Authorising Dynamic Spectrum Access under Space-Centric Management

Michael Whittaker, November 2008 (updated February 2009)

1.0 Introduction

Market-based (outsourced) spectrum management seeks to maximise spectrum efficiency and innovation by providing industry with freedom to **independently** choose the type of equipment and service. No one is in charge of an authentic market. Where an authority relationship exists – one party is in charge of the other, or a higher authority is in charge of them both – then transactions are not market transactions. Decentralisation brings dynamism. Free decision-making, that is, autonomy to choose the technology and service, is the key[1].

Telling industry they can in principle choose the technology and service is one thing, but providing them with a regulatory framework which allows them to choose independently of adjacent licensees and the regulator is quite another. Furthermore, good market design must restrict profit-seeking to constructive,

[1] Adapted from John McMillan "Reinventing the Bazaar: A Natural History of Markets" ISBN 0-393-32371-4, 2003.

rather than destructive behaviour. The overall challenge is to harness the power of the market to increase innovation, investment and productivity, while at the same time establish all the necessary practical interference benchmarks, provide equitable spectrum access and correct any market failures. Simply hoping that individual market participants might somehow magically do the right thing will not work. Essentially, the regulator must provide an unambiguous open spectrum market, with a level of intervention necessary to reduce the greater inequalities that competitive markets inevitably create.

Regulator activity should not be constrained and ultimately replaced by market forces. Such a concept, *free-market fundamentalism*, has once again been revealed as little more than personal greed dressed up as an economic philosophy. While this paper focuses on the definition of spectrum access rights, the role of government is not only to enforce contracts and design and protect the allocation of property rights but also to provide the necessary transparency and competitive neutrality to achieve a proper mix of private incentive and public responsibility[2].

1.1 Autonomy in Spectrum Access Rights

Different styles of international spectrum management presently range all the way from fully **centralised** to fully **outsourced** management. Through their licensing regimes, each style offers a different degree of decentralisation and licensee autonomy to choose the type of technology and service. The level of freedom to make that choice is entrenched in the detail of licence conditions.

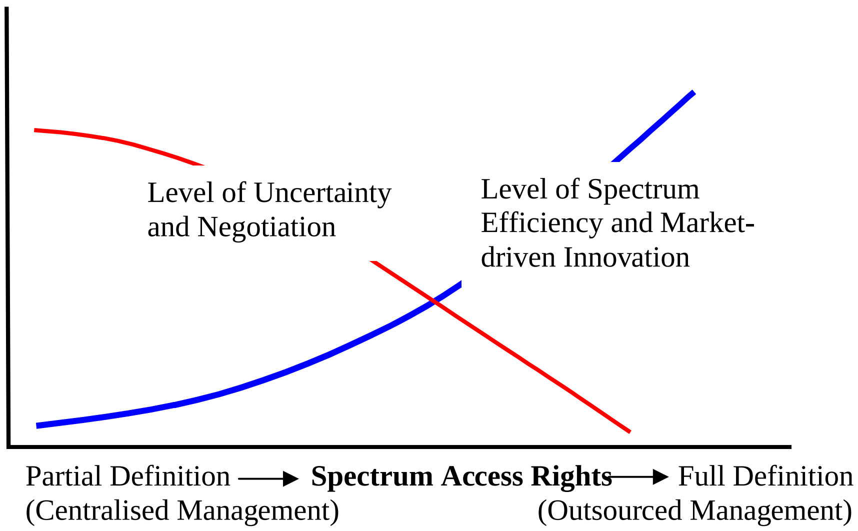
Driven more by politics than good engineering practice, international spectrum regulation in general, has been more a form of art than a science. Spectrum scarcity is artificial, a result of overly simplistic licence conditions or spectrum access rights related to interference management. Simplistic rights tend to maintain the centrality of the regulator in spectrum management and create outsourced management inefficiencies. While it is not essential and sometimes inefficient to define every detail of the rights of spectrum access, the design of a market mechanism must recognise important interdependencies and make related rights explicit and practical to utilise. Interference between devices is highly interdependent. Where a regulator provides:

- insufficient interference benchmarks; or
- overly simplistic interference benchmarks; or
- interference benchmarks which are impractical to implement; or
- interference benchmarks which are not authentic legal rights, a licensees' ability to make independent decisions about spectrum use decreases, and with it also decreases spectrum efficiency and the likelihood of innovation.

[2] Adapted from Kevin Rudd "The Global Financial Crisis" The Monthly, February 2009, www.themonthly.com.au.

Market-driven spectrum efficiency and innovation can only be maximised when spectrum access rights are completely, as well as clearly, defined – see Figure 1.

