Technology-neutral spectrum usage rights

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ACRONYMS

CoU	Change of Use
dBW	deciBels referenced to 1 Watt
EIRP	Equivalent Isotropically Radiated Power
EMC	Electro-Magnetic Compatibility
FDD	Frequency Division Duplex
FS	Fixed Service
GRMT	Generic Radio Modelling Tool
IF	Intermediate Frequency
IP	Intermodulation Product
IRs	Interface Requirements
MNO	Mobile Network Operator
OOB	Out-Of-Band
PFD	Power Flux Density
P-P	Point-to-point
RF	Radio Frequency
RSA	Recognised Spectrum Access
R&TTE	Radio & Telecommunications Terminal Equipment
SFR	Spectrum Framework Review
SMR	Spectrum Management Rights
SQB	Spectrum Quality Benchmark
SUR	Spectrum Usage Rights
TDD	Time Division Duplex
TFAC	Technical Frequency Assignment Criteria

1 INTRODUCTION

This report details the work undertaken by Aegis, Indepen and Transfinite concerning the implementation of technology-neutral spectrum usage rights. The work was carried out between June 2005 and January 2006.

Two volumes constitute the full report; this volume, the main body of the report, and an associated volume which contains details of a number of case studies undertaken during the course of the work.

1.1 Context of study

Following on from the Independent Spectrum Review (Cave Report) Ofcom announced its intention to liberalise use of the spectrum such that the market will be allowed to determine best use of the spectrum. It is proposed that this liberalisation be introduced in two phases. Initially Ofcom will assess whether a proposed change in spectrum use is acceptable but eventually it is expected that change in spectrum use will be negotiated in the market within a suitable technical and procedural framework. Transfinite have been contracted by Ofcom to define and implement prototype software that Ofcom may use to assess whether a proposed change in spectrum use can be accepted in the initial phase of spectrum liberalisation. It might reasonably be expected that the same or similar methodologies to those planned to be used by Ofcom in the first phase of liberalisation would be used when change of use is negotiated in the market. This study has looked at the possibilities for technology-neutral spectrum usage rights in the later phase of liberalisation but has taken account of the work being undertaken by Transfinite relating to the first phase of liberalisation.

The Spectrum Framework Review (SFR) set out at a high level a possible mechanism whereby technology-neutral spectrum usage rights could be introduced. Ofcom asked the study team to consider the options for implementing spectrum usage rights and to propose a longer term framework which takes account of the various technical issues and allows for flexibility in spectrum usage within a controlled interference environment. A number of case studies have been used to test some of the proposals made in this report.

In addition to these initiatives by Ofcom, the European Commission has made a number of significant moves towards the development of a policy to promote more flexible use of spectrum and greater use of market approaches to spectrum management. The Commission has emphasised the need for “a gradual but systematic liberalisation of radio spectrum use”.[1] In addition, the Radio Spectrum Policy Group has undertaken a consultation on its opinion on wireless application

[1] European Commission. June 2005. “A forward-looking radio spectrum policy for the European Union: Second Annual Report.” COM (2005) 411.

policy for electronic communications services (WAPECs), under which spectrum may be used on a technology and service neutral basis.[2]

It is important to note that the introduction of technology-neutral spectrum usage rights is not being done with respect to empty spectrum. The rights of existing licensees need to be taken into account at the same time recognising that some spectrum users (e.g. MoD) do not have specifically defined rights. It can be further noted that recently announced releases of spectrum are to a large extent already being provided on a technology-neutral basis on a case by case basis i.e. not in the context of an over-arching framework.

It is intended that the introduction of technology neutral rights should not result in any user being materially worse off than under the current system. However, in stating this intention, there are two points worth noting:

- Spectrum users currently experiencing no interference or interference that is well within limits, may well experience greater levels of interference in the future. Notwithstanding the comment that immediately follows, the greater levels of interference would still be expected to be within limits, the increase being due to greater density of spectrum usage or users increasing transmission powers up to the limits of their licence rights.
- It has to be recognised that one of the main objectives of technology-neutral rights is to provide greater flexibility in spectrum usage some of which comes from less control. Consequently there is potentially an increased risk of interference. It will be important to strike the right balance between increased flexibility and the potential for increased levels of interference.

Proposals made in this report have been made with a long term view in mind and without detailed legal advice. As such, it is likely that current legislation may not allow some parts of the proposed approach to be implemented. It has been assumed by the study team that changes to legislation would be possible at some point in the future. Even if this were not to be the case it is considered that significant parts of the proposed framework could still be implemented within current legislation.

1.2 Experience elsewhere

A number of countries, most notably Australia, Canada, New Zealand and the US, have already taken steps to introduce technology-neutral spectrum usage rights and this together with the historical literature on the subject[3] forms part of the context for

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[2] RSPG. November 2005. “Opinion on wireless access policy for electronic communications services.”

[3] Literature to the mid 1980s is reviewed in “management of the Radio Frequency Spectrum in New Zealand”, Appendices, NERA for the New Zealand Ministry of Commerce, 1988. More recently “A Proposal for a Rapid Transition to Market Allocation of Spectrum”, Kwerel and Williams, OPP Working Paper Series No 38, November 2002, FCC.

this study. We have drawn on the experience of these regimes with the management of interference issues in developing our proposals.

It is instructive to see the extent of the technical framework that has been introduced in these countries. While each country has tended to put a slightly different framework in place depending on the frequency band in question, we have compared the frameworks that apply to the frequency band around 3.5 GHz (2.3 GHz in the US, 2.3 and 3.5 GHz in Canada) initially intended for fixed wireless access type systems but auctioned on a technology-neutral basis – see **Annex A**.

What this comparison shows is that parameter values defining the rights (to whatever degree in each country) are generally derived from a foreseen use in the frequency band in question. There is a significant difference between the Australian approach which specifies a wide range of parameters and allows for registration of terminals in order to reduce the risk of potential interference problems, and the US where the technical framework is minimal and spectrum users are expected to resolve any interference problems that might arise.

1.3 Study methodology

The study fell naturally into two distinct phases. The first half encompassed the following activities:

- Discussions with stakeholders who responded to the SFR on the issue of technology neutral rights
- Discussions with spectrum managers in several countries that have liberalised spectrum use (Australia and New Zealand)
- Analysis of the current proposals leading to more detailed technical proposals for technology neutral rights

Analysis of the potential for market failure and recommendations on how to address any identified market failures. After the first half of the study was completed a workshop was held for interested parties at Ofcom (17 October 2005).

The second half of the study took the conclusions of the first half, modified them in the light of the workshop where appropriate, and applied them to a number of case studies to test whether the proposed framework is workable.

1.4 Structure of report

The main body of this report contains:

- A summary of the current situation (Section 2)
- Technical considerations relating to the interference environment and particular issues with respect to spectrum usage rights (Section 3)
- A proposed regulatory framework and the definition of spectrum usage rights (Section 4)

- A summary of the conclusions drawn from the case studies undertaken (Section 5)
- An outline framework to accommodate spectrum change of use (Section 6)
- Conclusions drawn from the work (Section 7)
- Three annexes containing a country comparison of technology neutral frameworks, methodologies that can be used to derive spectrum usage rights parameter values, and issues relating to the privatisation of Ofcom's management functions.

In addition, an associated volume contains details of a number of case studies undertaken during the course of the work.

1.5 Definition of terms

In order to be clear about the terms used in this report, the following are used as described below:

Technology-neutral – it is intended that spectrum usage rights be defined in a generic way by means of power emission masks and other such parameters. This means that any technology working within these rights is allowable. Taken one step further, if the rights do not define the type of system (e.g. fixed or mobile) then the system type can change as long as the new system operates within the rights that are defined. It will be seen that many of the difficulties associated with usage rights arise from deployment issues (i.e. the type of system).

Change of use – this is deemed to happen when a proposed new use of spectrum gives rise to parameter values falling outside those specified in the usage rights in question and which results in a potential increase in interference. This situation triggers the need for approval from Ofcom (First phase of liberalisation) or negotiation with neighbours (or some other market led process), spatially and/or in frequency (Second phase of liberalisation).

Reconfiguration – if the parameter values associated with a proposed new use of spectrum fall within those specified in the usage rights in question this is not deemed to be a change of use. This situation is considered to be a reconfiguration which the owner of the usage rights is entitled to implement without the need for any approval or negotiation.

High power transmitters: Use of this term relates to the potential generation of significant harmonic emissions or intermodulation products. The level might reasonably be set at 100 Watts but it might be considered reasonable to align the level with the current site clearance level of 17 dBW (50 Watts).

Close proximity: Use of this term relates to the potential for interference from out-of-band emissions and intermodulation products. Depending on the context close proximity could mean less than 1 metre (OOB interference from handsets) or 200 metres (IPs).

Necessary bandwidth: the width of the frequency band required to ensure a transmission is successful

Unwanted emissions consist of:

> **Out-of-band emissions:** immediately outside the necessary bandwidth and resulting from the modulation process
>
> **Spurious emissions:** outside the necessary bandwidth, including harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products.

Licensed / authorised bandwidth (assigned frequency band): often the same as or having some direct relationship to the necessary bandwidth (but see **Note** after next definition)

Guard band: a piece of unused spectrum between different radio systems designed to reduce interference from one system into the other to acceptable levels. It is determined by the out-of-band emission fall-off of the transmitter in one system and the receiver selectivity of the other (as well as the distance between the transmitter and receiver).

Note: In a command and control spectrum management regime guard bands are determined a priori based on a detailed knowledge of the systems to be deployed. It is often the case that the licensed bandwidth does not include guard bands and in these instances "ownership" of guard bands therefore resides with the regulator. In the future when change of use is meant to allow for the introduction of different technologies it is reasonable to expect guard bands to be managed by, and therefore impinge on the decision making process of, operators.

1.6 Acknowledgements

During the work reported here discussions were held with a number of interested parties in the radiocommunication industry. The authors of the report would like to acknowledge the time and effort provided by the participants in these discussions.

2 CURRENT REGULATORY SITUATION IN THE UK

2.1 Introduction

In this section we describe aspects of the current licensing framework relevant to this study. In particular, we describe technical aspects of current licences and Ofcom's policy in respect of spectrum liberalisation. The current situation provides a benchmark against which to judge any proposals for technology neutral spectrum rights, in the sense that any new regime will not necessarily address ambiguities or uncertainties concerning users' rights under the current regime and liberalisation proposals developed in this study should provide potential benefits relative to the current arrangements.

2.2 Technical aspects of current licences

One of the schedules attached to a typical radio licence specifies the technical conditions of operation. These technical conditions include:

- A characterisation of the type of system deployment and the equipment
- Roll-out obligations when appropriate
- The frequencies or frequency bands to be used
- Location or area of operation
- Reference to the appropriate Radio Interface Requirements (which in turn reference international equipment standards or national standards)
- Transmitted power permitted (this may be determined on an individual basis or it might be covered by Radio Interface Requirements / equipment standards)
- Unwanted emissions permitted (this may be determined on an individual basis or it might be covered by Radio Interface Requirements / equipment standards)
- Site clearance requirements (for EIRP > 17 dBW, and/or for aerial systems the highest point of which is > 30 m above ground level, and/or for additions to an existing aerial structure that increase the height by > 5 m and that the new height is > 30 m))
- Coordination requirements

In the context of packaging spectrum the following points relating to the current regulatory regime can be noted:

- International coordination is managed by Ofcom and this will continue to be the case under liberalisation
- National coordination between users of the same service (e.g. fixed links and private business radio) is managed by Ofcom using computer based tools and databases (e.g. MASTS and FiLSM). This also applies to a large extent with respect to TV broadcasting although in this case Ofcom manages the

framework and the detailed planning is undertaken by the users. Ofcom undertakes a greater level of detailed planning with respect to sound broadcasting.

- National coordination at geographic boundaries (e.g. Broadband Fixed Wireless Access) and between services (e.g. Fixed Wireless Access and Earth Stations) is managed by operators according to processes specified by Ofcom[4].
- Adjacent band issues are managed centrally and a priori. Guard bands are put in place and are not part of the licences on either side.
- Spectrum quality is not guaranteed by a licence but a measure of quality is implicit in the assignment process, where Ofcom has responsibility for this. The Technical Frequency Assignment Criteria documents (TFACs), as published by Ofcom, make assumptions about receiver performance and specify the protection level used during the assignment process. In the case of fixed point-to-point links the protection is calculated on a single entry basis – the single entry criterion is derived from the multiple entry (aggregate) protection requirement.
- For national licences having exclusive use of a portion of spectrum, assignments are self managed and there is no need to register terminals except to satisfy health concerns (e.g. mobile network base stations). Once again spectrum quality is not defined or guaranteed by a licence but the licence owner will have some knowledge of the interference environment due to users in adjacent parts of the spectrum. The extent of the knowledge may only go as far as the technical standards used and may not include information regarding system deployment which may not be publicly available.

Enforcement of licence conditions is currently undertaken by Ofcom investigating complaints, diagnosing the problem and taking action against users transmitting unlawfully. In cases where transmissions are lawful Ofcom seeks to rectify the problem. This may involve offering a user a different assignment that avoids the problem or suggesting a technical solution. Ofcom has not had experience of users complaining specifically that their service quality falls below the benchmarks implicit in the TFACs. Rather complaints occur if users experience what they consider to be undue interference – things do not work as well as they used to - and they cannot identify the source of interference. If interference is caused by government users then there is an informal process for sorting this out.

It should be noted that many local interference problems are currently sorted out by site managers and spectrum users themselves. It is not known whether this level of cooperation would continue under any new spectrum management regime. Although liberalisation will probably result in a lighter and more flexible regulatory

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[4] Ofcom spectrum coordination documents relating to Public Fixed Wireless Access in 3.4 GHz and Broadband Fixed Wireless Access in 28 GHz – both Version 1.1 dated November 2004.

regime, there is some expectation that with liberalisation and the granting of more explicit spectrum usage rights comes a more litigious attitude to problems and this argues for a clearer attribution of responsibility for resolving interference disputes than is the case at present in order to reduce the costs of disputes.

2.3 Current approach to liberalisation

2.3.1 Process

Liberalisation of the technical conditions attached to radio frequency licences is being introduced by Ofcom in three ways.[5] First, licences auctioned from 2006 on will not specify the service or technology to be used by licensees.[6] Rather constraints on use are defined in terms of general technical parameters, such as maximum permitted power or power density level (both in-band and out-of-band), and the bandwidth assigned includes any guard bands or buffer zones that may be required by the licensee to comply with technical restrictions on transmissions.

Secondly, licensees may apply to Ofcom on a case by case basis to request a variation to their licence characteristics. Applications will be considered by Ofcom in terms of their impacts on competition and spectrum management[7], in particular whether there is a risk of interference that could reduce the spectrum quality of other users below the levels implied by their respective TFACs, The processes for applying for a licence variation are set out in the Liberalisation Guidance Notes.[8] The key elements of the process are that

- Ofcom evaluates an application for a licence variation having regard to consistency with other users' TFACs, co-ordination guidelines, Treaty obligations, statutory obligations and directions from government
- Ofcom may notify other potentially affected users, depending on the risk of interference, the nature and significance of the proposed variation and the impact on competition and consumers
- Ofcom provides grounds for its decision and the decision may be appealed to the Competition Appeal Tribunal.

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[5] The policy is discussed in "Spectrum Liberalisation", Consultation document, Ofcom, 17 September 2004

[6] The programme of auctions is given in the Spectrum Framework Review: Implementation Plan-Interim Statement, Ofcom, 28 July 2005. For details of some of the early auctions see: "Auction of spectrum 1781.7-1785 MHz paired with 1876.7-1880 MHz, Information Memorandum, Ofcom, 24 November 2005; "Award of available spectrum: 412-414 MHz paired with 422-424 MHz, Ofcom 24 November 2005; "Award of available spectrum: 1785-1805 MHz, 15 December 2005.

[7] In accordance with Ofcom's legal powers and remit.

[8] http://www.ofcom.org.uk/radiocomms/ifi/trading/libguide/

In parallel, Ofcom plans to remove certain restrictions from all licences in a class to make some changes possible without requiring prior consent from Ofcom.[9]

Thirdly, changes to geographic or frequency boundaries of licences that do not involve a significant risk of interference will be allowed through spectrum trading as a partial transfer.

2.3.2 Nature of rights

Users rights to use spectrum under licences issued by Ofcom will be tradable and may be defined (or capable of being defined) in a non-technology and service specific manner. The rights are limited in a number of ways, in particular Ofcom may revoke a licence after a defined notice period (minimum 5 years) for spectrum management reasons where this includes

- To comply with a Community measure or international requirement
- To follow a direction from the Secretary of State
- Reasons of national security
- All other aspects of spectrum management[10]

Decisions on revocation for these reasons will be taken by Ofcom on a case by case basis. There are two aspects of the rights that we would like to emphasise, first that they are not property rights and secondly they do not of themselves imply a departure from international harmonisation, given that Ofcom may impose requirements to comply with such measures.

The rights granted under tradable licences are not spectrum property rights in the sense that they do not confer a right to exclude use of the spectrum by others without the holder's permission or to receive compensation if the rights holders interests are harmed. Under Ofcom's proposals rights may be revoked (without compensation) for "spectrum management" reasons the scope of which is not clearly defined. By contrast the regimes in Australia and New Zealand do confer property rights on holders of spectrum licences and management rights/licences respectively.

Property rights give rights holders greater certainty that their rights will not be diluted in future (or if they are they will receive compensation) and should therefore encourage greater long term investment than under a system where weaker rights are granted (e.g. bare licences)[11]. Transaction and enforcement costs may also be lower because rights are clearly defined. However, against this government's flexibility to change rights is limited and this could result in an offsetting loss of general economic welfare.

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[9] For details see the Liberalisation Guidance notes.

[10] Section 6, A Statement on Spectrum Trading, Ofcom 6 August 2004.

[11] That is contractual rights to do that which would otherwise be unlawful.

We have not reached any conclusions on the case for granting property rights rather then the more limited rights proposed by Ofcom, as this would require legal expertise which we do not possess.

3 TECHNICAL CONSIDERATIONS

3.1 Introduction

To give radio users have greater freedom concerning technology and services supplied certain conditions in existing radio frequency licences will need to be changed or be capable of being changed.[12] These include, for example, conditions on the type of system deployment and the equipment and various references to Radio Interface Requirements and equipment standards. These restrictions allow spectrum use by different licensees to be co-ordinated so that systems can be deployed economically while avoiding harmful interference between systems. Relaxation of these restrictions is likely to result in an increased risk of all users suffering harmful interference. Interference is an external cost borne by users other than the user undertaking transmissions and in an unregulated environment an excessive level of interference is likely to be produced, because the costs of interference are not borne by the interfering party. Regulatory controls on transmissions and a process for changing any such controls are therefore required even in a liberalised environment.

In this chapter issues in controlling the different types of interference that may arise are discussed and potential solutions evaluated. Processes for managing change of use are addressed in Chapter 6.

3.2 The interference environment

In a liberalised regime, the only constraint on spectrum use should be the controls necessary to avoid harmful interference and the study team has therefore sought to determine a set of controls that offer flexibility in spectrum use while not increasing the level of harmful interference.

It is well known that the propagation of radio signals cannot be contained within the assigned frequencies and geographic areas and receivers do not perfectly screen out emissions in adjacent bands. In a simplified form the resulting interference environment can be represented by the diagram below, noting that apart from the out-of-band emissions resulting from the modulation process, there are also spurious emissions that can be generated beyond the immediately adjacent bandwidth.

[12] We do not address any consequential changes to authorisations to provide electronic communications networks or services or broadcasting licences. It is also possible that in some cases European harmonisation measures will place a legal constraint on the technology or service deployed, in which case liberalisation will not be possible.

The emphasis here is very much on the impact of the various emission types emanating from a transmitter on a victim receiver, rather than the impact of unintentional emissions from a receiver on other receivers.

