Licence-Exemption Framework Review

A statement on the framework for managing spectrum used by licence-exempt devices

Statement

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Contents

Section		Page
	Foreword	1
1	Executive summary	2
2	Overview	10
3	Background	11
4	Application-specific spectrum vs. spectrum commons	20
5	Light-licensing and licence-exemption	26
6	Licence-exemption above 40 GHz	31
7	Licence-exemption of low-power transmitters	41
8	International positioning and harmonisation	48
9	Investigation of interference in relation to licence-exempt devices	54
10	Ofcom's approach for licence-exempt use of spectrum	56

Annex		Page
1	Impact assessment	58
2	Spectral efficiency of the spectrum commons	64
3	Aggregation of interference caused by low-power transmitters	73
4	Summary of stakeholder responses to the LEFR, and Ofcom's views on the issues raised	83
5	Glossary	108

Foreword

Management of spectrum broadly falls into two distinct areas – spectrum that is licensed to a particular user or set of users, and spectrum where devices are exempt from licensing. Over 90% of the spectrum that Ofcom manages falls into the licensed category and this is where many of our key initiatives reside, including the auctions programme for key bands such as 2.6 GHz and L-Band. However, as recognised in the Spectrum Framework Review (SFR), published in 2005, and in subsequent publications such as the ultra-wideband (UWB) consultation, provision of an appropriate amount of spectrum for licence-exempt applications can lead to significant benefits for industry stakeholders as well as citizens and consumers.

Licence-exempt devices include wireless local and personal area networks (using Wi-Fi and Bluetooth technologies), radio-frequency identification (RFID) devices, cordless phones, car key-fobs, garage door openers, and many other consumer devices. Licence exemption also offers an important opportunity for innovation, allowing wireless devices and applications to be tested without the need to acquire a licence.

The SFR set out a methodology for determining the appropriate amount of spectrum to provide for licence-exempt devices, but left for further study a number of specific questions such as whether "polite protocols" should be used, or whether bands should be reserved exclusively for certain applications. This document sets out a framework for future decisions relating to the licence-exempt use of the spectrum by addressing these key questions.

Most of Ofcom's work on spectrum auctions is concerned with licensed spectrum, although the ideas developed here will help inform decisions regarding the management of potential licence-exempt use in certain bands, such as the spectrum freed up after digital switchover (the so-called Digital Dividend). Similarly, issues such as the possible liberalisation of spectrum relate to licensed spectrum and are not affected by the discussion here. There is a relationship with our work on UWB which exempts certain low-power transmissions from licensing. This document does not aim to modify our current approach to UWB, but it does set out a similar approach to be adopted for all low-power transmissions, and with the relaxation of transmission limits at higher frequencies.

Despite the limited extent of linkages to other spectrum initiatives, we recognise that in some cases, stakeholders make a choice between using licensed services or licence-exempt devices for a particular application, and in this context, any changes in our policy towards licence-exemption may have an impact on licensed users.

This document, which follows the LEFR Consultation published in April 2007, presents a high-level framework and does not at this stage propose to make any imminent changes to the licence-exempt use of specific bands. If we decide that certain changes will be in line with our statutory duties we will address these through further consultations as appropriate.

William Webb
Head of R&D and Senior Technologist

Section 1

Executive summary

1.1 Introduction – What this statement covers

There has been a considerable proliferation in the licence-exempt use of the radio spectrum in recent years, ranging from communications applications via personal and local area networks to radio frequency identity tags and remote locking systems. The pace of growth in this sector looks set to continue with the emergence of many new technologies for applications such as ultra-high-speed personal area networks, home automation and short-range anti-collision radar.

The Spectrum Framework Review[1] (SFR) sets out Ofcom's overall strategy for the management of spectrum through a market-based approach involving spectrum auctions, trading of licences, and spectrum liberalisation. It also outlines, at a high level, our approach to determining whether spectrum use should be licensed or licence-exempt, based on criteria such as economic value derived from spectrum, risk of congestion, required quality of service, and Ofcom's legal and international obligations.

In accordance with our duties to maximise the value and efficiency derived from the spectrum, the SFR suggests that spectrum use should be licence-exempt if the value that is expected to be derived from the spectrum under such an approach is predicted to be greater than if spectrum use were licensed. It also notes that where harmful interference is unlikely (e.g. where the demand for spectrum in a given frequency band is less than the supply), then licensing may present an unnecessary overhead and a licence-exempt model may be more appropriate. These guidelines are taken as the starting point for this Licence-Exemption Framework Review (LEFR). All the measures proposed in this document are intended to further enhance the efficiency of the licence-exempt use of spectrum, increasing the value that it generates for the UK.

The SFR leaves unanswered a number of more specific issues concerning the management of spectrum used by licence-exempt devices, as listed below.

a) Should spectrum be reserved for exclusive licence-exempt use by a single wireless application (i.e. application-specific spectrum)? Or should multiple applications be allowed to share the spectrum (i.e. spectrum commons)?

b) What type of rules, if any, should be used to manage licence-exempt use of spectrum (e.g. rules of entry and operation within a spectrum commons)?

c) What is the relationship between light-licensing and licence-exemption? What are the circumstances under which one regime is preferable over the other?

d) Is there a frequency limit above which all spectrum use can be made exempt from licensing? If so, what is the value of this limit?

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1 "Spectrum Framework Review: A consultation on Ofcom's views as to how spectrum should be managed," Ofcom, November 2005. See: http://www.ofcom.org.uk/consult/condocs/sfr/.

e) Is there a transmission power limit below which all emissions can be made exempt from licensing? If so, what is the value of this limit and how should it vary as a function of frequency?

f) What should our international stance towards licence-exemption be?

g) Should there be any degree of protection towards licence-exempt users of spectrum beyond our current legal obligations?

The LEFR provides a framework within which decisions concerning the management of licence-exempt use of spectrum can be made. By examining the issues listed above, it develops an overall strategy for future licence-exempt authorisations. The LEFR is a guide to be consulted as questions surrounding licence-exempt use of spectrum arise; in just the same manner as the SFR is used as an overall guide on spectrum policy issues.

It is important to emphasise that, while the LEFR presents broad proposals with regards to the licence-exempt use of certain segments of the radio spectrum, any future authorisations of licence-exempt use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

1.2 A framework for managing licence-exempt use of spectrum

Today some 18 GHz of spectrum is allocated to licence-exempt use in the UK supporting a range of diverse applications, with telemetry services predominantly occupying bands below 1 GHz, broadband wireless communications between 2 GHz and 6 GHz, and short-range radars and relays at 10 GHz and beyond.

Note that transmissions by certain devices such as cellular handsets are exempt from licensing but use spectrum that is licensed to the associated network operator. Such devices fall outside the scope of the LEFR, as their operation is reliant on the existence of licensed transmissions by the network.

Studies commissioned by Ofcom indicate that the contribution to the UK economy of licence-exempt applications is significant. As an example, they assess that the net present value of public Wi-Fi local area networks (without taking congestion and interference costs into account) might be as high as £100 bn over the next 20 years. While this is estimated to be only a quarter of the net present value that could be generated by licensed cellular networks over a similar period, it does emphasise the importance of licence-exempt use of the radio spectrum, and the need for an appropriate framework for its management.

In this context, Ofcom has examined a range of relevant issues as outlined earlier. Our conclusions are summarised below.

Application-specific spectrum vs. spectrum commons and associated rules

Ofcom believes that, in general, application-specific spectrum allocations for licence-exempt devices result in inefficient utilisation and fragmentation of spectrum. Ofcom prefers the “spectrum commons” model, where a block of spectrum can be shared by as wide a range as possible of devices, subject to regulatory-defined mandatory constraints on radiated power profiles as functions of frequency, time, and space (i.e. politeness rules), in addition to standardised or proprietary polite protocols. We believe that this model would maximise the value derived from any spectrum set aside for licence-exempt uses.

We also believe that with the emergence of robust interference mitigation technologies, and their incorporation into the radio protocol stack at the design stage, licence-exempt devices will be capable of tolerating far greater levels of interference in the future. However, in order to further mitigate the impact of interference among wildly diverse applications, we propose the adoption of multiple "classes" of spectrum commons. Within each class, applications would have broadly similar interference generating characteristics, as enforced through regulatory-defined politeness rules. In summary, each class would be associated with a particular portion of the spectrum, with licence-exempt devices subject to a specific set of regulatory-defined politeness rules, as well as standardised or proprietary polite protocols.

We nevertheless note that in certain circumstances, for example where safety issues are at stake, application-specific authorisations may be necessary.

Ofcom does not propose the retrospective application of the spectrum commons model to existing licence-exempt authorisations, as this would in many cases result in harmful interference towards legacy technologies which may not be sufficiently tolerant of interference. Such retrospective applications of the model might, however, be envisaged in the future as part of a process of spectrum re-farming and where supported by a favourable impact assessment.

Light-licensing and licence-exemption

Light-licensing is a mechanism whereby the users of a band are awarded non-exclusive licences which are typically available to all, and are either free or only have a nominal fee attached to them. There may be further obligations associated with the provision of a licence such as the need to register the location of any transmitters and possibly to co-ordinate their deployment with other registered users.

By requiring the registration of transmitter locations, and possibly their technical characteristics, light-licensing provides an efficient means for: a) the protection of incumbent services in a band from interference due to new services; and/or b) explicit interference co-ordination among multiple light-licensed operators.

In its latter role, light-licensing is particularly helpful in conjunction with services involving fixed transmitters (e.g. point-to-point radio links), and interference co-ordination among similar applications. We believe that light-licensing is less effective for the management of spectrum where:

- the transceivers are owned and operated by parties who do not have the capability to perform interference analysis (e.g. short range consumer devices);
- the transceivers are operated by a large number of parties, and interference planning cannot be performed in an efficient manner;
- the transceivers correspond to a diverse range of applications, and interference planning is technically complex; and
- the transceivers are mobile, and result in a highly dynamic interference environment.

We believe that in such cases, licence-exemption is more appropriate. We also believe that with the emergence of autonomous self-deployment and sensing technologies, the boundaries between light-licensing and licence-exemption will be increasingly blurred.

Licence-exemption above 40 GHz

The radio spectrum above 105 GHz remains mostly unused due to constraints in transceiver technologies and radio-wave propagation. Future uses of this spectrum are likely to be either short-range (order of metres) links for consumer devices, or medium-range (order of tens to hundreds of metres) point-to-point fixed links. We estimate each of these categories to require between 10 to 15 GHz of spectrum over the next 20 years. Such demand is unlikely to result in congestion and we believe licensing to be an unnecessary burden.

However, not all the spectrum above 105 GHz is suitable for licence-exemption. Focusing on the 105–275 GHz band, we exclude from consideration all frequencies exclusively assigned by the ITU-R Radio Regulations for passive services (via Footnote 5.340)[2]. We also exclude from consideration all frequencies assigned for primary use by amateur and amateur satellite services. For the remaining spectrum, we propose a mix of licence-exemption and light-licensing. The latter regime is proposed for frequencies where there exists a potential risk of interference towards future passive services.

With regards to the 40–105 GHz band, we believe that the existing spectrum used in the UK for light-licensed applications is more or less sufficient to satisfy demand for the next twenty years. For licence-exempt use, however, we believe that there will be demand in this band for additional spectrum. For this reason we propose that the 59–64 GHz and 102–105 GHz bands be considered for licence-exempt use. The former band is already available for licence-exempt use in the US and Japan, and is currently being studied by CEPT SE19 and SE24 for Multiple Gigabit wireless systems and intelligent transport systems.

Licence-exemption of low-power transmitters

Subject to a recent EC decision, ultra-wideband (UWB) devices, as characterised by high-bandwidth (greater than 50 MHz) transmissions at power spectral densities below specific limits, are exempt from licensing and may operate on a non-interference, non-protected basis.

It is logical to conclude that any non-UWB device (i.e. of bandwidth less than 50 MHz) that transmits at a power spectral density which is not greater than the UWB limits, and that also complies with all UWB operational constraints, would cause no greater interference than a UWB device. Consequently, it follows that any such transmitter, irrespective of its bandwidth, would be a likely candidate for licence-exemption.

We further note that the path loss experienced by radio waves grows as a function of frequency. In fact, ignoring atmospheric absorption effects, the free-space radio link-budget alone deteriorates with the square of frequency for a specific receiver antenna gain. This implies that a high-frequency high-power transmitter can generate the same amount of co-channel interference as a low-frequency low-power transmitter.

Based on the above arguments, we believe that it is possible to specify generic power limits, such that transmissions at levels below these limits may be exempt from licensing. We propose that such limits should be equivalent to the UWB limits (including all operational constraints other than minimum bandwidth), with a relaxation for frequencies above 10.6 GHz to account for increased path loss with frequency.

[2] Note that this exclusion does not apply to licence-exemption of very low-power underlay transmitters, as discussed in Section 7 of this document.

International positioning and harmonisation

Harmonisation is to be understood as the common designation of frequency bands for specific uses by a number of countries and the designation of common minimum requirements to avoid harmful interference. It can be achieved by regulatory intervention or through market mechanisms and can be exclusive or non-exclusive.

Harmonisation can be beneficial in terms of achieving economies of scale and facilitating international roaming but can also impose costs if alternative applications or technologies are excluded from the harmonised spectrum. As a general rule, Ofcom believes that harmonisation should be led by market mechanisms as these are more likely than regulation to secure the optimal outcome. However, there may be circumstances which make regulatory intervention necessary in order to achieve the benefits of harmonisation.

Each case needs to be considered individually and be subject to a proportionately rigorous and in-depth impact assessment but, in general, Ofcom considers that the application of market forces to licence-exempt usage is problematic as a regulatory decision is required to make usage exempt from licensing. Hence regulatory harmonisation is likely to be justified. Where this occurs, Ofcom has therefore supported, and will continue to support, the making of EU Decisions regarding harmonisation of exempt usage and supports measures made under the R&TTE Directive[3].

Investigation of interference in relation to licence-exempt devices

The use of spectrum by licence-exempt devices is allowed on the basis that Ofcom would investigate and where necessary take enforcement action in cases concerning non-compliance with the regulations, and thereby, leading to harmful interference. This includes investigating and preventing use of transmitters that are non-compliant with the relevant UK Interface Requirements or R&TTE Regulations[4], as amended.

We do not anticipate that any additional regulatory instruments would be required for the protection of licence-exempt equipment. Harmonised technical standards are expected to be sufficient for mitigating the impact of interference caused by compliant radio transmitters, particulary at high frequencies where radio propagation conditions and the abundance of bandwidth imply a low probability of congestion.

[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=celex:31999L0005:en:html.

[4] http://www.opsi.gov.uk/SI/si2000/20000730.htm#sch9 as amended by http://www.opsi.gov.uk/SI/si2003/20033144.htm.

1.3 Proposals for management of spectrum for licence-exempt devices

Based on the analysis reported in this document, we propose the following recommendations with regards to licence-exempt use of the radio spectrum.

1) Where possible, any spectrum released in the future for licence-exempt devices should be used based on the spectrum commons model, wherein devices for multiple applications share the same frequencies, subject to *politeness rules*[5] and *polite protocols*[6]. While spectrum commons will be the default approach, exclusive licence-exempt use of spectrum by a specific application will be considered on a case-by-case basis where technical constraints, international obligations, or safety issues require such use.

2) Multiple classes of spectrum commons should be considered, with regulatory-defined mandatory *politeness rules* restricting the diversity of applications within the bandwidth of each class (thereby easing co-existence), and with *polite protocols* micro-managing intra- and inter-application interference. The specification of polite protocols should be undertaken by appropriate technology standardisation bodies or individual equipment manufacturers, and is beyond the scope of the regulatory bodies.

3) Light-licensing regimes should only be adopted when explicit co-ordination among the operators of the radio devices is both feasible and a technical necessity (i.e. when limitations in technology prevent autonomous self-coordination among the devices). Licence-exemption should be adopted otherwise, subject to adequate protection of incumbent users.

4) The status of operational light-licensed regimes should be regularly reviewed, on a case-by-case basis, with a view to conversion to licence-exemption only if autonomous self-coordination among the light-licensed radio devices is technologically feasible, economically viable, and provides adequate protection of incumbent users.

5) Spectrum in the 275–1000 GHz frequency range should be considered for wide-scale release to allow use by licence-exempt devices. This is with the exclusion of frequencies allocated for spectral line measurements specified by Footnote 5.565.

6) In the 105–275 GHz frequency range, 94 GHz of unused spectrum should be considered for a phased release to allow use by licence-exempt devices.

7) In the 40–105 GHz frequency range, the 59–64 GHz band (currently managed jointly by the MoD and Ofcom)[7], and the 102–105 GHz band (currently unused) should be considered for use by licence-exempt devices.

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[5] Politeness rules are constraints on radiated power profiles as functions of frequency, time, and space (e.g. spectral density, duty cycle, and beamwidth).

[6] Polite protocols are interference avoidance mechanisms implemented at the physical layer (PHY) and/or medium access control (MAC) layer of the radio protocol stack, that enable multiple autonomous devices to share the radio resource. An example is the listen-before-talk protocol of Wi-Fi.

[7] Any future licence-exempt authorisations in the 59–64 GHz band would be subject to approval by the MoD, and would correspond to appropriate limits on radiated power characteristics in order to allow co-existence with MoD (and other) use.

8) Radio devices transmitting at sufficiently low power spectral densities do not cause harmful interference to incumbent services, and should be exempted from licensing. A power spectral density lower bound for the licensing of radio devices should be considered which: a) is equal to the UWB limits for frequencies below 10.6 GHz; and b) is extrapolated from the UWB limits for frequencies above 10.6 GHz (accounting for increased signal attenuation with frequency). Transmissions below the specified limits may be exempt from licensing[8], subject to compliance with all UWB operational restrictions (other than minimum bandwidth) as specified in EC Decision 2007/131/EC.

9) Ofcom should develop its strategies within harmonisation frameworks both at the European level (CEPT and EU) and at a global level (ITU), proceeding on a case-by-case basis, and supporting each harmonisation decision by an impact assessment. Ofcom should also support initiatives by the EC aimed at speeding up the harmonisation processes where such harmonisation is judged to be beneficial. Harmonisation should impose a minimum of restrictions and be as application-neutral and technology-neutral as possible.

1.3.1 Impact on stakeholders

In developing the above recommendations Ofcom has paid utmost attention to the potential impact they might have on stakeholders. Ofcom has accounted for the interests of existing users, as well as those of future users of currently unused spectrum via the following measures:

- Requirements for frequencies exclusively assigned by the Radio Regulations for passive services (via Footnote 5.340) have been taken into account in our considerations.

- In proposing licence-exemption above 105 GHz, we have excluded bands (used or unused) with primary assignments to amateur, amateur satellite, earth exploration satellite (passive), radio astronomy (passive), and space research (passive) services.

- In proposing licence-exemption of low-power transmissions above 10.6 GHz, we have specified radiation limits which we anticipate would not have a significant impact on existing users of spectrum.

Ofcom is aware that the impact of its Framework Review recommendations will mainly be felt by future users of spectrum. Based on its analysis, Ofcom anticipates that this impact will be beneficial because the recommendations strive to optimise the efficiency and value of the licence-exempt uses of spectrum. In addition, Ofcom believes that these recommendations help to create an environment in which industry stakeholders are made aware of the likely directions of licence-exemption policy development, and find it easier to invest as a result.

Any future authorisations of licence-exempt use by Ofcom will be subject to specific consultations and impact assessments for the relevant bands. Although the above recommendations will form the basis for our future consultations, Ofcom will assess each case individually on its merits.

[8] The proposed limits are greater than those specified in the EC Decision 2007/131/EC for UWB devices (i.e. bandwidths greater than 50 MHz) at frequencies above 10.6 GHz. As a result, Ofcom would envisage supporting any future EC initiatives to relax the radiation limits for UWB equipment at frequencies above 10.6 GHz. For non-UWB devices (i.e. bandwidths less than or equal to 50 MHz), the proposed limits could apply except at frequencies where EU law requires exclusive use by certain applications.

In general, authorisations for licence-exempt use would be for an indefinite period, but there might be specific circumstances under which we would wish to revoke an authorisation. This would only occur following a detailed review and consultation, and would typically require an appropriate notice period.

1.3.2 Citizens and consumers

We believe that the approaches set out in this document will deliver significant benefits to citizens and consumers. This is because we believe that the right way to further the interests of citizens and consumers is not to unduly restrict the range of applications and technologies that are allowed to use the spectrum, but instead allow the market (rather than the regulator), to decide the best use. In the case of licence-exempt devices, we believe this can be achieved by adopting a "spectrum commons" model of use, where a range of different applications are allowed to share a common set of frequencies subject to appropriate rules and protocols.

Furthermore, under the approaches set out in this document, a significant amount of currently unused spectrum above 105 GHz would be made available for licence-exempt use by short-range devices. We will also exempt from licensing all devices which transmit below specific power levels. These changes will encourage industrial research and development, and bring benefits to consumers and citizens through increased competition in the provision of new and innovative radio communication goods and services.

1.4 Next steps

We expect to publish more detailed consultations on some of the specific issues addressed in this document. The areas of consultation and indicative timelines include:

- How flexible politeness rules for licence-exempt use might be defined and enforced in practice (2008).

- Wide-scale release of spectrum above 275 GHz for licence-exempt use subject to appropriate politeness rules (2008).

- Release of the 102-105 GHz band for licence-exempt use subject to appropriate politeness rules (2008-2009).

- Phased release of the 105-275 GHz band for licence-exempt use (2008-2012).

- Limits on EIRP spectral densities for licence-exemption of low-power transmitters (2008-2009).

Furthermore, Ofcom will support various initiatives at the European level which address issues related to the licence-exempt use of the radio spectrum. Examples of such initiatives include the RSPG Working Group on the collective use of the spectrum, and the CEPT SRD Maintenance Group.

Section 2

Overview

The Spectrum Framework Review (SFR) describes Ofcom's overall strategy for the management of spectrum. This consists of a market-let approach to the licensing of spectrum via auctions, trading, and liberalisation.

The SFR also outlines, at a high level, Ofcom's approach to determining whether spectrum should be assigned for licensed or licence-exempt use. In outline, in line with our duties to maximise the value and efficiency derived from the spectrum, the SFR suggests that spectrum use should be licence-exempt if the value that is expected to be derived from the spectrum under such an approach is predicted to be greater than if spectrum use were licensed. It also notes that where harmful interference is unlikely (e.g. where the demand for spectrum in a given frequency band is less than the supply), then licensing may present an unnecessary overhead and a licence-exempt model may be more appropriate. These guidelines are taken as the starting point for this Licence-Exemption Framework Review (LEFR).

The LEFR extends the SFR by examining a number of specific issues with regards to the management of spectrum used by licence-exempt devices. These include the relative merits of application-specific and commons models for spectrum use, the relationship between licence-exemption and light-licensing regimes, the question of whether devices transmitting at sufficiently high frequencies or sufficiently low powers should be exempt from licensing, the role of harmonisation, and the need for additional regulatory instruments to investigate cases of harmful interference.

This document is structured as follows.

A background to licence-exemption is presented in Section 3. This includes a description of Ofcom's vision of a market-based management of spectrum, criteria for deciding whether spectrum use should be licensed or licence-exempt, and Ofcom's legal obligations with regards to licence-exemption. This is followed by a survey of existing licence-exempt authorisations in the UK, and estimates of the economic value of a selection of licence-exempt applications.

Key issues with regards to the management of licence-exempt use of spectrum are addressed in some detail in Sections 4 to 9, along with corresponding conclusions for each issue. Ofcom's views on licence-exemption are summarised in Section 10.

Impact assessments for a number of issues examined in this document are presented in Annex 1. Annexes 2 and 3 contain technical analysis of the spectrum commons model, and the aggregation of interference due to low-power transmitters respectively. Stakeholder responses to the LEFR Consultation Document (published in April 2007) are discussed and addressed in Annex 4. Finally, a glossary of terms is provided in Annex 5.

Section 3

Background

3.1 Ofcom's approach to management of spectrum

3.1.1 The Spectrum Framework Review

Ofcom wishes to optimise the use of the spectrum and to encourage the emergence of dynamic and innovative services and organisations. As set out in the Spectrum Framework Review (SFR), Ofcom achieves this by[9]:

- providing spectrum for licence-exempt use as needed. We estimate that little additional spectrum (below 60 GHz) will be needed for this purpose in the foreseeable future, growing to just under 7% of the total spectrum;

- allowing the market to operate freely through the implementation of trading and liberalisation where possible. We believe we can fully implement these policies in around 72% of the spectrum; and

- continuing to manage the remaining 21% of the spectrum using command and control approaches.

Where spectrum is returned to the regulator it will normally be auctioned. In general, with auctioned spectrum Ofcom will seek to:

- minimise the number of constraints on its use. Ideally, we would not apply any technology or usage constraints, but instead rely on a spectrum mask;

- avoid using the spectrum as a means to achieve policy goals, for example, avoiding applying coverage obligations or structuring the auction to favour new entrants, unless clearly justifiable; and

- make the spectrum available as rapidly as possible.

For most spectrum we will allow trading with the minimum of restrictions, having the long-term aim of:

- Allowing simple and rapid change of ownership; and

- Allowing change of use of spectrum without any intervention from Ofcom and with no specific restrictions, although possible usage will be limited through the use of a spectrum mask.

[9] The spectrum percentages quoted here were originally presented in the SFR. They correspond to frequencies up to 60 GHz, exclude spectrum used by the MoD, and represent percentages of amounts of spectrum bandwidth relative to the band centre frequency, rather than absolute amounts. Note that the derivation of such figures is somewhat complicated by the fact that many bands are shared. We have taken the approach of counting the use of a band as subject to market forces if at least one of the shared applications will be tradable. Also note that the distinction between market forces and command & control is often not clear-cut. For these reasons the figures should be considered as illustrative.

In short, our approach to management of spectrum where we can fully apply trading and liberalisation can be summarised as follows:

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 these will not be changed without good cause.

In the medium to longer term we expect the effect of this to be that Ofcom increasingly withdraws from managing the radio spectrum through regulatory intervention. Inevitably, there will be circumstances when we cannot fully achieve this aim. In these cases we will explicitly explain why we have not done so.

3.1.2 Determining when use of a band should be licence-exempt

As described above, Ofcom's view equates to a *market-led* approach to spectrum management through the use of auctions, trading, and liberalisation. If it were possible, we would ideally like to allocate spectrum for licence-exempt use through a market mechanism.

To date, the view has been that market mechanisms are unlikely to be able to allocate spectrum for licence-exempt uses because it is difficult for multiple licence-exempt users to join together to purchase spectrum at auction.

It has been argued that one way around this problem is for an entity such as a band-manager or equipment manufacturer to purchase usage rights for a block of spectrum, and subsequently to convert this into a *private commons*. This is a perfectly reasonable argument, even though the business case for private commons is not yet fully proven. However, one should note that the creation of a private commons is essentially subject to the same principles as any "conventional" purchase of spectrum via auction or trading, and as such falls under a licensing model (even if it appears as licence-exempt to the end user).

Given the above arguments, despite the desire to make use of market mechanisms, regulators will need to decide on the appropriate location and amount of spectrum for licence-exempt use.

In determining the appropriate amount of spectrum for licence-exempt use, Ofcom's primary goal is to maximise the efficiency of spectrum use, measured in terms of the economic value that the use of spectrum is likely to bring to the country. Therefore, the primary test for licence-exemption is to estimate the economic value derived from the spectrum under a licence-exempt approach and to compare it with the corresponding value under licensing. If the former is greater than the latter, then licence-exemption will in general be the preferred option. This approach can be subject to much uncertainty (because any prediction of the future value derived from spectrum is often inaccurate) but is the best approach currently available to the regulator.

An additional test is to determine whether harmful interference is likely (e.g. where the demand for spectrum in a given frequency band exceeds supply). If harmful interference is unlikely, then typically the administrative overhead of licensing will be unnecessary and will reduce the economic value of the band. Hence, a licence-exempt model should be adopted.

A related issue is the length of time over which licence-exempt use is authorised in a portion of spectrum. In general, we would expect authorisations to be indefinite but with certain specific grounds for revocation. One set of such grounds would be due to circumstances such as conflicting European authorisations or directions from a Secretary of State. A different set would be if it became clear that there had emerged a licensed use that could provide significantly higher-value use of the spectrum, or that the licence-exempt usage anticipated was in practice delivering significantly less value than expected. In the latter case, we might perform an appropriately detailed review of the band to understand whether the authorisation should be changed. We would not expect to conduct such a review for some time after the authorisation in order to allow usage to emerge and mature and also to instil confidence in manufacturers and users in the use of the spectrum. If any such review were performed it would take due account of all relevant factors including whether there were other bands that the licensed application could use, the level of investment and legitimate expectations of the licence-exempt users, the practicality of clearing a band and the ability of the existing licence-exempt users to share with the proposed licensed approach. This review would be followed by a detailed consultation. In general, we would expect that, where notice was necessary, the notice period would need to be of a reasonable length of time, for example to allow licence-exempt usage to "naturally" decline within the band.[10]

Note that it is not the intention in this document to propose any alternative approaches for deciding whether use of a segment of spectrum should be licensed or exempt from licensing. Instead the objective is to set out an approach for the management of spectrum that is allocated for use by licence-exempt devices.

3.1.3 Terminology

It is helpful at this stage to describe some of the terminology used in this document. Figure 1 illustrates the relationship between some of the key terms.

Licensed use of spectrum refers to the market-led control, and potential trading, of spectrum by operators of wireless systems. An example is the use of spectrum by operators of cellular communication networks[11]. Furthermore, as explained earlier, the aggregation of demand by an entity such as a band-manager and the subsequent formation of a private commons essentially fall under a licensing model.

[10] An example of this is the decision in 1999 by the Radiocommunications Agency (predecessor to Ofcom) to re-assign the 418 MHz band used by short-range devices to terrestrial trunked radio (TETRA) services. For further details see the press release at: http://www.ofcom.org.uk/static/archive/ra/publication/press/1999/21dec99a.htm.

[11] It should be pointed out that use of spectrum by mobile handsets (uplink) is actually licence-exempt, even though the spectrum itself (whether part of a frequency-division duplex or not) is subject to licensing.

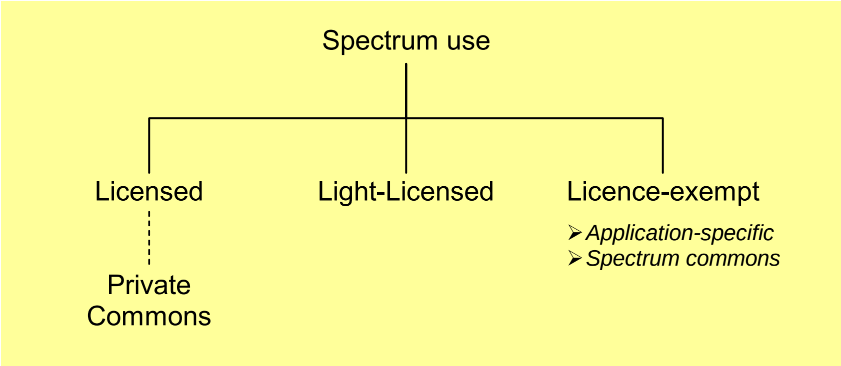

Figure 1. Terminology.

Spectrum used by licence-exempt devices can itself take two forms. The first is *application-specific* spectrum, where frequencies are reserved for exclusive licence-exempt use by a single application (e.g. spectrum used by DECT cordless phones). The second form is *spectrum commons*, where multiple wireless applications operate on a co-channel basis. The term *public commons* is also often used in the literature, where it refers to various models of open access to spectrum. As elaborated later in this document, we use the term spectrum commons to refer to the co-existence of licence-exempt devices for different applications within a band, subject to restrictions on emission characteristics.

Light-licensing resides somewhere between the licensing and licence-exempt models, and is particularly useful for fixed services. Here radio devices are subject to a registration process in order to allow for co-ordination among multiple operators, or to afford protection to existing users of the band.

3.2 Legal basis for exemption

We earlier listed a number of criteria for deciding whether spectrum use should be made exempt from licensing. It is important to note that Ofcom is also subject to certain legal obligations in this respect.

