futurepace
RF Solutions

Commercial Certainty in Spectrum Right Formulation

Michael Whittaker, July 2007 (updated October 2008)

Table of Contents

Abstract: *UK industry is mostly now aware of the impractical nature of Ofcom's aggregate power flux density formulation (**A-PFD**) for defining their primary spectrum usage rights. Reaction to the 2.6 GHz spectrum auction proposal has meant the elimination of A-PFD as an option in that auction*[1]*. Ofcom's only alternate proposal for spectrum rights, the '**spectrum mask**' approach, has been accepted by industry more through being the only alternate option provided by Ofcom together with the problems they envisage with the A-PFD formulation, than the innate flexibility provided by 'spectrum mask'. The reduced definition of the mask approach can result in unnecessarily costly and uncertain after-auction negotiation outcomes for licensees.*

*There remains a method of formulating flexible spectrum usage rights referred to as '**space-centric management**' which has minimum dependence on negotiation for its operation and which has already facilitated industry-driven innovation very successfully for over 11 years. While the technical and administrative implementation of the space-centric approach has not been studied in-depth by regulators in either the UK or the USA, it has been utilised in Australia by companies which operate in the UK and USA markets.*

*Space-centric management uses a number of explicit transmit rights i.e. rights that specify maximum radiated power **at** an antenna rather than maximum field strengths **away** from antennas. When correctly incorporated in a robust legal and technical framework, the practical effect of such rights can be to create precise levels of 'guardspace isolation' separately for, and in relation to, **all** interference mechanisms so that once sufficient spectrum is traded, licensees have all the necessary inputs to independently and without further negotiation, including if desired, without a mandatory equipment standardisation process:*

- *design and manufacture any type of new (innovative) technology and service;*
- *authorise the operation of that equipment; and*
- *efficiently self-manage interference between it and all other devices.*

The meaning of guardspace isolation is traditionally defined in relation to devices (device-centric management) where it has the same meaning as coordination, i.e. minimum distance, frequency and time separation between transmitters and receivers in relation to all interference mechanisms, to supplement hardware isolation and achieve interference free operation.

[1] "*BT was pleased to see that, for the awards of these particular frequency bands, Ofcom had decided not to proceed with the use of* (its) *Spectrum Usage Rights (SURs) for the specification of, and demonstration of compliance with, permissible in-band and adjacent band emission limits. We remain broadly supportive of the SUR concept but, along with many respondents to the earlier consultations embracing this topic, we did not believe the proposals were yet sufficiently mature, robust or tested*." **BT** Response to the Ofcom Discussion Document: The award of available spectrum: 2500-2690MHz, 2010-2025MHz, 28 September 2007.

In relation to a spectrum space (space-centric management) managed with explicit transmit rights, specified for all interference mechanisms, 'guardspace isolation' means minimum distance, frequency and time separation for a transmitter's emission levels, between its antenna and the geographic, frequency and time boundaries of the space .

Space-centric management can provide legally clear and technically precise inputs to all the self-managed industry processes that are necessary for commercial investment in innovative wireless services including services utilising cognitive radio and dynamic spectrum access[2].

1.0 Introduction

At the start of 2007, over 5000 WCDMA (850 MHz) base stations had been authorised under Australian spectrum licences during the previous 3 months using an online process. Justin Milne the Group Managing Director of Telstra BigPond said on 20 March 2007 *"Just a few months ago we launched our Next G™ wireless network (WCDMA 850MHz), which is the biggest and fastest mobile 3G network in the world, providing high-speed wireless broadband access to 98% of Australia's population. Because this network is not regulated we've been able to build it in record time and we can sell it at a price determined by the market to recoup our investment over time."* [3]

This simple and efficient authorisation process was only possible because the spectrum being used was administered under Australian-designed spectrum

[2] The space-centric approach is an option (Model 6) offered by CEPT to the European Commission as a framework for their WAPECS initiative see Section 4.4.6 of the public consultation CEPT Report 019, December 2007 at http://www.ero.dk/consultation. Note that Ofcom's aggregate PFD approach (A-PFD) is Model 3 in that document. Preliminary EC views on the interim CEPT/SE42 response were that Model 6 should be studied and adequately described in the final report. The benefit brought by the supporting centralised online device database consisting of industry certified data was also considered noteworthy by the EC.

[3] The Australian *Next G* network, referenced by a number of speakers, was the only example of recent significant innovation to be mentioned at the 2nd European Spectrum Management Conference in Brussels in June 2007. The *Next G* network won the IEC Wireless Broadband 2007 InfoVision Award in Berlin in October 2007 along with Ericsson who won the Broadband Appliances Award for its W25 wireless gateway which acts like a fixed line alternative/replacement for voice, IP Fax and broadband internet communication via the *Next G* and GSM network. Telstra's world-leading role in the deployment of the cutting edge *Next G* network also played a significant role in Australia being chosen in July 2008 to host a new Ericsson LTE Global Competence Centre for research and development, system trials and testing, and development of engineering guidelines, tools and processes for the introduction and operation of LTE networks worldwide, thus placing Australia at the forefront of advances in wireless broadband technology. As of October 2008 it covers 2 million square kilometres and 99% of the population.

licences. In this case there was no need for negotiation just a simple requirement to place certified data into a central online register established by the Australian regulator. The process was fully self managed, business decisions were taken, base stations deployed and authorised and all **without reference to the regulator. Nor was it necessary to negotiate with other licensees.** Importantly the rules that allowed the authorisation of WCDMA850 in 2007 were truly technology and service neutral since they were provided to industry 10 years previously in 1997.

The WCDMA850 innovation success story stands in strong contrast with the UK regulator Ofcom's long drawn out attempt at providing practical technology and service neutral spectrum usage rights see [2], [4], [5] and [6]. Ofcom says that "*A better way to control interference between licensees is to specify in a licence the interference a licensee is allowed to cause, rather than the signal it is allowed to transmit …This new approach is termed 'spectrum usage rights' or 'SURs'*"[4]. In this paper, the manner of formulation of spectrum usage rights by Ofcom which utilises limits for aggregate power flux density is denoted by "A-PFD" rather than by "SURs" (except where the content of an original document is quoted) which within CEPT has now become a generic term for all methods of spectrum usage right formulation.

A-PFD remains more in the nature of a theoretical treatise than an integrated and tested practical solution. To date, Ofcom has published no proposal that is capable of providing the practical and cost effective technical and legal tools necessary for the efficient functioning of a self-managed industry process[5]. Given the amount of time and money which has gone into the design process it is disappointing that greater progress has not been made. So much time had been lost that many industry players asked Ofcom not to further delay release of the 2.6 GHz spectrum whatever the cost in terms of unfinished technical definition. Too much is being left, and unnecessarily left, to later negotiation. At the moment it looks as though UK industry could spend an inordinate amount of time discussing amongst itself a solution for flexible spectrum use which provides industry with operational certainty and a controlled and predictable cost structure for regulatory compliance, when the fundamental principles underpinning that solution have been available now for more than 11 years.

Currently there are few internationally agreed definitions which describe the process of spectrum right design. The terms used in this paper may be quite different to definitions and concepts so far developed elsewhere and with

[4] See paragraph 1.6 of "Spectrum Usage Rights: A Statement on controlling interference using Spectrum Usage Rights", Ofcom, 14 December 2007

[5] "*The proposals and methodology for dealing with interference problems are still immature and need further development.*" **T-Mobile** response to Ofcom's 2.6GHz spectrum award consultation March 2007

which the reader may be familiar and for that reason, the paper needs to be read carefully[6].

Furthermore, this paper only discusses conditions for the operation of new services within the space of a spectrum licence and not the additional tasks of:

- protecting those legacy services which are required to be protected either outside or within the space; and
- on-going authorisation of new services outside spectrum licences.

Legacy services are managed in a different manner and frequencies for new services that are outside but near spectrum licensed space are assigned in a manner which preserves the utility and hence value of the spectrum licences.

2.0 Flexible Spectrum Licences

Regulators issue flexible spectrum licences in order to facilitate market-driven innovation. To maximise innovation, each spectrum licensee, after trading sufficient spectrum space, should be able to independently (or within industry alliances) and without further negotiation with either spectrum neighbours or the regulator (including if necessary, without a mandatory equipment standardisation process):

- efficiently utilise the licence conditions as very clear and precise inputs to an equipment design process for new innovative wireless technologies and services;
- proceed with certainty to authorise the operation of any type of new equipment;
- manage interference between their new equipment and devices operated outside the space of their spectrum licence without:
  - the inefficiencies of worst case over-engineered device coordination rules[7]; or
  - ambiguous interference settlement responsibilities; and
- preserve the utility and value of the spectrum licence, no matter what equipment/service types are being operated in adjacent spectrum licences, by having licence conditions which:
  - are incapable of forfeiture, and where compensation is paid, including by the regulator, for any involuntary reduction in utility; and
  - maintain reciprocal spectrum access[8].

---

[6] For example, (a) the definition of "out-of-band interference" in this paper is not the same as that being used by Ofcom; and (b) the phrase "Defined Interference Potential" used in reference [1] does **not** have the same meaning as "Power Flux Density" discussed in reference [2].

[7] 'Coordination' means minimum distance, frequency and time separation between transmitters and receivers that is used to supplement isolation built into equipment hardware, in order to ensure interference free operation.

[8] Traditional coordination procedures that supplement isolation built into equipment standards can not be relied upon to manage interference across spectrum space boundaries because they lead to non-reciprocal restrictions on spectrum access when applied to cases where dissimilar technology and services are operating in adjacent spectrum spaces.

While trade-offs are necessary, the design must optimally balance all these objectives.

2.1 Spectrum Access Rights

Any rights conferred by the conditions of spectrum licences can be referred to as spectrum access rights. Spectrum access rights are not property rights in a strict sense *i.e.* the spectrum space is not owned, rather they are property-like rights to utilise (access or operate a device within) a defined spectrum space subject to certain restrictions. Only the law can guarantee security of expectation in being able to utilise, retain and trade spectrum access rights. One of the main functions of legal systems is to provide remedies for breach of rights including payment for damages. If a right is breached, the right owner has a valid claim on society to protect him in the possession of it. Therefore, spectrum access rights should be written in a manner which is very clear in the way they define the extent of spectrum utilisation or access and where necessary, include pathways for compensation for any involuntary reduction in those rights.

The Australian spectrum licensing regime was specifically intended to embody a very high level of regulatory certainty for licensees and therefore required a new type of technical definition to achieve minimal negotiation and hence minimal cost and uncertainty in relation to wireless network rollout and interference management[9].

"Parliament intended that the allocation of spectrum licences should be more akin to a commercial dealing than the mere dispensation of a licence in the exercise of some prerogative power and the entrenching of the spectrum access rights within the existing legislative regime was particularly important. Until a licence is issued, there is nothing to sell. The most that could be sold before issue would be a right to the issue of a licence, but this would have seriously complicated both the process of 'sale' and the legislation. The better view would appear to be that the Act evinces a clear intention that the issue of spectrum licences should take place in a form of quasi-contractual dealing between the Regulator and prospective applicants. The quasi-contractual nature of the dealings is reflected in such documentation as the 'Deed of Acknowledgment' required by the allocation procedures. It is also reflected in the fact that prior to every spectrum auction the prospective licensees have been greatly concerned to know precisely what spectrum access rights they will obtain in return for the sums of money that they pay to the Commonwealth. In this regard the price-based allocation of spectrum is no different to any other

[9] That spectrum licences were intended to provide a licensee with "explicit and continuing rights" is clear from the second reading speech for the *Radiocommunications Bill 1992 (Cth)*. See Commonwealth, *Parliamentary Debates*, House of Representatives, 26 November 1992, 3754 (Mr Martin) at 3755.

commercial dealing, in which certainty is always a primary consideration. Indeed, when price-based allocations of spectrum were developed by the former Spectrum Management Agency (first for the allocation of apparatus licences and later for the allocation of spectrum licences), considerable resources were expended in achieving the degree of certainty, as regards both the allocation system and the spectrum rights, that would allow prospective licensees to commit major funds. The success of that approach is reflected in the success of the allocations, which have not suffered in any way from the difficulties experienced in overseas jurisdictions."[10]

The high level of commercial certainty required for an Australian spectrum licence derives from its nature as an indefeasible company asset as opposed to the mere dispensation of a licence thus necessitating a rigorous approach to the technical construction of licence conditions. Authentic spectrum rights which devolve the full task of spectrum management to industry were essential. Importantly, the technical conditions had to be constructed in a manner which promotes innovation by having no reliance on mandatory equipment standardisation processes.

The situation regarding Ofcom's licences is much less certain. *"The detail, scope and legal certainty of the current proposals are insufficient to ensure a robust business case for continued investment, or for this to be undertaken with an efficient cost of capital. There needs to be increased certainty regarding:*

- *what spectrum users would be buying;*
- *what rights they could enforce;*
- *what compensation they could seek; and*
- *the speed with which interference could be identified and resolved.*

In the absence of such increased certainty investors will be reluctant to provide funds to mobile operators for the acquisitions of spectrum subject to SURs (A-PFD), or to provide funds at a cost that will enable operators to engage in further investment on an efficient basis. Similarly the value of any spectrum acquired will be difficult to determine" [11]**.**

For the avoidance of doubt, Ofcom eventually clarified that its spectrum access licences were not exclusive and that there is little likelihood of compensation if Ofcom requires changes to licence conditions which reduce 'rights' (spectrum utility) without licensee agreement[12]. Ofcom has reserved its right to issue

[10]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)

[11] **T-Mobile** Response to the Ofcom Consultation on Compliance Issues for Spectrum Usage Rights Licences, November 2007

[12] Involuntary reduction can occur, for example, by Ofcom varying 2.6 GHz licences by introducing new national and cross-border spectrum sharing requirements.

additional licences after the auction for use of all or part of the auctioned spectrum and no refund will be made except at the absolute discretion of Ofcom[13].

2.2 Property Rights for a Spectrum Market

The economy is a highly complex system. Whether any particular market works well or not, depends on its design. A pragmatic approach is necessary. The challenge of market design is to devise mechanisms, or to allow mechanisms to evolve, that channel the pursuit of profits in a socially productive direction.

