OFFICE OF COMMUNICATIONS

Licence-Exemption Framework Review

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

Consultation

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Contents

Foreword

Management of spectrum broadly falls into two discrete 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 broadly reside, including the auctions programme for key bands such as 2.6 GHz and the 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 a range of stakeholders from industry to 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 an increasing plethora of 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.

There are relatively few linkages between this document and other spectrum-related initiatives in Ofcom. Most of the work on 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 liberated through digital switchover. 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 ask whether a similar approach should be adopted for all low-power transmissions, and whether the transmission limits should be relaxed 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 can have an impact on licensed users.

This document 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, as a result of this consultation, we decide that certain changes will be in line with our statutory duties we will address these through further consultations along with impact assessments as appropriate.

Section 1
Executive summary

1.1 Introduction – What this consultation 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 outline, 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 the spectrum can be shared by as wide a range as possible of devices, subject to regulator-defined constraints on radiated power characteristics, and polite protocols defined via harmonised technical standards. 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 technical standards at the specification 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 characteristics, as enforced through regulator-defined constraints on radiated power. In summary, each class would be associated with a particular portion of the spectrum, with licence-exempt devices subject to limits on radiated power (defined by the regulator), and one or more polite protocols (authorised by the regulator but defined by standards bodies).

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 imminent 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 coordinate 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; or b) explicit interference co-ordination among multiple 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 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). 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 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. 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 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 one may specify generic power limits, such that transmissions at levels below these limits may be exempt from licensing. We propose that such limits could be equivalent to the UWB limits, with a relaxation for frequencies above 10.6 GHz to account for increased path loss with frequency.

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 and 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[2].

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[3], 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.

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

3 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 for licence-exempt devices should be used based on the spectrum commons model, wherein multiple applications share the same frequencies, subject to well-defined constraints. Exclusive licence-exempt use of spectrum by a specific application should only be considered in cases where technical constraints, international obligations, or safety issues require such use.

2) Multiple classes of spectrum commons should be considered, with regulator-defined high-level *politeness rules*[4] restricting the diversity of applications within each class (thereby easing co-existence), and with authorised *polite protocols*[5] micro-managing intra- and inter-application interference. The specification of polite protocols should be undertaken within appropriate standardisation bodies and is beyond the scope of the regulator.

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.

4) The status of operational light-licensed regimes should be regularly reviewed with a view to conversion to licence-exemption once autonomous self-coordination among the light-licensed radio devices becomes feasible.

5) All spectrum in the 275–1000 GHz frequency range, should be considered for licence-exemption, 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 licence-exempt usage and 40 GHz of unused spectrum should be considered for light-licensed usage.

7) In the 40–105 GHz frequency range, the 59–64 GHz band (currently managed jointly by the MoD and Ofcom)[6], and the 102–105 GHz band (currently unused) should be considered for use by licence-exempt devices.

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4 Constraints on radiated power characteristics as functions of frequency, time, and space.

5 Techniques implemented at the physical layer (PHY) and/or medium access control (MAC) layers 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.

6 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[7].

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.

[7] 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.

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.

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 proposals 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 proposals 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 also propose to exempt from licensing all devices which transmit below specific power levels. These proposals would 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

This consultation, published on 12 April 2007, lasts for 10 weeks. The closing date for responses is 21 June 2007.

We warmly welcome stakeholder comments on the proposals presented in this document. We recognise the technical complexity and importance of the issues, and we will conduct stakeholder engagements during spring 2007 to allow stakeholders to express their views on the proposals we have put forward.

Alongside this document, we are also publishing a number of supporting documents, including reports by consultants covering a range of technical issues, as well as a plain English summary of the consultation. These are available on the Ofcom website at http://www.ofcom.org.uk/consult/condocs/lefr/.

We expect to release a statement on this consultation around October 2007, having taken into account any stakeholder responses to our proposals. Based on the results of this consultation, we also expect to publish in the future more detailed consultations on some of the specific issues addressed in this document – such as detailed proposals on implementation plans.

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 recommendations and consultation questions for each issue. Ofcom's views on licence-exemption are summarised in Section 10.

Annexes 1 to 3 contain guidelines for responding to this consultation, with a list of consultation questions provided in Annex 4. Ofcom will revise and re-issue this document according to feedback received during the consultation process. Impact assessments for a number of issues examined in this document are presented in Annex 5. Annexes 6 and 7 contain technical analysis of the spectrum commons model, and the aggregation of interference due to low-power transmitters respectively. Finally, a glossary of terms is provided in Annex 8.

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[8]:

- 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.

[8] The spectrum percentages quoted where 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-based* 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 in order to allow licence-exempt usage to “naturally” decline within the band.[9]

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 explore options for management of spectrum that is allocated for use by licence-exempt devices. In all cases when exploring these options we will be guided by our primary duty of maximising the efficiency of the use of spectrum.

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 purchase, and potential trading, of spectrum by operators of wireless systems. An example is the use of spectrum by operators of cellular communication networks[10]. 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.

[9] 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.

[10] 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.

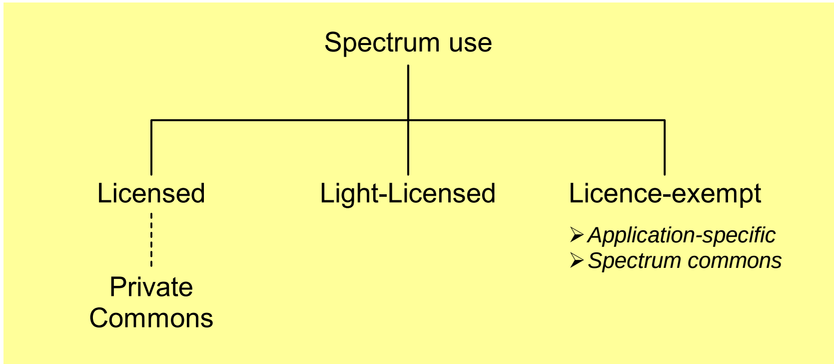

Figure 1. Nomenclature.

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 and technical standards.

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[11]:

> "*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 proposals presented in this consultation document are consistent with Ofcom's statutory duties and do 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.

[11] 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.

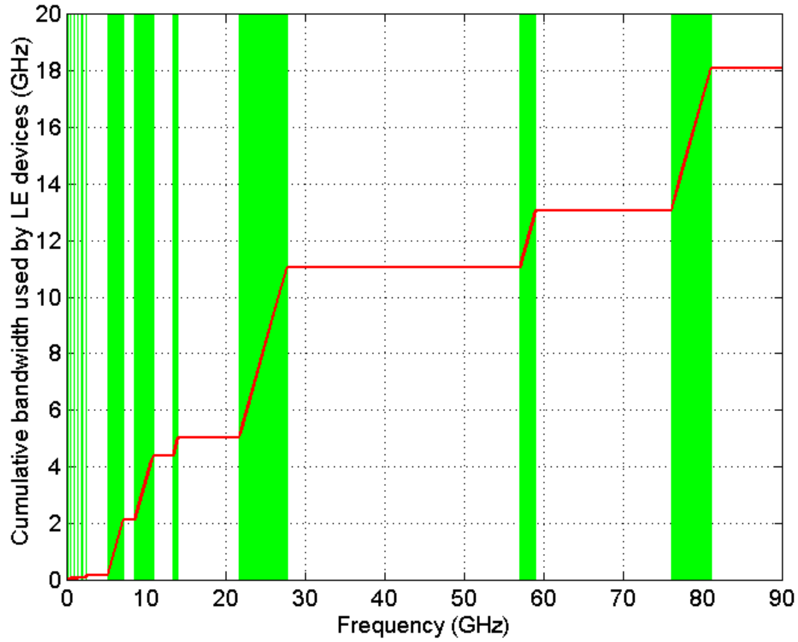

Figure 2. Distribution of spectrum used by licence-exempt (LE) devices.

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. Furthermore, since alternative options for spectrum use are available, an incremental value approach is often adopted[12].

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 usage as compared to the case where the application does not emerge at all.

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

[12] 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 often refers to a situation in which an application does not emerge at all (which may happen if the application does not get access to spectrum) or in which the application is assigned a different portion of spectrum.

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.

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[13].

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 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[14]	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.

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

[14] 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.

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.

	NPV (£bn) over 20 years for elasticity of demand ε[15]		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[16]		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

[15] 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.

[16] 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.

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.

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[17], 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

[17] 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 signature (i.e. power profile as a function of frequency, time and space).

mutual co-channel co-existence. Today, these applications operate in a mixture of spectrum commons and (less frequently) application-specific spectrum.
Examples of spectrum commons include several allocations in the 868–870 MHz band[18] for licence-exempt non-specific short-range devices[19], 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, as well as an invariably 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.