Figure 1. *Achieving Spectrum Efficiency and Increased Innovation*



Australia had to be very precise and clear in its design of spectrum access rights. Australian legislation requires exclusive access, and government compensation is payable if spectrum rights are not maintained. In Australia, and presently nowhere else, the issue of a spectrum licence by government provides rights akin to a commercial dealing involving a quasi-contract[3] for an indefeasible company asset[4]. Interference risk always remains clear and calculable.

Spectrum space has been traditionally allocated for use by a single equipment standard with guard space, applied in the form of frequency assignment 'taboos', supplementing hardware isolation. The complexity of interference management was hidden in the equipment standard, with the technical implications and possibilities not understood by most policy makers. While the old approach might have been acceptable in an era of less innovation and slower change, the new demands of spectrum liberalisation and flexible

[3] At the time of auction, spectrum licences are not issued and do not yet exist. However, a court would treat the money paid to government as if a contract existed for subsequent licence issue.

[4] There are certain restrictions on trading: "*can't transfer the licence for the purpose of providing security*". This means that certain forms of mortgage can not be used. The government did not want to have to take regulatory action against a bank. Licences can be used to raise a loan from a bank but the licence must stay in the name of the licensee. Recouping after a default would mean the bank trading (selling) a licence between the old and a new licensee.

spectrum access has decreased the usefulness of the centrality of the equipment standard in spectrum management[5]. A more scientific approach was applied in Australia in 1997. The interference management elements of a generic equipment standard were translated into explicit spectrum access rights. Such innovation necessitated new methods of formulation and even new language.

2.0 Space-Centric Management

Essentially unfettered by politics and entrenched interests and supported by relevant legislation including an already functioning online device database, Space-Centric Management (S-CM) was introduced 12 years ago to design the conditions of spectrum licences in Australia. While the benefits of S-CM have not yet been studied in-depth by regulators in either the UK or the USA, it has recently become an option for defining least restrictive technical conditions for WAPECS (see CEPT Report 19).

The heart of this spectrum licensing model can be described in three ways:

- the licence conditions act in the manner of a generic equipment standard, where the amount of spectrum space obtained through trading determines the actual equipment standard which may be operated; or
- the licence conditions provide a known level of guard space between each transmit antenna and the spectrum space boundaries, which is then used by a spectrum licensee as an input for design of the necessary hardware isolation for new innovative equipment; or
- the licence conditions are explicit transmit rights which define an implicit receive protection for neighbouring spectrum licensees in relation to the operation of new services (but not legacy services licensed and registered before spectrum licence issue, which for political reasons continue to be provided with traditional protection *via* site-specific and device-specific coordination procedures based on limits for maximum received interference power at each legacy receiver[6]).

The key element is a 5 dimensional spectrum space: a specified geographic area and maximum height, frequency band and time period - hence the term *space-centric management*. Higher numbers of dimensions (power/altitude/azimuth) are more scientific curiosities than practical management tools. While the licence conditions can be optimised for a specific service topology, they are not limited to operation of that topology alone. Once sufficient space for a new service has been traded, no further

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[5] Wireless standards are created by committees. Each manufacturer adds some features specific to their use. The result is that standards tend to be complex and slow in development. Importantly, the designs are not optimised because they involve a high level of compromise.

[6] The political power of legacy licensees can sometimes pose a formidable obstacle to spectrum reform. To maximise creative freedom, Australia has separate rules for new and legacy services. Legacy services are provided with traditional protection. New services operate under the new paradigm of space-centric management.

negotiation with the regulator or adjacent spectrum licensees is required. The benefits of this approach in terms of industry efficiency are major.

3.0 Providing a Practical Regulatory Framework

Different technologies and services utilise different amounts of spectrum space. Without giving some form of recognition to the size of the spectrum space actually being used by different types of devices as well as the size of the spectrum space that is available for them to operate within, non-reciprocal spectrum access and inequitable spectrum sharing will be an on-going problem. S-CM is designed to maintain exclusive and equitable access to adjacent spectrum spaces for any type of **new** technology and service. There is no need to re-negotiate and re-plan spectrum for every innovation, for example, rules devised in 1996 operated without change to enable authorisation of the Telstra WCDMA 850MHz *Next G™* network in 2006/7.

S-CM can be used for either outsourced or centralised spectrum management. Its main tenet is **complete definition** of all the rules necessary for practical and independent device authorisation and interference management. Commercial uncertainty generated by incomplete, partial or imprecise definition of spectrum access rules impedes innovation by providing competitors with an array of issues which they can use for prolonging arguments about who and what may access spectrum. Given the uncertainties of radio propagation, rules must be pragmatic. Confidence, clarity and certainty regarding the regulatory environment are needed in order to avoid impairment of flexibility and innovation.