A basic part of the government's role in market design is the defining of property rights. While contracts can solve certain problems, ownership is society's way of handling the unexpected. The surest way to destroy a market is to undermine people's belief in the security of their property. Ownership is the strongest source of incentive for productive effort and risk taking. Only where property exists underpinned by society (a legal system or equivalent cultural mechanism) can there be a market. Property rights require action by the State and they can be difficult to set up. Externalities (interference) can be resolved by bargaining within a framework defined by the law. Any externality can be viewed as resulting from the incompleteness of property rights. Since correcting an externality results in extra value being created, the market participants have an incentive to address it, and sometimes, given well defined property rights, it is possible to do so. Externalities are ubiquitous, so every one of them cannot and should not be taken into account, but where they are sizeable, they must be addressed if the market it to be workable. The design of the market mechanism has to recognise significant interdependencies. Interference between devices is highly interdependent.

Spectrum licensees must be given autonomy. Where an authority relationship exists – one party is in charge of the other, or a higher authority is in charge of them both – then any transactions are not market transactions. No one is in charge of an authentic market. Decentralisation brings dynamism. Free decision-making is the key.

A viable market has five important elements:
1. information flows smoothly;
2. property rights are protected;
3. people can be trusted to live up to their promises;
4. side effects on third parties are curtailed; and
5. competition is fostered[14].

[13] See para 2.14 and Annex 1, para 10 "Auction of spectrum: 1452 – 1492 MHz, Information Memorandum Update" 13 March 2008

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

2.3 Spectrum Right Formulation Options

The level and likelihood of interference between devices operating within spectrum space depends on the electrical characteristics of each device and the spacial relationships between them and is therefore, interdependent. Paradoxically, in an interdependent system, authentic freedom (flexibility) can only exist within a complete set of unambiguous rules.

Spectrum rights can be described as the rules of interaction between devices operating within adjacent spectrum spaces. The basic size of a spectrum space is specified by 5 dimensions: frequency (1), time (1) and volume (3). Quite a few more rules are required to ensure the rules for managing device interaction *i.e.* managing interference, are unambiguous.

Spectrum rights to manage interference can be formulated according to three different methods – see Table 1.

Table 1 – Options for Spectrum Right Formulation

Spectrum Right Formulation	**Rights Formulated using Field Strength Limits at each Antenna Inside a Spectrum Space, variable as a function of separation from the Spectrum Space boundaries**	**Rights Formulated using Field Strength Limits throughout (Outside/Inside) Defined Spectrum Spaces** (see text for explanation of the single row in this column.)
Explicit Transmit Rights (Implicit Receive Protection)	***(RP)*** Radiated Power Limits at each Antenna **Inside** a Spectrum Space *e.g.* Space-Centric Management (Australian Government policy) see Whittaker M. "Flexible Radio Spectrum Access" March 2006 [1]	***(FS)*** Field Strength Limits **Outside/Inside** a Spectrum Space *e.g.* Ofcom's spectrum usage rights (A-PFD), 12 April 2006, [2] and [4] see also Matheson R., Morris A. "*The Technical Basis for Spectrum Rights*" 3 May 2007
Explicit Receive Rights (Implicit Transmit Allowance)	***(IP)*** Limits for Received Interference Power at each Antenna **Inside** a Spectrum Space *e.g.* Modified ITU 'harmful interference' - variable receiver protection as a function of separation from space boundaries	***(FS)*** Field Strength Limits **Inside/Outside** a Spectrum Space *e.g.* 'Indicative Interference Levels' of A-PFD

With reference to Table 1, spectrum rights formulated as field strengths **throughout** spectrum spaces *i.e.* ***FS,*** can not be unambiguously described as either explicit transmit rights or explicit receive rights because each spectrum licensee is also a neighbour to another spectrum licensee and therefore field strength limits outside a space (transmit rights) are also the same field strength limits inside a space (receive rights). The term "explicit" is only appropriate for rights which specify precisely what is permitted to occur at each antenna operated by a spectrum licensee (Space-Centric Management (S-CM)) rather than, in the case of transmitters, specifying what probabilistic levels they all might cause to occur throughout a spectrum space (A-PFD/transmit) or in the case of receivers, what probabilistic interference levels they may experience

throughout a spectrum space (A-PFD/receive – Ofcom's Indicative Interference Levels).

This paper compares the commercial certainty provided by two formulations:

RP (Radiated Power)

> Spectrum rights formulated as maximum power permitted to be radiated **at** each antenna **inside** the spectrum space of a licence, see reference [1]; and

FS (Field Strengths)

> Spectrum rights formulated as maximum field strengths **throughout** spectrum spaces caused by the sum of powers radiated by transmitters **inside** the spectrum space of a licence, see reference [2].

Different spectrum right formulations, when utilised in particular technical constructions and legal frameworks, can lead to very different levels of commercial certainty and spectrum efficiency in regard to fostering innovative market-driven equipment design, equipment authorisation and interference self-management. This paper discusses ***RP*** as utilised in the Australian Space-Centric Management (S-CM) regime and formulation ***FS*** as utilised in the UK A-PFD regime.

2.4 The Benefit of Explicit Transmit Rights

Radio spectrum has been traditionally allocated on the basis of a licensee's right to use spectrum under the expectation that 'harmful' interference will not be experienced. Regulators have traditionally managed spectrum with their focus on receiver protection. The term 'harmful interference' 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*" and features extensively in relevant legal instruments. Because of the rather imprecise nature of this definition, interference management continues to involve high levels of compromise, consensus and collaboration between Member States. Some regulators tend to believe that the same process will work for their spectrum licences and are delivering partial solutions for spectrum rights which consequently require interference to be managed through much industry negotiation. In the absence of clear interference benchmarks for all interference mechanisms, licensees are left with no authoritative reference for these negotiations and being fearful of litigation can lose significant levels of spectrum utility through worst-case spectrum planning.

A recent report on radio interference regulatory models[15] explores "*the possibility of using interference definitions as a method of defining the rights of spectrum users in a liberalised environment*." The report "*suggests that a single universal definition of harmful interference suitable for all applications and technologies is unlikely to be realisable*". This result is not unexpected given the many years the ITU has wrestled with trying to quantify and give practical meaning to 'harmful interference'. Defining unacceptable levels of interference has never been straightforward. For flexible spectrum access, an interference level which causes problems for one technology may be inconsequential for another. Hence, Ofcom's attempt to "*specify in a licence the interference a licensee is allowed to cause - SURs"*, began with an already long unsuccessful history.

What a legal right comprises depends on what is said by what confers it. A right may be conferred 'positively' or 'negatively'. 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.

Explict transmit rights require no regulatory constraints on receiver design. Protection from interference is specified indirectly rather than directly. A spectrum licensee designs a network to cope with the levels of interference that are encountered when adjacent licensees operate their transmitters in accordance with their explicit transmit rights. The spectrum licensee decides which interference levels could be indeed harmful to its technology and service and designs its network accordingly. Such a process constitutes market-determined 'harmful interference'. With explicit transmit rights there is no requirement for regulators to define unacceptable interference levels and in this sense, the rights are incomplete. However, this aspect of the design provides a pathway through which licensees can later extract economies because they are not constrained by an inappropriate definition of actual interference. Importantly, the explicit transmit rights must contain a full set of benchmarks for all interference mechanisms in order to maximise that extraction efficiency.

For the avoidance of doubt, explict transmit rights relate to power radiated at an antenna and are independent of whatever interference is experienced at a receiver. It is a complete reversal of our conditioned way of thinking but a

[15] "Study on Radio Interference Regulatory Models in the European Community, 29 November 2007" commissioned by the EC and released 10 April 2008

useful option that is commonly overlooked for the definition of rights for flexible spectrum access. Of necessity, use of explicit transmit rights as primary rights together with implicit (secondary) receive protection requires a complete about face for the legal definition of 'harmful interference' for example, "*means interference caused by transmitters not operating in accordance with applicable Community and national regulations*". Such a definition could be used within the EU (but not necessarily outside its geographic boundaries) and be precisely implemented based on limits for power radiated at an antenna rather than receiver protection – see [3].

Only ***RP*** can be correctly described as an explicit transmit right since as already discussed, ***FS*** is somewhat ambiguous in this regard.

RP and ***FS*** limit resulting field strengths in different ways:

RP rights that directly limit the radiated power at each transmit antenna inside the space of a spectrum licence (in this case, field strength limits are set indirectly); or

FS rights that directly limit field strengths throughout spaces (outside/inside) of spectrum licences (in this case, field strength limits are set directly).

In both cases, licensees must use the information provided by the rights to self-manage interference. Because the same propagation loss variability determines, in the case of ***RP***, the statistics of the resulting interference levels and in the case of ***FS***, the allowed maximum transmitter levels, neither approach has the ultimate capacity (which depends on the overall legal and technical regime) to provide better accuracy for interference self-management than the other. Therefore, Ofcom's assumption (see [5] page 32) that for a transmitted PSD (Power Spectral Density) approach (*i.e.* ***RP***) "*power levels are a* ***relatively*** *inaccurate indication of the interference that can be expected by neighbours*" is incorrect. However, Ofcom's observation that a transmitted PSD approach (*i.e.* ***RP***) "*has the advantage of being simpler for the licensee or Ofcom to confirm that the licensee is within its limits since no modelling or measurement campaign is required*" is quite correct and is the reason why greater commercial certainty and lower costs can be achieved with ***RP***[16]. There are also significant additional spectrum efficiency benefits resulting from the use of ***RP*** which are discussed in Section 6 of this paper.

[16] Further in that extract, Ofcom mentions they have performed "*some modelling work*" concerning certain difficulties with TDD in relation to using a transmitted PSD approach. However, their problems are caused more by their over-simplified interference benchmarks for management of interference and lack of a comprehensive central device database. Ofcom also mentions that use of modelling for verifying compliance will now apparently "*reduce the complexity*" of their SURs approach. This has not yet been demonstrated especially without leading to loss of spectrum utility through over-simplification.

3.0 Interference Management

Whatever the choice of spectrum right formulation, ***RP*** or ***FS***, the spectrum rights should provide sufficient information to enable each licensee to efficiently self-manage the three categories of interference which occur in relation to adjacent spectrum spaces (see Figure 1)[17]:

- Category A (linear: in-band interference from area-adjacent spectrum licences)
- Category B (linear: in-band interference from frequency-adjacent spectrum licences)
- Category C (non-linear: out-of-band interference from frequency-adjacent spectrum licences)

The phrase "efficiently self-manage" means that sufficient information is made available to each licensee relating to each interference category so that:

- worst case over-engineered device coordination is not necessary;
- interference settlement responsibilities are very clear;
- very costly field strength measurements are never required; and
- equipment standardisation processes are voluntary rather than mandatory.

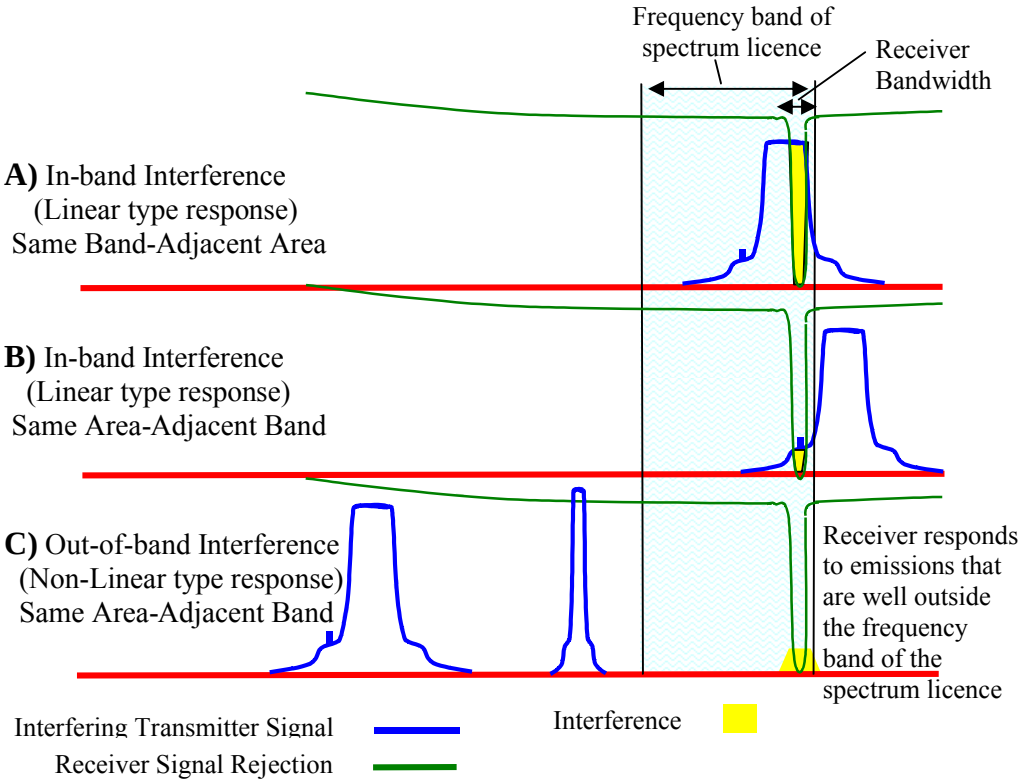
The bottom line is that in a self-managed process, someone in industry must be prepared to accept liability for certifying compliance with the licence conditions in order to authorise operation. Spectrum right formulation that results in excessive compliance certification costs because of high uncertainty/liability levels or alternately, very poor spectrum utility from fear of litigation, at best severely reduces the value of those rights and at worst renders futile the original purpose for spectrum rights' development.[18]

---

[17] When the spectrum licence is shared, there is a fourth category of interference "same area-same band" (see "Study on Radio Interference Regulatory Models in the European Community", Final report for the EC by Eurostrategies and LS Telcom, 29 November 2007). The management of incumbent legacy services which may share a space is not discussed here but it involves the fourth category of interference. In this case related spectrum access rights to manage that interference are designed by the regulator. For new services under a market-driven rather than centralised approach, the necessary interference benchmarks for spectrum sharing would be established by each spectrum licensee not the regulator and may involve use of cognitive radio for dynamic spectrum access. 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 spectrum licence. In some interference scenarios, time-related limits have been used as benchmarks for radiated power in otherwise 'exclusive' spectrum.

[18] "*A right only has value if it is capable of being enforced. Vodafone believes that, for proposed approach for SUR, the costs of enforcement to the affected licence holder can be so great as to make the rights unenforceable in practice.*" **Vodafone** response to Ofcom's 2.6GHz spectrum award consultation March 2007

Figure 1 – Three Categories of Interference



3.1 Device-Centric Management

Traditionally, three interference categories are considered in the design of any equipment standard. Hardware isolation is designed separately for, and in relation to, each interference Category A, B and C.