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 also 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

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

[19] These typically operate based on the generic European harmonised standards, currently covering frequencies from 9 kHz up to 40 GHz.

regulator may soon be made obsolete. Finally, 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, in the 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 (regulator-defined) high-level *politeness rules*[20] and (standards-defined) *polite protocols*[21] and interference-avoidance mechanisms, 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 a guaranteed mechanism for 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.

[20] Constraints on radiated power characteristics as functions of frequency, time, and space.

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

bits/s/Hz) which is greater than that of an application-specific allocation by a factor equal to the number of sharing applications[22].

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 application-specific allocation, as well as a lower tail which, if untreated, can extend towards zero. There are two key mechanisms for mitigating the impact of the lower tail.

Polite protocols have emerged as a powerful tool for the de-centralised mitigation of interference among wireless transceivers. The most well known is 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).

Frequency agility is another 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[23]. 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.

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. Technologies such as polite protocols and frequency-agile transceivers 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 6) 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

[22] See Annex 6, “Spectral efficiency of the spectrum commons”.

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

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[24] 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 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. In this pragmatic approach, the applications allowed into a specific class of spectrum commons are constrained to have similar characteristics, thereby avoiding interference issues among wildly diverse applications. Each class would be associated with a particular portion of the spectrum, with licence-exempt devices subject to limits on radiated power (defined by the regulator), and one or more authorised polite protocols (defined by standards bodies).

For example, in one class of spectrum commons the (regulator-defined) high-level limits or politeness rules may only permit ultra-low radiated power signatures. As a result, (standards-defined) explicit polite protocols or interference mitigation mechanisms at the lower layers of the radio protocol stacks may not be necessary in this class.

In a different class of spectrum commons, the (regulator-defined) high-level politeness rules may allow greater radiated power signatures, in which case it would be up to the radio standardisation bodies to specify appropriate polite protocols and interference mitigation mechanisms to permit co-existence.

The high-level politeness rules for each class of spectrum commons would be defined by the regulator, in consultation with the stakeholders. The regulator would also need to authorise the use of any standardised polite protocols within a spectrum commons. Based on their technical requirements, different applications would then utilise the appropriate authorised technologies and deploy in the most suitable class of spectrum commons.

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[24] 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.

Note that communications range is directly related to 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.

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. Exclusive licence-exempt use of spectrum by a specific application should only be considered in cases where technical constraints, international obligations, or safety issues require such use[25].

2) It is recommended that multiple classes of spectrum commons be defined, with regulator-defined high-level politeness rules limiting the diversity of applications within each class, and authorised standards-defined 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).

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?

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

[25] 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[26]:

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

- 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 5525–5875 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 data base are valuable tools for the efficient implementation of spectrum re-farming.

[26] 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.

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 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 this section, the characteristics and merits of light-licensing are compared and contrasted with those of licence-exemption. This is followed by a look at the future evolution of the two approaches, and a presentation of guidelines as to where one approach is preferred over the other.

5.2 Comparison

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 perform interference analysis in an efficient manner. 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 high-level politeness rules[27] 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[28] 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.

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27 Constraints on radiated power characteristics as functions of frequency, time, and space.

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

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[29], 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.

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[30]. This is quite independent of the technical feasibility of clearing the spectrum, the latter being the main concern with 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.

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[31].

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[29] 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.

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

[31] 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, they are also designed (by virtue of their low transmit power spectral density) not to case harmful interference.

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[32].

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 explicit co-ordination among operators of fixed radio links. In time, with advances in the state of the art in self-deployment and sensing 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 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 legacy (primary) licensed radio applications which 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 distinct types of application. 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.

2) It is recommended that the status of operational light-licensed regimes be regularly reviewed, with a view to conversion to licence-exemption[33] once autonomous and

[32] 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.

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

dynamic self-coordination among the light-licensed radio devices is technologically feasible.

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

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

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[34] 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[35]. 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

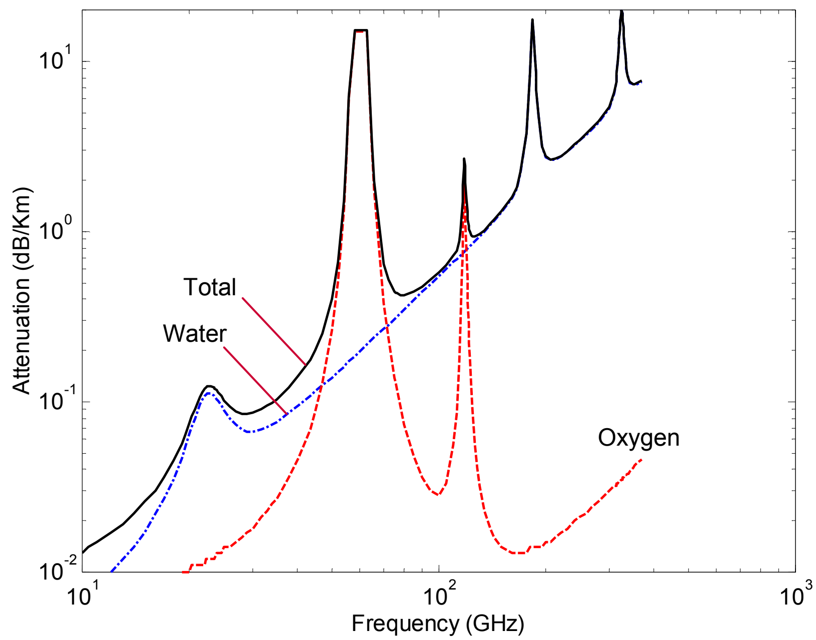
   High-gain antennas are increasingly used at higher frequencies in order to improve the link-budget. To this end, antenna patterns are designed to be highly directional, with beam-widths of several degrees not uncommon at tens of GHz. This helps to limit the spatial-signature of a transmitter's radiation, 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.

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

[35] "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.

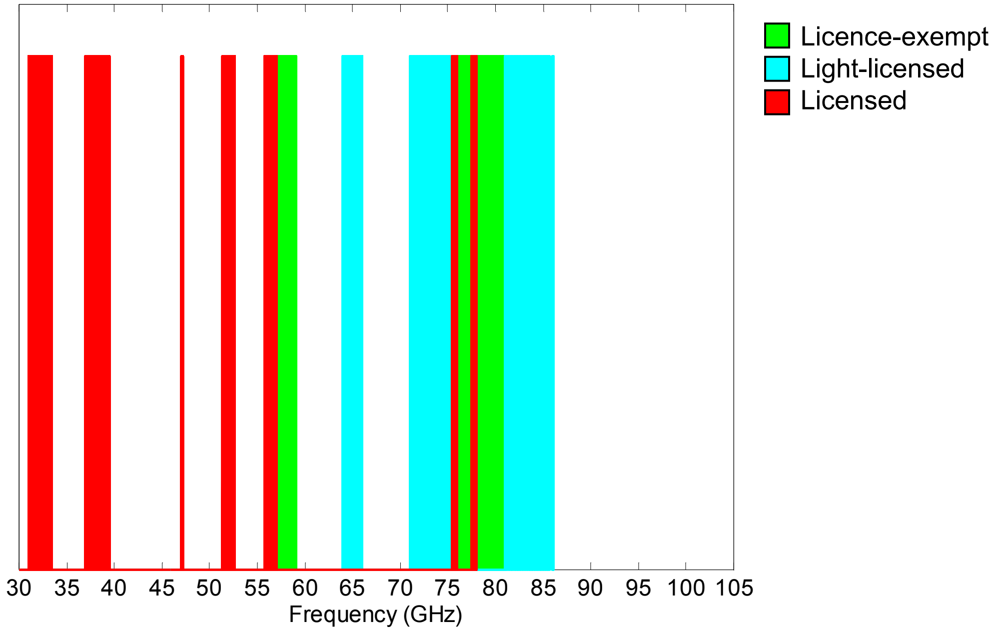


Figure 4. Mix of licensing regimes above 30 GHz.

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[36]. Furthermore, there is no intrinsic reason why such devices should be more expensive than lower-frequency microwaves devices.

[36] "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/.

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.

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[37]. 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*[38], is the preferred option for the above first

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37 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 2006.

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/.

38 Constraints on radiated power characteristics as functions of frequency, time, and space.

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 will naturally evolve toward licence-exemption.

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[39].

[39] 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.