3.1 Harmful Interference-Rx

The rules for S-CM do **not** use the traditional definition of receive protection '*harmful interference-Rx*'[7] because while it can be heard to be uttered with great seriousness, especially in European legislation, in practical engineering terms the definition is so imprecise as to be meaningless for the provision of rights for spectrum licensees. It is a prime source of regulatory uncertainty.

Given the high loss of spectrum utility arising from risk-averse management of the field variability of its counterpart '*interference temperature*', this concept is not much better, except perhaps in theoretical discussions[8].

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[7] Harmful interference-*Rx* in the European context "*means interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with applicable Community and national regulations*"

[8] For example, see Bater J *et al* "*Modelling Interference Temperature Constraints for Spectrum Access in Cognitive Radio Networks*", IEEE International Conference on Communications, June 2007 ICC '07 which compares a non-binary receiver-centric harmful interference-*Rx* metric with a simplified binary transmitter-centric harmful interference-*Tx* metric. The harmful interference-*Tx* metric used for the comparison has a fixed re-use

Furthermore, technical conditions based on aggregate power flux density limits which try to mimic '*harmful interference-Rx*' are also **not** used for S-CM because such conditions, when used as primary rights, can not be achieved in the field in a practical manner (they are used for example, in the USA as rights pertaining to out-of-area emissions[9] and also by Ofcom as their preferred form of spectrum usage rights which Ofcom refers to as 'SURs')[10].

Thankfully, there is a better option. An option which has been partially adopted by CEPT SE42 in their search for least restrictive technical conditions for Europe and an option which could also constitute a practical IEEE 1900.2 framework for coexistence analysis in dynamic spectrum access.

3.2 Harmful Interference-Tx

Lawyers have for some time recognised it is much more practical in drafting terms to establish the content of a right by defining it negatively *i.e.* permission is conferred to use the spectrum, subject to certain restrictions, rather than trying to describe the extent of the right in positive terms. Whatever is not expressly prohibited is permitted. Therefore, explicit (primary) transmit rights with implicit (secondary) receive protection is more practical. When such rights are defined in relation to **all** interference mechanisms they create spectrum regulations which easily translate into new equipment design.

The spectrum licence conditions of S-CM specify a **complete set** of explicit transmit rights in relation to **all** Interference Categories (IC).

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distance for all transmitters while the harmful interference-*Rx* metric requires a C/I threshold to be maintained over a range of possible receive levels. Common sense dictates that the likelihood for communication offered by a non-binary model would have to out-perform a simpler binary model. Alternately, in the real world, the same propagation loss variability determines, in the case of a harmful interference-*Tx* metric, the statistics of the resulting interference levels and in the case of a harmful interference-*Rx* metric, the allowed maximum transmitter levels (leading to a variable rather than fixed reuse distance). Therefore, neither metric has the ultimate capacity (which in practice also depends on the overall legal and technical regulatory framework) to provide greater levels of spectrum access than the other. However, a harmful interference-*Tx* metric offers greater legal clarity, spectrum efficiency in a risk-averse situation and commercial certainty as well as lower management costs. Note that the Bater paper acknowledges "*there is still controversy over its* (the harmful interference-*Rx* metric) *feasibility and usefulness*".

[9] The FCC PCS licences use, for example, a limit on the field strength that is predicted or measured "*at any location on the border of the PCS service area*".

[10] All the difficulties associated with using aggregate power flux density limits as primary spectrum usage 'rights' (*e.g.* Ofcom's SURs) rather than explicit transmit rights as spectrum usage rights, and there are many, are clearly set out in the paper "*Commercial Certainty in Spectrum Right Formulation*" available at www.futurepace.com.au

The rights embed notional levels of receiver protection and are established as mathematical functions of device separation from boundaries of a spectrum space:

- IC A. (*Geographic* Boundary) in-band interference: same-band adjacent-area;
- IC B. (*Frequency* Boundary) in-band interference: same-area adjacent-frequency;
- IC C. (*Frequency* Boundary/Non-linear) out-of-band interference: same-area adjacent-frequency; and
- IC D. (*Time* Boundary) in-band interference: same-band same-area.

Under S-CM the transmit rights consist of explicit conditions for power **radiated at an antenna.** This is not a power threshold at a boundary, but power radiated **at** each antenna (or antenna array). Permissible levels of measurement uncertainty must also specified for compliance purposes.

