Spectrum Commons Classes for Licence-Exemption

A consultation on the management of spectrum used by licence-exempt devices

Consultation

Publication date: 6 May 2008

Closing Date for Responses: 15 July 2008

Contents

Section 1

Executive Summary

1.1 This consultation advances the aims set out in the Licence Exempt Framework Review (LEFR) to develop a framework for the regulation of licence-exempt devices in the specific area of determining which applications should share licence-exempt bands and how they should behave with respect to each other.

1.2 The ideas presented here are for discussion. Subject to the responses it is our intention to introduce these ideas to inform debate within the international bodies such as the relevant European entities considering licence-exempt issues. These ideas are for future licence-exempt decisions and we are not planning to implement them in the UK in the short term.

1.3 The scheme we propose is to divide licence exempt applications into three classes of low, medium and high interference potential. The division would be performed on the basis of an Interference Indicator value calculated according to the likelihood of an application in causing interference and based on its technical parameters of bandwidth, duty cycle, range and expected deployment density. As a result, only applications with like interference potential would share spectrum. Within each class we propose that applications minimise their transmissions where possible and share the resource equitably through the use of polite protocols.

Background

Ofcom's approach to management of spectrum

1.4 The Spectrum Framework Review[1] (SFR) sets out Ofcom's overall strategy for the management of spectrum through a market-based approach. It also outlines, at a high level, our understanding to when spectrum use should be licensed or licence-exempt.

1.5 The SFR suggests that spectrum use should be licence-exempt if the value that is expected to be derived from the use 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.

1.6 The main practical 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. On the other hand, the less detailed control of interference is the biggest disadvantage associated with the licence-exempt usage of spectrum, and can result in a reduction in value.

Ofcom's approach to licence-exemption

1.7 The Licence-Exemption Framework Review (LEFR) further developed our approach to the management of licence-exempt use. One aspect addressed by the LEFR was

[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/.

the issue of spectrum commons vs. application specific spectrum allocations[2]. Ofcom believes that, in general, application-specific spectrum allocations for licence-exempt devices result in inefficient utilisation and fragmentation of spectrum.

1.8 The LEFR identified a number of aspects where further regulatory work was envisaged, including how flexible politeness rules for licence-exempt use might be defined and enforced in practice.

European activities in the licence-exemption area

1.9 A well known instance of licence exempt use of the spectrum is Short Range Devices (SRD). SRDs are regulated by the European Commission Decision 2006/771/EC and the national regulations based on ECC Rec.70-30[3]. The trend in ECC is towards a generic allocation instead of band allocations specific to technologies or applications. In parallel, the EC has recently requested studies on the benefits, economic value and ways of implementation of “Collective Use of Spectrum” (CUS).

Application of the concepts in this consultation

1.10 This consultation contains a proposal for a spectrum management mechanism based on classes of spectrum commons, and a proposal for regulatory requirements for politeness rules. It continues the work of the LEFR in the area of politeness rules and protocols and it seeks to align with the work of ECC and the EC on CUS.

1.11 We are not currently intending to retrospectively apply the principles set out in this consultation to existing licence-exempt devices. Instead, our proposal is that work in this area at national and international level and future licence exemptions made should be guided by the principles in this document.

Spectrum Commons Classes and requirements for an Interference Indicator

1.12 The LEFR showed that the benefits of spectrum commons are maximized when the technologies in a given frequency band are similar in terms of their technical parameters. To achieve this we propose the adoption of multiple “classes” of spectrum commons. Within each class applications would have broadly similar interference generating characteristics, which we will capture with a metric we term “Interference Indicator”.

1.13 The technical and operating characteristics of an application determine its Interference Indicator, and a class is defined as a range of Indicator values. A key element of a class-based spectrum commons is then how the Interference Indicator is defined and calculated. The Indicator represents the interference potential of a technology, hence the factors that contribute to interference have to be taken into account, namely: bandwidth, duty cycle, coverage and density of transmitters.

1.14 In addition, we believe that the Indicator should be: technology-neutral, independent of the victim device, and applicable to all systems.

1.15 The Indicator provides the means to compare the interference potential of applications. It does not have absolute meaning.

[2] In application-specific spectrum, frequencies are reserved for exclusive licence-exempt use by a single application (e.g. spectrum used by DECT cordless phones). Spectrum commons allow for multiple wireless applications to operate on a co-channel basis.

[3] Electronic Communications Committee Recommendation 70-30

The Interference Indicator

1.16 Interference occurs when undesired RF signal appears at the spatial location of a receiver, in its receiver channel frequency, at the time the desired signal is present, and with a power level high enough so that the reception of the desired signal is disturbed. This definition covers the three domains where concurrence is required for interference to appear: geographic or spatial, time and frequency domain. We propose to gauge the interference potential of a technology in each of the three domains separately, and then combine the results into the Interference Indicator.

1.17 We will evaluate each technology in a given scenario. We will select scenarios where the technology usage is busy, yet realistic. The scenario will define the application using the technology and determine factors such as traffic and density of transmitters.

Frequency domain

1.18 A transmitter whose channel occupies a large fraction of a shared band will have a high probability of overlap with a victim receiver within the band. We propose to take the ratio of channel bandwidth to shared bandwidth as an Indicator of interference potential: $BW_{Interferer} \ / \ BW_{SharedBand}$ This implies that a particular technology will not have a single Interference Indicator, but one that will vary depending on the frequency band considered for its use.

Time domain

1.19 A transmitter using the channel frequently will have a high probability of interfering with other users in the same channel. We take the duty cycle of a system as an Indicator of its interference potential in the time domain. We consider the duty cycle at the busy hour, and we acknowledge that it depends on the traffic for a majority of technologies. We propose to derive the traffic from the applications used in the scenario.

Geographic domain

1.20 For a victim operating at the same frequency and time as a transmitter, interference will only happen if the victim is physically located within reach of the transmissions. Two factors determine this:

- **Interference coverage of the transmitter**. This is the area where the power level of the signal from the transmitter is higher than a certain threshold. The coverage area is determined by the output power of the transmitter, the propagation conditions, the antenna pattern and the victim's sensitivity to interference.
  A victim will suffer interference if the level of the unwanted signal at its receiver is higher than a threshold, but this threshold is different for each receiver technology and implementation. Since we are seeking an Interference Indicator that is independent of the victim, we need to select a typical threshold. Based on the current performance of popular licence-exempt devices we have selected –80 dBm/MHz.

- **Density of victims**. Density, expressed in terms of interfering transmitters per area unit, can be used together with the coverage calculation above to give a measure of the usage of the space resource. For two technologies with the same coverage area per transmitter, the more ubiquitous one will result in a higher

value of interference.
The number of licence exempt units in any given scenario can only be estimated since there is no single licensee that controls them. Furthermore, technologies will normally be evaluated at their development phase, so density estimates will be based on sales projections and expected uses. Typically, we would work with interested parties to reach a consensus on this factor.

Construction of the Interference Indicator

1.21 We have defined and calculated the four factors that provide the level of occupancy of the resources in the frequency ($I_f = BW_{Interferer} / BW_{SharedBand}$), time ($I_t$ = Duty Cycle) and geographic domains (coverage & density). These factors are combined as follows to yield a single figure Interference Indicator:

$$Interference\ Indicator\ (frequency, time, space) = I_f \cdot I_t \cdot Coverage \cdot Density$$

The Interference Indicator of existing technologies

1.22 As an example of how the Indicator can be calculated in real life, we have looked at four existing licence-exempt technologies and a fifth one under development. We have calculated the Indicator for each technology in its own operating band, and in a hypothetical case where all would use the 2.4GHz ISM band.

	RFID	IEEE 802.11b	Bluetooth	Home automation	60 GHz WPAN
Normal allocation	1.1788	0.1641	0.1607	0.2008	0.0131
Allocation to the 83.5MHz wide 2.4GHz ISM band	0.0282	0.1641	0.1607	0.0014	1.0963

Table 1. The Interference Indicator of existing technologies

Spectrum Commons Classes

1.23 Classes are defined as ranges of Interference Indicator values. We believe that a scheme with three classes is the right compromise; fewer classes would mean that technologies with very different interference potential could be grouped together, and more than three could result in inefficient use of spectrum as bands tended towards becoming application-specific.

1.24 Prior to assigning a new band for licence-exempt use, Ofcom will have to decide what class (or classes) would be allowed in it. We propose that the decision is made fundamentally on the basis of the class predicted to generate the greatest economic value.

Politeness rules and protocols

1.25 Although the application of classes will ensure that dissimilar applications are in different bands, there is still a possibility of interference. In the LEFR we suggested that this possibility be reduced through the application of so-called “politeness rules” that require devices to take account of other users and act responsibly. However, a regulatory requirement for a particular polite protocol would steer developers towards a particular technical solution. This would be against current European regulations and hinder innovation. Instead, we will simply require that devices make a fair use of the resources and comply with a few high level rules towards interference mitigation. We think a fair wireless user is one that

- shares the resources equitably with other users, and
- behaves appropriately according to its needs.

1.26 We consider that the key capability for equitable sharing is to have some information about other users. In a decentralised licence-exempt environment we believe this can only be gained through sensing other use in the band. However, for low-interference devices we do not believe that a requirement for sensing would be justified.

1.27 We propose that in order to share equitably technologies belonging to medium and high interference class should

- Implement a method to become aware of other users of the same resources.
- Not monopolize the resources so that other users cannot access them.
- Implement a method to reduce its channel occupancy when there is congestion

1.28 We consider appropriate behaviour to be that where resource usage is kept to the minimum within the limits of their applications and technologies. For example, this might include transmit power control and a reduction in data rate when high rates are not required.

Impact on stakeholders

1.29 The impact of these proposals will be felt by future users of spectrum. Ofcom anticipates that this impact will be beneficial because the proposals strive to optimise the efficiency and value of the licence-exempt uses of spectrum.

1.30 In addition, we believe that these proposals help to create an environment in which industrial stakeholders are made aware of the likely directions of licence-exemption policy development, and find it easier to invest as a result.

Citizens and consumers

1.31 We believe that the proposals set out in this document will deliver benefits to citizens and consumers for two main reasons:

1.32 A spectrum management strategy based on classes of spectrum commons guarantees better interference conditions, and thus an environment that bring benefits to consumers and citizens in terms of the ability to use more licence-exempt applications.

1.33 Secondly, it is Ofcom’s goal to impose as few technology restrictions as possible. This will let the market and the users decide on the best solutions and hence maximise innovation.

Next steps

1.34 This consultation, published on 6 May 2008, lasts for 10 weeks. The closing date for responses is 15 July 2008. We expect to release a statement on this consultation around summer 2008, having taken into account any stakeholder responses to our proposals. Based on the results of this consultation, we will seek opportunities to present these proposals to the relevant European bodies.

Section 2

Overview

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

2.2 The SFR also outlines Ofcom's methodology to determine whether spectrum should be assigned for licensed or licence-exempt use. 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.

2.3 The Licence Exempt Framework Review (LEFR) extends the SFR by examining a number of specific issues with regards to the management of spectrum used by licence-exempt devices. Notably, it studies the relative merits of application-specific and commons models for spectrum use. Better spectrum efficiency is generally achieved if we have spectrum commons because this avoids separate allocations for each application, some of which will be underused, not least as the optimal split between separate allocations will change over time. However, if highly unlike applications are placed in the same band this will also tend to be inefficient as they will be unable to share the spectrum effectively.

2.4 A compromise is to have a number of classes of licence exempt bands for differing device types. This document looks in more detail how these classes are defined and the rules for their usage. The document is structured as follows.

2.5 Section 3 provides a background to licence exemption and to spectrum commons classes. Section 4 and section 5 set up the framework for the classes and introduce the concept of the Interference Indicator of a technology. The determination of which class a device should be placed into should be based on its Interference Indicator. This is a combination of the fraction of the overall bandwidth it uses, the fraction of time for which it transmits, its coverage and the density of devices. We calculate the Interference Indicator of a few current technologies in section 6 as a means to validate the concept.