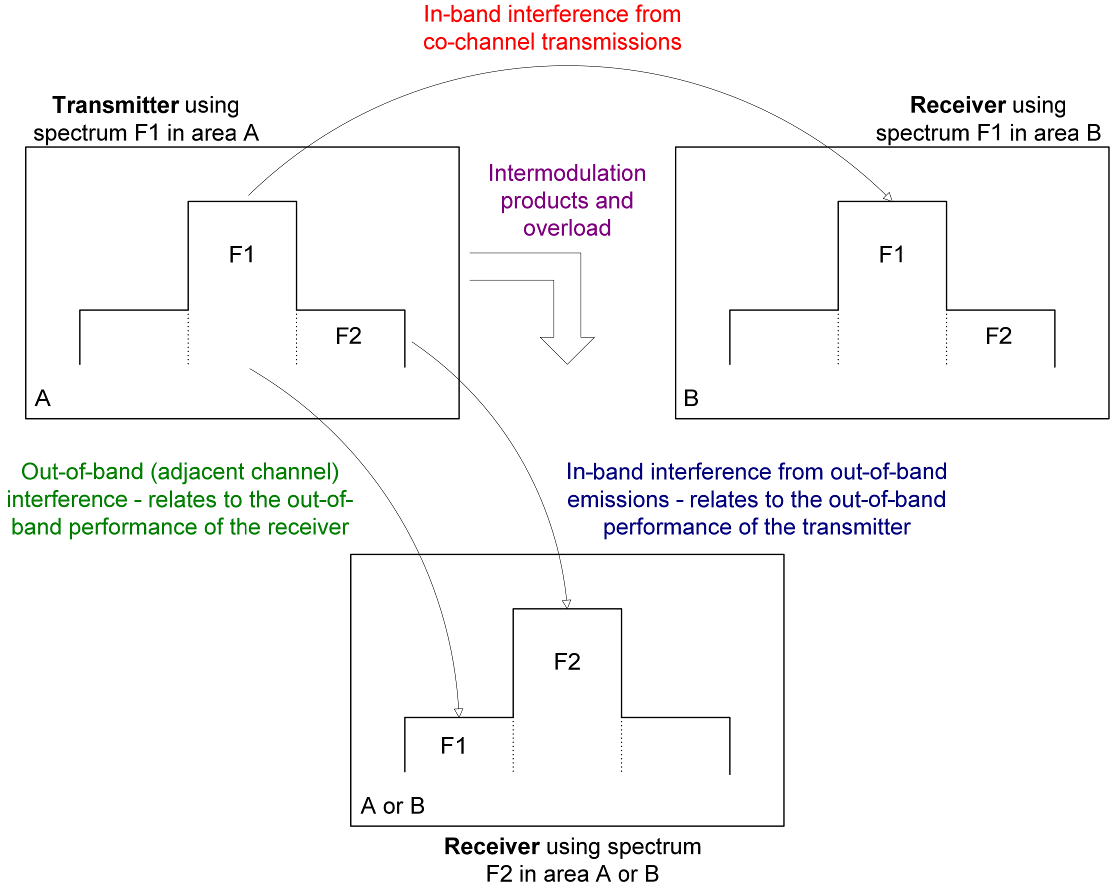

Figure 1: Types of interference

It can be seen in Figure 1 that the key types of interference are:

- The in-band interference from co-channel transmissions across geographic boundaries (as shown in red)
- The in-band interference from out-of-band emissions falling across frequency boundaries (as shown in blue)
- The out-of-band (adjacent channel) interference (as shown in green) is determined by the in-band power of the transmitter and the out-of-band performance of the victim receiver.
- The intermodulation products and overload (as shown in purple) are to some extent controlled by the out-of-band limits applying to the transmitter. There are, however, situations where intermodulation products arise unexpectedly in a receiver or passively due to non-linear conductivity in metal. Other spurious

emissions (e.g. harmonics / frequency conversion products) exist, both for transmitters and receivers.

It is these four types of interference (or interference entries) that have to be considered when deciding the degree of control that should be exercised under a liberalised regime.

3.3 Regulatory control

In trying to package the spectrum it has been proposed by Ofcom and others that transmission rights could be defined in terms of:

- Time
- Geographic boundaries
- Frequency boundaries
- In-band power limits
- Out-of-band power limits
- Interference mitigation factors

In addition an indication of what constitutes unacceptable interference would have to be defined.

Note that in the discussions that follow where signal strengths are described in terms of PFD this should not be taken to mean that this is the only unit that will be used to describe signal strength. Similarly, the use of EIRP and isotropic receiver are not unique.

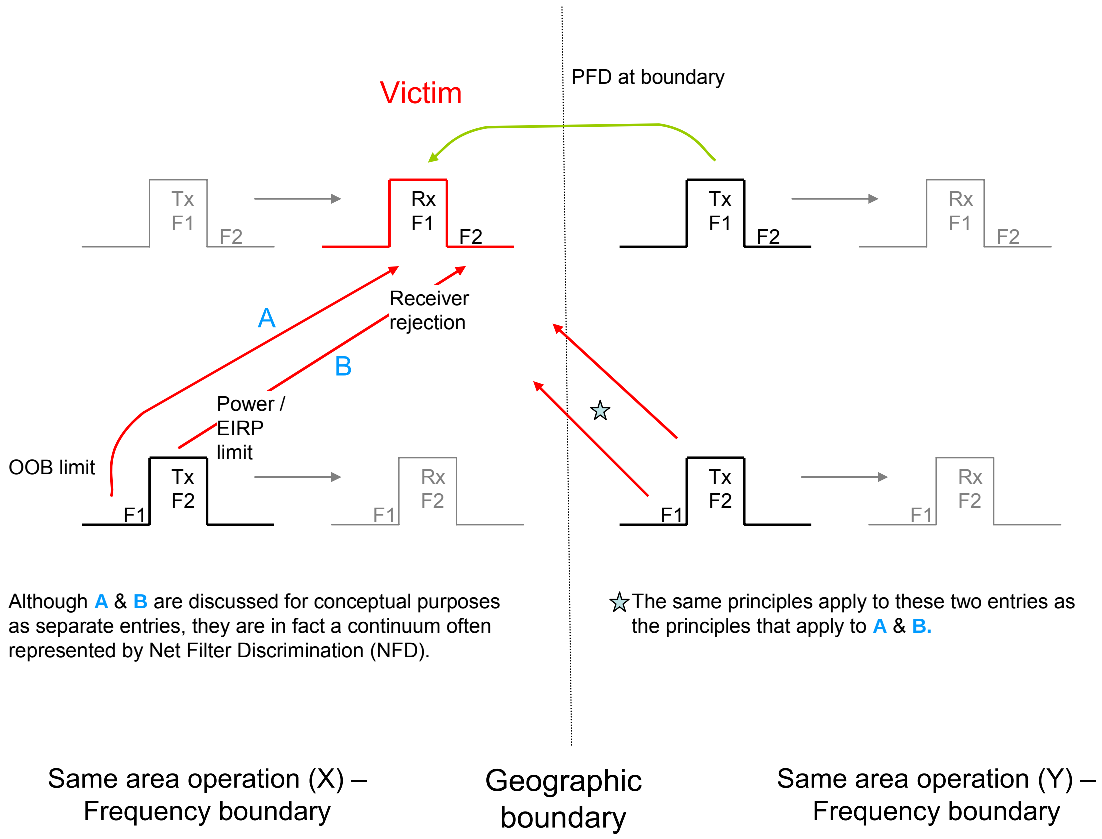

Figure 2: Controlling the interference entries

Ideally, all the interference entries that can arise should be controlled such that quality of service can continue to be ensured. It is instructive to note which can and which cannot be fully controlled in a liberalised environment. The options for controlling each type of entry are discussed in the following sub-sections with issues requiring later discussion highlighted.

3.3.1 In-band interference from co-channel transmissions

The options for controlling co-channel interference across a geographic boundary[13] need to ensure that the interference at a victim receiver is bounded. This can be achieved in a number of ways, the most important factor being a control on distance, whether this is achieved by specifying an actual distance or implicitly by specifying a PFD limit derived from an assumed distance (see Figure 3). Even if the limitation is expressed in terms of a maximum EIRP within an area, it still implies that receivers of a spectrum user in an adjacent area will be unusable within a certain distance of the boundary associated with the Maximum EIRP unless mitigating techniques are employed. Taking a PFD limit as an example it can be seen that the level at which the limit is set directly affects where the unusable area lies.

[13] The other interference entries arising from out of band emissions and receiver selectivity across a geographic boundary are effectively addressed in terms of principles by the same geographic area case considered subsequently – but note that limits may be different.

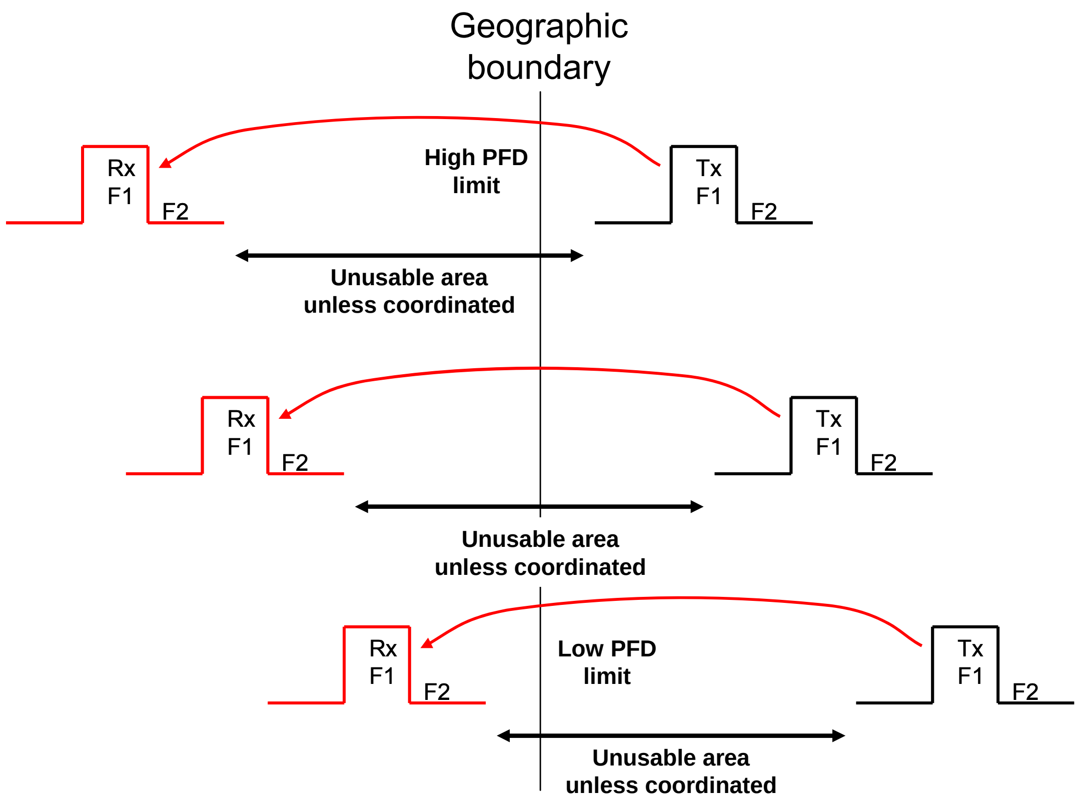

Figure 3: Setting the PFD limit

Insofar as a receiver is concerned it is the aggregate interference level that is of importance. Since the PFD limit at a boundary is designed to protect receivers on the other side of the boundary, and there is no knowledge of deployment density, it is appropriate that the boundary limit should be specified as an aggregate limit.

However, where this aggregation of signals at a point on the boundary is due to a number of transmitters employing directional antennas it is likely that the signal level set as a limit (assuming that the measurement receiver is specified as isotropic) would be very constraining. The implicitly higher signal levels generated by the directional antennas and the lack of discrimination at the isotropic receiver between them give rise to a malign interference situation. This will lead to significant spectrum inefficiencies unless coordination / negotiation is ensured. Alternatively, it will be necessary to have more than one style of spectrum usage rights. Directional antennas are a particular case relating to the deployment issue.

ISSUES – Large buffer zones – coordination / negotiation necessary to achieve use of this spectrum space. Aggregation issue. Directional antennas / Deployment issue.

3.3.2 Interference from out-of-band emissions

The options to be considered later for controlling the interference entries across the frequency boundary for same area operations[14] need to recognise that interference most often arises when the interferer and the victim are relatively close, although clearly with high power transmitters this will not necessarily be the case. As noted in the diagram earlier (see Figure 2) these entries, denoted A and B, are in fact a continuum both as far as the receiver frequency response (selectivity) and the transmitter frequency response (emission mask) are concerned. The combined effect of the two is often represented as the Net Filter Discrimination as a function of frequency offset, where co-channel equals a factor of one (0 dB). For conceptual purposes we have treated the entries separately.

It can also be noted that setting limits at a frequency boundary is analogous to the geographic boundary as represented in Figure 3 above. Depending on the level of allowable OOB emissions set at the frequency boundary and the performance of the equipment there will likely be unusable spectrum (i.e. a guard band) that falls within the spectrum associated with the transmitter. Knowledge of the level of OOB emissions may also require the receiver associated with the spectrum on the other side of the frequency boundary to provide a guard band.

3.3.2.1 Interference received in-band from out-of-band emissions

This can only be controlled by specifying out-of-band emission limits in one way or another. The receiver end of this entry is wide open and by its very nature has to be so.

Even when out-of-band emission limits are defined it is often possible to arrive at a situation where the close proximity of the transmitter of one system interferes with the receiver of another system. This is exacerbated when any of the systems are mobile. In effect when deployment is uncontrolled it is not realistically possible to prevent interference completely. It either has to be accepted that interference will occur when systems operate within a certain distance of each other or a control on physical deployment has to be put in place which is clearly difficult in the case of mobile / nomadic systems.

Furthermore, when deployment is uncontrolled, or where liberalisation means that system deployment might be changed radically such that emitter density increases, there is always the possibility that the risk of interference and / or the level of interference increases. In the case of the latter we are once again dealing with a question of aggregation.

ISSUES – Deployment issue. Aggregation issue.

[14] The principles should cover the same entries also coming across the geographic boundary.

3.3.2.2 Interference received out-of-band from adjacent band transmissions

This can be controlled by limiting the channel EIRP or power. At the same time the interfering impact of such an emission is influenced by the selectivity of the victim receiver.

This situation is similar to that immediately above which is not surprising given that it has already been noted that the effect of the two conceptual interference entries is in fact a continuum. However, in this case we do have the receiver selectivity as a control on the higher emitted power being considered.

ISSUES – Receiver specification. Deployment issue. Aggregation issue.

3.3.3 Intermodulation, overload and other spurious emissions

These aspects of interference generally only become an issue with relatively high power transmitters and / or transmission / reception equipment in relatively close proximity.

Intermodulation products (IPs) are generated from multiple signals by non-linearities in the transmit chain, the receiver or corroded / unclean metal junctions. While IP emissions from a transmitter will largely be controlled by an out-of-band / spurious emission mask, the case is not so clear cut with regard to the other two situations, although it is possible to define receiver performance to some degree. Furthermore, responsibility for generating IPs in these cases is not always obvious. For example, a receiver that has been operating satisfactorily for sometime may suddenly be affected by IPs with the installation of a new transmitter nearby interacting with an existing transmitter.

Overload occurs when a strong out-of-band signal, which might otherwise be satisfactorily filtered out by the rest of the receive chain, saturates the low noise amplifier at the front end and drives it non-linear. The degree of degradation due to overload depends on the performance of the receiver front end and the possible implementation of input filtering although this is generally undesirable from noise considerations.

Whereas out-of-band emissions discussed earlier occur immediately outside the necessary bandwidth of the transmission and result from the modulation process, spurious emissions occur over a much wider range outside the necessary bandwidth. Spurious emissions include harmonics, parasitic emissions, IPs and frequency conversion products. Receivers also generate spurious emissions.

ISSUES – Receiver specification (including spurious). Deployment issue. Who is responsible for IPs?-Registration required?

3.4 Issues

The section above regarding the interference entries that need to be controlled to one degree or another has highlighted a number of issues that need to be addressed. Also, given that spectrum management will continue to be needed, albeit in the market place rather than centrally, there are additional issues that should be addressed in terms of what triggers the need for negotiation and with whom, and what triggers a dispute and / or the need for enforcement. These issues are addressed in the following sections.

3.4.1 Neighbouring users

It is anticipated that once an interim period when Ofcom determines whether a proposed spectrum change of use is acceptable has expired, it will be the responsibility of spectrum users to negotiate such changes themselves. In a stable situation this effectively means that negotiation has to occur when there are changes that could cause interference across both geographic and frequency boundaries. The two fundamental questions this raises are:

- What triggers a need to negotiate a change of use ?
- Who are the neighbours with whom one has to negotiate and how can this be determined ?

3.4.1.1 The trigger to negotiate

The trigger for negotiation very simply occurs when a proposed change of use requires modification to any of the parameter values contained in the licence such that the modifications could cause increased levels of interference to other users of the radio spectrum operating in accordance with their licences. This of course assumes that the spectrum usage rights have been specified correctly and unambiguously, and that the inherent uncertainties associated with radio propagation have also been taken into account in specifying those rights. As might be expected, reductions in emitted power density levels whether in-band or out-of-band, and considered at an aggregate level, would not require negotiation as this is not so much a change of use as what can be termed as a reconfiguration.

So if the requirement to negotiate is triggered by exceeding the aggregate emission entitlement at one's frequency or geographic boundary there has to be a bound on the number of other spectrum users beyond the boundaries with whom one has to negotiate. These bounds are discussed below.

3.4.1.2 Frequency boundary neighbours

With respect to frequency there are effectively three domains; the in-band domain, the out-of-band domain and the spurious domain. Spurious emission levels are generally set at a sufficiently low level that they have little or no impact on other spectrum users when the spurious domain overlaps the necessary bandwidth of the victim receiver. This is not true however when high power transmitters are involved and harmonics fall in a victim receiver's necessary bandwidth, although if the OOB emission mask is specified in absolute terms this should not matter.

The out-of-band domain is generally taken to end at a point separated from the centre frequency of the emission by more than 250% of the necessary bandwidth. This is effectively the same as saying two channels beyond the edge of the necessary bandwidth. This could form a useful basis for determining which neighbours should be involved in any change of use negotiations, noting that high power transmitters would have to negotiate with a much wider community of spectrum users (in the frequency domain)[15]. Note that in this case we are talking about spectrum users operating in the same area, however, the area within which any assessment of potential interference is made should go beyond the area licensed for use by the transmitters in order to ensure that all potential victim receivers are addressed – see comments in section 3.4.1.4 regarding frequency and geographic boundary.

3.4.1.3 Geographic boundary neighbours

PFD limits at a geographic boundary will inevitably lead to large zones where spectrum users will be constrained in their operation unless coordination takes place. Under these circumstances it is therefore important that it is made easy for users to identify relevant neighbours when they want to operate outside the PFD limit. Note that in this case we are already talking about a subset of spectrum users who are operating co-channel or at least with frequency overlap.

It would be convenient to be able to say that only immediate neighbours, whose spectrum space abuts that of the spectrum user wishing to make a change, need be consulted. However, it is easy to envisage instances, particularly if adjacent areas are relatively small, where areas beyond the immediately adjacent ones might be affected. It is suggested that appropriate neighbours are determined with respect to a specified distance where this distance depends on the proposed power increase, frequency band and possibly height.

Although highly directional antenna systems might be made to fit into such a regime it is difficult to see how it can be done efficiently. This issue is addressed in Section 3.4.4 which looks at deployment issues.

3.4.1.4 Frequency and geographic boundary neighbours

Frequency boundary neighbours will generally be operating in the same geographic area. However, the same potential interference issues arising from out-of-band emissions could occur across geographic boundaries (as represented in Figure 2 earlier). In general interference from out-of-band emissions is a close proximity issue so only immediately adjacent neighbours will be affected. Once again high power transmitters do not satisfy the generalisation and a special rule should apply.

It should also be recognised that operating areas, as defined by boundaries, are not necessarily going to form a neat pattern or correspond between frequency bands. It is therefore difficult to simply deal with something happening within an area or between adjacent areas. It is more appropriate to deal with a distance as

[15] How much wider needs to be determined and it is likely to be the case that it will be application / system dependent.

determined by a few simple factors (e.g. power increase and frequency, and possibly height).

Where it has been proposed that the determination of neighbours be based on a given distance (relating to power increase, frequency, height) there are two options:

- Ofcom issues non-mandatory guidelines on a distance appropriate to the power increase, frequency etc
- Users initiating a change of use determine an appropriate distance based on their own expertise or advice from others.

In both cases, and subsequent to a change of use being implemented, it will still be open to other users with whom no negotiation has been carried out to claim that the change of use breaches their rights however defined.

In order for spectrum users to be able to identify who their neighbours are in the space and time domains it will be necessary to make available data covering at the very least:

- Name and contact details for the rights holder
- Frequency band(s) associated with the rights
- Geographic area associated with the rights

In addition it has to be recognised that some particularly sensitive receivers exist (e.g. Radio Astronomy). These also need to be identified in the data that is made available such that a proposed change of use can take them into account.

CONCLUSION – The trigger to negotiate with neighbours is any change to licence conditions which results in a potential increase in interference to neighbours.

The identity of frequency boundary neighbours should be determined by out-of-band emission overlap and not spurious emissions except in the case of high power transmitters. There is also a potential impact on immediately adjacent geographic neighbours, with high power transmitters having a wider impact. The geographic extent should be restricted by distance.

