

## Spectrum Management and Cognitive Radio in Ireland

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### 1 Introduction

Engineers have historically understood channel capacity in terms of bandwidth and the operation of Shannon's Law which provides a formula for the maximum error-free transport capacity on a communications link.

Software-defined radio (SDR) allows the adoption of new communication technologies by means of simple software upgrades, rather than replacing expensive hardware. These upgrades can be accomplished by direct wireless download. This reduces the cost of upgrading and allows immediate compatibility to be achieved among devices used by different agencies and organizations.

This has the possibility of more flexibly managing spectrum by time, frequency, space, power and coding of the transmitted wave form.

Cognitive radios (CR) are subset of SDRs. They are controlled by powerful microprocessors which have been programmed to analyze a number of the radio channel parameters. They have the ability to adapt the modulation technique, output power and frequency used to the results of the analysis performed. They provide the possibility of being re-programmed dynamically to accommodate different regulatory structures by adjusting frequencies, bandwidth, and directionality. This allows more effective use of expensive to replicate hardware and infrastructure.

Unfortunately the benefits of replacing policy-based spectrum management with device-centric spectrum management can be realized only when *all* devices in a frequency band are cognitive such that they can negotiate with each other. For this reason there is a continued need to co-ordinate with legacy systems in order to mitigate interference. (Lansford, 2004).

In the case of cognitive radio there is a need for national and international regulatory bodies to appreciate the emerging mechanisms for configuration management of this type. This will involve the monitoring of software/hardware network configurations and terminal control (e.g. automatic shutdown in the case of incorrectly configured equipment).

The extent of external control and where this control should be situated will not be straightforward given the many vested interests ranging from operators, users, national governments, handset manufacturers and software providers. There is therefore a clear imperative for extensive collaboration in these matters.

This paper discusses the approach taken by the Commission for Communications Regulation, Ireland (ComReg) to licensing SDR applications. The adoption of a new licensing regime for radio service and technology trials is discussed. One of the key features of the scheme is that it allows innovative new wireless services to be offered to

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the public on a trial basis. This will allow new service concepts to be tested in a realistic environment at an early stage of development, ensuring that subsequent commercial offerings are properly tailored to meet the needs of users.

## 2 Developments in cognitive Radio

Cognitive Radio, like artificial intelligence has no agreed upon definition. The lack of consensus on what CR is and is not or whether we should discuss instead cognitive networks or systems is the source of considerable regulatory confusion. For the purpose of this paper it is defined as “a transceiver that is aware, adaptive, and capable of learning from experience” (Le et al. 2007, p. 1037).

Mitola describes six processes which together allow a cognitive system to ‘employ model based reasoning to achieve a specified level of competence in radio-related domains’. This is also an useful analytical point of departure. (Mitola, 1999)

These processes are:

1. Observing the outside world.
2. Orientation of the system.
3. Planning one or more courses of action.
4. Deciding upon a course of action.
5. Acting to influence the operation of the system.
6. Learning from experience.

The possibility of a software and hardware architecture that is aware, adaptive and capable of learning holds much promise for solving the technical problems of cross-layer optimization, spectrum access and interoperability.

The facilitation of access is (or should be) the goal of spectrum management assuming that the mutually harmful relations between users can be mimised. It is the discussion of how this is to best accomplished that the regulatory *Real Politik* of radio spectrum decision-making begins to emerge. This is because of the continued need to co-ordinate with legacy systems.

So leaving aside government use of spectrum for the moment, the regulatory problem is how to stimulate users in the commercial context with exclusive rights holders of radio frequencies to adopt spectrum-efficient radio technologies, when it is not in their economic interest to do so. This is to be done while providing the appropriate incentive to private firms to invest in costly R&D as well as infrastructure roll out.

Traditionally, this has been accomplished through spectrum licences. As cognitive radios are expected to operate at frequencies that were originally licensed to incumbent radio services, in addition to available frequencies in unlicensed bands, understanding how radio licences have operated historically are a key aspect to reform. The next section deals with how individual licences operate within the Irish regulatory framework for spectrum management.