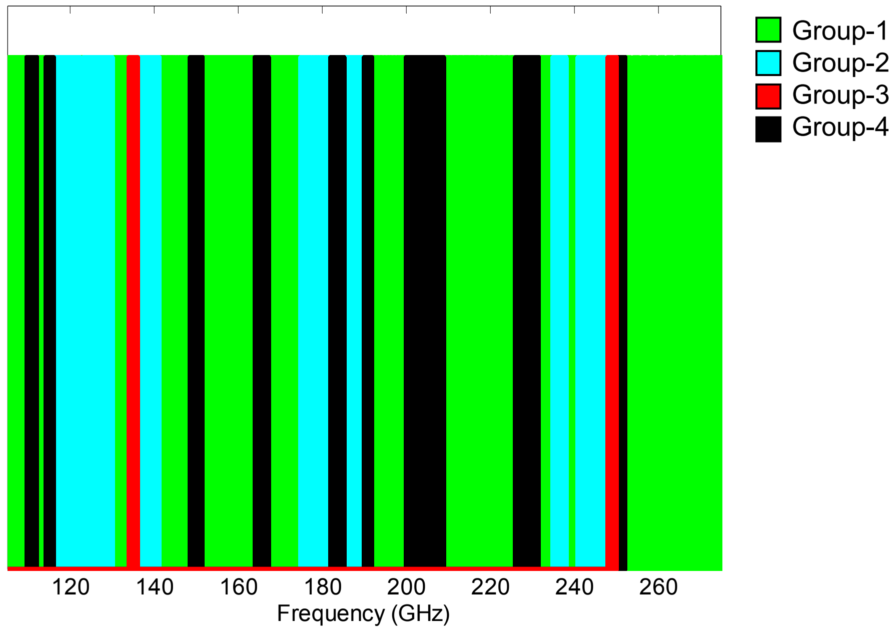

Figure 5. Frequency allocations 105–275 GHz.

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.

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[40].

[40] 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.

6.2.2 Conclusions and recommendations

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

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[41].

We do have a preference for Option-2 in the short- to medium-term. Licence exemption within multiple classes of spectrum commons[42] subject to (regulator-defined) high-level politeness rules[43] 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 regime can 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 licence-exempt usage, and 40 GHz of unused spectrum (Group-2) be considered for light-licensed usage[44].

2) It is recommended that all spectrum in the range 275–1000 GHz be considered for full licence-exemption, with the exclusion of spectral line measurement frequencies specified by Footnote 5.565.

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41 "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/.

42 See Section 4 for a discussion on spectrum commons.

43 Constraints on radiated power characteristics as functions of frequency, time, and space.

44 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.

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?

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

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[45]. 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[46]	
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.

[45] "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/.

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

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)[47];
2) used by radio astronomy services, passive services, and licensed applications such as point-to-point fixed links, and amateur use (5.15 GHz)[48];
3) managed by the MoD (or jointly with Ofcom) for which there is currently no significant industrial demand for civilian applications (6.5 GHz)[49]; and
4) already assigned for licence-exempt use (7 GHz)[50].

The above bands are depicted in Figure 7.

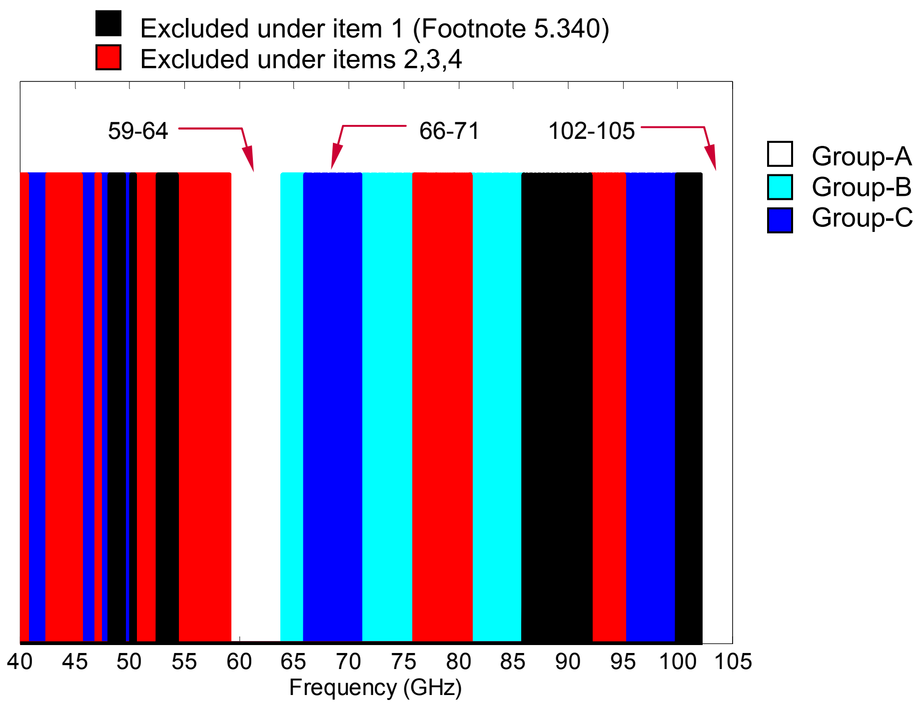

Figure 6. Spectrum potentially available for future applications in the 40–105 GHz band.

47 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.

48 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.

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

50 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.

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[51].

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.

[51] 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.

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.

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?

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[52].

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[53]. 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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52 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 will not be 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.

53 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 technical 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 band 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[54].

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	–45
3.8 to 4.2	–70	–30
4.2 to 4.8	–70[55]	–30[56]
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 licence-exempt short-range devices in the UK[57]. 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.

[54] 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.

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

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

[57] "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 devices transmit at power spectral densities which are at least two orders of magnitude (20 dB), and typically four to six orders of magnitude (40-60 dB) above the UWB specifications.

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.

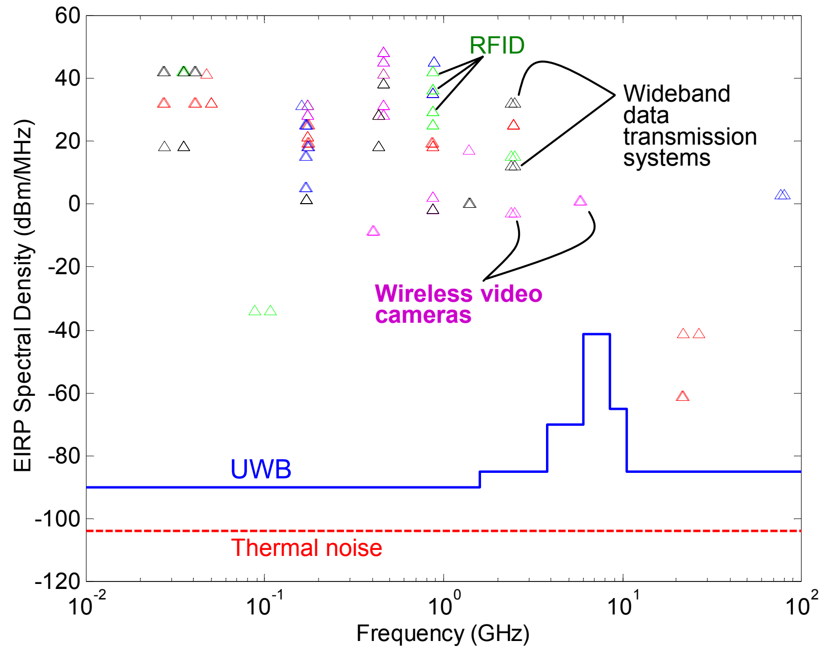

Figure 7. Mean EIRP spectral density limits for UWB devices, and a selection of non-UWB short-range devices.

It is interesting to note that a communication device which transmits at a power spectral density lower than the UWB limits is, by necessity, typically 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 a broad 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 7). 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[58]. This implies that ever increasing EIRP spectral densities can be tolerated at higher frequencies, with incumbent receivers still only experiencing 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.