Equipment is made licence-exempt by regulations made by Ofcom under the Wireless Telegraphy Act 2006 (WT Act 2006). Ofcom is required to exempt radio stations, equipment or apparatus where satisfied that their use is not likely to involve any undue interference to other legitimate use of radio spectrum.

Section 6(1) of the Communications Act 2003 states that Ofcom must secure that regulation by Ofcom does not involve:

> *"(a) the imposition of burdens which are unnecessary; or*
> *(b) the maintenance of burdens which have become unnecessary."*

Part 2, Chapter 1 of the WT Act 2006 deals with the granting of licences for wireless telegraphy and the exemption from the requirement to hold a licence.

Section 8(3) of the WT Act 2006 states that Ofcom may, by regulations, exempt from the requirement to hold a wireless telegraphy licence[12]:

[12] The requirement to hold a licence "*to establish or use a wireless telegraphy station*" or "*to install or use wireless telegraphy apparatus*" is set out in section 8(1) of the WT Act 2006.

> "*the establishment, installation or use of wireless telegraphy stations or wireless telegraphy apparatus of such classes or descriptions as may be specified in the regulations, either absolutely or subject to such terms, provisions and limitations as may be so specified*."

Section 8(4), read with Section 8(5), of the WT Act 2006, states that if Ofcom is satisfied that the use of apparatus "*is not likely to involve undue interference with wireless telegraphy*", Ofcom must make regulations under Section 8(3) exempting the establishment, installation and use of such apparatus from the requirement under Section 8(1) to hold a licence. The use of the apparatus must also not be contrary to an international obligation or any legally binding EU harmonisation or other measures in force.

The framework presented in this document is consistent with Ofcom's statutory duties and does not require any change to the statutory framework beyond changes to the exemption regulations.

3.3 Existing licence-exempt usage

Figure 2 illustrates the cumulative distribution of bandwidth within which licence-exempt use of the spectrum is authorised in the UK. This excludes licence-exempt use by devices such as cellular handsets where the spectrum is licensed to the network operator. The vertical bars identify the locations and bandwidths of the individual bands.

As can be seen, spectrum used by licence-exempt devices accounts for some 22% of the total bandwidth up to 80 GHz. Note that the licence-exempt use of the above spectrum is rarely application-specific. Furthermore, the spectrum is also often shared with other licensed applications or the MoD.

There are a large number of narrow bands used by licence-exempt devices at frequencies below 1 GHz. The services supported here involve low data rates and are typically associated with telemetry applications. Examples include inductive applications, model control, wireless alarms, hearing aids, radio microphones, medical and biological applications, private mobile radio, detection of movement, industrial telemetry, and radio frequency identification (RFID).

Examples of note between 1 GHz and 10 GHz include the authorisations at 1880–1900 MHz for DECT; at 2.4 and 5 GHz for applications such as radio local area networks and wideband transmission systems, and those at around 10 GHz for applications such as radar level gauges.

Other examples of note include authorisations at around 24 GHz for applications such as radar level gauges and vehicle radar, at around 57 GHz for point-to-point relays, and finally those at around 77 GHz for intelligent transport systems and vehicle radar.

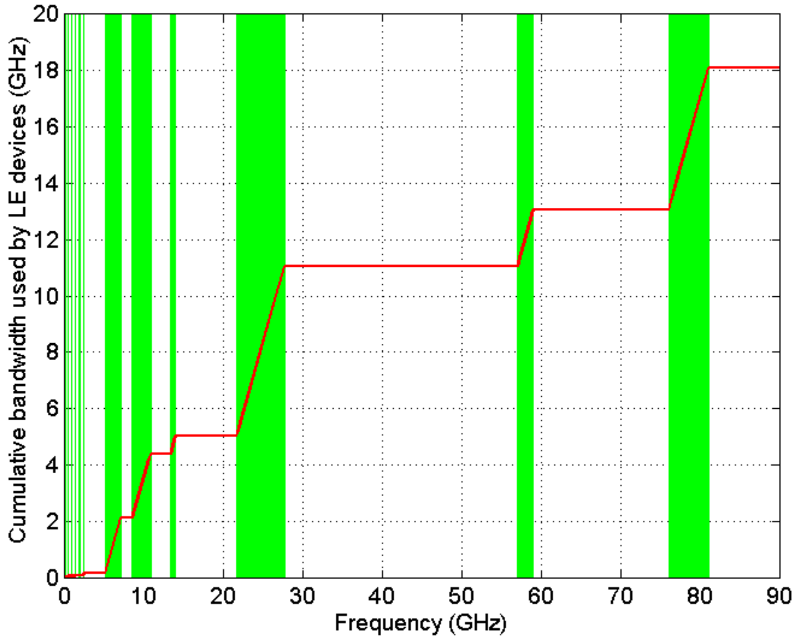

Figure 2. Distribution of spectrum used by licence-exempt (LE) devices.

3.4 The economic value of licence-exempt usage of spectrum

The SFR suggested that spectrum should be set aside for licence-exempt applications when the economic value of these applications was likely to exceed the value if licensed. This section discusses how the economic value of spectrum set aside for licence-exempt applications might be calculated.

The economic value of spectrum is typically evaluated by computing the value generated by the applications that utilise the spectrum, taking into account the forecast demand and supply for these applications, as well as the costs of anticipated interference. In the context of this review, Ofcom has gathered information about the potential economic value of several licence-exempt applications. The parameter of interest in this context is the additional economic value generated by licence-exempt applications as compared to the case where the applications do not emerge at all[13].

Clearly, there is substantial uncertainty in making any forward-looking estimate of economic value. This is particularly the case in the context of a review which addresses a timeline spanning some twenty years into the future. Given the rapid pace of progress in technology, the emergence of as yet unforeseen wireless applications is more likely than not. One only needs to point to the explosion in demand for cellular telephony, or wireless local- and personal-area networks. For this reason, any estimates of future economic value of spectrum beyond several years should be viewed at best as indicative of a likely order of magnitude.

[13] This is one type of incremental value approach. An incremental value approach looks at the additional value that is generated as compared to the value that is generated in an alternative scenario referred to as the counter-factual. Regarding spectrum valuation, the alternative scenario could refer to a situation in which a wireless application does not emerge at all (which may happen if the application does not get access to spectrum) or to one in which it is assigned a different portion of spectrum.

In the next subsections we briefly discuss the relative economic merits of licensed and licence-exempt usage of spectrum. This is followed by a presentation of the economic value of several licence-exempt applications expected to emerge over the next 20 years.

3.4.1 Key benefits and costs of licence-exempt usage of spectrum

The main benefit of licence-exempt usage of spectrum is the easier and faster access to spectrum that comes with licence-exemption as compared to with licensing. This results from the relative certainty of obtaining access (i.e., no competition or time delays for access to the resource), and from the low entry barriers (no, or limited, licensing procedures) associated with licence exemption. This is especially valuable for applications where the transmitter and receivers are owned by a large number of individuals (e.g. WLANs, garage door openers), the testing of new products and services, or for offering niche applications.

On the other hand, the occurrence of interference is a commonly cited disadvantage associated with the licence-exempt usage of spectrum, and can result in a reduction in value.

In licensed applications, interference among devices is typically centrally managed and controlled by specific network entities (e.g. a base station controller in cellular systems), as a result of which the network operator is able to guarantee a minimum quality of service. This is particularly important for delay-intolerant real-time communication services. In licence-exempt applications, however, interference is typically managed in a *de-centralised* fashion by the wireless devices themselves. Consequently, a minimum quality of service cannot be guaranteed. It should, however, be pointed out that the perceived impact of interference depends on the nature of the wireless service, and in any case is only significant when the spectrum is heavily congested.

As a result of their relative strengths and weaknesses, licensing and licence-exemption are the preferred spectrum management regimes for different types of applications. It is for this reason that in the Spectrum Framework Review Ofcom expressed its belief that there should be an appropriate balance between licensing and licence-exemption approaches to spectrum use.

We next provide an indication of the economic value of several licence-exempt applications identified as representative of the range of uses expected to emerge over the next 20 years.

3.4.2 Economic value generated by licence-exempt applications

Ofcom recently commissioned a project to evaluate the economic value generated by licence-exempt applications over the next 20 years[14].

Within this study, ten representative licence-exempt applications were selected and researched in terms of technology, demand, supply, congestion, interference, and scope for international harmonisation. A generic methodology was devised to generate an estimate of the incremental economic value of these applications, with specific attention to handling the uncertainty that is inherent to forecasting the value of new products over two decades.

Table 1 indicates the forecasted net present values (NPV) for each application over the 2006-2026 period based on three demand scenarios (low, medium and high). It should be

[14] "The economic value of licence-exempt spectrum", Final report, Indepen, Aegis, Ovum, December 2006. See: http://www.ofcom.org.uk/consult/condocs/lefr/.

pointed out that the presented figures are *unconstrained* values, in that the costs of congestion and interference are not accounted for.

Ofcom considers these estimates to be a useful indicator of the economic value that the selected licence-exempt applications might be expected to generate over the next 20 years or so.

Application[15]	NPV (£bn) for demand scenario		
	low	medium	High
1. Road user charging	0.3	0.6	0.9
2. Automotive short-range radars	2	26	68
3. Blood glucose sensors	0	9	19
4. RFIDs in retail	10	35	98
5. Public-access Wi-Fi	9	68	239
6. Home data networking	4	6	8
7. Wireless building automation	0.3	1.2	4
8. Fixed wireless links	0	0.6	1.7
9. Telemetry in utilities	8	11	13
10. Wireless home alarms	0.6	2.4	6.4

Source: Indepen, Aegis, Ovum

Table 1. Unconstrained net present values for ten licence-exempt applications over the 2006-2026 period.

The values of these projections vary significantly across the demand scenarios for several applications, including those identified as potentially the most valuable, that is, automotive short-range radars, RFIDs in retail, and public-access Wi-Fi. This uncertainty is the result of the numerous assumptions, including the specification of appropriate counter-factuals, that are required in order to forecast developments over a 20-year period for services and products that are either new or not yet commercialized.

In addition, Ofcom is aware that these are unconstrained projections and that intra- and inter-application interferences are likely to reduce the value that these applications can generate. Ofcom considers it sufficient to note that the above unconstrained projections should be seen as upper bounds. The economic valuation carried out for this review is meant to be broad in scope and more refined valuation estimates for these applications would be produced when considering specific bands or issues.

Ofcom considers that putting some of these figures into perspective, especially with respect to licensed application valuations, adds to the usefulness of these figures. Ofcom believes that the comparison of licence-exempt Wi-Fi and licensed cellular applications is worth exploring, given that these applications are estimated to generate significant benefits and are, in some limited cases, substitutes for each other.

Based upon recent spectrum valuation work Ofcom commissioned, the cellular mobile market as a whole can be shown to be expected to generate significantly more economic value than public-access Wi-Fi over the next 20 years or so. Table 2 provides an indication of the orders of magnitude that are derived when comparing the economic values of cellular and Wi-Fi, as calculated by these models for two levels of demand elasticity. Given the bandwidth available for these two applications, the table also gives an idea of the value per MHz of these applications for the 20 year period.

[15] It may be argued that private commons, rather than licence-exemption, is the more appropriate spectrum management regime in applications such as road-user charging.

	NPV (£bn) over 20 years for elasticity of demand ε[16]		Bandwidth requirements (MHz)	£bn/MHz
Cellular (2008-2028)	ε = –1.00	110	340	0.32
	ε = –0.33	405		1.19
Wi-Fi (2006-2026)	ε = –1.00	65	233	0.28
	ε = –0.33	105[17]		0.45

Source: Based on consultancy reports by Indepen, Aegis, Ovum, Analysys, Dotecon

Table 2. Indicative comparison of cellular and public-access Wi-Fi economic values per MHz.

Even though the studies differ in their assumptions and Wi-Fi's valuations are to be considered as more uncertain because its market is less mature and congestion and interference costs are not included, the comparison suggests that the per MHz value of cellular is higher than that of public-access Wi-Fi.

3.5 Conclusions

In this section we presented background material on Ofcom's approach to spectrum management, and discussed the criteria for deciding whether licence-exempt use of spectrum is preferred over licensed use within a band. We presented the legal basis for licence-exemption, as well as an overview of the current licence-exempt authorisations across the radio spectrum in the UK. Finally, we presented estimates of the economic values of a selection of licence-exempt applications over the next 20 years. It was seen that a number of such applications, such as public-access Wi-Fi, RFIDs in retail, and automotive radars can be expected to generate significant value.

The following sections provide a detailed analysis of a number of specific issues with regards to the management of spectrum used by licence-exempt devices. These include the relative merits of application-specific and commons models for spectrum use, the relationship between licence-exemption and light-licensing regimes, the question of whether devices transmitting at sufficiently high frequencies or sufficiently low powers should be exempt from licensing, the role of harmonisation, and the need for additional regulatory instruments to investigate cases of harmful interference.

[16] A higher value of demand elasticity in absolute terms refers to a situation in which there is a higher risk of substitution to alternative products, and hence a lower consumer surplus from that product.

[17] This figure is the average of the public access Wi-Fi values for the low, medium and high demand scenarios as reported in Table 1.

Section 4

Application-specific spectrum vs. spectrum commons

4.1 Introduction

As the name suggests, application-specific spectrum refers to a portion of the frequency spectrum reserved exclusively for use by a specific wireless application. An example of this is the 1880–1900 MHz band for licence-exempt DECT cordless phones.

Spectrum commons, on the other hand, is defined as a portion of the spectrum wherein multiple wireless applications operate on a co-channel basis. An example of this is the 2.4–2.4835 MHz band where Wi-Fi, Bluetooth, and a range of other licence-exempt devices reside.

It is evident that the impact of inter-application interference is a clear differentiator of these two spectrum allocation strategies.

According to our studies, application-specific spectrum is essential for those applications (licence-exempt or otherwise) where the quality of service requirements demand that:

- the radio transmitters be impolite[18], and might therefore cause intolerable interference towards any co-existing co-channel applications; or
- the receivers be protected from interference, since they can not tolerate interference from any co-existing co-channel applications.

One example of applications of the type that might need a dedicated assignment includes long-range non-line-of-sight, and/or delay-intolerant radio communications. However, given their impolite transmitters and/or interference-intolerant receivers, such applications have traditionally operated under exclusive technology-specific licences (e.g. broadcasting and cellular systems). We do not suggest here that such licensed use of spectrum be altered in the future.

Other examples include safety-critical applications whose receivers rely on the protection from interference that is afforded by an application-specific spectrum allocation regime. Examples include the 402–405 MHz band for licence-exempt ultra-low-power active medical implants, or the 76–77 GHz band for licence-exempt automotive radar. No other licence-exempt devices operate in these bands.

Many other applications, however, such as those supporting delay-tolerant services (e.g. telemetry), or those with a low power signature (e.g. short-range consumer communication devices, or line-of-sight directional radio links), are fully capable of mutual co-channel co-existence. Today, these applications operate in a mixture of spectrum commons and (less frequently) application-specific spectrum.

[18] A transmitter is deemed to be polite if it employs an explicit polite protocol (e.g. listen-before-talk), and/or has a small power profile as a function of frequency, time and space.

Examples of spectrum commons include several allocations in the 868–870 MHz band[19] for licence-exempt non-specific short-range devices[20], or the more well-known 2.4–2.4835 GHz band which supports wireless LANs and a multitude of other applications ranging from wireless video cameras to detection of movement sensors. A corresponding example of application-specific spectrum includes the 868.6–868.7 MHz band for wireless alarms.

One may observe that, far from being of purely academic interest, the spectrum commons is today an accepted spectrum allocation strategy for licence-exempt devices. It is also worth noting that, often where spectrum appears to be exclusively allocated for a specific licence-exempt application, further inspection reveals that the spectrum is also shared with other licensed applications. Co-channel co-existence of multiple applications is far from being the exception in the context of licence-exempt devices.

The spectrum commons and application-specific spectrum allocation strategies are compared in this section in terms of three distinct criteria:

- spectrum liberalisation;
- impact of interference; and
- impact of diverse applications.

4.2 Spectrum liberalisation and spectrum commons

The application-specific allocation of spectrum allows the regulator to manage interference effectively based on a command and control model. However, it also results in a regulator-imposed fragmentation of spectrum which is not subject to corrections by market forces, causing a non-uniform utilisation of spectrum as a function of frequency, depending on the uptake of various applications. These effects may manifest themselves as an artificial scarcity of spectrum.

In the context of licensed services, Ofcom's vision of a *market-led* approach to the licensing of spectrum, namely that of tradable, flexible, and negotiable licences, addresses many of the concerns relating to the inefficient utilisation of spectrum as described above. This view is based on the premise that the best use of the spectrum should be determined by the market itself, rather than be based on the regulators' predictions of future demand.

Of course, licensing is not appropriate, or indeed necessary, in certain scenarios. Examples include where wireless links are operated by large numbers of independent users, or where there is a low risk of harmful interference. Licence-exempt operation is then the preferred option.

In the context of licence-exempt devices, application-specific allocations can again result in the fragmentation of spectrum. Furthermore, with the rapidly evolving landscape of the market for wireless devices, any application-specific allocation authorised by the regulators may soon be made obsolete. Finally, it can be strongly argued that any application which strictly relies on the levels of protection afforded through exclusive spectrum allocations would best be supported via a licensing regime. It is therefore expected that, at least in the

[19] Specifically, 868-868.6, 868.7-869.2, 869.3-869.4, 869.4-869.65, and 869.7-870 MHz.

[20] These typically operate based on the generic Harmonised European Standards, currently covering frequencies from 9 kHz up to 40 GHz.

context of licence-exempt devices, the role of application-specific spectrum will increasingly diminish with time.

On the contrary, a spectrum commons approach for co-channel operation of licence-exempt devices, subject to *politeness rules*[21] defined by regulatory bodies and *polite protocols*[22] defined by equipment manufacturers, would enable a de-centralised management of interference among applications, resulting in a more uniform utilisation of spectrum as a function of frequency. In other words, a spectrum commons model aims to liberalise spectrum for licence-exempt devices, in the same way that a market-led approach aims to liberalise spectrum in a licensing regime.

Given the above arguments, and in accordance with Ofcom's desire to facilitate spectrum liberalisation, it is recommended that, where possible, any spectrum released in the future for licence-exempt devices be allocated based on the spectrum commons model.

4.3 Spectrum commons and interference

A criticism frequently directed at the concept of spectrum commons is its inability to provide quality-of-service guarantees in an environment dominated by co-channel interference among large numbers of devices, employing different technologies, and supporting diverse applications. It is argued that the absence of centralised control could ultimately result in scenarios where the levels of interference are so great that the spectrum is rendered unusable. This is sometimes referred to as the "tragedy of the commons".

On the other hand, application-specific allocation of spectrum for licence-exempt devices is an effective approach for mitigating, if not eliminating, inter-application interference. Consequently, at first glance, spectrum commons would appear to be the less attractive option.

While inter-application interference is a key issue in the implementation of licence-exempt spectrum commons, its impact can be controlled to some extent via a number of mechanisms. In many circumstances, geographic separation and shadowing caused by obstacles provide adequate attenuation of inter-application interference. This occurs because licence-exempt transmitters are typically associated with small power signatures (power profiles as a function of frequency, time, and space). Consequently, separations of the order of tens of metres often result in sufficient attenuation of interference.

Indeed, it can be readily shown that, as the attenuation of inter-application interference grows beyond a specific factor (defined by receiver target signal-to-interference-plus-noise ratios), then the spectrum commons model offers a spectral efficiency (i.e. bits/s/Hz) which is greater than that of an application-specific allocation by a factor equal to the number of sharing applications[23].

However, geographic separation cannot always be guaranteed. Consequently, the risk of intolerable interference among highly diverse applications can never be completely eliminated. As a result, the likely spectral efficiency of spectrum commons has a broad distribution, with an upper tail corresponding to a peak efficiency which exceeds that of

[21] Politeness rules are constraints on radiated power profiles as functions of frequency, time, and space (e.g. spectral density, duty cycle, and beamwidth).

[22] Polite protocols are interference avoidance mechanisms implemented at the physical layer (PHY) and/or medium access control (MAC) layer of the radio protocol stack, that enable multiple autonomous devices to share the radio resource.

[23] See Annex 2, "Spectral efficiency of the spectrum commons".

application-specific allocation, as well as a lower tail which, if untreated, can extend towards zero. Polite protocols are key mechanisms for mitigating the impact of the lower tail, and have emerged as powerful tools for the de-centralised mitigation of interference among wireless transceivers.

The most well known polite protocol is probably the carrier sensing multiple-access collision-avoidance (CSMA/CA) protocol used in the IEEE 802.11 family of wireless LANs (Wi-Fi). This is a listen-before-talk protocol which enables multiple devices (which would otherwise be subject to catastrophic co-channel mutual-interference) to utilise equal shares of the radio resource. This has the effect of dramatically reducing the probability of occurrence of low spectral efficiencies. Carrier-sensing protocols are being increasingly adopted in new radio technologies, including IEEE 802.22, and IEEE 802.15.4 (ZigBee).

Intelligent frequency hopping is another polite mechanism which can mitigate the probability of near-zero spectral efficiency in a spectrum commons. Consider an environment where a multitude of independent frequency channels are available for use by a transceiver[24]. While interference may well be intolerable within a given channel, this is far less likely to be the case for all channels at the same time and in a particular locality. A frequency-agile transceiver can exploit this through a combination of carrier-sensing and frequency hopping. In principle, the risk of interference can be arbitrarily reduced by indefinitely increasing the bandwidth of the commons, relying on frequency-agile transceivers to reduce the power spectral density of the interference floor.

In summary, while the interference environment for licence-exempt devices in a spectrum commons is undoubtedly less deterministic than that in application-specific spectrum, it need not have a catastrophic impact on the quality-of-service experienced. Geographic separation can often provide sufficient isolation among applications in a spectrum commons, providing significant gains in spectral efficiency over that achievable via application-specific allocation. Polite protocols such as carrier-sensing and frequency-hopping can mitigate the impact of interference in instances where radio isolation cannot be guaranteed.

4.4 Spectrum commons and diversity of applications

It can be shown (see Annex 2) that the ratio of spectral efficiency (i.e. aggregate value per Hz) in a spectrum commons, to that achievable via application-specific spectrum is maximised when:

1) the applications sharing the spectrum have similar bandwidths, resulting in maximum savings in utilised spectrum; and

2) each application suffers from a similar minimal fractional degradation in value as a result of inter-application interference.

Interestingly, the above apply irrespectively of the relative unconstrained values[25] of the individual applications.

Based on the above considerations, and noting that the *economic* spectral efficiency (£/Hz) derived from an application usually increases as the *information* spectral efficiency (bits/s/Hz) offered by the application grows, one may infer that the benefits of spectrum

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24 This would be the case, for example, if the supply of spectrum exceeded the demand. See Section 6.

25 The unconstrained value of an application is defined here as the value or benefit that is provided when the application operates in exclusive application-specific spectrum.

commons are maximized whenever the spectrum-sharing applications use technologies that are somewhat similar in terms of their technical parameters.

This result is consistent with the intuitive observation that it is difficult for a polite low-power application (perhaps even subject to an explicit polite protocol) to effectively co-exist with an impolite high-power application.

A spectrum commons that is intended to support an unbounded range of diverse applications may experience severe interference issues. Such an extreme model is the diametric opposite to an application-specific spectrum allocation strategy, and is unlikely to result in an efficient utilisation of the spectrum, even though it is ideal from the point of view of spectrum liberalisation.

Consequently, in order to benefit from the advantages of both application-specific spectrum and spectrum commons, we recommend the adoption of multiple “classes” of spectrum commons. Here, each class would be associated with a particular portion of the spectrum, and be managed by a specific set of mandatory politeness rules[26] defined by regulatory bodies. In this pragmatic approach, the applications allowed into a specific class of spectrum commons would be constrained, through the politeness rules, to have broadly similar interference generating characteristics, thereby avoiding co-existence issues among wildly diverse applications. Note that in addition to the politeness rules, the licence-exempt devices may also operate according to standardised, or possibly proprietary, polite protocols.

For example, in one class of spectrum commons the politeness rules defined by regulatory bodies may only permit very low radiated power profiles (e.g. low duty cycles). As a result, explicit polite protocols at the lower layers of the radio protocol stacks may not be necessary in this class.

In a different class of spectrum commons, the politeness rules defined by regulatory bodies may allow greater radiated power profiles, in which case it would be up to the radio technology standardisation bodies, or individual manufacturers, to specify appropriate polite protocols and interference mitigation mechanisms to permit co-existence.

Clearly, it is important that the politeness rules which govern a spectrum commons are:

1) specified at an appropriate level of detail, so that different polite protocols, whether these are defined by independent technology standardisation bodies or designed by individual equipment manufacturers, may co-exist without any one protocol unduly dominating others in utilising the available radio resource;

2) defined so as to allow, where feasible, possible trade-offs between various technical constraints in the dimensions of frequency, time, and space, in order to afford maximum flexibility to the designer of the underlying polite protocol technologies;

3) defined with a view towards advances in state-of-the-art radio technologies, in order to ensure that the implementation of key technologies is not obstructed.

The politeness rules for each class of spectrum commons would be defined by the regulatory bodies, in consultation with the stakeholders. Based on their technical requirements, different applications would then adopt appropriate technologies and deploy in the most suitable class of spectrum commons.

[26] Politeness rules are constraints on radiated power profiles as functions of frequency, time, and space.

Note that communications range is directly related to the level of radiated power, which in turn dictates the potential for interference towards victim receivers. One may therefore envisage different classes of spectrum commons based on the desired communications range. So, for example, given the nature of licence-exempt devices in operation today, one may define different classes of spectrum commons for communications ranges of the order of up to metres, 10s of metres, and 100s of metres. Within each class, one may envisage further partition of the spectrum into sub-classes of spectrum commons corresponding to more detailed restrictions on technical parameters.

4.5 Conclusions and recommendations

Spectrum commons is an effective tool for the liberalisation of spectrum for use by licence-exempt radio devices. While the interference environment in a spectrum commons is less deterministic than that experienced in application-specific spectrum, the impact of this can be mitigated via polite protocols and interference avoidance mechanisms, especially in scenarios where the supply of spectrum exceeds demand.

Furthermore, the benefits of spectrum commons are maximized whenever the applications sharing the spectrum use technologies with broadly similar characteristics. One may, for example, readily envisage the issues which would arise if short- and long-range licence-exempt radio systems were to co-exist at a given location within a spectrum commons.

Based on the above analysis, we make the following two recommendations.

1) It is recommended that, where possible, any spectrum released in the future for licence-exempt devices be allocated based on the spectrum commons model, wherein devices for multiple applications share the same frequencies, subject to politeness rules and polite protocols. While spectrum commons will be the default approach, exclusive licence-exempt use of spectrum by a specific application will be considered on a case-by-case basis where technical constraints, international obligations, or safety issues require such use.

2) It is recommended that multiple classes of spectrum commons be defined, with regulatory-defined mandatory politeness rules limiting the diversity of applications within each class, and standardised or proprietary polite protocols micro-managing the intra- and inter-application interference.

We believe that the latter recommendation is a pragmatic approach which strikes a balance between full liberalisation of spectrum (as afforded by a spectrum commons which supports an unbounded range of applications), and the creation of a more predictable interference environment (as achieved via application-specific spectrum).

Note that any future authorisations of licence-exempt use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

Section 5

Light-licensing and licence-exemption

5.1 Introduction

Light-licensing and licence-exemption are alternative techniques for the management of interference among multiple operators of radio communication systems.

Light-licensing can be used to achieve two distinct aims[27]:

a) In one realisation, light-licensing is a regime which allows spectrum access to new services, while affording protection to incumbent (primary) users of the band. This might be achieved through geographical exclusion zones for new users.

b) In a second realisation, light-licensing is a regime which allows multiple operators to conduct analysis of mutual interference, and co-ordinate the operation of their radio systems accordingly. The regulator might only become directly involved in the co-ordination of the radio links if a dispute were to arise.

An example of the first realisation is the light-licensing of fixed wireless access services in the 5725–5875 MHz (Band C) band, in order to facilitate co-existence with primary civil/military users and licence-exempt devices in the UK. An example involving both realisations is the light-licensed use of spectrum by fixed links at 71–76 GHz and 81–86 GHz in the UK.

Light-licensing is achieved through the:

1) award of non-exclusive national licences to operators;
2) creation of a registration process including identity, time and date records; and
3) creation of an open centralised database containing specific technical parameters such as site location, as well as antenna and transceiver specifications for each radio link deployed by the operators.

In the UK, light-licensing databases are at present established and maintained by Ofcom, with a nominal annual fee charged for each registered radio link. The licences are of an indefinite duration, but subject to revocation following a reasonable notice period (typically five years).

The database is particularly valuable in scenarios where the spectrum is jointly managed by both Ofcom and the MoD. In such cases it is necessary that the locations of deployed radios are recorded to address any future requirements of the MoD (the primary user). More generally, the registration process and technical database are valuable tools for the efficient implementation of spectrum re-farming.

The availability of technical data on the transceivers is particularly helpful when co-ordination among operators is envisaged. Here, the afforded priority and protection are date and time

[27] Note that the term "light" licensing is also sometimes used to refer to the electronic (on-line) process of issuing licenses as a means for reducing bureaucracy. Such processes are available for amateur and shipping licences, and fall outside the scope of this discussion.

based, so licensees can be required to ensure that a new link causing harmful interference to an earlier registered link is closed down or its technical parameters are modified to eliminate any harmful interference. Such a first-come first-served regime naturally favours early entrants, and may result in an unequal distribution of the radio resource among multiple operators. This is particularly the case where an early entrant pursues an aggressive network deployment.

In the next section, the characteristics and merits of light-licensing are compared and contrasted with those of licence-exemption, with special attention given to the issue of spectrum re-farming. This is followed, in the subsequent section, by a look at the future evolution of the two interference management regimes.

5.2 Comparison

5.2.1 Protection of incumbent services

As pointed out earlier, in one realisation, light-licensing of new services can be used to protect incumbent services in a given band. Such incumbents are typically the primary users of the band (as defined by the ITU-R Radio Regulations, or the UK Frequency Allocation Tables), and as such, are afforded priority over any secondary users sharing the spectrum. The incumbents may be military services (e.g. radars), scientific applications (e.g. radioastronomy), satellite services, or even licensed radio communications links.

Protection of the incumbent through light-licensing is typically achieved through:

1) an imposition of hard constraints on the geographical location of devices (an example being the definition of exclusion zones where light-licensed devices are not allowed to operate); and/or

2) a requirement on the light-licensed devices to use some form of detect-and-avoid mechanism[28].

In the context of the requirement for detect-and-avoid mechanisms (item 2), there are no significant distinctions between light-licensing and licence-exemption. Indeed, many licence-exempt devices are also required to use detect-and-avoid mechanisms in certain bands in order to mitigate interference towards incumbent services. An example is the use of dynamic frequency selection (DFS) by WLANs in the 5250–5350 MHz and 5470–5725 MHz bands.

However, in the context of imposing constraints on geographical location (item 1), light-licensing performs a role which licence-exemption (at least in its current form) can not perform. This is because licence-exempt transceivers are usually embedded in short-range consumer devices whose locations and numbers are difficult to control or monitor. Therefore, where restrictions on location and device numbers are a necessity for the protection of incumbent services, light-licensing is the preferred option.

5.2.2 Co-ordination among multiple operators

In its second realisation, light-licensing is primarily targeted at the management of application-specific spectrum where the locations of the transceivers are fixed (e.g. fixed point-to-point radio links), thereby allowing multiple operators (non-exclusive licensees) to

[28] An example is the authorisation regime for fixed wireless access services in the 5725-5875 MHz (Band C) band. These services are also subject to geographical exclusion zones.

perform interference analysis in an efficient manner. In this context, light-licensing is less effective for the management of spectrum where:

1) the transceivers are owned and operated by parties who do not have the capability to perform interference analysis (e.g. short-range consumer devices);
2) the transceivers are operated by a large number of parties, and interference planning can not be performed in an efficient manner;
3) the transceivers correspond to a diverse range of applications, and interference planning is technically complex; and
4) the transceivers are mobile, and result in a highly dynamic interference environment.