2.6 The issue of how many classes need to be defined is addressed in section 7. The number of classes should be as small as possible to prevent inefficiencies but not so small that even with polite protocols devices cannot coexist. We do not know of a way to deterministically calculate the right number of classes but suggest that there might be three classes, the lowest for very low interference devices such as garage door openers, the middle for personal area devices such as BlueTooth and the upper for local area devices such as WiFi. The number of classes can be changed over time if necessary.

2.7 Within a class a device should operate in a fair manner. In section 8 we explain that this means the device should share the resources equally with other systems, and behave appropriately according to the needs of its application. We do not require explicit polite protocols, instead we lay out a set of rules that would guarantee that systems operate fairly.

Section 3

Background

3.1 We introduce in this section our thinking and policies regarding the licence exempt use of spectrum. The Spectrum Framework Review outlines Ofcom approach to spectrum management, and the Licence Exemption Framework Review further develops this approach.

Ofcom's approach to management of spectrum. The Spectrum Framework Review[4].

3.2 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[5]:

- 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.

3.3 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.

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

- Allowing simple and rapid change of rights to use; and

- Allowing change of use of spectrum under technology neutral authorizations, although possible usage will be limited through the use of a spectrum mask.

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[4] This section appeared in the SFR and is repeated here for ease of reference

[5] 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. For these reasons the figures should be considered as illustrative.

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

i) Spectrum should be free of technology and usage constraints as far as possible. Policy constraints should only be used where they can be justified;

ii) It should be simple and transparent for licence holders to change the ownership and use of spectrum; and

iii) Rights of spectrum users should be clearly defined and users should feel comfortable that these will not be changed without good cause.

3.6 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.

Review of Licence Exemption policies

3.7 We present in this section the key elements of policing licence exempted spectrum. These are the background of the Licence Exemption Framework Review (LEFR) which is covered in the next section. With the LEFR, Ofcom solves some of the specific issues concerning the management of licence-exempt spectrum that the SFR had left unanswered.

3.8 It is helpful to quickly recap the terminology used in spectrum licensing. Figure 1 illustrates the relationship between the key terms. Licensed use of spectrum refers to the market-led purchase, and potential trading, of spectrum by operators of wireless systems.

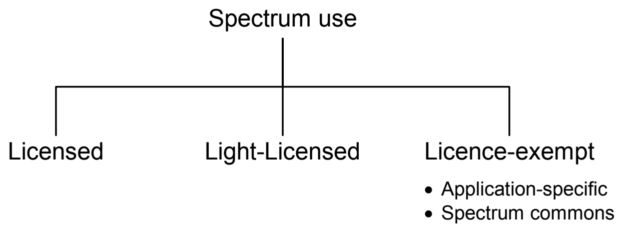

Figure 1. Nomenclature

3.9 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. 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.

3.10 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.

Benefits and costs of licence-exempt usage of spectrum

3.11 The main practical 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), for the testing of new products and services, or for offering niche applications.

3.12 On the other hand, the less detailed control of interference is the biggest disadvantage associated with the licence-exempt usage of spectrum, and can result in a reduction in value.

3.13 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. In short, although quality cannot be guaranteed users may still find it is perfectly acceptable.

3.14 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 SFR Ofcom expressed its belief that there should be an appropriate balance between licensing and licence-exemption approaches to spectrum use.

Determining when use of a band should be licence-exempt

3.15 In determining the appropriate amount of spectrum for licence-exemption, Ofcom's primary goal is to maximise the efficiency of spectrum use, measured in terms of the economic value that this use is likely to bring to the country. Ofcom also has a duty to exempt devices from licensing where they will not cause interference. In practice, as the work on ultra-wideband showed, this latter requirement typically only allows extremely low power operation and is not relevant to the concepts set out in this document.

3.16 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).

The Licence Exemption Framework Review

3.17 As we have seen above, Ofcom duties are to maximise the value and efficiency derived from the spectrum. Ofcom believes 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. Furthermore, the SFR 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.

3.18 These guidelines are the basis for the Licence-Exemption Framework Review (LEFR), whose key points are captured here:

- **Application-specific spectrum vs. spectrum commons**. Ofcom believes that, in general, application-specific spectrum allocations for licence-exempt devices result in inefficient utilisation and fragmentation of spectrum. Ofcom prefers the "spectrum commons" model, where a block of spectrum can be shared by as wide a range as possible of devices.
  However, in order to further mitigate the impact of interference among wildly diverse applications, we propose in the LEFR the adoption of multiple "classes" of spectrum commons. Within each class, applications would have broadly similar interference generating characteristics.

- **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. Licence-exemption should be adopted otherwise, subject to adequate protection of incumbent users.

- **Licence-exemption above 40 GHz**. Spectrum in the 275-1000 GHz frequency range should be considered for wide-scale release to allow use by licence-exempt devices. In the 105-275 GHz frequency range, 94 GHz of unused spectrum should be considered for a phased release to allow use by licence-exempt devices. In the 40-105 GHz frequency range, the 59-64 GHz band and the 102-105 GHz band should be considered for use by licence-exempt devices.

- **Licence-exemption of low-power transmitters.** Radio devices transmitting at sufficiently low power spectral densities do not cause harmful interference to incumbent services, and should be exempted from licensing. The LEFR proposes a power spectral density lower bound based on the Ultra Wide Band limits.

- **International positioning and harmonisation.** 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. Harmonisation should impose a minimum of restrictions and be as application-neutral and technology-neutral as possible.

3.19 The LEFR identifies a number of issues where further regulatory work is envisaged. Notably:

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

- Release of spectrum above 102 GHz for licence-exempt use.

- Limits on EIRP spectral densities for licence-exemption of low-power transmitters.

Collective Use of Spectrum (CUS)

3.20 During the last year the European Commission has commissioned several studies assessing various spectrum management approaches. Licence-exemption is considered under the generic category of collective usage, together with light licencing, underlay (i.e. UWB[6]) and overlay (i.e. cognitive radio). A report by consultants prepared for the Commission has defined CUS as "a spectrum management approach which allows more than one user to occupy the same range of frequencies at the same time without the need for individual (exclusive) licensing".

3.21 The Commission is seeking advice from the RSPG[7] on a European approach to CUS[8]. This includes:

- A common definition of Collective Use of Spectrum as a generic spectrum management model, and clarification of the relevant terminology.
- Reflection on the benefits of the Collective Use of Spectrum model at EU level, including how the various ways to implement collective use (generic allocations, application specific allocations, underlay, overlay, light licensing, private commons, politeness protocols, etc) might be integrated in a strategic approach.

European activities in the licence-exemption area

3.22 ECC Rec. 70-03 sets out the general position on common spectrum allocations for Short Range Devices in countries within the CEPT. The Recommendation is continuously revised to update the implementation status, insert new allocations or modify the existing ones. The ECC long term goal is to move from a list of application specific allocations (e.g. Alarms) to a list of frequency bands for generic use.

3.23 The process towards a generic band allocation for Short Range Devices is also driven by the European Commission. The work in the ECC is encapsulated by the EC Decision 2006/771/EC[9] and its amendments.

Rationale for this consultation

3.24 This consultation contains a proposal for a spectrum management mechanism based on classes of spectrum commons, and a proposal for regulatory requirements for politeness rules.

3.25 It follows the work of the LEFR, which identified these areas (politeness rules and classes of spectrum commons) as the subject of future regulatory work. In addition, although the consultation does not address all the issues in the discussion on Collective Use of Spectrum, it does present a possible way to implement CUS.

3.26 The proposals in this consultation are primarily intended for new allocations to licence-exempt use. In reality though, most spectrum is already assigned. Under-lay is the usual situation for the vast majority of LE Apparatus. RSPG has acknowledged this situation and it is exploring in the CUS work the increased potential for sharing between licensed and licence-exempt devices. Hence, although the scheme

[6] Ultra Wide Band
[7] Radio Spectrum Policy Group. http://rspg.groups.eu.int/meeting_documents/index_en.htm
[8] http://rspg.groups.eu.int/doc/documents/meeting/rspg13/rspg07_175_rfo_cus.pdf
[9] Decision 2006/771/EC: Commission Decision of 9 November 2006 on harmonisation of the radio spectrum for use by short-range devices

presented here is developed under the assumption that there is no higher power licensed service that the LE apparatus under-lays, it does allow for this situation by requiring LE technologies to detect and yield to licensed services.

3.27 We are not, at present, considering the application of these proposals to existing licence exemption allocations. The proposals will not replace Rec. 70-03 or their UK interpretation in UK Interface Requirements 2030. However, we think that future allocations should be guided by these principles. It is not uncommon for different classes of LE apparatus to currently share spectrum. These allocations have however been arrived at in less coordinated way. This document is therefore intended to add a framework to help establish a method to authorise differing classes of LE apparatus.

3.28 Since licence-exempt allocations are determined at European or even International level, we will present these proposals to the relevant groups.

3.29 Finally, it is worth noting that, in regards of licence exempt use, Ofcom does not define "licence exempt bands" but authorises equipment meeting certain requirements to be used without a licence[10].

[10] http://www.opsi.gov.uk/acts/acts2006/ukpga_20060036_en_1

Section 4

Spectrum Commons Classes

4.1 Spectrum commons classes are a key proposal in the LEFR for the management of licence-exempt spectrum. However, the LEFR only goes as far as suggesting the adoption of classes which would group applications with similar interference characteristics and might require the use of polite protocols. We will review here the arguments presented in the LEFR to support the introduction of classes, and these arguments will lead us to a specific proposal on how to implement the classes.

Justification for spectrum commons classes

4.2 The LEFR shows 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:

- the applications sharing the spectrum have similar bandwidths, resulting in maximum savings in utilised spectrum; and
- each application suffers from a similar minimal fractional degradation in value as a result of inter-application interference.

4.3 Interestingly, the above apply irrespectively of the relative unconstrained throughput[11] of the individual applications.

4.4 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 to effectively co-exist with an impolite high-power application.

4.5 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.

4.6 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. Having technologies with similar interference characteristics to use the same band, we will avoid harmful interference.

A Class as a range of Interference Profiles

4.7 Under the class regime, for an application to be allowed into a spectrum commons band it will have to belong to the class associated to that band. Applications in a specific class of spectrum commons would be constrained to have broadly similar

[11] 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.

interference generating characteristics, thereby avoiding co-existence issues among highly diverse applications.

4.8 The technical and operating characteristics of an application determine its interference profile, and a class is defined as a range of profiles. In addition to the class requirement, applications might be required to implement polite protocols or interference mitigation mechanisms to be allowed into certain spectrum allocations.

4.9 For example, the interference profiles under a given class may only permit very low radiated power (e.g. low duty cycles). As a result, explicit polite protocols at the lower layers of the radio protocol stacks may not be necessary in this class. A different class of spectrum commons might allow greater radiated power profiles, in which case manufacturers will have to incorporate appropriate polite protocols and interference mitigation mechanisms to permit co-existence.

4.10 It is important that the classes and interference profiles which govern a spectrum commons are

- defined so as to allow, where feasible, possible trade-offs between various technical constraints in the dimensions of frequency, time, and space, in order to afford maximum flexibility to the designer.

- specified at an appropriate level of detail and with a view towards advances in state-of-the-art radio technologies, in order to ensure that the implementation of key technologies is not obstructed.

4.11 We present now a proposal for a profile that we call Interference Indicator. We will set up first the requirements for the Indicator and then explain the way we calculate it.

Requirements for the Interference Indicator

4.12 We have presented the concept of spectrum commons classes, as a balance between an application specific band allocation and a pure spectrum commons. Under this approach, applications in the same class will have broadly similar interference characteristics and only applications belonging to the designed class would be allowed in a given band.

4.13 The question now is how to determine the Interference Indicator of an application. This section presents the requirements for this metric. First, we think that it must take into account all parameters that contribute to interference. These are:

- The fraction of the available bandwidth that a device uses.

- The fraction of time that it transmits for.

- The coverage area of the transmitter.

- The number of transmitters per unit area, i.e. its density.

4.14 The Indicator aims at providing the means to compare the interference potential of applications, it doesn’t need to have a physical significance. In other words, the Interference Indicator of a system is meaningless when looked in isolation; it only makes sense when compared with the profiles of other systems.