### 3 Irish regulatory framework for spectrum management

One of the Commission for Communications Regulation's (ComReg's) functions pursuant to the *Communications Act 2002* is the compliance of radio equipment.<sup>26</sup> This is achieved in large part through the issuance of radio licences. Operators in possession of a 'wireless telegraphy apparatus' are required to obtain an authorized licence<sup>27</sup> unless the apparatus in question is subject to an exemption order.<sup>28</sup> In this latter case the apparatus is 'licence-exempt' and need only adhere to specified order conditions.<sup>29</sup>

The licensing framework as established by the 1926 Act largely focused on apparatus and individual rights of use. Technical restrictions were specified assuming a certain application or technology. The technical limitations of these devices were subsequently specified in the licence conditions.<sup>30</sup> In this context it was relatively straightforward to predict and detect interference however this also created an institutional framework that was less responsive to technological development.

There was widespread agreement in response to a recent consultation conducted by ComReg that the focus of regulatory attention in this area should shift from the use of radio equipment to spectrum usage.<sup>31</sup> This would *inter alia* better take into account the increased availability and diversity of radio communications equipment.

A licensing framework based on technologies deployed within a given band rather than the licensed use of particular equipment would facilitate the delivery of electronic communications services, since operators would have greater flexibility with respect to the technology they could deploy within their awarded band.<sup>32</sup>

Achieving this end would seem to involve not restricting licensees to specific technologies or applications as a condition of their licenses. Since interference concerns remain as pressing as ever, the licensee would still be subject to usage constraints. But the objective would be to confine the licensee to specified emissions that could be radiated within the licensee's awarded band. Assuming these conditions were met the licensee would be free to deploy any technology or service.

In this regard, the view taken by ComReg is that "appropriate provision should be made for spectrum use rather than maintaining the Wireless Telegraphy (WT) licensing framework of licensing apparatus."<sup>33</sup>

The position taken in this regard would suggest that a transition to a new spectrum licensing regime could only be accomplished by departing significantly from the 1926

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<sup>26</sup> s. 10 (e) Communications Act 2002.

<sup>27</sup> s. 3(1) *Wireless Telegraphy Act 1926*.

<sup>28</sup> *Ibid* s. 3(6)(a).

<sup>29</sup> Regulation 9(2) Electronic Communications (Electronic Communications Networks and Services) (Authorization) Regulations 2003 S.I No. 306 of 2003.

<sup>30</sup> s. 6 *Wireless Telegraphy Act 1926*.

<sup>31</sup> ComReg (2003) Response to Consultation "Future of Electronic Communications Networks and Services – Rights of Use for Radio Frequencies," Doc. 03/39.

<sup>32</sup> *Ibid*.

<sup>33</sup> *Ibid* at p.10.

Act. An overhaul of the WT Act 1926 has been on the agenda of the Department Communications Energy and Natural Resources (DCENR) since 2001.<sup>34</sup>

### 3.1 Ireland and the EU

In the context of spectrum management no country, even Ireland, is an island. All EU member states have *inter alia*, made commitments to the development of an internal market that facilitates the free movement of goods and services with the objective of developing trans-European networks.<sup>35</sup> But as all member states have developed their own governance (and thus licencing) regimes there is a strong need to streamline this process.

One of the chief ways of achieving this type of uniformity amongst the licencing regimes of the various member states is through adherence to the principle of technological and service neutrality. As the success of any given future technology or service cannot be known in advance, the approach taken in the EU regulatory framework to facilitate technological development has been to create a regulatory environment that is ‘technology neutral.’ This term implies that regulations must neither impose nor discriminate in favour of the use of a particular type of technology.<sup>36</sup>

Although service neutrality is not defined in the *Framework Directive* this refers to the taking of proportionate steps to promote specific services where this is justified.<sup>37</sup>

However, while seeking to introduce flexibility of any kind into the licencing regime, there are the technical assumptions associated with interference constraints and spectrum efficiency. The assumptions made in the decision making process invariably reflect judgements concerning technologies that are going to be deployed within that band. The main objective of member states in this context is seen as ensuring a coherent authorization regime, in spite of differences in applications and spectrum conditions of use.