3.3 The Receiver is not Ignored

The receiver is not ignored. Receiver protection is embedded within all the transmit rights when they are designed. That protection is notional rather than guaranteed. For example, the rights for IC C include a notional receiver performance. This makes the rights independent of the varying levels of interference susceptibility, which actual receivers may exhibit. The regulator leaves spectrum licensees worry about different levels of degradation to their particular receivers resulting from the transmit rights. Licensees become responsible for making fully independent cost-benefit trade-offs with equipment design.

In the case of new services (but not legacy services as previously mentioned), an alternate **legal** definition of '*harmful interference-Tx*' is thus created which is precise and practical for enforcement because tests for interference can be specified in terms of easily measurable quantities[11]. Compliance only requires the conditions at transmit antennas be fulfilled, not that a certain level of receiver protection might or might not be achieved at distances away from those antennas. Spectrum licensees use the explicit limits for power radiated at antennas to aid design of their receivers to achieve whatever level of protection they desire. The regulator is no longer responsible for ensuring that a particular level of protection/degradation occurs. S-CM can be used to "*establish a well-thought-out framework for measuring/analysing the interference between radio systems*" operating in adjacent spectrum spaces not primarily for interference

[11] For example, *harmful interference-Tx* "*means interference caused by transmitters not operating in accordance with applicable Community and national regulations*". In Australia the term '*Unacceptable Levels of Interference*' is used in legal instruments.

settlement but for the avoidance of interference disputes altogether[12]! There has not been a single case of reported interference in Australia since inception of the policy in 1997.

4.0 Practical Benchmarks for *Harmful Interference-Tx*

A high level of engineering skill is necessary to specify a coherent set of benchmarks for *Harmful Interference-Tx* so that they achieve self-consistent levels of notional receiver protection. Australia provided such benchmarks in 1997. There has recently been a move towards adopting similar benchmarks elsewhere: FCC in August 2005, Ofcom in November 2005 and CEPT as recently as November 2007 see Table 1.

Table 1. Regulators currently utilising *Harmful Interference-Tx* benchmarks for spectrum licences

	Ofcom	**CEPT**	**FCC**	**Australia**
IC A: *Geographic* Boundary	not yet	not yet	not yet	yes
IC B: *Frequency* Boundary	partial[1]	partial[2]	partial[3]?	yes
IC C: *Frequency* Boundary (Non-linear)	not yet	not yet	not yet	yes
IC D: *Time* Boundary	not yet	not yet	not yet	yes[4]

[1] Ofcom eventually amended their 1.8 GHz spectrum award proposal from a fixed maximum EIRP expressed as dBm per carrier to an EIRP density mask expressed in dBm/kHz in November 2005. Ofcom were also 'forced' to utilise CEPT steady-state EIRP mask (BEM) for 2.6 GHz but still promote aggregate power flux density primary limits. Its legal status as '*harmful interference*' remains confused.
[2] Steady-state limits only (BEM), but transient limits also being currently pursued for 700 MHz. Its legal status as defining '*harmful interference*' is currently confused.
[3] The FCC dropped base station transmitter power output limits from their PCS licences and replaced them with radiated power as late as August 2005. "?" = subsequent policy decisions not researched.
[4] While spectrum licences are exclusive, management of emission levels spilling into adjacent spectrum licences utilises time domain limits as required.

While CEPT readily acknowledges the benefits of such benchmarks as being ease of derivation; precise definition; and level of practicality and relevance in field implementation, the strict separation of policy and technical development in the EU regulatory environment (commitology) makes it difficult for CEPT to make progress. The committee system achieves a level of consensus by making it difficult for one interest group to hi-jack the process (although organisations with greater resources do have more influence). Overall, technical studies tend to be conservative and the process is very slow and resource intensive.

The BEM of CEPT Report 19 is an explicit transmit right and has been a good start for Europe, but it is only a beginning. A complete set of explicit transmit rights is needed to enable a licensee to authorise and operate devices

[12] R. Venkatesha Prasad, Pzemyslaw Pawelczak, James A. Hoffmeyer, H. Steven Berger, "*Cognitive Functionality in Next Generation Wireless Networks: Standardization Efforts*", IEEE Communications Magazine, vol. 46, no. 4, pp. 72-78, Apr. 2008.

completely independently of the regulator and adjacent spectrum licensees, and if desired, without a formal equipment standardisation process. With a complete set of rights, any type of new equipment can be independently authorised by a spectrum licensee essentially in the time it takes to make a minimum number of laboratory measurements and check its field deployment against the spectrum access conditions of the licence.