Geographic boundary neighbours should be determined by distance from the boundary depending on proposed power increase, frequency band and possibly height.

Provision / "ownership" and management of guard bands will have to move from the regulator to spectrum users.

Access to relevant data will be required for spectrum users to be able to identify their neighbours.

3.4.2 Aggregation & apportionment

Aggregation and apportionment are two sides of the same coin. The former is concerned with multiple interferers summing at a victim receiver while the latter is concerned with dividing up the tolerable interference level at a receiver into allowances for individual interference entries (or groups of interference entries).

Insofar as a victim receiver is concerned it is generally the aggregate level of interference that is of concern even though in some instances the aggregate level will be dominated by one of the sources of interference. The aggregate interference into a victim receiver can of course be assessed if one has full knowledge of all potential sources of interference. In some instances this would require excessive processing power even if action is taken to constrain the community of potential interferers by making assumptions that enable the geographic area and frequency domain being considered to be restricted.

There is a concern that a change of use could involve a significant change in density and hence a potential increase in aggregate interference. It is therefore proposed that emission limits should be set as aggregate limits for a licensee.

These aggregate emission limits will still have to be derived from the tolerable interference level at a receiver. In many cases, and taking account of potentially interfering systems that may not have been implemented yet, it is already common practice to assume / derive a single interference entry criterion[16] that allows a much more straightforward assessment of whether a new assignment is possible or not. Similarly, it will be necessary to arrive at an aggregate limit associated with a single licence based on declared assumptions about the tolerable interference level at a receiver and the number of interfering licences. The derivation can be based on technical information in existing TFACs and assumptions that will need to be made about the foreseen interference environment.

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[16] When assessing whether interference is unacceptable or not, the starting point is the tolerable interference level at the receiver. The interference received, which is potentially made up of multiple interference entries from a number of interfering sources, is assessed against this threshold or criterion as it is often called. In order to make a simpler assessment as to whether a single interference entry arising from one of the interfering sources is acceptable, it is common practice to apportion the tolerable interference level at the receiver (which is attributable to multiple interference entries) to give a single interference entry criterion. The apportionment is based on informed assumptions about the overall interference environment.

CONCLUSION – Emission limits should be based on aggregate levels.

Each licence should have an aggregate emission limit both for in-band and out-of-band emissions, although, as will be seen later, the mechanism for controlling the latter is not straightforward.

Based on existing TFACs and assumptions about the interference environment, the link between receiver tolerable interference and aggregate emission limits for individual licences should be declared by Ofcom when the rights to use spectrum are first established.

3.4.3 Propagation modelling and measurements

Assuming that interfering signal strength levels will be part of the definition of spectrum rights the question of whether specified limits are being met will arise under a number of circumstances. In particular this question will arise when determining a change of use and when a spectrum user is concerned that limits are being breached and therefore have the potential to cause or are causing interference. A key factor when determining signal strengths is how the radio wave propagates from transmitter to receiver.

Propagation measurement programs can take a long time and be very expensive – even to test propagation for just one path. Therefore to ensure that CoU examinations and decisions can be completed in a reasonable time, they should be based upon propagation models not measurement. However there are limitations in the propagation models that could potentially result in inconsistencies between transmit rights and the assumed receiver performance (see section 3.4.5) and these could subsequently be identified via measurement .

Clearly it would be preferable to reduce the potential for inconsistencies by employing the most accurate and reliable propagation models available. Significant work has been undertaken developing models that have been peer reviewed at fora such as the ITU-R. Recommendations like ITU-R Rec. P.452 and P.1546 are the result of decades of research and measurement and have been extensively used in practical spectrum management in the UK, building stakeholder confidence in their use.

It should be noted that these models tend to have inherent limitations – for example ranges of valid transmitter and receiver antenna heights, frequency bands etc, and so care must be taken to ensure they are used appropriately. There are a number of areas where there are known limitations in propagation models[17] though Ofcom is commissioning work to resolve the most critical of these.

Definitions of spectrum rights should take account of the requirements of propagation models. For example a metric often quoted is *PFD level not to be*

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[17] For example how to model mobile to mobile paths using ITU-R Rec. 1546 or the general problem of correlation of different propagation paths when calculating aggregate interference.

exceeded defined on a boundary: however from a propagation modelling view this raises two issues:

1. What is the percentage of time for which this PFD level is not to be exceeded? Anomalous propagation conditions can increase interfering signal levels (e.g. due to affects such as ducting) for short periods of time. It is therefore necessary to associate the PFD level with an applicable percentage of time. For example the median PFD level associated with the 50% of time point.
2. Can the PFD level exceed the threshold beyond the boundary? While radio waves decrease with distance in empty space, the effect of terrain can result in areas where interference is higher at points further away. For example the boundary could be in a valley and the top of the hill beyond the boundary could be just line of sight to an interfering transmitter. It is therefore better to define that the PFD level should not be exceeded on or beyond a boundary.

When there is a requirement for a propagation model the one selected to be used could depend upon the circumstances. The figure below shows a proposal on how the appropriate propagation model could be selected:

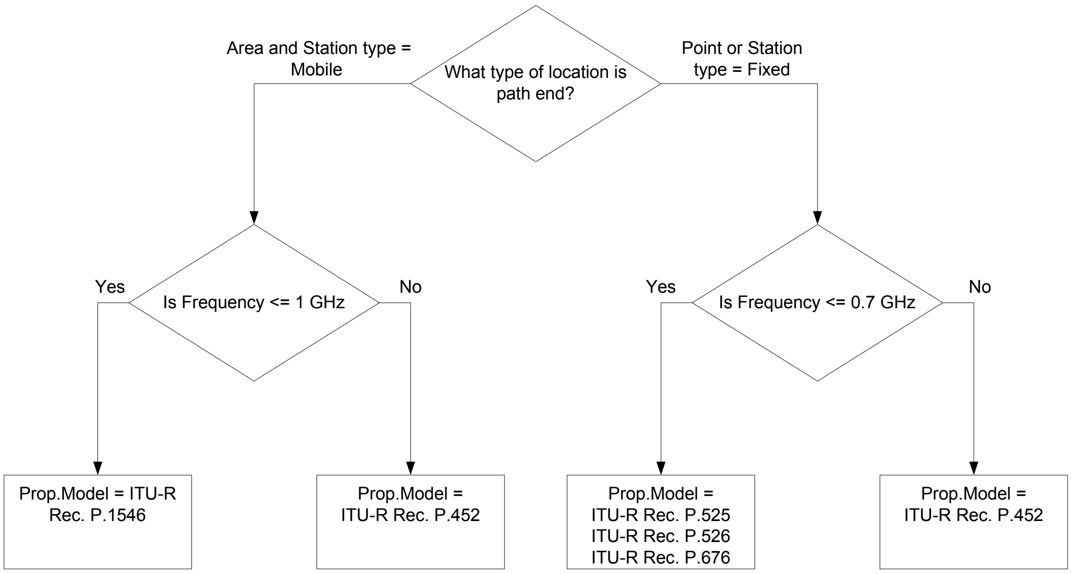

Figure 4: Selection of Propagation Model

This approach takes account of the range of frequencies that the propagation models have been validated for, and also the nature of the victim receiver – is it at a fixed point or located within an area (e.g. receiver of a mobile or broadcasting system).

Note that in negotiations between operators there would be the opportunity to select other suitable propagation models – for example ones that are very site specific.

When licences are defined with PFD on boundary constraints, operators will have to ensure that their deployments do not result in thresholds being exceeded. It would be their responsibility to pick the appropriate propagation model, though the regulator could give guidance.

CONCLUSION – Internationally agreed propagation models to be used where possible, but it is recognised that not all circumstances are covered.

Measurements not precluded as a means to determine the interference environment.

3.4.4 Deployment

3.4.4.1 Proximity & density

Moving from a command and control system to a liberalised regime potentially means that deployment becomes a variable. This is the case where liberalisation is designed to accommodate convergence such that there is no need to distinguish between fixed, mobile and nomadic.

However, as has been identified earlier, moving from a fixed system to a mobile (or nomadic) system causes the biggest uncertainty because of the potential for close proximity out-of-band interference. If technology neutrality is to accommodate system neutrality the risk of interference is unavoidable unless a control is placed on deployment.

Assuming that the controls of current licences are sufficient to minimise this problem, the most straightforward solution is for the current licences to be converted into technology neutral licences but <u>initially including the deployment restrictions of the current licences</u>. It can be noted that deployment restrictions sometimes include defined uplinks and downlinks and in those cases therefore implicitly discriminate between FDD and TDD systems. It is proposed that deployment restrictions could then be relaxed or removed through negotiation with neighbouring users if desired.

Another example where deployment constraints are important but implicit concerns TV broadcasting. The constraint here is that transmitters are co-sited. In the event that other transmitters of other systems were put into place at different sites the broadcast coverage would be degraded, often described as “hole punching”. The coverage can be restored by the implementation of repeaters. It is clear that implicit constraints should also be carried over, noting once again that they can be the subject of negotiation with other spectrum users.

In the case of new licences it would be possible to define the rights either with or without deployment restrictions. If no deployment restrictions are imposed it is likely that the emission rights would be more stringent than the alternative. In the case of the alternative, i.e. with deployment restrictions, it would be possible to relax / remove the restrictions through negotiation as above. An absence of deployment restrictions would be preferable but whether this can be achieved will depend on existing spectrum neighbours.

In moving to system neutrality and considerations of density of use it has to be recognised that analysis of the interference environment is very complex. This does not, however, help in answering the question as to how the situation should be managed. There appear to be four options for controlling interference across the frequency boundary (i.e. managing out-of-band emissions with respect to deployment):

- Define an EIRP mask, including the possibility of defining a minimum distance. Interference from devices located within this minimum distance would have to be accepted.
- Define the interference allowed in terms of an aggregate field strength not to be exceeded over X% of an area for Y% time.
- Mandate a technical coordination procedure
- Allow spectrum users to negotiate a solution

Ofcom has proposed a complementary set of rights (called restrictive rights) which come into play as soon as a change of use is considered. As the name implies these restrictive rights are designed to reduce the impact of a changed deployment on other spectrum users by only allowing systems to be implemented within a highly constrained technical envelope. The restrictive rights are only lifted once negotiations have been undertaken with neighbours and another set of specific rights has been agreed. In the event that spectrum usage rights include deployment restrictions, initially at least, then it should not be necessary to use a complementary set of restrictive usage rights. If there is a planned change of use involving the type of deployment (as defined in the initial rights) then the existing rights lapse until a new set of rights is negotiated with neighbours.

3.4.4.2 Directional antennas

Directional antennas are another case where deployment characteristics need to be taken into account. Taking fixed point-to-point links as the extreme example it is clear that the high density of use that is normally achieved results not only from their physical characteristics (providing high discrimination against interference due to directionality) but also from the fact that this discrimination is taken into account in a centralised planning process. It is important to note that for an interference path discrimination is effectively achieved from the directionality of the transmit antenna and the directionality of the receive antenna. There is no doubt that fixed link usage could be specified within a general technology-neutral framework. However, there are reasons why an alternative approach might be considered.

1 – Rights associated with a fixed point-to-point link specified in a general technology-neutral manner are not likely to be of much use to anyone else. Because of the dependency of that assignment not only on the directionality of the antennas at either end of the link, but also on the directionality of antennas associated with many other links, changing the use of that assignment to another application would not be straightforward as potentially one level of discrimination might be lost.

2 – Without some form of central planning, however achieved, it would be very difficult and time consuming to negotiate the implementation of a new fixed link or a change to an existing fixed link on a multi-bilateral basis. It is more than likely that shortcuts taken in obtaining access to the spectrum would result in links being accommodated in a grossly inefficient way.

For these reasons it might be appropriate to consider the issue of a more specific licence, albeit with some technology-neutrality, but associated with a particular type of equipment.

3.4.4.3 Other

Other aspects of deployment relate to intermodulation products and overload. These are addressed separately in section 3.4.7.

CONCLUSION – Existing licences, when converted to liberalised spectrum usage rights, should retain a definition of the current deployment. If required, such restrictions can be relaxed or removed through negotiation with neighbouring spectrum users.

New licences can start with or without a definition of deployment, the rights depending on which approach is chosen.

While systems using highly directional antennas could be accommodated within a general technology-neutral spectrum framework it is considered that this would likely result in gross inefficiencies. Centralised planning is required for this and it may be appropriate to define a different style of licence.

3.4.5 Receiver performance

The performance of receivers has not in the past been an explicit requirement insofar as licence conditions are concerned. There has been an indirect linkage in terms of the referencing of interface standards and/ or international / national standards by a licence schedule, although in many cases these standards have no mandatory requirements in terms of receiver performance (as a result of the R&TTE Directive). In cases where assignments are made by Ofcom receiver characteristics (as identified in TFACs) are used to determine whether an assignment is possible or not. It is clear that any assessment of interference requires some knowledge of receiver performance. If future assessment of interference, as part of the negotiation process between spectrum users, is to be left to the market place then it seems necessary that reference to a minimum receiver performance be maintained where currently available and introduced where not. In a framework that only includes the definition of transmit characteristics it becomes difficult to assess who you have to negotiate with and how they will be impacted by a proposed change of use. An indication of minimum receiver performance avoids this problem.

The definition of minimum receiver performance will need to be taken away from technology specific standards and/or TFACs and embodied in technology neutral standards, or interface standards, the licence / authorisation / list of rights itself, or maintained by the regulator. If it is intended that a spectrum user be able to exploit spectrum to its fullest extent then it will be necessary to associate the negotiable minimum receiver performance with the usage rights themselves.

It is important to note that the minimum receiver performance is not meant to be mandated. It serves as a benchmark with which the interference environment can be assessed. If an operator chooses to use receivers having a performance in some way inferior to the minimum receiver performance, then they will not be protected from interference levels used for the assessment (see later this section). They may however choose to negotiate with a neighbour to reduce the neighbour's emissions such that their own inferior receivers operate satisfactorily. At this point the parties may agree to embody the agreement in the rights or not.

There are three aspects of receiver performance that could be included in any definition of minimum receiver performance (but see also Section 3.4.7 on Intermodulation Products & Overload):

- Receiver RF / IF selectivity (attenuation v. frequency offset from centre of channel)
- Receiver blocking level (signal level v. frequency offset from centre of channel)
- Conversion ratios with respect to main intermodulation types

In addition given that receivers can also produce unwanted RF radiation in terms of spurious emissions it will be necessary specify a spurious emission mask. It is anticipated that the minimum receiver performance would be written into licences.

In the current regulatory regime, which is broadly command and control in all European countries, implementation of the R&TTE Directive and its requirement for essential requirements has led to a situation where the generation of interference is attributed to transmitters only. Notwithstanding, the fact that spurious emissions from receivers are also capable of causing interference, this is difficult to dispute and as such is accommodated within the current command and control regime. However, liberalisation brings with it the need for the market to be able to assess whether a change of spectrum use is acceptable or not in an unambiguous manner as possible. This requires, amongst other things, a definition of minimum receiver performance. This being the case, it will be necessary to see whether this requirement can be accommodated within a the current or a revised Directive.

The parameters mentioned so far indicate how a receiver would respond to out-of-band emissions and control the possibility of a receiver causing interference (spurious). However, if an assessment has to be made regarding the potential for interference resulting from a proposed change of use (whether this is by Ofcom or in the market), it may be necessary to have other receive parameters available such as antenna gain (and pattern), feed loss (where relevant) and noise figure.

Taken a step further this might lead to a need for a definition of spectrum quality, or more importantly a criterion or criteria against which an assessment can be made (whether by Ofcom or by the market) as to whether a proposed change of use can occur.

CONCLUSION – Minimum receiver performance needs to be defined as a benchmark not as a requirement. Can this be accommodated with respect to the R&TTE Directive ?

3.4.6 Spectrum quality

It can be argued that the rights of a spectrum user can be defined solely in terms of transmit rights or in terms of receive rights, the other being implied by the need to meet the one chosen to define the rights.

Given the uncertainties in propagation it is difficult to guarantee a particular level of interference will not occur unless significant margins are built in thereby leading to a degree of inefficiency. Furthermore, it is likely to be difficult to ensure that the transmit rights and receive rights remain consistent.

Noting that liberalisation is intended to be a two stage process, Ofcom has recognised that in order to engender confidence in the system and for the purposes of transparency it is proposed that receive “rights” will be used. It is proposed that these will take the form of Indicative Interference Levels (IILs) and will be derived from the existing interference management planning criteria contained in Technical Frequency Assignment Criteria documents (TFACs). As the name implies these Indicative Interference Levels are not guaranteed but they do represent levels of interference that will be considered appropriate when Ofcom assesses a proposed change of use.

Hence, in the first phase of liberalisation spectrum users will have transmit rights and receive “rights” , not rights as such but represented by IILs which can be regarded as benchmarks. Once confidence has been established in this approach, and implicitly the transmit rights have been demonstrated not to breach the IILs, it can be argued that it should be possible to jettison the IILs entirely, relying on the transmit rights to determine the interference environment.

From a spectrum user’s point of view there are two main questions that have to be addressed if the transmit rights-only approach is adopted:

- If I want to change the transmit rights specified in my licence how do I determine whether the proposed change is going to be acceptable to other licensees?
- With respect to my receivers at what point can I claim that I am receiving too much interference, or conversely, what level of interference should I assume I when planning my system ?

In order to make an assessment in the first case, knowledge of the other spectrum users’ system deployments and planning criteria would be required. This will not necessarily be in the public domain and will therefore need to be obtained as part of direct negotiation with the other spectrum users.

Insofar as the second case is concerned, as noted under enforcement issues in section 3.4.9, it will be difficult for a spectrum user to determine the overall level of interference from transmit rights with any accuracy. This could potentially lead to gross inefficiencies when users make assumptions as part of their planning process.

It is therefore considered appropriate that IILs or some other similar benchmark be retained in order to indicate likely spectrum quality for planning (and enforcement) purposes and for the basis of discussions in negotiations.

CONCLUSION – In the near term there is a requirement for a criterion specified with respect to victim receiver against which change of use can be assessed. This is a benchmark not a guaranteed right.

In the longer term it can be argued that transmit rights should be sufficient to determine the interference environment in which receivers operate. Information on spectrum users' transmit rights has to be made publicly available for this to be the case. However, it is considered that this approach could lead to significant inefficiencies and that there is therefore a case for retaining interference benchmarks associated with receivers.

3.4.7 Intermodulation Products & Overload

There are varying views on whether this is a significant enough issue to incur additional regulatory burden. It appears there are three options:

- On the basis that it does not occur very often do not introduce any regulatory requirements (apart from OOB / spurious limits for transmitters which will be there anyway) on the grounds that the benefits of additional regulation are not sufficient to outweigh the costs of enforcement/restrictions on spectrum use. Overall both the costs and benefits are likely to be small given the infrequency with which these problems occur.
- Specify a minimum receiver performance to reduce the risk. Receivers not meeting this specification cannot expect to be protected. However, it may not be possible to protect receivers that do meet the specification unless the next option is implemented.
- In order to ascertain responsibility for correcting the problem (i.e. who has priority) it will be necessary to register all transmitters (above a certain power) and receivers (if they require protection). This first-in-time method has been adopted in Australia.

Only two comments have been made on this issue by interested parties with many not expressing an opinion one way or the other. One party preferred minimal regulatory control and was prepared to take the risk associated with such an approach, whereas the other party regarded receiver registration as an acceptable burden if it ensured protection. Receiver registration could be made optional.

> **CONCLUSION –** It is clear what options there are but it is not clear which would be preferable. The preferred option to might usefully be derived from the Ofcom consultation process.

3.4.8 Coordination and mitigation techniques

It has already been noted that aggregate power limits at geographic boundaries (measured in terms of power flux density [PFD] or other appropriate measure of field strength) are likely to result in significant buffer zones where operations will not be possible without some sort of agreement being negotiated. The earlier discussion assumes that a proposed change of use breaching the aggregate PFD limit will trigger the need to negotiate with neighbours (as defined earlier). The form of this negotiation and the methodology to determine a satisfactory sharing arrangement may or may not be defined. Coordination methods have been defined by Ofcom with respect to a number of existing frequency bands and, as noted in Section 2 which briefly discusses the current regulatory situation in the UK, these coordination methods are referenced in licences where appropriate.

While it is often the case that coordination methodologies are developed and agreed within international technical gatherings (e.g. ITU and CEPT) it is not necessarily the case that such methodologies cover all situations. This is akin and somewhat related to the situation regarding propagation models as discussed in Section 3.4.3.

In situations where coordination methodologies do not exist it might be expected that spectrum users would establish an approach to arrive at an agreement. There is however the possibility that blocking tactics could be used unless a methodology is imposed by a third party. Alternatively, an industry code of practice could be established in advance of negotiations commencing.