4.15 A possible implementation of the Indicator could be a single numerical figure calculated from the factors. This would easily allow us to compare different technologies in terms of their interference potential. It might require some kind of weighting of the factors, which needs to be carefully tuned to avoid unfairness. An alternative would be a set of numbers, each related to one of the factors that impact interference. However, such a method will make classes more difficult to set up, and Indicator values more difficult to compare. Hence, we believe that a calculation that incorporates all relevant parameters and yields a single value Indicator is the best option. In following section we will show how we can define an Interference Indicator based on these parameters.

4.16 In addition, we believe that the Indicator should also have the following properties:

- **Lack of bias**. The Indicator should not bias the manufacturer unnecessarily towards particular technical solutions such as opting for a wider bandwidth when a greater duty cycle would have been preferable.

- **Independent of the victim device**. The Interference Indicator is a tool that will be used for regulation of bands with licence exempt use, hence we do not know the characteristics of the systems that will be interfered. It applies to interferers, not to a particular scenario with defined aggressor and victim. Therefore, its calculation must use transmitter parameters only and be independent of the characteristics of the victim receiver.

- **Completeness**. It should be possible to derive the Interference Indicator of any wireless system, i.e. the same calculation should be applicable to all kinds of radio systems. The method should be robust enough to provide a result for any possible future application that might be proposed for a licence exempt band. This is particularly challenging given the great diversity of radio uses, and forces us to look for a truly generic technique.

4.17 A final clarification is needed before moving forward. So far we have used the terms application and technology loosely. However, in the layered view of a telecommunications system, these are distinctly different aspects. An application can be understood as the service provided to the user, e.g. a voice call, whereas a technology supports that application. An application can be provided over several technologies, e.g. voice calls over GSM networks or over WiFi; and a technology may support different applications, e.g. Bluetooth is used to link wireless headsets to mobile phones but also for wireless keyboards and mice.

4.18 The parameters that have bigger impact on interference are characteristics of the RF layer of a system. Furthermore, existing regulations generally state requirements for RF characteristics. Thus it makes sense to think in terms of technology and not of application. We will do so from now on, except in the case of device density and duty cycle where we will need to come back to an application based mindset.

4.19 In this section we have proposed an approach to licence exempt bands based on classes of spectrum commons, which will be defined as ranges of values of a certain Interference Indicator. We think that this Indicator should be derived from a comprehensive set of factors that influence the interference potential of a radio application. Its calculation must be independent of the victim characteristics, fair in its evaluation of diverse systems and applicable to any system. We believe that the most practical representation of this Indicator is a single figure resulting from a formulation whose parameters are all the relevant factors. In the following sections we will propose a realization of such Indicator.

Q1: Do you agree that the spectrum commons class of a technology should be based on its interference characteristics?

Section 5

Defining the Interference Indicator

5.1 We presented the requirements for the Interference Indicator in the last section. We will now propose an implementation that fulfils those requirements. The method will calculate factors based on the characteristics of a technology in the frequency domain, time domain and space domain; and combine the factors in a simple way to yield a single figure.

What is interference and how we measure it

5.2 We need first to clarify what we understand by interference. In essence, interference is the inability of a receiver to correctly decode the wanted signal due to the presence of an unwanted signal. However, we need a bit more detail to fully characterize the interference potential of an application. We propose the following definition:

> Interference occurs when undesired RF signal appears at the spatial location of a receiver, in its receiver channel frequency, at the time the desired signal is present, and with a power level high enough so that the reception of the desired signal is disturbed.

5.3 This is not in contradiction with the definition of harmful interference in the Wireless Telegraphy Act[12]; it focuses instead on the three domains where concurrence is required for interference to appear: geographic or spatial domain, time domain and frequency domain. We propose to gauge the interference potential of a technology in each of the three domains separately, and then combine the results into the Interference Indicator. For each domain, we imagine that the parameters in the two other remain constant and we try to understand how the interference varies with changes in its parameters. However, it is not always possible to isolate one domain from the parameters of another as we will see below.

5.4 The definition above highlights that interference appears only when the reception is disturbed. This aspect is very much dependent on the victim device: certain technologies would support high levels of unwanted signal better than others. Furthermore, different implementations of the same technology may be better than others at decoding the desired signal in presence of noise or interference. Hence, the level of unwanted signal that constitutes interference will vary strongly across applications, technologies and even implementations. Since we are looking for an indication of interference to a generic receiver, this level will have to be chosen in a generic manner.

5.5 In addition, we will be looking at interference in a statistically averaged way. We will assume that the interfered system selects its operating frequency randomly and that its clock is not synchronized with the interferer. We will not specify a normalized receiver bandwidth. We assume also that the interferer operates without knowledge of a victim system being in its proximity, and that the victim does not take any action to avoid the interference.

5.6 The assessment of interference potential is made assuming that no polite protocols are being used. The purpose of the interference profile is to assess a technology on

[12] Wireless Telegraphy Act 2006, Section 115, Paragraph (5)

the basis of its RF and deployment characteristics. We will discuss the use of polite protocols and their effect in subsequent sections.

5.7 Finally, we will evaluate a technology in a given scenario. We propose to select scenarios where the technology usage is busy, yet realistic. For example, for Wi-Fi this would be a block of flats with broadband access. The scenario will define the application or applications using the technology and the usage patterns. This will drive factors such as traffic and density of transmitters.

5.8 These assumptions let us make analysis and results that are generic and applicable to any interferer. We now look in detail at each of the three domains:

Frequency domain

5.9 We focus here on the situation where collision occurs in the frequency domain, i.e. the probability that the victim receiver channel and the interferer transmission channel overlap, and on the interference due to that overlap. We assume that the interferer power levels are high enough to affect the victim, and that transmissions occur at the same time. Parameters in the time and power domains remain constant so that we can isolate the impact on interference of variations of the frequency domain factors.

5.10 Clearly, a transmitter whose channel occupies a large fraction of a shared band will have high probability of overlap with a victim receiver positioned at a random central frequency within the band. The degree of interference arising from the overlap will depend on the technologies involved, their implementations in the interfering transmitter and the victim receiver, and the extent of the overlap. Indeed, aspects such as filter steepness and receiver's mitigation techniques will play a major role, but cannot be handled in a generalized manner.

5.11 We will look only at the overlap geometry and how the bandwidth of the channels and the positions of the centre frequencies impact the interference. We consider that interference is defined as unwanted energy present in the receiver channel, i.e. it appears when the two channels overlap even if the overlap is only a small fraction of the channel bandwidths.

5.12 On this scenario where the interferer central frequency Cf is fixed and the victim randomly chooses its own, the probability of overlap is a factor of the interferer and victim bandwidths and the width of the shared band.

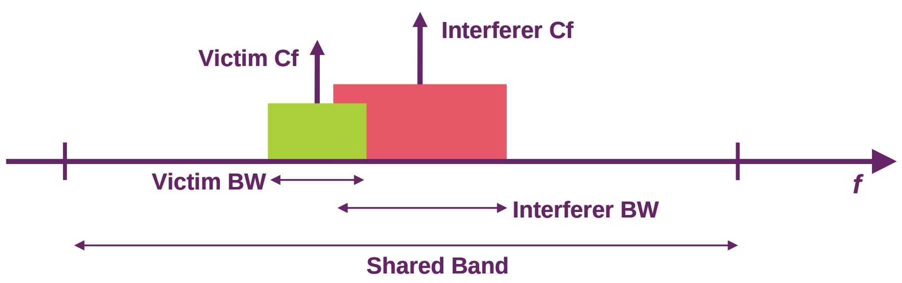

Figure 2. Interference in the frequency domain

5.13 We propose to take the ratio of channel bandwidth to shared band width as an Indicator of interference potential: $\frac{BW_{Interferer}}{BW_{SharedBand}}$. Hence, the interferer potential of a given technology in a shared band depends on two factors: the transmitter channel bandwidth and the width of the band. The percentage of occupancy of the frequency resources is then a measure of the interference effect of a technology in the frequency domain.

5.14 It may happen that certain technology can be used in different bands. In this case, the Indicator would be different for each allocation.

5.15 As frequency increases, the width of the band allocations also tends to increase. Hence for a given technology and throughput, the interference potential is usually lower in high frequency band allocations than in lower band allocations. This was already observed in the LEFR for frequencies above 40 GHz:

> 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.

Q2: Do you think that the ratio of channel bandwidth to the width of the band is a good representation of the use of the frequency domain resource and the interference potential of a technology in this domain?

Time domain

5.16 A transmitter operating with high duty cycle will have a high probability of interfering with other systems and hence this should be accounted for in the interference profile. As in the frequency case above, the amount of disturbance in a receiver caused by time collisions is a function of the technologies involved, their implementations and the degree of overlap in the transmissions.

5.17 As above, we will consider the probability of overlap as an Indicator of interference. In this case, we will consider a victim receiving continuously, i.e. its duty cycle is one, and an interferer with its declared duty cycle. Clearly, this is an oversimplification since the victim will normally have a duty cycle of less than one and the actual probability of overlap will be a complex function of victim and interferer duty cycles and their frame durations. However, we must not forget that we are after a method of categorizing interferers, regardless of the characteristics of the victim.

5.18 In this scenario, the probability of the victim symbols being overlapped will be equal to the duty cycle of the interferer.

Figure 3: Interference in the time domain

5.19 Hence, we propose to take the duty cycle as an Indicator of the probability of overlap and as an Indicator of the interfering potential as a function of the time occupancy of the channel.

5.20 For a majority of technologies the Duty Cycle depends on the traffic. For example, the channel occupancy of an 802.11 transmitter will be high when it is streaming video and low for internet browsing. This is a factor of the application rather than the technology, so we cannot assign a duty cycle on the basis of technology parameters alone. We have mentioned above that we will evaluate a technology in use in a particular scenario. The scenario will define the applications and the traffic they require, which will be a fraction of the capacity that the technology can support. This ratio will be the occupancy of the channel. This calculation will not be required for simple technologies and applications where the duty cycle is fixed.

5.21 A second aspect is the time of day and the duration of the scenarios. Most telecommunications systems have a natural duty cycle. For example, office phone lines are busy from 9 to 5 and unused at night, and residential broadband use peaks in the evenings. Although we could average the interferer activity through the day, we believe we must focus on the worst case situation. We think that the busiest hour gives a better indication of a technology's interference potential than a day duty cycle. Furthermore, the usage patterns of transmitters and victims will coincide along the day in many cases. For example, Bluetooth is likely to be used in an office space at the same time as WiFi. Hence, we propose to use busy hour activity when calculating channel occupancy in the time domain.

Q3: Do you think that the duty cycle is a good representation of the use of the time domain resource and the interference potential of a technology in this domain? Do you agree that the duty cycle should be evaluated at the busy hour?

Geographic domain

5.22 For a victim operating at the same frequency and time as a transmitter, interference will only happen if the victim is physically located within reach of the transmissions. There are two aspects of interference in the spatial or geographic domain:

- **Interference coverage of the transmitter.** This is the area where the power level of the signal from the transmitter is higher than a certain threshold. The coverage area is determined by the output power of the transmitter, the propagation conditions, the antenna pattern and the victim receiver sensitivity to interference.

- **Number of transmitters in the area.** Clearly, a victim is more likely to be affected if the number of potential interferers in the area is high. Since we are looking at the interference potential of technologies, and not of a single system or a single radio link, density is relevant. For example, a single Bluetooth device might interfere slightly with a WiFi system in its proximity, but several independent BlueTooth devices may have a strong impact.

5.23 We look in detail at these two aspects in the following sections.

Q4: Do you think that the interference coverage plus the density of transmitters give a good representation of the use of the space resource and the interference potential of a technology in this domain?

Interference coverage area

5.24 We propose to calculate a coverage area as a function of range and antenna pattern. We define range as the distance from the transmitter, in the direction of maximum gain of the antenna, at which the signal power reaches the threshold value. This distance is derived from the required pathloss, which comes from the following:

$$Pathloss(d) = EIRP - P_{threshold}$$

5.25 Where the EIRP is the Equivalent Isotropic Radiated Power and accounts for the transmitter output power and the antenna gain.

5.26 In a radio link, the pathloss is defined as the ratio of the received signal power to the transmit signal power. Losses due to propagation in free space conditions are proportional to the square of the distance and the frequency. However, energy propagation in other scenarios will be subject to reflections, refractions, delay spreads and other effects. Several empirical and theoretical models are available to approximate common scenarios, and hence we propose to use these models where applicable[13].