In addition, before operating equipment, the hardware isolation is supplemented by a coordination procedure where guardspace isolation is provided between transmitters and receivers, also separately for, and in relation to, each interference Category A, B and C.

For example, **Hardware Isolation:**

(a) Category A: *e.g.* minimum wanted-to-unwanted ratio
(b) Category B: *e.g.* out-of-band transmitter emission and receiver IF filter roll-off characteristics
(c) Category C: *e.g.* receiver RF filter and interference susceptibility

Guardspace Isolation:

(a) Category A: *e.g.* co-channel reuse distance;
(b) Category B: *e.g.* adjacent channel(s) reuse distance
(c) Category C: *e.g.* blocking and intermodulation checks

3.2 Space-Centric Management

'Guardspace isolation' in relation to devices (Device-Centric Management) has the same meaning as 'coordination', *i.e.* minimum distance, frequency and time separation between transmitters and receivers in relation to all interference mechanisms, to supplement hardware isolation and achieve interference free operation. In relation to a spectrum space (Space-Centric Management) managed with explicit transmit rights, specified for all interference mechanisms, 'guardspace isolation' means minimum distance, frequency and time separation for a transmitter's emission levels, between its antenna and the geographic, frequency and time boundaries of the space .

4.0 Spectrum Right Regime using *RP*: Australia's Space-Centric Management

Space-Centric Management (S-CM) in Australia utilises ***RP*** for the technical construction of licence conditions and operates by limiting power at a transmit antenna inside a spectrum space in order to limit field strength, in clearly defined ways, outside the spectrum space. While the field strength that results is generally described as a 'defined interference potential' (see [1] and [3]) its practical effect is to create precise levels of guardspace isolation separately for, and in relation to, each interference Category A, B and C.

S-CM limits radiated power at each transmit antenna in order to establish **precise levels of guardspace isolation at spectrum space boundaries** in relation to the three interference categories:

(a) Category A (linear) at the geographic area boundary: **device boundary criterion** established for the complete licence boundary;
(b) Category B (linear) at the frequency boundaries: **radiated out-of-band emission limits** for each antenna; and
(c) Category C (non-linear): **maximum in-band limit** plus **model coordination procedure** (minimum frequency-distance requirements) in relation to a licensee's new device and existing registered devices operating **outside** the area and frequency boundaries of the spectrum licence.

For example, the device boundary criterion authorises transmission (but only in relation to Category A interference) when certain distances from the transmitter, calculated according to the power the device radiates in radial directions as well as its effective antenna height in each radial direction, are fully contained by the geographic area of the spectrum licence. The device boundary criterion is a single, precisely defined algorithm contained in a legal Determination. This ensures the spectrum rights in relation to Category A interference are perfectly precise and clear - see Figure 2 for more information (extract taken from reference [3])[19]. The device boundary is specially formulated to take broad account of terrain height variations because taking detailed account is impractical for the purpose of defining spectrum rights. Furthermore, precise legal conditions are defined for a self-consistent set of radiated out-of-band emission limits (Category B interference) and the model coordination procedure (Category C interference).

S-CM allows a licensee to self-manage interference between his devices and any devices operating in adjacent spaces without negotiation because **the licensee can simply and independently, precisely determine the necessary hardware isolation on the basis of the precise levels of guardspace isolation provided by the spectrum rights**.

Figure 2 - Extract of Paper

The device boundary criterion should not be viewed as a model for coverage or service area. It is a clearly defined transmit right, independent of what levels may actually occur on, or past a geographic boundary. The primary objectives when designing the device boundary criterion are:

- to establish a single, clear and legally robust rule for the transmit right and thereby, the settlement of Category A interference without difficulty including without legal intervention; and
- for wireless network design purposes, inform area-adjacent spectrum licensees of the maximum level of in-band power that can be radiated in a particular direction from a particular site at any time during the licence period so that those licensees may act to protect their receivers.

Secondary objectives when designing the device boundary criterion are:

- to allow area-adjacent licensees to establish services as close to the common geographic boundary as possible without having to resort to the cost and uncertainty of negotiation; and
- if negotiation turns out to be necessary, set a clear starting point from where negotiation may progress.

Licensees use the device boundary criterion as a starting point for their proprietary coordination procedures, which include high resolution propagation models of their own choice, to establish the necessary level of receiver protection from interference caused by transmitters in area-adjacent licences.

Copyright © 2006 by Michael Whittaker 9

[19] A more detailed description about the implementation and objectives of the device boundary, radiated out-of-band emission limits and model coordination procedure is contained in [3]. Note that the ITU paper [3] speaks in terms of "interference potential" rather than "precise levels of guardspace isolation". These are the two sides of the same coin except that "guardspace" is probably a more immediate term for the equipment designer.

The rights provide a fixed level of guardspace isolation while hardware isolation (equipment design) remains a variable. Instead of having equipment design driving the levels of guardspace isolation (the traditional manner in which device-centric coordination rules are designed), the process is reversed with the guardspace isolation of S-CM (the spectrum rights) driving equipment design. If necessary the guardspace isolation may also be varied using the licence conditions as clear negotiation benchmarks. However, negotiating a different level of guardspace isolation is effectively the same as trading spectrum space. Provided sufficient spectrum space is first obtained, spectrum licensees can be confident that new equipment designed according to the licence conditions (if necessary, without undergoing an equipment standardisation process) will be able to be authorised to operate and then efficiently coordinated with devices authorised under adjacent spectrum licences.

Under S-CM, business type neutrality or information content neutrality is always assumed to be the case and therefore ***service means*** *"characteristics of equipment deployment within the 5 dimensions of spectrum space"* and ***technology means*** *"characteristics of equipment which are independent of deployment within spectrum space"*..

S-CM offers a high level of commercial certainty through the very precise and clear technical, and perhaps more importantly, legal definitions, that ***RP*** makes possible for the authorisation of transmitters. So precise in fact that:

- litigation is actively discouraged because requirements for compliance are very obvious (neither are costly field strength measurements ever required);
- innovation is encouraged because each spectrum licensee may, without negotiation, independently (or in industry alliances):
  - design new (innovative) equipment;
  - authorise that equipment; and
  - efficiently self-manage interference.

There has been no litigation in 11 years of operation with Australian spectrum licensing and companies such as Ericsson and Motorola have been able to utilise the rights of their client's Australian spectrum licences to provide turnkey wireless networks without any problems arising.

5.0 Spectrum Right Regime using *FS*: Ofcom's Aggregate PFD Approach

The essential design proposals of Ofcom's spectrum usage rights (A-PFD), [2] later amended by [5] (later amendments shown in blue highlight) are:

(a) in relation to Category A interference: the aggregate power flux density (PFD) at ~~or beyond~~[20] [definition of geographic boundary] should not exceed X_1 dBW/m^2 /[reference measurement bandwidth] at a ~~any~~ height ~~up to~~ H m above ~~local terrain~~ ground level ~~for more than P% of the time~~ at more than Z% of locations;

(b) in relation to Category B interference: the aggregate out-of-band PFD at ~~any point up to~~ a height H m above ground level should not exceed X_2dBW/m^2/MHz ~~for more than Y% of the time~~ at more than Z% of locations in ~~any~~ a test area[21] ~~A km^2~~ ;

(c) in relation to Category C interference: the aggregate in-band PFD at ~~any point up to~~ a height H m above ground level should not exceed X_3dBW/m^2/MHz ~~for more than Y% of the time~~ at more than Z% of locations in ~~any~~ a test area ~~A km^2~~

Ofcom's concept of spectrum rights using A-PFD is the direct specification of the interference a licensee is allowed to cause. In spite of whatever degree of future amendment they might undergo, it is not possible to **easily or efficiently** translate the primary rights of aggregate interference field strengths into precise and clear design criteria for new innovative equipment[22]. Nor does it simplify, as Ofcom contends, the process of spectrum neighbours negotiating amended interference levels.

---

[20] As CEPT has previously discovered, removal of "or beyond", a seemingly innocuous change has unfortunate consequences. See para 6.12 of reference [5] "*To verify compliance to a geographical PFD limit, the 'victim' licensee highlights a reference point on the geographical boundary where they believe that interference is occurring".* It is first rather unlikely that actual interference will be occurring **on the boundary** and second, it will be further complicated when high terrain exists past the boundary. Note that the test points found from "radius R", which is to be specified in the licence, "*are expected to be located along the relevant segment(s) of the boundary".*

[21] An example of a test area provided by Ofcom is a square area containing at least 10 transmitters.

[22] "*The SUR specification of out-of-band and in-band interference is not **easily** translated into the emissions mask requirements needed for the design and manufacture of radio transmitters, receivers, and systems. This could lead to a possible inconsistency between equipment specifications and regulatory requirements.*" **Motorola** response to Ofcom's 2.6GHz spectrum award consultation March 2007

5.1 Implementation Difficulties

The need for commercial certainty immediately led Australia to a pragmatic solution whereas the initial UK proposal was in the nature of a theoretical treatise which tried to manage interference rather than provide UK industry with practical tools that enabled them to manage interference by themselves. While Ofcom's ***FS***/A-PFD approach is at first, theoretically appealing (primary rights that directly specify the interference a licensee is allowed to cause rather than the signal it is allowed to transmit), it is impractical to implement. The ***FS***/A-PFD formulation will never constitute an optimum technical and legal solution. The optimum form for spectrum rights is always an integrated and balanced technical, administrative, legal and economic solution.

Much of the initial debate in the UK focussed on economic issues. The desired outcome of effective management of interference cannot be achieved by relying on the application of economic principles alone. Design optimisation requires trade-offs that can lead to use of alternate technical forms of spectrum rights which take better account of the totality of issues. Ofcom's initial consultation document incorrectly assumed that the technical form of spectrum rights can be defined first without considering all administrative, legal and economic factors[23]. On one hand, over-focus on some aspects of the definition of spectrum rights created an impractically detailed and complex proposal that led to an unnecessarily high level of regulatory control, audit and consultation requirements[24, 25]. These requirements are anathema to a business needing to operate efficiently in a competitive market. On the other hand some other important aspects of technical definition were ignored.[26]

It is not administratively practical to establish spectrum rights which manage the level of interference at a detailed level, for example, rights directly involving field strength measured away from transmit antennas for certain percentages of locations (and time). Instead, pragmatic limits that are technically clear and legally robust must be adopted which subsequently support licensees in self-managing the actual level of interference and at a detailed level.

---

[23] "*This consultation only addresses the technical aspect, and it is not clear how the technical parameters would be applied to a legal framework of rights and obligations.*" **Vodafone** response to Ofcom consultation on Spectrum Usage Rights, June 2006

[24] "*Motorola is concerned over the feasibility of actually controlling interference using a regulatory regime based on the level of complexity that will be produced by the current proposals.*" **Motorola** response to Ofcom consultation on Spectrum Usage Rights, June 2006

[25] "*The main disadvantages of SUR using PFD are that they are complicated to define, the relationship to current license conditions is opaque, and their practical feasibility is unproven.*" **Vodafone** response to Ofcom consultation on Spectrum Usage Rights, June 2006

[26] See PolicyTracker "Will Ofcom's spectrum usage rights deliver?" 20 June 2006.

5.2 Field Measurement versus Modelling

Implementation difficulties led Ofcom to a more pragmatic approach. As of September 2007, Ofcom allows either propagation modelling or field measurement[27] to verify compliance with the primary rights *i.e.* ***FS***. Ofcom now states that "*modelling is our preferred option for verification of compliance*" and "*SUR (A-PFD) licensees can request a change of the licence verification method*" to either modelling or measurement. Furthermore, "*Ofcom* (now) *believes that in almost all cases, the only practical method to verify interference across geographical boundaries will be by modelling*"!

When:

- modelling is allowed to verify compliance with ***FS***; **and**
- a single model has been fully defined for all device deployments[28]; **and**
- the model is legally established by Ofcom as the only method to be used;

the aggregate PFD limits are then not the primary limits or primary spectrum usage rights, becoming merely a part of the calculation by which limits on transmit power radiated at an antenna are obtained. The primary restriction then becomes the radiated power **at** the antenna not field strengths away from antennas, *i.e.* not the actual levels of the interfering field strength. Thus use of modelling for compliance can result in Ofcom's concept for spectrum usage rights no longer being applied, that is, **primary rights** as the **direct specification** of the interference a licensee is allowed to cause, is no longer occurring. However, since "*SUR (A-PFD) licensees can request a change of the licence verification method*" to either modelling or measurement it is presently unclear whether Ofcom envisage their spectrum usage rights (Aggregate PFD) as always being the primary rights.

Basic detail about licence conditions incorporating propagation modelling to support both FDD and TDD operation has been published by Ofcom [6]. There are a steadily increasing number of pragmatic elements in the porposals *e.g.* the PFD limit to manage interference across the geographic boundary used to be "at or beyond" the boundary. Now it is simply "at the boundary" and "at" is to be specified as a distance "R". Over-simplification will not provide, as Ofcom has claimed for its aggregate PFD spectrum usage rights, more certainty as to

---

[27] Ofcom's original SUR consultation document proposed that "*In order to determine whether there is undue interference from a neighbouring licensee a process of measurement is required.*" A procedure for measuring received signal levels was given.

[28] "*BT can provisionally support the specification of emission rights at 95% of locations. However, full support would be conditional on satisfactory testing with an agreed combination of propagation model, terrain database and clutter database.*" **BT** Response to the Ofcom Consultation Document: The award of available spectrum: 1452-1492 MHz, 11 September 2007

interference levels throughout a neighbouring geographic area.[29] In general, the final licence conditions will be quite complex compared to the simpler conditions of S-CM and therefore, more costly for licensees to implement and maintain. Importantly, the practical need for the level of operational restrictions imposed by the final licence conditions has not been fully assessed with Ofcom leaving any inefficiency to later negotiation between adjacent licensees.

Overall, the design is hamstrung by the premise on which their spectrum usage rights have so far developed (*i.e.* providing licence conditions claimed to manage interference at a detailed level rather than pragmatic licence conditions providing clear and precise benchmarks which make it practical for licensees to self-manage interference) and is unlikely to provide legal or technical certainty for licensees because it offers many opportunities for ambiguity. Ofcom's licence conditions are disproportionate compared to the simpler conditions of Australian spectrum licences. Given the effective conceptual reversal caused by the use of modelling (the primary rights are no longer direct specification of the interference levels a licensee is allowed to cause) a rethink of their original formulation for spectrum usage rights would be beneficial[30].

In terms of formally defining legal rights for licensees, sophisticated propagation models are very complex and difficult to draft in strict legal terms (being called up as a software package is also not legally appropriate)[31].