In any event whenever a change to a PFD limit is negotiated and agreed the new limit has to be recorded as part of the licence.

> **CONCLUSION –** Coordination and mitigation techniques can be negotiated between spectrum users.
>
> Agreed changes to PFD limits will need to be recorded as part of the licence.

3.4.9 Enforcement

Enforcement of licence conditions by Ofcom will continue to be an essential part of the new regulatory regime and it might reasonably be expected to take on a more important role. Enforcement is designed to prevent undue interference from happening for whatever reason, where the definition of undue interference has been determined to be the same as harmful interference. Under the Communications Act interference is said to be harmful if:[18]

[18] Para 183, Communications Act 2003

(a) it creates dangers, or risks of danger, in relation to the functioning of any service provided by means of wireless telegraphy for the purposes of navigation or otherwise for safety purposes; or

(b) it degrades, obstructs or repeatedly interrupts anything which is being broadcast or otherwise transmitted-

(i) by means of wireless telegraphy; and

(ii) in accordance with a licence under this Act, regulations under the proviso to section 1(1) of this Act or a grant of recognised spectrum access under Chapter 2 of Part 2 of the Communications Act 2003 or otherwise lawfully."

There is a certain imprecision, intentional or otherwise, regarding the point at which interference becomes undue. A degradation can be large or infinitesimally small so under this definition any interference, however small, is harmful and it could be argued should be investigated. This is clearly not a tenable situation and it is important that something more practical is put in place. The procedural issues are addressed later in this report. The question from a technical point of view is what should the level be that allows a spectrum user to make an enforcement request.

If the interference obstructs or repeatedly interrupts a radio service (apart from those services which are not afforded protection e.g. licence-exempt spectrum) it is surely the case that enforcement action is required. However when it comes to degradation what level should be used as a trigger for requesting enforcement action or at least investigation. As noted earlier the trigger for the need for spectrum users to negotiate a change of use may simply be breaching a signal strength level at a geographic boundary. This parameter might also be used by the spectrum user having the receiver that is suffering interference to trigger a request for enforcement / investigation. However it is difficult to separate emissions from numerous neighbours and we therefore have to look for an appropriate aggregate threshold. If PFD limits for users are specified in terms of “at or beyond” the boundary, the sum of the power of these limits may well be a lot higher than what happens in reality. Such a threshold would be too high.. There are two options to address this situation:

- Set the PFD limits to a low rather than high level thereby requiring negotiation in the majority of cases and hence visibility of spectrum users’ operations.
- Set an aggregate <u>receive</u> PFD level (as a trigger level) that allows for an investigation to be called for. This level can be calculated from the transmit PFD limits using realistic assumptions about deployment. Furthermore, this will be closely related to the assumptions made in deriving the (transmit) PFD limits as discussed in 3.4.2.

CONCLUSION – The trigger for an enforcement or investigation request regarding degradation can be based either on a detected signal strength being exceeded directly related to other users’ transmit rights or on an aggregate <u>receive</u> PFD level at the victim receiver.

4 REGULATORY FRAMEWORK AND DEFINITION OF RIGHTS

4.1 Background

In general, if a radio system is specified in greater detail then interference analysis becomes more accurate and fewer assumptions need be made in order to ensure that receivers are protected. Less margin is then required to protect against unknowns - for example transmit station locations and antenna pointing – and there is therefore typically an increase in technical spectrum efficiency. However defining radio systems in such detail can result in increased overhead, especially if a licensee expects frequent re-configurations.

Two possible types of licence might therefore be foreseen, depending upon the level of detail known and flexibility required:

- **Specific Licence**: the licensee has a particular solution in mind and does not expect significant or frequent changes in the equipment types or locations. The licensee is likely to have limited access to spectrum (in frequency and or geography) and therefore technical efficiency becomes important. By specifying the specific system they wish to implement, interference analysis can be undertaken in detail, resulting in increased technical spectrum efficiency;
- **General Licence**: The licensee is likely to require frequent reconfigurations to match variable user demand and roll-out requirements. The licensee is likely to have access to spectrum over large areas (frequency and or geography) and is therefore able to accept the decreased technical efficiency at the boundaries that comes from specifying the licence in less detail, although there is always the possibility of improving the spectrum efficiency through coordination with other spectrum users. There will however be benefits from the higher economic efficiency resulting from the increased flexibility.

Examples of the first, Specific Licences, include Fixed Links and Business Radio systems. They typically are likely to require infrequent re-configurations and have characteristics known in significant detail. Therefore there will be an increase in technical spectrum efficiency compared to use of area licences, resulting in higher density of systems and correspondingly lower cost of spectrum per user. Defining rights via General Licences would bring a degree of flexibility that is not required but potentially at the cost of lower technical spectrum efficiency.

An example of where a General Licence would be valuable would be a Mobile Network Operator (MNO) that requires the flexibility to deploy base stations based upon demand quickly and flexibly without extensive regulatory overhead. While this could be achieved via Specific Licences, each reconfiguration would require a CoU application. Unless the examination process were very low cost (for example using automated software and online databases) this would result in significant overhead. As in general the MNO would be licensed to operate over a wide area, there would be no need to manage in-band interference in the majority of cases and other methods might be feasible to manage OOB interference paths.

As different licence types benefit different types of spectrum users, there is at least initially advantage in providing a framework that accommodates both licence types.

It is clear from the technical discussions in the previous chapter of this report that spectrum can be defined by way of a number of dimensions which allow for flexible use as suggested in Ofcom's Spectrum Framework Review. This is akin to the general licence discussed above

It is equally clear that the use of spectrum so defined only becomes practical with the definition of operations at an equipment level, which comes out of system planning. The definition of operations at an equipment level is akin to the specific licence discussed above.

It is therefore proposed that every piece of spectrum can be defined by Ofcom in terms of Spectrum Management Rights (SMR) with Spectrum Usage Rights (SUR) falling within the Spectrum Management Rights. The owner of Spectrum Management Rights is responsible for exploiting use of that piece of spectrum and managing the use of the band including in the first instance interference within the Spectrum Management Rights. The owner may issue Spectrum Usage Rights as they see fit so long as the conditions of the Spectrum Management Rights are met. Otherwise it would be necessary for the Spectrum Management Rights owner to negotiate a change of its SMR parameters with any affected neighbours.

The principles behind this proposal are described in the following sections.

4.2 Regulatory framework

At present there are different types of licence for different applications and different legal structures to access the radio spectrum – some users have licences, others RSA, others Crown rights, and others are licence exempt as shown in the figure below.

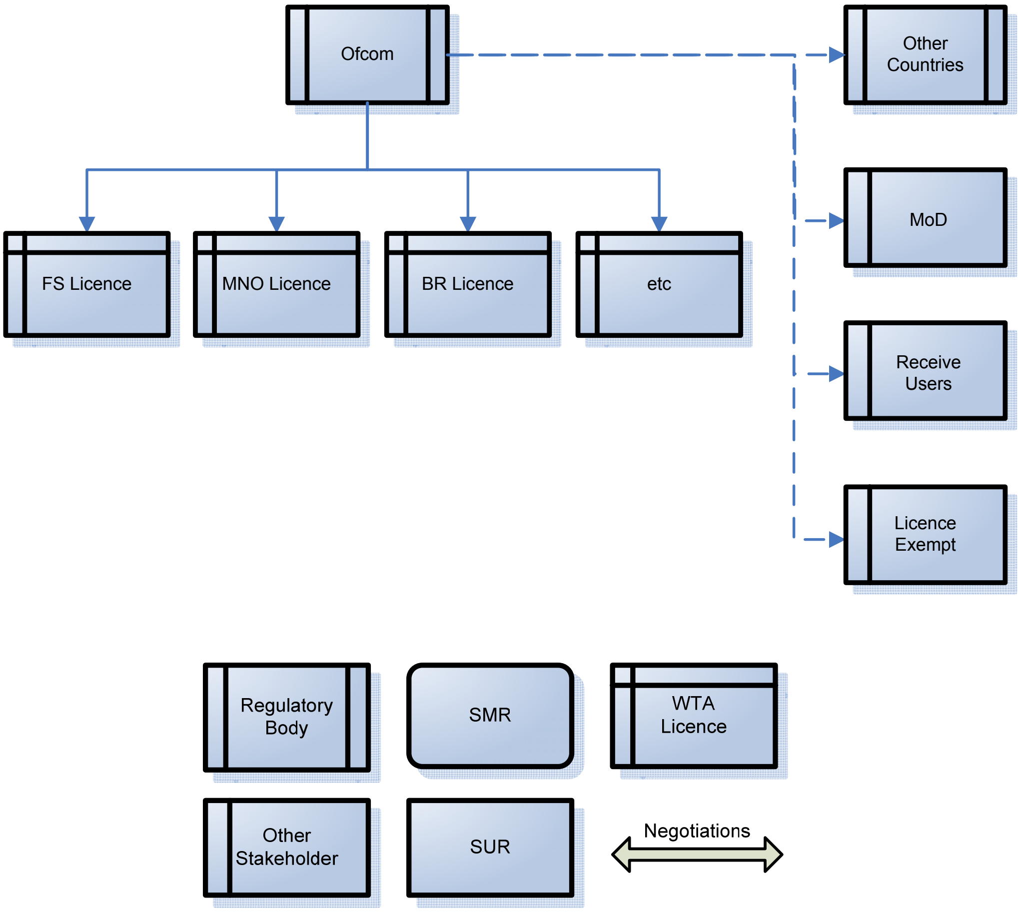

Figure 5: Existing Licensing Regime

Any new structure should be consistent with the principles in Ofcom's spectrum vision, namely:

1. *Spectrum should be free of technology and usage constraints as far as possible. Policy constraints should only be used where they can be justified.*
2. *It should be simple and transparent for licence holders to change the ownership and use of spectrum; and*
3. *Rights of spectrum users should be clearly defined and users should feel comfortable that they will not be changed without good cause.*

4.2.1 New rights

To provide a generic framework that can manage all of those with a stake in management of the UK's radio spectrum in a way that is consistent with this vision, a regulatory structure based upon two new instruments is proposed, namely:

Spectrum Management Rights (SMR): describes general rights over segments of spectrum extending in frequency and geography[19]. SMR owners would have the right to issue Spectrum Usage Rights that are compatible with their SMR terms and conditions under a defined process. It could be anticipated that these rights would be national[20] and cover significant blocks of spectrum so as to reduce transaction costs when users wish to seek a change of use.

Spectrum Usage Rights (SUR): describes the right to transmit and/or receive at specific location or service area[21] with specific characteristics. Each SUR would be associated with its parent SMR.

Note that receive only systems would not necessarily be required to operate with Spectrum Management Rights or with Spectrum Usage Rights. However there would be benefit in gaining one to ensure their need to be protected is recognised. It is noted that RSA has not yet undergone a complete consultation cycle with stakeholders and so there remains uncertainty about its role. The proposed structure is designed to accommodate such instruments should Ofcom decide to use them.

Some existing licence types would map onto Spectrum Management Rights (such as mobile 2G and 3G, FWA) while others onto Spectrum Usage Rights (such as Fixed Links and Business Radio). We envisage that the proposed rights structure will be first implemented in vacant spectrum that is auctioned and in time will be extended to occupied bands. The conditions in existing licences would be transferred across into the new rights structure.

New legislation may be required to define the rights and the processes by which new rights are created, modified and cancelled. All rights would be limited by Ofcom's overarching powers to modify rights or take back spectrum where this is required for reasons of national security, to comply with European or international regulations and for spectrum management reasons.

4.2.2 Registration of rights

We envisage there would be a register of rights, comprising the Spectrum Management Rights Register and the linked Spectrum Usage Rights Register, and that registration would confer legal title to the rights. This is essential to ensure the legal integrity of the system, for otherwise there is a risk that rights will be sold illegally (as happens with land in countries where the land registration system is

[19] The dimension of time can also be associated with the management and usage rights. This has been put to one side for the purposes of clarity.

[20] Regional rights similar to the 28 GHz Broadband Fixed Wireless Access licences would also be possible.

[21] For example the service area of a Business Radio network or Broadcast transmitter.

incomplete). Furthermore having all spectrum use information in one place reduces transaction costs for organisations wishing to undertake trades or a change of use.

Spectrum Management Rights Register: containing all SMRs, terms and conditions, constraints etc. An SMR confers a right to transmit emissions and to receive certain specified levels of protection, and to create Spectrum Usage Rights.

Spectrum Usage Rights Register: containing all SURs including all terms and conditions of the SUR (e.g. sites and the characteristics of transmissions from these sites). An SUR confers a right to transmit emissions and to receive certain specified levels of protection.

SMRs can only be issued by Ofcom, but may be traded and aggregated or disaggregated. Only SMR holders and Ofcom may issue SURs. Ofcom will become an SMR holder for those bands it continues to manage.

While an SMR holder might not be obliged to register its own use of the spectrum (as this is granted by the SMR) it is likely to be prudent for it to do so, for reasons of legal certainty and to enhance its rights in case arbitration of interference disputes is based in part or in whole on first in time considerations (see Section 6 for further discussion of this issue). Whether an SMR holder should be obliged to register its use of the spectrum is an open issue. Registration has the advantage that all information on spectrum use is in a single place and could be available to other users wanting to investigate the impact of a change of use and/or co-ordinate their use. In our view, obliging an SMR holder to register SURs for each of their transmitters is preferable as the cost would be low and the benefits could be significant.

The SMR Register could be managed by Ofcom or a third party under contract to Ofcom. We anticipate that Ofcom will have a role here because it needs to maintain such a register to fulfil its spectrum management duties and because there needs to be clear way of establishing legal title to use the spectrum and receive protection from interference.

There could also be *notional* SMRs defined and registered to ensure that there is information available on the rights of and protections to be given to users that are not currently licensed by Ofcom such as licence exempt users, Crown users and users in other countries. The issue of the public availability of data on the Register is discussed in Section 6. For the reminder of this document we assume that in time Crown users will have formal SMRs. If this is not the case, and the current position prevails, then rights owners would need to be aware that they have in principle limited protection from interference from such users.

The SMR register is shown in the figure below. It shows the mapping to existing WTA licences, but we envisage these licences would no longer exist and new legislation will be required to establish Spectrum Management and Usage Rights.

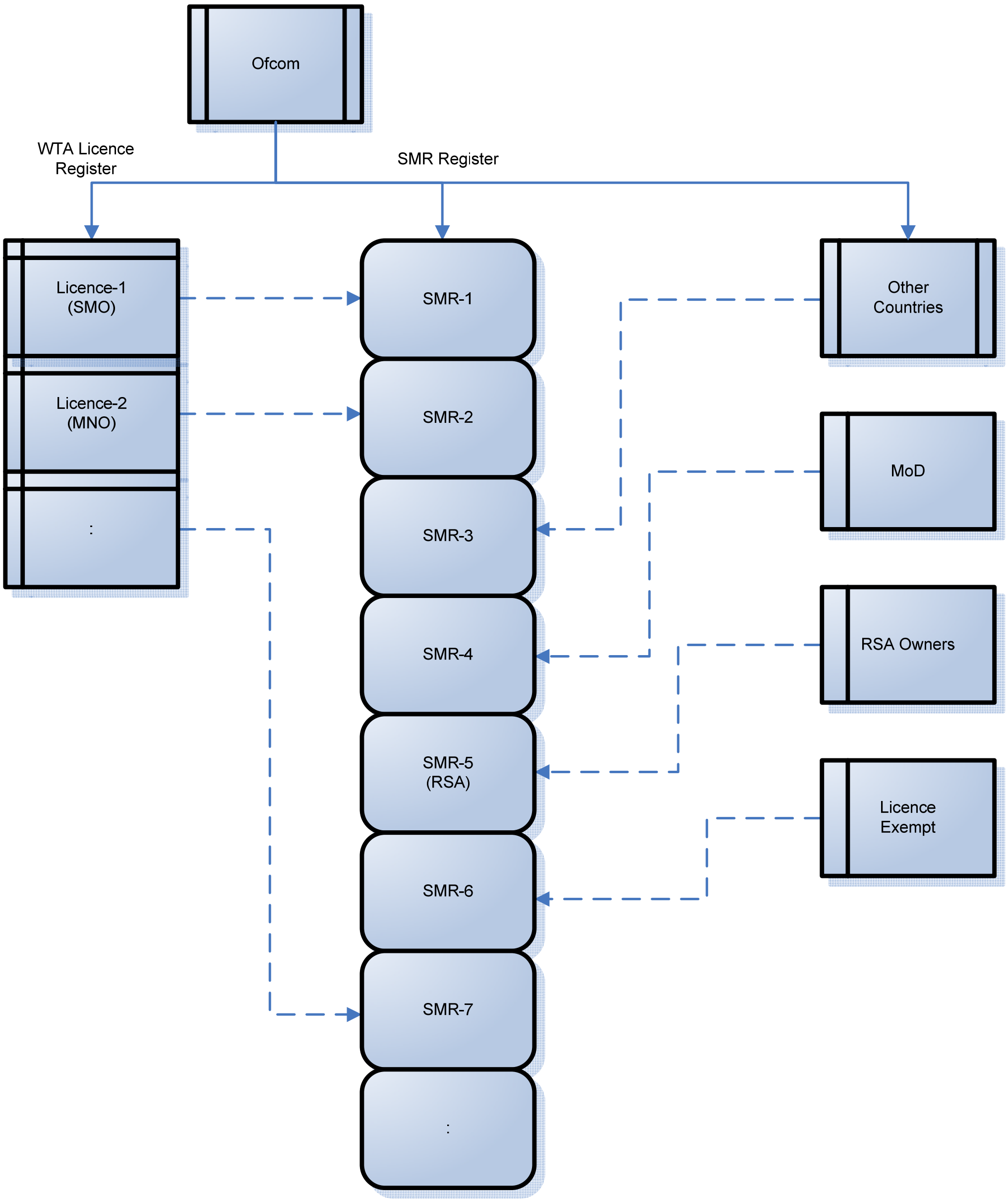

Figure 6: Spectrum Management Rights Register

Each SMR would have associated with it all the SURs generated under its rights. This structure is shown in the figure below. SURs might derive from licences originally issued by Ofcom or might be created by SMR owners for their own use or the use of third parties.

SURs would need to be registered in the database to establish legal title and so there is information available for spectrum planning purposes. However, there will be some exceptions on grounds of national security e.g. MoD and security services where SURs may not be registered and the user would simply operate within the constraints of its Spectrum Management Rights.

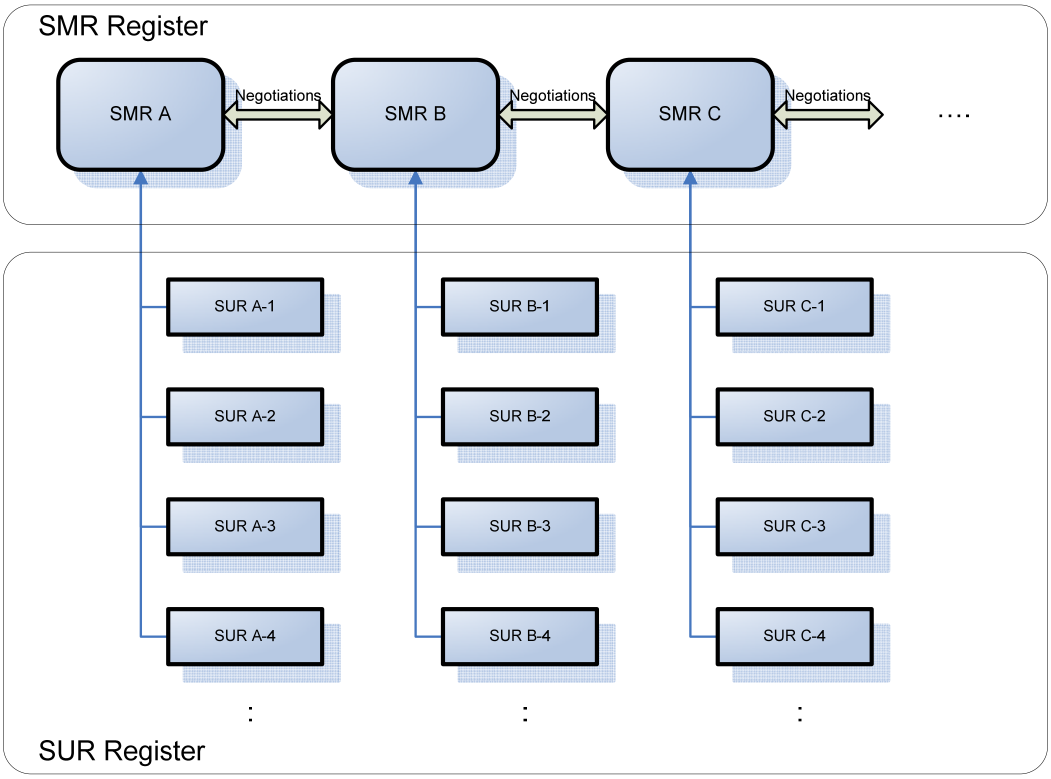

Figure 7: SMR and SUR Registers

4.2.3 Making Small Changes

A key requirement of the regulatory structure is to be able to accommodate small changes without undue cost i.e. few (if any) parties need to be consulted and any certification of the change that is required can be done at low cost. Small changes could involve the creation or modification of one or small set of SURs e.g. an operator installs and activates a new base station or modifies their system in a small way. It can be assumed that small changes are likely to occur frequently.