4.1 IC A: Geographic Boundary

If consistent rules for spectrum trading are to be provided, transmit rights pertaining to IC A are necessary to support the management of not only country borders but also internal geographic boundaries within a single country. Such rights would be practical for internal Member State boundaries of the EU if there was agreement on the legal definition of *harmful interference-Tx*.

4.2 IC B: Frequency Boundary

The explicit transmit right of S-CM pertaining to IC B is similar to the Block Edge Mask (BEM) of CEPT SE42 Report 19. BEM is now rightly preferred by European industry over Ofcom's proposals for primary limits of aggregate power flux density.

4.3 IC C: Frequency Boundary (Non-Linear)

Rights pertaining to IC C support the management of non-linear type interference mechanisms. Non-linear type interference involving high power devices can be efficiently managed only by reference to a central device database, irrespective of what form of spectrum rights are used. Such a database can not be obtained by off-air monitoring but must be legally and technically integrated into the licence conditions, preferably as part of a device certification process. The explicit transmit rights of S-CM together with a centralised device database allow neighbouring licensees to accurately and efficiently estimate the levels of both linear and non-linear interference they can expect because notional data is not used for compliance verification. This in itself is an efficiency driver.

The interdependent nature of interference means that flexible spectrum management can only be enabled by an increase in regulatory function to offset the greater complexity. The centralised online device data base of S-CM is one such example[13]. The data elements for spectrum licensing where established in

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[13] "*The cost and risk of characterizing spectrum use can be reduced through establishing an information registry for authoritative data about primary users. Posted information could include for example geographic locations of transmitters and receivers, waveform characteristics such as modulation and bandwidth, or times of day when the system does not operate. This type of information enables secondary users to execute more aggressive spectrum access algorithms at acceptably low risk. Notification of secondary users when registry data is updated would assure quick response to changes in primary user behavior.*

Australia in 1997[14]. When legally and technically integrated into the regulatory framework it provides increased operational certainty, and in the case of DSA, reduced complexity and acceptable business risk. The central device database serves a multitude of essential legal and technical purposes, assisting licensees with managing IC A through IC D[15].

Before 1998 in the USA[16], certain spectrum (geographic) licensees were required to notify the FCC of the details of all stations for the purpose of coordination and interference prevention between spectrum licensees and grandfathered incumbents. After 1998 the FCC implemented its online Universal Licensing System (ULS) and all spectrum licensees were then **not** required to notify device details. The FCC believed reducing this 'regulatory burden' was in the public interest. The FCC intended neighbouring operators to identify each other and coordinate privately. The FCC replaced the economies and certainty of a central device database with the uncertainty and higher costs of multiple *ad hoc* industry databases. A relatively light regulatory burden became a much heavier external burden. Furthermore, the FCC also required spectrum licensees to maintain device information and to provide it to incumbents and the public as well as to the FCC on request.

While spectrum licensees are always primarily responsible for coordination, it is reasonable to expect the regulator to provide them with the most efficient regulatory framework in which to accomplish their task *i.e.* a centralised device database. The FCC jettisioning of the many economic and technical benefits of a central device database occurred in an era in which government was over-confident in the possibilities of industry self-management. Without appropriate support and oversight, it is a mistake to be confident in the ability of a spectrum market to efficiently self-manage. The FCC's general attitude of the time was that interference could be managed "*through the mutual greed of licensees*". Certainly, there would have been little disagreement with the FCC's decision

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One of the primary challenges of a registry is to assure that the information posted is correct; both regulatory and market mechanisms that assist this are worth exploring. An effective registry mechanism can reduce the interference risk of non-cooperative DSA, compared to a regime where secondary users operate without external information. As a result regulatory authorities can establish more liberal easements. This effect is synergistic with the benefits of a registry: both lead to higher spectrum utilization. The policy and technical issues associated with the registry approach are a valuable area for further investigation." John M. Chapin, William H. Lehr 'The Path to Market Success for Dynamic Spectrum Access Technology' IEEE Communications Magazine, May 2007

[14] See *Radiocommunications (Register of Radiocommunication Licences) Determination No. 1 of 1997* and http://web.acma.gov.au/pls/radcom/register_search.main_page. Industry mirror database may be maintained by initialising with a CDROM and updating on a daily basis via online difference files.

[15] See Section 5 of Whittaker M "*Authorising Devices under Australian Spectrum Licences*" June 2008, available at www.futurepace.com.au for a list of benefits, as well as Attachment A, for the linkages between the benchmarks and Australian legal instruments.

16 See FCC Order, 17 September 1998.

from private frequency coordinators, their eyes fixed on the client capture and profit to be made from the higher costs for spectrum licensees having to resort to *ad hoc* databases. However, greed is no substitute for good regulation.