### 3.2 Difficulties in seeking to implement ‘technology neutral’ radio licenses - harmonization or flexibility?

EU policy proposals on technology neutrality are somewhat confusing in that they seem to further both a flexible licensing regime at the EU level and harmonization at the same time.<sup>38</sup> This is due to the fact that what is to be agreed upon by EU member states with respect to the identified bands is not stated explicitly.

Clarity in this regard is afforded by recalling the distinction that exists between the technical and non-technical management of radio spectrum. Technical management within the EU includes harmonization and allocation. This should reflect general policy

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<sup>34</sup> DEMNR “Wireless Telegraphy Act” available at <http://www.DEMNR.gov.ie/Communications/Business+and+Technology/WT+Act/WT+Act.htm>

<sup>35</sup> For discussion see R. Akalu, “EU spectrum reform and the Wireless Access Policy for Electronic Communications Services (WAPECS) concept” *info* VOL. 8( 6) 2006, pp. 31-50.

<sup>36</sup> Directive 2002/21/EC of the European Parliament and of the Council of 7 March 2002 on a common regulatory framework for electronic communications networks and services. Recital 18.

<sup>37</sup> *Ibid.* The example of a specific service that would not necessarily be subject to service neutrality is digital television.

<sup>38</sup> See Radio Spectrum Policy Group (2005) Opinion on Wireless Access Policy for Electronic Communications Services (WAPECS) RSPG05-102final, available online at [http://rspg.groups.eu.int/doc/documents/meeting/rspg8/rspg\\_05\\_102.pdf](http://rspg.groups.eu.int/doc/documents/meeting/rspg8/rspg_05_102.pdf).

principles identified at the Community level. Non-technical management refers to the spectrum licensing procedures and award processes<sup>39</sup> which take place at the national level.

In the context of spectrum management in the technical sense, harmonization relates primarily to *de jure* harmonization – i.e. mandatory measures facilitating the co-existence of different radio equipment or networks within a given band. *De jure* harmonization measures promote economies of scale by granting investment certainty and facilitating interoperability. This type of harmonization in relation to the deployment of pan-EU services would require a *Directive* or *Decision* as such a measure could not be imposed unilaterally by any one member state.<sup>40</sup>

*De facto* harmonization in contrast, occurs where industry participants adopt similar technology uses in a given frequency band in response to market forces or commercial imperative without such use being imposed by regulators.

The concept of flexibility in the context of non-technical spectrum management can be understood as “increasing the ability of the spectrum regulatory framework to facilitate and adapt, in a timely manner, to user requirements and technological innovation by reducing constraints on the use of spectrum and barriers to access spectrum.”<sup>41</sup>

Increasing user access to spectrum and reducing regulatory constraint relates primarily to licencing procedures and award processes. A necessary implication of the departure from the ‘command and control’ model is that the relaxation of regulatory conditions entails a diminution of administrative discretion since the process involves the granting of increased rights to licencees who will in turn seek to exercise these new rights fully.

As all stakeholders seek to maximize the degree of flexibility with respect to spectrum currently held or sought, they will tend to use the term flexibility to support contradictory objectives.<sup>42</sup>

### 3.3 Spectrum Trading and spectrum markets

It is important to understand technological neutrality in the context of spectrum trading and the greater use of market process to assign spectrum usage rights.

For primary assignment of spectrum it is commonly asserted that spectrum auctions provide a “mechanism for the regulator to ensure that any newly released spectrum into the market is acquired by those who value it the most.”<sup>43</sup>

This ‘mechanistic’ approach to spectrum assignment is however premised on a model of ‘rational’ bidders operating in a perfectly competitive market. In order to understand how spectrum auctions can be best used in spectrum management, it is necessary to

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<sup>39</sup>Decision No 676/2002/EC of 7 March 2002 on a regulatory framework for radio spectrum policy in the European Community (Radio Spectrum Decision).Recital 11.