For small changes to be low cost SMRs should be defined so as to allow considerable deployment of equipment within the band/geographic area specified in the licence without triggering a formal change process.

4.3 Ownership and Rights

Spectrum Management Rights could be held by either private companies or public bodies such as Ofcom, CAA and MoD. Spectrum Usage Rights could be owned by the same organisation as the holder of the parent SMR or a different one. For example an MNO would own both an SMR and associated SURs as in the figure below. In this case each SUR would have similar characteristics (as typically it will be for a single application and service).

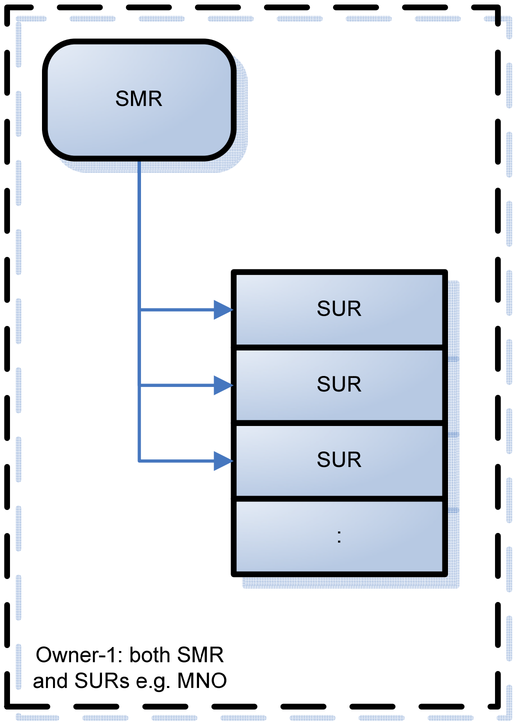

Figure 8: SMR and SURs with same owner

However a band managed by Ofcom might issue SURs that are owned by different types of users, as in the figure below, and each SUR could have a variety of characteristics because they would be used to provide different applications and services.

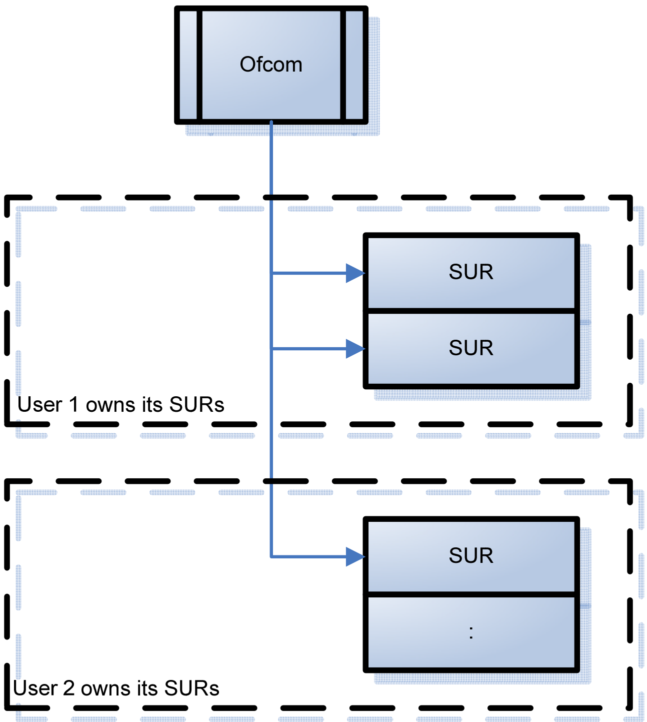

Figure 9: SURs owned by spectrum users

Privately managed and owned bands could have SURs either owned by the SMR holder or by each end user.

In bands managed by Ofcom the objective would not be commercial but would be to meet its statutory obligations under the Communications Act. In principle, it would seem desirable to give similar flexibility in modification of rights in Ofcom managed bands as in bands managed by commercial organisations. However, at the SMR level we think this could conflict with Ofcom's statutory duties, as is discussed in Section 6

4.3.1 Spectrum Management Rights (SMR)

The SMR owner's rights would include but not be limited to the following:

1. "Exclusive" management rights to use radio spectrum within specified range of (frequency, geography). It is important to note that the extent of exclusivity is likely to be circumscribed by Ofcom's powers to change rights for spectrum management reasons and this could include deployment of technologies such as UWB;
2. Right to introduce/modify SURs following a specified procedure. The details of this procedure would need to be developed but may include a minimum set of parameters for the SUR, a requirement to register SURs and a requirement to obtain the consent of the SUR holder in the case of modifications;
3. Right to operate up to an envelope of parameters (e.g. EIRP). These parameters are discussed further below;
4. Right to negotiate changes to the SMR parameters with neighbours in geography or frequency subject to certification that changes will not cause harmful interference to other parties and site clearance is obtained where required;
5. Right to trade all or part of the SMR.

If an SUR was not compliant with aspects of its rights then the SMR holder would have to take legal action to enforce the SUR.

The SMR holder would be expected to sort out interference disputes within the frequency and geographic coverage area of its SMR. If such disputes could not be resolved and all parties were acting lawfully then the dispute could be taken to arbitration (see Section 6). If the dispute involved a case of unlawful interference then enforcement action would rest with Ofcom.

4.3.2 Spectrum Usage Rights (SUR)

Spectrum Usage Rights would give the owner

1. Rights to operate according to a set of defined transmission parameters and receive specified levels of interference protection (see below)
2. Right for their receiver characteristics to be taken into account when other's proposed change of use is assessed

3. Right to trade the SUR. This may require the approval of the SMR holder, depending on the terms and conditions written into the SUR.[22]

An SUR might give rights to negotiate changes to transmission parameters with neighbours, perhaps subject to the approval of the SMR owner. However, this would depend on whether the SMR owner had granted this right when issuing the SUR.

As noted above, some existing WTA licences such as Business Radio and Fixed Services will be mapped directly to SURs in bands managed by Ofcom. The structure would be similar:

- Parent SMR controlled by Ofcom with characteristics as above;
- New users issued with SUR
- Process to manage the introduction of new SURs without causing interference into other users.
- Process to manage the change of use of existing SURs without causing interference into other users.

4.4 Parameters defining the rights

A wide range of possible parameter sets could be used to define the rights from a technical point of view. The following criteria are used as a set of checks that the parameters selected are suitable:

1. **Transparent**: it should be easily apparent what the licence holder is permitted to do and what protection from interference they can expect;
2. **Technologically neutral**: the parameters selected should be those necessary to ensure efficient management of the radio spectrum including interference issues without requiring identification of particular services;
3. **Complete and consistent**: there should as far as possible be little or no ambiguity and the data set should not contain inconsistencies;
4. **Measurable**: to ensure that compliance with licence terms can be verified.

Even given these checks on suitability, it should be noted that a significant range of alternatives remain, and so regulators will have a choice of parameter sets. As an example, two possible sets of Management Licence parameters are given below.

[22] The extent to which an Area SUR holder might change the associated Equipment SURs will depend on the precise terms of the Equipment SURs. Equipment SURs issued initially by Ofcom could have different durations and payment terms (probably related to those for existing WTA licences) from those issued by the Area SUR (see Section XX below).

4.4.1 SMR parameters

Under the existing command and control regulatory regime a number of licences have been issued giving the right to transmit without registration and coordination of individual stations with Ofcom. Typically licences specify a technology and service to be used, and then only limited additional parameters (such as extent in geography and frequency). This has been acceptable as the additional parameters required for interference analysis can be taken from technology and service information available to the regulator.

In a regime that defines licences in a technologically neutral manner and where change of use and re-configuration could occur with minimal or potentially no involvement of Ofcom, additional parameters need to be defined.

There are several methods that could be employed: the two approaches selected use the methods below to manage in-band and OOB interference:

1. PFD on boundary (in-band) and EIRP mask (OOB);
2. PFD on boundary (in-band) and PFD within percentage of reference areas (OOB).

These options are described in the sections below. At this stage it is not clear which would be the most acceptable approach to stakeholders as neither is ideal.

Note that both define interfering signals in units of power flux density with units dBW/m^2/reference bandwidth. Other measures and units could be applied such as field strength or receive signal into an isotropic receiver with equal validity.

4.4.1.1 Spectrum Management Licence with PFD limit and EIRP mask

This licence approach is based upon use of PFD masks for in-band interference paths, while OOB paths are managed using an EIRP mask.

In defining an EIRP mask there are several options, as explored later in the case studies. Those options are:

- High EIRP mask – Based on typical usage. However, high deployment density leads to a high risk of interference.
- Low EIRP mask – Reduced risk of interference but also reduced flexibility and/or increased cost.
- EIRP mask and minimum distance – Defining the EIRP mask in association with a minimum distance which translates into an area under the control or ownership of the organisation responsible for the transmitter. This can also be seen as the distance within which other users of the spectrum would have to accept interference.
- Variable EIRP mask – A distinction might be made between rural and urban areas where the risk of interference due to close proximity differs.

Notwithstanding the variations indicated above, the tables below shows the key transmit and receive licence parameters.

Field	Units	Limit	Comments
EIRP[1]	dBW	No more than (when measured and averaged over the bandwidth defined below)	Existing classes define this field in a range of ways including transmit power or power density. EIRP is a common format that has the benefit of being measurable. It is defined as the maximum in time, but mean over the bandwidth defined as being in-band, for all carriers (i.e. for CDMA systems the aggregate of all active channels) from the specified transmitter. Systems that employ power control to adjust for propagation effects could specify a set of EIRPs with associated percentage of time to define a CDF, i.e. array [EIRP in dBW, % time]. If the EIRP CDF would vary due to other factors (such as location), the CDF specified should not be exceeded for any location for any percentage of time. In-band and Out-of-band values need to be specified.
Location	Latitude (deg) Longitude (deg) Height (m)	Within [x] m of lat/long No more than specified height	Alternative methods could be Northings and Eastings within the OS grid, but Latitude, Longitude is a more generic method given that some interference scenarios include stations outside the OS grid (i.e. international coordination). Height is defined in metres about local terrain, which in turn is defined as metres above OS reference Newlyn mean sea level[2] Typically this would be a set of points representing a boundary The height would be the maximum height of transmitters of the licence
In-band PFD	dBW/m^2/BW	Not more than	This would control the aggregate power crossing the geographic boundary by ensuring the licensee to meet the following constraint: *The predicted mean aggregate power flux density should not exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground level at or beyond the border line and for more than Z% time.*
Frequency	Hz	Within tolerance of [x] Hz	Centre frequency of in-band transmissions.
Bandwidth	Hz	Within tolerance of [x] Hz	Bandwidth of in-band licensed emissions

Table 1: Spectrum Management Licence: Key Transmit Parameters

Notes:

1. Even with PFD on boundary constraints this would be required for Site Clearance and to manage interference from transmitters operating in-band to victim systems detecting it OOB due to limitations in their receive filters.

Field	Units	Limit	Comments
In-band PFD	dBW/m^2/BW	Not more than	This would control the aggregate power crossing the geographic boundary by providing the licensee with the following definition of spectrum quality: *The predicted mean aggregate interfering power flux density from all other licences is not expected to exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground level at or within the border line and for more than Z% time.*
Indicative Interference Level (IIL)	dBW	Not more than	This represents the interference environment relating to OOB interference at close quarters.
Separation distance	m	Within tolerance of [x] m	This distance is associated with the IIL. The IIL can be expected to be greater than that specified within this distance of a transmitter.
RX Mask	dB	n/a (1)	The RX mask would define the receive filter attenuation with respect to its performance in-band
Location	Latitude (deg) Longitude (deg) Height (m)	n/a (1)	As for transmit case above
Frequency	Hz	n/a (1)	Centre frequency of in-band reception
Bandwidth	Hz	n/a (1)	Bandwidth of in-band reception

Table 2: Spectrum Management Licence: Key Receive Parameters

Notes:

As for the Spectrum Usage Licence cases, there could be apportionment rules to go from the aggregate Indicative Interference Level to the level a single licence can generate. See the section below for more information on aggregate receive PFD levels and single licence transmit PFD levels.

4.4.1.2 Spectrum Management Licence with In-band and OOB PFD limits

This licence approach is based upon use of PFD masks for both in-band and OOB interference path management, and also as guidelines for aggregate interference levels.

This method would introduce a new measure of interference whereby a PFD level would be set to manage co-located but OOB emissions. However these can not be 100% of locations as near a transmitter any particular PFD level can be expected to be exceeded. Therefore it would be necessary to define what percentage of locations this level could be exceeded.

In addition, in order to provide both interfering and victim licensee with a common baseline, this percentage would not be calculated over either's licensed area, but to a reference (for example one kilometre squared). Hence the format would be similar to:

> *The predicted mean aggregate power flux density should not exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground for more than Z % of locations within any area of size A within its service area*

This format could be used to calculate a CDF of PFD vs probability that PDF is exceeded that could be used in interference analysis.

The tables below shows the key transmit and receive licence parameters.

Field	Units	Limit	Comments
EIRP[1]	dBW	No more than	Defined as above
Location	Latitude (deg) Longitude (deg) Height (m)	Within [x] m of lat/long No more than specified height	Defined as above. Typically this would be a set of points representing a boundary The height would be the maximum height of transmitters of the licence
In-band PFD	dBW/m^2/BW	Not more than	This would control the aggregate power crossing the geographic boundary by ensuring the licensee to meet the following constraint: *The predicted mean aggregate power flux density should not exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground level at or beyond the border line and for more than Z% time.*
OOB PFD	dBW/m^2/BW % locations	Not more than	This would control the aggregate power crossing the frequency boundary by ensuring the licensee to meet the following constraint: *The predicted mean aggregate power flux density should not exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground for more than Z % of locations within any area of size A within its service area* There is likely to be different values of X, Y, and Z for different frequency offsets from the centre frequency. This measure could also vary by geographic location.

Frequency	Hz	Within tolerance of [x] Hz	Centre frequency of in-band transmissions.
Bandwidth	Hz	Within tolerance of [x] Hz	Bandwidth of in-band licensed emissions

Table 3: Spectrum Management Licence: Key Transmit Parameters

Notes:

1. Even with PFD on boundary constraints this would be required for Site Clearance and to manage interference received due to receive filters being overloaded

Field	Units	Limit	Comments
In-band PFD	dBW/BW	Not more than	This would control the aggregate power crossing the geographic boundary by providing the licensee with the following definition of spectrum quality: *The predicted mean aggregate interfering power flux density from all other licences is not expected to exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground level at or within the border line and for more than Z% time.*
OOB PFD	dBW/BW % locations	Not more than	This would control the aggregate power crossing the frequency boundary by providing the licensee with the following definition of spectrum quality: *The predicted mean aggregate interfering power flux density from all other licences should not exceed a value of X dBW/m^2/Ref.BW at any height up to Y m above ground for more than Z % of locations within any area of size A within its service area and for more than W% time.*
RX Mask	dB	n/a (1)	The RX mask would define the receive filter attenuation with respect to its performance in-band
Location	Latitude (deg) Longitude (deg) Height (m)	n/a (1)	As for transmit case above
Frequency	Hz	n/a (1)	Centre frequency of in-band reception
Bandwidth	Hz	n/a (1)	Bandwidth of in-band reception

Table 4: Spectrum Management Licence: Key Receive Parameters

Notes:

As for the Spectrum Usage Licence cases, there could be apportionment rules to go from the aggregate PFD a single licence can generate and the aggregate from all licences as received by a victim licence. It is likely that any changes would be negotiated directly between licensees themselves based upon these signal levels and baseline apportionment rules.

4.4.2 SUR parameters

A Spectrum Usage Licence is one which defines the radio characteristics of a system in sufficient completeness as to allow detailed interference analysis. This structure should be able to define systems of a wide range of services, including at least the following existing licences classes:

- Fixed point to point links;
- Business radio;
- Earth stations;
- Radio and TV broadcasting;
- Radar;
- Mobile network that register all Base Station locations;
- FWA networks that register all Base Station and User Terminal locations.

The parameters need to be defined in such as way as to completely and consistently define the radio characteristics. If done correctly the licence structure will be able to accommodate new services in addition to the existing licence classes listed above.

However the result is the need for a large number of parameters to be collected, as it replaces two sources which define radio parameters:

1. Licence Class documents: which define the parameters that are assumed to apply to all user licences of a certain licence class. Examples would be transmit power and bandwidth, and typical sources of these assumptions are the TFACs and IRs, which often also contain information about licence planning;
2. User Licence document: which specifies the parameters for a specific licences within a class, i.e. those values that can vary between licences. Examples would be latitude and longitude of transmitters.

In a generic technology neutral structure the concept of licence class disappears, resulting in a generic technological neutral structure containing:

1. Licences defined using a database structure which describes all the parameters necessary to model in detail its radio characteristics;
2. Algorithms that would be used to undertake CoU analysis using the parameters defined in the database format;

By necessity such a licence database structure must give licensees the required flexibility yet be well defined, and therefore will need significant documentation. The structure given is based upon one proposed to be used by the project developing a Generic Radio Modelling Tool (GRMT) for Spectrum Trading. More information including database structure can be found in that project's documentation.

Spectrum Usage Licences are assumed comprise a number of elements called *Systems*. These Systems can either be transmitting or receiving, and licences can contain any number of either of these including zero.

The tables below show the key elements and issues relating to a technologically neutral approach to defining spectrum usage rights. There are two tables, one for the parameters of transmit systems and another for receive.

Field	Units	Limit	Comments
EIRP(1)	dBW	No more than	Defined as above
Spectrum Mask	dB	No more than (when measured within a reference bandwidth such as 30 kHz)	Specified using an array defining difference between EIRP density in-band to that a frequency offset, with linear interpolation in dB between points i.e. array [Difference in EIRP density in dB, frequency offset from centre frequency in Hz]
Location(2)	Latitude (deg) Longitude (deg) Height (m)	Within [x] m of lat/long No more than specified height	Defined as above
Frequency	Hz	Within tolerance of [x] Hz	Centre frequency of in-band transmissions.
Bandwidth	Hz	Within tolerance of [x] Hz	Bandwidth of in-band emissions
Antenna	dB	Gain not more than	A number of different methods to define antenna gain pattern and pointing are defined in GRMT project documentation

Table 5: Spectrum Usage Licence: Key Transmit Parameters

Notes:

1. The EIRP and location fields could also be inputs into the Site Clearance process;
2. Location could be a specified point or anywhere within an area (for example a Business Radio's service area). The latter would be defined as either a set of points defined as above or via a single point to be a circular service area centre together with a field defining its radius.

Field	Units	Limit	Comments
Indicative Interference Level (IIL)	dBW % time % locations	No more than	IIL general format is: *Interference at the receiver is not expected to exceed X dBW for more than Y % of time at more than Z% of locations* For systems with single receivers Z would be 100%. A receive system can have more than one set of [threshold, % time, % locations] i.e. short term and long term.
RX Mask	dB	n/a(1)	The RX mask would define the receive filter attenuation with respect to its performance in-band as a table [attenuation in dB, frequency offset with respect to centre frequency in Hz], with linear interpolation in dB between points.
Location	Latitude (deg) Longitude (deg) Height (m)	n/a(1)	As for transmit case above
Frequency	Hz	n/a(1)	Centre frequency of in-band reception
Bandwidth	Hz	n/a(1)	Bandwidth of in-band reception
Antenna	dB	n/a(1)	A number of different methods to define antenna gain pattern and pointing are defined in GRMT project documentation
Peak Gain	dBi	n/a(1)	Peak gain of the antenna of the receiver

Table 6: Spectrum Usage Licence: Key Receive Parameters

Notes:

1. It would not be necessary for licensee's equipment to meet the values specified in the licence. However the licensee should be aware that all assessments of compatibility into this licence would assume receivers with the values given.