The FCC ULS began as a public online licence filing system and has now undergone ten years of enhancement. In a slight turnaround, the FCC recently utilised it for registering stations for interference management in the 3650 MHz band. All stations operated in these non-exclusive geographic spectrum licences must be registered in the ULS[17] for coordination purposes. The ULS will also likely be called upon to help manage interference for DSA/CR in broadcast band 'white spaces'[18].

Ofcom continues to resolutely shy away from the benefits of a central online device database. Ofcom refers to non-linear interference as that related to '*transmitter density*'. Absence of a central device database and the inability for licensees to know exactly where a device is located together with its basic operating characteristics, has meant that Ofcom has no other option for management of the many forms of non-linear interference but through use of an overly-simplistic and thus inefficient, broad-brush aggregate PFD design incorporating very inaccurate estimates of '*transmitter density*', because they involve notional test points within notional test areas at notional heights for compliance. Such a design is much too inefficient for managing non-linear interference mechanisms.

In the case of mixed FDD/TDD operation or unsymmetric uplink/downlink bandwidths, S-CM does not require the regulator to specify '*guard blocks*' or '*restricted blocks*' of a fixed size because another advantage in specifying technical benchmarks for IC C is that the necessary size of any guard band as well as the licensee who is to provide it, is embedded within, and may be calculated from the benchmarks on a case by case basis throughout the entire licence period. Similarly, neighbouring licensees do not have to negotiate to return utility to a '*restricted block*' and therefore, do not have to risk the inefficient outcomes of strategic gaming which often occur during such negotiations. Reliance on industry negotiation should never be an excuse for regulatory indecision or over-cautious worst-case licence conditions.

4.4 IC D: Time Boundary

Rights pertaining to IC D are specified when the spectrum space is not exclusive. Note that spectrum can also be shared in the sense that out-of-band and out-of-area emissions fall outside the frequency and area dimensions of a

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[17] View the ULS at http://wireless.fcc.gov/uls and see it used to create a daily updated mirror database to support Comsearch's marketing tool for coordination services at www.3650search.com.

[18] A 'White Spaces Database Group' has been formed to advise government on detailed design.

spectrum licence. In some interference scenarios, time-related limits can be used as benchmarks for radiated power in otherwise 'exclusive' spectrum.

5.0 Commercial Certainty from Complete Definition

Australia's complete set of practical technical benchmarks for *harmful interference-Tx* are:

- IC A (*Geographic* Boundary) – *device boundary*: benchmarks for in-band radiated power related to the management of out-of-area emissions;
- IC B (*Frequency* Boundary) – *antenna EIRP spectrum mask*: benchmarks for out-of-band radiated emission related to the management of *e.g.* "near-far", transient and spurious interference;
- IC C (*Frequency* Boundary - Non-linear) – *model coordination procedure*: radiated benchmarks related to the management of non-linear out-of-band interference, with the necessary technical and legal certainty supported by reference to a central online device database; and
- in the case of non-exclusive spectrum, IC D (*Time* Boundary) – *dynamic spectrum access*: benchmarks for radiated power related to time-sharing the same spectrum space.

The technical clarity and legal certainty of S-CM provides:

- precise benchmarks for independent design, authorisation and coordination of new innovative equipment; and
- allows a clear chain of liability to be established for interference settlement.

These issues are especially important in the case of dynamic spectrum access using cognitive radio (DSA/CR).

6.0 Liability Assignment for Interference Settlement

Under S-CM, responsibility for interference settlement sits with the manager of a particular spectrum space. There are just two scenarios:

- the regulator as spectrum manager (**centralised**); or
- the spectrum licensee as spectrum manager (**outsourced**).

Of course, either manager can subsequently re-assign liability to other entities in a legislative or contractual manner creating a chain of liability, including persons who perform the compliance certification process, as well as suppliers of equipment and software.

6.1 Liability under Outsourced Management

In the case of outsourced management, all devices must operate within the very clear transmit rights IC A to IC D (as well as additional criteria for any site-specific legacy incumbent/primary services[19]). In the case of exclusive spectrum, the spectrum licensee may independently design and apply additional IC D/Time Boundary transmit rights for DSA/CR when deciding to operate such devices or when allowing their operation under third party agreements.

Persons accredited (but not employed) by the regulator, certify compliance of devices with the licence conditions and place the certified data in a central online device database. Certification maintains the technical and legal integrity of the data. Only those devices, which have high likelihood of causing interference, must be registered.