In such cases, licence-exemption subject to appropriate politeness rules[29] would be more appropriate (see Section 4 for further details). Here, interference management would either be unnecessary (due to the small transmitter power signatures), or would be performed *autonomously* and in a de-centralised manner via polite protocols[30] and interference mitigation/avoidance mechanisms.

Such de-centralised management of interference is ideal for short-range consumer devices. This is evident today, with carrier-sense multiple-access collision avoidance (CSMA/CA) protocols in Wi-Fi equipment, and fast frequency-hopping in Bluetooth, to name prominent examples.

Operating deep within the radio protocol stack, such technologies eliminate the need for explicit co-ordination between the operators of the equipment, and can respond rapidly to time-variant interference conditions. The protocols also scale well with the number of devices involved, and can be designed to allow a fair distribution of the radio resource.

5.2.3 Spectrum re-farming

An issue often cited in support of light-licensing is the perceived difficulty in the future re-farming of spectrum used by licence-exempt devices. This inevitably raises concerns with regards to the reversibility of a decision to authorise licence-exempt use of spectrum. In comparison, light-licensing allows users to be contacted and their licences potentially revoked, although there may still be many difficulties in re-farming the spectrum.

Note that spectrum allocated for use by licence-exempt devices would be re-farmed only if competing demand for the same spectrum were to materialise due to the emergence of a high-value licensed application. Indeed, the value of the licensed application would need to exceed the aggregate value of all applications supported within the licence-exempt spectrum commons[31], with no other suitable spectrum available for the licensed application. While this is an unlikely scenario (if it were deemed likely, then the spectrum would not have been assigned for licence-exempt use to begin with), it is a possibility which needs to be addressed.

[29] Constraints on radiated power profiles as functions of frequency, time, and space.

[30] Techniques implemented at the physical layer (PHY) and/or medium access control (MAC) layer of the radio protocol stack, that enable multiple autonomous devices to share the radio resource.

[31] In line with its aim of facilitating spectrum liberalisation, Ofcom prefers a spectrum commons model (as opposed to application-specific spectrum allocation) in the context of licence-exemption. See Section 4.

Furthermore, it should be pointed out that the future re-farming of spectrum is always achieved at a cost to the current users of spectrum, irrespective of the licensing regime[32]. This is quite independent of the technical feasibility of clearing the spectrum, the latter being the main cited concern with regards to licence-exemption. While the absence of registration processes and usage databases in a licence-exemption regime does represent a challenge in this respect, the re-farming of spectrum can still be performed, albeit via less direct methods as described below.

Spectrum can be cleared of licence-exempt devices in a number of ways.

1) The decision to re-farm a portion of spectrum is invariably followed by a notice period, during which one would inevitably observe a decline in the manufacture of new licence-exempt devices for the relevant band as the market pursues alternative solutions. This results in a natural decay in the number of operational licence-exempt devices in the band. This is a slow process that can take several years to complete. It is also likely that a small number of licence-exempt devices may continue to operate in the cleared band.

2) Generally, licence-exempt devices are unable to co-exist with licensed devices unless there is sufficient isolation between the two. This is because the former are typically associated with polite protocols and/or low power signatures, while the latter are typically associated with impolite transmitters. Consequently, the impact of mutual interference is usually not symmetric. As a result, deploying licensed services will, in most cases, result in those using licence-exempt devices to suffer interference and as a result stop use and seek alternatives[33].

3) *Evacuation* mechanisms can be implemented within the protocol stacks of licence-exempt devices, which upon detection of a licensed application would force the device (and possibly nearby devices) to abstain from utilising the spectrum. The trigger for evacuation may be the result of sensing, or may be explicitly signalled by an external entity (e.g. through broadcast beacons). In any case, such capabilities would need to be standardised[34].

5.3 Future evolution and recommendations

One can envisage an increased blurring of the distinction between light-licensing and licence-exempt regimes as a function of time.

Today, light-licensing regimes rely on access to an open database of radio link locations and technical parameters, allowing a) protection of incumbent services through imposition of geographic exclusion zones and hard limits on device densities; and/or b) explicit co-ordination among operators of fixed radio links. In time, with advances in the state of the art in self-deployment mechanisms, automatic database access, and sensing (for detection of users and/or information beacons) technologies, such co-ordination will increasingly be performed autonomously by the radio equipment, in a dynamic and de-centralised fashion, and with little or no human intervention. Such technologies are already emerging in

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[32] This cost is minimised through a notice (or grace) period, prior to the clearing of the spectrum.

[33] Exceptions to this rule are licence-exempt underlay transmitters (e.g. ultra-wideband) which are designed to tolerate interference from co-channel narrowband applications. But, on the other hand, such transmitters are also designed (by virtue of their low transmit power spectral density) not to case harmful interference.

[34] Examples of such mechanisms are being developed within IEEE 802.22 in order to allow licence-exempt devices to utilise unused spectrum in the UHF TV bands.

applications such as fixed broadband wireless access where they aim to simplify the deployment of customer premises equipment.

Approaching from the opposite direction, today licence-exempt devices rely on a de-centralised management of interference via polite protocols implemented within the radios' physical and medium access control layers. This functionality already goes a long way towards achieving what is broadly referred to as intelligent or *cognitive* radio. Research, development, and standardisation is already under way in the use of beacons and databases as a means to enhance the levels of cognition, thereby enabling co-existence with incumbent radio applications which themselves do not adhere to politeness rules or protocols (e.g. TV services).

However, until such time when one can no longer readily differentiate between the two spectrum management regimes, light-licensing and licence-exemption remain distinct solutions for the management of interference in different scenarios:

- In terms of protecting incumbents, light-licensing is the preferred regime when geographic exclusion zones and limits on device densities are a necessity.
- In terms of co-ordination among operators, light-licensing is the preferred regime for geographically fixed radio links involving few operators, while licence-exemption is preferred for mobile devices involving large numbers of operators.

Based on the above arguments, we make the following two recommendations.

1) It is recommended that light-licensing regimes be adopted only when explicit co-ordination among the operators of the radio devices is both feasible and a technical necessity (i.e. when limitations in technology prevent autonomous self-coordination among the devices). Licence-exemption should be adopted otherwise, subject to adequate protection of incumbent users.

2) It is recommended that the status of operational light-licensed regimes be regularly reviewed, on a case-by-case basis, with a view to conversion to licence-exemption[35] only if autonomous and dynamic self-coordination among the light-licensed radio devices is technologically feasible, economically viable, and provides adequate protection of incumbent users.

Ofcom will review each case on its own merits, but we do expect to see a move toward licence-exemption over time. However, any future conversions by Ofcom of light-licensing regimes to licence-exemption will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

Finally, it should be noted that this review is only concerned with the relative merits of the light-licensing and licence-exemption regimes. The question of opportunistic (or so-called cognitive) overlay access – by either light-licensed or licence-exempt devices – to licensed spectrum is a different matter all together and falls outside the scope of the LEFR. The possibility of such opportunistic access is very much dependent on the nature of the licensed service and would need to be addressed on a case-by-case basis, with associated impact assessments as appropriate.

[35] This would be in the form of a spectrum commons subject to politeness rules limiting the diversity of co-exiting applications.

Section 6

Licence-exemption above 40 GHz

6.1 Introduction

Two reasons may be identified as to why devices might be exempted from licensing.

1) The first reason is if the economic benefits of the exempted use are greater than that of alternative licensed use. An example of this might be in the 2.4 GHz band, where the proliferation of licence-exempt consumer devices using technologies such as Wi-Fi and Bluetooth has generated considerable value.

2) The second reason, which is of particular relevance here, is if the demand for spectrum in a given frequency band is less than the supply, in which case congestion[36] is unlikely to occur, and hence the overhead of licensing is an unnecessary burden.

In the Spectrum Framework Review we noted that economic theory suggests that where spectrum is unlikely to become congested, then devices should be exempt from licensing.

Broadly speaking, one may state that the probability of radio congestion reduces at higher frequencies. This can be explained as follows.

a) Propagation loss limits the range of interfering signals

Radio waves are subject to increasing attenuation at higher frequencies. This is due to increasing free-space path-loss and shadowing via obstructions such as walls, in addition to atmospheric absorption by gases and water vapour. The latter effect is particularly dominant above 40 GHz, as illustrated in Figure 3[37]. This results in a rapid drop in received signal power levels with distance at higher frequencies, thereby reducing the probability of harmful interference for a given radiated power.

b) Directional antennas mitigate the impact of interference

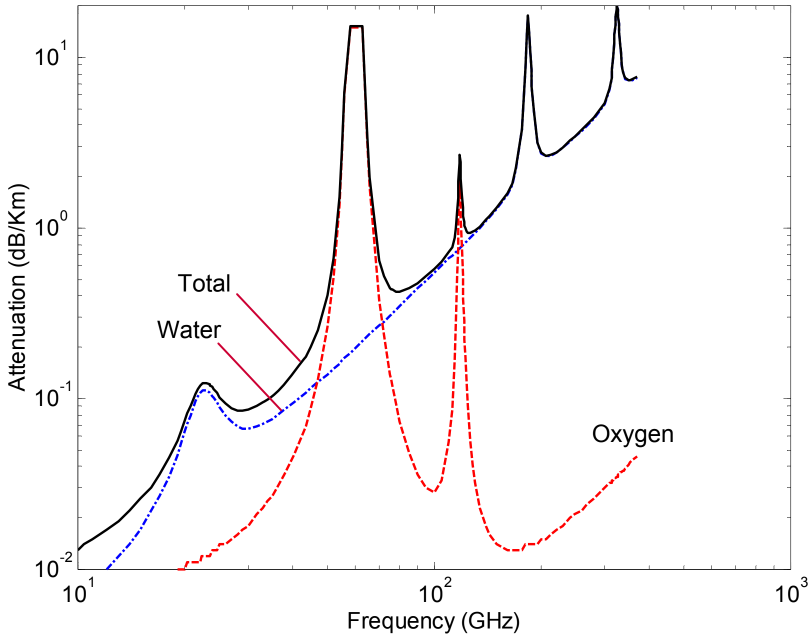
High-gain antennas are increasingly used at higher frequencies in order to improve the link-budget. To this end, antenna patterns are designed to be highly directional, with beam-widths of several degrees not uncommon at tens of GHz. This helps to limit the spatial signature of a transmitter's radiation, and to suppress unwanted signals at the receiver, thereby reducing the probabilities of generating and receiving harmful interference. Put simplistically, if a transmitter emits radiation along a narrow beam, a victim receiver would only be subjected to high levels of interference if it were to enter the beam.

[36] In this context, congestion refers to the potential for radio devices to generate harmful interference toward other devices.

[37] "Higher frequencies for licence-exempt applications," Final report, Quotient Associates, Indepen, University of York, February 2007. See: http://www.ofcom.org.uk/consult/condocs/lefr/.

c) Large swathes of frequency imply low probability of co-channel collisions

For a given link throughput, an increase in the amount of available spectrum represents an increasing opportunity for transmitters to avoid one another in frequency or time. The avoidance mechanisms may be implemented via carrier-sensing, beacons, or even pseudo-random hopping in time and frequency.



Source: Quotient Associates

Figure 3. Increase in atmospheric gaseous and water vapour absorption with frequency.

Based on the above arguments, one may conclude that since the likelihood of congestion reduces at higher frequencies, then so does the need for licensing.

This conclusion is indeed confirmed by observing the mix of licensing regimes in the UK across the radio spectrum, as illustrated in Figure 4. One can see that licensed uses of spectrum tend to dominate up to 40 GHz, with an increasing proportion of licence-exempt or light-licensed uses, as well as unused spectrum, between 40 and 105 GHz. Also note that almost the entire spectrum beyond 105 GHz is currently unused.

The above observation naturally raises the question of whether there is a frequency limit above which all spectrum can be made exempt from licensing. In the context of this question, one may identify two distinct portions of the spectrum: frequencies between 40 and 105 GHz, and, frequencies beyond 105 GHz. We address these separately in the following subsections.

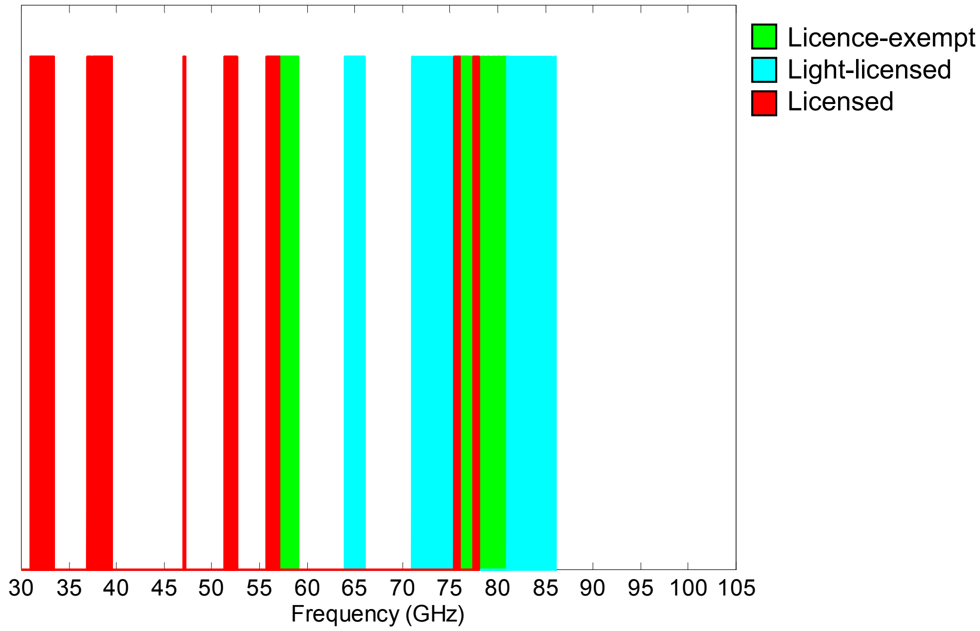


Figure 4. Mix of licensing regimes above 30 GHz.

6.2 Licensing regimes: beyond 105 GHz

The radio spectrum beyond 105 GHz has been mostly unused, in particular for purposes of wireless communications. This can be attributed to two key factors.

1) Constraints in transceiver technologies

   The development of Gigahertz technology has been driven primarily by scientific applications, including radio astronomy and remote sensing. Radio devices operating at hundreds of Gigahertz remain highly specialised, expensive, and of limited performance.

   For frequencies approaching 100 GHz, solid-state transceivers with output powers of 10 mW and noise figures of 10 dB are now commercially available for point-to-point links. Research commissioned by Ofcom suggests that there are no fundamental barriers to the development of devices at higher frequencies, and that solid state transceivers at up to 200 GHz could be commercially available within 10 years depending upon market demand[38]. Furthermore, there is no intrinsic reason why such devices should be more expensive than lower-frequency microwaves devices.

2) Constraints in radio-wave propagation

   As described earlier, at frequencies beyond 40 GHz, radio waves are increasingly subject to line-of-sight propagation, signal attenuation due to obstructions, and atmospheric loss due to gaseous and water vapour absorption.

[38] "Higher frequencies for licence-exempt applications," Final report, Quotient Associates, Indepen, University of York, February 2007. See: http://www.ofcom.org.uk/consult/condocs/lefr/.

Improvements in the state of the art in micro-electronics over the next 10 to 15 years will undoubtedly result in a growing supply of radio communication applications at frequencies above 105 GHz. However, the poor radio propagation conditions will always impose severe limitations on the achievable communication range in comparison to lower frequencies.

Consequently, the likely uses above 105 GHz may be broadly categorised as follows.

1) Short-range radio links for consumer devices. Example applications include indoor high-speed WLANs, home entertainment systems, and personal area networks. Communications would be line-of-sight, and limited to ranges of the order of tens of meters (within a single room). Transmitter output power and antenna gain, rather than atmospheric absorption, dictate the link-budget in these applications.

2) Medium-range fixed radio links for uses such as point-to-point communications, and radio repeaters (e.g. in mesh networks). Communications would again be line-of-sight, but with a range of the order of hundreds of meters through the use of highly directional antennas. Atmospheric absorption would degrade the link-budget significantly at greater distances.

Studies commissioned by Ofcom have identified projected upper limits of between 10 to 15 GHz of spectrum required for each of the above categories over the next 15 years[39]. This implies that there is certainly no shortage of spectrum for these applications at frequencies above 105 GHz, and congestion is highly unlikely to occur in the foreseeable future.

Based on the above analysis, one may conclude that the overhead of licensing is an unnecessary burden for frequencies above 105 GHz.

As discussed in Section 4, licence-exemption within a spectrum commons, subject to appropriate high-level politeness rules[40], is the preferred option for the above first category of uses. In the short-term, light-licensing is the preferred approach for the second category of uses, where the locations of the transceivers are fixed and interference analysis can be performed efficiently. In the long-term, with advances in autonomous self-deployment and sensing technologies, light-licensing regimes may naturally evolve toward licence-exemption.

[39] The scenario considered for the medium-range application is that of an urban mesh network of point-to-point links. This consists of street-level base stations with directional antennas pointing in four orthogonal directions at every junction within a Manhattan topology. Each node supports 8 operators. Each operator connects adjacent nodes with 2 links, one in each direction. Each link has a capacity of 622 Mbits/s (i.e. STM-4) and a channel bandwidth of 56 MHz. A re-use factor of 22 is assumed. This can be effectively halved to 11 by judiciously reversing the direction of use of any pair of frequencies. An overhead of 10% is assumed for guard bands, resulting in a total bandwidth requirement of approximately 11 GHz. For further details see "Future options for efficient backhaul," Final report, PA Consulting Group, January 2007.

An example for the short-range application is the "SuperBus" discussed in "Higher frequencies for licence-exempt applications," Final report, Quotient Associates, Indepen, University of York, February 2007.

See both reports at: http://www.ofcom.org.uk/consult/condocs/lefr/.

[40] Constraints on radiated power profiles as functions of frequency, time, and space.

6.2.1 Frequency allocations

While there is currently little use of the radio spectrum beyond 105 GHz, it is important that policies regarding these bands comply with international obligations and do not compromise future uses of the spectrum.

In this respect, the ITU-R Radio Regulations are of particular relevance. These specify the services which may be assigned within different bands for purposes of international harmonisation. Member States of the ITU may use any part of the spectrum within their own territory for any purpose, provided such use does not cause harmful interference to other legitimate users operating in accordance with the Radio Regulations.

One may categorise the Radio Regulations spectrum allocations from 105 GHz to 275 GHz according to the following groupings.

Group-1: Spectrum allocated for fixed and mobile applications, among others, including radio astronomy, space research, earth exploration satellites, inter-satellite links, fixed/mobile/radio-navigation satellites and radio-location. This accounts for some 94.2 GHz.

Group-2: Spectrum that is not allocated for fixed and mobile applications, but to applications such as earth exploration satellites (passive), inter-satellite links, space research (passive), fixed/mobile/radio-navigation satellites, radio navigation, and radio astronomy. This accounts for some 40.45 GHz.

Group-3: Spectrum that is allocated for primary use by amateur and amateur-satellite services. This accounts for some 4 GHz.

Group-4: Spectrum allocated exclusively for passive services such as earth exploration satellites, radio astronomy, and space research. This accounts for some 31.35 GHz.

The above allocations are illustrated in Figure 5. Note that no allocations exist for frequencies above 275 GHz[41].

[41] According to Footnote 5.565, the frequency band 275-1000 GHz may be used by administrations for experimentation with, and development of, various active and passive services. In this band a need has been identified for certain spectral line measurements for passive services. Administrations are urged to take all practicable steps to protect these passive services from harmful interference until the date when the allocation table is established in the above-mentioned frequency band. For this reason, the specified spectral line frequencies are excluded from our consideration.

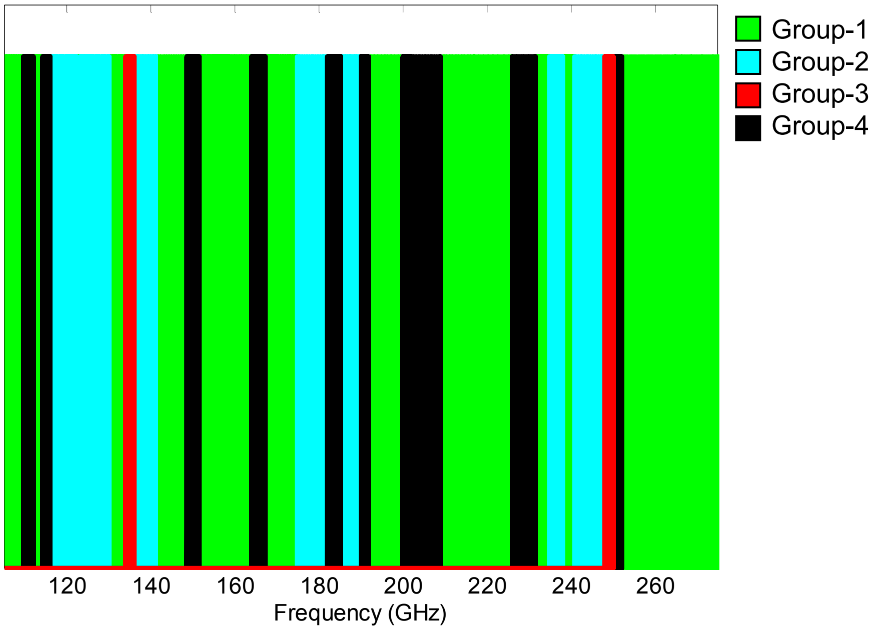


Figure 5. Frequency allocations 105–275 GHz.

Group-4 allocations are protected through Footnote 5.340, which prohibits all emissions in the relevant bands. We therefore do not consider the possibility of licence-exempt or light-licensed devices within these bands[42].

We also exclude the relatively small Group-3 allocations for amateur services, given that there is currently some usage of the bands for scientific and propagation experiments.

While Group-2 allocations do not include mobile and fixed services, the relevant bands can potentially be used by licence-exempt or light-licensed devices within the UK. This would be subject to specific radiation limits to avoid harmful cross-border interference to the sensitive (typically passive) services assigned by the Radio Regulations within these bands. Given the limited radio propagation at these frequencies, cross-border interference is seen as unlikely, although co-ordination at certain geographical locations may be necessary.

Bands associated with Group-1 allocations are the most suitable category for use by licence-exempt devices, since a number of different services, including fixed and mobile, are expected to co-exist therein[43].

6.2.2 Conclusions and recommendations

Given the nature of the ITU-R assignments for the 105–275 GHz spectrum, three options are proposed.

[42] Note, however, that the licence-exemption of very low-power underlay transmitters within these bands is addressed in Section 7.

[43] Note that many of these bands are subject to Footnote 5.149, which urges administrations to take all practicable steps to protect the radio astronomy service from harmful interference. Given that the uses envisaged in these bands extend to ranges of at most a few hundred metres, and are either indoor or highly directional, we consider such harmful interference to be unlikely, and in any case controllable via politeness rules. Also note that radio astronomy services already enjoy access to more than 30 GHz of spectrum protected under Footnote 5.340 over 105-275 GHz.

Option-1: Release all 135 GHz of spectrum corresponding to Group-1 and Group-2 allocations for use by licence-exempt devices.

Option-2: Release 94 GHz of spectrum corresponding to Group-1 assignments for licence-exempt devices. Release 40 GHz of spectrum corresponding to Group-2 allocations for use by light-licensed devices.

Option-3: Do not release any spectrum above 105 GHz until such time as there is clear evidence of demand for use by licence-exempt or light-licensed devices.

We do not favour Option-3. We believe this to be an over-cautious approach in a space where there is little likelihood of congestion and harmful interference. Such an approach will ultimately slow down the pace of innovation and the emergence of new high-frequency services[44].

We do have a preference for Option-2 in the short- to medium-term. Licence exemption within multiple classes of spectrum commons[45] subject to politeness rules[46] defined by regulatory bodies can be used to readily accommodate short-range (up to tens of metres) mobile links, and medium-range (up to hundreds of metres) fixed radio links within the 94 GHz of Group-1 bands. Meanwhile, light-licensing of Group-2 bands, involving a registration process, would facilitate co-existence of medium-range fixed radio links with any future passive services assigned to these bands (i.e. earth exploration satellites and space research), particularly in terms of cross-border co-ordination and potential exclusion zones.

In the long-term (i.e. beyond 20 years), with advances in autonomous self-deployment and sensing technologies, the light-licensing regimes may be reduced to full licence-exemption, as in Option-1.

Based on the arguments presented, we make the following two recommendations.

1) It is recommended that, in the 105–275 GHz frequency range, 94 GHz of unused spectrum (Group-1) be considered for a phased release to allow use by licence-exempt devices. A further 40 GHz of unused spectrum (Group-2) can be considered for light-licensed usage.

2) It is recommended that spectrum in the range 275–1000 GHz be considered for wide-scale release to allow use by licence-exempt devices. This is with the exclusion of spectral line measurement frequencies specified by Footnote 5.565.

Note that any future authorisations of licence-exempt or light-licensed use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

[44] “The future of regulation – not,” P.Cochrane, in *Communications: the next decade*, a collection of essays prepared for the UK Office of Communications, November 2006, http://www.ofcom.org.uk/research/commsdecade/.

[45] See Section 4 for a discussion on spectrum commons.

[46] Constraints on radiated power profiles as functions of frequency, time, and space.

6.3 Licensing regimes: 40 – 105 GHz

A study commissioned by Ofcom has provided an estimate of the bandwidth required to support potential future uses of the 40–105 GHz band over the next 15 years[47]. The estimate corresponds to a total of roughly 30 GHz of bandwidth for twelve applications, as indicated in Table 3 along with potential licensing regimes.

We consider this to be an upper bound on the total required bandwidth, since it is unlikely that all applications will emerge, and it will be possible for certain applications to share the same frequencies.

Application	Required Bandwidth (GHz)	Licensing Regime
Indoor Gigabit WLAN	5.3	licence-exempt
Outdoor Gigabit WLAN	4.95	licence-exempt
Wireless HDTV cameras	3.4	licence-exempt
Short-range surveillance radar	1	licence-exempt
	11.25[48]	
Point-to-point fixed wireless links	9.1	Light-licensed
Broadband fixed wireless access	4.2	Light-licensed
Intelligent transport systems	1.3	Light-licensed
High-altitude platforms for HDTV	1.2	Light-licensed
Mobile broadband for public safety	0.17	Light-licensed
High capacity repeaters	0.114	Light-licensed
	16.08	
Satellite to aircraft	1.7	Licensed
Direct broadcasting satellite	1.2	Licensed
	2.9	

Source: Quotient Associates

Table 3. Estimated spectrum requirements for potential future applications in the 40–105 GHz band.

6.3.1 Frequency allocations

One may identify a total of approximately 35 GHz of spectrum potentially available for future applications in the 40–105 GHz frequency range. This figure is arrived at by excluding frequencies that are:

1) subject to Footnote 5.340 for protection of passive services (11 GHz)[49];
2) used by radio astronomy services, passive services, and licensed applications such as point-to-point fixed links, and amateur use (5.15 GHz)[50];

[47] "Higher frequencies for licence-exempt applications," Final report, Quotient Associates, Indepen, University of York, February 2007. See: http://www.ofcom.org.uk/consult/condocs/lefr/.

[48] Assuming that wireless HDTV cameras share spectrum with indoor Gigabit WLAN.

[49] Consisting of the 48.2-49.44 GHz, 50.2-50.4 GHz, 52.6-54.25 GHz, 86-92 GHz, 100-102 GHz bands.

3) managed by the MoD (or jointly with Ofcom) for which there is currently no significant industrial demand for civilian applications (6.5 GHz)[51]; and
4) already assigned for licence-exempt use (7 GHz)[52].

The above bands are depicted in Figure 6.

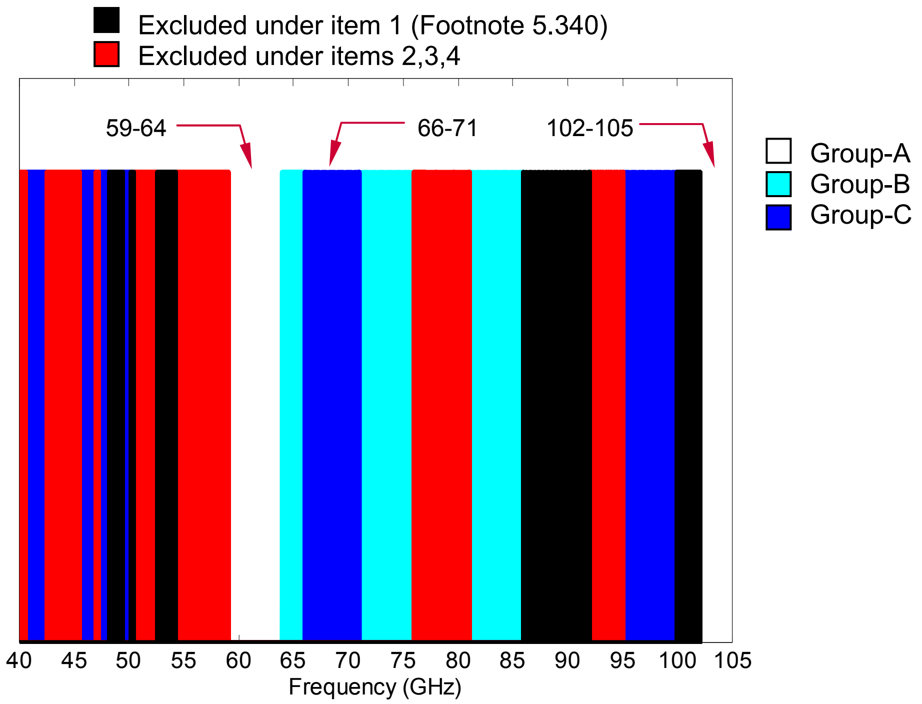


Figure 6. Spectrum potentially available for future applications in the 40–105 GHz band.

Further inspection reveals that the remaining 35 GHz may be categorised according to the following groupings.

Group-A: Spectrum potentially suitable for licence-exempt applications. This accounts for 8 GHz, consisting of the 59–64 GHz and the 102–105 GHz bands.

The 59–64 GHz band is jointly managed by the MoD and Ofcom in the UK, and is currently the subject of a number of compatibility and co-existence studies within CEPT. Specifically, CEPT SE24 is addressing the use of the 63–64 GHz segment for intelligent transport systems (ITS). CEPT SE19 is investigating the use of 59–66 GHz (with possible extension down to 57 GHz) for multi-Gigabit wireless systems (MGWS), consisting of WPANs, WLANs, and fixed links[53].

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50 Consisting of the 42.5-43.5 GHz, 47-47.2 GHz, 51.4-52.6 GHz, 54.25-55.78 GHz, 55.78-57 GHz, bands.

51 Consisting of the 39.5-40.5 GHz, 43.5-45.5 GHz, 50.4-51.4 GHz, 92-95 GHz bands.

52 Consisting of the 57-59 GHz, 76-77 GHz, and 77-81 GHz bands for licence-exempt fixed-links, road transport and traffic telematics (RTTT), and short-range automotive radars respectively.

53 Note that the 57-64 GHz and 59-66 GHz bands have been set aside for licence-exempt use in the USA and Japan respectively. This has resulted in international standardisation initiatives such as the evolving IEEE 802.15.3c specifications for millimetre-wave WPANs at 60 GHz.

The 102–105 GHz band is currently unused and is allocated by the Radio Regulations to fixed, mobile, and radio astronomy services.

Group-B: Spectrum currently used in the UK for light-licensed applications. This accounts for 12 GHz, consisting of the 64–66, 71–76, and 81–86 GHz bands, for point-to-point fixed links.

Group-C: Spectrum allocated by the Radio Regulations to fixed or mobile usage, as well as various broadcast/fixed/mobile/radio-navigation satellite services. This accounts for around 15 GHz of currently unused (or lightly used) spectrum.

The unused 66–71 GHz band is of particular interest in this category, due to its proximity to the 59–66 GHz band in Group-A.

Given the estimated upper limit of 30 GHz of bandwidth required for new applications over the next 15 years, one may conclude that the Group-A and Group-B bands identified above are broadly sufficient to satisfy much of the projected future demand for spectrum by licence-exempt and light-licensed devices in the 40–105 GHz range.