4.4.3 SMR / SUR issues

4.4.3.1 Relationship between SMR and SUR Indicative Interference Levels

The SMR holder will have a licence that defines an indicative interference level. In issuing SURs within the envelope of the SMR the IIL associated with the SUR will likely represent a higher interference level than that in the SMR. This is because the SMR holder will have undertaken a planning exercise that accommodates several SURs. The result of that planning exercise will be to create a certain level of interference between the SURs while at the same time meeting any performance objectives that the SURs require.

4.4.3.2 *Percentage time*

It can be seen that some of the parameter values are defined in terms of percentage time because of variable propagation behaviour.

Radiocommunication systems often have performance objectives (specified with respect to percentage time) which relate to the "worst month" in a year. The propagation data available often relate to "annual" statistics taking account of variations from year to year. The relationship between "worst month" and "annual" can be modelled. For the purposes of specifying parameter values that are part of SMRs and SURs, even though there are conversion models available, it is considered more appropriate that there should be consistency and that only one of the measures should be used. It is proposed that the "worst month" be used.

5 CASE STUDIES

This section summarises the technical case studies undertaken as part of this project. More detailed information can be found in the separate document "Final Report – Case Studies".

5.1 Objectives and Questions

The technical case studies were undertaken in parallel with development of the overall framework. Their objective was to:

- Improve understanding of the issues relating to interference management within a flexible framework;
- Analyse the implications of particular sets of management or usage rights;
- Address some of the issues raised by respondents to the Spectrum Framework Review (SFR);
- Determine the relative strengths of proposals under range of scenarios (e.g. bands and types of system);
- Provide feedback into the development of the overall regulatory framework;
- Build confidence in the approaches proposed.

Question addressed included:

1. How can spectrum management and usage rights be defined to control interference within a flexible regulatory framework?
2. What alternative processes could be considered by which an SMR introduces SURs?
3. How does the process for one SMR to introduce SURs protect other SMRs from interference?
4. What are the implications in terms of risk and constraints in the process by which an SMR introduces SURs?
5. Is it feasible for Ofcom to give SUR owners the right to change their parameters and yet give assurances to other SURs they will be protected from interference?

5.2 Case Studies Considered

In order to test the framework and proposals with sufficient vigour the consortium ensured that the range of scenarios considered covered:

- Analysis at both the SMR and SUR level within the framework;
- Examples of both public and private management and use of spectrum;
- Inclusion of both in-band and out-of-band interference paths;

- Inclusion of a range of applications covering broadcasting, fixed, mobile and radiolocation services.

As there is significant differences between the rights at the SMR level and the SUR level these were considered separately.

SMR Case Studies Considered

1. In-band sharing between public user of spectrum (radar) and a mobile operator;
2. In-band sharing between two operators providing mobile services;
3. Out-of-band sharing between two operators who initially are both providing mobile services.

SUR Case Studies Considered

1. In-band change of use from BR to DAB;
2. Out-of-band change of use from BR to DAB;
3. In-band change of use from point to point FS link changed to low power mobile network.

5.3 Issues Raised by Case Studies

The following points were suggested by the case studies considered:

Management of in-band interference between SMRs

- Aggregate PFD on boundary is an effective tool to manage in-band interference between SMRs;
- Due to variations due to propagation and traffic levels, a percentage of time should be defined and associated with the aggregate PFD level;
- The aggregate PFD level could be defined either at a high level (to allow transmissions near the boundary) or low level (to allow reception near the boundary);
- Use of a high PFD level introduces uncertainty about interference levels as it is not possible to predict how the aggregate PFD level will attenuate beyond the boundary with any accuracy without significant additional information about the system including deployment of transmitters, use of power control etc;
- A technically robust method to define aggregate PFD level and associated percentages of time is to derive them from the characteristics of typical or expected receivers in the neighbouring area. Aggregate PFD levels beyond the boundary can then be assumed to be constant (for example see Annex B);
- As the aggregate PFD level at a point can vary by height, a maximum level should be included in the SMR constraint. A suitable format is then:

> *The aggregate PFD at or beyond [definition of boundary] should not exceed X dBW/m^2/[reference bandwidth] at any height up to H m above local terrain for more than P % of the time;*

- Operators with an aggregate PFD on boundary constraint would have the option of agreeing to use technical coordination to operate in locations that otherwise would excluded;
- Use of EIRP and a deployment boundary introduces uncertainty of interference levels due to the difficulty in predicting aggregation effects. This uncertainty could be resolved by parties mutually agreeing to technical coordination;
- Use of technical coordination can lead to high technical spectrum efficiency but requires close cooperation between parties.
- Technical coordination introduces issues relating to resolution of congestion at spectrum hot-spots. One solution is use of the principle of first come first serve.
- Technical coordination approach could be beneficial where the excluded area is large and hence the cost of not cooperating high (e.g. where use of directional antennas such as with the fixed service) or where deployment of stations by the geographically adjacent operator can assessed on a case by case basis.

Management of out-of-band interference between SMRs

- Management of out-of-band interference between SMRs is harder to manage than in-band interference;
- No single set of parameters was found to be able of reducing the risk of interference without the risk of lower technical spectrum efficiency;
- Use of a EIRP mask defined at the edge of the SMR's licensed frequency band is a technologically neutral simple method to define transmit rights, but can introduce the risk of interference into receivers as there are no controls on densities of deployment;
- Use of low EIRP mask derived from typical characteristics of victim receivers in adjacent bands reduces the risk of interference into adjacent bands but introduces the risk of lower spectrum efficiency (see Annex B);
- Use of high EIRP masks derived from typical transmitter masks increases the risk of interference into adjacent bands but reduces the risk of lower spectrum efficiency;
- A number of approaches to balance the risks related to EIRP masks can be considered – such as adjusting the distance at which interference could occur or for out-of-band levels to vary between rural and urban areas;
- A technological neutral measure of out-of-band interference that does include information about deployment densities is the out-of-band PFD mask.
- It was found that OOB PFD masks are complex to define and measure as it potentially varies by environment, location, frequency and time. In addition it

allows locally high levels of interference and gives no information about where this could be expected, only probabilities;

- Technical coordination with database of SURs can result in low risks of interference combined with the potential for high spectrum efficiency;
- Technical coordination has been proposed for use in other countries (e.g. New Zealand and Australia) and would remain an option to be agreed during negotiations between SMR owners. Its use would be greatly facilitated if a database of SURs was available;
- Use of system specific standards is a low risk, potentially highly spectrum efficient method of managing out-of-band interference. It is not suggested that these should be imposed by Ofcom: rather that they would either be agreed between SMR owners or be the result of the constraints imposed on encumbrant licences;

Change of use between SURs

- The values of SUR parameters issued by a SMR owner should be consistent with the envelope of parameters for that SMR;
- The parameters of SURs should be defined in a technology neutral format in sufficient detail to permit technical coordination to be undertaken;
- For the systems considered it in general proved feasible to map technology specific licence classes to a technology neutral set of SUR parameters;
- The SUR parameters requiring the greatest care in mapping to technologically neutral format related to the interference measure and threshold;
- To determine what interference would be expected, it is necessary to include characteristics of typical receivers;
- These receive parameters should include an Indicative Interference Level or IIL;
- The IIL would be an indication of expected interference levels, not a guarantee or right;
- A suitable format of the IIL for receivers at a fixed point is:

  Interference level at the receiver is not expected to exceed X dBW for more than Y percent of the time.

- A suitable format of the IIL for receivers deployed over an area is:

  Interference level at the receiver is not expected to exceed X dBW for more than Y percent of the time at more than Z percent of locations.

- These IIL levels would define the aggregate interference level and apportionment would be required to go to single entry levels. SUR owners should be aware of the apportionment process used.

- In order to ensure that the IIL for a particular SUR are not excessively tight, an envelope of IILs should be defined for the SMR;
- In order to ensure that the changes to an IIL proposed by one SUR will not constrain other SURs, a check should be made that the new IIL is consistent with existing transmission rights and rejected if it is not;
- SUR owners can be given the right to change their SUR parameters as long as they remain within the envelope of SMR parameters and the predicted interference levels into other SURs are within their IILs.
- In some bands SUR owners could be constrained in their ability to request change of use by the contract between them and the SMR (for example private SMOs)
- It is technically feasible for SUR owners to be offered the flexibility to request change of use as long as the SURs are defined in sufficient detail and the IILs are set at an appropriate level;

General

- The use of two levels of rights, namely SMRs and SURs, proved an effective way of capturing the rights of existing and future spectrum stakeholders;
- Interference issues were found to arise from the introduction or modification of SURs rather than anything inherent in SMRs;
- The process by which SURs can be introduced or modified becomes a key tool in the management of interference;
- No one single technical solution for the process of how SURs can be introduced or modified was found to be optimal in all circumstances;
- Each SMR should clearly specify the process by which its SURs can be introduced or modified;
- The regulatory framework should clearly specify how SMR owners could change the process by which SURs can be introduced or modified;

6 FRAMEWORK FOR CHANGE OF USE

6.1 Introduction

This section assesses options for the processes for administering a change of use and for licence enforcement, including a description of the responsibilities of the parties involved. The options we have considered take account of current situation, experience with change of use in other liberalised spectrum regimes and the definition of management and usage rights given in the previous chapter. Options are assessed against the following criteria

- Timeliness – transactions can be completed in a timely manner so that incentives to innovate are preserved[23] and new services can be deployed quickly
- Low cost – the administrative costs for all parties[24] involved in making a change of use and enforcement costs should be kept low for reasons of productive efficiency and to preserve incentives to innovate
- Clarity – the steps in the process should be transparent and unambiguous and the responsibilities of all parties are clear so as to keep administrative and other costs down
- Provide appropriate incentives – those who cause costs should bear them.
- Efficiency – promoting economically efficient use of the spectrum

However the processes for making a change of use are defined, transaction and enforcement costs will be lower the fewer the number of parties to negotiate with. This argues for defining spectrum management rights so that they cover large blocks of spectrum (in geography and frequency) including guard bands. In those parts of the spectrum where use is currently very fragmented, such as in spectrum below 500 MHz and in fixed link and PMR bands managed by Ofcom, either new management rights need to be created and sold or it will be difficult to achieve significant liberalisation of spectrum use through market transactions.

The discussion below assumes

- There are two types of rights issued, management rights and usage rights, whose parameters are as defined in the previous chapter.
- The existence of an on-line licence register which would contain at a minimum the name, frequency used and area covered/general location for all licensees

[23] If the CoU process takes a long time others will have time to copy proposed innovations, thereby reducing the incentive to innovate.

[24] In particular, the party initiating the change of use, the parties affected by the change, and Ofcom.

and recognised spectrum access (RSA) holders. The main purposes of the register are to provide legal certainty concerning rights and to reduce transaction costs. The availability of licence information is discussed further below.

- The licensee seeking the change of use is responsible for initiating and concluding negotiations for all necessary changes to licences. An alternative approach would be to place the responsibility for undertaking negotiations on the affected parties and to assume that the absence of any action by third parties implied consent without compensation to the necessary changes. We have rejected this option on the grounds that the costs of making changes should fall on the party that causes them and benefits from the changes.

Finally, it is important to note that some but not all changes to rights that might be agreed between neighbours need to be registered. Changes that would not need to be registered are those involving a reduction in emissions, in particular

- decreasing power levels unless a neighbour who has negotiated the decrease wants to preserve the benefit to sell on (and the other party agrees)
- a spectrum user who wants to use receivers that do not meet the minimum performance levels and who negotiates with a neighbour to lower their out-of-band emissions. As above this does not need to be registered unless the spectrum user who has negotiated the concession wants to preserve the benefit to sell on.

The remainder of this Chapter is structured as follows:

- Section 6.2 discusses the broad steps in making a change of use.
- Sections 6.3-6.5 discuss respectively how a user determines the impact of a change on other users, issues in negotiating change of use and the registration process.
- Section 6.6 proposes an approach to dealing with interference disputes
- Section 6.7 contains a summary of our conclusions.

Annex C discusses transitional issues, focussing in particular on the transfer of Ofcom's management functions to the market.

6.2 Steps in Making a Change of Use

To make a change of use (CoU) a user will at a minimum need to

1. Determine the impact on other users
2. Negotiate with affected users to obtain consequential changes to their rights
3. Register the licence changes, so that they are legally enforceable

We also considered whether there was a need for users to notify to Ofcom and possibly also publicly state their intention to seek a CoU. Possible reasons for notification of a CoU could include one or more of

- to put all users on notice that the proposed change of use may occur so they can approach the party initiating the change if they anticipate the change could cause them harmful interference
- to act as trigger for the release of spectrum use information that is not accessible through the licence register. This might include, for example provision by Ofcom of information (within a specified time period) concerning international co-ordination constraints, in cases where international co-ordination agreements are not published, or provision concerning government use of spectrum
- to act as a trigger for the start of a protocol for engagement with government users, where they are expected to be affected by change of use proposals.
- to act as a trigger for a request for site clearance according to the procedures overseen by the Cabinet Office Working Group on Radio Site Clearance (WGRSC).[25]

We expect that at this stage the licensee would also seek to discuss with Ofcom whether it is likely to reject the proposed change of use (see Section 6.5 for a discussion of the grounds for rejecting a change of use application).

The licensee would need to provide Ofcom with information on the change in licence parameters it is seeking. If the notification was to be made public, this information would be published by Ofcom[26] on its website and could also be notified to users through e-mail alerts. Ofcom would not play any role dealing with comments from users. Rather all communications about the change of use would have to be directed at the applicant.

There are two issues we need to consider concerning notification of a change of use

- should notification of a change of use be made public or not?
- is notification mandatory or only required at the discretion of the user wishing to make the change?

6.2.1 Public notification or not?

The potential advantages of public notification are that it allows all potentially affected parties, and in particular distant neighbours, to consider whether they will be affected by the proposed change and it provides a clear point at which to trigger site clearance and interactions with Ofcom/government concerning international and government users.

[25] OfW 191 : UK Radio Site Clearance Procedure, November 2004

[26] Or a third party on Ofcom's behalf if this function was contracted out.

The main potential disadvantage of public notification is that it provides third parties wishing to block the change with the opportunity to lodge competing or conflicting applications for change of use. While this could in principle be addressed by a first in time rule this in itself is likely to provide incentives for parties to notify changes they have no intention of making, thereby blocking genuine change of use applications. Evidence that this is likely to happen is given by the experience of the first in time process used for orbital slot applications to the ITU, where the application process has been flooded by submissions for so called "paper" satellites leading to long delays in the allocation of slot capacity.

A further disadvantage is that publication arguably reduces the incentives on the party seeking a change of use to check carefully that he has identified all other users potentially affected by the proposed change. In addition, if other parties do not object it might be argued that they have in effect consented to the change and thereby given away some of their rights to future interference protection. We are not lawyers so do not know whether such arguments would have any force. But if they did, then publication is likely to lead to third parties objecting whether they are affected or not so as to ensure they do not lose any future rights.

We conclude on balance that notification should not be made public largely because of the likelihood of third parties notifying mutually exclusive changes, thereby potentially blocking economically beneficial changes of use.

6.2.2 Mandatory notification or not?

Site clearance will be mandatory for all changes which involve power levels greater than 17 dBW, and/or antenna height more than 30 m above ground level, and/or a height increase of more than 5 m for an existing (cleared) structure, and hence in these cases it would be in the clear interests of parties making a change of use to notify (on a confidential basis) the change in advance of seeking registration otherwise the change of use will be delayed.

Similarly it would be prudent for parties making a change of use to check with Ofcom in advance of registration whether any emissions outside the UK and into bands used by government are constrained to current levels or whether there is some scope for relaxation of these constraints. It is likely that users (and Ofcom) will have no knowledge of certain government uses of spectrum and hence as a precautionary measure it may always be necessary for Ofcom to check with government users that proposed changes involving transmissions above a certain power level for certain frequency ranges (to be specified) are not likely to cause interference problems. In these circumstances it would clearly be in the interest of parties making a change of use to notify changes to Ofcom on a confidential basis in advance of registration in order to avoid delays.

We conclude therefore that users will have strong interests to notify changes of use to Ofcom and so there is no need to make this mandatory.

6.3 Determining the impact of the CoU on other users

If a licensee is contemplating a change of use then it will need to assess the scale of impact on other users in order to determine whether it is worthwhile embarking on the change of use process. This activity could occur before and after a change of use is notified to Ofcom. The interference impact assessment should be the licensee's responsibility, and not Ofcom's as it is the licensee who causes and benefits from the change of use and so they should bear the related costs of making the change, including the cost of the interference impact assessment. The interference assessment would be made using relevant ITU/CEPT models where they exist and otherwise using either models agreed by the parties to the trade or models derived under an industry code of practice.[27]

To assess interference impacts the licensee will require information on the rights of all potentially affected users. The licence register will contain some but possibly not all relevant information for current licensed users.[28] If the register is for some reason incomplete (e.g. if for security reasons location information is incomplete) then the licensee will need to contact potentially affected parties directly for relevant information.

The question then arises as to whether third parties are obliged to provide the requested information and how any such an obligation might be imposed on licensees. While mandatory requirements to provide specified information could in principle reduce transaction costs they could also be difficult to enforce if the party contacted has no interest in negotiating with the licensee seeking the change of use (see also Section 6.4.2 on hold-out) . Furthermore there is the risk of "fishing" expeditions with licensees seeking information for reasons other than needing to make a change of use. We therefore conclude that users should not be obliged to provide requested information.

In any event, there would be no need for requirements to disclose spectrum use information if the licence register held sufficient information – namely the information given in the definitions of rights given in Section 4 – and this information was accessible to any party wishing to make a change of use. The information is required by Ofcom, spectrum managers, spectrum users and parties wishing to acquire spectrum in order to

- Trade spectrum

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[27] An algorithm for change of use will be produced under the GRMT project. This could in principle be publicly available and used to check CoU impacts between two licensees.

[28] Ideally the licence database will contain and publish all relevant licence information as listed in the definition of SMRs and SURs given in the previous chapter. However, this may not be possible in practice.

- Undertake the technical and commercial analysis required to underpin a change of use
- Undertake interference investigations
- Increase spectrum efficiency through co-ordination with neighbours or other users sharing a band (e.g. cognitive radio)

Efficiency is promoted if the costs of access to information are low. This suggests the information should be available electronically and that any vetting of the parties who can access the information should be simple to achieve. There will inevitably be constraints on the information on the register and that can be made publicly available concerning use of spectrum by the MoD (and possibly other parts of government) for national security reasons. As discussed further below, it may be that yes/no electronic interfaces to requests for co-ordination with the MoD could be set up.

There may also be pressure to restrict access to information on spectrum use for reasons of commercial confidentiality. Commercial confidentiality issues could clearly arise in advance of a new service or technology being deployed, however, we have suggested that change of use is not publicly notified. Hence we are uncertain as to the aspects of a user's current (rather than planned) network deployment that are of concern here, as the geographic scope and location of transmitters can generally be deduced from service availability and visual observation. In this regard we note that availability of information concerning use by commercial users in Australia and New Zealand has not proved to be a problem. We therefore conclude that information on the SMR/SUR register, except that concerning MoD and other use that affects national security, should be made publicly available.

6.4 Negotiating Change of Use

Once the party wising to make a change of use has determined the impact on its neighbours then it will need to negotiate terms with them for making changes (including financial compensation). A number of issues arise in this regard.

Firstly, information for various types of spectrum user will not be on the register and we need to consider what happens in these circumstances. Secondly, some neighbours may refuse to negotiate terms for allowing the proposed CoU or may prolong negotiations excessively (e.g. over many months/years) – we refer to this as hold-out.

6.4.1 Uses and users that may not be registered

The following cases need to be considered

- Users that operate receive only equipment (e.g. satellite receivers)
- Licence exempt users

- Users in neighbouring countries
- Future users i.e. the spectrum has not yet been assigned by Ofcom
- Users with Crown immunity i.e. government users

6.4.1.1 Receive only equipment

At the moment, Ofcom protects these users through its assignment policy and enforcement activities and this may suggest some protection will need to be offered, although there is no formal right to protection.

If RSA is introduced in the near future then these users could obtain a formal right to interference protection which would be registered in which case there would not be a problem. If RSA is not introduced, but Ofcom's current policy of providing interference protection continues, then the nature of this protection will need to be codified and for ease of access should be available through a link from the register.

6.4.1.2 Licence exempt users

Licence exempt bands are protected from interference from neighbouring bands, though there is no protection from other users within the band (assuming they are operating legally). This protection will need to be codified and placed on the register, so that it can be enforced legally. However, in general it will not be possible to negotiate changes to this protection because there will not be any single owner of the right to protection in the licence exempt band – rather there are likely to be many unidentifiable users who in effect jointly possess the right to interference protection. In these circumstances, protections given to licence exempt bands will need to be taken as a hard constraint.