---

[29] "*We also have some concerns that paragraph 2.7 of the consultation suggests that interference should be assessed on the geographical boundary. As few (useful) propagation models are monotonic, it's possible that interference would be acceptable on a boundary, but not at certain points beyond it.*" **BBC** Response to Ofcom Consultation: Spectrum Usage Rights: Licence verification approaches 9 February 2008

[30] "*Orange strongly believes that Ofcom should spend time ensuring that the framework for the implementation of SURs is correct prior to attending to compliance issues.*" **Orange** response to Ofcom consultation 'Spectrum Usage Rights: Further Information', November 2007

[31] "*ITU Recommendation P.1546 is a well-respected propagation model. However, it contains a number of alternative assumptions and optional steps, and it is intended for engineering purposes* ***rather than for the definition of legal rights****. The model is described largely in words, which are not always precise. As a result, the implementations of this model in different software planning tools can produce different, but equally valid, results. It is therefore not sufficient for the schedule of the licence to make a general reference to the ITU Recommendation; Ofcom needs to specify an explicit algorithm based on P.1546, and all of the associated assumptions. All propagation models are only valid over certain ranges of parameters, and P.1546 is no exception. We are concerned that Ofcom is proposing to use this propagation model outside of its stated range of validity. It is unclear how meaningful the results will be in many situations, and indeed whether the model can be applied at all in some circumstances. There is no evidence in the consultation document that Ofcom has tested its proposals.*" **Vodafone** response to Ofcom consultation on 1452 – 1492 MHz; August 2007. Note also that Ofcom's much heralded software modelling tool is no longer being provided to industry because Ofcom apparently "do not expect there to be a role for our modelling tool"! Licensees would view access to the tool quite differently as providing commercial certainty -

Sophisticated, propagation models are in a continuing state of refinement and can not be "set in stone" as a critical element of spectrum rights.

Noting that different technical constructions of ***RP*** and ***FS*** are possible, what follows is a strict comparison of spectrum right formulation ***RP*** as expressed by S-CM (Australian regime) with formulation ***FS*** as expressed by A-PFD (UK regime), that is, in the case of the UK, all affected licensees have either:

- elected field measurement for establishing compliance with the A-PFD; or
- the propagation model for compliance with A-PFD is:
  - not singular (not free of ambiguities and discontinuities); or
  - not fully defined for all device deployments; or
  - not legally formalised as establishing the primary rights.

The differences between S-CM and A-PFD are substantial.

6.0 Comparison of Spectrum Right Regimes *(RP/S-CM* and *FS/A-PFD)*

For both S-CM and A-PFD regimes, licensees must use the information provided in the spectrum rights to self-manage interference. As a general observation, only the ***RP*** spectrum right formulation can provide a precise legal definition, unaffected by the uncertainty associated with field strength prediction. This has a very significant consequence. It means licensees do not have to apply worst case design techniques out of fear of litigation. The problem with an ***FS*** spectrum right formulation is that all the rights are dependent on a field strength away from a transmit antenna where the measurement/prediction uncertainty makes them impractical and inefficient as spectrum rights for both technical and legal reasons.

The unfortunate outcome of an ***FS*** formulation for legal rights is that a spectrum licensee has to be over-careful about signal levels that might be received by other spectrum licensees. ***RP*** is the only approach where a spectrum licensee need only worry about interference to **his own receivers.** This removes the inefficiencies associated with worst case over-engineered coordination caused by fear of litigation. With an ***RP*** formulation a spectrum

---

Ofcom unlikely to disagree with the results of its own software in settling an interference dispute. "*Two key issues require validation: Are the SUR completely and unambiguously defined? and How reliably do the SUR equate to the interference experienced by spectrum users? The first of these can be validated by Ofcom developing a modelling tool for the assessment of SUR. We believe that Ofcom needs to do this as a 'due diligence' activity. Once it has done this, it would be straightforward for Ofcom to make this tool publicly available. We therefore believe that Ofcom reached the wrong conclusion on this point in its Statement on SUR. We are not aware of any commercially available tool that is capable of implementing Ofcom's SUR without substantial development. The companies in this field are generally small. They could be very reluctant to develop their tool for this purpose, because of the risk of exposure to legal action over SUR resulting from disputed implementation of ambiguous definitions*." **Vodafone** response to Ofcom consultation on Spectrum Usage Rights, January 2008.

licensee decides how much additional (or less) guardspace they need in order to protect **their own** receivers using whatever proprietary propagation models they wish to use. Except for any legacy receivers requiring protection (protection of legacy devices is not dealt with in this paper), the licensee has no concern whatever for the receivers of adjacent licensees.

With an ***RP*** formulation of spectrum rights the licensee is able to determine whether the precise levels of guardspace are appropriate for their equipment. If they need less guardspace, they have excess and can relax hardware requirements or sell the excess to adjacent licensees, if they need more guardspace they tighten hardware requirements or purchase additional guardspace from their neighbours. In general, licensees prefer to utilise isolation provided by hardware rather than involve themselves in the uncertainties of negotiation to obtain additional guardspace isolation. They are able to calculate their requirement for total isolation on the very clear transmit rights for each antenna provided by an ***RP*** formulation and not on the uncertainty of what field strengths might or might not be created throughout a spectrum space required by an ***FS*** formulation. While industry negotiation might be an optimal approach for a regulator to rid itself of responsibility in designing a workable systems of spectrum rights (*e.g.* by providing partially defined spectrum rights and leaving the undefined elements to industry negotiation), it is not a cost-efficient approach for the licensee at all.

Furthermore, it is more important for the parameters of all the necessary spectrum rights to have been established, than the particular numerical value of each parameter selected (the level of guardspace isolation provided by the spectrum licence conditions). The parameters for ***RP*** establish spectrum value by providing clear and precise benchmarks for spectrum licence utility before a spectrum auction or before spectrum trading, as well as clear benchmarks with which to begin negotiation between licensees, if that ever becomes necessary. Importantly, the spectrum licensee purchasing the licence, not the regulator, decides the utility of the parameter values in relation to the type of equipment they wish to operate. Therefore, to enable an efficient spectrum market to develop, it is more important for the regulator to first establish all the necessary benchmarks, than what particular level of guardspace may have been pre-determined by the regulator in setting those benchmarks.

6.1 Comparison of RP and FS Formulations – Category A interference

Category A interference is **linear-type** in-band interference from transmitters operated under area-adjacent spectrum licences.

The essential difference between ***RP*** and ***FS*** formulations in relation to Category A interference is that ***RP*** provides a pragmatic but very precise and clear right, independent of what field strengths may actually occur on, or past a geographic boundary. ***FS*** creates commercial uncertainty for a licensee

because they have to concern themselves with the vagaries of propagation prediction and the field strengths that might or might not occur from compliance **at** the boundary of their licence (formerly, Ofcom policy was also **outside** the geographic area). The uncertainty of propagation prediction in a risk-averse situation can significantly decrease a licensee's spectrum utility. While the level of decreased utility depends on the initial size of their geographic area (because Category A interference only occurs near a geographic boundary), spectrum right design should obviously support spectrum trading where smaller geographic areas might need to be purchased. Spectrum right design should not be dependent on always having very large geographic areas.

Importantly, while the uncertainty of propagation prediction must be managed by the licensee irrespective of which formulation is used, ***RP*** avoids risk-averse coordination completely by being an explicit transmit right at each antenna *i.e.* licensees need only take account of propagation variability with regard to protecting their own receivers. This allows them to take greater risk in coordination because there is no likelihood of litigation. Taking greater risk means they use much lower (dB) reliability margins in their coordination procedures thus extracting more utility from their licences. An ***FS*** formulation creates the unnecessary regulatory burden of having to often over-protect the receivers of adjacent spectrum licensees whereas ***RP*** avoids it completely.

With the uncertainty of propagation removed from spectrum right definition, the traditionally combined processes of device authorisation and device coordination become quite separate tasks. This makes the application of dynamic spectrum access quite simple. Authorised operating frequencies can be easily predetermined from the licence conditions for use by a cognitive radio which subsequently manages interference dynamically.

6.2 Comparison of RP and FS Formulations – Category B interference

Category B interference is **linear-type** in-band interference from transmitters operated under frequency-adjacent spectrum licences.

The essential difference between ***RP*** and ***FS*** formulations in relation to Category B interference is again that ***RP*** is a very precise and clearly defined right, independent of what field strengths may actually occur outside the frequency boundaries of a spectrum licence at locations away from a transmit antenna. This acts to focus a licensee's concern only on managing interference to their own receivers, thus bringing the related benefits already described.

There is a similarity between ***RP*** and a type of spectrum right formulation known generally as an 'EIRP spectrum mask' or 'Block Edge Mask' (BEM)[32] which utilises radiated out-of-band emission limits specified as power spectral density to manage steady-state (mean) broadband type emissions outside the frequency band of a spectrum licence. Note that separate limits for transient (peak) and frequency discrete (spurious) types of emissions are also required.

S-CM utilises an "**antenna** EIRP spectrum mask" to take account of increased levels of noise that can result from multi-carrier power amplifiers or multiple transmitters attached to a single antenna. For compliance verification and certification purposes, the antenna EIRP spectrum mask must be accompanied by definitions of maximum allowed measurement error. The allowed error must take account of equipment manufacturing tolerance as well as overall measurement accuracies for each component used in estimating the antenna EIRP spectrum mask[33]. There are standard statistical methods for calculating overall uncertainty from its component elements. The definition used in Australia is "***measurement error*** *means the uncertainty relating to the measured value of a parameter required to achieve a 95% level of confidence that the true value of the parameter is within the range:*

(a) measured value minus the uncertainty; to

(b) measured value plus the uncertainty[34]*.*"

Establishing the maximum allowed measurement error is necessary for independent application of authentic spectrum rights.

While the out-of-band emission limits are an important part of interference management the spectrum mask approach is sometimes presented as being all that is necessary for complete interference management and thus, as a simplification of regulation. For example, Ofcom's 2.6 GHz licences contain only a BEM, with no interference benchmarks for either out-of-area interference at future geographic boundaries obtained through spectrum trading or non-linear out-of-band interference at frequency boundaries. UK industry persuaded Ofcom to utilise the ***RP*** (BEM) formulation for its 2.6 GHz auction in response to the envisioned difficulties with the alternate ***FS*** formulation. While Ofcom has explained the 2.6 GHz framework away in terms of "well it was a special situation and the operators said they would be able to make do with the partial conditions" it is blatantly obvious that the real reason is that, given the effluxion of time, it was the only practical alternate option provided

[32] BEM for various frequency bands were developed by CEPT Report 019 (WAPECS) as a partial technical solution for flexible spectrum access. There was insufficient time to fully develop the necessary additional tools for the management of out-of-area and non-linear interference. For these, the report merely adopted without critique, traditional but inefficient PFD and fixed guard band solutions respectively.

[33] If desired, an error *allowance* can be specified in relation to each emission limit.

[34] The value of "95% level of confidence" comes from Australia's *National Measurement Act*.

by Ofcom at that date. Under these conditions, the complexity of interference management is merely shifted to industry with a mandatory requirement (or a practical necessity) for licensees to negotiate an industry code for the full management of interference including exchange of device and deployment information[35]. Some of the problems with spectrum licensees negotiating codes for interference management are having your competitor in charge of establishing the utility of your spectrum licence as well as leakage of intellectual property and business plan information. Innovation is more likely to be successful when the utility of spectrum licences is fully defined before any award or auction.

6.3 Comparison of RP and FS Formulations – Category C interference

Category C interference is **non-linear**-type out-of-band interference from transmitters operated under frequency-adjacent spectrum licences.

An ***FS*** formulation for managing Category C interference suffers from the same uncertainty associated with field strength limits away from antennas described above in relation to the other two interference categories.

The essential difference between ***RP*** and ***FS*** formulations is that ***FS*** is far too vague and can not allow a licensee to efficiently take account of non-linear interference mechanisms when designing new innovative equipment and managing related interference. In order to avoid worst case coordination by licensees and increase efficiency in spectrum usage, **a non-linear interference mechanism must be managed with a non-linear type right**.

Therefore, as well as having a maximum in-band power limit to provide an upper bound to the extent of Category C interference mechanisms[36], S-CM supplements Category C management with a **model coordination procedure.** This procedure provides precise technical and robust legal benchmarks for Category C interference by specifying it in terms of transmitter EIRP and not

[35] "It should be noted that Ofcom will not be placing a formal coordination obligation on licensees in this respect, rather it is expected that licensees will cooperate voluntarily" Ofcom Statement on the award of the 2.6GHz and 2010 MHz bands 4 April 2008

[36] Ofcom has recently offered licensees the option of having an EIRP limit as a licence condition in addition to their ***FS*** conditions ("block edge masks" are also offered as an option in the same document). Industry comments were: "*If the Spectrum Usage Rights proposed by Ofcom met the objectives stated in the Spectrum Framework Review, there would be no need for Ofcom to define any restrictions on those rights. The proposal by Ofcom in this consultation to define an additional mask restriction is effectively recognition by Ofcom that its present proposals for SUR do not fully meet those objectives*" from **Vodafone** comments on Ofcom's Consultation (September 07) on Spectrum Usage Rights and "*BT notes that the recent L-band auction proposals reverted to include the need for a transmit spectral mask as well as power flux density (PFD) limits which appears to be a departure from the original aims of the SUR concept, in particular increasing its complexity.*" **BT** Response to the Ofcom Consultation on Spectrum Usage Rights: Further Information 15 November 2007

receiver protection. The model coordination procedure establishes minimum frequency-distance separation between a new transmitter and existing and formally registered devices (transmitters and receivers) operating **outside** the area and frequency boundaries of the spectrum licence. This does not mean that coordination has to be performed before device authorisation is possible. However, the model coordination procedure establishes rights related to a precise level of non-linear guardspace isolation for the most common non-linear interference mechanisms, for when they do occur. The practical effect of application of the coordination model is to clearly define transmit rights (guardspace provision) relating to Category C interference. The notional receiver model it incorporates should not be viewed as an explicit receive right. Application of the model provides a very simple yes/no criterion for determining which licensee is causing Category C interference and consequently, who is responsible for its settlement.

The proposal for managing Category C interference under A-PFD is based on the assumption that out-of-band interference is limited to devices which are co-located[37]. This assumption is either an error[38] by Ofcom or a requirement for Category C interference to be managed through ongoing and slow equipment standardisation processes.

A general solution for spectrum rights must address the general interference situation.