5.27 The effect of directive antennas is to increase the power radiated in certain directions and to reduce it in others. We will account for the first effect in the EIRP as antenna gain, yielding a rise in the radiated power and hence in range, and for the second as a reduction in the coverage from the area enclosed by a full circle to a pie defined by the antenna beamwidth. The interference coverage area is then:

$$Interference\_coverage\_area = \pi \cdot range^2 \cdot \frac{beamwidth}{360}$$

5.28 We will assume an ideal directive antenna, so that it radiates in the horizontal plane in a perfect beam whose aperture angle is the beamwidth given by the specifications. We are making the approximation here that the power radiated out of the specified main beam is negligible, but we acknowledge that it may not be always the case, i.e. with high side lobes.

Threshold level

5.29 A key parameter in the range calculation is the threshold level. A generic victim will suffer interference if the level of the unwanted signal at its receiver is higher than the threshold. As we said above, it is the receiver characteristics that determine this threshold. However, we are seeking a generic threshold, independent of the victim. We have looked at existing technologies to get a range of realistic values for the threshold.

5.30 The easiest option would be to take the noise level as the threshold value. The signal level decreases with the distance and it will eventually become indistinguishable from the background noise. It can be argued that a power level slightly higher than noise might interfere with devices which have very sensitive receivers. However, this would give unrealistically large coverage areas, and in practice a majority of technologies are unaffected by unwanted signals several dB's higher than the noise level.

5.31 The best alternative is to look at the specification of co-channel interference requirements in existing systems. For example, the BER of a Bluetooth receiver must

[13] For example, IEEE802 standardization groups use a pathloss model for the 2.4 GHz band consisting of free space loss (slope of 2) up to a breakpoint distance and slope of 3.5 after the breakpoint distance. We propose to use the propagation models commonly used in literature and standardization for the scenarios and frequency ranges under analysis.

not exceed 0.1% for a -60 dBm wanted signal in the presence of a -71 dBm co-channel interferer.

5.32 Listen-Before-Transmit specifications, for example those in ETSI standard for Short Range Devices[14], present a similar requirement. Indeed, the threshold that triggers the channel busy indication can be understood as the level of energy in the channel that would make the communication fail. The threshold level is normally variable or implementation dependent, but we have seen values in the range of -70 dBm to -90 dBm in simulations.

5.33 And as a third option, in the absence of any indication of the co-channel interference that a receiver can tolerate, we can use the specified receiver sensitivity as a proxy for its threshold.

5.34 It must be noted that all these values are technology specific so the power is spread over different channel bandwidths. We believe that the threshold should not be affected by the technology under test. This means that the threshold should be expressed as power density (dBm/MHz) and not power (dBm).

5.35 We propose a generic threshold level of -80 dBm/MHz. We believe this is close to the average of the levels that would represent interference to current technologies. As explained above, we believe that the threshold should be independent of the channel bandwidth of the technology, and hence expressed as a power density. In any case, as long as the same threshold is used in evaluating all devices, it does not matter unduly if it is set somewhat too high or low – the effect will be the same across all devices evaluated.

5.36 Nevertheless, different thresholds for different band allocations could be envisaged. The interference tolerance of devices operating at a few hundred GHz can be very different from that of UHF devices.

Q5: Do you agree with our method to calculate the interference coverage area of a transmitter? What is your view on a threshold level of -80 dBm/MHz to determine the interference range? Do you think the threshold level should be expressed as power density (dBm/MHz) or as power (dBm)?

Density

5.37 Another important measure of interference potential is device density, expressed as the number of devices per unit area. One can imagine a scenario with a victim receiver and randomly positioned transmitters, as shown in figure 4. Clearly, the receiver will have higher probability of being interfered the higher the density of transmitters. A possible way out of the problem is a careful deployment where transmitters and victims are placed so that interference does not appear. This is the situation in light licensing conditions, but not in licence exempt bands where no one is in control of the locations.

[14] ETSI EN 300 220-1: Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW

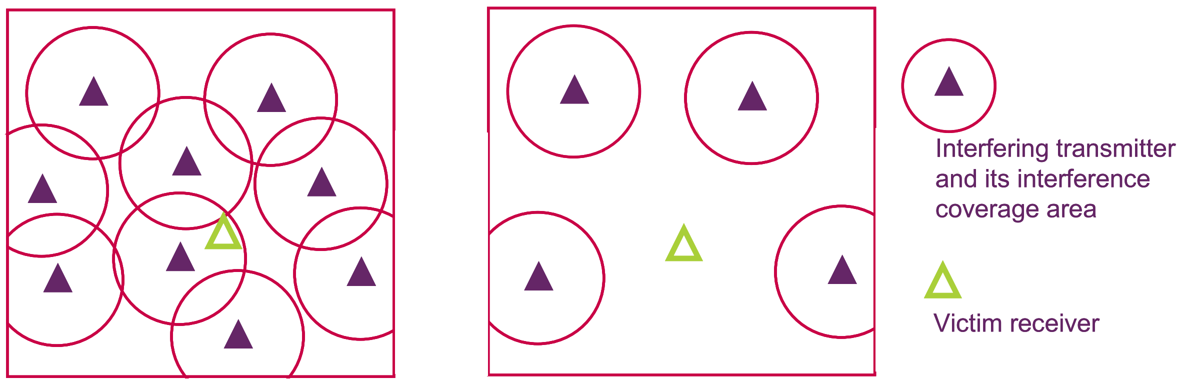

Figure 4. Density of interferers

5.38 Density, expressed in terms of interfering transmitters per area unit, can be used together with the coverage calculation above to give a measure of the usage of the space resource. For two technologies with the same coverage area per transmitter, the more ubiquitous one will result in a higher value of interference.

5.39 We need to better understand the density factor before we can introduce it in our calculations. A first issue to consider is the area: we could estimate the number of transmitters of a given technology at country level and divide by the country area. However, interference does not happen at such a large scale but in scenarios where there is a high concentration of aggressors. A technology can be very popular in certain busy areas while absent in others. Hence we propose to estimate density at a busy, yet realistic, scenario where a technology is deployed.

5.40 Sometimes it is easier to estimate density for an application than for a technology. A given technology can be used for different applications and thus be found in scenarios with very different densities. For example, Bluetooth can be used to link a wireless headset to an iPod, or to interconnect a desktop to its mouse. Our view is that we should continue thinking in terms of technology, but in certain cases we should estimate application usage and derive technology density from it. This approach will help in the situations where a technology has different end uses appearing in the same scenario. Taking the example above, the worker at a desk could listen to her iPod through a wireless headset while typing on her wireless keyboard.

5.41 We propose that our busy scenarios account for this. In short, we will generally find scenarios where a technology is used for one single application, but it may also happen that the busiest scenario is one where the technology is used, at the same time and place, by diverse applications.

5.42 Finally, a word of caution. The number of licence exempt units in any given scenario can only be estimated since there is no single licensee that controls them. To make things more difficult, the Interference Indicator will normally be evaluated when technologies are in their development phase or before commercialization, so density estimates will be based on sales projections and expected uses, adding uncertainty to the evaluation. We believe that despite these complications, a density factor must be part of an accurate description of the interference potential of any technology. Typically, we would work with interested parties to reach a consensus on the density figure.

Q6: Do you agree with using a busy yet realistic scenario to derive the transmitter density of a technology?

Construction of the Indicator

5.43 The Indicator, then, should be based on the frequency factor, the time factor and the number of devices within coverage range. A simple approach is to multiply these factors together. Roughly, increasing the operating bandwidth by a factor *k* and increasing the duty cycle by the same factor will have the same impact in the system capacity and, more relevant here, the interference it generates. Hence, it makes sense to multiply the time and frequency factor so that developers can trade usage in both domains in the way it best suits their application.

5.44 We can also multiply the two factors from the space domain: interference coverage and density. To picture the relation, it helps to think of an ideal scenario with a uniform deployment of transmitters and with cellular-like antenna patterns, and to bear in mind that interference means that a signal from the transmitter is present at the receiver with a power level higher than the threshold.

5.45 If the coverage-density product is less than one, then not all space is covered, i.e. there are areas without interference. If the product is bigger than one, there is a fraction of the area that is covered by more than one transmitter, hence there is higher level of interference. And if the product is exactly one, all the points in space are interfered by one transmitter only. These scenarios are shown in figure 5 below.

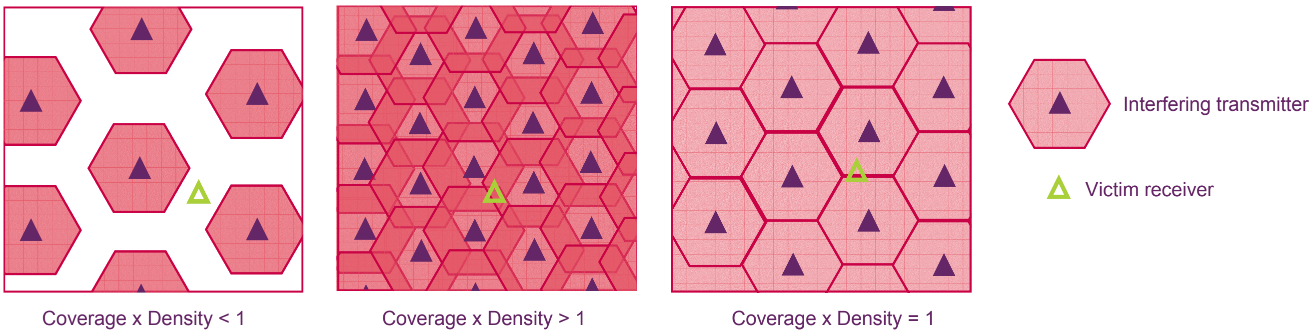

Figure 5: Coverage x density

5.46 We can imagine a victim which can move freely to find the best location. If the coverage-density product is lower than one, the victim will be able to find an interference free spot. If the product is one or higher, and we face the worst case scenario of a uniform distribution, there will not be interference-free areas. A product of one or higher and a non-uniform distribution will leave interference-free zones, at the cost of other zones being highly interfered, i.e. interfered by two or more transmitters.

5.47 The uniform distribution with product one (or higher) blocks the victim's operation completely; it cannot go anywhere to receive. We may say that the interfering technology is taking all the space domain resource, and we will mark it as impolite in the space domain.

5.48 The example here is an idealization, it is highly unlikely that licence exempt devices are uniformly deployed and that their coverage is as depicted. However, it can be generalized to say that the product of coverage and density gives an indication of the usage of the geographic resource and thus of the interference generated by a technology in a given deployment scenario.

5.49 We have presented simple ways to combine the frequency factor with the time factor, and coverage with density. The next step is to combine all in a single calculation. Here again, we believe that a simple product of all factors will take into account the effect in all domains in a fair manner. We propose that the Interference Indicator is calculated as follows:

$$Interference\ Indicator\ (frequency, time, space) = I_f \cdot I_t \cdot Coverage \cdot Density$$

5.50 Where the frequency domain factor I_f and the time domain factor I_t are dimensionless and can take values from 0 to 1 (or from 0 to 100%), the *Interference Coverage* is expressed in km^2, and the *Density* is in units/km^2. The range of values that the product *Coverage x Density* may take is not bounded.

5.51 We mentioned above the case of a scenario where diverse applications use the same underlying technology. In that scenario, it will likely happen that one or more of the factors take different value according to the application.

5.52 An example of this is the use of Bluetooth in an office space. Its duty cycle is 50% when used in a wireless headset, while it is only 12.5% when it replaces the cable between a computer and a keyboard. In addition, the number of units active will be different for these two applications: we will be looking at Bluetooth enabled cell phones in the first case and Bluetooth enabled desks in the second. The scenario is the same in both cases: an office space during work hours. The frequency factor and coverage are the same too, but the densities and duty cycles are different.