6.4.1.3 Users in neighbouring countries

In this case, interference protection is provided by international co-ordination agreements and we assume that these cannot be changed. However, licensees will need to understand the constraints these agreements impose and so it will be necessary for the agreements (or a distillation of the constraints they impose) to be either contained in the register or made available by Ofcom to any party notifying a change of use.

6.4.1.4 Future users

The case of future users will be of decreasing importance over time as Ofcom licences more and more bands, however, issues could arise in the short to medium term. Here we consider the situation where Ofcom is band manager and a neighbouring commercial band manager[29] wishes to make a change of use that could increase the amount of interference experienced in vacant parts of the

[29] We note that the discussion in this section also applied to the case where a user within a band managed by Ofcom wishes to make a change of use.

spectrum that Ofcom manages. The issue of whether Ofcom should or even could negotiate compensation for the implied sale of vacant spectrum needs to be considered. We compare the following options

1. Non-negotiable interference constraints at borders in bands where Ofcom is the band manager
2. Ofcom has discretion to negotiate compensation for change of use.

Option 1 would limit the extent of change of use and/or increase users' costs in making a change. Ideally there would be a less constraining solution. Under Option 2, Ofcom assigns spectrum to the user making the change of use on a non-competitive basis which is likely to run counter to Ofcom's duties to provide transparent, non-discriminatory spectrum access. However Ofcom could notify that it was minded to make the assignment and ask if there were any other parties interested in the assignment. If there were other parties a competition would be run. To be practical a streamlined procedure for undertaking a competition would be necessary to avoid delays and reduce transaction costs (e.g. arising from competitors seeking to block or delay the change of use.)[30]

If there was no competition, then Ofcom could assign the spectrum on a FCFS basis and set either a) an annual change based on the prevailing charges for the band or b) a one-off price reflecting a future stream of current charges for the duration of the licence. The annual charge approach is simple to implement but assumes such charges will continue in future and this might not be the case if the rest of the band was auctioned at some point. The lump sum charge approach is subjective as it requires assumptions about future prices and discount factors and so risks being open to dispute.

Neither option is satisfactory. This issue led the study team to conclude that for liberalisation to work most effectively across all frequency ranges Ofcom would need to transfer its management rights to the private sector. Some the issues that would need to be addressed in doing this are discussed in **Annex C**.

6.4.1.5 Government users

At present Ofcom manages the interface between government and commercial users, for example by negotiating increased sharing of government spectrum and protection of commercial users' interests in the context of changes in government spectrum use (and vice versa). This process can be very time consuming (i.e. take years).

There are two issues which will make it difficult (if not impossible) for a licensee to determine whether a change of use has an impact on government users, namely rights to spectrum use are not in general defined at present and information on

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[30] This approach is used in Norway to assign spectrum in many frequency bands. http://www.npt.no/portal/page?_pageid=118,46191&_dad=portal&_schema=PORTAL

spectrum use is not held/known by Ofcom. Codification of existing spectrum use by government users in terms of for example relevant PFD and area boundary[31] would be helpful to facilitate existing change of use processes now and in a liberalised environment. However, even when codified, the information may not be able to be made publicly available for security reasons. In these circumstances, Ofcom involvement in negotiations seems inevitable as it is the only third party with relevant expertise. Direct negotiations between government and commercial users would not seem practical given the latter will have no or little knowledge of the former's spectrum use and government users may be reluctant to release information directly to commercial users.

One way of dealing with some of the security issues would be for interfaces between government and other users to be automated, with the government user providing a web-interface to which commercial users can submit their requirements and receive a yes, no or maybe response.[32] In the latter case, further discussions would need to follow and we consider this would best be done with some Ofcom involvement.

A further potential issue which will affect CoU negotiations with government users concerns the incentives these users have to engage in a negotiation. The need for stronger incentive structures for public sector bodies to use spectrum efficiently and proposals for such structures have been noted by the Independent Audit of Spectrum Holdings.[33] While this issue is beyond the scope of this report, we note such incentive structures could help speed up any negotiations with government users.

In summary, we conclude there is an urgent need to define the spectrum use rights of government users and where possible and necessary (e.g. for security reasons) develop automated interfaces between commercial and Crown users. Mechanisms to strengthen incentives for government users to engage in negotiations over changes in their spectrum use rights may also need to be implemented.

[31] As some government use may be temporary information about frequency and duration of use would also be useful.

[32] In accordance with recent agreements with the Federal Communications Commission regarding the provisions of broadband services at 70, 80, and 90 GHz (Report and Order - Allocations and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands, WT Docket No. 02-146), the US National Telecommunications and Information Administration (NTIA) is moving ahead with plans to establish a web-based mechanism to facilitate the coordination of federal and non-federal operations in these frequency ranges. In the interim a 14 day turnaround on assignment decisions is currently provided by the NTIA. http://ntiacsd.ntia.doc.gov/webcoord/status.cfm

[33] "Independent Audit of Spectrum Holdings" Professor Martin Cave. December, 2005 http://www.spectrumaudit.org.uk/final.htm

The CoU process will need to include a protocol for dealing with change of use that may affect government users. This protocol will need to specify the roles of Ofcom, the commercial and government users, and suitable timescales for government users/Ofcom responding to information requests and for making decisions about whether the Crown user is prepared to negotiate a change of use. Such a protocol should help reduce transaction costs and delays in making change of use.

6.4.2 Hold-out

The issue considered here is hold-out by a commercial licensee i.e. a situation in which a licensee either refuses to accept payment in return for allowing the proposed CoU or prolongs negotiations excessively (e.g. over many months or years).

In bi-lateral bargaining situations outcomes depend on the buyer's and the seller's relative bargaining power and efficient trades may fail to occur, because of information asymmetry, strategic behaviour and transactions costs.[34] Inability to agree terms – of which hold-out is an example - is therefore to be expected some of the time in bi-lateral negotiations.

Hold-out might also be motivated by the desire to block competitive entry rather than just being a means of extracting a high payment. However, it is likely to be difficult to distinguish behaviour aimed at protecting rights for some future use from behaviour aimed at eliminating competitors. There are good commercial reasons for users to "hoard" spectrum as waiting has a flexibility value, particularly in rapidly changing technology markets. Furthermore, in such markets it is difficult to tell in advance whether a particular action would have an anti-competitive effect.

One approach to dealing with perceived competition issues is reliance on competition law. In this case it would be necessary for the complainant to demonstrate that the refusal to trade would have an anti-competitive effect e.g. eliminate an actual or potential competitor. It is often argued that competition law cases take too long in fast moving sectors with the effect that competition is deterred and/or competitors go bankrupt waiting for the courts to make a decision. Against this competition law should have a deterrent effect given the possibility to levy fines.

An alternative approach would be for Ofcom to intervene and make a rapid competition assessment, although even in this case there would be the possibility of appeal to the Competition Appeal Tribunal. We believe Ofcom would have great difficulty distinguishing anti-competitive behaviour from behaviour justified on reasonable commercial grounds. We therefore conclude that reliance on competition law is a better approach.

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[34] This is shown theoretically in "Efficient Mechanisms for Bi-lateral Trading, Myerson and Satterthwaite, Journal of Economic Theory, 29, 1983 and empirically in Bargaining and Market Behaviour in Jerusalem, Ljubljana, Pittsburgh and Tokyo, Roth et al, American Economic Review, 81, 1991.

In addition competition issues, hold-out could result in inefficient use of spectrum.[35] If Ofcom considers this to be a serious problem it could in principle exercise its powers to revoke licences (with 5 years notice) for spectrum management reasons. Such should have to be used only in extreme circumstances otherwise confidence in the value and security of SMRs/SURs is likely to be undermined.

Problems of hold-out caused by information asymmetry and strategic behaviour could be mitigated by intermediaries providing relevant information and reducing transaction costs. It is possible that Ofcom (or an expert third party) could have an informal or a formal role in helping to resolve differences of opinion, for example by using its engineering expertise to indicate possible solutions to potential interference problems.[36]

We understand that informal involvement by the regulator in unresolved negotiations over change of use proved effective in Australia. This approach will only be possible if the parties to the negotiation agree to Ofcom's involvement. There is no guarantee that disputes will be resolved or resolved in a timely manner. The latter might be addressed by giving industry participants the option of formal binding arbitration with prescribed timescales. This would have to be a voluntary procedure as users could have good commercial reasons for not selling their rights. As a general point, we consider that the extent of Ofcom's involvement in negotiations should be strictly limited so that responsibility for resolving disagreements primarily sits with spectrum licensees.

In summary, licensees cannot and should not be forced to trade their rights to enable a change of use by a third party. Possible anti-competitive behaviour should be addressed through competition law and intermediaries might help reduce the likelihood of hold-out occurring.

6.5 Applying for and registering licence variations

If negotiations conclude satisfactorily, then the CoU licensee and all other affected licensees will need to apply for licence variations. It is at this stage that Ofcom formally approves or rejects the proposed CoU. If the changes are accepted they are written into the register and licence variations are issued. Ofcom may wish to alert users to any changes on its website.

Ofcom's decision to approve a trade or not should be made with reference to clearly defined criteria and reasons should be given for decisions so as to reduce regulatory uncertainty The draft trading regulations[37] refer to the following three

[35] This issue is discussed in the context of property rights in "Designing Property Rights for the Operation of Spectrum Markets", M Cave and W Webb, Warwick Business School, August 2003

[36] Section 9 of the 1949 Wireless Telegraphy Act makes provision for an appeal Tribunal. In addition Part 2 Chapter 3 (185+) of the Communications Act deals with disputes and appeals including spectrum matters, with the possibility to appeal to the Competition Appeal Tribunal.

[37] Spectrum Trading and Wireless Telegraphy Register Regulations, Statement, 2 December 2004.

reasons for refusing a trade and we would expect them to also apply in the case of licence variations

- Interests of national security
- Compliance with Community obligations and international agreements
- Compliance with a direction from the Secretary of State under sections 5 or 156 of the Communications Act 2003.

Ofcom could in principle reject licence variations on competition grounds. However, as discussed above we consider that these matters should be dealt with through the application of competition law.

Ofcom should not have a role in approving the technical aspects of the licence variations, as this would not put sufficient responsibility on the parties to the variations to address potential interference problems in negotiations. Furthermore there is a potential conflict with its responsibilities in enforcing licences and more generally regulating the sector (e.g. making assignments and determining initial licence conditions).

The issue of whether parties to a negotiation can be "trusted" to arrive at a sound set of agreements or whether the agreements need to be certified by a suitably qualified engineer needs to be considered. There are clearly costs to introducing a system of certification but these are unlikely to be large, particularly when compared with the potential interference and transaction costs associated with an incorrect application for a change of use. The requirement for certification also underlines the importance of getting the calculations and modelling underpinning the proposed change of use calculations right.

6.5.1 Experience elsewhere

Both New Zealand and Australia have a system of approval by a certified engineer or an accredited person to guard against poorly negotiated agreements. In both cases individuals must apply to the spectrum manager to be certified/accredited. These individuals may be employees of spectrum users or independent.

In New Zealand it was first required that an engineer must certify that the exercise of licence rights would not endanger the functioning of any radio-navigation services or the functioning of radio services essential to the protection of life or property and are technically compatible with services operated under existing licences. This approach was found to be too conservative and the regime has been changed so that it focuses on compatibility analysis rather than actual performance. [38]

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[38] Chapter 6, Radiocommunications Act Review, Discussion Paper Preliminary Conclusions, Ministry of Commerce, December 1995

It is currently the case in both Australia and NZ that certified/accredited persons are required to have [39]

- A diploma or degree in electronic, radio or telecoms engineering or an equivalent qualification
- Relevant experience in radiocommunications such as in frequency assignment, interference assessment, site management and radiocommunications network design
- Professional indemnity insurance (this is strongly recommended rather than required in NZ). In Australia the person must also indemnify the regulator and its staff from any claims resulting from work performed by accredited persons.

In both cases certification/accreditation are for life but may be withdrawn in specified circumstances (e.g. incorrectly issuing certificates, supplying false information, being in breach of relevant legislation). In addition, in both cases the regulator offers a certification service in competition with services offered by private firms and in-house company engineers. One reason for the continued involvement of the regulator in the provision of these services is that there was a concern that there would not be sufficient numbers of certified engineers in the private sector to meet the demand. In Australia the regulator undertakes around 50% of the frequency assignment work.

The Australian regulator is currently undertaking a consultation on its approach to accreditation with a view to further developing and improving the market in providing accreditation services, including possibly reducing the scope of accreditation services it offers and mutual recognition of NZ and Australian qualifications.[40]

In both cases, the administrations consider there are merits in having compatibility checks certified by an engineer (who may be an employee of a licensee). We suggest a similar approach is adopted in the UK to guard against the possibility of unintended interference arising from insufficient analysis of the consequences of a CoU.

6.5.2 Proposals for UK scheme

Change of use proposals would need to be certified as being compliant with the relevant engineering models, the proposed changes to licence conditions, and the calculations as having been undertaken correctly.

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[39] Applications for Approved Radio Engineer or Approved Radio Certifier status, PIB 34, Issue 4, June 2004, Ministry of Economic Development. Under this scheme the engineer is also required to prove competency in engineering problems.

[40] "Accreditation of persons under the Radiocommunications Act 1992", Invitation to Comment, June 2005, ACMA

Ofcom would need to administer the certification process and determine the minimum required qualifications. These could include an academic qualification in electronic, radio and telecoms engineering or equivalent and at least 5 years of radio-engineering experience. Qualifications such as CEng in the UK and Eur Ing at a European level could be sufficient.

We suggest that certified engineers are expected to have professional indemnity insurance up to a specified maximum sum.

6.6 Interference disputes

The mechanism for dealing with interference disputes needs to address cases of unlawful and lawful interference. The former occurs because of non-compliance with licence conditions whereas the latter occurs despite compliance with the technical aspects of the spectrum management regime, in part because engineering models are an imperfect representation of the real world and are probabilistic.

It is expected that initial investigation of interference problems would be undertaken by the holders of SMRs to determine whether the interference is caused by any of their SUR holders or an external party. In the latter case the SMR holder would be expected to consult with neighbouring SMR holders to identify the likely source of the interference and to resolve the problem. Only if this does not prove satisfactory would be the matter be referred to Ofcom for investigation.

6.6.1 Unlawful interference

In the case of unlawful interference Ofcom would have powers to stop the unlawful transmission, although the problem may be resolved by an SMR holder taking action against offending SUR holder that operates under the SMR.

In Australia and New Zealand licensees were granted civil legal remedies for unlawful interference but in practice civil actions have not been taken as users prefer to rely on negotiated solutions and/or the regulator investigating and taking the necessary action. Court action is regarded as too expensive, licensees sometimes do not have access to all the information required to support a court case, levels of proof are likely to be high and the courts are not regarded as having the necessary expertise.

6.6.2 Lawful interference

A situation of lawful interference may arise for a variety of reasons including

- The modelling used to support assignments and CoUs do not capture all aspects of the real world radio environment
- Intermodulation products arise from interactions between different systems at a location that is not managed by a single party
- The complainant’s receivers do not meet the minimum requirements. In this case no action is required

- Ofcom made an error in making an assignment in which case it could be liable for the costs of rectifying the problem as is the case at present.

A mechanism for dealing with the first and second situations is needed assuming the dispute cannot be resolved by private negotiation between the users concerned. Procedural options such as mediation and arbitration and the criteria for making decisions need to be considered.[41]

6.6.2.1 Procedural options

Mediation is a voluntary process in which outcomes are not legally binding and the mediator assists the dialogue between the two parties but does not propose solutions. The advantage of such a process is that it is relatively low cost but the major disadvantage is that it may not resolve the dispute. There is also the question of who would be the mediator. This could either be an independent party skilled in mediation, preferably with some technical knowledge, appointed by Ofcom or it could be Ofcom itself. The latter option is not ideal as assignments made by Ofcom could be part of the problem. Furthermore Ofcom must act in a way that is consistent with its statutory duties and as such may find it difficult to act as an independent party to a dispute. Hence if mediation is pursued it would be up to the parties involved to find a suitably qualified mediator.

Arbitration is a more formal process that could be initiated by one or both parties, with witnesses called, obligations on parties to supply documents requested, legally binding decisions and limited rights of appeal. Decisions made by an arbitral tribunal are enforced through the courts. Any arbitration process would be governed by the Arbitration Act 1996[42] and we understand that this could mean that some changes to the rights of appeal to Ofcom given under the Communications Act (e.g. section 185) might be required. Arbitration would be undertaken by an arbitral tribunal and the Act specifies the process for appointing members of the tribunal. Arbitration has the following advantages over mediation

- Decisions are binding and processes are time limited
- There are costs to engaging in arbitration and this should act as an incentive on the parties to resolve disputes between themselves.

The main disadvantage with this approach is that changes to legislation may be required. However, assuming legislative problems can be overcome we recommend that users have the possibility of going to arbitration to settle disputes concerning lawful interference. This does not of course rule out the possibility that the parties to the dispute first seek to resolve the problem through mediation.

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[41] In all cases there is always recourse to the courts though as noted above this seems unlikely to be used and/or effective in dealing with interference disputes.

[42] Except in Scotland where other legislation applies.

6.6.2.2 *Criteria for making decisions*

If arbitration is provided for then the arbitral tribunal would need to establish whether harmful interference was being experienced and if so make a judgement as to how it should best be remedied. Criteria that might be applied in making such a judgement need to be established. These could include one or more the following

- safety of life services are given highest priority
- a first in time rule, in which the rights of the system first registered prevail
- do nothing i.e. the system suffering the interference has to fix the problem
- economic benefits test

Assuming safety of life services are clearly defined at the outset we assume there will be general agreement on the first criterion, though this does not deal with a dispute between two safety of life services and this suggests a hierarchy of safety of life services is needed. We assume that there are current procedures to address this situation and that they can be carried over into the new regime.

The pros and cons of the other three criteria are given in Table 7. Doing nothing might always be an option if either the first in time rule or the economic benefits tests are not clear and the interference impacts are small. The economic benefits test is the most difficult to apply and is least certain but best promotes economic efficiency. The first in time rule is simple and low cost but could distort spectrum use decisions.

It is clear that none of these is ideal and it might therefore be appropriate for the tribunal to decide which should be applied depending on circumstances.

	Pros	**Cons**
First in time rule	Simple, objective and predictable, and so administration costs are likely to be low	Provides incentives to register early and inhibits licence variations[43] May not give best outcome in terms of economic benefit
Do nothing	Simple, objective and transparent and so administration costs are likely to be low	May be regarded as unfair May not give best outcome in terms of economic benefit
Economic benefits test	Economic efficiency promoted	Possibly opaque and open to interpretation Higher informational burden and so higher transaction costs Greater regulatory uncertainty

Table 7: Pros and cons of criteria for determining disputes over lawful interference

[43] A first in time rule operates in Australia and these effects have been observed.

6.7 Summary

A summary of our proposals for a change of use process is given in Figure 10.

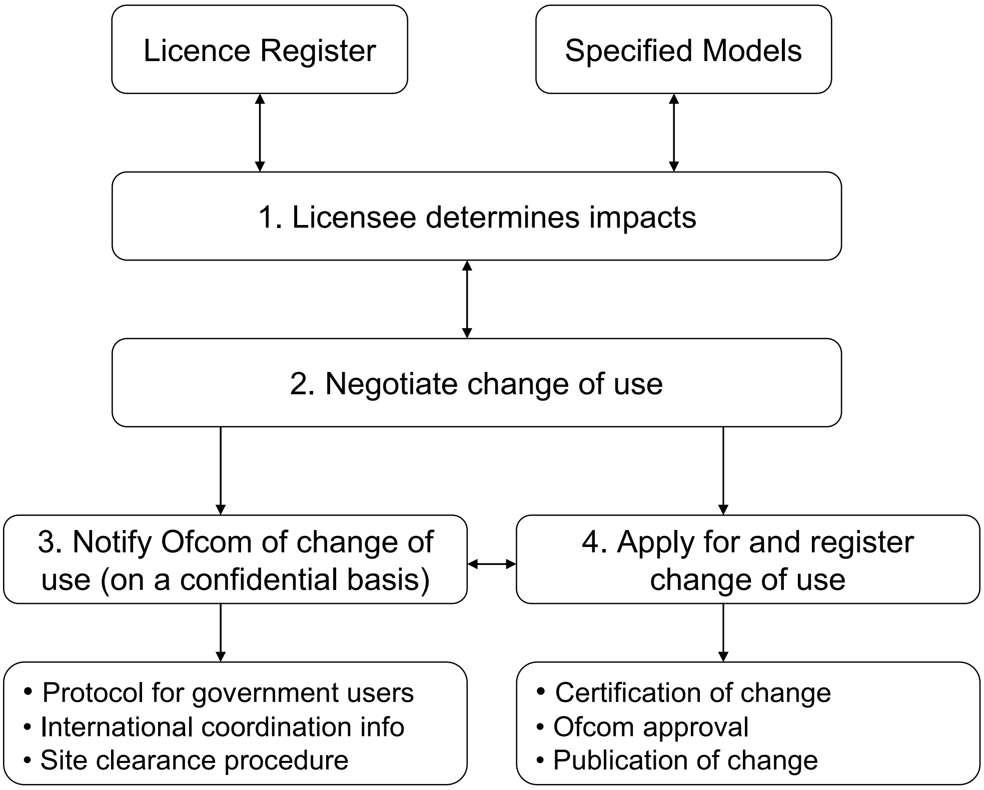

Figure 10: Elements of the Change of Use Process

The key procedural elements are 1) the notification of a change of use, which triggers a number of information release/negotiation processes including the protocol for dealings with Crown users and site clearance procedures, and 2) registration of change of use which requires Ofcom approval. A licence register provides the main information source for assessing the impact of the change of use on other licensees. Information pertaining to various other spectrum users that is not on the register, say for national security reasons (e.g. information concerning government users, international users), will need to be supplied by Ofcom.