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

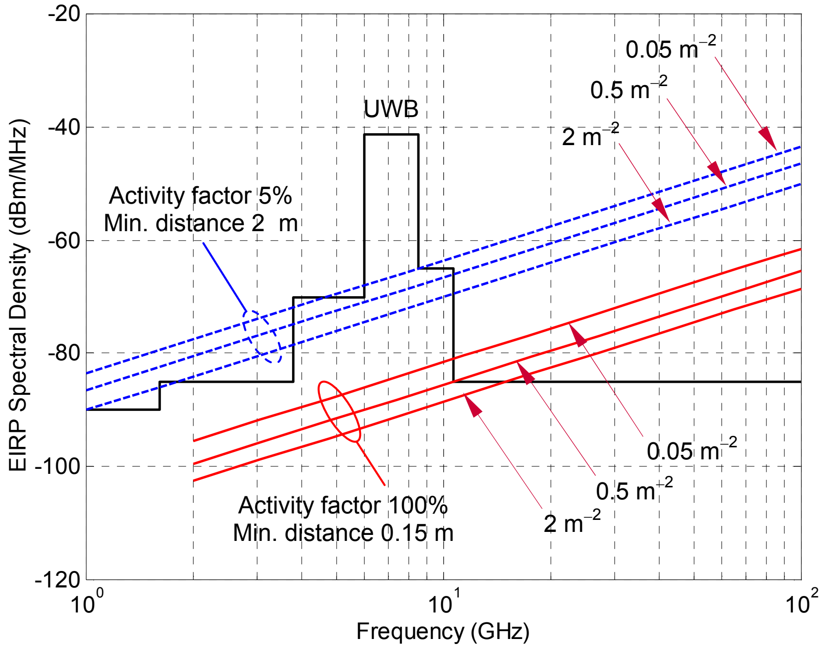

Figure 8. Limits on mean EIRP spectral density, subject to constraints on aggregate interference.

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[59]. 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.

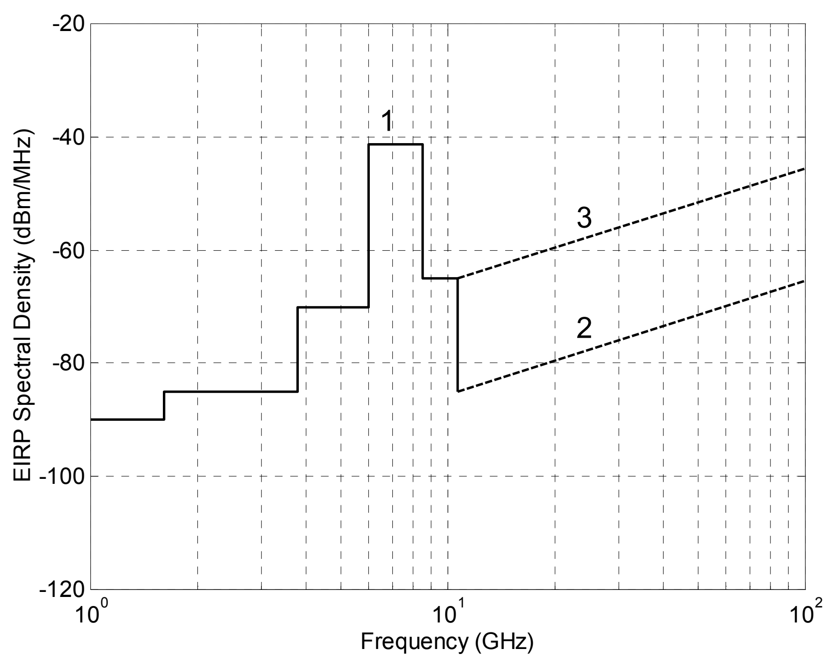

Figure 9. Proposed mean EIRP spectral density lower bounds for the licensing of radio devices.

[59] 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.

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[60] requires exclusive use by certain applications.

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

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

[60] 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[61] overall taking account of the costs and risks. 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.

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[61] 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[62] 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[63], and this directive enables member states to devise "interface requirements"[64] 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[65]. 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.

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

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

64 Interface requirements specify parameters such as operating frequencies, channel bandwidths, and limits on radiated power, and also identify the technical standards authorised for use in a band.

65 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".

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 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)[66].

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[67] (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:

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

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

- 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 it moves 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.

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 a band is shared across a number of applications and technologies (i.e. frequency is not allocated on an application- or technology-specific basis)[68]. 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 at 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.

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

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 EU) 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.

Another important issue is with regards to impact of spectrum usage rights (SURs)[69] 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[70].

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 there is intended to 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.

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

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.

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.

Q10: Do you agree with the harmonisation strategy discussed above in the context of licence-exempt devices?

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 communication 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.

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?

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 authorised polite protocols defined by standardisation bodies;

- 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.

Annex 1
Responding to this consultation

How to respond

A1.1 Ofcom invites written views and comments on the issues raised in this document, to be made **by 5pm on 21 June 2006**.

A1.2 Ofcom strongly prefers to receive responses using the online web form at http://www.ofcom.org.uk/consult/condocs/lefr/howtorespond/, as this helps us to process the responses quickly and efficiently. We would also be grateful if you could assist us by completing a response cover sheet (see Annex 3), to indicate whether or not there are confidentiality issues. This response coversheet is incorporated into the online web form questionnaire.

A1.3 For larger consultation responses - particularly those with supporting charts, tables or other data - please email reza.karimi@ofcom.org.uk attaching your response in Microsoft Word format, together with a consultation response coversheet.

A1.4 Responses may alternatively be posted or faxed to the address below, marked with the title of the consultation.

Dr. Reza Karimi
Ofcom
Technology & Spectrum Operations (Floor 2)
Riverside House
2A Southwark Bridge Road
London SE1 9HA

Fax: 020 7981 3730

A1.5 Note that we do not need a hard copy in addition to an electronic version. Ofcom will acknowledge receipt of responses if they are submitted using the online web form but not otherwise.

A1.6 It would be helpful if your response could include direct answers to the questions asked in this document, which are listed together in Annex 4. It would also help if you can explain why you hold your views and how Ofcom's proposals would impact on you.

Further information

A1.7 If you want to discuss the issues and questions raised in this consultation, or need advice on the appropriate form of response, please contact Reza Karimi on 020 7981 3567.

Confidentiality

A1.8 We believe it is important for everyone interested in an issue to see the views expressed by consultation respondents. We will therefore usually publish all responses on our website, www.ofcom.org.uk, ideally on receipt. If you think your response should be kept confidential, can you please specify what part or whether all of your response should be kept confidential, and specify why. Please also place such parts in a separate annex.

A1.9 If someone asks us to keep part or all of a response confidential, we will treat this request seriously and will try to respect this. But sometimes we will need to publish all responses, including those that are marked as confidential, in order to meet legal obligations.

A1.10 Please also note that copyright and all other intellectual property in responses will be assumed to be licensed to Ofcom to use. Ofcom's approach on intellectual property rights is explained further on its website at http://www.ofcom.org.uk/about/accoun/disclaimer/.

Next steps

A1.11 Following the end of the consultation period, Ofcom intends to publish a statement in summer 2007.

A1.12 Please note that you can register to receive free mail updates alerting you to the publications of relevant Ofcom documents. For more details please see: http://www.ofcom.org.uk/static/subscribe/select_list.htm.

Ofcom's consultation processes

A1.13 Ofcom seeks to ensure that responding to a consultation is easy as possible. For more information please see our consultation principles in Annex 2.

A1.14 If you have any comments or suggestions on how Ofcom conducts its consultations, please call our consultation helpdesk on 020 7981 3003 or e-mail us at consult@ofcom.org.uk . We would particularly welcome thoughts on how Ofcom could more effectively seek the views of those groups or individuals, such as small businesses or particular types of residential consumers, who are less likely to give their opinions through a formal consultation.

A1.15 If you would like to discuss these issues or Ofcom's consultation processes more generally you can alternatively contact Vicki Nash, Director Scotland, who is Ofcom's consultation champion:

Vicki Nash
Ofcom, Sutherland House, 149 St. Vincent Street, Glasgow G2 5NW.

Tel: 0141 229 7401
Fax: 0141 229 7433

Email vicki.nash@ofcom.org.uk

Annex 2
Ofcom's consultation principles

A2.1 Ofcom has published the following seven principles that it will follow for each public written consultation:

Before the consultation

A2.2 Where possible, we will hold informal talks with people and organisations before announcing a big consultation to find out whether we are thinking in the right direction. If we do not have enough time to do this, we will hold an open meeting to explain our proposals shortly after announcing the consultation.

During the consultation

A2.3 We will be clear about who we are consulting, why, on what questions and for how long.

A2.4 We will make the consultation document as short and simple as possible with a summary of no more than two pages. We will try to make it as easy as possible to give us a written response. If the consultation is complicated, we may provide a shortened version for smaller organisations or individuals who would otherwise not be able to spare the time to share their views.

A2.5 We will normally allow ten weeks for responses to consultations on issues of general interest.

A2.6 There will be a person within Ofcom who will be in charge of making sure we follow our own guidelines and reach out to the largest number of people and organizations interested in the outcome of our decisions. This individual (who we call the consultation champion) will also be the main person to contact with views on the way we run our consultations.