5.53 To cope with such multi-application scenarios, we propose to calculate the Interference Indicator as the sum of the Indicators of each application in the scenario:

$$Interference\ Indicator = \sum_{i}^{applications} I_{f,app\_i} \cdot I_{t,app\_i} \cdot Coverage_{app\_i} \cdot Density_{app\_i}$$

5.54 The formula above represents the last step in the process of defining the Interference Indicator. We have derived an Indicator that can be used to categorize technologies according to their interference potential. The Indicator fulfils the requirements that we laid on section 4: it is based on all relevant parameters, it is fair, applicable to any technology, and independent of the interfered device.

5.55 It must be noted that current requirements in ECC Rec. 70-03[15] for Short Range Devices take a similar approach, albeit not as explicit as an interference formula. Indeed, different apparatus already successfully share spectrum. Two examples of this are:

- The 433/434 MHz band where a trade-off between TX power and duty cycle is allowed, permitting low and high duty cycle apparatus to co-exist.
- The 863 to 870 MHz band where devices with different digital modulation, duty cycle, TX power and LBT functionality are allowed.

5.56 These are examples of an uncoordinated approach to the objective of spectrum sharing; the proposal in this consultation aims at achieving the objective in a coordinated manner.

[15] http://www.erodocdb.dk/docs/doc98/official/pdf/REC7003E.PDF

5.57 In the following section, we apply the formula to a number of existing licence exempt technologies. We do this to see how it performs and the range of values that it yields, so that we can validate the concept.

Q7: Do you agree with the Interference Indicator being a product of the frequency domain factor, the time domain factor, the interference coverage area and the transmitter density?

Section 6

The Interference Indicator of existing technologies

6.1 In order to test the validity of the assumptions made above and to understand what range of Indicator values can be expected, we have applied the Interference Indicator formula to a variety of technologies that operate, or will operate in the near future, on licence exempt bands.

6.2 The results are preliminary and illustrative. Some of the parameters come straight from specifications but others such as channel occupancy or unit density are estimations. A proper calculation of the Indicator would require consultation with users and industry so that the parameters used are as accurate as possible and widely agreed. Finally, we must remember that these are busy scenarios and hence normal use will see lower levels of occupancy and interference.

6.3 We have looked at the following cases. The details of the assumptions and parameters are in Annex 6.

- **Radio Frequency Identification (RFID).** The scenario simulates RFID interrogator equipment in the UHF band operating in a pallet distribution centre. The technical parameters are taken from the relevant ETSI standard, and the operating parameters from the feasibility study performed in ETSI.

- **Bluetooth.** Office scenario with two applications: Bluetooth enabled desktops, keyboards and mice, and Bluetooth wireless headsets and mobile phones. Technical parameters are taken from Bluetooth specification, and operating parameters are estimated.

- **Wi-Fi, IEEE 802.11b.** Residential broadband access in a block of flats. Technical parameters are from IEEE standard and operating parameters are estimated.

- **Home automation.** Control and sensor devices in a residential home scenario. Technical parameters are from the industry standard, and the scenario has been defined with contribution from industry experts.

- **60 GHz WPAN, WirelessHD & IEEE 802.15.3c.** Residential scenario in a block of flats, wireless link between a HDTV source and a HDTV screen. Cable replacement is a key anticipated application of this high throughput, very short range technology. This standard is under development at the IEEE 802.15.3c group, we have used the current assumptions for the technical parameters and estimated the scenario parameters.

6.4 Table 2 below presents the values of each factor, the product coverage-density, and the Interference Indicator. Note that the time and density factors are application specific in the Bluetooth scenario.

	I_f	I_t	Coverage	Density (units/km^2)	Coverage x Density	Interference Indicator
RFID	0.100	0.100	0.5 km^2	234.8	117.878	**1.1788**
IEEE 802.11b	0.263	0.012	3362 m^2	15000.0	50.435	**0.1641**
BT Voice	0.012	0.083	2800 m^2	20000.0	56.018	0.0559
BT HID[16]	0.012	0.250	2800 m^2	12500.0	35.011	0.1048
Bluetooth						**0.1607**
Home automation	0.166	0.0001	0.43 km^2	20000.0	8673.2	**0.2008**
60 GHz WPAN	0.309	0.931	7.28 m^2	6250.0	0.046	**0.0131**

Table 2. Interference Indicator of RFID, Wi-Fi, Bluetooth and WPAN

6.5 The results in table 2 come from busy scenarios. The density figures may seem high because they are scaled up to 1 km^2 areas, but the scenario coverage areas are never that large. This means that 1 km^2 areas supporting the number of units reported in the table do not happen in reality, only smaller areas with the proportional number of units.

6.6 This comment also applies to the coverage-density product. This product can be understood as the number of units per coverage area. However, a scenario, taken from real life, whose area is smaller than the technology's coverage area will have a number of units per coverage area lower than stated in the table. This is the case of the IEEE 802.11b scenario, where the footprint of the block of flats will be smaller than the 3362 m^2. We believe that this does not reduce the validity of the calculations or the resulting Indicator.

6.7 We have only studied five technologies and five scenarios, but we can already see that the proposed Indicator yields results that are reasonable and align with the broad understanding of the interference potential of these technologies. In these busy yet normal scenarios, only the RFID application has an Interference Indicator higher than one. The main reason is the long propagation range, due to the high transmitted power (2 Watt) and the propagation conditions of the UHF band. Interestingly, Bluetooth and Wi-Fi have a similar Indicator values.

6.8 One can note from table 2 that the frequency factor is normally low, few technologies will have a channel bandwidth that spans the entire shared band. Also, for allocations in the same band, technologies supporting high throughput applications such as IEEE802.11b have higher values of I_f . Third, we can also observe that streaming or real time applications such as WPAN have higher interference factor on the time domain than burst type applications.

6.9 The frequency factors I_f above have been calculated after the current allocations of the technologies: RFID in the UHF band, Wi-Fi and Bluetooth in the 2.4 GHz ISM band, and WPAN in the expected 60 GHz licence exemption. The widths of these bands are too different, and so the Indicators do not allow us to compare the technologies in equal terms. To do this, we need to make the hypothesis that all technologies will share the same licence exempt band. This will be the real life situation when a new band is released and different applications and technologies are submitted.

[16] Human Interface Device. Bluetooth profile for interconnection of keyboard and mouse to a computer.

6.10 Table 3 presents the results for an allocation of the technologies into the 2.4 GHz ISM band, whose bandwidth is 83.5 MHz. Note that the values for Wi-Fi and Bluetooth remain the same.

	I_f	I_t	Coverage	Density (units/km^2)	Coverage x Density	Interference Indicator
RFID	0.002	0.100	0.5 km^2	234.8	117.878	**0.0282**
IEEE 802.11b	0.263	0.012	3362 m^2	15000.0	50.435	**0.1641**
BT Voice	0.012	0.083	2800 m^2	20000.0	56.018	0.0559
BT HID	0.012	0.250	2800 m^2	12500.0	35.011	0.1048
Bluetooth	0.012					**0.1607**
Home automation	0.0012	0.0001	0.43 km^2	20000.0	8673.2	**0.0014**
60 GHz WPAN	25.868	0.931	7.28 m^2	6250.0	0.046	**1.0963**

Table 3. Interference Indicator of RFID, Wi-Fi, Bluetooth and WPAN for an allocation in the 83.5 MHz wide 2.4 GHz ISM band

6.11 In table 3 we have only modified I_f . Clearly, the propagation range and coverage will be modified with the move to 2.4 GHz, but this is ignored for the purposes of this example. The channel occupancy of RFID is now 0.2%, while it jumps 2,500% for the WPAN application[17]. As a result, the Indicators now show that the WPAN has the highest interference potential, and the RFID the lowest. This illustrates how the same technology, when used on different allocations, may have very different interference potential.

6.12 This section completes the development of the Interference Indicator. We laid out its rationale and requirements in Section 4, and we have presented its calculation step by step. We have also tested it against some technologies. In the following section, we build on the Indicator to make a proposal for a collection of spectrum commons classes.

[17] Obviously, this is not physically possible. It is not possible either to use a 2.4GHz carrier for an application with a 2GHz channel bandwidth such as WPAN.

Section 7

A proposal for classes

7.1 We have developed a method to assess the interference potential of any wireless technology. The method takes relevant factors into account and yields an Interference Indicator that can be used to compare and categorize technologies. However, we must bear in mind that its objective is to be able to decide whether certain technology is allowed in a licence-exempt use. For this, we agreed to use the concept of spectrum commons class. A band with licence-exempt use will only accept technologies that belong to certain classes, where a class is defined by a range of values of the Interference Indicator.

7.2 In this section we will propose a number of classes and their boundaries in terms of Interference Indicator values. After this, we briefly discuss how we will decide on what class would be allowed in new licence-exempt allocation.

Number of classes and their boundaries

7.3 The outcome of the Interference Indicator formula is continuous, so the choice of class count and boundaries is to some extent arbitrary. One single class means a pure spectrum commons policy which, clearly, is not what we are looking for. Two classes would be the next option: a high Indicator value, high interference class and a low interference, low Indicator class. This partitioning has merit in terms of simplicity. However, we believe that given the spread of technologies and applications, there is significant risk of having widely different technologies in the same class.

7.4 We propose to establish three classes initially, with scope for subdivisions according to the needs of future spectrum allocations. We think that a scheme with three classes presents a good compromise to categorize diverse applications with the Interference Indicator that we have defined. It is also worth remembering that the Interference Indicator is approximate and if bands were narrow the errors inherent in the Indicator estimation could easily move a technology to a different band. This precludes a structure with too many classes.

7.5 Once the number of classes is settled, we must decide on their boundaries. Clearly, the low interference class will start at an Interference Indicator value of zero, and the high interference class will not have an upper bound. These aside, we have freedom to set the boundaries at any value.

7.6 An interesting value point is an Indicator figure of one. A conceptually simple way for a technology to achieve this value would be to occupy the entire shared band, i.e. I_f of one; to transmit continuously, i.e. I_t of one; and to have coverage over the entire scenario area, i.e. the product coverage x density equal to one and uniform distribution. A victim will have no chance of operating in this scenario: it will not find available bandwidth, it will never have a silent channel, and it cannot move anywhere to be free of interference.

7.7 A victim receiver will find very difficult to operate when the interferer has an Indicator value slightly lower than one, but it can be argued that such interferer technology leaves a fraction of frequency, time or space available for others. The further down the Interference Indicator goes, the more resources that a technology leaves available to other systems.

7.8 We can hence categorize systems with an Indicator value greater than one as high interferers[18], and we will have to impose additional requirements upon them if they are to share a band with other systems. We can use a value of one as the threshold between high and medium interference classes.

7.9 The choice of a value for the boundary between low and medium interference classes is less obvious. It is difficult to agree on the level that categorizes a low interferer; we lack here the conceptual threshold given by the usage of all resources. We will need to take a more empirical approach. For this, we can take guidance from the ECC Rec. 70-03 for Short Range Devices. We find there several bands where manufacturers have the choice of either a maximum duty cycle or an LBT requirement. The maximum duty cycle values vary with the band and the application from the set 0.1%, 1% and 10%.

7.10 We could decide on one of these values as the low interference boundary. Or we could consider these values as occupancy in a single domain, and decide that low interference comes from low occupancy in all domains. This would give us a much tighter requirement. Ultimately, the choice is arbitrary. We propose a value of the Indicator of 0.01 which we think is a good compromise: a value of 0.001 would likely put all technologies in the middle range, while a value of 0.1 might be achieved by relatively high interferers such as Bluetooth under certain scenarios. Figure 6 displays the proposed classes.

Figure 6. Spectrum Commons Classes

7.11 This scheme has few classes to manage, which is an advantage from the perspective of simplicity. On the other side, it clearly separates very low interference systems from high interference ones.

7.12 Nevertheless, this proposal could be modified when the actual band allocations take place. For example, one can think of the medium class being divided in two. We have noted that the choice of 0.01 for the low-medium classes boundary as somewhat arbitrary, and so the boundary values could be different. Or a new class could be defined for a particular band allocation.

The class of a technology also depends on the applications

7.13 We have seen in section 5 how the Indicator value of a technology depends on the applications that we use in the assumptions. The applications assumptions will most likely drive the time occupancy and the density factors. A technology could be used for a low interfering application, such as telemetry or home temperature sensors, and a high interfering one, such as cable replacement. It could fall into different classes according to the application and, if a device is capable of supporting the both uses,

[18] Note that the Wireless Telegraphy Act requires that licence-exempt devices do not involve undue interference. High Interferer must be understood here in relation to other licence exempt devices, not to licensed users.

users might be tempted to activate its high interfering application in a low interfering allocation.