Any additional demand could be satisfied through licence-exempt or light-licensed usage of the Group-C bands (particularly 66–71 GHz) that are also assigned by the Radio Regulations for various satellite services. Although co-existence with satellite services may well be feasible, we do not consider this option to be strictly necessary, since as shown in Section 6.2, ample spectrum is available beyond 105 GHz for licence-exempt and light-licensed applications.

6.3.2 Conclusions and recommendations

Based on the above arguments, we make the following recommendations with regards to the 40–105 GHz frequency range.

1) It is recommended that the 59–64 GHz band (managed jointly by the MoD and Ofcom), and the 102–105 GHz band (currently unused) be considered for use by licence-exempt devices.

2) It is recommended that licence-exempt or light-licensed use of Group-C bands (allocated to various satellite services) be delayed until such time as there is clear evidence of the economic benefits of pursuing such option.

Licence-exempt use of the 59–64 GHz band would be in line with similar authorisations in the US and Japan, and international standardisation activities for use of this spectrum for millimetre-wave wireless personal area networks.

We do, however, note that the MoD is responsible for the management of both mobile and radiolocation services in the 59–64 GHz band. Consequently, any authorisations of licence-exempt spectrum use in this band would only be made subject to approval by the MoD.

Licence-exempt use of the 102–105 GHz band would be in line with our recommendations for spectrum above 105 GHz.

Finally, we emphasize that any future authorisations of licence-exempt use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

Section 7

Licence-exemption of low-power transmitters

7.1 Introduction

We are obliged to exempt from licensing all devices that do not cause harmful interference. To date, devices have been exempted from licensing subject to certain limits on transmission parameters, defined in such a way so as to minimize the probability of interference to other occupiers of the frequency band.

The question addressed here is whether it is appropriate or possible to define a transmission power limit below which the resulting interference can be considered as harmless, and consequently the transmitting devices can be automatically exempted from licensing[54].

This question is closely related to the imminent emergence of ultra-wideband (UWB) technologies. A UWB device transmits signals over wide bandwidths at low power spectral densities, thereby reducing the probability of harmful interference toward other co-channel, comparatively narrowband, occupiers of spectrum. The wide bandwidth of the transmissions is also exploited at a UWB receiver in order to mitigate the impact of co-channel interference from other occupiers of spectrum.

In 2002, UWB achieved initial approval in the United States for licence-exempt communication devices, with the Federal Communications Commission (FCC) specifying upper limits on the amount of power that can be radiated across 3.1 to 10.6 GHz. Similarly, the harmonised introduction into the EU of UWB technology is subject to the recent European Commission Decision 2007/131/EC[55]. While UWB has not been approved internationally, relevant harmonised regulations are being drafted in various regions worldwide.

Should UWB devices become widespread, their transmission power limits could set a de-facto lower bound for the licensing of all radio devices. In this section we consider the implications of UWB in this regard, describe how generic radiation lower bounds for licensing can be defined across all frequencies, and understand the resulting impact on spectrum usage by incumbent services.

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[54] An existing example of this is the Wireless Telegraphy (Testing and Development Under Suppressed Radiation Conditions) (Exemption) Regulations 1989. These Regulations provide for the exemption from the provisions of section 1(1) of the Wireless Telegraphy Act 1949 of stations or apparatus for wireless telegraphy operated under suppressed radiation conditions on specified frequencies for testing or development purposes (which are defined to include the modifying, servicing or repairing of such stations or apparatus and scientific research, training, instruction or experimentation in radio theory or practice). Accordingly, it is not necessary to hold a licence to establish, install and use such stations or apparatus. These regulations extend up to 960 MHz.
See: http://www.opsi.gov.uk/si/si1989/Uksi_19891842_en_1.htm.

[55] Commission of the European Communities, "Decision on allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonised manner in the Community," 2007/131/EC, 21 February 2007.
See: http://ec.europa.eu/information_society/policy/radio_spectrum/ref_documents/index_en.htm.

7.2 Ultra-wideband (UWB)

The EC Decision 2007/131/EC defines equipment using UWB technology as:

> *"… equipment incorporating, as an integral part or as an accessory, technology for short-range radiocommunication, involving the intentional generation and transmission of radio-frequency energy that spreads over a frequency range wider than 50 MHz, which may overlap several frequency bands allocated to radiocommunication services;".*

The devices permitted under this Decision are exempt from individual licensing and operate on a non-interference, non-protected basis, with EIRP spectral density requirements as specified in Table 4.

Note that UWB equipment is expected to operate in the 4.2 to 4.8 GHz band on an interim basis, and above 6 GHz in the long term. Also note that the rather low power levels for frequencies beyond 10.6 GHz are defined in order to protect passive services (such as radio astronomy and earth exploration satellites) operating in the 10.6-10.7 band[56].

Frequency range (GHz)	Maximum mean EIRP density (dBm/MHz)	Maximum peak EIRP density (dBm/50MHz)
< 1.6	–90	–50
1.6 to 3.4	–85	–45
3.4 to 3.8	–85[57]	–45
3.8 to 4.2	–70	–30
4.2 to 4.8	–70[58]	–30[59]
4.8 to 6	–70	–30
6 to 8.5	–41.3	–0
8.5 to 10.6	–65	–25
> 10.6	–85	–45

Table 4. UWB equivalent isotropic radiated power (EIRP) requirements.

The limits on mean EIRP spectral density for UWB devices are presented in Figure 7, along with similar specifications for a selection of non-UWB (i.e. of bandwidth less than 50 MHz) licence-exempt short-range devices in the UK[60]. The latter data applies to devices used for applications such as telemetry, medical-biological, wideband data transmission, alarms, RFID, radio microphones, hearing aids, wireless audio, and wireless video cameras.

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[56] The bands 10.60-10.68 GHz and 10.68-10.7 GHz are protected by Footnotes 5.149 and 5.340 of the Radio Regulations respectively. The former urges administrations to take all practicable steps to protect the radio astronomy service from harmful interference, while the latter prohibits all emissions.

[57] A maximum mean EIRP density of –41.3 dBm/MHz is allowed in the 3.4 to 4.8 GHz bands provided that a low duty cycle restriction is applied in which the sum of all transmitted signals is less than 5% of the time each second and less than 0.5% of the time each hour, and provided that each transmitted signal does not exceed 5 milliseconds.

[58] A limit of –41.3 dBm/Hz is allowed until 31 December 2010.

[59] A limit of 0 dBm/50MHz is allowed until 31 December 2010.

[60] "UK radio interface requirement 2030: Licence-exempt short range devices," Ofcom, November 2006. See: http://www.ofcom.org.uk/radiocomms/isu/licence_exempt/requirements/.

Figure 7 clearly indicates that non-UWB short-range devices transmit at power spectral densities which are at least two orders of magnitude (20 dB), and typically eight to twelve orders of magnitude (80-120 dB) above the UWB specifications. This illustrates the extent to which the operation of UWB devices is limited to extremely short ranges, which in turn allows such devices to operate as an underlay with a low probability of causing harmful interference towards incumbent services.

It is also logical to conclude that any non-UWB device (i.e. of bandwidth less than 50 MHz) that transmits at a power spectral density which is not greater than the UWB limits, and that also complies with all UWB operational constraints, would cause no greater interference than a UWB device. Consequently, any such device, irrespective of its transmission bandwidth, would clearly be a candidate for licence-exemption.

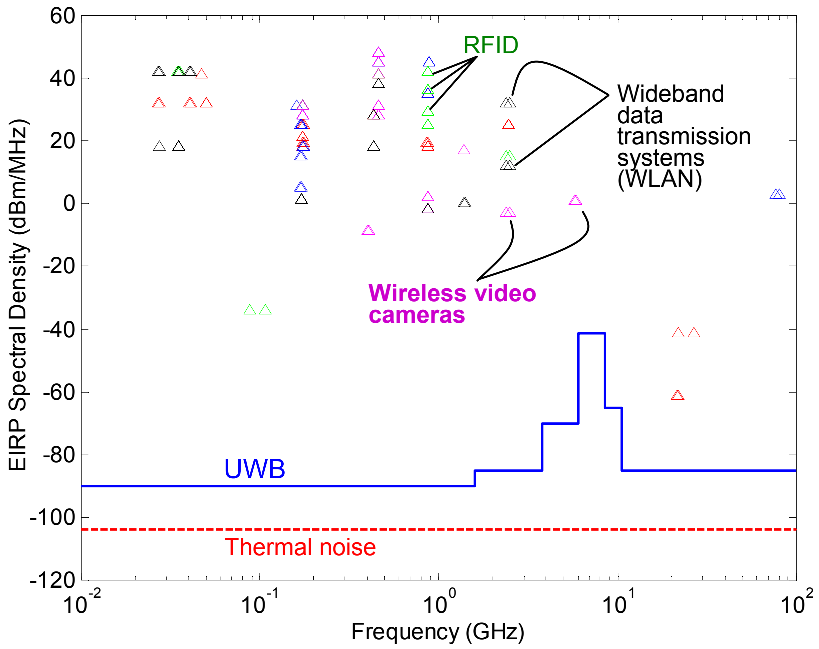

Figure 7. Mean EIRP spectral density limits for UWB devices, and a selection of non-UWB short-range devices.

It is interesting to note that a communication device which transmits at a power spectral density lower than the UWB limits is, by necessity, likely to be associated with a wide bandwidth. This is due to the fact that for communication distances beyond fractions of a metre, the signal power spectral density at the receiver is likely to be close (if not below) the power spectral density of ambient noise. Information theory indicates that under such circumstances bandwidth expansion, and the resulting processing gain (i.e. ratio of bandwidth to data rate), is essential for avoiding severe degradations in throughput.

7.3 Transmission masks and interference aggregation

Generic power spectral density lower bounds for the licensing of radio devices may be readily computed by evaluating the aggregation of interference generated by multiple transmitting devices, and assessing its impact on the performance of co-channel incumbent radio receivers. If transmission limits are defined such that the resulting interference is at an acceptable level, the transmitting devices may be exempted from licensing.

The definition of "acceptable" interference is of course debatable, and is dependent on the nature of the incumbent radio services. Nevertheless, it is possible to define transmission limits based on an application- and technology-neutral definition of acceptable interference. Such limits could then be relaxed for special cases of coexistence. An example of the above approach is presented next.

Here, upper limits on mean EIRP spectral density are derived subject to the constraint that the resulting aggregate interference power spectral density generated by a multitude of devices only exceeds 5% of the ambient noise power spectral density with a probability of 0.1% (see Annex 3). The limits are computed via Monte-Carlo simulations for different device densities, transmitter activity factors, and minimum distances of transmitters from the victim receiver. Devices are assumed uniformly distributed in an area of 1256 square metres. Ambient noise is computed based on thermal noise and a receiver noise figure of 10 dB. Radio propagation is modelled based on path-loss (exponent of 3.5 for distances beyond five metres) and log-normal shadowing (standard deviation of 3 to 4 dB). Omni-directional antennas are assumed. The results are depicted in Figure 8 along with the UWB limits on mean EIRP spectral density.

The positive gradients (20 dB per decade) of the limits on EIRP spectral density account for the deterioration in free-space radio propagation link-budget with the square of frequency for a specific receiver antenna gain[61]. This implies that ever increasing EIRP spectral densities can be tolerated at higher frequencies, with incumbent receivers still only experiencing a fixed marginal degradation in their performance (equivalent to a 5% rise in the noise floor with a probability of 0.1% for the above example).

As can be seen, limits on EIRP spectral density can be relaxed, subject to a reduction in the allowed transmitter short-term activity factor. Further relaxation is possible via more intelligent polite protocols in the time and frequency domains, such as listen-before-talk or detect-and-avoid.

Note that the limits on transmission power computed above are conservative, in the sense that they are based on a somewhat strict definition of acceptable interference, and a generic aggregation scenario involving statistical models of path loss, shadowing, and interferer locations.

Higher limits could result if one explicitly accounted for the additional radio isolation which often exists between an interferer and victim receiver caused by geographic separation, or by severe attenuation (shadowing) at high frequencies due to obstacles such as walls. Furthermore, directional antennas are frequently used at frequencies above 3 GHz as a means of boosting the link-budget in the face of increasing path loss. The use of directional antennas, at the incumbent receiver or the interfering transmitter, can also help mitigate interference and further increase the limits on EIRP spectral density.

[61] Other frequency-dependent attenuation effects due to gaseous and water vapour absorption may be ignored over short distances.

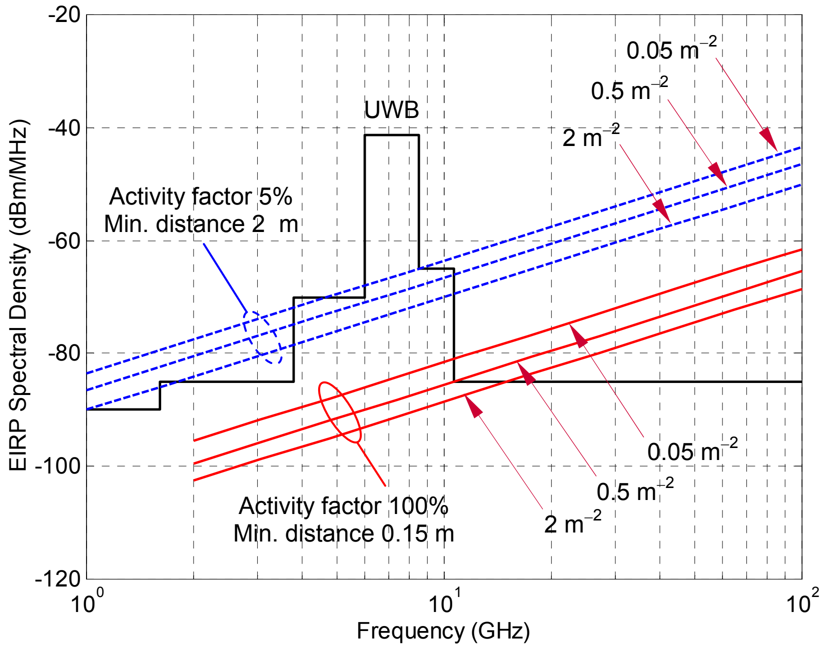

Figure 8. Limits on mean EIRP spectral density, subject to constraints on aggregate interference.

The potential to relax the transmission constraints as a function of frequency is indeed evident from the UWB limits for emissions in the 3.8–6 GHz and 8.5–10.6 GHz ranges, defined to allow co-existence with applications such as point-to-point fixed links. One may envisage the extension of these limits, based on a 20 dB per decade gradient, as a lower-bound for licensing at frequencies beyond 10.6 GHz. At frequencies below 10.6 GHz, the UWB mask itself would set the lower bound.

7.4 Conclusions and recommendations

It has been argued that the UWB limits on radiated power spectral density define a de-facto lower bound for the licensing of radio devices. In other words, a device that transmits below the UWB limits would generate less interference than a UWB device, and as such should be considered for exemption from licensing.

It has also been demonstrated that generic power spectral density lower bounds for the licensing of radio devices can be computed by defining constraints such that the transmissions do not cause harmful interference to incumbent services occupying the spectrum. Conservative examples of such bounds were presented based on a generic definition of acceptable interference and the fact that the free-space radio propagation link-budget deteriorates with the square of frequency for a specific receiver antenna gain. The latter effect implies that the bounds would generally allow greater radiated powers at higher frequencies.

Based on the above analysis, it is recommended that a generic power spectral density lower bound for the licensing of radio devices is considered by Ofcom which:

1) is equal to the UWB limits on power spectral density for frequencies below 10.6 GHz;

2) is equal to $-85 + 20\log(f_{\mathrm{GHz}}/10.6)$ dBm/MHz (mean EIRP density), or
$-45 + 20\log(f_{\mathrm{GHz}}/10.6)$ dBm/50MHz (peak EIRP density),

   for frequencies above 10.6 GHz which are subject to Footnote 5.340, or which support sensitive services such as radio astronomy and earth exploration satellites; and

3) is equal to $-65 + 20\log(f_{\mathrm{GHz}}/10.6)$ dBm/MHz (mean EIRP density), or
$-25 + 20\log(f_{\mathrm{GHz}}/10.6)$ dBm/50MHz (peak EIRP density),

   for all other frequencies above 10.6 GHz,

where f_{GHz} represents frequency in units of GHz. Transmissions at levels below the specified limits may be exempt from licensing, subject to compliance with all UWB operational restrictions[62] (other than minimum bandwidth) as specified in EC Decision 2007/131/EC. The proposed mean EIRP spectral density limits are illustrated in Figure 9 with labels corresponding to the above recommendations.

It should be emphasized that the masks proposed above 10.6 GHz serve as guidelines only. The limits eventually adopted would depend on the specific bands and the interference resilience of incumbent services, but would broadly allow greater radiation levels at higher frequencies.

Any future authorisations of licence-exempt use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

[62] Such operational restrictions include the requirement that an UWB device is either used indoors (and will cease transmission within 10 seconds unless it receives an acknowledgement from an associated receiver that its transmission is being received) or, if it is used outdoors, it is not attached to a fixed installation, a fixed infrastructure, a fixed outdoor antenna, or an automotive or railway vehicle.

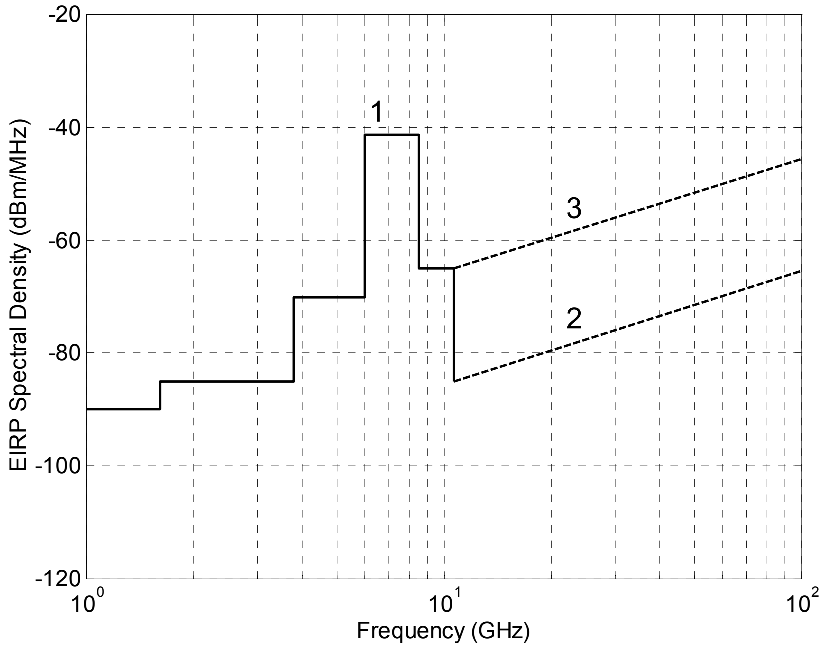

Figure 9. Proposed mean EIRP spectral density lower bounds for the licensing of radio devices.

Also note that the proposed limits would apply to the licence-exemption of both UWB and non-UWB devices, with the latter generating less interference due to their lower transmission bandwidths.

For the case of UWB devices (transmission bandwidths greater than 50 MHz) the proposed limits at frequencies above 10.6 GHz are greater than those specified in the EC Decision 2007/131/EC (see Table 4). As a result, Ofcom would envisage supporting any future EC initiatives to relax the technical requirements for UWB equipment for frequencies above 10.6 GHz.

For non-UWB devices (bandwidths less than or equal to 50 MHz), the proposed limits could apply except at frequencies (above or below 10.6 GHz) where EU law[63] requires exclusive use by certain applications.

[63] An example is the Council of the European Communities Directive 87/372/EEC of 25 June 1987 on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community.

Section 8

International positioning and harmonisation

8.1 Introduction

In the context of this document, harmonisation is to be understood as the common designation of frequency bands for specific uses by a number of countries and the designation of common minimum requirements to avoid harmful interference. It can be achieved by regulatory intervention or through market mechanisms and can be exclusive or non-exclusive.

As discussed below, harmonisation can be beneficial but also carries risks in that the spectrum can effectively be sterilised if the designated application fails to enter service or to succeed commercially. Failure to make best use of spectrum can impose substantial costs on consumers and on society.

In line with its views on spectrum management, Ofcom believes that harmonisation is in general better achieved through market mechanisms than by regulatory intervention.

However, as explained earlier, the application of market mechanisms to licence-exempt applications is problematic and it is necessary for the regulator to decide what spectrum should be allocated to licence-exempt use. For this reason, Ofcom accepts that decisions on harmonisation of spectrum for licence-exempt applications often cannot be left to market mechanisms and require regulatory intervention in the form of mandatory harmonisation. However, this should be done only where the harmonisation is judged to be beneficial overall taking account of the costs and risks[64]. This requires a proportionately rigorous and detailed impact assessment to be carried out before decisions are taken. Key questions to be considered by such an impact assessment include:

- Do the benefits of the proposed harmonisation exceed the likely costs?
- Is regulatory intervention necessary in order to secure benefits that would otherwise be lost?
- Will the costs and risks of regulatory intervention exceed the benefits?

The nature of much licence-exempt use makes it likely that harmonisation will be beneficial. This is because of a combination of the benefits for consumers arising from economies of scale in manufacturing equipment, the price-sensitivity of many licence-exempt products, and the convenience of being able to use equipment in many countries. Moreover, as a practical matter, it can be difficult to exclude licence-exempt devices from sale in one country if they may be legally sold and used in another. Nonetheless, each case needs to be considered on its merits and this requires an impact assessment to be produced.

64 This is more likely to be the case for a spectrum commons model, than for an application-specific model of spectrum use.

The issue of harmonisation for licence-exempt usage of spectrum is presented in this section, including a brief overview of the European harmonisation framework, and a discussion of the benefits and costs associated with harmonisation. The material in this section draws heavily from a recent study[65] commissioned by Ofcom.

8.2 European harmonisation framework

European harmonisation for licence-exempt usage of spectrum is carried out within the framework of the European Conference of Postal and Telecommunications Administrations (CEPT), but this has largely been by consensus. More recently, the European Commission has been taking an interest in this process and has become actively involved in cases where harmonisation can be seen to be in line with the Community's horizontal policy objectives such as the consolidation of the internal market and the creation of a competitive environment. Decisions on spectrum harmonisation in the EU historically took the form of directives but now tend to be taken by the Radio Spectrum Committee in accordance with the Radio Spectrum Decision 676/2002/EC of 7 March 2002; these are binding on EU member states. Such Decisions also take account of the Radio and Telecommunications Terminal Equipment (R&TTE) Directive 1995/5/EC[66], and this directive enables member states to devise "interface requirements"[67] which may be specified in licences or in exemption regulations. The Directive also supports single market objectives through free circulation of equipment complying with these interface requirements.

Most of the activity in the harmonisation of licence-exempt use has been in the area of short-range devices, where the CEPT's development of Recommendation 70-03 is seen by the industry and regulators to be a great success. The CEPT has also produced a report on short range devices (SRDs) harmonisation in response to a mandate from the European Commission[68]. This reaches a number of conclusions, including the following:

- In considering frequency bands for harmonisation, the relative economic and other benefits should be taken into account;
- In deciding whether individual or general authorisation will be more beneficial, there should be an economic assessment of alternative uses and consideration of congestion affecting similar bands or similar uses;
- The allocation of frequency bands should be based on the wider consideration of the European consumer and not on the narrow interests of individual manufacturers;
- Manufacturers, when developing new products, should seek to use the existing frequency bands identified for SRDs before requesting new allocations of valuable spectrum and requests for additional harmonised spectrum should be clearly justified.

Recommendation 70-03 sets out the general position on common spectrum allocations for short-range devices for countries within the CEPT. It is also intended that it can be used as a reference document by the CEPT member countries when preparing their national regulations in order to keep in line with the provisions of the R&TTE Directive. The

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65 "The economic value of licence-exempt spectrum," Final report, Indepen, Aegis, Ovum, December 2006. See: http://www.ofcom.org.uk/consult/condocs/lefr/.

66 For further information visit: http://www.ofcom.org.uk/radiocomms/ifi/tech/RTEE/rtte_faq/.

67 Interface requirements specify parameters such as operating frequencies, channel bandwidths, and limits on radiated power, and also identify the European Harmonised Standards against which devices may authorised for use in a band.

68 Report 5 in response to the EC Mandate to CEPT on "SRD Radio Spectrum Harmonisation" can be accessed at http://www.ero.dk/ by clicking on "CEPT Reports" under "Deliverables".

Commission has since issued two Mandates to the CEPT to see how harmonisation can be improved yet further, and has very recently issued two Decisions on harmonisation of the radio spectrum for use by short-range radio devices and by radio frequency identification devices (RFIDs in the UHF band).

Other recent examples of the Commission's activities in the licence-exempt space include Decisions on the harmonised introduction of ultra-wideband equipment, harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment, on the harmonisation of the 24 GHz range radio spectrum band for time-limited use by automotive short-range radar equipment, and on the harmonised use of radio spectrum in the 5 GHz frequency band for the implementation of wireless access systems including radio local area networks (WAS/RLANs)[69].

8.3 Costs and benefits of harmonisation

Harmonisation for applications operating on a licence-exempt basis may bring the following benefits:

- The creation of a European-wide market for equipment and services, thereby reducing manufacturers' risks and allowing them to take advantage of scale economies. This includes reduction of equipment costs by limiting the number of frequency bands for which equipment must be manufactured.

- The promotion of competition between equipment suppliers and choice to consumers.

- The creation of the possibility for international roaming[70] (particularly important for certain applications).

- The reduction of the likelihood of harmful interference between services operating in different countries, particularly in border areas.

This last benefit is much weaker for licence-exempt applications than for licensed applications. Most licence-exempt devices operate at low power levels and therefore almost always operate over much shorter distances than licensed devices. So cross-border interference issues are less significant – especially for the UK which shares a land border only with the Republic of Ireland and where bilateral agreements offer the most efficient solution.

The above considerations indicate that the economic value of licence-exempt use of spectrum can be boosted by harmonisation:

- for products which are internationally mobile, and where the equipment must interoperate with infrastructure in various countries (e.g. Wi-Fi), or must operate reliably without receiving or generating interference as they move from country to country (e.g. car door openers);

- where there are significant economies of scale in production; and

- where demand for the application is price sensitive.

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[69] For further details of these Decisions visit: http://ec.europa.eu/information_society/policy/radio_spectrum/ref_documents/index_en.htm.

[70] This may also require standardisation for interoperability between consumer equipment and different networks.

There are also certain costs and risks associated with harmonisation. Harmonisation could:

- constrain the UK's ability to match supply and demand for spectrum to meet national conditions; and
- constrain the UK's ability to allow re-farming or trading of spectrum so that higher value uses can replace lower value uses.

Critically, if an inappropriate application or technology is selected, then harmonisation could result in bands being underused, or not used at all.

The above costs and risks will be greater if harmonisation designates a single application or technology, or restricts access to a narrow range of either. These costs and risks are reduced for licence-exempt spectrum commons where frequencies are shared across a number of applications and technologies (i.e. frequency is not allocated on an application- or technology-specific basis)[71]. This flexibility allows national variations in relative demand or the commercial failure of a particular licence-exempt application to be accommodated without introducing inefficiencies in spectrum use. For these reasons, the UK has been pursuing a policy of harmonisation on the basis of minimum regulation, and application and technology neutrality. These principles have been embedded in the CEPT's Report on SRDs.

Finally, harmonisation is often a slow process which limits the speed with which suppliers that require access to the harmonised spectrum can develop commercial devices. So harmonisation can:

- constrain the ability of UK firms to innovate rapidly in radio technology by selling innovative, interference-free devices in the home market soon after development and then exporting them into receptive markets elsewhere; and
- discourage UK entrepreneurship in license-exempt radio technology since harmonisation is a time consuming process that puts the entrepreneur at a real disadvantage.

8.4 Consequences for Ofcom

Ofcom should carefully develop its harmonisation strategies within the existing institutional frameworks that deal with harmonisation both at the European level (CEPT and EC) and at a global level (ITU). Given that the costs and benefits of harmonisation vary depending on the specific applications and frequency bands at stake, it is optimal to proceed on a case-by-case basis and to support each decision by a proportionately rigorous and in-depth impact assessment.

As new licence-exempt applications are enabled in portable devices, global harmonisation becomes increasingly important. In some cases Ofcom may have little choice but to implement decisions taken elsewhere in the world as harmonisation is impacted by market developments. If the rules fail to keep pace with market developments, licence-exempt devices are often used illegally, either intentionally or inadvertently. Such developments suggest that Ofcom should be proactive in anticipating and responding to developments outside the EU as well as within it, in making decisions about licence-exempt use of spectrum.

[71] See Section 4 for a discussion on application-specific spectrum and spectrum commons.

Another important issue is with regards to the impact of spectrum usage rights (SURs)[72] for licensed applications and the sharing of spectrum with licence-exempt devices. Licences in SUR form would restrict permissible emissions into frequency bands and geographic locations of neighbouring users. However, there would (as far as possible) be no restrictions on the technology and service deployed. This approach is intended to give licensees greater flexibility in spectrum use while providing adequate protection against harmful interference. In November 2006 Ofcom published a note announcing its intention to proceed with work to develop specific SURs[73].

At the same time, there are a growing number of licence-exempt applications seeking to share spectrum in licensed bands either as an underlay or an overlay to the incumbent licensed use – for example UWB in 3–10 GHz, Wi-Fi in 5GHz radar bands, and low-power FM radio transmitters in the FM radio band. Many of these applications will be harmonised on a European basis and it is intended that there be no increase in the risk of interference to the licensed user as a result of the sharing. However, in practice, certain proposals for underlays and overlays may involve an increased risk of interference that is sometimes justified with reference to the benefits from the licence-exempt use. Analysis of the likelihood of interference is typically undertaken with reference to an existing or imminent licensed use of the affected bands. Generally there is no regard for the possibility that the use of the band might change in future. This means that there is a risk that the permitted licence-exempt underlay/overlay could block future changes of licensed use. In particular changes involving a move from fixed to mobile use are likely to be problematic. Underlays and overlays could reduce the value of licensed bands and thereby inhibit trading activity.

To resolve this, if underlay technologies are to be permitted then any newly assigned frequency bands should have the underlay spectral mask (e.g. akin to the FCC's Part 15 mask) defined at the outset, so that those acquiring spectrum rights are clear about what they are buying. Such an approach is encapsulated in the indicative interference levels proposed for SURs.

This suggests that Ofcom should only support harmonisation initiatives aimed at increasing sharing between licence-exempt and licensed services if the associated technical conditions are such that it (and the affected licensees) are confident there will be no material risk of interference. It is important in doing this that Ofcom specifies any relevant underlay spectral mask.

8.5 Conclusions and recommendations

The issue of harmonisation for licence-exempt use of spectrum was addressed in this section. It was seen that, while harmonisation is associated with costs as well as benefits, licence-exempt use has characteristics that favour harmonisation and that often make regulatory intervention necessary to secure the benefits. However, each case needs to be considered on its merits.

[72] "Spectrum Usage Rights," A Consultation, Ofcom, 12 April 2006.
[73] See: http://www.ofcom.org.uk/consult/condocs/sur/next_steps2/.

Based on the arguments presented, we make the following recommendations:

1) Ofcom should develop its strategies for licence-exempt use within harmonisation frameworks both at the European level (CEPT and EU) and at a global level (ITU), proceeding on a case-by-case basis, and supporting each harmonisation decision by a proportionately rigorous and in-depth impact assessment. Ofcom should also support initiatives by the European Commission aimed at speeding up the harmonisation process where harmonisation is found to be beneficial.

2) Harmonisation should impose a minimum of restrictions and be as application-neutral and technology-neutral as possible.

Section 9

Investigation of interference in relation to licence-exempt devices

The use of radio spectrum by licence-exempt devices is invariably allowed on a *non-interference and non-protected* basis, meaning that no harmful interference may be caused to any radio communication service and that no claim may be made for protection of these devices against harmful interference originating from radio services.

Interference caused by licence-exempt devices toward other services is typically controlled through the use of polite protocols (such as listen-before-talk) and/or low transmission power signatures. Interference experienced by licence-exempt devices is typically mitigated through the use of technologies such as spread-spectrum and interference avoidance.