In practice, if it is not managed by receiver hardware as well as device coordination, Category C receiver intermodulation interference from two or more transmitters can occur with the transmitters separated up to 10's of kilometres. Traditional management for receiver intermodulation must be reflected in the design of new spectrum rights if they are to encourage innovation and consequently, related interference benchmarks provided, not left to inspired guesswork or the even less attractive prospect of negotiation by licensees during a typically slow equipment standardisation process, especially without the support of having initial negotiation benchmarks for that interference mechanism provided by the regulator.

S-CM promotes innovation by not relying on slow equipment standardisation processes and therefore, establishes all the necessary guardspace isolation benchmarks for new innovative equipment design. Unfortunately, A-PFD must continue to rely on equipment standardisation to account for its shortfall in spectrum right definition for managing Category C interference.

---

[37] See [5] section 4.19 "*These aspects of interference generally only become an issue with equipment in relatively close proximity*". .

[38] "*Orange believes that the control of (intermodulation) is not quite as straightforward as Ofcom is suggesting and that they need to be taken into account in subsequent modelling.*" **Orange** response to Ofcom consultation on Spectrum Usage Rights, June 2006

6.4 Central Device Database

Use of a model coordination procedure for S-CM requires a centralised (online) device database. Experience in Australia has shown that spectrum licensees are very happy with the requirement for a centralised device database and not only because of the legal and technical transparency that it creates in relation to the management of Category C interference[39]. A centralised database of certified device data is an essential tool for the self-management of interference generally, as well as being an essential input for licensees to establish the real utility/value of a spectrum licence for an auction and subsequent trading. Once database elements and an online central register are established by the regulator, industry is also able to proceed to automate its coordination and compliance verification processes, which is a significant saving for industry. Given its key function in so many spectrum management activities including interference investigation and audit, provision of a central online device database is never a disproportionate burden on either the regulator or industry.

Professor Martin Cave's "Review of Radio Spectrum Management: An independent review for Department of Trade and Industry and HM Treasury" of March 2002 recommended "shifting the balance of the responsibilities for interference management further towards operators" using "three important prerequisites" of (1) a central public device database; (2) interference benchmarks; and (3) enforcement arrangements. "*The introduction of public on-line frequency assignment/technical information*" would change the existing requirement for only "*systems with similar characteristics..to share frequencies*" and thus "*facilitate the review's proposals for a flexible and market-led spectrum management environment*". However, while a central database of general licence information supports Ofcom's A-PFD, the inclusion of detailed information about transmitters and receivers (devices) is currently viewed by Ofcom as being unnecessary[40].

---

[39] A very small part of Australia's register is maintained as "Secret".

[40] "*Under section 31(1) of the Wireless Telegraphy Act 2006 Ofcom may make, by regulations, provision for the establishment and maintenance of a wireless telegraphy register. Under section 31(2) of the 2006 Act Ofcom may only include relevant information in the register if it is information of a description prescribed by regulations. The Wireless Telegraphy (Register) (Amendment) Regulations 2008 allows for basic information about spectrum licensees such as names, contact details, class of licence, the band(s) of frequencies and, where appropriate, the geographical area of operation. It does not provide precise details about individual transmitters due to "security concerns*"" The 'security concerns' were apparently a reaction to EMR/EMF mast activists. Given the natural visual impact of masts as well as the general availability of RF scanners, a central device database provides little additional assistance to mast activists and 'security concerns' are not well founded. In any polity genuine security concerns exist, these should be dealt with sensibly within the spectrum management regulatory regime, not used as an excuse for stifling innovation. Ofcom's Business Radio Reform Statement of 5 September 2008 went slightly further in extolling the benefits of site-specific information mentioning "*other benefits from the publication of this information, for example in terms of user self-management of spectrum and improved transparency*" but the same vague dataset remains.

Throughout the years since Professor Martin Cave's report it has become more and more inevitable from Ofcom's ensuing policy decisions concerning information availability about devices in support of market liberalisation, that if Ofcom do not regulate for a central public device database, the market is likely to be dysfunctional.

A viable market design keeps transaction costs in check. High transaction costs can cause markets to be dysfunctional. The quality of the goods for sale is often not immediately apparent. If it cannot be reliably checked, the buyer might be reluctant to purchase. A market works well only if information flows smoothly through it. Lowering transaction costs is a task not only for entrepreneurs, but also for public policy. The search for information is the central experience in a market. A successful market has mechanisms that hold down transaction costs arising from the necessary dispersion of information[41].

In reference [5], para. 4.24, Ofcom provides the following advice about the management of Category C interference "*Where intermodulation is found to occur as a result of the interaction of two transmitters, it will be the responsibility of the licensee who deployed its transmitter most recently to resolve this. Ofcom expects it to be clear in most cases from data such as mast rental contracts which transmitter has been deployed most recently*". In one way this represents a significant and welcome change by Ofcom. A necessary first-in-time policy (but without interference benchmarks) for the settlement of receiver intermodulation interference has finally been provided. But Ofcom now suggests that the data of mast rental contracts will provide a practical solution for managing this type of interference.

Problems with this approach are:

- the proposed policy assumes the interference will be caused by two transmitters which are co-located;
- the proposed policy is for settling interference after it occurs and is not helpful for licensees who may wish to use coordination to ensure it does not occur in the first place; and
- the proposed policy assumes access to the mast rental contracts of competitors will be granted and that they will provide an exact and reliable date of device deployment.

In reference [6] Ofcom is proposing to request a licensee being investigated for non-compliance, to supply *inter alia* "*information such as transmitter location and transmit power*" to enable Ofcom to confirm compliance with A-PFD via a propagation model specified within the licence. This is a classic example of

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

placing the "fox" (the investigated licensee) in charge of the "hen house" (the critical data supply). There is really no alternative to a central database for providing legal and technical transparency for all licensees when managing the interdependent system that is interference.

In some bands, Ofcom proposes that licensees should negotiate a Code of Practice on Engineering Coordination between themselves within 6 months after licences are awarded, which deals *inter alia* with identifying the type of information that needs to be communicated between licensees and the arrangements for its exchange[42]. Expecting industry to sort out the data exchange requirements after the auction is unreasonable and does not constitute responsible or competent regulation[43]. These proposals by Ofcom not only point to the necessity of a central database of device details, they also highlight serious flaws in the Ofcom proposals, flaws which, by entrenching managerial inefficiencies, create unnecessary costs for UK industry and ultimately the consumer.

Lack of a UK central public device database and the options it offers for more accurate and efficient interference management is the main reason Ofcom has had to persist with the vague rights offered by A-PFD in spite of overwhelming industry opposition. Establishing a system of property-like rights for flexible spectrum access requires a central public device database at its centre because of the interdependent nature of interference. The spectrum space asset can only be delineated from a matrix of devices by accurately controlling the interference levels resulting from all interference mechanisms at the frequency and geographic (and time) boundaries of the spectrum space. Irrespective of whether primary spectrum usage rights are based on ***RP*** or ***FS***, in general they can not function efficiently without a central public device database. Furthermore, once a database has been implemented, it is simple to demonstrate that ***RP*** provides the most efficient method by which to confer authentic legal rights capable of achieving optimal spectrum use.

---

[42] While a licensee is to only exercise "*best endeavours*" in following any industry developed Code of Practice, Ofcom retains the right to determine at its sole discretion a Code of Practice which if not followed will constitute a breach of the Licence (See Annex 1, Schedule 1, para 4. 14 "Auction of spectrum: 1452 – 1492 MHz, Information Memorandum Update" 13 March 2008.)

[43] "*The proposal to mandate codes of practice on engineering coordination runs the risk of discouraging new players from participating in the auction and innovative uses of the spectrum. It will take considerable expertise and significant resources to play a full part in the development of a code of practice, at the same time as deploying a network before launch. A player with an innovative use of spectrum would probably be forced to disclose a considerable amount of sensitive information before commercial launch in order to secure their interests in the code of practice.*" **Vodafone** response to Ofcom consultation on 1452 – 1492 MHz; August 2007

To its credit, the Australian regulator provided a central online database, essential for legal and technical certainty not only for licensees but also for the regulator, in relation to all spectrum licences issued, beginning 1997. The insurmountable problem associated with leaving critical technical benchmarks or administrative procedures to be thrashed out in an industry group after licence issue is that a small new innovative company faces the prospect of a strong established competitor using strategic gaming to be effectively in charge of determining a varied utility/value for the innovator's spectrum.

6.5 FDD and TDD Operation

Some commentators in Europe propose unrestricted interleaving of FDD and TDD services in spectrum licences, supported by more stringent out-of-band emission limits, but also requiring further technical coordination decided through negotiation among adjacent licensees after a spectrum auction[44]. Under these circumstances the value of licences would be severely reduced by uncertain after-auction outcomes as there would be insufficient spectrum rights established for full management of base-station to base-station interference by the initial licences.

Other European commentators advise against any interleaving of TDD and FDD whatsoever in order to keep the need for coordination of base stations at less than 100 m separation.[45] The current coordination distance necessary for FDD/TDD interleaving would be much larger than 100 m because of the existing poor FDD base station receiver filter rejection performance. Base station receiver selectivity and blocking performance would have to be improved to support interleaving. Proposals exist for ETSI to investigate improving FDD and TDD transmitter and receiver standards to accommodate interleaving. Unfortunately, time-to-market for innovative design is hindered by slow equipment standardisation processes.

The technical conditions for Ofcom's 2.6 GHz spectrum auction have got around the limiting base station receiver performance by providing additional isolation, but in a rather inefficient FDD-biased and device-centric manner, by imposing a fixed 5 MHz very low power 'restricted block' for the TDD channel at frequency boundaries which separate paired and unpaired spectrum, as well as boundaries which separate licensees of unpaired spectrum[46]. The

[44] See SE42(08)007 - Annex22 - CEPT Report 19 - Comments from Inquam.doc
[45] See SE42(08)007 - Annex23 - CEPT Report 19 - Comments from Vodafone.doc
[46] 'Restricted blocks' or low power fixed bandwidths are a simplistic and device-centric method of managing FDD uplink/TDD base-to-base interference through the effective guard bands they create. Given the improbable deployment scenarios that must be used before modelled terminal-to-terminal interference becomes significant at these boundaries, in general, 'restricted blocks' are not required to manage terminal-to-terminal interference for either the FDD uplink/TDD or FDD downlink/TDD frequency boundaries. The occasional scenario where terminal-to-terminal interference might become a significant rather than

division between paired and unpaired spectrum is to be determined at the auction. The 'restricted block' together with additional receive filtering, is to manage base-to-base interference at greater than 100m separation. Additional transmit filtering will also become necessary by virtue of the more stringent licence requirements for transmitter out-of-band emissions. Overall, the design is a partial solution with an over-reliance on current equipment standards. It has little provision for the equipment changes which will occur over the 20 year licence terms, except through over-reliance on uncertain and costly negotiation with both Ofcom and adjacent spectrum licensees. Existing equipment standards should only guide, rather than be entrenched by, the design of licence conditions.

While both Ofcom's special non-A-PFD solution for 2.6 GHz and S-CM both utilise a transmit spectrum mask, S-CM approaches the provision of service flexibility in a much more efficient manner. S-CM also utilises where necessary, additional filtering and antenna height limits, however, S-CM avoids a **fixed** guard band solution by providing **all** the necessary interference benchmarks for licensees to employ a guard band with a width that depends on the level of transmitter power involved. Ofcom's "restricted block" approach is subsumed by S-CM's solution which for the full licence term, establishes interference benchmarks which allow each spectrum licensee to independently authorise a range of equipment, including that resulting from future innovation[47].

Under S-CM, when spectrum rights are optimised for FDD services, an authorisation process is usually also required for high power mobile repeater stations as well as point to point services, which require base station transmitters to operate in the base receive FDD bands. Such an authorisation process can also be extended to adjacent FDD/TDD and unsynchronised TDD/TDD operation. Therefore, while S-CM might optimise spectrum licence conditions for either FDD or TDD services, in the case of FDD optimisation, S-CM provides a supplementary TDD authorisation process referred to as "internal guardspace" authorisation.

---

insignificant problem is better left to a cost/benefit decision by each operator to install a micro/picocell than impose the unnecessary cost of a global change to terminal performance.

[47] The full set of Australian explicit transmit rights do exactly what Vodafone, in their response to Ofcom's DDR consultation (August 2008), believes Ofcom's SURs should do: "*There should be a close relationship between the SURs and the size of guard bands for different services. These together should define the interference between different services, as well as between networks of the same service. The definition of* (fixed) *guard bands is effectively recognition by Ofcom that the SURs do not achieve the objectives in the Ofcom Spectrum Vision. If this vision is completely achieved, there would be no need for guard bands to be defined explicitly – the SUR would define the conditions for use of spectrum adjacent to other licence holders such that interference is not caused*."

Different technologies and services utilise different amounts of spectrum space. Therefore, technology and service neutrality can only relate to the spectrum access pathway. Under S-CM, **neutrality means** "*the rules necessary for spectrum access by all technologies and all services are provided by the initial licence conditions*", without the uncertainty and cost of an over-reliance on subsequent negotiation. When spectrum rights are optimised for FDD services, additional guardspace must consequently be supplied by a licensee in order to authorise TDD operation.

In general, licensees are provided with three ways in which to authorise transmitters:

1. provide a minimum defined level of guardspace between a device and the boundaries of a licence;
2. provide any additional internal guardspace for TDD services when the licence conditions have been optimised for FDD services (optimisation usually occurs in a generic manner via transmitter deployment constraints); and
3. provide whatever guardspace is necessary externally by aggregating adjacent licences under spectrum-sharing agreements (offers the option of having guard space below the minimum level at internal shared boundaries)[48].

In the case of authorisation method 2, the purpose of an additional guard band[49] is to ensure the interference potential in adjacent spectrum licences from a TDD service is not increased (or the utility of adjacent licences is not reduced) beyond the level established by the basic FDD-optimised transmit rights[50]. For case (1), operation in a band optimised for FDD base station receivers, where the basic transmit rights do not support the use of TDD base transmitters, the interference potential (upon which the size of the guard band is established) is usually dominated by Category C interference in frequency-adjacent FDD base receivers[51]. For case (2), operation in a band optimised for FDD base station transmitters, the basic transmit rights commonly prevent application of the model coordination procedure for the management of any Category C interference in the TDD base receivers, and therefore, the licensee must design

[48] The regulator becomes involved when any required guard space falls outside all issued spectrum licences.
[49] A guard area may also be required depending on how near the base station is to the geographic area boundary and whether or not deployment constraints (restrictions) for transmitters require low antenna heights.
[50] See relevant s.145 Determination of Unacceptable Levels of Interference: "*The ACA may register a transmitter whose operation could cause an unacceptable level of interference to the operation of other radiocommunications devices, when guard space, provided either within a single licence or within a number of shared licences, is used to achieve the levels of isolation for emissions transmitted between spectrum spaces to the same extent as provided by this determination.*"
[51] A guard band also assists with the management of Category B interference.

a TDD base receiver to take account of the remaining Category A and B transmit rights of frequency-adjacent FDD base transmitters. Note that depending on the level of balance between FDD and TDD prioritisation, the spectrum rights could be designed to also apply the model coordination procedure in the FDD base transmit band.