Competition issues will be dealt with through competition law. Bi-lateral negotiations over change of use might be aided by the use of mediation or arbitration but this would be for the parties to the negotiation to decide.

Ofcom's role would involve providing an interface for dealings with government users, supply of information on international co-ordination requirements, and approving the change of use. We have suggested that the compatibility analysis underpinning applications for a change of use would need to be certified by an engineer. Ofcom could only refuse applications on grounds of national security or if the application violated EU law, international co-ordination agreements or directions from the Secretary of State.

Unlawful interference disputes would be treated the same way as they are now but we have suggested that lawful interference disputes may require a new approach. We have recommended that a means of resolving disputes through arbitration should be established, involving an ad hoc independent arbitration body and setting down criteria that would govern its decisions.

7 CONCLUSIONS

In a liberalised regime, the only constraint on spectrum use should be the controls necessary to avoid harmful interference and the study team has therefore sought to determine a set of controls that offer flexibility in spectrum use while not increasing the level of harmful interference. In doing this we have developed a framework that accommodates:

- Existing licensed systems (operating in much the same way as present)
- System planning within each piece of spectrum for single / multiple users and systems types
- Different organisations and types of organisation undertaking the system planning
- Different degrees of flexibility, risk of interference and quality of service
- The ability to change the usage of a piece of spectrum

We reiterate that the proposals we have developed do not take account of constraints imposed by UK and EC legislation.

Framework and definition of rights

It is proposed that every piece of spectrum can be defined by Ofcom in terms of Spectrum Management Rights (SMR) with Spectrum Usage Rights (SUR) falling within the Spectrum Management Rights. The owner of Spectrum Management Rights is responsible for exploiting use of that piece of spectrum and managing the use of the band including in the first instance interference within the Spectrum Management Rights. The owner may issue Spectrum Usage Rights as they see fit so long as the conditions of the Spectrum Management Rights are met. Otherwise it would be necessary for the Spectrum Management Rights owner to negotiate a change of its SMR parameters with any affected neighbours. It is proposed that use of spectrum by an SMR holder should be registered through issuing itself with SURs, so as to reduce transaction costs and improve spectrum efficiency.

The specific parameters used to define rights are presented in Chapter 4. We have given a number of options for dealing with out of band emissions and intermodulation and overload. In both cases choices depend on judgements concerning the trade-offs between the impact on the increased risk of interference versus the flexibility offered to rights holders. The views from consultation responses could assist in determining the option to adopt.

The case studies we have undertaken have shown that the use of two levels of rights, namely SMRs and SURs, proved an effective way of capturing the rights of existing and future spectrum stakeholders. Interference issues were found to arise from the introduction or modification of SURs rather than anything inherent in SMRs. The process by which SURs can be introduced or modified becomes a key tool in the management of interference, however, no single technical solution for the process of how SURs can be introduced or modified was found to be optimal in all circumstances. This means that each SMR should clearly specify the process by which its SURs can be introduced or modified and the regulatory framework should clearly specify how SMR owners could change the process by which SURs can be introduced or modified;

Process for making a change of use

To make a CoU a licensee will need information concerning the spectrum rights of all potentially affected users, including licensed users, licence exempt users, government users, future users and international users. As much of this information as possible should be publicly available on a licence register. This information together with models for assessing the impact of a CoU (e.g. ITU/CEPT models and possibly also industry agreed models) will be used to assess impacts and will form the basis of negotiation between users.

The CoU process proposed in this document involves notification of the details of the change to Ofcom, so that constraints imposed by Crown users and international agreements can be addressed and to initiate site clearance procedures where these are necessary. We have suggested that Ofcom should provide an interface for dealings with Crown users. It is anticipated that it will not be possible to make changes to interference parameters for bands managed by Ofcom, given Ofcom's statutory obligations mean it cannot negotiate such changes. In the longer term this problem could be avoided by transferring Ofcom's band management functions to the private sector.

If interference disputes and disputes about whether a CoU that has been implemented violates a third parties' rights cannot be resolved through negotiation or voluntary mediation, then users would have the right to apply for compulsory arbitration. They would also have the option of taking complaints to the courts.

A ANNEX A: COUNTRY COMPARISON

	Australia	New Zealand	US	Canada
Example auction / date	3.4 – 3.6 GHz / 2000	3.4 – 3.6 GHz WLL / 2002	2305 – 2360 MHz Wireless Communication Services (WCS) / 1997	2.3 GHz WCS 3.5 GHz FWA / 2004
Frequency packaging	26 parcels of 3.5 MHz 2 parcels of 4.5 MHz	9 parcels of 2 x 7 MHz (i.e. all paired)	2 parcels of 2 x 5 MHz 2 parcels of 5 MHz unpaired	1 parcel of 2 x 15 MHz (WCS) 3 parcels of 2 x 25 MHz (FWA) 1 parcel of 25 MHz unpaired (FWA)
Geographic packaging	14 areas (major cities and towns) 5 regional areas	Management rights = national.	52 Major Economic Areas 12 Regional Economic Areas	172 Tier 4 service areas
Technology / service	P-P and P-MP services expected. Technology neutral. Frequency parcels allow for pairing but this is up to the bidders.	Intended for WLL but technology / service not mandated. TDD v. FDD noted as a potential problem.	Fixed / Mobile / Radiolocation. Satellite DARS allowed to compete in some frequency blocks. Technology not specified.	FWA = Fixed WCS = Fixed / Mobile Technology not specified. Even though there is band pairing TDD can be used anywhere.
Duration	15 years. No right of renewal.	20 years. No right of renewal.	10 years with renewal expectancy as long as “substantial service” provided.	10 years with 10 year renewal expectancy if put to use to an acceptable level.
Splitting and transferability	Divisible and tradeable in STUs where the smallest dimensions are 0.25 MHz and ~9 km. Resulting licences must have a minimum contiguous bandwidth of 2.5 MHz.	Responsibility of band manager. Management rights can be transferred.	Partitioning and disaggregation.	Transferable and divisible (but no smaller than 25 sq km).
Spectrum cap	Specific limits on Telstra. 67.5 MHz for all other bidders.	Not more than 3 parcels	None	100 MHz in a service area (WCS and FWA combined)

Transmitter constraints	EIRP +52 dBm/30 kHz for fixed xmitters and +25 dBm/30 kHz for mobile xmitters. Emission limits (including receiver spurious below) outside the band expressed in absolute EIRP / various bandwidths ranging from 30 kHz to 1 MHz for: * Broadband emission / wide beamwidth xmitter * Broadband emission / narrow beamwidth xmitter * Narrowband emission / wide beamwidth xmitter * Narrowband emission / narrow beamwidth xmitter	Adjacent frequencies emission mask (EIRP, dBW/m^2/MHz). No in-band limit.	In-band limit = 47 dBµV/m at licensee's service area boundary – median value, predicted or measured. Out of band emissions (relative, but formulated in such a way that they are absolute levels). The mobile OOB restrictions to protect S-DARS makes mobile system infeasible.	EIRP +32 dBW (FWA) (higher if technical justification), +33 dBW (WCS, Fixed), +13 dBW (WCS, Mobile) Out of block emission mask relative, but for WCS essentially an absolute level. For WCS different values for mobile and fixed.
Receiver constraints	Spurious emission limits for wide beamwidth xmitter. Spurious emission limits for narrow beamwidth xmitter. Minimum receiver performance is defined to manage out of band interference.			Spurious emission limits: -70 dBW/MHz < 21.2 GHz -60 dBW/MHz > 21.2 GHz
Spectrum quality	Registration of receivers not mandatory but advised because of interference settlement process (first in time). Level of protection as defined for previous auctions claimed not to be required because the minimum bandwidth of 2.5 MHz "is sufficiently large for licensees to avoid interference from adjacent areas. Interference would be avoided by relocating their service within their own spectrum space as necessary, including within their own frequency band.	Protection limit (in band) from adjacent users – worst case – reflects the emission mask above. Power floor level (in band) in the absence of others – best case. Both expressed as EIRP, dBW/m^2/MHz. Bidder has to ensure suitability for purpose – no representations made in this respect.	No protection offered (apart from illegal operations). Licensees have to resolve issues (incl. intermodulation). No protection from interference caused by tropospheric or ionospheric propagation.	S-DARS emissions characterised.

Adjacent band issues (other services)	None specifically identified.	Earth station reception in the band 3589 – 3639 MHz.	Satellite-DARS	Satellite radio S-DARS (WCS)
Incumbents	National security services to remain until 2002	None in-band. All adjacent band incumbents identified.	Quiet zones	P-P moved out, P-MP coordination required (WCS) P-P moved out, FSS/Radiolocation stations identified
Other conditions	Deployment constraints (number of same frequency xmitters at a site, effective antenna heights depending on beamwidth) apply. Transmitters have to be registered for use (some mobiles exempted). Accredited person has to provide an interference impact assessment for this to happen. Unacceptable level of interference fully defined (including device boundary method) in advisory guidelines. Registration of receivers not mandatory but advised because of interference settlement process (first in time) – important for some intermodulation issues for example. Receiver minimum performance requirement specified. First in time used used with respect to coordination and interference disputes.	Registration of transmitters required – to be certified by qualified and registered persons.		Coordination when service areas < 60 km apart (FWA), 120 km (WCS) PFD trigger = -114.5 dBW/m^2/MHz (FWA), -110 dBW/m^2/MHz (WCS). 0 to 500 m above local terrain

B ANNEX B: DERIVATION OF SUR PARAMETERS

This annex describes methodologies that can be used to derive the SUR parameters of aggregate PFD on boundary and out-of-band emission levels for the low EIRP mask case.

B.1 Aggregate PFD

One approach to manage aggregation of interference for in-band paths is to define an aggregate PFD level at a boundary. Technical analysis has shown that it is not possible to predict accurately how PFD levels will decrease beyond a boundary. Therefore the most technically robust method to derive PFD threshold levels is from interference thresholds designed to protect a reference victim receiver at the boundary.

The PFD level to specify can be derived from the interference threshold and characteristics of a reference receiver as follows:

$$PFD = I_P + 10\log_{10}\frac{4\pi}{\lambda^2} - G_{rx} - L_{feed} + 10\log_{10}\left(\frac{BW_{PFD}}{BW_{RX}}\right)$$

Where:

PFD = power flux density in dBW/m^2/reference bandwidth

I_P = interference level in dBW not to be exceeded for more than P percent of time measured at a reference receiver

λ = wavelength of signal in metres

G_{rx} = receive peak gain in dBi. For isotropic receivers this will be zero

L_{feed} = receiver feeder losses in dB. If measured at the antenna this field will be zero

BW_{PFD} = reference bandwidth in Hz used to define PFD

BW_{RX} = receiver bandwidth in Hz used to define interference level

Interference thresholds typically have an associated with percentage of time for which the interference level can be exceeded. This percentage, P, should also be associated with the aggregate PFD threshold. In addition, as the measured PFD levels can vary by height, the SUR should define the maximum applicable height, H.

Hence the aggregate power flux density SUR derived as above should be defined in the following format:

> *The aggregate transmitted PFD at or beyond [definition of boundary] should not exceed [PFD] dBW/m^2/[Reference Bandwidth] at any height up to [H]m for more than [P]% of the time;*

B.2 Out-of-band EIRP

One method to manage out-of-band interference is to define an EIRP mask for frequencies outside the licensed bandwidth of the interferer. As noted in this report, these levels could be:

- High: derived based upon standardisation documents for transmitters;
- Low: set at a level to avoid interference unless receivers are close to transmitters.

This section specifies how to calculate out-of-band emission levels in the latter or low EIRP case. The EIRP mask defines the absolute power levels that a transmitter may emit at frequencies specified relative to the licensed central value. Note that values have been specified in units of dBW but dBm could also be used if applied in a consistent manner.

The approach is based upon the calculation of interference assuming certain receiver characteristics and a minimum separation distance that can either be ensured or within which interference would be tolerated by end users.

Hence:

$$EIRP_{OOB}(f) = I_m - L_{fs}(d) + 10\log_{10}\left(\frac{BW_{TX}}{BW_{RX}}\right)$$

Where:

$EIRP_{OOB}(f)$ = out-of-band EIRP emission level in dBW referenced to transmit bandwidth BW_{TX} at separation frequency f from transmitter centre frequency

I_m = median interference level in dBW measured at a reference receiver

$L_{fs}(d)$ = free space path loss in dB for separation distance *d* (see below)

BW_{TX} = bandwidth in Hz used to measure out-of-band emission levels

BW_{RX} = bandwidth in Hz used to define median interference level

The interference is assumed to occur over very short distances for which it is not appropriate to consider variation in signal due to propagation effects. Therefore these are assumed to represent the median or 50% of time levels.

The free space path loss can be calculated from the separation distance as follows:

$$L_{fs} = 20\left(\log_{10}(f) + \log_{10}(d)\right) + 92.45$$

Where:

L_{fs} = free space path loss in dB

f = frequency in MHz

d = minimum separation distance in metres

If a minimum separation distance can not be defined then $L_{fs}(d)$ can be replaced by a minimum coupling loss between interfering transmitter and victim receiver.

B.3 Interference Threshold

Both the aggregate PFD on boundary and out-of-band EIRP emission levels above are derived from interference thresholds. These are typically specified or calculated based upon documents such as Ofcom TFACs, ETSI specifications, ITU-R Recommendations, and ECC Reports and Recommendations.

In addition to direct specification, two common ways of specifying permitted levels of interference are via the ratio of interference to the system noise (ie the I/N) or the ratio of the wanted to interfering signals (ie the C/I). Note that values have been specified in units of dBW but dBm could also be used if applied in a consistent manner.

In the former case the interference threshold can be derived from the I/N as follows:

$$I = 10\log_{10}\left(kTB\right) + \frac{I}{N}$$

Where:

I = interference threshold at the receiver within the reference bandwidth in dBW

k = Boltzman's constant = 1.38 x 10^{-23} J/K

T = receive system temperature in Kelvin

B = receive reference bandwidth in Hz

I/N = interference to noise ratio in dB for receive system

Similarly for the case where the C/I has been defined the interference threshold can be derived as follows:

$$I = C_o - \frac{C}{I}$$

Where:

I = interference threshold at the receiver within the reference bandwidth in dBW

C_o = minimum receive level within the reference bandwidth in dBW required to obtain a usable signal

C/I = ratio of wanted to receiver in dB at which system will just operate without interference

C ANNEX C: PRIVATISING OFCOM'S MANAGEMENT FUNCTIONS

In this section we consider some of the issues that may arise if Ofcom transfers ownership of bands it currently managers to the private sector. Issues considered include

- How is Ofcom's management right delegated?
- What is the scope of incumbents' rights (and by implication managers' rights)?
- How will interference issues be managed?

In the text below we assume all rights are tradable and change of use is possible in principle.

C.1 Delegating Ofcom's band management functions

In line with Ofcom's general policy in respect of assigning spectrum licences we would expect that rights to own and manage bands currently managed by Ofcom would be auctioned unless there were good reasons to do otherwise. An SMR to develop and manage the band would be sold subject to protecting the rights of incumbents as discussed below. This is sometimes referred to as an overlay licence. We also note that could be benefits in auctioning larger rather than small blocks so as to reduce subsequent transaction costs associated with making a change of use (as a result of there being fewer parties to negotiate with).

An alternative and possibly more limited approach is one in which Ofcom competitively awards a contract to a band manager (possibly based on a sum bid or on other criteria) to simply manage the spectrum for a given period of time i.e. "ownership" would not be transferred The management contract would specify the terms and conditions of use by incumbents and the ways in which the band manager may change the use of the band. If the band manager can issue new SURs then this approach is very similar to that under an overlay licence. If the manager has little if any control over the form and ownership of rights, because these powers are retained by Ofcom, then the role is much more limited, more like existing band managers such as CSS, JRC and JFMG. However, this approach does not address issues concerning change of use that led to consideration of Ofcom delegating its band management functions and so we do not consider it any further.

Ofcom will need to retain responsibility for international negotiations and is likely to want to retain powers to reclaim spectrum in circumstances where this is necessary to comply with EU and international law, and for reasons of national security.

C.2 Scope of an incumbents' rights and obligations

We assume that the rights and protections provided at present in incumbents' equipment licences are carried across to the new regime – though protections may become more explicit. Incumbents' obligations with respect to interference would be unchanged, namely the incumbent must behave lawfully.[44] The new manager would be responsible for investigating and where possible sorting out any interference problems experienced by users in its band. In cases of unlawful interference under an SMR, Ofcom would have ultimate responsibility for enforcement.

The issue of the duration of the incumbents' rights needs to be considered. If there is no time limit on incumbents' rights (as is effectively the case with the rolling 5 year licences recently granted by Ofcom[45]) and the new manager wishes to change the incumbents' use in some way (possibly buy them out fully or change their transmission parameters) then problems of holdout will occur with incumbents seeking to extract the full value of any change through negotiations with the new manager.[46] This could lead to considerable delays to making changes, high transaction costs and remove any incentive for the new manager to make changes (because there is a risk most of the surplus is extracted by incumbents).

We therefore anticipate that for an initial licence period the fees paid to the new owner would be specified in licences, so as to give all parties certainty and so the incumbent is not vulnerable to expropriation of the value of its investments. After the initial (say five year) period fees would be open to negotiation. The new manager would need to have the right to terminate licences if licence fees are not paid. In effect this means that incumbent's licences would be limited to a 5 year duration after which the SMR holder could renegotiate access.

If incumbents have coverage obligations that are to persist then these too will need to be written into the new licences. The duration of these obligations would need to be consistent with the initial duration of incumbents' licences in order to avoid a conflict been licence obligations and rights.

An incumbent must operate in compliance with its licence, but could an incumbent do deals with other users without the permission of the overall band manager? If an incumbent was given this freedom, it could reduce the value of new manager's licence as the manager's plans for developing the band could be limited. For this reason and to ensure the new manager can still comply with its licence obligations, we suggest that there are conditions in incumbents' SURs that require them to seek the manager's approval before making changes to SUR parameters. Of course,

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[44] The new manager would be responsible for ensuring out of band limits were in compliance with its licence.

[45] We understand that at present incumbents have 5 year rolling licences with a 5 year notice period for changes where these may be justified for spectrum management and national security reasons and to ensure compliance with international and national law.

[46] The issue of whether to place time limits on incumbents' rights in the context of auctioning overlay licences has been examined by Cramton et al (1996). P Cramton, E Kwerel and J Williams, October 1996, "Efficient relocation of spectrum incumbents".

Ofcom and commercial band managers are likely to have different objectives and so may take a different approach to reaching conclusions on whether to grant approvals.

C.3 Summary

Table C.1 summarises the conclusions on the responsibilities and rights of a new SMR and incumbent SUR owners when Ofcom delegates band management to a private sector organisation.

Table C.1: Summary of Situation with Spectrum Managers

	Manager	**Incumbent licensee**
Type of rights	SMR	SUR
Duration of rights	N years plus rolling 5 year licences	Initially Y years where Y is substantially less than N. Duration after Y years subject to renegotiation
Tradability/flexibility	SMRs/SURs tradable and flexible but changes to incumbents' SMRs/SURs must be negotiated.	Changes subject to approval of the manager as well as any neighbours
Interference management responsibilities	Manager responsible for sorting out problems within its band. Unresolved cases of unlawful interference enforced by Ofcom. Unresolved cases of lawful interference go to arbitration (see Section 4).	SUR owner must comply with SUR conditions
SUR payments	Initial payment (say in auction)	Payment terms set for initial fixed duration (Y years), then subject to negotiation
Responsibility for any coverage obligations	Manager must respect coverage obligations	Coverage obligations must be meet by incumbents