Although licence-exempt use of spectrum is authorised on a non-protected basis, regulatory instruments do exist for their protection against *illegal* transmissions. These are described next.

With certain exceptions, before radio apparatus can be placed on the market or put into service in the UK, they must comply with the provisions of the R&TTE Directive enacted in the UK by the Radio and Telecomunications Terminal Equipment Regulations 2000 SI 730 (as amended)(R&TTE Regulations).

As explained in Section 3.2, normally a licence is required to operate radio transmitting equipment in the UK, however there are provisions that provide for the licence-exempt use of particular categories of apparatus. In either case, all equipment must comply with certain specifications (as set out in the UK Interface Requirements and/or licence terms) and must be the subject of an R&TTE compliance process. It is a criminal offence to place non-compliant apparatus on the market or to bring them into service in the UK. It is the responsibility of the person who first manufactures or imports apparatus from outside the EU Member State to ensure that apparatus is compliant with the R&TTE Regulations before it is placed on the market.

Ofcom can and does take enforcement action against any party who has been found to have committed such offences. Enforcement action may take the form of a written warning, formal caution, prosecution, and seizure. The R&TTE Regulations provide for the service of a Notice of Suspension of Supply of Apparatus, provide for the searching of premises with and without a search warrant, and create an offence of obstructing an authorised officer in the execution of their duty. Ofcom investigators can also make test purchases of suspected non-compliant apparatus.

All enforcement action is decided on a case by case evaluation of the circumstances. Prosecution is normally reserved for the more serious offences, or where the accused appears to be intransigent.

Investigations into non-compliant apparatus are normally triggered by one of the following: complaints of interference, market surveillance as part of an EU Campaign, or market surveillance as part of an intelligence-led Ofcom project. Work is normally prioritised according to public safety, interference, unfair competition and consumer protection.

In summary, there is a framework in place for the protection of licence-exempt equipment from interference caused by licensed or licence-exempt transmitters that are non-compliant with the UK Interface Requirements or the R&TTE Regulations.

It is not envisaged that any additional regulatory instruments would be required for the protection of licence-exempt equipment. Harmonised technical standards are expected to be sufficent for mitigating the impact of interference caused by compliant radio transmitters, particulary at high frequencies where radio propagation conditions and the abundance of bandwidth imply a low probability of congestion.

Finally, one might anticipate the case of certain licence-exempt devices, such as health monitors, where interference could have serious safety implications. One might conclude that the only way to guarantee a minimum quality of service for such devices would be to provide them with their own exclusive spectrum (or at least to severely restrict other types of application in the band). However, application-specific allocation of spectrum could also reduce the economic value of the band (see Section 4). It therefore needs to be clear that such applications will generate more economic value than a mix of many more applications operating in the presence of greater interference. Hence, before a new device that was critically susceptible to interference was placed on the market, an impact assessment would need to be performed as to whether it should have access to its own exclusive spectrum (or be protected in some other manner), and the implications clearly discussed with the relevant manufacturers and operators. Those manufacturers and operators that choose to use existing bands without discussions with the regulator do so at their own risk.

It should also be emphasized that, where licence-exempt devices are owned and operated by individual citizens and consumers, then the security of any information transmitted over the licence-exempt wireless connections, and their adequate protection against eavesdropping, is the responsibility of the end user.

Section 10

Ofcom's approach for licence-exempt use of spectrum

Ofcom has a duty to maximise the efficient use of the radio spectrum. Part of achieving this duty is the appropriate management of licence-exempt usage. Based on the discussions in this document, and subject to consultation, we will do this by:

- providing spectrum for licence-exempt use where it will enhance the efficiency of spectrum use, and where possible, based on a spectrum commons model where the spectrum can be used by as wide a range as possible of applications, subject to regulator-defined constraints on radiated power characteristics, and polite protocols defined by appropriate technology standardisation bodies or individual equipment manufacturers;

- supporting the licence-exempt usage of unused high-frequency bands, especially those above 100 GHz, where the supply of spectrum far exceeds demand; and

- supporting the exemption from licensing of all low-power transmissions below the UWB limits (with a relaxation of those limits at frequencies above 10.6 GHz).

We believe that light-licensing and licence-exemption serve different purposes in the short term, but will converge over the long term through advances in sensing and autonomous self-deployment technologies.

We believe that as a regulatory intervention is required to set aside a band for licence-exempt applications, then it will often be appropriate to extend this regulatory intervention to consider harmonisation. We believe harmonisation to be particularly valuable in the case where licence-exempt devices are internationally mobile, where there are significant economies of scale in production, and where demand for the application is price sensitive.

Ofcom will develop its strategies within harmonisation frameworks both at the European level (CEPT and EU) and at a global level (ITU), proceeding on a case-by-case basis, and supporting each harmonisation decision by an impact assessment. Ofcom will also support initiatives by the European Commission aimed at speeding up the harmonisation processes where such harmonisation is judged to be beneficial.

We do not believe that additional regulatory instruments are required for the protection of licence-exempt equipment. Harmonised technical standards are expected to be sufficent for mitigating the impact of interference caused by compliant radio transmitters. Those who deploy licence-exempt devices for safety-critical applications without prior discussion with the regulator, do so at their own risk.

Next Steps

In order to progress the implementation of our approach for licence-exempt use of spectrum, we expect to publish more detailed consultations on some of the specific issues addressed in this document. The expected areas of consultation and their approximate timelines include:

- How flexible politeness rules for licence-exempt use might be defined and enforced in practice (2008).
- Wide-scale release of spectrum above 275 GHz for licence-exempt use subject to appropriate politeness rules (2008).
- Release of the 102-105 GHz band for licence-exempt use subject to appropriate politeness rules (2008-2009).
- Phased release of the 105-275 GHz band for licence-exempt use (2008-2012).
- Limits on EIRP spectral densities for licence-exemption of low-power transmitters (2008-2009).

Furthermore, there are a number of initiatives at the European level addressing issues related to the licence-exempt use of the radio spectrum. Examples include the activities of the CEPT SRD Maintenance Group in investigating the possibility of developing limits below which ultra-low-power SRDs could exist without being subject to the usual regulatory arrangements, or the undertakings of the newly formed RSPG Working Group on the collective use of the spectrum. Ofcom will support initiatives such as these through input documents and further studies.

Annex 1

Impact assessment

A1.1 Introduction

The analysis presented in this annex represents an impact assessment, as defined in Section 7 of the Communications Act 2003 (the Act).

Impact assessments provide a valuable way of assessing different options for regulation and showing why the preferred option was chosen. They form part of best practice policy-making. This is reflected in Section 7 of the Act, which requires that we generally should perform impact assessments where our proposals would be likely to have a significant effect on businesses or the general public, or when there is a major change in Ofcom's activities. However, as a matter of policy Ofcom is committed to carrying out and publishing impact assessments in relation to the great majority of our policy decisions. For further information about our approach to impact assessments, see the guidelines "Better policy-making: Ofcom's approach to impact assessment", which are on our website: http://www.ofcom.org.uk/consult/policy_making/guidelines.pdf.

A1.2 The citizen and/or consumer interests

In relation to spectrum, the citizen and consumer interests are optimised by any step that helps create an environment in which spectrum is efficiently used and generates maximum economic value. Ofcom is serving the interests of citizens and consumers when it develops guidance on how it intends to manage the licence-exempt uses of spectrum. Indeed while doing so Ofcom seeks to ensure the efficient management and use of the spectrum assigned for licence-exemption, in a way that generates the greatest benefits.

In particular Ofcom pays special attention to ensuring that, as far as can be ascertained, no undue (harmful) interference emerges, and that as few product or technology restrictions as possible are imposed.

This would promote innovation and stimulate competition in the provision of new radio communication services, while protecting the interests of existing and future users of spectrum, including those of the citizen/consumer.

Furthermore, Ofcom's careful support of harmonisation efforts should enable the consumers and citizens to reap the benefits of lower equipment prices, lower cross-border interference, and hurdle-free international mobility.

A1.3 Ofcom's policy objective

Ofcom's aim in providing the Licence-Exemption Framework Review (LEFR) is to further fulfil its duties and obligations with regards to the management of spectrum. Specifically, Ofcom wishes to optimise the licence-exempt use of the spectrum and to encourage the emergence of innovative services.

We will pursue this goal through:

a) the provision of spectrum for licence-exempt use as needed, and where possible, based on a spectrum commons model;

b) the support of licence-exempt usage of unused bands above 105 GHz; and

c) the support of exemption from licensing of low-power transmissions.

The LEFR supplements the Spectrum Framework Review (SFR), which left for further study a number of specific issues concerning the management of spectrum used by licence-exempt devices. The objective of the LEFR is to provide an overall approach for future licence-exempt authorisations, which is to be consulted as questions surrounding licence-exemption arise and whose goal is to further enhance the efficiency of use and the value of the radio spectrum.

This framework presents broad proposals with regards to the licence-exempt use of certain segments of the radio spectrum. Any future authorisations of licence-exempt use by Ofcom will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

Ofcom hopes that this framework will become an important guide for dealing with future issues relating to licence-exempt uses of spectrum, in a way that provides reasonable clarity to all stakeholders and spectrum users as to what Ofcom seeks to achieve and how it intends to do so.

Impact analyses for our recommendations with regards to the above policies are presented in this section.

A1.4 Application-specific spectrum vs. spectrum commons

Application-specific spectrum refers to a portion of the frequency spectrum reserved exclusively for use by a specific wireless application. Conversely, spectrum commons is defined as a portion of the spectrum where multiple wireless applications can operate on a co-channel basis, subject to regulator-defined politeness rules, and authorised politeness protocols defined by standardisation bodies.

Options and risks

The following options are considered:

> **Option 1** – Ofcom does not indicate any preference for the application-specific or spectrum commons models for the licence-exempt use of spectrum. It assesses for each individual application which approach fits best.
>
> **Option 2** – Ofcom relies on the application-specific model to manage licence-exempt use of spectrum.
>
> **Option 3** – Ofcom relies on the spectrum commons model to manage licence-exempt use of spectrum. The application-specific approach is adopted only where technical constraints, international obligations, or safety issues require this.

Ofcom believes that Option 2 results in an inefficient utilisation of the spectrum. Application-specific authorisations primarily exist due to the requirements of legacy technologies which, due to a lack of adequate mitigation capabilities, are intolerant of even moderate levels of interference. Furthermore, application-specific authorisations result in a fragmentation of the spectrum, which is not subject to corrections by market forces.

Ofcom is of the view that Option 1 does not provide sufficient certainty to spectrum users and spectrum equipment manufacturers about the regime they can expect to see imposed.

This is likely to generate defensive and risk-averse strategies to mitigate the uncertainty. In addition, Ofcom fears that Option 1 may encourage parties to spend more time and effort than necessary to influence the selection of the approach that best suits the parties' interests.

Ofcom prefers Option 3 as it would result in a liberalisation of spectrum for licence-exempt uses. Furthermore, with the emergence of robust interference mitigation technologies, and their early incorporation into technical standards at the specification stage, future licence-exempt devices are capable of tolerating far greater levels of interference.

There are, however, risks associated with the adoption of the spectrum commons model. Despite advances in interference mitigation technologies, there are limits to their capabilities when faced with a diverse range of licence-exempt uses corresponding to highly different transmission parameters (e.g. radiated powers).

In order to avoid interference risks among wildly diverse applications, Ofcom proposes the adoption of multiple classes of spectrum commons, within each of which applications are constrained to have broadly similar characteristics. This would be enforced through regulator-defined politeness rules, specifying limits on parameters such as maximum radiated power.

A detailed analysis of the spectrum commons model is presented in Section 4 of this document.

Impact on stakeholders and competition

There is no impact on current licence-exempt users of spectrum because Ofcom does not propose the imminent retrospective application of the spectrum commons model to existing licence-exempt allocations. Indeed, this would in many cases result in harmful interference towards legacy technologies. Such retrospective application could, however, be envisaged in the future where spectrum re-farming is considered as a result of a favourable impact assessment.

The spectrum commons model is Ofcom's preferred strategy for future authorisations of licence-exempt usage of unused spectrum. Since the spectrum commons approach is expected to result in the liberalisation of spectrum for licence-exempt use, it should be easier for diverse applications to emerge and for the set of applications active in a band to change over time without Ofcom's intervention. This is expected to encourage the emergence of innovative services and hence to stimulate competition.

A1.5 Licence-exemption above 105 GHz

The radio spectrum above 105 GHz remains mostly unused due to constraints in transceiver technologies and radio-wave propagation. Future uses of this spectrum can be categorised as either short-range links for consumer devices, or medium-range point-to-point fixed links, with each category expected to require between 10 to 15 GHz of spectrum. Such demand is unlikely to result in congestion, and as such, licensing is an unnecessary burden. There are however, a large number of options with respect to the choice of frequency bands for licence-exempt and light-licensed use in the spectrum above 105 GHz.

Options and risks

The following options are considered:

Option 1 – Do not release any spectrum above 105 GHz for either licence-exempt or light-licensed use until such time as there is clear evidence of demand for such use.

Option 2 – Release all spectrum above 105 GHz for licence-exempt use.

Option 3 – Exclude from consideration all frequencies which are assigned to sensitive services, and release the remaining spectrum partly for licence-exempt use and partly for light-licensed use.

Ofcom believes Option 1 to be an over-cautious approach, with the risk of delaying the emergence of new applications and slowing the pace of innovation in this space.

Ofcom notes that Option 2 follows logically from the fact that interference among licence-exempt devices is highly unlikely above 105 GHz. However, it is of the view that this option is also associated with the risk that licence-exempt devices may generate harmful interference toward other future users of these frequencies, including sensitive services such as radio astronomy, earth exploration satellites, and space research. Ofcom does not prefer this option.

Ofcom prefers Option 3, as it mitigates the risks associated with Option 2 by tailoring the proposed licensing regimes in accordance with the spectrum allocations for future services above 105 GHz. In doing so, it balances the need to minimise the possibility of undue interference caused by licence-exempt devices toward other potential future users, with the desire to maximise the opportunity for innovation. It achieves this in three ways:

- It excludes from consideration all frequencies above 105 GHz which are assigned by the Radio Regulations for primary use by amateur and amateur satellite services, or those which are assigned exclusively for passive services such as earth exploration satellites, radio astronomy, space research and spectrum line measurements.

- It proposes light-licensing over 40 GHz of the remaining frequencies which are assigned by the ITU-R Radio Regulations to a diverse range of passive and active services. Although the list does not include fixed services, these could be authorised to operate within the identified bands through light-licensing in the UK. Any risks of harmful interference, both within the UK and across borders, toward future passive and active services would be mitigated through the control mechanisms afforded by light-licensing.

- It proposes licence-exemption over the remaining 94 GHz of spectrum below 275 GHz which are assigned by the Radio Regulations for mobile and fixed services, in addition to a range of other services. It also proposes licence exemption for all remaining frequencies above 275 GHz.

Further details on this preferred option are presented in Section 6 of this document.

Impact on stakeholders and competition

There is no impact on current users of spectrum as the addressed spectrum is mainly unused. The risk of interference toward future services within the spectrum is minimised by a judicious choice of frequencies for licence-exempt use.

It is expected that the availability of spectrum above 105 GHz for licence-exempt devices would promote competition among equipment manufacturers, and provide significant choice to UK consumers in terms of innovative short range applications.

A1.6 Emission power limits for licence-exemption

Ultra-wideband (UWB) devices, as characterised by high-bandwidth transmissions at power spectral densities below specific limits, are exempt from licensing and may operate on a non-interference, non-protected basis. It is logical to conclude that any device that transmits at a power spectral density which is lower than the UWB limits would at worst cause as much interference as a UWB device. It follows that any such transmitter would also be a likely candidate for licence-exemption.

We further note that, the path-loss experienced by radio waves grows as a function of frequency. This implies that a high-frequency high-power transmitter can contribute the same amount to a co-channel victim receiver's interference floor as a low-frequency low-power transmitter. Based on the above argument, we believe that the UWB limits on radiated power spectral density can be relaxed at frequencies beyond 10.6 GHz, with the implication that any transmitter radiating below the increased limits should be considered for exemption from licensing.

Options and risks

The following options are considered for defining the emission power limits below which all transmissions should be considered for licence-exemption:

Option 1 – Use the UWB limits for all frequencies.

Option 2 – Use the UWB limits for all frequencies below 10.6 GHz, but define relaxed versions of the UWB limits for frequencies above 10.6 GHz in order to account for poorer radio propagation at higher frequencies.

Ofcom is of the view that Option 1 is over-cautious, in that the UWB limits specify a constant emission limit for frequencies above 10.6 GHz. Given that the free-space radio propagation link-budget deteriorates with the square of frequency, such a limit implies far lower levels of received co-channel interference by incumbent users at higher frequencies than at lower frequencies.

Ofcom prefers Option 2 and believes that there is room for relaxation of the UWB limits for frequencies above 10.6 GHz. There are an infinite number of possibilities with respect to the choice of radiation power limits below which devices may be exempt from licensing above 10.6 GHz. The UWB emission masks themselves represent an obvious choice for the definition of such limits. Two sets of limits are of particular interest:

- The UWB limits for 8.5–10.6 GHz (or indeed 3.8–6 GHz). These are defined such that the resulting emissions do not cause harmful interference towards incumbent services, from short-range local-area and personal-area networks, to point-to-point fixed links.

- The UWB limits for 10.6 GHz and above. These are defined to avoid harmful interference toward sensitive passive services in the 10.6–10.7 GHz band.

Furthermore, one may note that the radio propagation link-budget deteriorates with the square of frequency for a specific receiver antenna gain. This means that a transmitter operating at a specific frequency can generate as much interference for a co-channel victim receiver, as a transmitter operating at half the frequency, and a quarter of the radiated power. This suggests that the two sets of UWB limits above can be relaxed as a function of frequency based on a square-law, thereby defining radiated power limits for licence-exemption of devices operating co-channel with active and passive services respectively.

Ofcom is aware that for both options it is possible that future applications will emerge which cannot operate economically in the presence of low-power licence-exempt devices. Ofcom believes that this is unlikely, and that the experience it will acquire by dealing with these issues for UWB at frequencies below 10.6 GHz will help assess the likelihood of this issue at frequencies above 10.6 GHz.

Further details on the proposed relaxed limits are presented in Section 7 of this document.

Impact on stakeholders and competition

There is minimal impact on users of spectrum, as the defined radiation limits are based on a conservative extrapolation of UWB emission limits as a function of frequency. These indeed correspond to very low radiation levels. For example, it can be readily shown that devices radiating –85 dBm/MHz at 10.6 GHz, and geographically distributed with a uniform density of 0.5 devices per squared metre, would result in a 5% increase in the ambient noise power spectral density with a probability of only 0.1% (see Annex 3).

It is expected that the possibility of licence-exempt (underlay) operation at very low power levels at frequencies above 10.6 GHz would promote competition among equipment manufacturers, and provide significant choice to UK consumers in terms of innovative short-range applications.

Annex 2

Spectral efficiency of the spectrum commons

A2.1 Introduction

As discussed in Section 4 of this document, one may broadly categorise spectrum allocation as either application-specific or spectrum commons. Application-specific spectrum refers to a portion of the frequency spectrum reserved exclusively for use by a specific wireless application. Spectrum commons, on the other hand, is defined as a portion of the spectrum wherein multiple wireless applications operate on a co-channel basis.

Naturally, the impact of inter-application interference is a clear differentiator of these two spectrum allocation strategies. It is the objective of this short study to perform a broad analysis of the conditions under which one strategy is superior to the other from the point of view of aggregate spectral efficiency. Such analysis can provide guidance for the regulator in deciding on the appropriate rules for the successful establishment of spectrum commons.

A2.2 Modelling

Consider M wireless applications, with *unconstrained utilities* $v_1 \cdots v_M$, and requiring bandwidths $W_1 \cdots W_M$ (in units of Hz) respectively for their operation.

The utility of an application is defined here as a measure of the benefit that it provides. This could be the economic value (in units of £) of the application, or perhaps the data rate (in units of bits per second) which it delivers. The unconstrained utility of an application is the benefit that it generates when there is no radio interference experienced from other applications. Depending on the spectrum allocation strategy, interference among applications can result in reduced or *constrained* utilities $v'_1 \cdots v'_M$.

Let us also define the *spectral efficiency* of the radio spectrum as the ratio of the aggregate utility derived from the various wireless applications, divided by the total bandwidth used. In what follows we derive and compare the spectral efficiencies associated with application-specific spectrum and spectrum commons respectively.

<u>Application-specific spectrum</u>

Envisage a scenario where each application is assigned an exclusive segment of the radio spectrum. This is depicted in Figure A2.1 for the case of $M = 2$ applications. Such an application-specific allocation implies that there is no mutual interference among the applications[74]. This, in turn, means that the utilities of the applications are not constrained. Hence, one may write the spectral efficiency as

[74] Out-of-band interference due to spectral leakage is ignored, as it is of secondary importance when compared to co-channel interference. Out-of-band interference is typically mitigated through appropriate guard bands and/or transceiver filtering technologies.

$$U_{\text{EXCLUSIVE}} = \frac{\sum_{i=1}^{M} v_i}{\sum_{i=1}^{M} W_i}. \qquad (1)$$

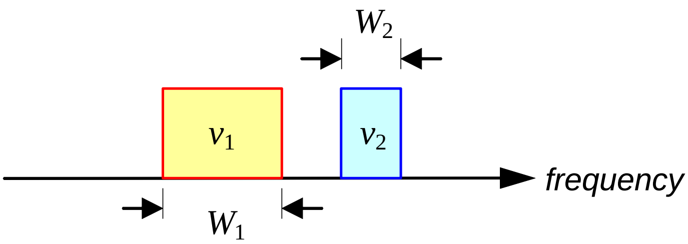

Figure A2.1. Application-specific allocation for M = 2 applications.

Spectrum commons

Now envisage a scenario where the applications operate in a co-channel manner within a spectrum commons, as illustrated in Figure A2.2 for the case of $M = 2$ applications. Spectrum commons implies mutual co-channel interference among the applications, which inevitably causes some reduction in the application utilities. Assume that the mutual interference results in reduced or constrained utilities, $v_i' = \lambda_i v_i \;\; i = 1 \ldots M$, for the individual applications, where $0 \le \lambda_i \le 1$. The parameter λ_i represents the fractional degradation in the utility of an application. One may then write the spectral efficiency as

$$U_{\text{COMMONS}} = \frac{\sum_{i=1}^{M} \lambda_i v_i}{\max_i W_i}. \qquad (2)$$

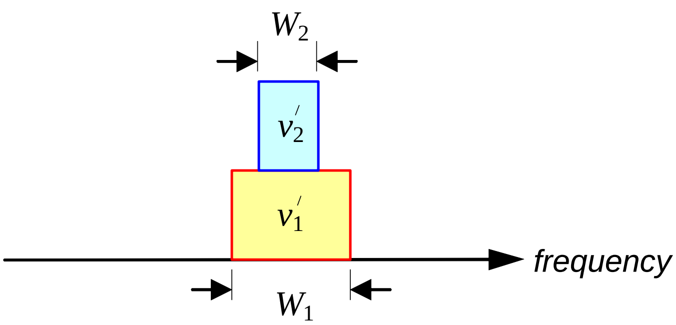

Figure A2.2. Spectrum commons for M = 2 applications.

A2.3 Comparison of spectral efficiencies

Given Equations (1) and (2), one may write the ratio, R, of the efficiency of spectrum commons over that of application-specific spectrum as

$$R=\frac{U_{\text{COMMONS}}}{U_{\text{EXCLUSIVE}}}=\frac{\sum_{i=1}^{M}W_i}{\max\limits_{i}\ W_i}\ \frac{\sum_{i=1}^{M}\lambda_i v_i}{\sum_{i=1}^{M}v_i}\ . \tag{3}$$

One may immediately see that

$$1\leq\frac{\sum_{i=1}^{M}W_i}{\max\limits_{i}\ W_i}\leq M\ , \tag{4}$$

where the maximum value M is achieved when all applications have the same bandwidths (i.e. when $W_i = W$ for $i = 1\cdots M$), and the minimum value of unity is achieved when all applications except one have zero bandwidth. The former scenario corresponds to a maximum saving in used spectrum. One may therefore conclude that the ratio of spectral efficiency in a spectrum commons, to that achievable via application-specific spectrum is maximised when the applications sharing the spectrum have similar bandwidths, resulting in maximum savings in utilised spectrum.

One can also observe that

$$\lambda_{\min}\leq\frac{\sum_{i=1}^{M}\lambda_i v_i}{\sum_{i=1}^{M}v_i}\leq\lambda_{\max}\ , \tag{5}$$

where $\lambda_{\min}$ and $\lambda_{\max}$ are the minimum and maximum values of λ_i respectively. It is clear that, irrespective of the individual unconstrained application utilities v_i, the above ratio is maximised if all applications suffer from the same minimal fractional degradation as represented by $\lambda_{\max}$ (i.e. when $\lambda_i = \lambda_{\max}$ for $i = 1\cdots M$). One may therefore broadly conclude that the ratio of spectral efficiency in a spectrum commons, to that achievable via application-specific spectrum is maximised when each application suffers from a similar minimal fractional degradation in utility as a result of inter-application interference.

Finally, from Equations (4) and (5) one may conclude that

$$R\leq M\lambda_{\max}\ , \tag{6}$$

and therefore that application-specific spectrum allocation is superior to spectrum commons if $R \leq 1$, or equivalently if $\lambda_{\max} \leq M^{-1}$.

A2.4 Numerical examples

A number of illustrative numerical examples are presented below for M = 2 applications.

Figures A2.3 to A2.5 show the ratio, R, of the spectral efficiency in a spectrum commons to that achievable via application-specific spectrum for different bandwidth ratios W_1/W_2, unconstrained utilities v_1 and v_2, and fractional degradations λ_1 and λ_2 in utility.

<u>Equal unconstrained utilities</u>

It can be readily shown from Equation (3) that, when the unconstrained utilities of the applications are equal, and when the applications have equal bandwidths, then R is equal to the sum of the fractional degradations, i.e.,

$$R = \sum_{i=1}^{M} \lambda_i \, .$$

On the other hand, when the unconstrained utilities of the applications are equal, but the bandwidth of one application is significantly greater than the others, then R approaches the sum of the fractional degradations divided by M, i.e.,

$$R \to \frac{1}{M} \sum_{i=1}^{M} \lambda_i \, .$$

These observations are illustrated in Figure A2.3. Note that R is maximized when the applications have similar bandwidths (i.e. $W_1 = W_2$) and suffer from similar degradations (i.e. $\lambda_1 = \lambda_2$).

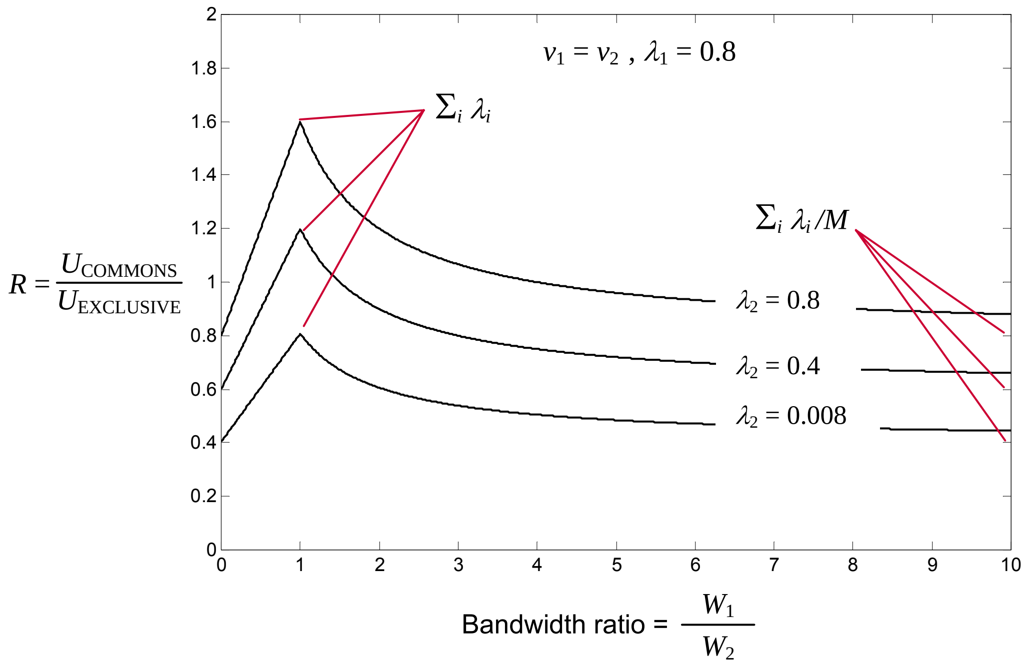

Figure A2.3. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (equal unconstrained utilities).

Highly different unconstrained utilities

Consider the case where the unconstrained utility of application n is significantly greater than that of the other applications.

Also assume that all applications suffer from the same fractional degradation in utility when operating in a spectrum commons, i.e. $\lambda_i = \lambda_n$ for $i = 1 \cdots M$. Then it readily follows from Equation (3) that, $R \rightarrow M\lambda_n$ when the applications have equal bandwidths, and $R \rightarrow \lambda_n$ when one of the bandwidths dominates.

Furthermore, R is insensitive to the fractional degradation in the utility of those applications which already have a low unconstrained utility. This is illustrated in Figure A2.4 for M = 2 applications, where the unconstrained utility of application 1 dominates (i.e. $v_1 >> v_2$) and the impact of increasing degradation in the utility of application 2 is not significant.

Conversely, R is highly sensitive to the fractional degradation in the utility of those applications which have a high unconstrained utility. This is illustrated in Figure A2.5 for M = 2 applications, where the unconstrained utility of application 2 dominates (i.e. $v_2 >> v_1$) and the impact of increasing degradation in the utility of application 1 is significant.

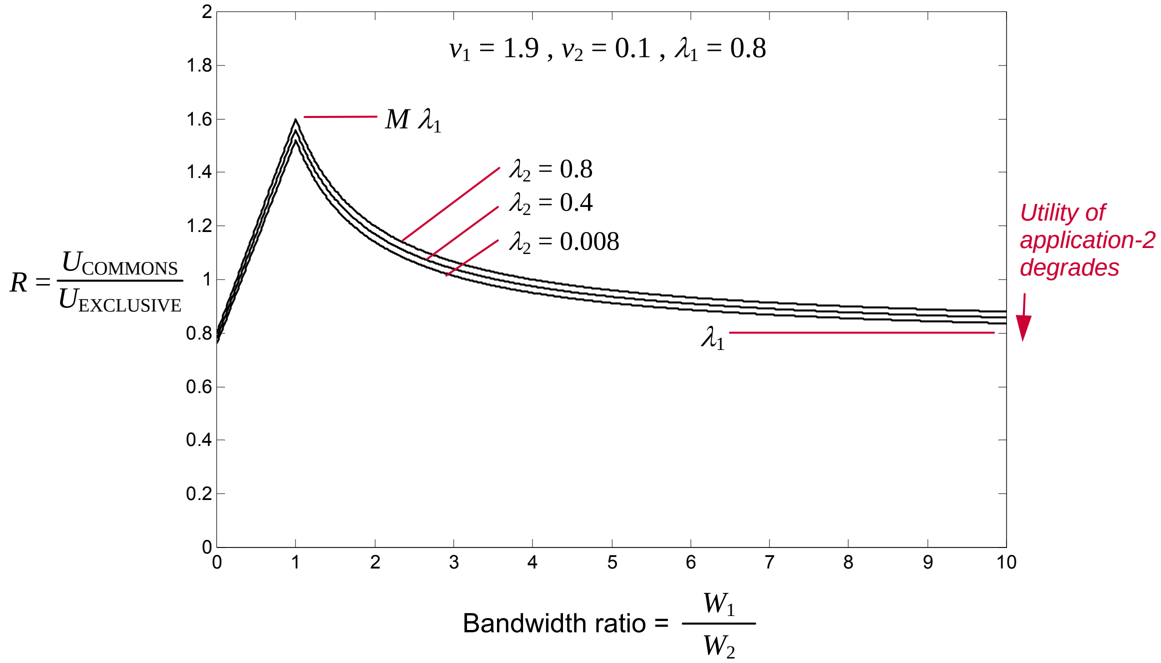

Figure A2.4. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (unequal unconstrained utilities).