Under guardspace authorisation, if an RF filter must be provided (depends on the level of in-band power and the proximity of devices) for the frequency-adjacent spectrum licensee's receivers (case 1) or the spectrum licensee's own receivers (case 2), the attenuation skirt of the filter utilises the guard band. In case 1, if an RF filter must be provided, a first-in-time policy for registered frequency-adjacent receivers (for Category C interference only), effectively requires the licensee providing the guard band to pay for the provision of filtering capacity up to the model. To fully manage Category C interference, RF filters with higher attenuation may be required, in which case the model receiver performance establishes a start point for any negotiation. In case 2, depending on the degree of FDD/TDD prioritisation as discussed above, there may be no first-in-time policy and a licensee must design base receivers (including if necessary provision of guard bands) to manage all interference mechanisms in all deployment situations. Authentic technology and service neutrality is only possible with a national centralised online device database that supports application of the model coordination procedure including the first-in-time policy[52].

In modelling studies, interference is high for both co-located and in-proximity TDD/FDD base stations when using the parameters of equipment standards and without any interference mitigating techniques. However, equipment often performs much better in practice than the parameters in their related equipment standards[53] and there are also a number of actions that can further limit interference between base stations. The guard band size necessary to manage base to base Category C (and Category B) interference is related to the level of front-end receiver filtering, maximum transmitter radiated power, transmitter deployment constraints and site engineering (*e.g.* level of co-located antenna coupling loss). For the uplink, interference between mobile stations and base stations may be severe, as shown by a worst-case analysis, but it can be mitigated by co-location of base stations or by any of the above mentioned interference mitigating techniques. For the downlink, Monte Carlo simulations (a statistical analysis rather than a worst-case analysis) show that for uniformly-distributed outdoor users, base station to mobile station interference

[52] The non-mandatory requirement for equipment standardisation processes was taken advantage of very early in the history of Australian spectrum licensing to authorise the operation of non-standard equipment.

[53] Wilkinson, T. Howard, P. "*The practical realities of UTRA TDD and FDD co-existence and their impact on the future spectrum allocations*" IEEE 15th Int, Symp. on Personal, Indoor and Radio Comms., September 2004, Barcelona.

will have a small or negligible impact on the system capacity when averaged over the system. A worst-case analysis of interference between mobile stations shows that the impact can be severe when the mobile stations are close to each other. However, Monte Carlo simulations suggest that interference between mobile stations will have a small or negligible impact on the system capacity for first-adjacent channels when averaged over a system of uniformly-distributed outdoor or indoor users, including 'hotspots' served by picocells. The unusual scenario of interference between mobile stations in outdoor 'hotspots' served by macrocells is being investigated by CEPT[54].

Under S-CM, in spectrum optimised for FDD and subject to a licensee having access to sufficient spectrum to supply any necessary additional guardspace as well as operate a TDD service, the licensee is able to make a trade-off between the cost of provision of guard band (and guard area) and the commercial benefit of operating the TDD service. Thus, subject to having sufficient spectrum, licensees can make independent and confidential decisions about future use of TDD/FDD as well as operate repeaters and point to point services without the delay caused by negotiation with a regulator or some other intermediary.

The model coordination procedure, maximum in-band limit and out-of-band antenna EIRP spectrum mask of S-CM, establish all the necessary benchmarks which enable licensees to independently manage all TDD/FDD interference mechanisms, free of a mandatory equipment standardisation process and usually without negotiation with adjacent spectrum licensees. The overall objective is to create spectrum rights which enable spectrum licensees to efficiently manage interference by themselves rather than having spectrum rights or mandatory equipment standardisation processes which try to directly manage interference for them. The beneficial results are:

- under spectrum licence rules optimised for FDD:
  - a licensee can also operate TDD through a trade-off between cost of provision of guard band and guard area and the benefit of utilising a TDD service (subject to the licensee having access to sufficient spectrum to supply any necessary guardspace as well as operate the service);
  - similarly, a licensee can also authorise high power outdoor mobile repeater stations as well as point to point stations in the band optimised for FDD base receivers;
- worst-case engineering to manage Category C interference becomes unnecessary: technically precise and legally robust licence conditions are provided for the efficient management of Category C interference mechanisms and where necessary, beginning negotiation;

[54] This paragraph has been adapted from "Comments from E-Plus and O2 (Germany) regarding the Draft CEPT Report 019", SE42(08)007, Annex24, 19 February 2008.

- authorisation to operate innovative equipment is independent of slow mandatory equipment standardisation processes;
- greater economic efficiency is obtained by using variable, rather than fixed guard bands, which are independently established by a spectrum licensee from interference benchmarks contained in the licence conditions;
- deciding how to partition a band between TDD and FDD in preparation for a spectrum auction does not become a critical issue.

All these beneficial results become available when precise and clear interference benchmarks are established as spectrum rights for Category C interference mechanisms and a central online device database supports the authorisation process.

6.6 When Aggregated Power is a Consideration

In many cases, the level of interference in a receiver can be assessed on the basis of one dominant interfering signal. This may not be appropriate when there are many unwanted transmitters:

- causing the in-band interference;
- in the same localised area; and
- without dynamic transmit power control or a transmit duty-cycle limit.

In this case, the signal level statistics of the total (aggregated) in-band[55] interference power can be affected[56] to such a degree that allowances might need to be made by the regulator when the spectrum rights are established. If necessary, both ***RP*** and ***FS*** formulations can be designed to take account of aggregated power.

For S-CM there is a choice when establishing the device boundary criterion (management for Category A interference) as to whether any increase in interference potential from possible transmitter aggregation is so small that it can be subsumed by the difference that occurs between the modelled explicit transmit right for a single transmit antenna and the real-world interference levels that result, or whether it should be added as a reliability margin to further expand the size of the device boundary. Whether a margin is added depends on

[55] Category C interference is not affected by aggregated power issues.

[56] While there is also fast fading due to multipath propagation, the slow fading (shadowing) due to terrain obstacles, of a number of unwanted transmitter emissions can be modelled by the power sum of a number of correlated log-normally distributed components. For example, for 8 transmitters, the long term signal statistics (for a correlation coefficient of zero) results in an effective increase in mean power of 13 dB, but with a reduced variance of 4.2 dB (down from for example 6 dB), owing to the combining of the lognormal variations that occur for a single transmitter. For a correlation coefficient of +0.8 the effective increase in mean power is 9 dB with a variance of about 6 dB. See Aysel Safak '*Statistical Analysis of the Power Sum of Multiple Correlated Log-Normal Components*' IEEE Trans. on Veh. Tech., Vol 42, No 1, February 1993

the risk of increased interference. The level of risk is related to the location of licence area boundaries. If licence area boundaries are to be often drawn through areas of very high population then in-band transmitter deployments might be sufficiently dense to significantly affect the overall signal statistics, in which case it might be useful to add a margin to suitably expand the device boundary. However, since geographic boundaries are not often (if ever) intentionally drawn through areas of very high population, a margin is not usually added.

For Category B interference the risk is independent of the location of area boundaries since frequency boundaries exist everywhere throughout a geographic area. Therefore, if the concentration of transmitters complying with the above three conditions will be high *e.g.* no dynamic transmit power or duty-cycle control, then an aggregation margin is a consideration in addition to those factors already described in [3]. An antenna EIRP spectrum mask that is variable or stepped can be stipulated, dependent on deployment density, dynamic transmit power control, transmit duty-cycle and other factors.

For both Category A and B interference the decision to apply an aggregation margin as well as the value of that margin should carefully consider the likely correlation coefficient between the wanted and unwanted signals. Increasing signal correlation decreases the level of co-channel interference[57]. In a shadowed environment, signals in a localised area are often correlated because the same obstacles are involved. For typical situations where the angle of separation of the signal arrivals is not large (*i.e.* directional antennas are involved) the correlation coefficient can be between 0.4 and 0.6.

6.7 Ofcom's defence for using FS - 'transmitter density'

The key argument used by Ofcom against use of an ***RP*** formulation is that it "*do(es) not account for transmitter density*"[58], and they cite the Nextel interference case in the USA (800 MHz public safety interference) as

[57] "*Motorola believes that the best approach for equipment is a technology neutral emission mask and radiated transmit power limit without the complexity of a probability-based specification. Although a simple emission mask/power limit does not address aggregation of interference from more than one transmitter, it ensures consistency between equipment specifications and regulatory requirements and defines limits that are easily measured and enforced*." **Motorola** response to Ofcom consultation on Spectrum Usage Rights, June 2006

[58] See Ofcom's Digital Dividend Review: 550-630 MHz and 790-854 MHz, Consultation on detailed award design, 6 June 2008 "*5.3 However, transmit masks do not directly control the interference levels experienced by neighbours, as they do not account for transmitter density. The more transmitters of a given power that there are in a given area, the higher the risks of neighbours experiencing significant interference from them. Hence, with this form of TLC, neighbouring licensees will have less information on the interference levels that they can expect from the transmissions concerned*"

supporting evidence for their continued acceptance of the complexity and in the final analysis, rather vague protection offered by their ***FS*** limits [59].

The efficiency of technical licence conditions depends on their overall design, *i.e.* the complete technical and legal regime not just the manner of limit formulation. Settlement of the Nextel interference was highly political and any technical implications must be drawn from it very carefully. After careful analysis, the Nextel case[60] actually supports the use of ***RP*** in a thorough and rigorous technical and legal design incorporating:

- the use of a central device database together with precise non-linear transmit rights; and
- the setting out-of-band transmit rights with regard to total emission from an antenna or array rather than the individual conducted emissions of a number of transmitters that can be attached to a single antenna or array.

Both of the above design elements are included in S-CM. Significantly, both elements were absent from the relevant USA licence conditions.

The likelihood of non-linear interference increases according to the number, location and characteristics of nearby transmitters or '*transmitter density*', for example, the increase in likelihood of receiver intermodulation interference is exponential. Absence of a central public device database and the inability for licensees to know exactly where a device is located and its basic operating characteristics, has meant that Ofcom has been left with no other option for management of the many forms of non-linear interference but through use of an overly-simplistic and thus spectrum inefficient, broad-brush, one-size-fits-all design utilising very rough estimates of '*transmitter density*', involving notional test points within notional test areas at notional heights[61]. Such a design is much too simplistic and vague to provide licensees with spectrum rights which enable them to efficiently manage non-linear interference mechanisms.

Australia's S-CM, which establishes primary interference benchmarks as power radiated at an antenna (or antenna EIRP spectrum masks), informs neighbouring licensees of the exact level of both linear and non-linear interference via those benchmarks and the centralised device database it incorporates. The database constantly monitors and informs licensees about actual transmitter density.

---

[59] Comments by Webb at the 3rd Annual European Spectrum Management Conference, Brussels, 24-26 June 2008.
[60] See Section 6.6 of [1] for more information.
[61] A typical size for a test point can be 50m by 50m. In any test area, there may be hundreds or thousands of test points. The test area is an area covering at least 10 transmitters. Its size is determined based on how large it needs to be in any given location in order to enclose at least 10 transmitters. Generally, it can be expected to cover many square kilometres!

In spite of Ofcom's protestations about ***RP*** formulations, their A-FPD design utilising ***FS*** can not possibly directly control the interference levels experienced by neighbours because notional data is used for compliance verification and therefore, unlike S-CM, neighbouring licensees do not have access to the necessary detailed device information to accurately estimate the interference levels they can expect from the transmissions concerned. Transmit rights together with a centralised public device database allow neighbouring licensees to accurately estimate the levels of not only non-linear but also the in-band interference they can expect.

A possible further situation cited by Ofcom to support their use of an ***FS*** formulation is high powered broadcast transmitters frequency-adjacent to lower powered cellular systems. This support is not, in a technical sense, well based. There are far more efficient methods for managing this type of situation using explicit transmit rights, compared to the complexity and vague spectrum usage restrictions imposed by Ofcom's ***FS*** limits set within its current framework. Since February 1998, 800 MHz Australian spectrum licences have offered fully defined and efficient technical conditions based on explicit transmit rights which allow high powered broadcasting after provision of guard bands by the licensee. As with TDD operation in spectrum optimised for FDD the conditions go one step further by allowing provision of guard bands by the licensee which have a width that depends on the total radiated power. Inefficient fixed width guard bands are not used.

6.8 Ofcom's SURs are more like SUCs

In cases where one transmitter dominates interference in an adjacent spectrum licence, the out-of-area A-PFD limit is the same as Ofcom's "indicative interference level" field strength inside the adjacent licence. Ofcom has stated their "indicative interference levels" are not what they consider to be legally enforceable rights just "indicative" of what a licensee might encounter. The logical consequence is that the primary A-PFD limits are also not legally enforceable rights on which a licensee can rely[62] and further, it is effectively confirmed by one of Ofcom's key spectrum visions "*users should feel comfortable that they (the rights) will not be changed without good cause*". Surely spectrum rights purchased at auction from the regulator for a price

[62] "*It appears that the restrictions are designed to protect neighbouring users against harmful interference from a licence holder by replacing technical restrictions on spectrum use in the licence with emission restrictions but either way the neighbour cannot rely on them as anything more than an indication of the interference he may suffer. Equally the licence holder cannot know that compliance with the restrictions will protect him from intervention by Ofcom on interference grounds. That is because the interference levels calculated on the basis of neighbouring transmit rights can only be indicative. If in fact harmful interference occurs and Ofcom takes the view that it is "undue" Ofcom would no doubt intervene so as to further restrict the licence holder. In these circumstances, it is misleading to characterise the SUR as rights.*" **Orange** response to Ofcom Spectrum Usage Rights, June 2006

determined by the spectrum utility inherent in those rights should not be changed **at all** by a unilateral action of the regulator unless compensation is paid by the regulator.