Certification is distributed between **two** separate responsibilities in relation to licence conditions which can have one of **two** separate natures:

- **certain nature:** conditions contained in a legal Determination for the purpose of clarity and certainty – covers compliance with particular explicit transmit rights required for certificate issue; and
- **uncertain nature** (accredited person has a choice of propagation models)**:** conditions contained in legal Guidelines, which means there is a higher element of risk-management - covers compliance with any remaining explicit transmit rights not included in the Determination *e.g.* IC C, and any explicit receive protection for specific legacy incumbent/primary services – the responsibility is related to the level of success at keeping reported interference below a specified rate.

Different audit criteria, for the withdrawal of accreditation, are applied to the two responsibilities by the regulator for enforcement purposes[20]. Liability is distributed between the two requirements. Contractual arrangements between the licensee and accredited person must also deal with the related liability[21]. The regulator requires accredited persons to be covered by professional indemnity insurance against loss or damage for up to $2 million before issuing a certificate and with a run-off period of 5 years.

[19] These criteria provide a maximum received interference power at each legacy receiver, which is an implementation of the definition *Harmful Interference-Rx*. However, the important distinction is that, depending on the detail of the spectrum right formulation, an Rx formulation can be practical to apply in the site-specific/device-specific scenario but impractical for establishing flexible access rights throughout an entire spectrum space. Legacy services licensed before introduction of space-centric management continue to be managed with traditional coordination rules, thus allowing for a green-field analysis for new services.

[20] See ACMA Radiocommunications (Accreditation — Prescribed Certificates) Principles 2003

[21] For a more detailed examination of the liability issues see “Legal Analysis of ACA Proposals for Reform of Device Registration Procedures under Spectrum Licensing”, Ian Coe, Bailey Dixon Lawyers and Consultants 2005, available at www.futurepace.com.au

Registered devices must be labelled with their registration number for interference investigation purposes.

Traditionally under apparatus licensing, equipment is 'type-approved' or bench-tested against a particular equipment standard. However, under S-CM equipment type-approval is performed against the transmit rights rather than an equipment standard. Device deployment as well as a bench-test of representative equipment is assessed. Equipment standards are helpful rather than necessary for this process. The process is similar to the new situation in Europe brought about by the BEM of CEPT Report 19 where equipment manufacturers must follow Harmonised Standards but operators now don't. In this case, Europe now allows different technical solutions covered by a single regulation.

In Europe and in theory, a manufacturer may also market equipment without referring to a Harmonised Standard, provided that compliance though a technical file is demonstrated by a notified body. In practice, notified bodies are reluctant to take the commercial risk of giving a positive opinion on spectrum sharing solutions other than those implemented in the Harmonised Standards and this will be even more likely for the complex sharing solutions necessary for cognitive radio. The RSPG is recommending revision of the R&TTE directive for CEPT/ETSI to give guidance to notified bodies in determining if any deviation from Harmonised Standards would impact the spectrum sharing conditions. Unfortunately, the notified bodies want more than simple guidance, they want a level of liability exposure that is **practical** to manage. Europe must differentiate regulatory hopes from commercial realities.

In Australia, the legal and technical clarity of S-CM reduces the liability exposure to practical levels, enabling accredited persons to accept the commercial risk of certifying the operation of new devices. Australia also applies a more direct and comprehensive approach based on certifying that the spectrum space access conditions are fulfilled, which not only includes a bench-test of representative equipment but more importantly, also maintains equitable spectrum access for dissimilar technologies and services.

6.2 Liability under Centralised Management

In the case of centralised management, the regulator must provide all the necessary technical (regulatory) parameters and administrative framework (certification) to effect device authorisation.

TV white space is a case of centralised spectrum management. While the spectrum rights for incumbent/primary services are unlikely to be ever completely defined, nevertheless, because management is centralised, the responsibility is on the regulator to provide the necessary technical conditions for authorised DSA/CR as well as a competent compliance and enforcement regime. In Australia the accreditation regime applies to centralised as well as outsourced spectrum management.

To be of any practical use the technical conditions would need to be easily measurable transmit conditions/rights. Such transmit rights would of course impact to some degree on the spectrum quality of other spectrum users. Being a political realist, certain legacy primary users[22] might need to be provided with more certain protection. Therefore, additional rules in the form of traditional protection *via* site-specific and device-specific limits for maximum received interference power at legacy receivers can be used to override the explicit transmit rights for new services. But in the case of new services, the rights are a precise definition of *harmful interference* in transmit terms *i.e.* '*harmful interference-Tx*'.

7.0 Designing IC D Transmit Rights for DSA

IC D explicit transmit rights for DSA relate to the three proposed methods or hybrids thereof:

- geo-location/database;
- beacon signals; and
- spectrum sensing.