<sup>40</sup> For example Council Directive 87/372/EEC of 25 June 1987 on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community.

<sup>41</sup> Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT) ECC Report 80 p. 19.

<sup>42</sup> *Ibid.*

<sup>43</sup> See M. Cave *et. al.* Essentials of Modern Spectrum Management, Cambridge University Press: 2007. p. 41.

explore conceptual underpinnings of the above proposition so as avoid speaking at cross-purposes. Such discussion can ultimately serve to facilitate the effectiveness of auctions.

A first order consideration is to define clearly what actually is meant by ‘value’ in relation to spectrum. The term value has no objective measure; it therefore has little intrinsic operational relevance. From the standpoint of spectrum management, value is simply a word, what matters is the meaning ascribed to it. When value is discussed in relation to an auction, what is really being discussed is price. How much money will the auction raise?

The tacit assumption is that revenue generated from the auction correlates to social value. Generally speaking, the efficacy of a spectrum auction turns on the extent to which this correlation is valid.

Spectrum auctions (which can be understood as a proxy for the market) relies heavily on the provision of spectrum trading. Since auctions only approximate market outcomes, trading is viewed as a means through which the market inefficiencies (arising from the auction), may be ‘corrected’.

Allowing users to trade spectrum is a means through which a user that is willing to pay more to obtain spectrum held by another is able to acquire this. Market exchanges however require clearly defined property rights. Without this the costs associated with making the transaction become prohibitive as neither the buyer nor the seller can adequately describe the subject matter of the transaction.

If the spectrum use rights are fixed, subject to contiguous separation which is generally agreed upon by all users and are perpetual (viz. akin to real property markets), then spectrum trading will work well.

In Ireland at the present, licence transfers between undertakings requires regulatory consent. Trading refers to the transfer of spectrum without prior consent of the regulator in a secondary market. Taken together, the introduction of spectrum trading and liberalization in the form of licence flexibility is expected to increase the need for spectrum monitoring.<sup>44</sup>

This is because with less regulatory oversight and more flexibility given to licencees with respect to the technology they deploy, the exercise of their licence and whether they are able to transfer their licence to subsequent users without regulatory consent, the likelihood of unexpected interference scenarios would become greater.

The thinking here is that such conflicts are to be resolved by the courts. But it should be remembered that courts deal with *ex post* inter-party conflict rather than intra-party radio network planning (the province of regulatory agencies). It is also likely that court procedures will be used strategically to frustrate and delay market entry.

#### **4 Wireless Test and Trial Licensing**

We return to how to better facilitate cognitive radio given the above constraints. One such initiative within Ireland has been the Wireless Test and Trial Licencing scheme.<sup>45</sup> This licence allows the licensee the testing or trialing innovative wireless services

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<sup>44</sup> ECC Report 80 *supra* n. 9 at p. 7.

<sup>45</sup> Wireless Telegraphy (Research and Development) Licence S.I. 113 of 2005.

within Ireland at specified locations . It may also be issued to licence a new wireless service which does not fit within an existing licensing category.

Distinction is made between ‘testing’ and ‘trailing’ radio technologies within the scheme. A Wireless Test Licence allows the licensee to carry out research and development using radio spectrum which may involve the testing, development, evaluation, improvement and/or advancement of new and novel wireless applications. This licence does not allow the licensee to provide services to third parties or involve members of the public.

A Wireless Trial Licence by contrast does allow the licensee to carry out trials of novel or innovative radio services involving members of the public or other third parties, for the purpose of testing applications and apparatus.

## 5 Trial results to date

This paper focuses on the innovative work by the Centre for Telecommunications Value Chain Research.<sup>46</sup> In 2007 CTVR was awarded a test licence for use at the DySPAN 2007 conference. The licence authorised the research and development of software-based reconfigurable radios in two 25MHz bands, centred at 2.080 GHz and 2.350 GHz respectively, in a number of locations across Ireland.