A2.7 If we are not able to follow one of these principles, we will explain why. This may be because a particular issue is urgent. If we need to reduce the amount of time we have set aside for a consultation, we will let those concerned know beforehand that this is a 'red flag consultation' which needs their urgent attention.

After the consultation

A2.8 We will look at each response carefully and with an open mind. We will give reasons for our decisions and will give an account of how the views of those concerned helped shape those decisions.

Annex 3
Consultation response cover sheet

A3.1 In the interests of transparency and good regulatory practice, we will publish all consultation responses in full on our website, www.ofcom.org.uk.

A3.2 We have produced a coversheet for responses (see below) and would be very grateful if you could send one with your response (this is incorporated into the online web form if you respond in this way). This will speed up our processing of responses, and help to maintain confidentiality where appropriate.

A3.3 The quality of consultation can be enhanced by publishing responses before the consultation period closes. In particular, this can help those individuals and organisations with limited resources or familiarity with the issues to respond in a more informed way. Therefore Ofcom would encourage respondents to complete their coversheet in a way that allows Ofcom to publish their responses upon receipt, rather than waiting until the consultation period has ended.

A3.4 We strongly prefer to receive responses via the online web form which incorporates the coversheet. If you are responding via email, post or fax you can download an electronic copy of this coversheet in Word or RTF format from the ‘Consultations’ section of our website at www.ofcom.org.uk/consult/.

A3.5 Please put any parts of your response you consider should be kept confidential in a separate annex to your response and include your reasons why this part of your response should not be published. This can include information such as your personal background and experience. If you want your name, address, other contact details, or job title to remain confidential, please provide them in your cover sheet only, so that we don’t have to edit your response.

Cover sheet for response to an Ofcom consultation

BASIC DETAILS

Consultation title:

To (Ofcom contact):

Name of respondent:

Representing (self or organisation/s):

Address (if not received by email):

CONFIDENTIALITY

Please tick below what part of your response you consider is confidential, giving your reasons why

Nothing ☐ Name/contact details/job title ☐

Whole response ☐ Organisation ☐

Part of the response ☐ If there is no separate annex, which parts?

If you want part of your response, your name or your organisation not to be published, can Ofcom still publish a reference to the contents of your response (including, for any confidential parts, a general summary that does not disclose the specific information or enable you to be identified)?

DECLARATION

I confirm that the correspondence supplied with this cover sheet is a formal consultation response that Ofcom can publish. However, in supplying this response, I understand that Ofcom may need to publish all responses, including those which are marked as confidential, in order to meet legal obligations. If I have sent my response by email, Ofcom can disregard any standard e-mail text about not disclosing email contents and attachments.

Ofcom seeks to publish responses on receipt. If your response is non-confidential (in whole or in part), and you would prefer us to publish your response only once the consultation has ended, please tick here. ☐

Name Signed (if hard copy)

Annex 4

Consultation questions

The following is a list of consultations questions raised in this document:

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?

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

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

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

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?

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

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?

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

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

Q10: Do you agree with the harmonisation strategy discussed above in the context of licence-exempt devices?

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?

Annex 5
Impact assessment

A5.1 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.

A5.2 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.

A5.3 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.

A5.4 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 the LEFR consultation 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.

A5.5 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 the LEFR consultation 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.

A5.6 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 the LEFR consultation 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 7).

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 6
Spectral efficiency of the spectrum commons

A6.1 Introduction

As discussed in Section 4 of the LEFR consultation 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.

A6.2 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.

Application-specific spectrum

Envisage a scenario where each application is assigned an exclusive segment of the radio spectrum. This is depicted in Figure A6.1 for the case of $M = 2$ applications. Such an application-specific allocation implies that there is no mutual interference among the applications[71]. This, in turn, means that the utilities of the applications are not constrained. Hence, one may write the spectral efficiency as

[71] 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.

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

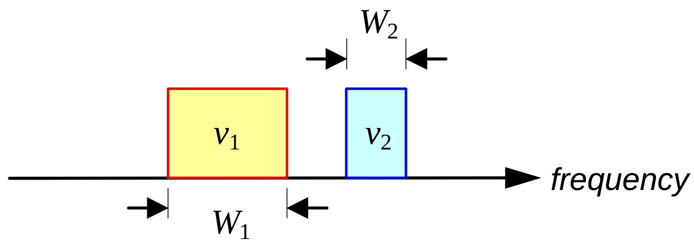

Figure A6.1. Application-specific allocation for M = 2 applications.

Spectrum commons

Now envisage a scenario where the applications operate in a co-channel manner within a spectrum commons, as illustrated in Figure A6.2 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

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

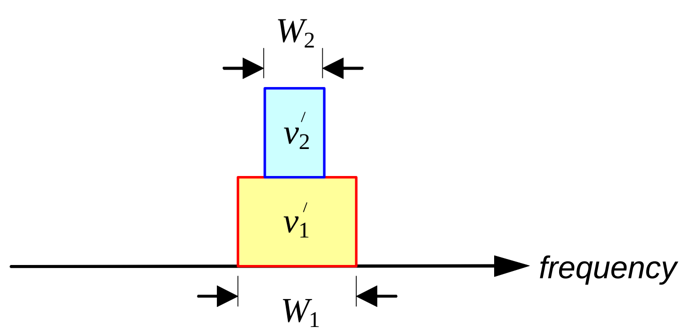

Figure A6.2. Spectrum commons for M = 2 applications.

A6.3 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

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

One may immediately see that

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

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

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

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

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

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

A6.4 Numerical examples

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

Figures A6.3 to A6.5 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.

Equal unconstrained utilities

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.,

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

These observations are illustrated in Figure A6.3. Note that R is maximized when the applications have similar bandwidths (i.e. $W_1 = W_2$) and suffer from similar degradations (i.e. $\lambda_1 = \lambda_2$).

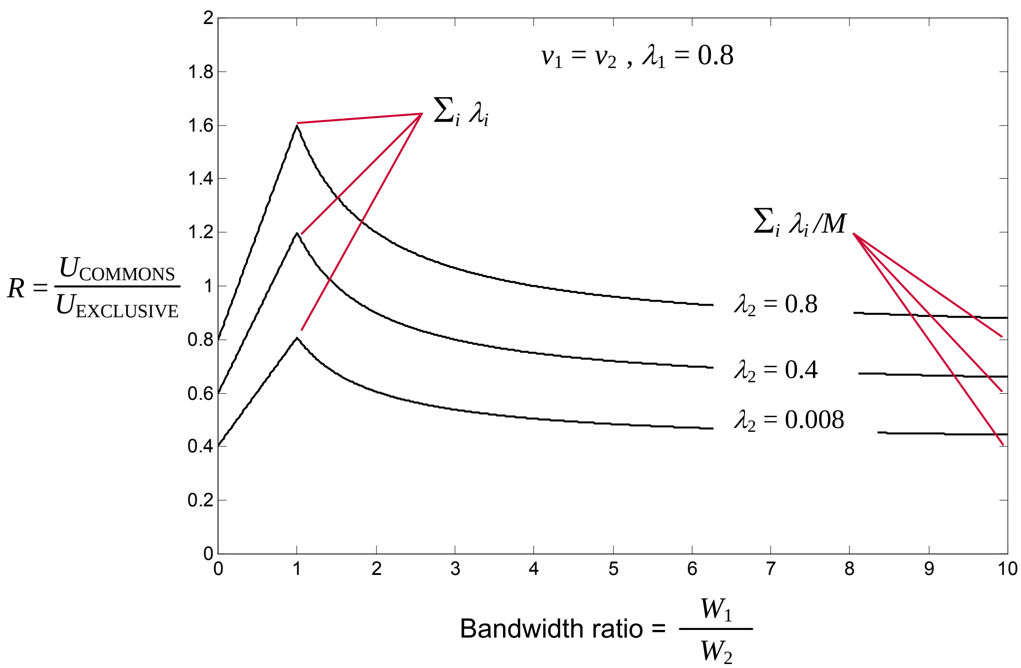

Figure A6.3. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (equal unconstrained utilities).

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, $R \to M\lambda_n$ when the applications have equal bandwidths, and $R \to \lambda_n$ 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 A6.4 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 A6.5 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.