7.14 Clearly, this should not be allowed. It is the task of the manufacturer or the standardization body to ensure that the device only behaves as high interferer when operating in the band allocated to the high interference class.

Deciding on a class for a new licence exempt band

7.15 We intend to use spectrum commons classes for licence exempt allocations, and we have proposed a mechanism to decide the class a technology belongs to. However, in practice Ofcom will have to deal with three issues before using this mechanism in newly liberated spectrum:

- **Should the spectrum be available for licence exempt use?** The Spectrum Framework Review lays out the approaches followed by Ofcom to balance the different models of spectrum management. It suggests calculating the likely economic value for licensed and licence exempt applications and selecting the one with the highest value. Ofcom will also take into account its wider duties regarding its spectrum functions[19].

- **If licence-exempt use, what class, or classes, should be allowed in the band?** We propose that the decision is made fundamentally on the basis of economic value. In this case we would predict the economic value likely to be derived from each of the different classes and select the class with the greatest value. However, other aspects must be considered, for example the services in adjacent bands. It is very difficult to isolate two technologies that are collocated in the same device, so ideally they should be allocated bands as far as possible.

- **Are there primary users in the new band?** This is the case in most new allocations for licence-exempt use and Ofcom has to decide if protection of primary users from the licence exempt entrants must be guaranteed. If this is the case, specific politeness rules would be imposed on the new entrants. This is further detailed in the next section.

7.16 In the following section we look at what additional requirements might be imposed so that technologies in the same class can co-exist.

Q8: Do you think that three classes of spectrum commons is the right number? What is your view on the proposed boundary values for the three classes?

[19] Wireless Telegraphy Act 2006, Section 3

Section 8

Politeness rules and protocols

8.1 We have defined a method to categorize wireless systems according to their interference characteristic and a class structure that groups systems with similar characteristics. Systems belonging to the same class will be allowed to operate in the same frequency band, on the basis that their interference profile is not very different. However, this does not mean that they will not interfere each other and that interference limitation measures are not needed.

8.2 In this section, we suggest that technologies should implement measures to ensure that they exploit the resources in a fair manner, and we propose high level requirements based on this overarching goal.

A definition of fairness

8.3 In licensed bands, access to the resources is controlled by the licensee. But in licence exempt allocations, interference-free operation cannot be guaranteed. To mitigate it, the regulator imposes limits for transmitted power or duty cycle, or techniques known as spectrum etiquette or polite protocols.

8.4 Although there is no precise definition of a polite protocol, its general objective is to guarantee a sharing of the resources. This acknowledges that a system is not alone in a band, and hence procedures are required to ensure that it can access the resources that it needs, and that it lets others do the same.

8.5 Polite protocols are normally specified by standardization bodies such as the IEEE or by the organizations developing proprietary technologies, and are part of the technology specifications. It is outside of the scope of Ofcom to do this. A regulatory requirement for a polite protocol would steer developers towards a particular technical solution. This would be against the Radio and Telecommunications Terminal Equipment Directive[20] and hinder innovation. Instead, we will require a fair use of the resources and a few high level rules.

8.6 We explain below what we understand by fair, and we present in the following sections some rules that in our view would provide sufficient guidance to achieve our objectives. Following this, it is up to the developers and the standardization bodies to produce protocols according to our requirement.

8.7 There is considerable academic work on the subject of fair allocation in telecommunications networks. The seminal paper by Kelly[21] addresses the issue of charging, rate control and routing on a fixed packet network. In a more recent paper, Briscoe[22] suggests looking at fairness in terms of the cost rather than the data flows. These models focus on charging within fixed networks, but the concepts are applicable to access as well. Closer to our wireless licence-exempt scenario,

[20] http://www.ofcom.org.uk/radiocomms/ifi/tech/RTEE/rtte_faq

[21] Kelly, Charging and rate control for elastic traffic, European Transactions on Telecommunications, volume 8 (1997)

[22] Briscoe, Flow Rate Fairness: Dismantling a Religion, CCR online, 2007

Nandagopal et al.[23] propose a contention based protocol that achieves fairness at the MAC layer.

8.8 These models of fairness presuppose a centralized access control or, at the very least, common access protocols among the participants. In the situation we are trying to address, we will have neither. As explained above, we do not believe it appropriate to mandate a particular polite protocol let alone a particular multiple access protocol. For these reasons, we do not believe the academic models developed so far are applicable to the situation we are addressing. Instead, we approach fairness in regards of the use of the resources. We think a fair wireless user is one that:

- shares the resources equitably with other systems, and
- behaves appropriately according to its needs.

8.9 For a system to be capable of sharing equitably with other users, it must know that they are there. This can be achieved thorough different strategies such as channel sensing or off-line coordination. If the channel is occupied, a fair system will move to another channel or wait until it becomes available. If the capacity demanded by users exceeds the available resources, a fair system will reduce its usage so that all get an equal share of the resources.

8.10 A system behaves appropriately when it uses the minimum amount of resources that allow it perform its task. It does not need to be aware of other users in the area to do this, but nevertheless these will benefit from the fact that it does not waste resources.

Q9: Do you agree with our definition of fairness and that all systems should be required to behave in a fair manner?

Interference situations and mitigation rules

8.11 We can think of two distinct situations when a system can be harmful to others:

- When **accessing** the resources, if they are already taken.
- When **using** the resources, if others need access.

8.12 If a system transmits without knowing whether the channel is already taken, it may interfere with any current user and it may also suffer interference from that user.

8.13 Once a system has got access to the channel, it should not act as if it has absolute rights to use it. Instead, it should let others access the resources too.

8.14 We can plot in a matrix the two situations above against the key capability for interference mitigation: whether the system has information about other users. This matrix can be used to structure our consideration of politeness rules or techniques in the remainder of this section.

[23] Nandagopal et al., Achieving MAC Layer Fairness in Wireless Packet Networks, MOBICOM 2000

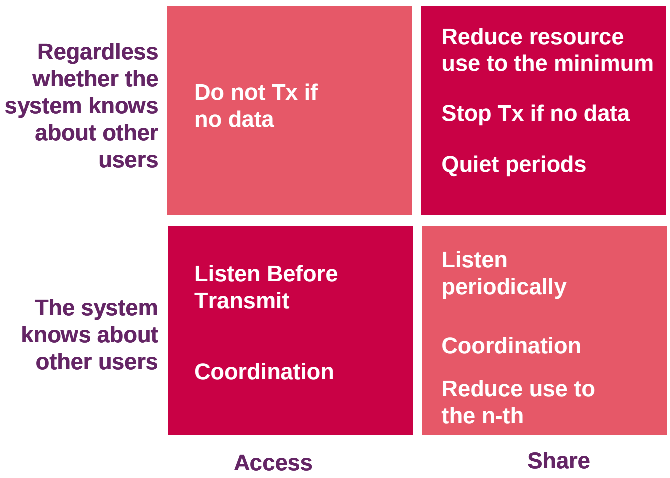

Figure 7. Politeness rules

8.15 We introduced the term politeness rules before and we should now define it better. A politeness rule is different from a politeness protocol. We understand the rules to be a high level description of an interference mitigation technique, and the protocol to be the precise implementation of the rule.

8.16 Current technologies already implement a variety of the techniques in figure 7. Some are able to sense the channel for other users, either generic or a specific technology. Other systems do not implement this functionality at all, relying on their low power profile or low duty cycle to avoid interfering other users.

Looking at the interference mitigation rules in detail

8.17 We look at these rules in more detail below, focusing in the circumstances under which we may require developers to implement them. In principle, one can imagine that all technologies in a licence exempt band should implement a fairness mechanism of some sort. In this sense, the two upper quadrants present rules that are minimum requirements and that should be broadly applicable.

- **Do not transmit/Stop transmission if there is no data.** A system should not use resources unless it has data to transmit. Data in this case can also include items such as beacon transmissions, polling or the associated signalling if needed as part of the implementation, but should be minimised as far as possible.
  It must be noted that many of the current users of licence exempt bands are short range, battery powered devices. These systems are already designed to reduce transmit time to the minimum, not for interference reasons but to limit power consumption.

- **Reduce resource usage to the minimum**. When transmitting, a system should reduce its use of resources to the minimum necessary to achieve the communication it requires. This notably applies to the power level, since normally the channel bandwidth is fixed and the time occupancy is determined by the upper layers. The requirement means that the transmit power should be enough to guarantee the link margin but not more. In practice, this requires a power control loop whereby the receiver reports the signal quality and the transmitter raises or lowers its power accordingly.
  Clearly, this cannot be implemented in one way devices such as simple garage door openers. Furthermore, it will not be of much use for technologies with short

and bursty transmissions. However, it is a fair requirement for a technology with a high duty cycle.

- **Quiet periods**. The system should periodically suspend transmissions to allow other users a chance to access the channel.

8.18 We now consider the rules placed in the lower quadrants of figure 7.

- **Listen before transmit (LBT).** This is probably the best known polite protocol. The transmitter senses the channel before transmission, and if busy it will either wait or move to a different channel. It may be enhanced with "request to send" techniques that partly overcome the "hidden node" problem[24].
  Sensing techniques can be blind or signal specific. A blind technique does not know about the features of a specific signal and is based on energy detection, whereas a signal specific technique will know about the signal it is looking for. The performance of the LBT will be very dependent on this.

- **Coordination.** Systems in the same band and geographic area could exchange information about the resources they occupy. Systems can coordinate over the air if they have common physical layer protocols or via a database where the location and characteristics of each system are stored. The light licensed bands are an example of the latter.
  In principle, coordination could provide an interference free environment. In practice, coordination is rarely applicable to licence exempt bands. Different technologies cannot communicate over the air, there is no central point to collect data about all systems and most devices do not have fixed locations anyway.

- **Listen periodically.** The goal is that the current user lets other systems access the channel. The system suspends transmissions and waits and listens for a period. If another user was waiting for the channel to be free, it will grab the opportunity and take the channel. The first user may either wait for the channel to be free or move to another channel.
  As in the case of the quiet periods, unless it knows the characteristics of other technologies in the band, the system would not know how long to wait. But in this case the wait does not need to accommodate a full data frame of the potential user, just its contention window.
  Alternatively, the system using the channel can monitor its bit error ratio. If this degrades, it might be due to an interferer in the channel and would be a signal to the system to take appropriate action including ceasing transmission.

- **Reduce use to the n^{th}.** A first step towards a fair share of the resources is to know if there are other contenders; this is what the rules above focus on. A second step would be to determine an equal share when the demand exceeds the resources. One can think of a busy channel where several systems contend for access. Why should the current user suspend transmissions if it risks not being able to gain access again?
  We propose that when n co-existing users are using the channel, each should aim at using only $1/n^{th}$ of the resources. Clearly, if all the competing users cannot be detected, as will often be the case, then each user cannot measure exactly what fraction of the resources it should use. Protocols should be devised,

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[24] LBT can be subject to the 'hidden node' problem where a transmitter is not prevented from causing interference to a receiver because the wanted transmitter to that receiver is out of range from the interfering transmitter. RTS/CTS is an extension in which the transmitter requests confirmation from the destination before transmitting.

however, that tend to result in fair sharing even without each user having a perfect understanding of the environment.
An enhancement would be to require occupancy of 1/(n+1) when n users are present. This would ensure that a fraction of the resources is left available for newcomers, undetected users, or systems not able to participate in the scheme.
A further enhancement would be to introduce the concepts of equitable and proportional share.
These rules require sophisticated coordination or channel sensing mechanisms and would work well only if all participants follow them.

Proposal for regulatory requirements

8.19 We have seen various rules that would ensure systems share the resources. It is now worth discussing where such rules make sense. For low-interference devices (ie those in a low interference class) we do not believe that the requirement to be aware of other users would be justified. This is because low interference technologies are often simple, low power, low consumption devices that can co-exist thanks to their physical parameters as noted above.