The CTVR software-based reconfigurable radio platform has 3 principal elements:

1. A novel reconfigurable software radio architecture (IRIS)
2. An experimental handheld baseband-to-RF hardware module
3. A novel wideband antenna

The researchers have shown using the license, that the platform can be populated with information, components, algorithms, methods, logic and intelligence as desired. Ireland’s geographical location allows making unused spectrum available for such purposes easier than would otherwise be the case.<sup>47</sup>

Using the bands licensed under the test licence the group has been able to create, and repeat, experiments which can evaluate the performance of highly complex algorithms.<sup>48</sup> The network architecture seeks to establish the rules for technical co-existence (i.e. the ability of two or more nodes/entities to share a common frequency band) by exploiting whitespace (viz. unused spectrum at any particular point of observation). The imperative for greater utilization of the spectrum was highlighted by occupancy measurements performed in Dublin 2007 that no more than 13.6% of the

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<sup>46</sup> The Centre for Telecommunications Value-chain Research is a multi-institutional, multi-disciplinary research centre head-quartered at Trinity College, Dublin. The centre includes University College Cork, University College Dublin, NUI Maynooth, University of Limerick, Tyndall Institute, Dublin Institute of Technology and Dublin City University. Industrial partners include Bell Labs Ireland, Xilinx and EADS.

<sup>47</sup> This was a key observation as part of the Irish development strategy advanced in 2005. See FORFAS (2005) “Wireless an area of opportunity for Ireland.”

<sup>48</sup> See Nolan, K. *et al.* “Dynamic Spectrum Access and Coexistence Experiences Involving Two Independently Developed Cognitive Radio Testbeds” in Proceedings of the IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN’07), 22-25 April 2007, Dublin, pp: 270 -275.

spectrum opportunities (in frequency and in time) are utilized in Dublin during a high use period when measured from an elevated location.<sup>49</sup>

The researchers have also described ‘cyclostationary signatures’ which can be intentionally embedded in a digital communications signal, detected through cyclostationary analysis and used as a unique identifier.<sup>50</sup> This enables transmitter and receiver technology to overcome a number of the challenges associated with network coordination in emerging cognitive radio applications and spectrum sharing regimes. The research output of the group is both impressive and considerable. With such a wealth of data and results, one would expect to see regulatory agencies radically transforming the licensing regimes in order to allow the citizenry to avail of this novel and technically superior system. Alas this is not the case. The next section discusses regulatory reform proposals that seek to facilitate cognitive radio.

## 6 Regulatory reform proposals to facilitate cognitive radio

Much of the debates concerning reform of regulatory rules to facilitate CR turn on the Hardin’s exposition of the ‘tragedy of the commons.’ (Hardin, 1968). The fundamental problem he notes lies in the fact that “[f]reedom in a commons brings ruin to all” (Hardin 1968, p. 1244). As has been noted since not *all* devices are cognitive the problem how to manage cognitive and non-cognitive radio technologies remains and thus regulatory intervention of one kind or another will be warranted.

CR presents itself as a technical solution. Hardin defines a technical solution “as one that requires a change only in the techniques of the natural sciences, demanding little or nothing in the way of change in human values or ideas of morality” (Hardin 1968, p. 1243). Hardin concludes that the population problem has no technical solution; it requires a ‘fundamental extension of morality.’ Hardin’s seminal paper was applied to the problem of overpopulation. However his remarks are of great relevance the class of problems into which the management of spectrum falls.

Since it is mathematically impossible to maximize two dependent variables at the same time, the possibility of a technology solution (CR or otherwise) that will satisfy all users simultaneously is unlikely to materialize. The decision to favour one solution to the commons problems will invariably involve a choice of some kind or another. This can be buried within technical protocols or market mechanisms, depending on the proponents’ level of technical understanding of wireless technologies. A brief survey of two reform proposals that seek to facilitate CR-like technologies will be illustrative.

In discussing spectrum auctions, Eli Noam outlines a proposal for what he terms ‘open spectrum access’ (Noam 1998). At present physically, no device exists for spectrum brokerage yet. This has not stopped engineering researchers from attempting from envisioning this architecture from a technical perspective, e.g. DIMSUMNet architecture of Bell Labs (Buddhikot, 2005).