An additional benefit of the central online device database of S-CM is provision of a database for authorising DSA. A geo-location/database system can support high-power high-site transmitters which then act in a master-client role authorising low-power low-site devices.

Alternately, in the broadcast bands, the primary stations can incorporate beacon signals containing information about channels which are not used in their service areas.

Spectrum sensing is useful for low power[23] devices. Benchmarks for sensing periodicity, detection sensitivity and reliability would be required. While such criteria describe receiver operation they are explicit transmit rights because, from a legal point of view, transmission would not be authorised unless a related measuring receiver operated within the benchmarks.

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[22] Only 12% of US households, which do not get their TV via satellite or cable, would be affected.

[23] Around 100mW, which limits the extent of IC C as well as the range over which secondary devices sense other secondary devices instead of primary devices.

When designing explicit transmit rights they should:

- be specified in a manner which provides a practical, precise and flexible design envelope for new equipment;
- be consistent with the derivation of similar limits *e.g.* those for EMC for computers, electrical devices, cellular phones etc.
- except in the case of specific legacy primary services which might be provided with more certain protection, use radiometric measurements for detection rather than depending on presumed emission signatures;
- not be based on worst-case interference scenarios but overall interference likelihood;
- take account of a site owner's (includes a home owner/building manager) capacity to self-manage interference at that location;
- given the speed of current innovation, be designed with an eye to the future rather than interim technologies; and
- be supported by a competent compliance and enforcement regime including where necessary, registration of the certification of a device and methods of device identification in the field.

8.0 Conclusion

Without an overarching regulatory framework of authentic legal rights made up of practical benchmarks for interference in relation to all mechanisms, it is a mistake to be confident in the ability of a spectrum (space) market to efficiently self-regulate (self-correct) interference. Good spectrum market design requires a level of regulatory supervision striking a balance between innovation and regulation through full disclosure of the interference risks associated with authentic spectrum ownership. Clearly defined mutual responsibility is the only way to manage the interdependent system that is the interference occurring between devices operated within adjacent spectrum spaces. Good market design allows for self-correction without collateral damage.

The BEM of WAPECS was a good start for increasing equipment choice in Europe. Unfortunately, BEM only manages one interference category. Similar benchmarks are needed for all the other categories if interference management is to be made a purely national competence.

In practice, BEM, an explicit transmit right, is clearly superior to Ofcom's proposals for primary limits based on aggregate power flux density (Ofcom refers to their preferred type of limit formulation as 'SURs'). But spectrum and economic efficiency can only be maximised when each spectrum market has a complete pre-defined **set of explicit transmit rights** to provide the **autonomy** to operate **any** technology and service as well as make spectrum trading a practical process.

In general, market design must ensure profit-seeking leads to constructive rather than destructive behaviour. Complete definition supplies all the necessary regulatory oversight. Conflict and delays caused by negotiation with regulators and spectrum neighbours can be eliminated, including destructive equipment standards wars.

Space-centric management establishes practical benchmarks for all interference categories for the spatial dimensions of *Geography*, *Frequency* and *Time* in a unique manner, to provide an authorisation pathway for all technologies and all services without any further negotiation with either the Regulator or adjacent licensees. New equipment can be certified to operate within a day if the necessary spectrum space is available. Device registration in a central online database allows the automation of certification and interference management and facilitates dynamic spectrum access as well as spectrum trading. An accreditation scheme provides a clear chain of liability for device certification. The level of liability involved with certifying compliance of a device with the spectrum access conditions remains manageable. Interference risk and the associated liability always remain clear and calculable.

In Australia, the issue of a spectrum licence has provided very flexible, equitable and authentically legal spectrum access rights which require neither negotiation nor Harmonised Standards for their implementation. Harmonisation occurs naturally as fully independent business decisions. Mixed TDD/FDD and unsymmetric uplink/downlink bandwidth applications are possible, without wasteful restricted blocks/guard bands of a fixed size.

The Australian regulatory framework has operated successfully for over a decade. It has enabled innovation and fast-track roll-out such as the Telstra 850 MHz *Next G*™ network, a world first launched in October 2006. Over 5000 base stations were certified by one person during a 3 month period. This would not have been possible without the commercial certainty offered by the Australian regulations. The spectrum licence conditions were designed in 1996. While politics and economics may change over time, the physics upon which the conditions were established is immutable.

Equally importantly, there has never been any related litigation in Australia and the turnover rate for trading in spectrum licences (not including apparatus licences) from 1998 to 2007 ranged from 1% to 19% per year, averaging at about 8% a year - approximately the same as for commercial property.

Space-centric management can provide a complete regulatory framework for DSA/CR authorisation whether under a centralised or outsourced management model.

