environment that is chosen. The business opportunities that are enabled by the specific choice should serve the objectives of both the entrepreneur and the government.

Exploring Use Cases can be a good instrument to bring all interested parties together and in an explorative modus to find and enable a "sweet spot" for the use of new technology. A "sweet spot" is enabled if the institutional arrangements and the characteristics of the new technology are aligned in such a way that an intended business opportunity can be realized.

This exploration can take place in a Community of Practice. The national spectrum regulator is in a perfect position to initiate and facilitate such an exploration in a Community of Practice.

An initial exploration of possible business cases revealed that the type of CR technology to be used and the appropriate regulatory regime to support it depend on the specifics of the intended business case and the specifics of the users with which the bands will be shared. When a viable combination is found, the national spectrum regulator should set up the specific regulations

to facilitate the CR deployment and thereby make an important step towards a more efficient utilisation of the radio spectrum.

It is recommended to introduce this Community of Practice for Cognitive Radio on a European level. Such a Community could make use of, and build upon, the already existing platform COST-TERRA. In order to encompass all interested stakeholders, this platform should be extended with representatives of service providers, user communities and industry players.

References

ANKER, P. (2010): "Does Cognitive Radio need Policy Innovation?", *Competition and Regulation in Network Industries*, 11 (1): 2-26.

ANKER, P. & LEMSTRA, W. (2011): "The governance of radio spectrum: licence-exempt devices", In W. Lemstra, V. Hayes & J. Groenewegen (Eds), *The Innovation Journey of Wi-Fi: The Road to Global Success*, Cambridge: Cambridge University Press. pp. 288-330.

BAUMOL, W. J. & ROBYN, D. (2006): *Toward an Evolutionary Regime for Spectrum Governance - Licensing or Unrestricted Policy*. AEI-Brookings Joint Center for Regulatory Studies.

BEEK, J. V. D. & RIIHIJARVI, J. (2011): "UHF white space in Europe – a quantitative study into the potential of the 470-790MHz band", IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN). Aachen.

BERTHO LAVENIR, C. (1991): *Great discoveries: Telecommunications*. Geneva: International Telecommunications Union.

CAVE, M., DOYLE, C., *et al*. (2007): *Essentials of Modern Spectrum Management*. Cambridge: Cambridge University Press.

COASE, R.
- (1959): "The Federal Communications Commission", *Journal of Law and Economics*, 2 (October): 1-40.
- (1960): "The Problem of Social Cost", *Journal of Law and Economics*, 3 (1): 1-44.

CODDING, G. A. (1952): *The International Telecommunication Union. An experiment in international cooperation*. Leiden: Brill.

ECC (2008): *CEPT Report 24: 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)*. Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT).

FCC (2010): *FCC 10-174 Second Memorandum Opinion and Order In the Matter of Unlicensed Operation in the TV Broadcast bands (ET Docket No. 04-186) and*

Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band (ET Docket No. 02-380). Washington: Federal Communications Commission.

HAUG, T. (2002): "A commentary on standardization practices: lessons from the NMT and GSM mobile telephone standards histories", *Telecommunications Policy*, 26 (3-4): 101-107.

HAYKIN, S. (2005): "Cognitive radio: brain-empowered wireless communications", *IEEE Journal on Selected Areas in Communications*, 23 (2): 201-220.

HAZLETT, T. (2001): "The Wireless Craze, The Unlimited Bandwidth Myth, The Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's 'Big Joke': An Essay on Airwave Allocation Policy", AEI-Brookings Joint Center Working Paper No. 01-2. SSRN: http://ssrn.com/abstract=286932.

HOLLAND, O., DE NARDIS, L., *et al*. (2012): "Pluralistic licensing", IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks.

ITU (1965): *From Semaphore to Satellite*. Geneva: International Telecommunications Union.

KIRBY, R. C. (1995): "History and Trends in International Radio Regulations", IEE International Conference on 100 Years of Radio.

KÜNNEKE, R. & FINGER, M. (2009): "The governance of infrastructures as common pool resources", Workshop on the Workshop 4. Indiana University Bloomington, June 3-6, 2009.

LEMSTRA, W., ANKER, P., *et al*. (2011): "Cognitive Radio: Enabling technology in need of coordination", *Competition and Regulation in Network Industries*, 12 (3): 210-235.

LEMSTRA, W., HAYES, V., *et al*. (2011): *The Innovation Journey of Wi-Fi: The Road To Global Success. Cambridge*. Cambridge University Press.

MITOLA, J. & MAGUIRE, G. Q. (1999): "Cognitive radio: Making software radios more personal", *IEEE Personal Communications Magazine*, 6 (4): 13-18.

MUELLER, M. (1993): "New Zealand's revolution in spectrum management", *Information Economics and Policy*, 5 (2): 159-177.

OSTROM, E. (1990): *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.

ROBINSON, J. O. (1985): "Spectrum Management Policy in the United States: An Historical Account", OSP working paper 15.

RSPG

- (2011a): *RSPG10-348 Final "RSPG Opinion on Cognitive Technologies"*. Brussels.
- (2011b): *RSPG11-392 Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches*. Brussels.