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<sup>49</sup> Erpek, T. and Steadman, K., “Spectrum Occupancy Measurements: Dublin, Ireland, Collected On April 16-18, 2007” available online at [http://www.sharedspectrum.com/measurements/download/Ireland\\_Spectrum\\_Occupancy\\_Measurements\\_v2.pdf](http://www.sharedspectrum.com/measurements/download/Ireland_Spectrum_Occupancy_Measurements_v2.pdf)

<sup>50</sup> See Sutton, P. *et al.* “Cyclostationary Signatures in Practical Cognitive Radio Applications” IEEE Journal on Selected Areas of Communications, VOL. 26( 1) 2008.

Essentially Noam calls for an open access system where access fees (set by clearing houses and based on network congestion) would be required by spectrum users. Noam seeks to transcend both licence-exempt and property rights models of spectrum with this approach.

Weiss and Jondral table the concept of ‘spectrum pooling.’ (Weiss and Jondral, 2004) For them, spectral efficiency will be enhanced by overlaying a new mobile radio system on an existing one without requiring any changes to the actual licensed system. The idea is similar to Noam’s but here, the licence holder obtains a rent for use of spectrum during idle periods. They assert “once the technical obstacles are overcome and the feasibility of spectrum pooling is proven, politics cannot refuse this idea.” (Weiss and Jondral, 2004, p. 8)

They conclude that “a lot of work remains to be done in this field, but one thing is sure: the better the technical concept, the greater the potential acceptance of legislators, regulators and future customers.”(Weiss and Jondral, 2004, p. 14)

Quite why Western Judeo-Christian culture has developed such an extraordinary obsession with technology is examined by Noble in his *Religion of Technology* where he addresses the question. He argues that, at its core, technology embodies a tenet of religious millenarianism promising the transcendence of mortal life. (Noble 1997). But to Weiss and Jondral’s point, the lack of reform of the *Wireless Telegraphy Act 1926* is evidence enough of the proposition that established regulatory practices die very hard indeed.

There’s nothing wrong with the above proposals, but what is important to appreciate is that spectrum management is and will remain fundamentally about choice. These choices, just or unjust will take place in the context of regulatory decision making. Human choices that cannot be rendered unbiased by reference to technologies or markets.

Perhaps what is needed is not so much pursuit of a panacea, but willingness to meaningfully engage with the fundamental problem to find a workable solution. This returns us to the regulatory process and how decisions are made within it. Hardin argues that “[w]e must find ways to legitimate the needed authority of both the custodians and the corrective feed-backs” (Hardin 1968, p.1246).

Operators may rail (sometimes with good reason) against decisions of regulatory agencies, but some entity has to make decisions for better or worse, the relevant question is whether they have the powers and competence to do so.

This will involve providing greater clarity on the extent to which government should intervene in providing an efficient infrastructure to foster growth and competitiveness in the communications sector. Imperfection and injustice is generally preferable to chaos. The challenge is not so much how to change, but when to allow it and with what consequence.

Regulators need to better engage those affected by regulatory decisions in their assessment of whether changes in market structure in specific radio sectors for example are required to better appropriate returns to the economy as a whole. This will involve greater independence, commitment to longer-term social goals and choices that will invariably harm the interests of certain users. Historically this has always been the way forward; it’s just always difficult to accept.

## 7 Conclusion

The management of spectrum presents a dilemma with no optimal solution – science, technology and even markets all have significant drawbacks. What is important to appreciate is that they all depend on governance institutions to allow them to operate.

In many cases (and Ireland is no exception), reform of the regulatory structure is the last thing considered. Probably with good reason as it is perhaps easier to negotiate the laws of physics than it is to reason with an incumbent.

Regulatory reform proposals tend to mirror technical solutions, which while impressive can never please everyone, all the time. Regulatory decision making in the final analysis involves choice. Markets and technologies are paths taken, not end-points. It is the process that determines these questions that requires our greatest attention. Or as Hardin would say, what is required is no less than a ‘fundamental extension in morality’.

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