8.20 For interferers in higher classes, we believe channel sensing is better tailored to licence exempt bands than coordination mechanisms. While we acknowledge the advantage of the latter when several systems with the same technology co-exist, for most licence-exempt uses we do not think that a coordination database can be put in place[25], or that widely different technologies can communicate over the air.

8.21 We think that sensing mechanisms that rely on the knowledge of the characteristics of a specific signal are much more effective than blind detection, notably when those characteristics differ greatly from the system's own (for example in terms of bandwidth, channel raster, modulation). However, we would like to get views on this point.

Q10: What is your opinion on the effectiveness of blind detection sensing techniques compared to signal specific techniques?

8.22 We believe it is feasible for a technology to reduce its use of resources according to the number of systems sharing them although we accept that this will not be exact and so propose that the resource use should be expressed as 1/n ± X %.

8.23 We propose that all technologies to be used under licence-exempt conditions should be designed to avoid unnecessary waste of the resources. We acknowledge that this requirement is often naturally fulfilled by low power battery operated devices, and that a certain amount of signalling will always be required.

8.24 We propose that technologies belonging to medium and high interference class should

- Implement a method to become aware of other users of the same resources, so as not to start transmitting if it would interfere with another user.
- Not monopolize the resources so that other users cannot access them.
- Implement a method to reduce its channel occupancy when there is congestion (according to the n^{th} rule).

[25] Note that this would imply light licence conditions rather that pure licence exemption.

8.25 Where we require that systems implement a detection or coordination mechanism, we realize that systems cannot be designed to deal with future, as yet unspecified technologies. Hence we propose that systems should:

i) Detect, to varying degrees, any users through a simple energy-sensing technique and behave in a fair manner.

ii) Detect and coordinate with any users employing the same technology as the system in question.

iii) Detect and coordinate any existing users of the band, primary users in particular.

8.26 In terms of energy-sensing we propose that systems should measure energy levels in a given bandwidth (e.g. 1MHz) for a specified time period (e.g. 1s). The actual values would be specified in conjunction with particular bands since, for example, the likely bandwidths used will vary between bands. If the energy levels were above a given threshold (e.g. -80dBm), also specified in conjunction with typical bands, then the device should consider the band to be occupied.

8.27 These requirements will give the first technology allowed in a band a "first mover advantage", since it is not required to sense item (iii) above. Whilst this may not seem fair, we do not see any way to completely avoid it. Item (i) partly addresses the issue requiring all systems to look for transmitted energy and to behave as fairly as possible.

8.28 Item (iii) requires late comers to detect and coordinate with users of a pre-authorized licence-exempt technology. This should be achieved in the same terms as users of the pre-authorized technology detect and coordinate with each other. This means, for example, that similar detection requirements apply, and that similar channel access techniques should be used. Primary users can be seen here as pre-authorized technology, with first mover advantage over all the licence-exempt technologies. All licence-exempt devices would be required to detect and yield to the primary user.

Q11: Do you agree with the proposed polite rules?

Section 9

Conclusions

Introduction

9.1 Ofcom has a duty to ensure optimal 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 bands for licence exempt use under a framework of classes of spectrum commons. A band may then be used by a wide range of applications subject to belonging to the same class.

- Ensuring that applications with similar interference characteristics fall into the same class. To achieve this, we introduced the concept of an Interference Indicator as a measure of the interference characteristics of a technology. The Indicator is based on the usage of the resources in the frequency, time and space domains.

- Proposing a structure with three classes corresponding to low, medium and high values of the Interference Indicator.

- Requiring that systems behave in a “fair” manner. For most devices this means being aware of other users and making sure they share the resources equitably.

Classification of technologies

9.2 We will classify technologies according to their interference potential. There is not a widely agreed definition of this potential, but we think the metric should be fair, comprehensive (i.e. take all factors into account) applicable to any system, and independent of the interference victim. Fundamentally, it should be a measure of the use of the common resources, i.e. the more a technology occupies a resource, the higher its interference potential.

9.3 We consider the resources to be the frequency domain, the time domain and the geographic domain. As measures of the amount of frequency and time resources exploited, we define a frequency factor which is the channel bandwidth divided by the total band width, and a time factor which is the duty cycle in the busy hour. We define the use of the geographic domain as the product of the interference coverage area and the density of transmitters. We then form the Interference Indicator as the product of the factors above. We believe that such Indicator gives a fair estimation of the interference a technology will cause to other users of the band.

Establishment of classes

9.4 We propose three classes for devices of increasing interference potential. We think three is the right number to avoid two potential issues: having very different technologies falling in the same class, and having similar technologies in different classes. We propose to set the boundaries for the low interference class at values of the Interference Indicator of 0 and 0.01. We also propose a value of 1 for the boundary between the medium and high interference class. The latter would not have an upper bound.

Behavioural requirements

9.5 We would not require specific polite protocols since we believe this unnecessary constrains the technology choices of developers. Instead, we ask that systems behave in a “fair” manner. By “fair”, we understand a technology that

- shares the resources equally with other systems, and
- behaves appropriately according to its needs.

9.6 Nevertheless, we believe a minimum requirement is needed for medium and high interferers, and we express this as a set of polite rules. These rules can be summarized as being aware of other users and making sure they share the resources equally.

9.7 Most licence-exempt allocations have a primary user. Our proposals can cope with this, since the polite rules above will require technologies to detect and yield to the primary user.

9.8 We understand that the proposals in this consultation cannot be applied immediately. Notably, we do not intend to apply them to existing licence-exemption users. Our intention is to use them as a guideline for future allocations. Since most of the allocations are harmonized at least at European level, we will seek opportunities to present these proposals to the relevant European bodies. There is ongoing work in Europe on these issues, and we intend that our proposals will inform this debate.

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 Tuesday 15th July 2008**.

A1.2 Ofcom strongly prefers to receive responses using the online web form at http://www.ofcom.org.uk/consult/condocs/scc/, 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 cesar.gutierrez@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.

César Gutiérrez
Ofcom
Riverside House
2A Southwark Bridge Road
London SE1 9HA

Fax: 020 7981 3770

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 at 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 César Gutiérrez on 020 7783 4686.

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 2008.

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

A4.1 The following is the list of questions raised in this document:

Q1: Do you agree that the spectrum commons class of a technology should be based on its interference characteristics?

Q2: Do you think that the ratio of channel bandwidth to the width of the band is a good representation of the use of the frequency domain resource and the interference potential of a technology in this domain?

Q3: Do you think that the duty cycle is a good representation of the use of the time domain resource and the interference potential of a technology in this domain? Do you agree that the duty cycle should be evaluated at the busy hour?

Q4: Do you think that the interference coverage plus the density of transmitters give a good representation of the use of the space resource and the interference potential of a technology in this domain?

Q5: Do you agree with our method to calculate the interference coverage area of a transmitter? What is your view on a threshold level of -80 dBm/MHz to determine the interference range? Do you think the threshold level should be expressed as power density (dBm/MHz) or as power (dBm)?

Q6: Do you agree with using a busy yet realistic scenario to derive the transmitter density of a technology?

Q7: Do you agree with the Interference Indicator being a product of the frequency domain factor, the time domain factor, the interference coverage area and the transmitter density?

Q8: Do you think that three classes of spectrum commons is the right number? What is your view on the proposed boundary values for the three classes?

Q9: Do you agree with our definition of fairness and that all systems should be required to behave in a fair manner?

Q10: What is your opinion on the effectiveness of blind detection sensing techniques compared to signal specific techniques?

Q11: Do you agree with the proposed polite rules?

Annex 5

Impact Assessment

Introduction

A5.1 The analysis presented in this annex represents an impact assessment, as defined in section 7 of the Communications Act 2003 (the Act).

A5.2 You should send any comments on this impact assessment to us by the closing date for this consultation. We will consider all comments before deciding whether to implement our proposals.

A5.3 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 means that generally we have to carry out 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

The citizen and/or consumer interest

A5.4 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.

A5.5 In particular Ofcom pays special attention to ensuring that, as far as can be ascertained, no undue (harmful) interference emerges. The downside of licence-exempt use of spectrum is precisely this, since there is no licensee to overlook and coordinate. Hence, all efforts towards a better co-existence in licence-exempt bands should bring benefits to consumers and citizens in terms of efficiency and greater economic value. A spectrum management strategy based on classes of spectrum commons guarantees better interference conditions and thus an environment where applications can achieve greater efficiency.

A5.6 A second goal for Ofcom is that as few product or technology restrictions as possible are imposed. The proposals here achieve this. First, the class a technology belongs to is decided on the overall interfering characteristics of the technology, thus not biasing developers to particular solutions. Second, we do not look to impose specific polite protocols, but generic rules instead.

A5.7 Ensuring these goals would promote innovation and stimulate competition in the provision of new radio communication services.

Ofcom's policy objective

A5.8 Ofcom's aim in providing this consultation 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.

A5.9 We will pursue this goal through:

a) the management of licence-exempt spectrum thorough classes of spectrum commons;

b) the definition of classes of spectrum commons based on the interference potential, and its realization in the proposed Interference Indicator

c) the requirement for medium and high interfering technologies to follow a number of polite rules.

A5.10 This consultation supplements the LEFR and other efforts in Ofcom to introduce a generic approach to the regulations of licence exempt bands. The objective of this consultation is to provide an overall approach for the management of future licence-exempt authorisations. It is to be consulted as questions surrounding licence-exemption arise.

A5.11 This framework presents broad proposals with regards to the licence-exempt use of 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.

A5.12 Ofcom hopes that this consultation, together with the LEFR, 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.

A5.13 Impact analyses for our recommendations with regards to the above policies are presented in this section.

Management of licence-exempt bands through spectrum commons classes

A5.14 Spectrum commons classes sit in between pure spectrum commons and application specific management methods. Technologies are grouped in classes according to their interference potential, and for a given band one (or more) classes are allowed. The LEFR already established a preference for spectrum commons over application specific, but merely recommended a class approach. Existing licence-exempt allocations, for example those regulated by UK Interface Requirements 2030 (which is based on ECC Rec.70-30), set requirements for channel bandwidths, maximum power levels, duty cycles polite techniques and allowed applications. In cases, IR 2030 allows for trade-offs between the requirements. When analyzing the spectrum commons management method, the following options appear:

- **Option 1.** Ofcom relies on a pure spectrum commons model to manage licence-exempt use of spectrum.

- **Option 2.** Ofcom follows the current approach of Rec.70-30; setting specific requirements for the physical parameters, the polite techniques or the applications allowed in the band.

- **Option 3.** Ofcom introduces class-based spectrum commons.

A5.15 We believe Option 1 is inefficient because systems with very different interference characteristics cannot co-exist in the most efficient manner. This is a realisation of the fact that, all other factors being equal, low power systems cannot co-exist with high power systems.

A5.16 We believe that Option 2 does not allow for sufficient flexibility in the use of the bands. This is already recognized in ECC, where the trend is to make band allocations as generic as possible removing, for example, requirements regarding the applications allowed in the band.

A5.17 Ofcom prefers Option 3 as it would bring flexibility in the use of spectrum whilst avoiding having very different technologies in the same band.

Definition of classes of spectrum commons based on the Interference Indicator

A5.18 Ofcom believes that systems should be categorized according to their potential to interfere others. There is not a widely agreed definition of this potential, but Ofcom thinks it should be fair, comprehensive, i.e. take all factors into account, applicable to any system, and independent of the interference victim. It should be a measure of the use of the common resources, i.e. the more a technology occupies a resource, the higher its interference potential.

A5.19 The Interference Indicator complies with these requirements and gives a fair indication of the interference potential of a technology. When proposing to use the Indicator as the basis for the class structure, Ofcom has considered the following options

- **Option 1.** Ofcom does not indicate at this point a preference for a way of defining classes, and instead it will define a method and a class specific to each band allocation.

- **Option 2.** Ofcom uses the proposed Interference Indicator to set up the classes of all future allocations.

- **Option 3.** Ofcom agrees on having a common method of defining classes, but rejects the Interference Indicator and searches for a better foundation to the class mechanism.