Given, there is no clear right of compensation in the Wireless Telegraphy Act 2006 for degraded utility for an issued licence resulting from unilateral direct or indirect changes to spectrum usage rights by Ofcom during a change of use process, A-PFD are more accurately described not as SURs (Spectrum Usage Rights) but SUCs (Spectrum Usage Conditions), as they do not fulfil the usual requirements for 'rights' in the strict legal sense[63]. This inconsistency is discussed by Orange (and seemingly misinterpreted by Ofcom) in their response to Ofcom's SURs consultation document: *"Orange is surprised that Ofcom has not addressed the constraints imposed on it by the current legal framework, under which it is able to confer little in the way of 'rights' on the holder of a spectrum licence and consequently has little material from which to build a coherent system of spectrum usage rights. The difficulty is vividly illustrated by the fact that SUR are not rights at all but a 'method of specifying technical restrictions in licences'".* Effectively in agreement with the Orange observation that "*proposals within the consultation document (that) amount to little more than 'tinkering' with the Wireless Telegraphy Act (WTA) licence conditions*", Ofcom is retaining its view that the current legal framework is sufficient "*to impose technical conditions given by SURs*"[64]. Unfortunately, Ofcom also continues to refer to its technical conditions as 'rights'. While technical licence conditions might indeed be supported under the WTA, Orange says "*it is misleading to characterise the SUR as rights*"[65].

Vodafone appears to agree with Orange: "*The consultation document* (Ofcom's Consultation (September 07) on Spectrum Usage Rights) *largely summarises information from previous consultations, and it does not significantly advance the objective stated in para.1.3 to clarify the framework under which SUR would operate. In our response to the first consultation on SUR, we asked Ofcom to start to develop a regulatory framework for the implementation of*

---

[63] For example, see Annex 1, para 10 "Auction of spectrum: 1452 – 1492 MHz, Information Memorandum Update" 13 March 2008. "*If the Licence is surrendered or revoked, no refund, whether in whole or in part of any amount which is due under the terms of this Licence or provided for in any Regulations made by Ofcom under s.12 and s.13(2) of the Act will be made except at the absolute discretion of Ofcom in accordance with regulation [57] of the Regulations.*"

[64] "*Ofcom views that it is possible to impose technical conditions given by SURs within the existing legal framework*" Spectrum Usage Right Statement 14 December 2007.

[65] **Orange** response to Ofcom consultation 'Spectrum Usage Rights: Further Information', November 2007 "*At the risk of repeating ourselves, and as stated in previous responses, there is a clear need for Ofcom to create a robust legal basis to define property rights and to establish what constitutes harmful interference. Ofcom has still not consulted on this issue. It seems that we continue to fiddle with the technical detail without standing back and ensuring that the legal framework is correct*"

SUR. ....SUR based on modelling contains many obligations and restrictions, but almost no rights for the use of spectrum. A licence based on rights needs to be structured differently."

Ofcom is often vague on the issue of just which "rights" are being devolved, for example see [5], "*specification of interference levels* (as spectrum usage rights) *allows neighbours to plan their networks more accurately, with less uncertainty or margin for error because they have a better idea of the interference levels to expect*" when elsewhere in the same document "*interference levels are not a guaranteed right that a licensee can rely on*". In the same document, Ofcom says "*A better way to control interference between licensees is to specify in a licence the interference a licensee is allowed to cause, rather than the signal it is allowed to transmit*". However, the WTA apparently states that licence terms relate to transmissions from particular equipment "*SURs control the PFD radiated by equipment*". There is little certainty with regard to exactly what right is to be purchased. As discussed previously, a ***FS*** formulation is inherently ambiguous as to whether it delivers transmit or receive rights. The typographic error in [5] (see para. 2.1) is prophetic "*Rights of spectrum users should be clearly defined and users should feel comfortable that they will not be **charged** without good cause"* for indeed, with technical conditions capable of forfeiture, the value of such licences will not be very high. Ofcom are emphatic about shaking off any self-interest in auction revenue[66]. However, the price obtained at auction is a clear indication of the value of licences to everyone not just the licensee. The total value to society of such licences will not have been maximised. UK society would be better served by Ofcom becoming emphatic about designing a more practical legal and technical framework.

6.9 Partial Solutions for Spectrum Rights

There is a tendency for regulators to prefer partial solutions when formulating spectrum rights. In the USA, Weiser and Hatfield observe[67]: "*At present, the regulatory strategy for guarding against interference is notoriously undefined, moves too slowly to offer effective guidance, raises transaction costs (as well as entry barriers), and leads to the under use of spectrum…..The not-so-hidden secret of the FCC's traditional spectrum policy regime is that it avoids the very difficult tasks of defining property rights clearly enough to allow for marketplace transactions and instituting an effective enforcement regime. To advance its spectrum policy reform agenda, the FCC will have to define*

[66] "*our objective for the DDR is to maximise the total value to society that using the digital dividend is likely to generate over time. It is emphatically not our objective to award the digital dividend to maximise revenue for the Exchequer.*" Digital Dividend Review: geographic interleaved awards 470 - 550 MHz and 630 - 790 MHz 12 June 2008

[67] Weiser, Phil and Hatfield, Dale N., "Spectrum Policy Reform and the Next Frontier of Property Rights". George Mason Law Review, Vol. 60, No. 3, April 2008

spectrum rights and protections against interference (and the correlative right to interfere) far more clearly than has historically been the case."

The resulting vagueness of partial solutions for spectrum rights simply continues the centrality of regulatory bodies in the after-auction management process including the inefficient strategic gaming that often occurs during related consultation processes. As previously discussed, Ofcom has not provided a common device database and quite a few other essentials necessary for full outsourced management. Ofcom says "*The market is better able to determine optimal outcomes such as boundary conditions, than the regulator*". Ofcom expects industry to supply the missing bits after the auction.

At a London conference in 1995, where Australia first presented S-CM in an international forum, I was puzzled by the incomplete definition of rights for PCS licences in the FCC's presentation. I later asked the FCC official how licensees were to manage interference. The answer, "*through the mutual greed of licensees*" came as a bit of a surprise to me. Greed is no substitute for essential regulation. Similarly, Ofcom's misplaced faith that industry gaming will reach optimal outcomes is no excuse for their regulatory indecision.

One must wonder just what Ofcom is auctioning. The interdependent nature of interference requires consistent interference benchmarks and common administrative tools. Industry can now only become more and more dependent on Ofcom for change of use as well as for interference management in general. Ofcom's original vision: "*In the medium to longer term we expect the effect of this to be that Ofcom increasingly withdraws from managing the radio spectrum*" is not being realised. Instead, their role is expanding: "*we have modified our original proposals to increase Ofcom's involvement in the process of negotiating changes to SURs*". Deciding just whose neighbouring "*rights*" are "*affected*" under a change of use is problematic to such an extent that Ofcom is now fully "*responsible for advising as to the affected parties*". Why does Ofcom design technical licence conditions which preserve its centrality in spectrum management when market-driven innovation is their objective? Such designs might make spectrum management more flexible for the regulator but they subsequently provide less flexibility for the licensee, increasing the risk of a reversion towards administrative regulation and weakening the move towards spectrum allocation through market mechanisms. The resulting licences are likely to have reduced tradability.

Using S-CM, Australia has demonstrated it is possible to create a robust legal and technical regulatory framework for full self-management of flexible spectrum access by industry. Market-driven innovation has been active for the past 11 years. Regulatory bodies have been completely removed from technology and service decisions. Anything less puts an unnecessary brake on market-driven innovation.

6.10 Effects of Legislation

Much of the success of Australian spectrum licensing can be attributed to its Radiocommunications Act 1992 as amended[68]. While the Act did not correctly foresee the final technical solution there were sufficient legal "hooks" to create a high level of commercial certainty. Table 2 is a comprehensive comparison of the legal framework for Australia's spectrum rights (Radiocommunications Act 1992) with that of the UK (Ofcom Statement [5] and the Wireless Telegraphy Act 2006).

The technical precision and legal certainty of S-CM ensure disputes have never arisen. Interference has been fully self-managed by industry without any intervention by the regulator with significant savings, especially in terms of minimal delay, for both government and industry.

[68] http://scaleplus.law.gov.au/html/pasteact/0/300/top.htm

Table 2. Comparison of Legal Frameworks

Australian spectrum licences (section numbers are in relation to the Radiocommunications Act 1992 as amended):	**The UK offers its licensees (paragraph or page numbers are in relation to Ofcom's SURs Statement [5]):**
• have core conditions for out-of-band and out-of-area emission limits which can not be varied by the regulator except with written licensee agreement (see s.66);	• Ofcom's key spectrum vision: "*users should feel comfortable that they (the rights) will not be changed without good cause"*. Ofcom will consider a change request even if negatively affected licensees disagree (para 6.22). In the case of interference resolution Ofcom "*will take appropriate action. This will depend on what is proportionate and necessary in the circumstances.*" (para. 6.15.1).
• allow licence resumption either by written licensee agreement or a compulsory process which includes determination of compensation payable by the regulator (see s.93 and SCHEDULE) and through this extensive provision, the Act supports the indefeasible nature of certain non-core licence conditions which also play a critical role in determining spectrum utility/value;	• revocation or variation of a licence without compensation: Ofcom appears to foresee compensation being payable between licensees under private agreements but not between itself and a licensee if Ofcom requires changes that degrade the utility/value of a licence (para 1.22). Also, Ofcom "*will take responsibility*" for "*harmful interference*" if adjacent licensees are operating within their licence terms (see para 6.20)[69]. Ofcom goes on to say in relation to provision of a level of guarantee for Indicative Interference Levels "*no respondent suggested what sort of guarantee will be appropriate, how it will work, and who will pay any damages*" (see page 34)

[69] No details are given about what level of responsibility will be taken. Ofcom also offers affected licensees the option to "*choose to agree between them that they will not claim harmful interference against one another*"! Perhaps more importantly from a practical standpoint Ofcom says "*Currently there are no strict guidelines that have to be followed to show harmful interference and this will not change as the result of the introduction of SURs*" ([5], page 41)

Australian spectrum licences (section numbers are in relation to the Radiocommunications Act 1992 as amended):	**The UK offers its licensees (paragraph or page numbers are in relation to Ofcom's SURs Statement [5]):**
• are supported by a comprehensive central public database which incorporates certified operating characteristics of radiocommunications devices (not just first-in-time status), for both certification audit, interference investigation and coordination. The regulator: - must establish a public (s.151) central register (s.143); - must pre-determine the necessary data for spectrum licences, third party authorisations and devices (see s.144); and - must require licensees to register and label certified transmitters, including later variations, as confirmation they are compliant with licence conditions (see s.69 and s.300);	• very limited centralised database *e.g.* in the case of interference investigation the "*necessary* (transmitter) *information is requested* (by Ofcom) *from investigated licensees*" (para 6.10) or obtained from "*data such as mast rental contracts*" or a Code of Practice, negotiated between licensees within 6 months after licences are awarded, for identifying the type of information that needs to be communicated between licensees and the arrangements for its exchange.
• enforce compliance through audit of persons accredited by the regulator for the certification task and if appropriate, accreditation withdrawal (see Part 5.4). Licensee may make application to the Federal Court for injunction, court directions and/or damages regarding a licensee's right to the protection preserved by adjacent licensees maintaining compliance with the spectrum licence conditions (see s.50)	• Ofcom remains central to compliance enforcement "*If a SUR licensee transmits outside its licence conditions, Ofcom has powers to investigate and take action (including prosecution or licence variation/revocation) as appropriate. The legislation requires a warming to be first issued.*" (para 6.5) and "*the measured EIRP of the relevant transmitters may be measured and compared to the supplied information*" (para 6.16). In the case of "*a discrepancy between the predicted and actual effect of transmission*", "*Ofcom will generally expect the parties to resolve the situation themselves in line with the terms of their agreement. If they cannot, or if the victim was not party to such an agreement, Ofcom will consider appropriate intervention action*" (para 6.15.3). In the case of civil action s.108 of the WTA applies.

Australian spectrum licences (section numbers are in relation to the Radiocommunications Act 1992 as amended):	The UK offers its licensees (paragraph or page numbers are in relation to Ofcom's SURs Statement [5]):
• in the case of interference involving apparatus licences, licensees can either rely on the regulator for enforcement using inspectors and fines for non-authorised operation (Part 5.5) settling interference disputes where necessary by appointment of a conciliator, compulsory conference and issue of directions by the regulator (see Part 4.3)	• as above
• provide compensation to, and prevent holdout by, incumbent legacy licensees via the setting of a re-allocation period (minimum of 2 years) after which they must cease to operate or negotiate with the spectrum licensee[70] (see Part 3.6)	• use competition policy to manage holdout
• allow suspension and cancellation of licences subject to review by the Administrative Appeals Tribunal (see Part 5.6)	• variation or revocation of a licence by Ofcom (see WTA Schedule 1)

7.0 Conclusion

While reliance on clearly defined exclusive spectrum rights and market management mechanisms might not be appropriate for all spectrum bands, it is capable of delivering innovative wireless communication outcomes if sufficient spectrum is licensed by way of genuine legal rights having technical constructions creating cost efficient pathways for design (if desired, without a formal equipment standardisation process), authorisation and interference management of all technologies and all services.

Management of the variability of propagation is an important issue. The choice of propagation model is better left to spectrum licensees irrespective of the manner of spectrum right formulation. Therefore, a key issue is how to provide

[70] The political power of the licensees of legacy services can sometimes pose a formidable obstacle to market-based spectrum reform. In Australia, incumbent legacy services are provided with coordination protection but only for a short, two-year transition period after a spectrum licensee takes control of the space (two-years is the minimum period allowed by the legislation). This, plus a timely warning, is the only form of compensation for legacy services, and is made possible by apparatus licence renewal not being guaranteed under legislation.

licensees with all the necessary **practical technical benchmarks** necessary for the efficient management of that variability.

Two approaches for establishing interference benchmarks as spectrum rights have been discussed:

- ***RP***: maximum radiated power at each antenna; and
- ***FS***: maximum field strength throughout spectrum spaces.

Both formulations are types of transmit rights (noting the previously discussed ambiguous nature of ***FS***) and each formulation has the same capacity to provide equal accuracy for interference self-management because the same propagation loss variability determines in the case of ***RP*** the statistics of the resulting interference levels and in the case of ***FS*** the allowed maximum transmitter levels. However, the different spectrum right formulations, when utilised in particular technical constructions and legal frameworks, can lead to very different levels of commercial certainty and spectrum efficiency with regard to fostering innovative market-driven equipment design, equipment authorisation and interference self-management.