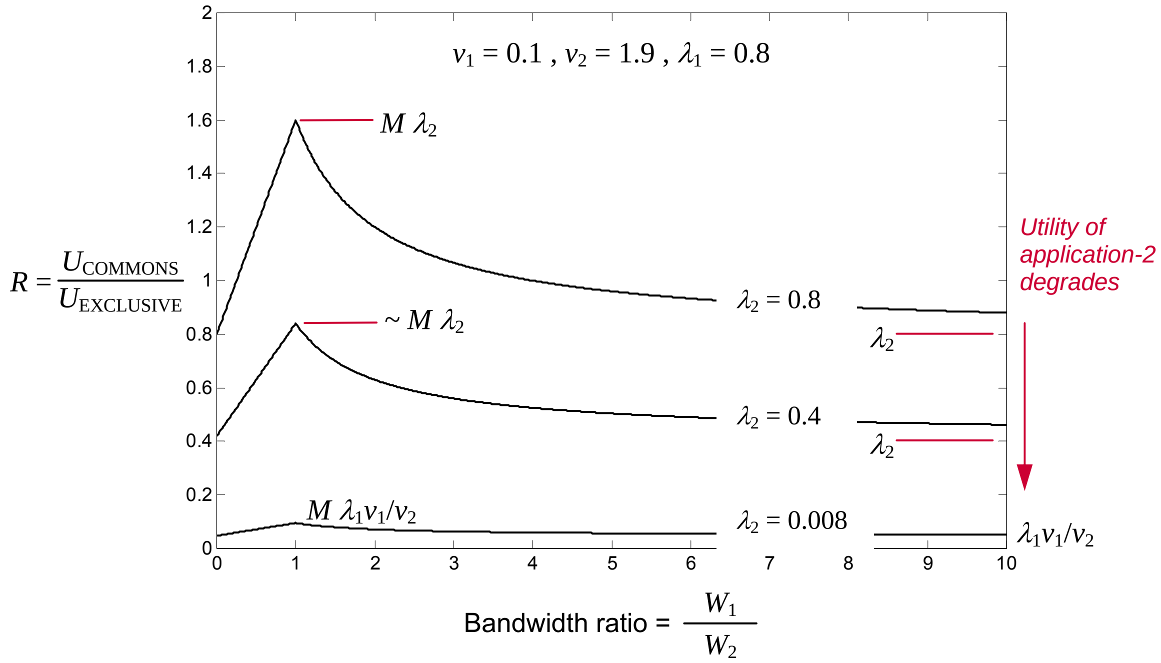

Figure A2.5. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (unequal unconstrained utilities).

A2.5 Impact of inter-application interference

In the previous sections we showed that the ratio, R, of the spectral efficiency in a spectrum commons to that achievable via application-specific spectrum is maximized when the M applications have similar bandwidths W, and their utility degrades equally from the effects of mutual interference by a fraction λ. In such circumstances it was shown that

$$R = \frac{U_{\text{COMMONS}}}{U_{\text{EXCLUSIVE}}} = M\lambda\,.$$

Of course, for spectrum commons to be the preferred spectrum allocation strategy, we require that $R \geq 1$, or equivalently that $\lambda \geq M^{-1}$.

In this section we identify the physical radio conditions under which the above equality holds. So far, we have been concerned with an abstract definition of an application's utility. Here we define an application's utility, v, to be directly proportional to its link information capacity, C, in units of bits per second. In this case, spectral efficiency, U, would have units of bits per second per Hz. Then using Shannon's capacity formula, one may write

$$R = \frac{U_{\text{COMMONS}}}{U_{\text{EXCLUSIVE}}} = M\lambda = M\frac{\lambda v}{v} = M\frac{C_{\text{COMMONS}}}{C_{\text{EXCLUSIVE}}} = M\frac{W\log_2(1+\text{SINR}_{\text{COMMONS}})}{W\log_2(1+\text{SINR}_{\text{EXCLUSIVE}})}, \qquad (7)$$

where SINR is the signal-to-noise-plus-interference ratio at the receiver.

One may write the SINR in an application-specific spectrum allocation regime as

$$\mathrm{SINR}_{\mathrm{EXCLUSIVE}} = \frac{P_{\mathrm{S}}}{P_{\mathrm{N+I}}}, \tag{8}$$

where P_{S} is the wanted signal power, and $P_{\mathrm{N+I}}$ is the sum of the noise power, P_{N}, and intra-application interference power, P_{I}, at the receiver. Note that in order to achieve reasonable spectrum efficiencies it is required that $\mathrm{SINR}_{\mathrm{EXCLUSIVE}} >> 1$, and subsequently that $P_{\mathrm{S}} >> P_{\mathrm{I}}$ and $P_{\mathrm{S}} >> P_{\mathrm{N}}$.

In a spectrum commons regime, with M–1 co-channel interfering applications of broadly similar characteristics, one may write

$$\mathrm{SINR}_{\mathrm{COMMONS}} = \frac{P_{\mathrm{S}}}{P_{\mathrm{N+I}} + \delta(M-1)(P_{\mathrm{S}} + P_{\mathrm{I}})} \approx \frac{P_{\mathrm{S}}}{P_{\mathrm{N+I}} + \delta(M-1)P_{\mathrm{S}}}, \tag{9}$$

where $0 < \delta < 1$ represents the degree of radio *coupling* between the applications, or the extent to which inter-application interference is attenuated (e.g. due to obstacles or geographical separation). Note that for simplicity (in order not to have to specify both SINR and SNR) we have assumed that $P_{\mathrm{S}} >> P_{\mathrm{I}}$.

Substituting (9) into (7), we have

$$R = \frac{U_{\mathrm{COMMONS}}}{U_{\mathrm{EXCLUSIVE}}} = M\lambda \approx \frac{M \log_2\left\{1 + \frac{P_{\mathrm{S}}}{P_{\mathrm{N+I}} + \delta(M-1)P_{\mathrm{S}}}\right\}}{\log_2(1 + \mathrm{SINR}_{\mathrm{EXCLUSIVE}})}. \tag{10}$$

Values of R as a function of inter-application coupling, δ, and for different numbers of applications, M, are depicted in Figure A2.6. One can observe that for inter-application coupling of less than around –5 dB, spectrum commons becomes the preferred option (i.e. $R \geq 1$). Furthermore, as the coupling between applications reduces to zero, the spectral efficiency of spectrum commons grows linearly with M. This is expected, since with the performance of the applications unaffected, the full benefits of the savings in spectrum use become apparent.

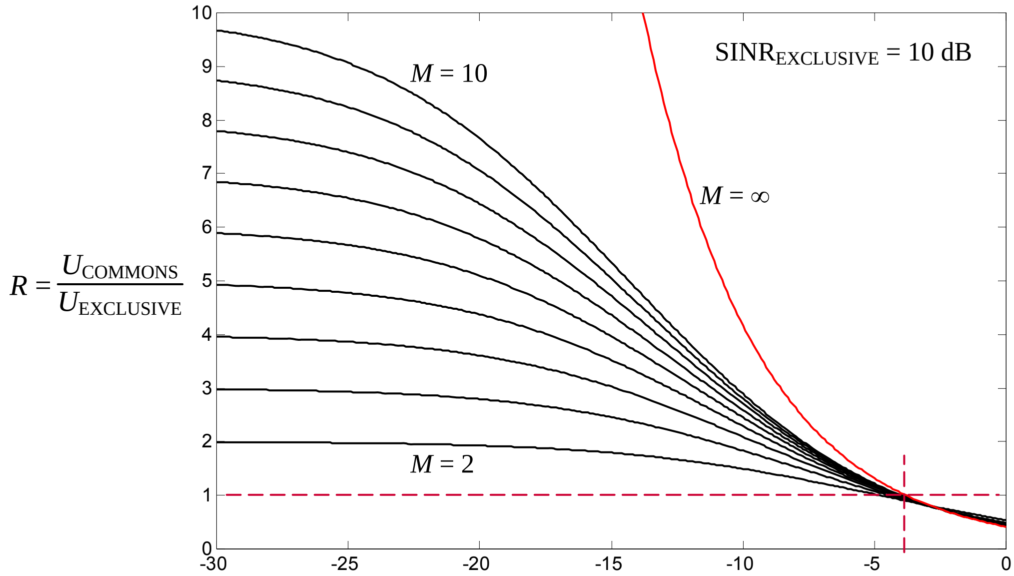

Figure A2.6. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of inter-application radio coupling.

As rough guide, one may state that[75] spectrum commons is the preferred option (i.e. $R \geq 1$) when

$$\delta < \frac{1}{\ln(1+\mathrm{SINR}_{\mathrm{EXCLUSIVE}})}.$$

A2.6 Conclusions

By developing simple models for the interaction among multiple applications in terms of their bandwidths and utilities, it was shown that the ratio of spectral efficiency in a spectrum commons to that achievable via application-specific spectrum is maximised when:

- the applications sharing the spectrum have similar bandwidths, resulting in maximum savings in utilised spectrum; and

75 This can be derived by computing the asymptotic behaviour of R as the number of applications, M, grows towards infinity. Indeed we have

$$\lim_{M\to\infty} M\log_2\left\{1+\frac{P_{\mathrm{S}}}{P_{\mathrm{N+I}}+\delta(M-1)P_{\mathrm{S}}}\right\} = \lim_{M\to\infty} M\log_2\left\{1+\frac{1}{\delta(M-1)}\right\}$$

$$= \lim_{M\to\infty}\frac{\frac{1}{\ln 2}\ln(1+\delta^{-1}M^{-1})}{M^{-1}} = \lim_{M\to\infty}\frac{\frac{1}{\ln 2}\frac{-\delta^{-1}M^{-2}}{(1+\delta^{-1}M^{-1})}}{-M^{-2}} = \frac{\delta^{-1}}{\ln 2}$$

in which case

$$\lim_{M\to\infty} R \approx \frac{\delta^{-1}}{\ln(1+\mathrm{SINR}_{\mathrm{EXCLUSIVE}})}.$$

- applications suffer from similar minimal fractional degradations in utility as a result of inter-application interference.

Interestingly, the above apply irrespectively of the relative unconstrained utilities of the individual applications.

Furthermore, by relating an application's utility to the information capacity of its radio links, it was shown that, as the attenuation of inter-application interference grows beyond a specific factor (defined by receiver target signal-to-interference-plus-noise ratios), then the spectrum commons model offers a spectral efficiency (i.e. bits/s/Hz) which is greater than that of an application-specific allocation by a factor equal to the number of sharing applications.

Annex 3

Aggregation of interference caused by low-power transmitters

A3.1 Introduction

As discussed in Section 7 of this document, one may specify generic transmission power spectral density lower bounds for the licensing of radio devices. Such bounds or limits may be computed by defining constraints such that the transmissions do not cause harmful interference to incumbent services occupying the spectrum. Transmissions at levels below the specified limits would be exempt from licensing.

The objective in this section is to evaluate the impact on the interference-floor, of a large number of devices transmitting in the vicinity of a victim receiver of an incumbent service. Such analysis can provide guidance for the specification of radiation limits of the type discussed above.

Generic limits on the devices' maximum radiated power spectral density (PSD) may be computed subject to the constraint that the resulting aggregate interference PSD. S_{I}, received by a victim receiver exceeds a fraction, δ, of the ambient noise PSD, S_{N}, with a probability less than ε; i.e. that

$$\Pr\left\{ S_{\mathrm{I}} \geq \delta\, S_{\mathrm{N}} \right\} \leq \varepsilon\,, \qquad (11)$$

with $S_{\mathrm{N}} = k\,T\,\mathrm{NF}$, where k is Boltzmann's constant, T is the temperature (Kelvins), and NF is the receiver noise figure. The aggregate interference PSD itself may be written as

$$S_{\mathrm{I}} = \sum_{i=1}^{K} S_{\mathrm{I}}^{(i)} = \sum_{i=1}^{K} G_{\mathrm{R}}\, G_{\mathrm{T}}^{(i)}\, g^{(i)}\, v^{(i)}\, S_{\mathrm{T}}^{(i)}, \qquad (12)$$

where i is the transmitter index, $G_{\mathrm{T}}^{(i)}$ is the transmitter antenna gain, G_{R} is the receiver antenna gain, $g^{(i)}$ is the propagation gain, $v^{(i)} \in \{0,1\}$ is the transmitter activity multiplier, and $S_{\mathrm{T}}^{(i)}$ is the transmitter PSD (in units of Watts/Hz). Note that $S_{\mathrm{T}}^{(i)} G_{\mathrm{T}}^{(i)}$ is the EIRP spectral density.

The propagation gain includes effects such as path loss and shadowing loss. The multiplier, v. takes into account of the fact that a device may not transmit continuously, in which case $\Pr\{v=1\} = p_v$, for an activity factor of p_v .

A3.2 Monte-Carlo simulations

<u>Aggregate interference statistics at a reference of 2 GHz</u>

Aggregate interference statistics are computed via Monte-Carlo simulations at a reference frequency of 2 GHz, where at each trial a total of K transmitting devices are uniformly distributed in the vicinity of a victim receiver. The radio parameter values assumed are summarised in Table A3.1.

The cumulative probability distribution function (CDF) of the received aggregate interference PSD is presented in Figures A3.1 and A3.6 for a normalized EIRP spectral density of 1 mW/MHz (0 dBm/MHz), reference frequency of 2 GHz, and for different device densities, activity factors, and minimum distances of transmitters from the victim receiver.

Parameter	Value	Comment
Frequency	2 GHz	Reference frequency
Minimum distance	0.15 m 1 m 2 m	Minimum distance from victim receiver.
Maximum distance	20 m	Maximum distance from victim receiver. Greater distances need not be considered due to excessive path-loss.
Device density	2 m^{-2} 0.5 m^{-2} 0.05 m^{-2}	High, medium, and low spatial densities of uniformly distributed devices.
Tx antenna gain	1	Omni-directional transmission.
Rx antenna gain	1	Omni-directional reception.
Tx PSD (EIRP)	1 mW/MHz	Normalized reference transmission level.
Path loss	Exponent = 2 within 5 m Exponent = 3.5 beyond 5 m	IEEE TGn Model B[76]. (see also Section A3.4)
Shadowing loss	Log-normal σ_S = 3 dB within 5 m σ_S = 4 dB beyond 5 m	IEEE TGn Model B. σ_S is the shadowing standard deviation.
Multi-path fading	N/A	Averaged over multi-path fading.
Number of trials	10,000	

Table A3.1. Simulation parameters.

76 V.Erceg, *et al.*, “TGn Channel Models (IEEE 802.11-03/940r2),” High Throughput Task Group, IEEE P802.11, 15 March 2004.

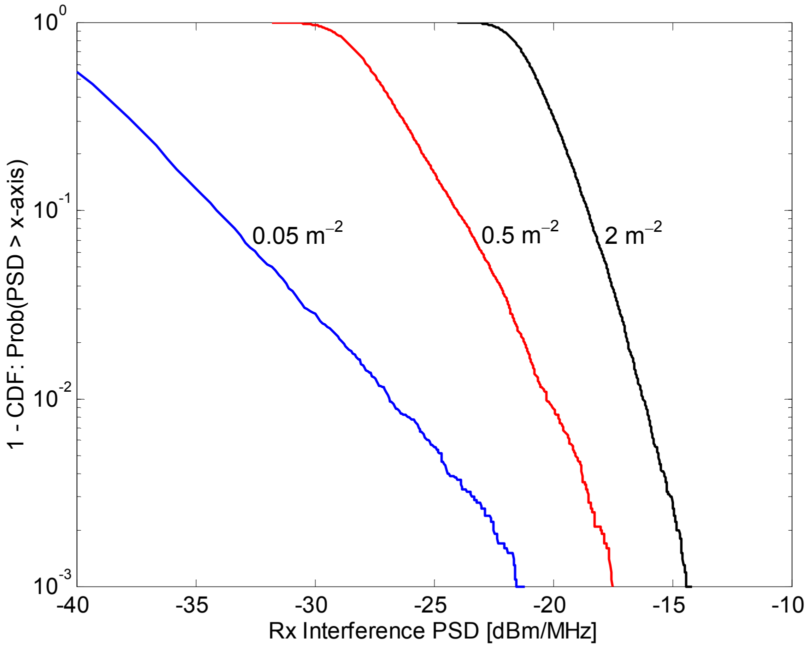

Figure A3.1. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 0.15 m, activity factor of 100%.

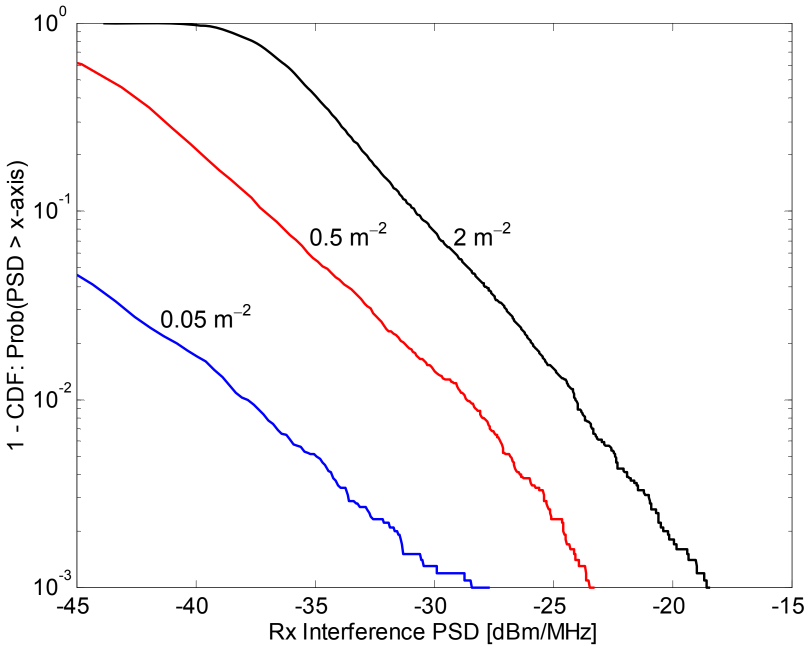

Figure A3.2. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 0.15 m, activity factor of 5%.

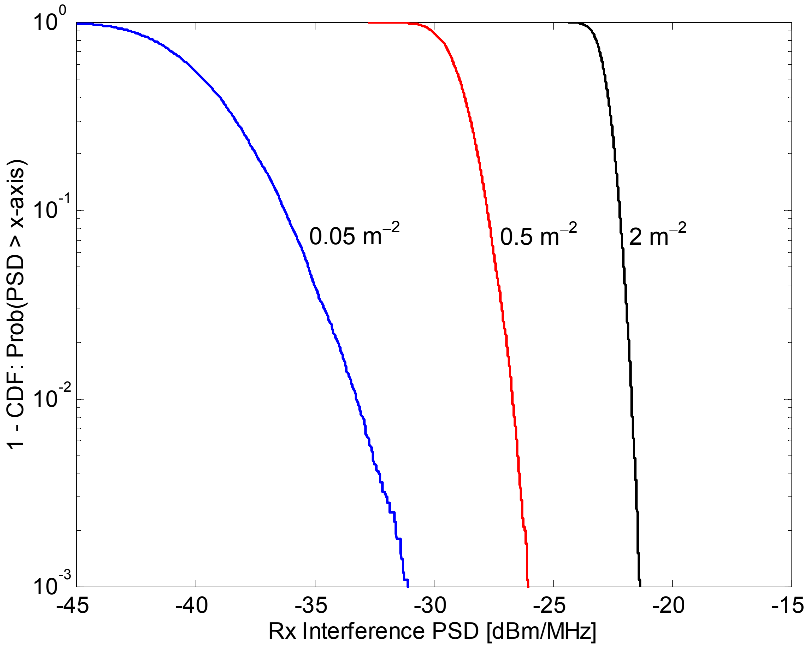

Figure A3.3. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 1 m, activity factor of 100%.

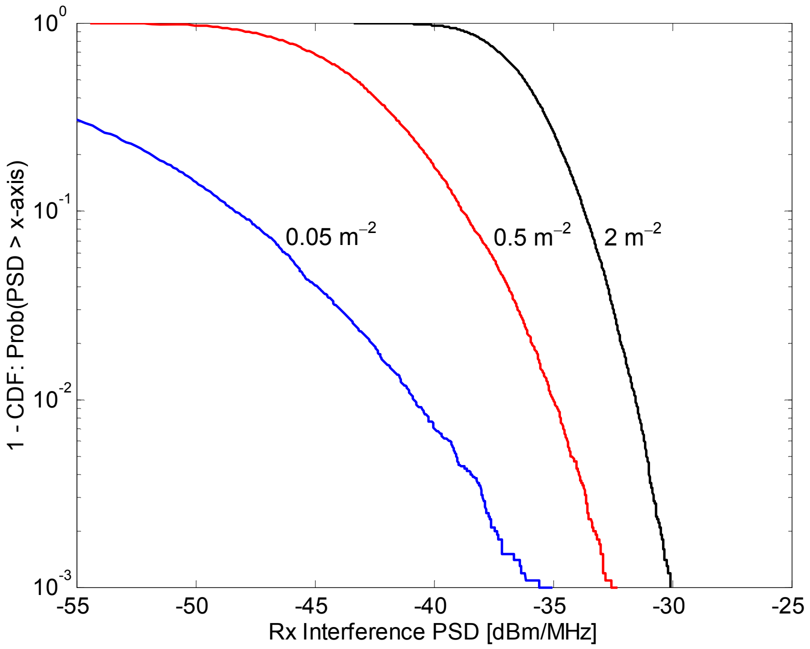

Figure A3.4. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 1 m, activity factor of 5%.

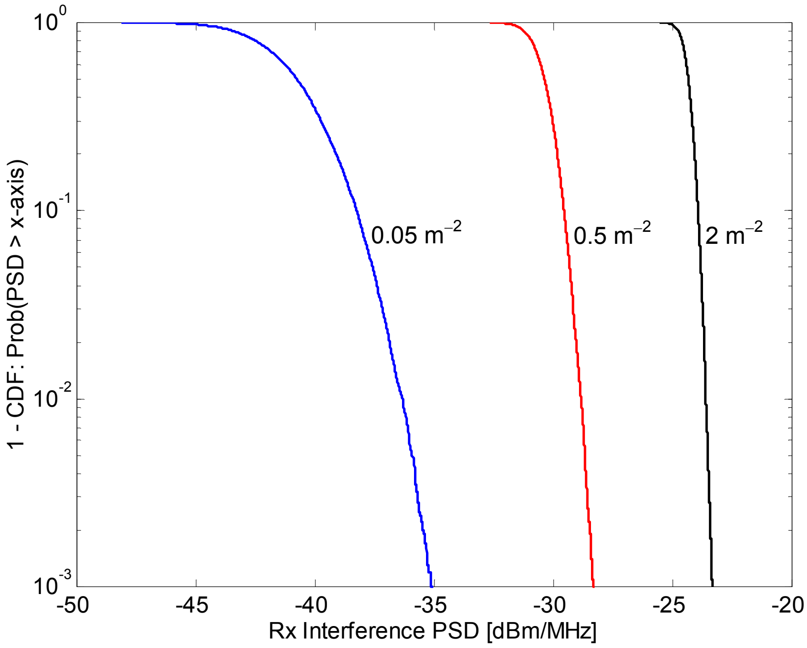

Figure A3.5. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 2 m, activity factor of 100%.

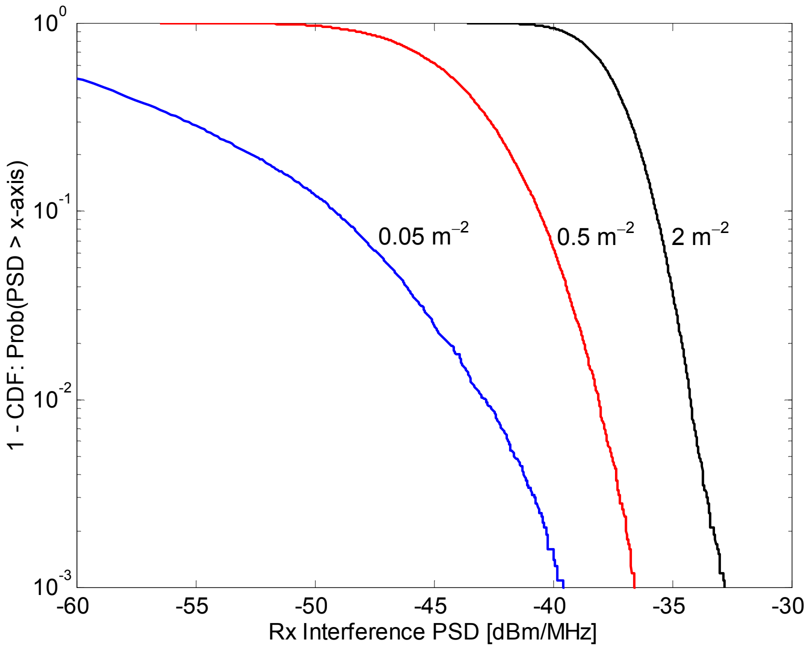

Figure A3.6. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 2 m, activity factor of 5%.

From the above statistics one can readily derive the threshold, $S_{\mathrm{Threshold}}$, which the received aggregate interference PSD, S_{I}, exceeds with a given probability, ε, when devices transmit with a normalised EIRP spectral density of 0 dBm/MHz.

Given the above information, one can then compute the EIRP spectral density for which the received aggregate interference PSD exceeds a fraction δ of the noise PSD with probability, ε.

This can best be demonstrated via the following example. For a victim receiver with a noise figure of 10 dB, the noise PSD is

$$S_{\mathrm{N}} = k\,T\,\mathrm{NF} = 1.3804 \times 10^{-23} \times 290 \times 10 \quad = 4 \times 10^{-20} \text{ W/Hz}$$
$$= -104 \text{ dBm/MHz.}$$

Setting $S_{\mathrm{Threshold}} = \delta\, S_{\mathrm{N}}$ and δ = 0.05, we have

$$S_{\mathrm{Threshold}} = \delta\, S_{\mathrm{N}} = -117 \text{ dBm/MHz.}$$

Figure A3.1 indicates that for a normalised EIRP spectral density of 0 dBm/MHz, and a device density of 0.5 m^{-2}, the received aggregate interference PSD exceeds a threshold of $S_{\mathrm{Threshold}}$ = –17.5 dBm/MHz with a probability ε = 10^{-3}.

One can then conclude that, for a device density of 0.5 m^{-2}, the received aggregate interference PSD would exceed a threshold of $S_{\mathrm{Threshold}} = \delta\, S_{\mathrm{N}}$ = –117 dBm/MHz with a probability ε = 10^{-3} if the devices transmitted with an EIRP spectral density of 0+(–117–(–17.5)) = –99.5 dBm/MHz.

Similarly derived EIRP limits for low-power devices are presented in Tables A3.2 to A3.4 for different device densities, and minimum distances of transmitters from the victim receiver. The EIRP values are those that would result in an aggregate interference-floor which exceeds 5% of a victim receiver's noise-floor with a probability of 0.1%.

		Device Density 2 m^{-2}	0.5 m^{-2}	0.05 m^{-2}
EIRP (dBm/MHz)	Activity factor 100%	–117 –(–14.5) = –102.5	–117 –(–17.5) = –99.5	–117 –(–21.5) = –95.5
	Activity factor 5%	–117 –(–18.5) = –98.5	–117 –(–23.5) = –93.5	–117 –(–28.5) = –88.5

Table A3.2. Limits on transmission PSD for which $\Pr\{S_{\mathrm{I}} \geq 0.05\, S_{\mathrm{N}}\} = 10^{-3}$. Minimum distance 0.15 m.

		Device Density 2 m^{-2}	0.5 m^{-2}	0.05 m^{-2}
EIRP (dBm/MHz)	Activity factor 100%	–117 –(–21.5) = –95.5	–117 –(–26) = –91	–117 –(–31) = –86
	Activity factor 5%	–117 –(–30) = –87	–117 –(–32.5) = –84.5	–117 –(–35.5) = –81.5

Table A3.3. Limits on transmission PSD for which $\Pr\{S_{\mathrm{I}} \geq 0.05\, S_{\mathrm{N}}\} = 10^{-3}$. Minimum distance 1 m.

		Device Density		
		2 m^{-2}	0.5 m^{-2}	0.05 m^{-2}
EIRP (dBm/MHz)	Activity factor 100%	–117 –(–23.5) = –93.5	–117 –(–28.5) = –88.5	–117 –(–35) = –82
	Activity factor 5%	–117 –(–33) = –84	–117 –(–36.5) = –80.5	–117 –(–39.5) = –77.5

Table A3.4. Limits on transmission PSD for which $\Pr\{S_I \geq 0.05\ S_N\} = 10^{-3}$. Minimum distance 2 m.

EIRP spectral density masks

The EIRP limits computed in the previous section for a reference frequency of 2 GHz may be translated to other frequencies by taking into account of the changes in radio propagation characteristics as a function of frequency. In the absence of any widely accepted statistical propagation models that cover all frequency bands of interest from 1 to 100 GHz and beyond, we make the following assumptions:

- The growth of free-space path-loss with the square of frequency (i.e. 20 dB per decade) is the only source of frequency-dependence (see Section A3.4).
- We continue to use the two-mode path-loss model of Table A3.1 with path-loss (exponent of $n = 2$) for distances below 5 m, a path-loss exponent of $n = 3.5$ for distances beyond 5 m, and shadowing-loss standard deviations of 3 dB and 4 dB respectively.

In practice, penetration losses through building materials and foliage do increase with frequency, resulting in frequency-dependent path-loss exponents and shadowing standard deviations. It is for this reason, as well as a reduction in diffraction effects, that radio communications at frequencies beyond a few GHz increasingly require the transmitter and receiver to be in line of sight. At frequencies above 30 GHz, additional frequency-dependent factors such as gaseous and water vapour absorption can become dominant over long distances, with losses exceeding 10 dB/km at 60 GHz (see Section 6 of this document).

The above affects are ignored in this study, and are likely to be of secondary importance over the limited distances (≤ 20 m) considered. The implication is that, in practice, the contribution to the interference floor of the computed EIRP spectral density limits is likely to be even lower than those predicted here; i.e. our analysis is conservative.

The computed EIRP spectral density masks are presented in Figures A3.7 to A3.9 for different device densities, activity factors, and minimum distances of transmitters from the victim receiver, along with the mask for ultra-wideband (UWB) devices.

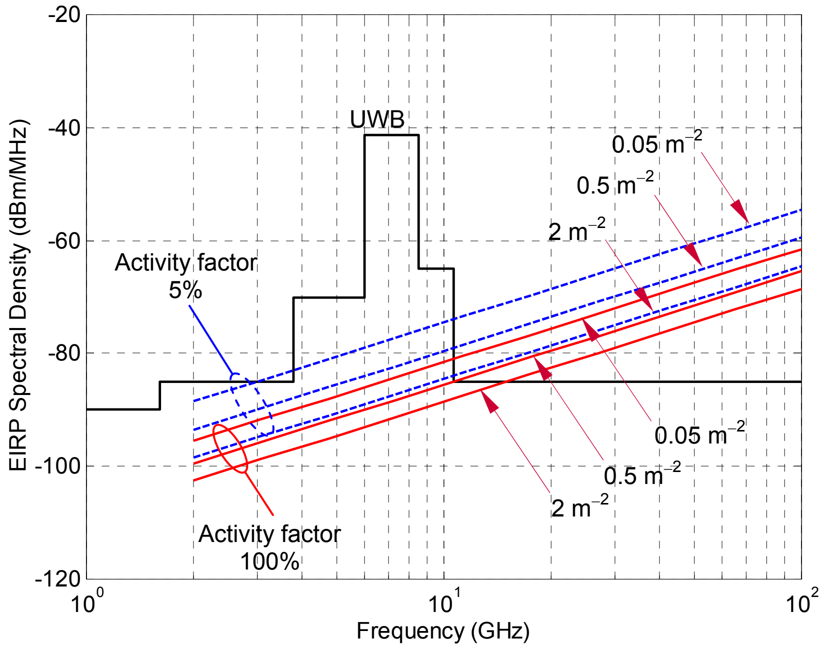

Figure A3.7. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 0.15 m.