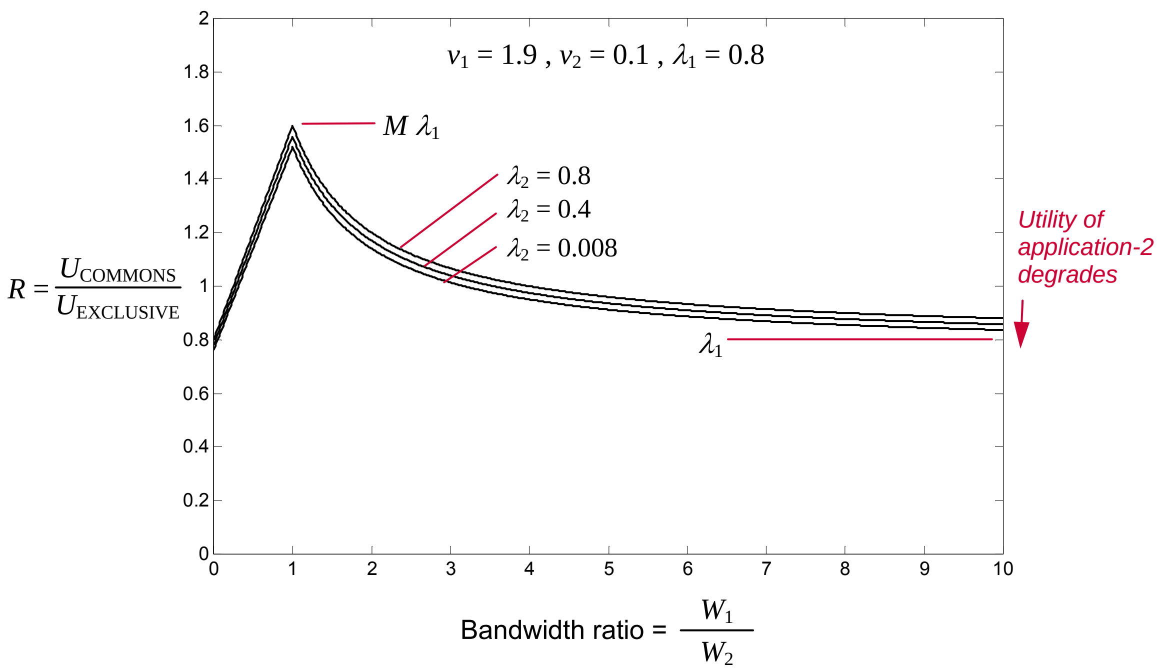

Figure A6.4. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (unequal unconstrained utilities).

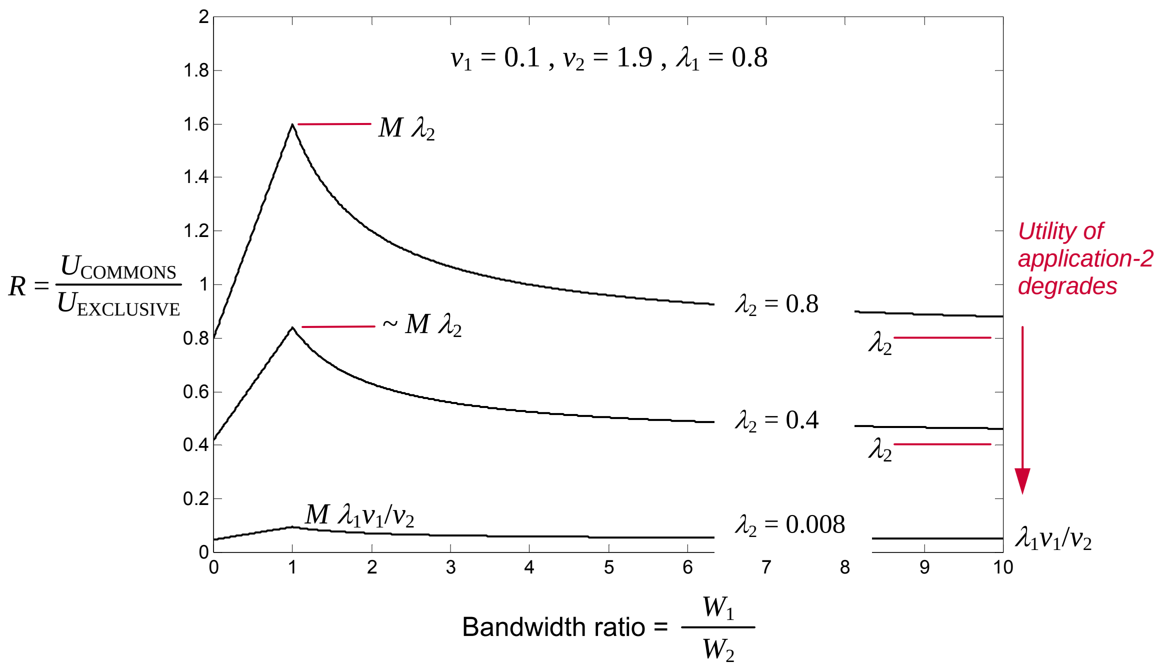

Figure A6.5. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of bandwidth ratio (unequal unconstrained utilities).

A6.5 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

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

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 < δ < 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

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

Values of R as a function of inter-application coupling, δ, and for different numbers of applications, M, are depicted in Figure A6.6. 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.

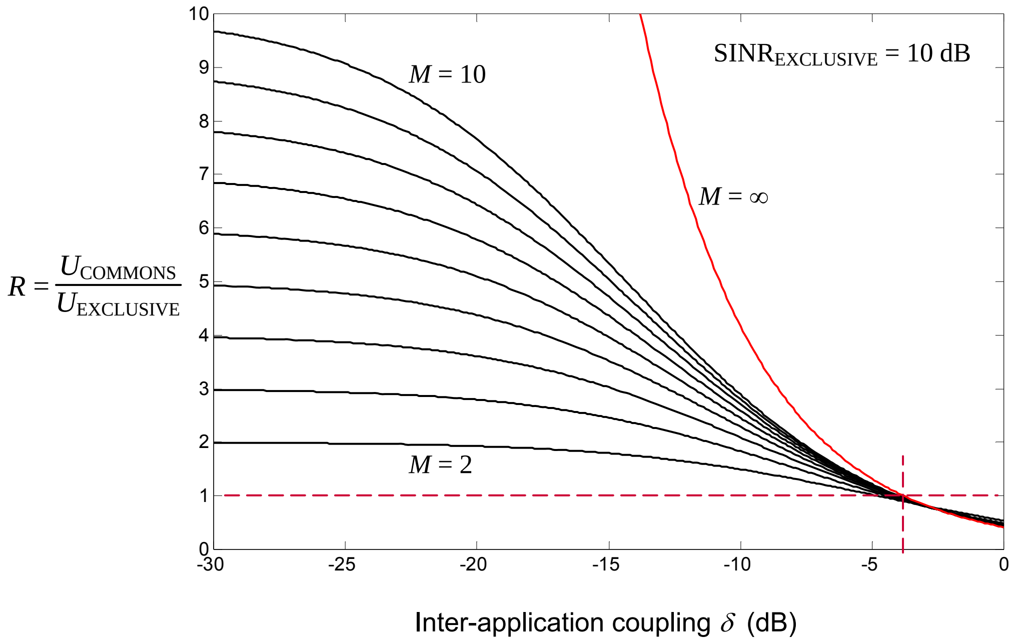

Figure A6.6. The ratio of spectral efficiencies of spectrum commons and application-specific spectrum as a function of inter-application radio coupling.

As rough guide, one may state that[72] spectrum commons is the preferred option (i.e. $R \geq 1$) when

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

A6.6 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:

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

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

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

in which case

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

- the applications sharing the spectrum have similar bandwidths, resulting in maximum savings in utilised spectrum; and
- 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 7

Aggregation of interference caused by low-power transmitters

A7.1 Introduction

As discussed in Section 7 of the LEFR consultation 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.

A7.2 Monte-Carlo simulations

Aggregate interference statistics at a reference of 2 GHz

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 A7.1.

The cumulative probability distribution function (CDF) of the received aggregate interference PSD is presented in Figures A7.1 and A7.6 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[73]. (see also section A7.4)
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 A7.1. Simulation parameters.