Two spectrum right regimes have been compared:

- Australia's Space-Centric Management (***RP***/S-CM): in relation to all interference mechanisms, specify in a licence the minimum distance, frequency and time separation for transmitter emission levels at an antenna in relation to the geographic, frequency and time boundaries of the licensed space; and
- Ofcom's Aggregate PFD (***FS***/A-PFD): specify in a licence certain types of probabilistic interference levels a licensee is allowed to cause throughout licensed spectrum spaces.

Table 3 provides a summary comparison of these two regimes.

Table 3. Summary Comparison of *RP*/S-CM and *FS*/A-PFD Regimes

Issue	***RP***/S-CM **(Space-Centric Management/Australia)**	***FS***/A-PFD **(Aggregate PFD Limits/UK)**
State of Development	11 years of acceptance and successful implementation by industry	significant levels of industry unease and still at a theoretical level e.g. recent effective conceptual reversal of Ofcom's SURs caused by the introduction of use of propagation modelling for compliance verification (the primary rights, the aggregate PFD limits, can no longer be the direct specification of certain interference levels a licensee is allowed to cause)

Issue	***RP*/S-CM (Space-Centric Management/Australia)**	***FS*/A-PFD (Aggregate PFD Limits/UK)**
Licence Utility/Value	spectrum auction is akin to a commercial dealing involving a quasi-contractual deal for an indefeasible company asset (the precisely defined utility of the spectrum licence)	spectrum auction is a dispensation of a licence with defeasible conditions
Licence Utility/Value	compensation payable by the regulator if: • licence resumed; or • the regulator decreases the spectrum utility without licensee agreement	revocation or variation of a licence without compensation (no compensation likely payable by the regulator for making a unilateral change to licence terms which degrades utility)
Licence Utility/Value	no negotiation with adjacent licensees or the regulator once sufficient spectrum has been traded	negotiation integral to functioning of licence conditions even though an adjacent licensee is under no obligation to negotiate (resulting high cost and commercial uncertainty)
Licence Utility/Value	pragmatic licence conditions providing clear and precise radiated power benchmarks which make it practical for licensees to maximise spectrum utility using their own proprietary propagation models	licence conditions claimed to directly manage all interference levels and mechanisms at a detailed level for all licensees and in the same manner
Licence Utility/Value	licensees can maximise spectrum utility because they must only protect their own receivers from interference caused by adjacent transmitters (except in the case of those legacy services requiring protection)	compliance requirements in risk-averse situations lead to unnecessary loss of spectrum utility through fear of litigation by an adjacent licensee
Licence Utility/Value	simple licence conditions	disproportionate licence conditions (compliance is unnecessarily costly)
Licence Utility/Value	pre-designed and simple rules for the operation of dynamic spectrum access	very complex authorising procedures for dynamic spectrum access
Licence Utility/Value	strict partitioning of TDD and FDD spectrum is unnecessary - supplementary "guardspace authorisation" procedure for TDD (as well as high power mobile base station repeaters and point to point services in a band optimised for FDD base receive), where licensees utilise spectrum rights related to Category C interference to establish the amount of additional guardspace isolation and if required, which licensee must supply it and pay for base station filtering	reduced spectrum utility caused by a more conservative design when trying to incorporate both FDD and TDD operation

Issue	***RP*/S-CM (Space-Centric Management/Australia)**	***FS*/A-PFD (Aggregate PFD Limits/UK)**
Licence Utility/Value	provide compensation to, and prevent holdout by, incumbent legacy licensees via the setting of a re-allocation period (minimum of 2 years) after which they must cease to operate (can also negotiate with the spectrum licensee for continued operation)	use competition policy to manage holdout (uncertain consequences)
Interference Management	explicit transmit rights	ambiguous transmit/receive 'rights'
Interference Management	Category A interference (in-band area-adjacent): managed by a pragmatic but very precise and clear right referred to as a device boundary and specially formulated to take broad account of terrain height variations	Category A: if correctly implemented, detailed and very complex
Interference Management	Category B interference (in-band frequency-adjacent): managed by a precise "antenna EIRP spectrum mask"	Category B: increasing reference to radiated "spectrum mask or EIRP", which is another of Ofcom's SURs conceptual reversals since it is a non-field-strength condition
Interference Management	Category C interference (out-of-band): precise benchmarks for the efficient self-management of non-linear type interference mechanisms	Category C: spectrum inefficient management of non-linear interference using a "one-size-fits-all" single field-strength condition for all the non-linear-type interference mechanisms
Interference Management	designed to take account of aggregated power	designed to take account of aggregated power
Interference Management	harmful interference: alternate but very precise and clear legal definition based on power radiated **at** an antenna and not receiver protection, originating in traditional coordination (guardspace isolation) but new concept being its transference to spectrum space boundaries	harmful interference: no precise guidelines and no future change resulting in uncertain interference settlement responsibilities
Interference Management	fully self managed: regulator only has oversight role for enforcement involving audit of persons accredited by the regulator for the certification task and if appropriate, accreditation withdrawal	Ofcom increasingly central to licence management and compliance enforcement

Issue	***RP*/S-CM (Space-Centric Management/Australia)**	***FS*/A-PFD (Aggregate PFD Limits/UK)**
Interference Management	supported by a comprehensive central public database established by the regulator and which incorporates certified and pre-determined data describing operating characteristics of radiocommunications devices (including first-in-time status), for certification audit, interference investigation and coordination.	insufficient central public database (no transmitter or receiver data): Ofcom intends to decide non-compliance using data obtained from "mast rental contracts" and "investigated licensees" as well, "Codes of Practice" are to be negotiated between licensees after an auction for identifying the type of information that needs to be communicated between licensees and the arrangements for its exchange.
Market-Driven Innovation	fixed and very precise and clear level of guardspace isolation for **all** interference mechanisms facilitates design of hardware isolation *i.e.* fully variable market-driven equipment design	not possible to **easily or efficiently** translate the 3 "broad-brush" aggregate interference field strength limits into precise and clear design criteria for new innovative equipment
Market-Driven Innovation	promotes innovation by having non-mandatory reliance on equipment standardisation processes	continued reliance on equipment standardisation processes *e.g.* technical construction of 'rights' is based on assumption that all out-of-band interference is limited to devices which are co-located

Some important observations from Table 3 are:

- ***RP*/S-CM is by far the best approach for providing simple, clear and precise spectrum rights through which licensees can confidently design new equipment, authorise its operation and efficiently manage interference to their own services using their own propagation models or through a dynamic spectrum access approach with cognitive radio;
- under ***RP*/S-CM and *FS*/A-PFD, which are both transmit rights, an alternate legal definition for 'harmful interference' involving the other end of the radiocommunications chain, the transmitter rather than the receiver, is necessary;
- the technical conditions that define the utility of a licence must be indefeasible with compensation payable if the utility is reduced by the regulator without licensee agreement;
- the need for negotiation with other licensees as well as ongoing regulator involvement must be minimised to maximise commercial certainty;
- when the licence conditions have been optimised for FDD, the conditions relating to TDD operation (as well as high power mobile base station repeater and point to point services) must allow derivation of the size of the guard band by the licensee, specify the licensee who is to provide the guard

band, and if necessary, who pays for any necessary additional base station filtering;
- holdout by legacy services must be managed with clear upfront rules, not by later competition policy;
- a central online public database consisting of not only spectrum licence details but also pre-determined characteristics of transmitters (and receivers) must be created for audit, interference investigation, certification documentation and coordination; and
- equipment standardisation processes must be optional, not mandatory, in order to provide a realistic "window of opportunity" for market-driven innovation.

RP/S-CM is a solution offering low management and enforcement costs because it provides technical precision with legal certainty. Precise and clear definition provides the level of commercial certainty necessary for investment in the design and manufacture of innovative equipment because of guaranteed authorisation and efficient interference self-management. Unfortunately, ***RP***/S-CM is an option for spectrum right design which does not appear to have been studied in-depth by either regulators or industry in the UK or for that matter the USA[71].

From a legal perspective the alternate definition of 'harmful interference' for ***RP*** is so clear for the full licence term by being based on transmitter power rather than receiver protection, it renders litigation and costly and time

[71] "*Another approach, known as 'Space-centric spectrum management' has been successfully used in Australia for one class of licences. We are extremely disappointed that Ofcom has maintained a blinkered focus on the Aggregate PFD approach; there is no evidence that it has* ***seriously considered*** *other approaches, either before the first consultation on SUR or as the result of responses to any of the consultations.*" **Vodafone** response to Ofcom consultation on Spectrum Usage Rights; Sept 2007. Ofcom responded with "*Prior to the publication of the SUR consultation, Ofcom has commissioned external consultants to look into a range of possible approaches to SURs. These were described in our SUR consultation document and the consultants' report is on our website*". The Ofcom response does not constitute convincing evidence that it has ever seriously considered other approaches. "*In its first consultation on SUR, Ofcom proposed to base them on Aggregate Power Flux Density (PFD) limits. It had not sought the views of stakeholders before this consultation, and we believe that consideration of alternative approaches from the outset could have resulted in more rapid progress towards a workable SUR regime. Ofcom continues to pursue this approach despite the substantial difficulties that it has encountered in two different methods of assessing aggregate PFD limits, and despite the views of stakeholders expressed in previous consultations. It is becoming ever clearer that this approach is inherently extremely complex, and possibly completely unworkable*." **Vodafone** response to Ofcom consultation on Spectrum Usage Rights, January 2008. "*Any solution must be legally robust, easy to implement, measurable, enforceable and unambiguous. We remain unconvinced that this is true for SURs (*aggregate power flux density limits). *Ofcom has so far progressed the SUR regime without taking any steps to validate it at a practical level by applying it to a current network*." T-Mobile Cleared DDR consultation response, August 2008.

consuming field strength measurements unnecessary. ***FS*** does not provide the same level of legal clarity.

Spectrum rights based on ***RP*** do not directly manage interference but in practice neither do ***FS***. However, an ***RP*** formulation provides a clear and precise guardspace isolation at spectrum space boundaries, which is designed separately for, and in relation to, each interference Category A, B and C. Because the rights are in relation to all interference mechanisms they give equipment designers clear directions about the level of additional isolation for the three interference categories they must provide with hardware. The rights also clearly specify the size of the spectrum space necessary to authorise the operation of a new design and after authorisation, give clear directions about how to manage interference. Spectrum rights based on ***FS*** can not be applied with anywhere near the same level of precision to any of these processes[72] By providing legally clear and technically precise inputs supported in law as genuine rights, ***RP***/S-CM provides licensees with the commercial certainty necessary for investment in innovative wireless services including services utilising dynamic spectrum access.

Despite containing a number of new policies, Ofcom's Regulatory Statement on spectrum usage rights [5] is now their "*conclusion to the development of SURs* (A-PFD)". However, their spectrum vision remains out of sight. Ofcom's oft repeated view that "*most supported our proposals*" is not borne out by a reading of the relevant consultation responses. Under ***FS***/A-PFD change of use is unlikely to be simple or transparent, the rights of spectrum users will never be clearly defined and users are unlikely to ever be comfortable about their purchased rights being unilaterally degraded without compensation from Ofcom whatever the cause may be. The harnessing of market management mechanisms first requires that a practical framework for market operation be provided.

8.0 References

[1] Whittaker M. "*Flexible Radio Spectrum Access: Moving from Device-Centric to Space-Centric Management"* FuturePace Solutions, March 2006, ISBN 0-9775232-0-9, see www.futurepace.com.au

[2] Ofcom Spectrum Usage Rights (SUR) consultation document, 12 April 2006, see www.ofcom.org.uk

[72] *"In summary, the SUR proposals are not fit for purpose and H3G strongly believes that the spectrum masks approach should be used. The current SUR proposals would makes it difficult to assess the actual interference risk and make planning investment in the Spectrum Bands more uncertain and costly. Further, without further modification and provision of a proper framework for the SUR approach, Ofcom should not consider any future licence modifications to change licences to such a basis."* **Hutchison 3G UK** response to Ofcom's 2.6GHz spectrum award consultation March 2007

[3] "*SPACE-CENTRIC MANAGEMENT: A General Solution for Equitable Access to Radio Spectrum Space under Conditions of Flexible Use*" ITU Workshop On Market Mechanisms For Spectrum Management, Document: MMS/05, Geneva, 22-23 January 2007, see http://www.itu.int/osg/spu/stn/spectrum/material.html.

[4] Webb W. "*Regulation - A licence to do (almost) anything you want WILLIAM WEBB DESCRIBES A MORE FLEXIBLE APPROACH TO SPECTRUM LICENSING*" Communications Engineer, Vol 4, Jan 2007, pgs 12-16.

[5] "Spectrum Usage Rights: A statement on controlling interference using Spectrum Usage Rights", Ofcom, 14 December 2007

[6] "Spectrum Usage Rights: Licence verification approaches", Ofcom, 9 January 2008 and related Statement 15 May 2008.

9.0 About the Author

Michael.Whittaker@futurepace.com.au, B Sc. (Physics), Grad. Dip. Electronics, has over 24 years experience in radio spectrum planning, working for the Australian Government beginning 1984, pioneering automated frequency assignment systems and publishing in that field. Michael led the introduction of flexible spectrum management techniques in Australia in 1994 becoming the principal architect of the manner of formulating conditions for flexible spectrum licences which consist of explicit transmit rights i.e. rights that define maximum radiated power **at** an antenna rather than maximum field strengths **away** from antennas and support either the outsourced or centralised regulatory authorisation of spectrum access for any type of technology and service. When correctly designed, the practical effect of such rights is to create precise levels of 'guardspace isolation' separately for, and in relation to, all interference mechanisms so that after trading sufficient spectrum, licensees have all the necessary inputs to independently and without further negotiation, including if desired, without an equipment standardisation process: design any type of new (innovative) technology and service; authorise the operation of the equipment; and efficiently self-manage interference. This approach is able to provide equitable spectrum access when dissimilar equipment is operated in adjacent

spectrum spaces and create practical rules for authorising dynamic spectrum access by software reconfigurable devices including cognitive radio.

Michael was chairman of the Technical Liaison Group in 1997, a government sponsored industry consultative forum which established the licence conditions for 800 MHz and 1.8 GHz spectrum licences. Michael also later designed the 28/32 GHz and 3.4 GHz spectrum licence conditions and is now a director of FuturePace RF Solutions designing web-based online transmitter certification and authorisation services for outsourced self-management of interference, incorporating automated compliance and coordination checks and where required, integration of real time EMF/EMR human exposure management for complex shared sites at which those transmitters operate.