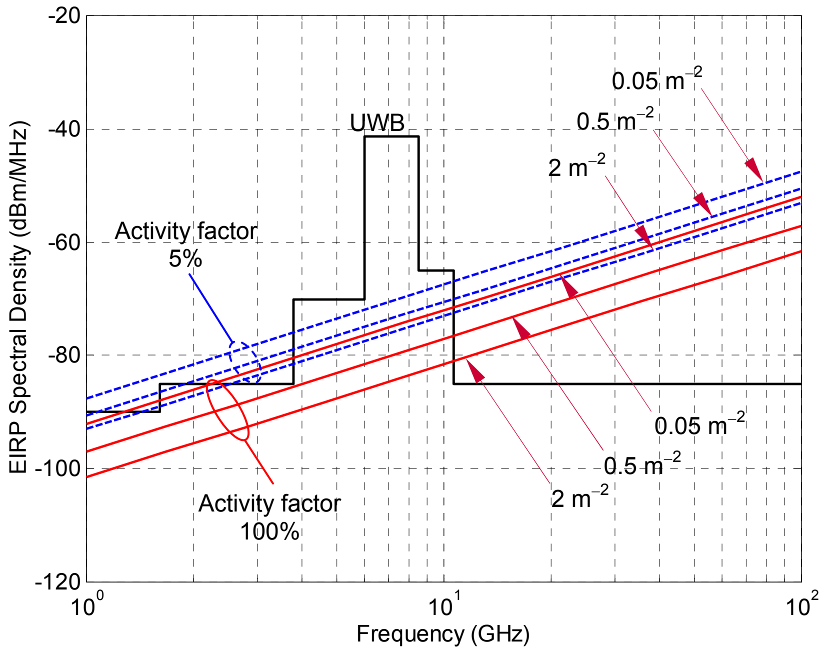

Figure A3.8. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 1 m.

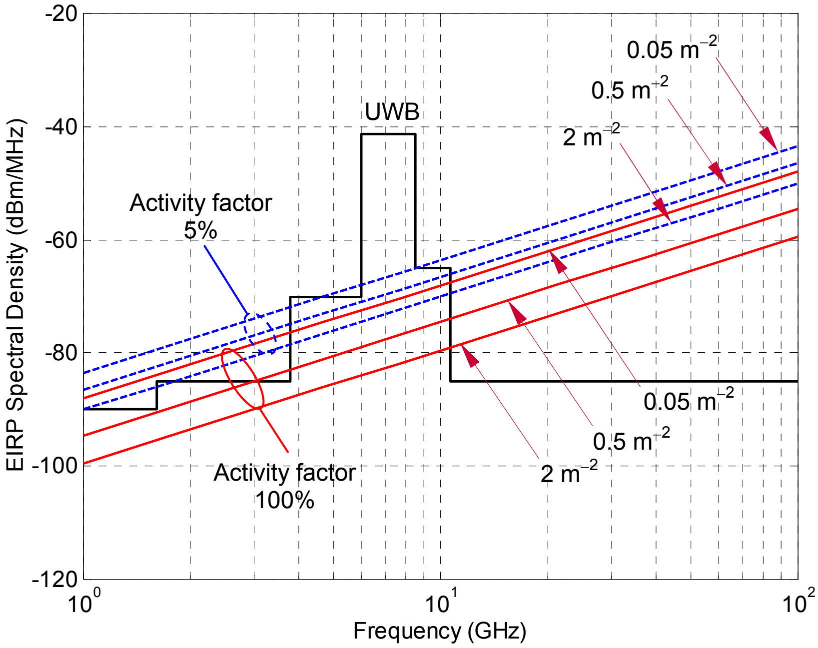

Figure A3.9. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 2 m.

A3.3 Conclusions

The aggregation of transmissions by a large number of low-power devices, and its impact on the interference-floor experienced at a victim receiver was investigated via Monte-Carlo simulations.

A methodology was presented for deriving EIRP spectral density limits for such devices so that the resulting aggregate interference would exceed a fraction δ of the thermal noise-floor with a probability of ε. It was shown that such limits broadly correspond to a gradient of 20 dB per decade as a function of frequency.

Such analysis can provide guidance in the specification of limits for low-power devices such that the resulting transmissions do not cause harmful interference to incumbent services occupying the spectrum.

A3.4 Appendix: Propagation model

A two-mode path-loss model may be specified as follows,

$$L(d) = \begin{cases} L_{\mathrm{FS}}(d) \ \ \mathrm{dB} & d < d_{\mathrm{BP}} \\ L_{\mathrm{FS}}(d_{\mathrm{BP}}) + 10n\log_{10}\dfrac{d}{d_{\mathrm{BP}}} \ \ \mathrm{dB} & d \geq d_{\mathrm{BP}} \end{cases} \tag{13}$$

where d is the distance in metres, n is the path-loss exponent, d_{BP} is the break-point, and free-space path-loss is given by

$$L_{\mathrm{FS}}(d) = \frac{(4\pi\, d)^2}{\lambda^2} = \frac{16\pi^2 f_0^2}{c^2} d^2, \tag{14}$$

where f_0 is the operating frequency, λ is the operating wavelength, and c is the speed of light. The free-space path loss may also be written in the logarithmic domain as

$$L_{\mathrm{FS}}(d) = -147.56 + 20\log_{10}(f) + 20\log_{10}(d) \text{ dB}. \tag{15}$$

The propagation “gain”, g , used in Equation (12) accounts for both path loss and log-normal shadowing, and may be written in the logarithmic domain as

$$10\log_{10}(g) = -L(d) + g_{\mathrm{S}} \text{ dB}, \tag{16}$$

where g_{S} is a zero-mean Gaussian-distributed random variable with standard deviation σ_{S} .

Annex 4

Summary of stakeholder responses to the LEFR, and Ofcom's views on the issues raised

A4.1 Introduction

This annex provides a summary of the stakeholder responses to the LEFR Consultation Document (published in April 2007). All non-confidential responses are available in full on the Ofcom website[77].

The next section provides a general overview of stakeholder responses. This is followed by a section summarising the responses to each of the questions that were asked in the Consultation Document, along with a discussion of Ofcom's views on the issues raised. The final section in this annex deals with stakeholder responses which are not directly related to the specific questions asked in the Consultation Document.

We have not listed every response here, but have singled out those which we believe raise important issues or which are not in full agreement with our proposals. In some cases, we agree with the issues raised and as a result have made changes to the LEFR. In other cases, we are not persuaded to change our views and we discuss in this annex why this is the case.

A4.2 General overview of responses

Overall 23 responses to the LEFR Consultation Document were received. These were from a range of stakeholders including equipment manufacturers, wireless network operators, and organisations representing various users of spectrum. While many were strongly supportive of the proposals set out in the LEFR, a number of issues were also raised. The key issues raised are summarised below, along with brief descriptions of Ofcom's views on these.

Application-specific spectrum vs. spectrum commons

Stakeholders were mostly in agreement with Ofcom's general preference for a spectrum commons model as opposed to the application-specific approach for the licence-exempt use of the spectrum. A few, however, noted that spectrum commons may not be the preferred option in all circumstances. Stakeholders were also mostly supportive of the proposed concept of multiple classes of spectrum commons.

Based on the feedback from stakeholders, we have now reviewed our position on the use of proprietary polite protocols. Accordingly, it is proposed that any polite protocol, so long as it complies with the politeness rules defined by the regulatory bodies, should be allowed to operate in a spectrum commons without the need for individual regulatory authorisation. This is irrespective of whether the protocol is proprietary or defined within a technology standardisation body.

77 http://www.ofcom.org.uk/consult/condocs/lefr/.

Judging from certain responses, there appears to be a degree of confusion with regards to some of the terminology used in the LEFR Consultation Document. In particular, the terms “Technical Standards” and “Harmonised Technical Standards” used in the LEFR were intended to refer to *technology standards* (e.g. the IEEE 802.11x family) which contain specifications of the radio protocol stack, and may include polite protocols (e.g. CSMA/CA). These are now replaced with the terms “Standardised Technology” or “Technology Standards” in the LEFR Statement.

The above terms should not be confused with “Harmonised European Standards/Norms” (e.g. ETSI EN 300 328) which, strictly speaking, are also “technical standards” but are created by standardisation bodies (e.g. ETSI) under a mandate from the European Commission, and set out regulatory minimum technical requirements (but not the technologies themselves). These are akin to politeness rules.

Light-licensing and licence-exemption

All Stakeholders were in agreement with the distinctions between licence-exemption and light-licensing as described in the LEFR. Most responses also broadly agreed with the view that licence-exemption and light-licensing might converge at some point in the future. However, a number of stakeholders raised concerns regarding a policy of default conversion of light-licensing to licence-exemption.

We have clarified that the LEFR does not propose a policy of default conversion, and that any future conversions by Ofcom of light-licensing regimes to licence-exemption will generally be subject to specific consultations.

License-exemption above 40 GHz

Most responses were broadly supportive of the LEFR proposals for future release of specific bands above 40 GHz for license-exempt use. A number of stakeholders suggested that, given the absence of commercial demand for these frequencies at this time, a wide-scale spectrum release for licence-exempt use might not be justified and recommended a more cautious approach, including that of holding back some spectrum in reserve.

We do not favour the option of holding back the release of spectrum for licence-exempt use in this instance. We consider this to be an over-cautious approach. Ofcom believes that a phased approach to the release of spectrum over 102–275 GHz, accompanied by specific consultations, will allow an appropriate level of caution to be exercised. For the frequency range 275–1000 GHz, Ofcom believes that a wide-scale release of the spectrum (excluding spectrum covered by Footnote 5.565) is viable subject to a consultation, and that a phased approach is not necessary.

License-exemption of low-power transmitters

Many of the stakeholder responses were not in full agreement with the proposed exemption of all transmissions at EIRP spectral densities below the UWB limits. Specifically, the key feedback was that the proposals have focused only on the power spectral density characteristics of UWB devices, and appear not to have considered other operational restrictions on such devices. A second feedback was that the limits adopted for the purpose of exemption from licensing should be considered on a case-by-case basis for specific bands and taking full account of incumbent services.

With regards to the first comment, we agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other

UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

With regards to the second comment, any future authorisations by Ofcom of licence-exempt use will generally be subject to consultations with associated impact assessments, as appropriate, for the various bands and incumbents therein. However, we note that co-existence studies are unlikely to be necessary for each and every incumbent service above 10.6 GHz, since many of these services are similar to those occupying the 3-10 GHz band where co-existence with UWB devices has already been demonstrated through compatibility studies.

Harmonisation

Stakeholders were mostly in agreement with the harmonisation strategy proposed in the LEFR. Ofcom will engage in international debate with its partners in order to promote the adoption of different classes of spectrum commons through harmonised standards (politeness rules).

Investigation of interference

Stakeholders were mostly in agreement with the conclusion that additional regulatory instruments are not required for the protection of licence-exempt equipment. Ofcom will continue to monitor congestion in bands used by licence-exempt devices and will act appropriately, as part of its statutory responsibilities for ensuring efficient use of the spectrum.

A4.3 Question-by-question review of stakeholder responses

Note that stakeholder responses and feedback are indicated in *italics* in this section.

Q1: Do you agree that the spectrum commons model should be the preferred approach for licence-exempt use of spectrum, and that application-specific allocations should only be considered where technical constraints or safety issues require this?

While most stakeholders were in agreement with this preference, the following points were raised:

1) *Licence-exempt use, either co-channel or adjacent channel, of spectrum should not be allowed within bands allocated to safety of life services without having undertaken the relevant sharing studies.*

   Ofcom's view

   Agreed. As pointed out in the LEFR, any future authorisations by Ofcom of licence-exempt use will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands. It is therefore unlikely that there will be authorisations which would cause harmful interference to safety-critical or sensitive services.

2) *More detailed impact assessments would be required to implement spectrum commons in a specific band. There may be instances where application-specific allocation would be more economically efficient.*

Ofcom's view

Agreed. See also item (1) above. Ofcom has a "general" preference for the spectrum commons model, and considers it to be the default approach for spectrum use by licence-exempt devices. However, Ofcom will consider application-specific allocations on a case-by-case basis where there is sufficient evidence to recommend it. This position is re-emphasised in Recommendation 1 of the LEFR Statement.

3) *The spectrum commons model should not be employed in spectrum used for weak signal Amateur Radio and Amateur Satellite communications.*

Ofcom's view

Agreed. See item (1) above.

4) *Not all licence-exempt applications should require polite protocols.*

Ofcom's view

Agreed. As pointed out in the LEFR (e.g. see examples of classes in Section 4.4), polite protocols may not be required in cases where the politeness rules are sufficient to adequately reduce the likelihood of harmful interference.

5) *Technologies such as RFID require a guaranteed level of service in order to deliver added value, which can not be afforded in a spectrum commons. Standard-based allocations should therefore be considered, subject to mandatory politeness rules and polite protocols. Such an approach is necessary in order to achieve a sufficient guarantee of service.*

Ofcom's view

Ofcom believes that application- and technology-specific models for spectrum use result in a regulator-imposed fragmentation of spectrum which is not subject to corrections by market forces. In this sense, these models are not in line with our policy of application and technology neutrality.

Nevertheless, as pointed out in the LEFR (e.g. see Section 1.2), we do recognise that application of the spectrum commons model to existing licence-exempt authorisations may in many cases result in harmful interference towards incumbent technologies (e.g. RFID) which may not be sufficiently tolerant of interference. Ofcom does not propose the retrospective application of the spectrum commons model to such bands, unless as part of a future spectrum re-farming process.

We do, however, agree that adherence to the politeness rules defined by regulatory bodies should be mandatory. It is important that such rules are not unduly restrictive and are designed to afford sufficient flexibility to transmitters to perform trade offs among various technical parameters. This is clarified in the text (Section 4.4), and emphasized in Recommendation 2 of the LEFR Statement.

Q2: Do you agree with the proposal for multiple classes of spectrum commons?

Almost all stakeholders were supportive of the concept of multiple classes of spectrum commons. The following points were also raised:

1) *Sharing between license exempt devices would be enhanced by limiting use of bands to devices that share or operate in a similar fashion. Care must be taken, however, to avoid over-stringent regulations that limit innovation or give an advantage to a very narrowly defined technology.*

   Ofcom's view

   Agreed. The definition of appropriate politeness rules by the regulatory bodies is critical to the success of a spectrum commons model. These should be defined at the appropriate level of detail in order to a) prevent certain protocols from unduly dominating others in accessing the radio resource, b) afford flexibility in the design of technologies, by accounting for possible trade-offs among different technical constraints, and c) ensure that the implementation of key technologies is not obstructed.

   It should be pointed out that politeness rules already exist today in the form of Harmonised European Standards (e.g. EN 300 328). These are defined by ETSI under a mandate from the European Commission to establish a set of standards to be recognised as giving a presumption of conformity with the R&TTE Directive's essential requirement of avoiding harmful interference.

2) *Only considering protocol proposals from standards bodies would suppress investment, delay market roll-out, and limit innovation. Innovation happens cyclically, with proprietary technologies leading to standards which are themselves the basis for the next round of proprietary innovation. A regulatory approach that focuses only on standards alone would freeze this process. A further problem with standards is that it is difficult for fledgling entrepreneurial companies to influence them; therefore a standards requirement will actually help large companies, and hinder small ones. Finally, regulatory bodies should avoid having to make judgments on what is or is not an acceptable standards body.*

   Ofcom's view

   The LEFR's proposed restriction on polite protocols to include only those defined within technology standardisation bodies was intended to provide a means of ensuring that any polite protocol permitted into a spectrum commons is indeed "polite". We recognised that regulatory bodies would not have the resources to test the politeness of each individual polite protocol that stakeholders may wish to use in a spectrum commons. Our approach was therefore to allow the market (or rather the industry) to decide on the "politeness" levels of polite protocols. To this end, we proposed that:

   a) Proprietary protocols should not be authorised for use by LE devices in a spectrum commons. In this way the regulatory bodies would ensure that rogue "impolite" protocols do not enter the commons.

   b) Authorised protocols need to be defined by technology standardisation bodies, where stakeholders collaborate in defining the PHY-MAC protocols. The large number of competing parties involved in the standardisation process would mean that the protocols would have a good chance of being "reasonably" polite. This has been the experience, at least with the IEEE suites of protocols for short-range communications.

Yet the question still remained as to how regulatory bodies could ensure that polite protocols from independent technology standardisation bodies are equally polite towards each other. Having reviewed this question, we believe the answer is closely tied to the relationship between politeness rules and polite protocols. Our conclusion is that if politeness rules are defined at an appropriate level of detail, it is possible to prevent any one protocol from significantly dominating others in terms of its use of the radio resource[78]. Based on this logic, it follows that any polite protocol, so long as it complies with the politeness rules defined by the regulatory bodies, should be allowed to operate in a spectrum commons without the need for individual regulatory authorisation. This is irrespective of whether the protocol is proprietary or defined within a technology standardisation body. This conclusion has been reflected in the text and Recommendation 2 of the LEFR Statement.

Q3: Do you agree with the distinction made between the licence-exemption and light-licensing regimes?

All responses agreed with the distinctions described in the LEFR.

Q4: Do you agree with the view that the licence-exemption and light-licensing regimes will converge in the future?

Most responses broadly agreed with the view that licence-exemption and light-licensing might converge at some point in the future. However, many raised concerns regarding the conversion of light-licensing to licence-exemption. These are presented below:

1) *We agree that some (but not all) services and applications may be able to move from a light licence to licence exempt. This should only happen after consultation with all users, operators, service providers and manufacturers who have an interest in any band that is being targeted for conversion. In addition Ofcom should give long term guarantees that conversion from light licensing to licence exempt will not have a detrimental effect on existing users. Ofcom should also be prepared to revert to light licensing for the band if existing users are subjected to interference that damages their services or operations.*

Ofcom's view

Agreed. Note that Ofcom does not propose the imminent conversion of light-licensing regimes to licence-exemption. Ofcom will review each case on its own merits, but we do expect to see a move toward licence-exemption over time. However, any future conversions by Ofcom of light-licensing regimes to licence-exemption will generally be

78 To illustrate this, let us consider a scenario involving polite protocols X and Y. Two devices using polite protocol X would, on average, share the radio resource equally (i.e. 50/50). However, two devices using polite protocols X and Y, respectively, would almost certainly not share the radio resource equally. For example, if both protocols use listen-before-talk (LBT), but X has shorter back-off times, then X will (on average) dominate Y. The radio resource might be shared 70/30. The extent to which one protocol can dominate another depends on the level of detail at which politeness rules are defined. In the context of the earlier example, if politeness rules define the maximum allowed duty-cycle over sufficiently short time-scales (i.e. of the order of packet intervals), then the LBT back-off times of protocols X and Y are unlikely to be too different (the protocols would be designed to make the best of the duty cycle limit). Dominance of one protocol over the other will (on average) not be huge. The radio resource may be shared more fairly, say 55/45.

subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands.

This latter point is emphasised in Section 5.3 of the LEFR Statement following the two recommendations.

2) *We believe that the light licensing regime may be appropriate in certain circumstances, and so we would support its retention as an alternative to the licence exempt regime when appropriate.*

Ofcom's view

Agreed. In Section 5.3 of the LEFR we noted the trends in a) growing use of self-deployment and sensing technologies by light-licensed systems, and b) potential use of beacons and databases by licence-exempt devices. We concluded that these point to a convergence of light-licensing and licence-exemption regimes in the future. We also pointed out that, until such time when convergence is complete, the two regimes remain distinct solutions for the management of interference in different scenarios. We therefore do support the retention of light-licensing as an alternative to licence-exemption. See also item (1) above.

3) *Only to some extent. Some of the reasons for light-licensing given will not be helped by technical advances. Furthermore automatic co-ordination may be technically possible but not universally used (and in some case it may not be justified to make it mandatory.*

Ofcom's view

We firmly believe that all aspects of light-licensing could, in principle, be implemented through autonomous co-ordination via a combination of self-deployment, database access, and sensing technologies. However, we do recognise that such autonomous co-ordination may not be the preferred option in all circumstances. See also items (1) and (2) above.

4) *We believe whilst there will be a trend for the regimes to merge there will still be applications within a single frequency band which are dissimilar and require differing approaches.*

Ofcom's view

Agreed. See also items (1) to (3) above.

5) *At this stage it appears they address very different requirements and so it is not clear that this is the case. We do not agree that it is possible at this stage to instigate a policy of default conversion to licence-exemption (5.3(2)).”*

Ofcom's view

Agreed. The LEFR does not propose a policy of default conversion to licence-exemption. To clarify this, the wording of Recommendation 2 is modified in Section 5.3 of the LEFR Statement. See also items (1) to (3) above

6) *We do not agree that it is possible at this stage to instigate a policy of default conversion to licence-exemption (5.3(2)) because light licensing addresses the need to limit the total number of deployed devices in some bands that are deemed to need that limit, and detect and avoid strategies are fundamentally flawed for many types of content delivery.*

Ofcom's view

Agreed. The LEFR does not propose a policy of default conversion to licence-exemption. See item (5) above.

7) *There are distinct roles for both regimes and we would not be in favour of default exemption.*

Ofcom's view

Agreed. The LEFR does not propose a policy of default conversion to licence-exemption. See item (5) above.

8) *Light licensing is necessary when spectrum is shared with a licensed service, unless it is an underlay. In our view in-band sharing should be allowed under the control of the incumbent licensee as part of the trading regulations.*

Ofcom's view

In the LEFR we note that light licensing can be used to achieve two distinct aims, namely, a) allowing access to new services while protecting incumbent users, and b) enabling mutual interference co-ordination among multiple operators.

The LEFR Consultation Document primarily addressed the second role of light-licensing, as this has clear synergies with licence-exemption regimes. Issues relating to the protection of incumbent users were not addressed in the LEFR. A brief discussion is now added in Section 5.2 of the LEFR Statement.

We believe that, where hard limits on device densities (e.g. geographical exclusion zones) are a necessity for the protection of incumbent services, light-licensing is the preferred option today. We also believe that with advances in self-deployment mechanisms, automatic database access, and sensing technologies, such protection can equally be achieved through licence-exemption.

It should be noted that the LEFR only addresses the relative merits of the light-licensing and licence-exemption regimes. The question of opportunistic (overlay) access – by either light-licensed or licence-exempt devices – to licensed spectrum is a different matter all together and falls outside the scope of the LEFR. The possibility of such opportunistic access is very much dependent on the nature of the licensed service and would need to be addressed on a case-by-case basis, with associated impact assessments as appropriate.

This latter point is now emphasised in Section 5.3 of the LEFR Statement following the two recommendations.

Q5: Do you agree with the proposed mixture of licence-exempt and light-licensed use of the 105–275 GHz spectrum? Do you agree with the bands that have been identified for such use?

Most responses were supportive of the proposed mixture of license-exemption and light-licensing proposed for the 105–275 GHz spectrum. The following points were raised:

1) *It is important that use of this spectrum for scientific purposes be protected.*

   Ofcom's views

   Agreed. To this end, as described in the LEFR, spectrum allocated by the Radio Regulations to earth exploration satellites, radio astronomy and space research (Group-4, accounting for roughly 31 GHz) has been excluded from our considerations. Furthermore, any future authorisations by Ofcom of licence-exempt use will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands. The likelihood of any interference to scientific services will be evaluated and addressed therein.

2) *Due consideration should be given to ensuring the protection of low noise floor segments in this part of the spectrum for the Amateur Radio and Amateur Satellite services.*

   Ofcom's views

   Agreed. To this end, as described in the LEFR, spectrum allocated by the Radio Regulations for primary use by amateur and amateur satellite services (Group-3, accounting for roughly 4 GHz) has been excluded from our considerations. See also item (1) above.

3) *Technology development is quite challenging in this frequency range and there appears little proof of commercial demand that would justify wide-scale spectrum release for licence-exempt or light-licensed systems at this time. A more cautious approach is recommended.*

   Ofcom's views

   Ofcom does not favour the option of holding back the release of spectrum in this instance. We consider this to be an over-cautious approach. Recent examples have indicated that the release of spectrum for licence-exempt use tends to kick-start research and development activity within the industry, which subsequently results in creation of demand for spectrum use.

   Furthermore, it is Ofcom's obligation, under the Wireless Telegraphy Act 2006, to exempt from licensing any use of spectrum which is not likely to result in undue interference. As described in the LEFR, our studies indicate that radio congestion and hence harmful interference are unlikely above 105 GHz.

   However, while time-lines have not been discussed in the LEFR, Ofcom does not propose the immediate wide-scale release of all 94 GHz of the identified Group-1 frequencies over the 105-275 GHz band. Given the diverse and fragmented nature of the Radio Regulation allocations, and the need to define different politeness rules to protect adjacent use, we believe that a phased (i.e. band-by-band) release of such spectrum over the next 5 years is the only pragmatic approach.

Ofcom believes that such a phased approach, accompanied by specific consultations, will allow an appropriate level of caution to be exercised.

4) *It may be prudent to keep some Group-1 spectrum "in reserve". While spectrum will not be scarce in the near future, in the long term applications may emerge which might benefit from the absence of other users. There appears to be no downside in keeping some Group-1 spectrum for such licensed (or perhaps light-licensed) use.*

Ofcom's views

A spectrum reserve at frequencies above 105 GHz could only be justified if an application was expected to emerge in the future which:

a) could not operate in the presence of other co-channel uses; and

b) could not be accommodated at other frequencies.

As explained in the LEFR, the constraints on radio propagation at frequencies above 105 GHz imply that the use of the spectrum is limited to short-range to medium-range (line-of-sight) radio links. Today, many links of this type are capable of operating in the presence of other co-channel uses, where they are assisted by various interference avoidance and mitigation technologies. With advances in such technologies, and the availability of vast amounts of spectrum above 105 GHz, one can only conclude that item (a) above is unlikely.

We also note that the Group-2 frequencies (amounting to 40 GHz of unused spectrum) have been proposed for light-licensing in the 105-275 GHz band. As described in the LEFR, our studies indicate that this is more than enough bandwidth to accommodate the (unlikely) emergence of applications which may be intolerant of co-channel uses. One may then conclude that item (b) above is also unlikely.

On balance, therefore, Ofcom believes that a spectrum reserve is not justified.

In any case, Ofcom believes that a phased (i.e. band-by-band) approach to releasing Group-1 frequencies for licence-exempt use mitigates the need to hold back any of the Group-1 frequencies in reserve. See also item (3) above.

Finally, it should be noted that the release of spectrum for licence-exempt use does not necessarily preclude the use of the same spectrum by licensed services at some future date through re-farming.

Q6: Do you agree with the view that the use of the 275–1000 GHz spectrum should be licence-exempt?

Stakeholder responses here were broadly similar to the responses to Q5. The following points were raised:

1) *It is important that use of this spectrum for scientific purposes be protected.*

Ofcom's view

Agreed. To this end, as described in the LEFR, spectrum allocated by the Radio Regulations for spectral line measurements (under Footnote 5.565) have been excluded from our considerations. These account for around 68% of the available spectrum over 275–1000 GHz.

2) *The frequencies listed in Footnote 5.565 leave the door open to additional frequencies being defined. We would welcome comments by Ofcom on how stable any exemption or allocation would be relative to this footnote and developments at future WRC conferences. Such regulatory uncertainties can hinder equipment development just as much as the technology itself. Also, Ofcom's liberal approach to these higher bands seems somewhat at odds with the European position on no-change for such frequencies under WRC-07 AI-7.2.*

Ofcom's view

As explained in Section 3.1.2 of the LEFR, while we would expect all authorisations of licence-exempt spectrum use to be for an indefinite period, there are certain specific grounds for their revocation, including the emergence of other more valuable uses of spectrum. Therefore, depending on the value of licence-exempt applications which may emerge over the 275–1000 GHz frequency band, Ofcom will react appropriately to any future motions to extend the frequencies listed under Footnote 5.565. It should be noted that the implementation of any such extensions would inevitably be associated with notice periods of the order of 4 to 6 years through the WRC process.

3) *The opening of the bands below 275 GHz (Question 5) will probably provide sufficient opportunity for licence exempt operation for the foreseeable future. Consequently we do not see any demand for using bands above 275 GHz. However we don't foresee any problems if Ofcom were to open these bands on a licence exempt basis, although we believe that Ofcom does not need to act until the demand for using these bands has been identified.*

Ofcom's view

Based on the same arguments presented in Question 5 for the 105–275 GHz band, Ofcom does not favour the option of holding back the release of spectrum in this instance.

Furthermore, given the absence of any allocations by the Radio Regulations above 275 GHz (other than frequencies allocated for spectral line measurements under Footnote 5.565), we believe that a wide-scale release of the spectrum for licence-exempt use is viable and a phased approach is not necessary.

4) *It may be prudent to keep some spectrum "in reserve". In the long term applications may emerge which benefit from the absence of other users. There appears to be no downside in keeping some spectrum for licensed or light-licensed use.*

Ofcom's view

Based on the same arguments presented in Question 5 for the 105–275 GHz band, we believe that a spectrum reserve is not justified for frequencies above 275 GHz.

Q7: Do you agree with the view on the levels of future demand for licence-exempt usage in the 40–105 GHz spectrum? Do you agree that the Group-A bands identified above should be considered for licence-exempt use? Do you agree that licence-exempt and light-licensed use of the Group-C bands identified above should only be considered when there is evidence of demand for such use?

Almost all responses were supportive of our view on the exemption of Group-A bands (59-64, 102-105 GHz). The following points were also raised:

1) *It somewhat surprising that the LEFR has proposed releasing significant quantities of spectrum above 105 GHz on a licence-exempt basis, even though there is currently no identified demand for such use, whilst it is proposing that evidence of demand is required for the [license-exempt or light-licensed use of] Group-C bands in the range 40–105 GHz. It is proposed that most of Group-C frequencies should be made available for licence-exempt use as soon as possible.*

   Ofcom's view

   As explained in the LEFR (see also our views on responses to Question 5) we do not foresee the emergence of radio applications which could not be accommodated under licence-exempt or light-licensing regimes in the vast amounts of unused spectrum available above 105 GHz.

   The situation is somewhat different in the 40-105 GHz bands which already support many licensed, light-licensed and licence-exempt services. Here, two points are of relevance:

   a) Our analysis indicates that Group-A and Group-B bands will already provide an adequate mix of frequencies for licence-exempt and light-licensed services for the next 15 years.

   b) The mainly unused Goup-C bands are allocated by the Radio Regulations to fixed or mobile usage, as well as various broadcast/fixed/mobile/radio-navigation satellite services. There are potential difficulties in supporting such long-range satellite links at other frequencies (say above 105 GHz). This is primarily due to the harsh propagation environment and challenging transceiver technologies. Furthermore, terrestrial satellite receivers can be particularly susceptibility to interference from other co-channel uses.

   Based on the above two factors, we believe it is prudent not to consider Group-C spectrum for licence-exemption or light-licensing at this time. Nevertheless, as pointed out in the LEFR, we do not completely rule out licence-exempt or light-licensed usage of certain Group-C bands at some point in the future.

2) *It could be relevant to consider (57) 59–64 (66) GHz to be categorised as Group-B (light-licensed) given the dual administration, and the perceived difficulties that could arise should WPANs and outdoor point-to-point links co-exist within the 60 GHz band.*

   Ofcom's view

   The 60 GHz bands are being extensively studied in Europe at present for a number of applications. The authorisation vehicle will depend on compatibility studies and the impact assessments. We acknowledge that the band may eventually support a mix of licensed, light-licensed, and light-licensed services.

Q8: Do you think it could be desirable for transmissions at levels below certain power spectral density limits to be exempt from licensing?

Many of the stakeholder responses were not in full agreement with the proposed exemption. Specifically, the following issues were raised:

1) *The proposals from Ofcom have focused only on the low power spectral density characteristic of UWB devices, and appears not to have considered the other operational restrictions on such devices (as given in ECC Decision (06)04), particularly the restriction to indoor operation which was a factor in the compatibility studies which led to the permission for their operation. It would appear that the precedence of UWB is being used as the basis of the argument for justifying licence exempt operation of low power spectral density devices, in which case we believe that the same operational restrictions should be applied in all cases.*

   Ofcom's view

   Agreed. The proposed licence-exemption would apply to low-power devices which transmit at EIRP spectral densities that are lower than the UWB limits, and also comply with all other UWB operational restrictions (e.g. restrictions on outdoor use) as mandated in the EC Decision 2007/131/EC. This is now clarified in Section 7.4 of the LEFR Statement.