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

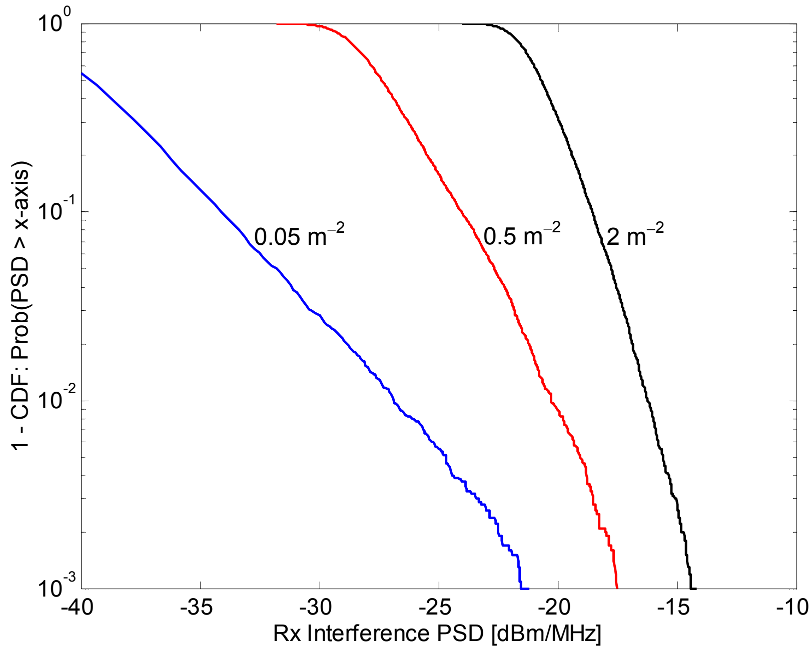

Figure A7.1. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 0.15 m, activity factor of 100%.

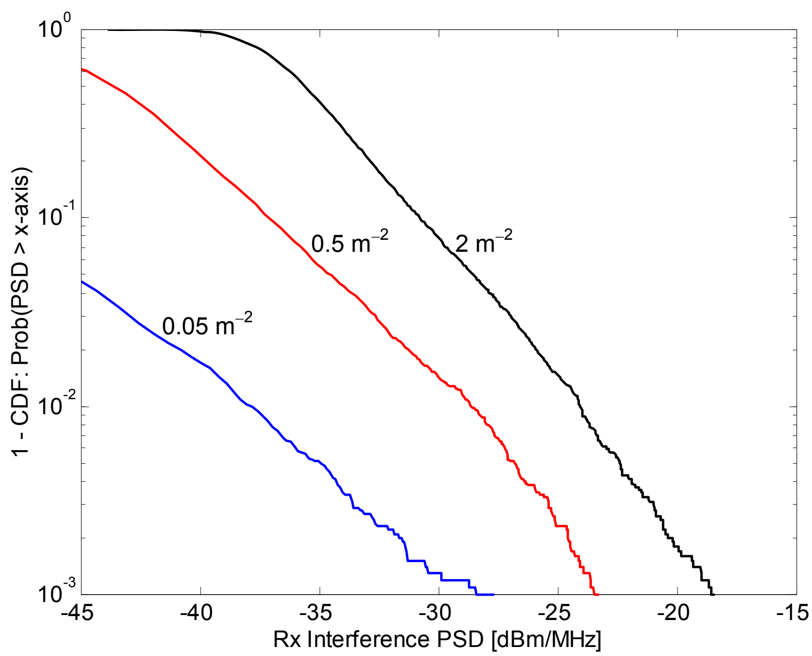

Figure A7.2. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 0.15 m, activity factor of 5%.

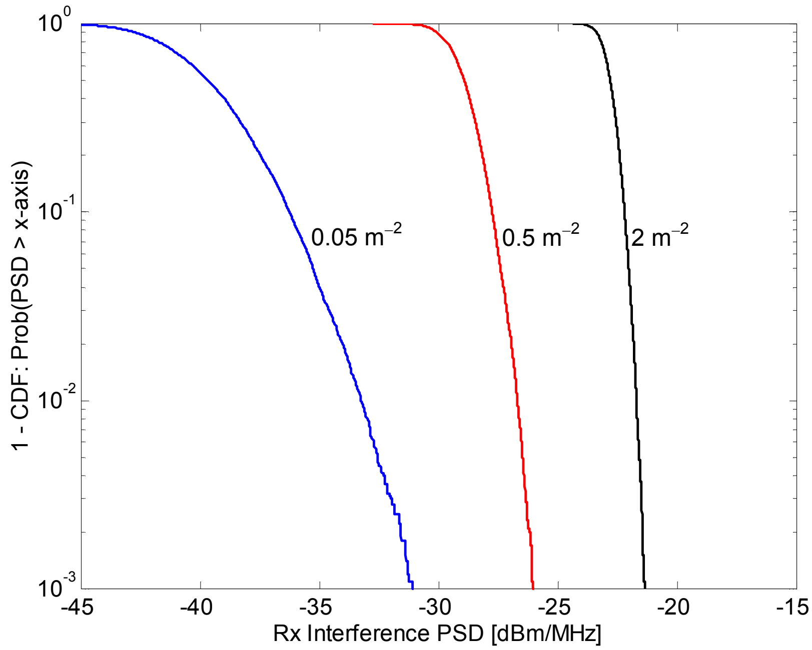

Figure A7.3. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 1 m, activity factor of 100%.

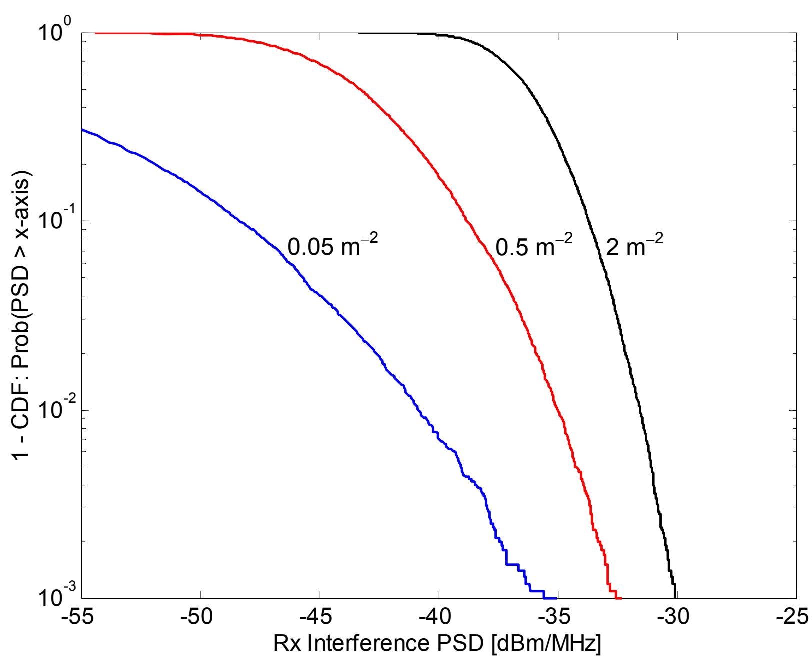

Figure A7.4. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 1 m, activity factor of 5%.

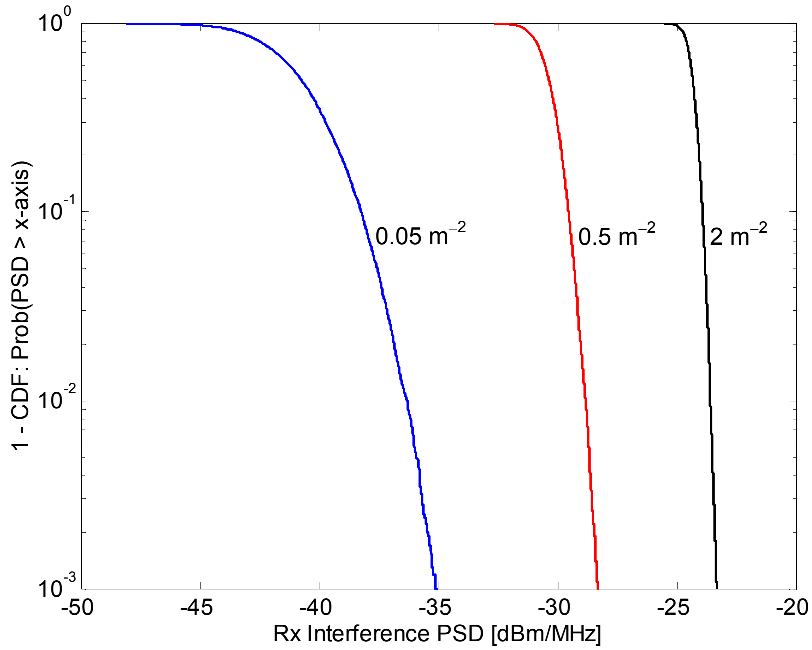

Figure A7.5. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 2 m, activity factor of 100%.