2) *Yes, but only if the levels are set to an appropriately conservative level. Reference to the UWB limits may not be wholly appropriate and a suitable margin on power limits, together with qualifications and restrictions on the conditions that such LE devices can be used under, would need to be defined. We would prefer similar studies, qualifications and restrictions to those undertaken in the case of the development of the UWB Regulations to cover other low-power technologies. As this is a framework consultation it does not make specific (band-by-band or technology-based) proposals. Ofcom states that additional consultations will be published on such proposals in due course. We look forward to engaging in those future discussions.*

   Ofcom's view

   The UWB limits, as defined in EC Decision 2007/131/EC, already specify the levels of underlay transmission legally permitted for bandwidths greater than 50 MHz. As discussed in the LEFR, a non-UWB (i.e. bandwidth less than 50 MHz) transmitter which radiates subject to UWB limits and operational constraints would, by definition, cause even less interference than an UWB device, and is therefore clearly a candidate for exemption.

   We do agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

   With regards to frequencies above 10.6 GHz, we believe that the proposed limits on EIRP spectral density (based on a conservative interpolation in frequency of the UWB limits just below 10.6 GHz) serve as appropriate baselines for exemption of all low-power transmitters (UWB or otherwise). Note that co-existence studies are unlikely to be necessary for each and every incumbent service above 10.6 GHz, since many of these services are similar to those occupying the 3-10 GHz band where co-existence with UWB devices has already been demonstrated through compatibility studies.

3) *Yes in theory. However Ofcom should consider the difficulties of enforcement and measurement. If regulations/limits are not enforceable limits may be exceeded routinely (which in aggregate, could be harmful to overall capacity). Therefore it might be better to only exempt certain bands (e.g. 3.8-10.6GHz which have been thoroughly examined for UWB use.)*

Ofcom's view

The enforcement of any regulation for exemption of low-power transmitters would, as in the case of UWB regulation, be performed through the requirement for compliance with the specifications set out in the UK Interface Requirements, and implemented via a R&TTE compliance process. Also note that enforcement of such regulation at frequencies above 10.6 GHz would be no different from the enforcement of current UWB regulations (which also extends above 10.6 GHz, albeit with a flat mask) and is not expected to be problematic.

Ofcom will monitor the levels of interference generated by exempted low-power transmitters and will act appropriately as part of its statutory responsibilities for ensuring efficient use of the spectrum.

4) *Yes. However, we consider that the limits adopted for the purposes of exemption from licensing should be considered on a case-by-case basis for specific bands and taking full account of incumbent services. We do not agree with the view that the UWB limits on radiated power spectral density define a de facto lower bound for the licensing of radio devices because the limits for UWB are a compromise based on accommodating different implementations of UWB. Whilst we agree with the view that generic power spectral density lower bounds for the licensing of radio devices can be computed by defining constraints such that the transmissions do not cause harmful interference to incumbent services occupying the spectrum, we do not agree with a generic definition of acceptable interference. This is because the term acceptable interference is one intended solely for use in the context of agreement between coordinating administration (see Radio Regulation No. 1.168). As Ofcom identifies, licence-exempt services do not readily lend themselves to frequency coordination.*

Ofcom's view

See also items (1) and (2) above.

We agree that the level of acceptable received interference in a band depends on the nature of the services supported by the victim receivers operating within that band. However, ambient thermal noise represents an irreducible natural interference floor at the input of any radio receiver operating at any frequency band. As such, we believe that it is quite appropriate to define generic levels of acceptable interference as measured with respect to the thermal noise floor. Indeed, this approach is common practice in radio engineering.

5) *We would not support the license exempting of devices producing a power spectral density below certain limits. Measurement campaigns have shown that the impact on the reception of wanted signals by interferers is dependant on a number of factors including but not exclusively limited to the power spectral density limit.*

Ofcom's view

We do agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

6) *This appears very problematic and liable to result in harmful interference. We note the graph of Figure 7 in the consultation in which it is shown that other wideband systems utilise higher transmit powers. We do not see the relevance of this in the light of the proposal. Figure 7 clearly shows that the bands for these other higher power wideband services has been carefully chosen to avoid exactly the problems highlighted in this response and which protection would be lost in the event that an underlay approach were to be adopted. Furthermore and even more important, an examination of the transmit powers completely fails to properly encapsulate the fact that interference will occur due to the close proximity of the underlay service transmissions to the receivers of the primary service. We do share concerns on the commons/noise floor. For example, we believe that Ofcom has taken what was a 80-90% indoor use emission specification (going back to the EU/CEPT basis/assumptions) to effectively modify the entire outdoor noise floor. It should be noted that wideband transmissions have a higher capacity to interfere with receivers than do narrowband transmissions.*

Ofcom's view

Figure 7 of the LEFR indicates the EIRP spectral densities for a selection of non-UWB (bandwidths less than 50 MHz) licence-exempt short-range devices currently operating in the UK, many of which operate in close spectral proximity of (or sometimes even co-channel with) licensed services or military use. This figure shows the huge disparity (up to 12 orders of magnitude) which exists between the EIRP spectral densities of non-UWB licence-exempt devices and the UWB limits. This illustrates the extent to which the operation of UWB devices is limited to extremely short ranges, which in turn allows them to operate as an underlay with a very low probability of causing harmful interference towards incumbent services.

Furthermore, we fully agree that a small spatial separation between an underlay transmitter and an incumbent service's receiver might result in harmful interference. This has been accounted for in the LEFR, where it is demonstrated that the proposed limits on EIRP spectral density are derived such that harmful interference would be unlikely for separations as low as 0.15 metres.

Finally, we agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

7) *A full analysis is required before transmissions are exempted from licensing in bands which are already licensed or occupied by existing users. Section 7.2 of the consultation states that: "It is logical to conclude that any device that transmits at a power spectral density which is lower than the UWB limits would, at worst, cause as much interference as a UWB device, and certainly far less interference than the non-UWB licence-exempt short-range devices available today. Consequently, any such device, irrespective of its transmission bandwidth, would most likely be a candidate for licence-exemption." However the power spectral density limits have been derived based on assumptions regarding the characteristics of UWB devices e.g. with respect to the number of devices, deployment scenarios (UWB devices are assumed to be operated mainly indoor), signal*

structure including duty cycle. These assumptions are not likely to be the same for other transmissions. UWB has been studied on a band-by-band basis over many years to derive these power spectral density limits and should not be applied generally to all licence-exempt devices. Any additional increase of the noise level by new devices could cause interference or impact the capacity of existing radio systems leading to additional costs in infrastructure for mobile network operators. The limits may be acceptable from the perspective of UWB but should not simply be transposed to other licence exempt technologies without a full analysis of the impact to existing users of the radio spectrum and taking into account the characteristics of both the licence-exempt and existing systems. If non-UWB devices can not meet the UWB limits then there does not seem to be any point in setting general limits for licence exempt devices which could impact on existing users of the radio spectrum.

Ofcom's view

As implied in the last sentence of the above stakeholder response, today non-UWB licence-exempt short-range devices transmit at EIRP spectral densities that are significantly higher (typically 8 to 12 orders of magnitude) than those specified by the UWB limits (see Figure 7). This means that, if similar non-UWB devices were to transmit at EIRP spectral densities below the UWB limits then their operation would be restricted to extremely short ranges, and in all likelihood would not cause harmful interference toward any incumbent licensed services which they might underlay.

We therefore do not believe that the extension of licence-exempt regulations to low-power non-UWB devices would result in a material increase in interference beyond that which would be generated by UWB devices. In any case, Ofcom will monitor the levels of interference generated by exempted low-power transmitters (UWB or otherwise) and will act appropriately as part of its statutory responsibilities for ensuring efficient use of the spectrum.

We note that the UWB limits are technology neutral, but include operational restrictions (such as conditions for outdoor use and duty cycle) as well as limits on maximum EIRP spectral density. We accept that all such restrictions (and not just the power limits) should be satisfied for the exemption of non-UWB low-power transmitters.

Finally, there are a number of initiatives at European level considering the requirements for generic extensions of low-power transmitters. A number of these stem from Report 014[79] on spectrum usage for short-range devices (SRDs), which was prepared by the CEPT in response to a Mandate from the EC. This report made a number of recommendations, including the recommendation that CEPT investigates the possibility of developing limits below which a new class of generic ultra-low-power SRDs could exist without being subject to the usual regulatory arrangements. This report was accepted by the Commission and the CEPT is now taking steps to implement its recommendations. The subject is now a standing item on the agendas of the SRD Maintenance Group (set up by the CEPT to maintain Recommendation 70-03 on SRDs) and the UK will be pressing for action on these recommendations. Ofcom will support initiatives such as these through input documents and further studies.

8) *We agree that transmissions at levels below certain power spectral density limits may be exempt from licensing if they transmit in a band that is already licence exempt. We*

[79] "Development of a strategy to improve the effectiveness and flexibility of spectrum availability for short range devices (SRDs)", CEPT Report 014. See: http://www.ero.dk/.

believe that such equipment should not be allowed to operate in bands that are subject to any form of licensing. If popular licence exempt equipment is introduced in licensed bands there would be a high risk of interference to existing users caused by an increase in the noise floor due to high numbers of the product and the length of time it is used.

Ofcom's view

Based on EC Decision 2007/131/EC, sufficiently low-power UWB devices are already exempt from licensing even if they operate in licensed bands. The EIRP spectral density limits proposed in the LEFR, and the well-studied UWB limits upon which they are based, have been defined such that harmful interference to incumbent services is unlikely for realistic spatial separations and device densities. Ofcom will monitor the levels of interference generated by exempted low-power transmitters and will act appropriately as part of its statutory responsibilities for ensuring efficient use of the spectrum.

9) *In general we do not agree with the approach suggested. Many amateur receivers are high performance and thermal noise limited to enable weak-signal reception. The Ofcom graphs (notably Fig-7) suggest permitting a rise of 20 dB above the noise floor all the way down to the long range HF and VHF bands where we are already encountering significant rises in unintended emissions. The proposal therefore seems to give scope for further increases in harmful interference to licensed services and as such is unwelcome.*

Ofcom's view

See item (8) above.

Q9: Do you agree with the transmission limits proposed in this document?

1) *We note that the masks proposed by Ofcom above 10.6 GHz serve as guidelines only. They are not therefore proposed limits but guidelines. We consider that the limits adopted for the purposes of exemption from licensing should be considered on a case-by-case basis for specific bands and taking full account of incumbent services.*

Ofcom's view

Agreed. Any future authorisations by Ofcom of licence-exempt use will generally be subject to consultations with associated impact assessments, as appropriate, for the various bands and incumbents therein. We do, however, note that co-existence studies are unlikely to be necessary for each and every incumbent service above 10.6 GHz, since many of these services are similar to those occupying the 3-10 GHz band where co-existence with UWB devices has already been demonstrated through compatibility studies.

2) *Significant further work investing the effects on specific technologies is required to ensure that appropriate limits are defined.*

Ofcom's view

We agree that further study is required to identify the impact of low-power underlay transmissions on the types of incumbent services which currently occupy frequencies above 10.6 GHz. There are a number of initiatives at European level considering the requirements for generic licence-exemption of low-power transmitters, and Ofcom will support these initiatives through input documents and further studies.

However, we also believe that the methodology presented in the LEFR, based on an application-neutral and technology-neutral definition of acceptable interference, is the most efficient approach for the computation of underlay transmission limits over frequency ranges spanning many tens of GHz.

3) *In general, we could agree with the transmission limits proposed in the document, although we do wonder whether a 20 dB tightening of the permitted emissions is sufficient for those bands which are subject to Footnote 5.340 ("All emissions are prohibited in the following bands …"). Above 10.7 GHz, the Footnote is not protecting narrow bands which could be "accidentally" straddled by a UWB type device; it is protecting bands which may be several hundreds of Megahertz wide (e.g. 23.6 – 24.0 GHz), which might deserve greater protection.*

Ofcom's view

The UWB limits specify a maximum mean (peak) EIRP spectral density of −85 dBm/MHz (−45 dBm/MHz) at a frequency of 10.6 GHz and for frequencies beyond. These happen to be 20 dB lower than the (already low) UWB limits specified over the frequency range 8.5 to 10.6 GHz, and are assumed to be sufficient to protect the frequency range 10.68-10.7 GHz which is protected by Footnote 5.340. Given the increase of path loss as a function of frequency, a similar level of protection can be afforded to bands subject to Footnote 5.340 at frequencies above 10.7 GHz by interpolating (as a function of frequency) the UWB limits defined at 10.6 GHz.

4) *Note also that regarding the text above Figure 7, the high powers used by licence exempt devices in certain bands does not indicate that much lower values used in other, perhaps more sensitive, bands will be without problem, which is implied here. Devices in 2.4 GHz etc. are designed to cope with that environment.*

Ofcom's view

Figure 7 of the LEFR indicates the EIRP spectral densities for a selection of non-UWB (i.e. channel bandwidths of less than 50 MHz) licence-exempt short-range devices currently operating in the UK, many of which operate in close spectral proximity of (or sometimes even co-channel with) licensed services or military use. This figure illustrates the huge disparity (up to 12 orders of magnitude) which exists between the EIRP spectral densities of today's non-UWB licence-exempt devices and the UWB limits. It is precisely this disparity which allows UWB devices to operate as an underlay with a low probability of causing harmful interference towards incumbent services.

5) *The greatest difficulty would appear however to relate to equipment that could be used both indoors and outdoors where power limitations/control suitable for indoor applications could be detrimental if the unit was then used in an outdoor environment.*

Ofcom's view

This issue is not unique to the licence-exemption of low-power transmitters as proposed in the LEFR. The same issue also applies to authorised licence-exempt UWB devices in operation today. According to the EC Decision of 21st February 2007, such devices are subject to certain restrictions with regards to how they may be deployed in outdoor environments. In circumstances where these restrictions are not adhered to, the offending devices would not be compliant with EU regulations, and would therefore be subject to appropriate investigation and enforcement action by the relevant national regulatory bodies.

6) *We note that even the EU Decision had many caveats against the simple adoption of such limits. We note that even this outcome was the result of intense debate with the deployment of UWB in some of the bands being agreed only under the condition that it be date-limited to a point at which it was estimated that the intended service would be deployed to a much greater extent than today. Thus the UWB would be withdrawn to avoid harmful interference with the intended service as it comes on stream. The application of strict limitations in duty cycle were intended to permit certain specific applications where it was thought the potential loss of up to 18 seconds of service an hour to be less harmful (but note that 600MHz of spectrum was even so time-limited in availability for UWB). Our conclusion is that the Framework should apply at least all these restrictions or their equivalent as required under the Decision.*

Ofcom's view

We do agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

7) *No. Ofcom have taken the UWB emission limits out of the context they were developed in where they have several caveats and assumptions in respect to mitigation, duty cycle, sunset clauses, limited outdoor use etc. In effect a largely indoor standard is being used to support a unilateral redefinition of the outdoor noise floor. This would be particularly risky as the lower microwave bands offer low loss long range outdoor propagation and would affect both amateur and commercial services. This approach is entirely unwelcome. We also feel it is counter to the carefully balanced regime for UWB that ERO TG3 has developed and is the topic of implementation via a separate Ofcom consultation. In the high mm-Wave and THz bands their may be some scope for this approach due to increases in thermal background/sky noise but any such approach should be fully studied and consulted upon at the European level. It is also unclear how any such new limits would integrate with the EU EMC Directive.*

Ofcom's view

We do agree that the UWB limits on EIRP spectral density, alone, are not sufficient for exemption of low-power non-UWB devices, and that all other UWB operational constraints (e.g. restrictions on outdoor use) as mandated in Decision 2007/131/EC should also apply. We have now clarified this in the LEFR Statement.

We do not believe that it is necessary for the LEFR proposals on licence-exemption of low-power transmitters to be integrated with the EU EMC Directive, as they address intentional and unintentional radiations respectively.

8) *We do not agree with these limits as they are based on those determined for UWB which were compromise levels agreed on the basis of the use of the technology and not on the absolute protection limits required.*

Ofcom's view

See Ofcom's views on responses to Question 8.

Q10: Do you agree with the harmonisation strategy discussed above in the context of licence-exempt devices?

While almost all responses were supportive of the proposed harmonisation strategy, the following point was raised:

1) *It is extremely difficult to reconcile the international harmonisation strategy with the policy of grouping applications into multiple classes directed towards certain bands. The problem being that unless this Framework is also adopted internationally in the same manner with the same outcomes, the UK could become technologically isolated. We note that an additional major advantage of harmonisation is in the convenience it provides to devices or users who roam internationally. It is generally accepted that harmonization will increase the global market for some unlicensed devices and may help reduce the cost for even non-roaming devices, but that this is only a valid expectation if harmonization is done in such a manner that there are no technical difference with other regions of the world.*

Ofcom's view

As explained in the LEFR, Ofcom believes that harmonisation is in general better achieved through market mechanisms than by regulatory intervention. However, the application of market mechanisms to licence-exempt applications is problematic in this context. This is because, due to the inability of individual users to acquire access to spectrum via tradable licences, the regulator needs to intervene to a) identify spectrum for licence-exempt use, and b) establish rules for its management. Therefore, Ofcom accepts that decisions on harmonisation of spectrum for licence-exempt applications often cannot be left to market mechanisms and require regulatory intervention in the form of mandatory harmonisation.

Note that, by allowing multiple applications to share the same frequencies, the spectrum commons model actually enables licence-exempt use of the spectrum to be adapted to the market needs of individual nation states. Furthermore, it should be clarified that the "grouping" of applications into different classes of spectrum commons would not be in the form of an explicit classification, but would be implemented indirectly through technical politeness rules governing the operation of radio transmitters in each spectrum commons. Similar rules already apply today in Europe in the form of European Harmonised Standards and the R&TTE Directive.

Given the above benefits, we hope that the policy of using the spectrum commons model as the preferred approach for licence-exempt use of spectrum will be adopted internationally, and that classes of spectrum commons will be established world-wide through harmonised standards and norms. Ofcom will engage in international debate with its partners in order to promote harmonisation through such standards.

Q11: Do you agree with the view that no additional regulatory instruments, beyond those available today, are required for the protection of licence-exempt equipment?

While most stakeholders agreed with the above view, the following points were raised:

1) *There is a risk that, as licence-exempt products become more popular, are used more, and are used in the more popular licence-exempt bands, there could be considerable in-band interference and Ofcom might then be obliged to deal with such a situation.*

Ofcom's view

Studies[80] commissioned by Ofcom have indicated that, at least today, spectrum bands used by licence-exempt devices are far from congested. We do, however, accept that the situation might change at some point in the future, and that the proliferation of licence-exempt devices might result in congestion and low quality of service in certain bands. If the applications are of sufficiently high economic value then it will be important that suitable alternative frequencies (and the necessary technologies) are then available to allow a frequency migration path, and to mitigate the impact of such congestion. Ofcom will continue to monitor congestion and act appropriately, as part of its statutory responsibilities for ensuring efficient use of the spectrum. We do not envisage that this would require any additional regulatory instruments.

2) *The only regulatory instruments or other approaches that would be welcome would be those that favour licensed services. We encourage Ofcom to consider and promote, for example politer protocols, improved SRD receiver standards, frequency migration to more suitable bands etc.*

Ofcom's view

As pointed out in the LEFR, any future authorisations by Ofcom of licence-exempt use will generally be subject to specific consultations with associated impact assessments, as appropriate, for the concerned bands. It is therefore unlikely that there will be authorisations which would cause harmful interference to licensed services.

3) *With increasing liberalisation (trading, increasing power levels through licence changes etc) there is a new risk to licence-exempt devices from adjacent bands. Ofcom (or the applicants?) needs to consider this when considering "change of use" applications.*

Ofcom's view

Agreed. The introduction of flexible Wireless Telegraphy licenses requires that any changes in spectrum usage rights be negotiated and approved among licensees in adjacent bands in order to ensure that harmful interference does not arise.

Given that licence-exempt users are typically not in a position to partake in such negotiations, Ofcom will act on their behalf to ensure that any changes in the spectrum usage rights proposed by the licensee do not result in increased levels of harmful interference. Ofcom will do this as part of its statutory responsibilities for ensuring efficient use of the spectrum. We do not envisage that this would require any additional regulatory instruments.

[80] "Autonomous interference monitoring system Phase 2," Final report, Mass Consultants Limited, March 2007. See: http://www.ofcom.org.uk/research/technology/overview/state_use/aims2/.

A4.4 Other considerations raised by respondents

Although the LEFR posed no questions on the discussions in Section 3.4 relating to the economic value of licence-exempt use of spectrum, a number of stakeholders commented on some of the arguments presented in the text. These comments fall under the following three themes:

- Predicted economic values of specific LE applications, public-access Wi-Fi and cellular communications;
- Mix of licensed and licence-exempt usages across the spectrum;
- Interventionist versus market-led approaches to spectrum management;

The points raised within each theme are summarised and addressed below.

1) Predicted economic values of specific LE applications, public-access Wi-Fi, and cellular communications

Three respondents commented on the economic values and the indicative comparison of values forecasted to be generated by cellular mobile and public-access Wi-Fi over the next 20 years reported in Table 2.

The comments include the following:

- The home data networking figures in Table 1 do not include the value of entertainment-related home networking and this value is expected to be significant. Therefore home data networking valuation figures should be interpreted with caution.
- The value figures for cellular were derived in a different study and hence the comparison is not considered valid.
- Due to the assumptions required to develop 20-year forecasts, the calculations are associated with significant uncertainty; the resulting figures are therefore not reliable and those used in the comparison are in fact of a same order of magnitude, thereby weakening the conclusion that cellular mobile generates significantly more value per MHz than public access Wi-Fi.
- The figures reported in Table 2 for public-access Wi-Fi are lower than those derived by Indepen and used in Table 1; in other words, Ofcom’s suggestion that “the per MHz value of cellular is higher than that of public-access Wi-Fi” is less optimistic than that reached by the consultants. It is not clear why this is the case since not all the methodologies and models have been published.
- If these calculations and comparison had been used to allocate spectrum today to Wi-Fi, Bluetooth, etc., these applications would not have been given any spectrum.
- More work and transparency is required in order to strengthen the evidence, especially if the objective is to reach a decision about whether to allocate a specific spectrum to license or licence-exempt use. In particular the issue of innovation and social value generated by licence-exempt applications should be taken into account.

Ofcom's view

As a first step to addressing these points it is worth explaining what the presented valuation figures are, and what they can and cannot show. The objective of the valuation exercise reported in Table 1 is to show the value that various licence-exempt applications are expected to generate in the next 20 years. The objective of the indicative comparison reported in Table 2 is to put the valuation figures into perspective with respect to licensed applications.

The figures reported in both tables represent the value that these applications are expected to generate in the next 20 years if the forecasted demand is satisfied (i.e. sufficient spectrum is assumed to be available). If the application provides a service that does not yet exist, it is the total value created by this service that is reported. If the application enables the provision of a better service, it is the additional value generated by that application that is reported.

Now that the context for these valuation figures has been clarified, the specific comments are addressed in order.

Given the specific purpose of the valuation exercise, and due to limited data availability and time, it was decided that home entertainment networking would not be included in the valuation of home data networking. As a result, Ofcom agrees that this home data networking valuation should be used with caution.

The figures for cellular were extracted from studies which have been undertaken to support a number of Ofcom's current spectrum award projects. They also represent net present values, and hence the comparison can be considered as valid.

Ofcom notes the comment relating to the impact of uncertainty on the reliability of valuation figures and the disagreement on the force of the conclusion derived from the indicative comparison, namely that the cellular mobile market can be expected to "generate significantly more economic value".

Any forecasting of value over 20 years relies on assumptions and is surrounded by uncertainty, especially when it concerns innovations as is the case with some of the applications under consideration. The extent to which the specific figures can be relied upon depends on the use these figures are put to. Ofcom has not relied on these figures or indicative comparisons to reach any decision or to form any proposal in the LEFR. Therefore Ofcom is not unduly concerned by the level of uncertainty present in these figures, especially since we have indicated that more refined valuations would be produced when considering specific bands or issues.

Concerning the question of whether or not the figures justify the statement "significantly more economic value", Ofcom remains inclined to view the differences between the economic values of cellular mobile and public-access Wi-Fi as meaningful. Indeed the former is estimated to be higher than the latter by 50% to 400% depending on the demand elasticity.

The relationship between the values quoted in Table 2 for public-access Wi-Fi (namely £65bn and £105bn) and those calculated by Indepen *et al* as reported in Table 1 (namely £9bn, £68bn, and £239bn) can be explained in terms of the interplay between two methodological steps.

Firstly, Ofcom decided to report in Table 2 the economic values for two levels of demand elasticity ($\varepsilon = -0.33$ and $\varepsilon = -1$), since these results are sensitive to the demand elasticity assumed.

Secondly, Ofcom chose to average the public-access Wi-Fi economic values across the three demand scenarios – something that is signalled in Footnote 17 of the LEFR Statement. This averaging was performed in order to allow a meaningful comparison with cellular mobile.

The figures in Table 1 for public-access Wi-Fi (£9bn, £68bn, and £239bn) are derived under the assumption of a demand elasticity of $\varepsilon = -0.33$. The average of these figures over the three demand scenarios is equal to £105bn, which is the figure reported in the fourth row of Table 2. The figure in the third row of Table 2 for public-access Wi-Fi (£65bn), however, is derived for a demand elasticity of $\varepsilon = -1$, and is consequently smaller. This is because a higher value of demand elasticity in absolute terms refers to a situation in which there is a higher risk of substitution to alternative products and hence a lower consumer surplus from that product.

In order to decide whether or not to allocate some specific spectrum for use by licence-exempt devices, Ofcom would carry out a different comparison, namely an economic value test, which compares incremental values for the specific frequencies under consideration taking into account spectrum constraints. Therefore the indicative comparison reported in Table 2 would not be relevant.

An economic value test captures the producer surplus and the consumer surplus, as well as the innovation and social values of the applications. To derive the consumer surplus requires identifying all consumers, something that might be difficult when they are scattered and less vocal, as is often the case with licence-exempt users. Ofcom is aware of the risk of underestimating the demand that might result and the impact of innovation and social values. Ofcom acknowledges that these are difficult issues that any economic value test for a particular band should address.

2) Mix of licensed and licence-exempt usages across the spectrum

Another comment related to a different aspect of spectrum allocation to licensed and licence-exempt usages. It stated that a right balance of spectrum management is to have a judicious mix of licensed and licence-exempt uses in all major frequencies.

Ofcom's view

Ofcom re-affirms that, as stated in the SFR, it will use economic value tests in order to assign spectrum to different uses. This approach investigates which application generates the highest incremental value in any specific spectrum band. Since radio propagation characteristics vary depending on the frequencies at stake, it is reasonable to expect that some bands might be more suitable for licence-exempt applications and others for licensed applications. Therefore this approach may bring about a mix of licensed and licence-exempt uses that differs across the frequency spectrum.

3) Interventionist versus market-led approaches to spectrum management

A respondent commented that auctions are interventionist because they require decisions about how to package spectrum, and added that spectrum commons shares features of market-led mechanisms because it is the market that decides which applications succeed.

Ofcom's view

This combination of remarks seems to suggest that the respondent wished to make the point that not everything relating to licensing should be seen as market-led, and that similarly, not everything linked to licence-exemption should be viewed as interventionist.

First it is worth clarifying that the decision for spectrum to be assigned to licensed or licence-exempt uses should not be confused with the auction process or the spectrum commons model. Indeed the assignment decision precedes the stage where auctions take place or where licence-exempt applications emerge as driven by the market. The assignment decisions are performed by regulatory bodies and rely on the outcome of economic value tests. The allocation of the assigned spectrum to various applications takes place afterwards. In the case of licensed use this allocation is usually performed via auctions or beauty contests, which Ofcom manages. For licence-exempt applications, Ofcom imposes specific technical (politeness) rules, subject to which, all compliant devices compete for the use of the spectrum. Therefore, in both cases Ofcom is involved in a spectrum assignment decision which is interventionist by definition, and which is then followed by allocation to various applications (through auctions or exemption rules) where market forces drive the process.

Second, it is worth noting that with the development of spectrum liberalisation and trading, licenses that are now allocated through auctions are designed to be flexible and tradable. This is aimed at reducing the impact of the initial spectrum packaging decision made by Ofcom on how spectrum uses evolve over time.

Annex 5

Glossary

Bluetooth	A technical standard for short-range wireless communications between devices such as mobile phones and headsets. Also known as IEEE 802.15.1.
Broadband fixed wireless access (BWFA)	A means of connecting to homes and offices using wireless, as opposed to copper wires or fibre optics.
CEPT	The European Conference of Postal and Telecommunications administrations. A Europe-wide organisation whose aims include harmonised use of the spectrum.
Cognitive Radio (CR)	A radio which can sense when portions of spectrum are not being used, adapt itself to fit the available unused spectrum, transmit briefly and then move on to the next available portion of spectrum. Also sometimes referred to as opportunistic (overlay) spectrum access.
Command & control	A way of managing the radio spectrum where the regulator makes all the key decisions including what a portion of spectrum is to be used for and who can use it.
DECT	The Digital European Cordless Telephone. A cordless phone technical standard widely deployed in homes and offices.
EC	The European Commission. The executive body of the European Union (EU).
GSM	The Global System for Mobile Communications. The existing (second generation) cellular technology widely deployed around the world.
HDTV	High-definition television.
ITU	The International Telecommunication Union. A body that seeks to harmonise telecommunication activities around the world, including access to spectrum. The ITU-R Radio Regulations specify, among others, frequency allocations for various applications.
Link-budget	A calculation of how radiated power decreases as it propagates over the air and through electronic components prior to the signal being processed at the receiver.
Market mechanisms	An approach to managing spectrum where key decisions are made by the licence holders acting to buy and sell spectrum, rather than by the regulator.
Medium access control layer (MAC)	Operations performed by radio communication devices in order to secure and manage reliable access to the radio resource (e.g. data re-transmission, polite protocols).
MoD	Ministry of Defence (UK).

Physical layer (PHY)	Operations performed by radio communication devices in order to prepare bits of information for transmission via radio waves (e.g. modulation/de-modulation and error-correction coding/decoding).
Polite protocols	Mechanisms whereby a device modifies its transmission characteristics when it discovers the existence of transmissions by other devices, thereby allowing the radio resource to be shared in a fair manner. Also known as polite etiquettes.
Politeness rules	Limits on radiated power signatures.
Power signature	Power profile as a function of frequency, time, and space.
Protocol stack	Complete suite of operations performed by a radio communication device, consisting of multiple layers such as the PHY and MAC.
Radiated power	The strength of the radio wave transmission. The greater the radiated power, the further the radio wave will travel, but this in turn will increase the chances of causing interference.
Spectrum	The set of all radio frequencies.
Spectrum commons	A set of radio frequencies where multiple wireless applications are allowed to share the spectrum on a co-channel basis. This is the opposite of application-specific spectrum, where spectrum is reserved for exclusive use by a single application.
Spectrum liberalisation	Allowing licence holders to change the use to which they put their spectrum, within constraints to prevent interference.
Spectrum trading	The ability of users to buy and sell spectrum licences without prior approval from the regulator.
SRD	Short range device.
TETRA	The Terrestrial Trunked Radio system. A technical standard for the type of radios used by emergency services and some business users.
UWB	Ultra-wideband. A technology that transmits at high data rates over short distances by using low-power signals spread across many different parts of the spectrum. Such sharing of the spectrum with incumbent radio services is also sometimes referred to as an underlay.
Wi-Fi	A WLAN technology used to connect computers wirelessly in homes, offices and increasingly in “hotspot” areas such as airports. Also known as IEEE 802.11.
WLAN	Wireless local area network. Consists of one or more mobile stations with wireless connection to a nearby access point.
WPAN	Wireless personal area network. Consists of short-range links between various consumer devices.