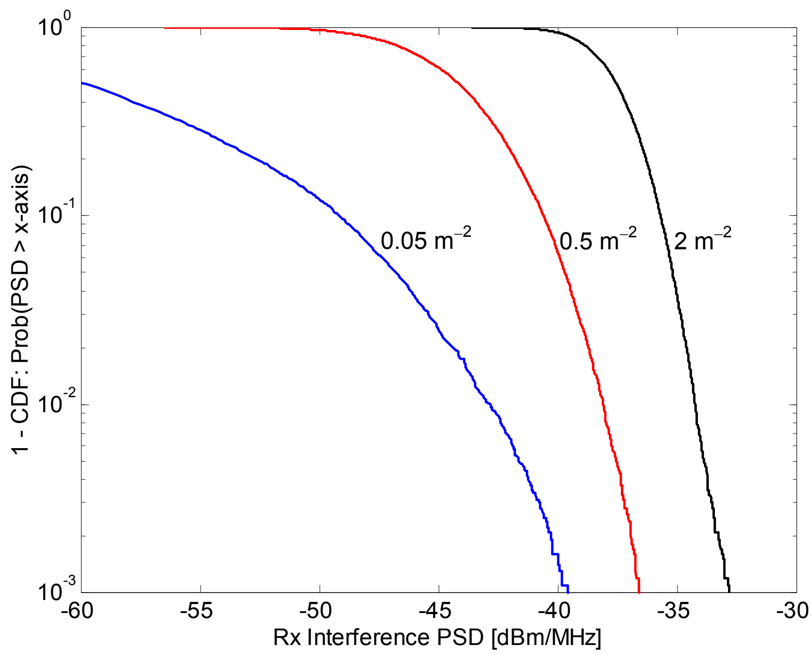

Figure A7.6. Statistics for aggregate interference PSD at 2 GHz. EIRP of 0 dBm/MHz, minimum distance of 2 m, activity factor of 5%.

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

$$S_{\mathrm{N}} = k\,T\,\mathrm{NF} = 1.3804\times10^{-23} \times 290 \times 10 = 4\times10^{-20} \quad \text{W/Hz}$$
$$= -104 \quad \text{dBm/MHz.}$$

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 A7.1 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 A7.2 to A7.4 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}	Device Density 0.5 m^{-2}	Device Density 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 A7.2. 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}	Device Density 0.5 m^{-2}	Device Density 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 A7.3. Limits on transmission PSD for which $\Pr\{S_I \geq 0.05\ S_N\} = 10^{-3}$. Minimum distance 1 m.

		Device Density 2 m^{-2}	Device Density 0.5 m^{-2}	Device Density 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 A7.4. 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 A7.4).

- We continue to use the two-mode path-loss model of Table A7.1 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 the LEFR).

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 A7.7 to A7.9 for different device densities, activity factors, and minimum distances of transmitters from the victim receiver, along with the mask for ultra-wideband (UWB) devices.

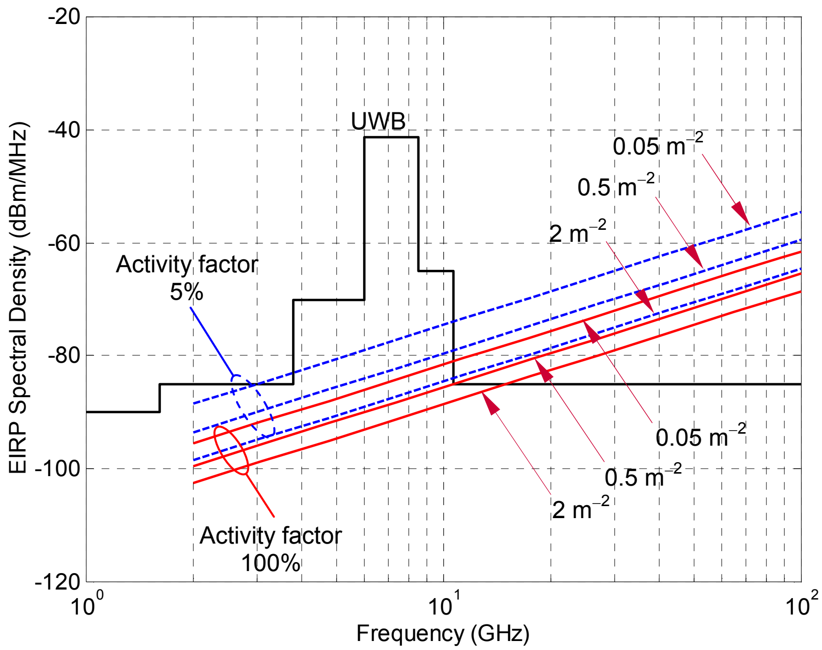

Figure A7.7. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 0.15 m.

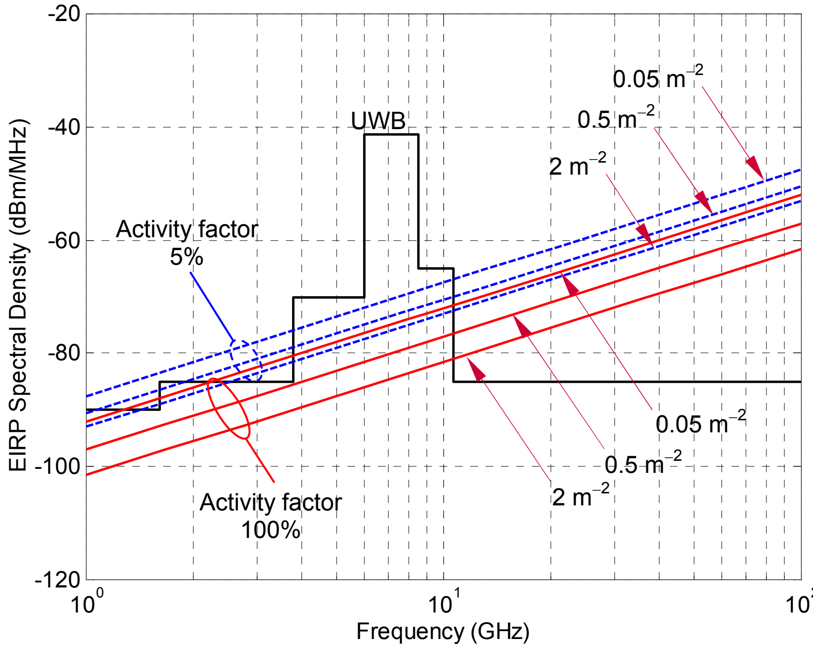

Figure A7.8. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 1 m.

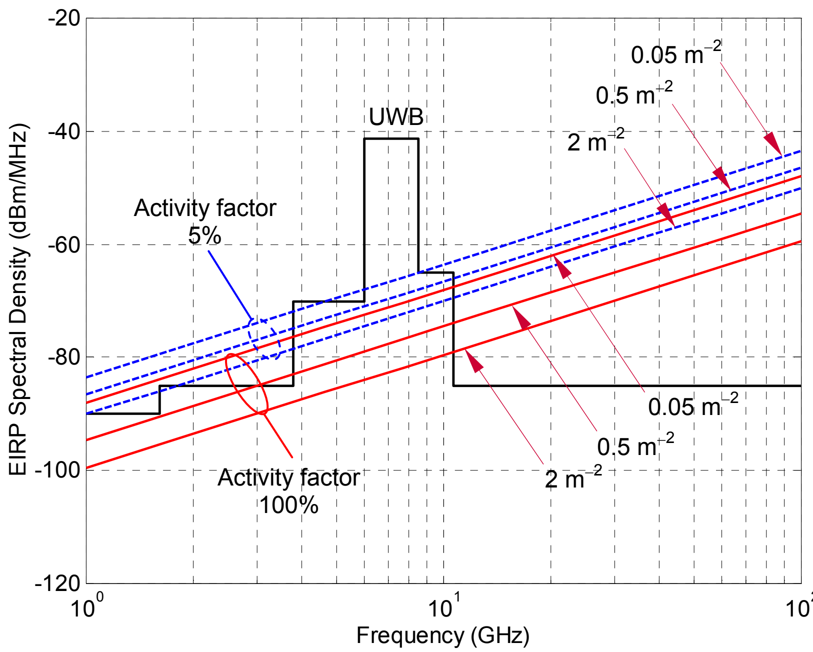

Figure A7.9. EIRP spectral density limits for low-power devices, such that resulting aggregate interference exceeds 5% of thermal noise with a probability of 0.1%. Minimum distance from measurement point of 2 m.

A7.3 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.

A7.4 Appendix: Propagation model

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

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

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

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

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

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

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

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

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

Annex 8
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.
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 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.
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.
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.