A5.20 Ofcom believes that, ideally, all licence-exempt bands should be managed the same way. This would simplify the work of developers and reduce regulatory uncertainty. For this reason, Option 1 is not preferred. The argument applies also to Option 3 where, in addition, Ofcom believes that the proposed Interference Indicator is an optimum way to portray the interference potential of a technology. However, Ofcom is open to proposals on how to better this Indicator.

A5.21 Hence, Ofcom prefers to agree on a common method to measure interference, and to use it for all future licence-exempt allocations.

Requirement for medium and high interfering technologies to follow a number of polite rules

A5.22 Even if systems belong to a same class and thus have similar interference characteristics, this does is not guarantee that they can co-exist without interfering with each other. To achieve this, specific politeness measures may be required. The goal is to have all systems behave in a "fair" manner, meaning that they share the resources equally and that they behave appropriately according to their needs.

A5.23 A key feature for this is to know that other users are in the proximity. Systems in the low interference class may not need to implement this feature, since their physical parameters (TX power, duty cycle) make them fair users already. But for medium and higher interferers, a explicit requirement is needed. The following options were considered:

- **Option 1.** Ofcom requires specific implementations of polite protocols for certain classes.
- **Option 2.** Ofcom lays out an overarching requirement of fairness and specifies generic polite rules for the higher interference classes.

A5.24 Ofcom does not believe that a detailed specification of polite protocols is within its duty. Having such specifications in a regulatory document would unnecessarily constrain developers to follow a given technique to achieve the goal of co-existence, instead of allowing the engineer ingenuity to come up with better solutions. For this reason, Option 2 is preferable to Option 1.

Impact on stakeholders and competition

A5.25 There is no impact on current licence-exempt users of spectrum because Ofcom does not currently propose the retrospective application of the classes of spectrum commons model to existing licence-exempt allocations. Such retrospective application could, however, be envisaged in the future where spectrum re-farming is considered as a result of a favourable impact assessment.

A5.26 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.

A5.27 Any future authorisations of licence-exempt use by Ofcom will be subject to specific consultations and impact assessments for the relevant bands. Although these proposals would form the basis for our future consultations, Ofcom will assess each case individually on its merits.

Annex 6

Calculating the Interference Indicator of existing technologies

A6.1 The following sections present the source data and the calculations leading to the Interference Indicator values presented in section 6. It must be noted that these are examples on how the Indicator is calculated; by no means should the results and parameters be taken as a firm proposal from Ofcom. The parameters are taken from technical specifications and technical studies, from discussion with experts or simply estimated. In determining the Indicator for a technology Ofcom would normally expect to consult and take advice.

6.1 RFID in the UHF band

A6.2 RFID interrogator with 2W output power and 100 KHz transmission bandwidth. The scenario and the propagation model are taken from the feasibility study performed by ETSI ERM TG28/TG34 and available in ETSI TR 102 649.

	Parameter	Value		Notes
[1]	EIRP	35.1	dBm	ETSI EN 302 208, 2W erp
[2]	Operating Frequency	866.5	MHz	
[3]	Tx BW	0.1	MHz	ETSI TR 102 649
[4]	Channel BW	0.2	MHz	ETSI EN 302 208
[5]	Band Width	2	MHz	865,6 MHz to 867,6 MHz
[6]	Duty Cycle	10%		ETSI TR 102 649
[7]	Antenna Beamwidth	30	degrees	ETSI TR 102 649

Table 3. RFID technology parameters

	Parameter	Value	Notes
	Density scenario	From ETSI TR 102 649 sec. D, number of interfering units: $N_{INT}(R_{INT}) = \frac{2\pi No}{k^2} \times [1-(k R_{INT}+1)\times \exp(-k R_{INT})]$	
	No	480	ETSI TR 102 649
	k	2	ETSI TR 102 649
	R	0.564 km	For a 1km2 area
[8]	Density	234.7 Units/km2	

Table 4. RFID operation assumptions

Parameter	Value	Notes
Pathloss	$PL=50.2 + 35 \log_{10}(d/10)$	ETSI TR 102 649 sec D

Table 5. RFID propagation model

	Parameter	Value		Notes
[9]	Target level at coverage boundary	-80	dBm/MHz	
[10]	RFID Level at coverage boundary	-90	dB	[9] + 10*LOG10([3])
	Required Pathloss	125.15	dBm	[1]-[10]
	Required distance	1384.9	m	From the propagation model
[11]	Interference coverage range	1384.9	m	
[12]	Interference coverage area	0.50	km2	=π*[11]^2*([7]/360)

Table 6. RFID interference coverage area

	Parameter	Value		Notes
[13]	Frequency factor	0.1		[4]/[5]
[14]	Time factor	0.1		[6]
[15]	Coverage	0.5021	km2	[11]
[16]	Density	234.7	units/km2	[8]
	Coverage * density	117.8		
	Interference Indicator	**1.18**		[13]*[14]*[16]*[16]

Table 7. RFID Interference Indicator

6.2 IEEE 802.11b

A6.3 The scenario models Wi-Fi for broadband access in a residential block of flats. Broadband data and penetration are taken from Ofcom studies or estimated.

	Parameter	Value		Notes
[1]	EIRP	20	dBm	IEEE802.11
[2]	Operating Frequency	2440	MHz	IEEE802.11
[3]	Channel BW	22	MHz	IEEE802.11
[4]	Band Width	83.5	MHz	ECC Rec.70-03
[5]	Maximum Duty Cycle	100%		Approximate
[6]	Antenna Beamwidth	360	degrees	Product Specifications

Table 8. IEEE802.11b technology parameters

	Parameter	Value		Notes
	Broadband download speed	2	Mbps	
[7]	Broadband monthly download	6	Gb	
[8]	Effective 802.11b throughput	6	Mpbs	
[9]	Average Broadband daily download	0.2	Gb	[7]/30
[10]	Downlink/Uplink ratio	1.33		1:3 ratio

Table 9. IEEE802.11b operation assumptions per user

Parameter	Value	Notes
Pathloss	$PL = PL_{breakpoint}^{freespace} + 35 \cdot \log \frac{d}{d_{breakpoint}}$	IEEE 802.11-03/940
Breakpoint distance	5 m	IEEE 802.11-03/940

Table 10. IEEE802.11b propagation model

	Parameter	Value		Notes
[11]	Target level at coverage boundary	-80	dBm/MHz	
[12]	IEEE802.11 Level at coverage boundary	-66.5	dB	[11] + 10*LOG10([3])
	Required Pathloss	86.5	dBm	[1]-[12]
	Required distance	32.7	m	From the propagation model
[13]	Interference coverage range	32.7	m	
[14]	Interference coverage area	3362	m2	=π*[13]^2*([7]/360)

Table 11. IEEE802.11b interference coverage area

	Parameter	Value		Notes
[15]	Link throughput used	0.0740	Mbps	[9]*[10]*1000/3600
	Assumes 1 hour usage per day			
[16]	Occupancy per link	0.0123	erl	[15]/[8]
	Note: 1 erl is one 22MHz channel continuously busy			

Table 12. IEEE802.11b channel occupancy (1 unit)

	Parameter	Value	Notes
	Dense residential scenario: block of flats, 80 m2/flat, 8 flats per floor, 3 floors		
[17]	Density of residential units	37500 flats/km2	(1km2 / 80m2) * 3
[18]	Broadband penetration	50%	
[19]	802.11 in residential broadband	80%	
[20]	Number of 802.11 devices in scenario	15000 units/km2	[17]*[18]*[19]

Table 13. IEEE802.11b unit density in scenario

	Parameter	Value		Notes
[21]	Frequency factor	0.2635		[3]/[4]
[22]	Time factor	0.0123	erl	[16]
[23]	Coverage	0.00336	km2	[14]
[24]	Density	15000	units/km2	[20]
	Coverage * density	50.4		
	Interference Indicator	**0.1641**		[21]*[22]*[23]*[24]

Table 14. IEEE 802.11b Interference Indicator

6.3 Bluetooth

A6.4 Office scenario with Bluetooth enabled cell phones and Bluetooth enabled computers.

	Parameter	Value		Notes
[1]	EIRP	4	dBm	BT Specifications
[2]	Operating Frequency	2440	MHz	BT Specifications
[3]	Channel BW	1	MHz	BT Specifications
[4]	Band Width	83.5	MHz	ECC Rec.70-03
[5]	Maximum Duty Cycle	100%		
[6]	Antenna Beamwidth	360	degrees	Product Specifications

Table 15. Bluetooth Technology Parameters

	Parameter	Value		Notes
	Office scenario, 20 m2 per desk, 50x10m floor			
[7]	Desks per km2	50000	Desks/km2	1 cell phone per desk
[8]	% of BT enabled cell phones	40%		
[9]	% of BT enabled desks	25%		
	Voice service			
	HV2 packet: This packet carries 20 information bytes protected with a 2/3 FEC. The packet is sent every four time slots. Packet length: 625 us			
[10]	BT channel occupancy (voice)	50%		(1 UL slot + 1 DL slot)/ 4 slots
[11]	Busy Hour Traffic	0.166	erlang/user	2 calls of 5 mins per user
	Note: 1erl. = 1 voice communication			
	Human Interface Devices (HID)			
	100 reports/s, two slots (master & slave) per report			
[12]	BT channel occupancy (1 HID)	12.50%		
[13]	Busy Hour Traffic	2	links	PC to keyboard, PC to mouse
[14]	Activity Rate	100%		All devices active

Table 16. Bluetooth operation assumptions

Parameter	Value	Notes
$L_{total} = 20 \log_{10} f + N \log_{10} d + L_f(n) - 28$		ITU P.1238 model
N=30 for 2.4 GHz office environment, floor penetration factor Lf = 0 for one floor		

Table 17. Bluetooth propagation model

	Parameter	Value		Notes
[15]	Target level at coverage boundary	-80	dBm/MHz	
[16]	Bluetooth level at coverage boundary	-80	dB	[15] + 10*LOG10([3])
	Required pathloss	84	dBm	[1]-[16]
	Required distance	29.8	m	From the propagation model
[17]	Interference coverage range	29.8	m	
[18]	Interference coverage area	2801	m2	=π*[17]^2*([6]/360)

Table 18. Bluetooth Interference Coverage Area

	Parameter	Value		Notes
[19]	per user due to voice	0.0833	erl	[5]*[10]*[11]
[20]	per desk due to HID	0.25	erl	[5]*[12]*[13]*[14]
	Note: 1 erlang = 1 BT channel (1MHz)			

Table 19. Bluetooth channel occupancy in the busy hour

	Parameter	Value		Notes
[21]	Voice units /km2	20000	units/km2	[7]*[8]
[22]	HID units /km2	12500	units/km2	[7]*[9]

Table 20. Bluetooth unit density

	Parameter	Value		Notes
[23]	Frequency factor	0.2635		[3]/[4]
[24]	Time factor (voice)	0.0833	erl	[19]
[25]	Time factor (HID)	0.2500	erl	[20]
[26]	Coverage	0.0028	km2	[18]
[27]	Density (voice)	20000	units/km2	[21]
[28]	Density (HID)	12500	units/km2	[22]
[29]	Interference Indicator (voice)	0.0559		[23]*[24]*[26]*[27]
[30]	Interference Indicator (HID)	0.1048		[23]*[25]*[26]*[28]
	Interference Indicator	**0.1607**		[29]+[30]

Table 21. Bluetooth Interference Indicator

6.4 60 GHz WPAN

A6.5 Based on the ongoing work at IEEE 802.15.3, Short Range – High Speed technology operating in the 60 GHz band. Scenario models the usage of the technology as High Definition Video cable replacement, linking a HDTV source to a HDTV screen.

	Parameter	Value		Notes
[1]	EIRP	25	dBm	All tech parameters sourced from IEEE 802.15-07/942r2
[2]	Operating Frequency	60	GHz	
[3]	Channel BW	2160	MHz	
[4]	Band Width	7000	MHz	
[5]	Max Duty Cycle	100%		
[6]	Antenna Beamwidth	360	degrees	

Table 22. WPAN Technology Parameters

	Parameter	Value		Notes
	Dense residential scenario: Block of flats, 80m2/flat, 8 flats per floor, no floor to floor propagation			
[7]	Number of residential units /km2	12500	Units/km2	
[8]	Penetration	50%		
[9]	Usage rate in the busy hour	100%		
	Modified UM2, single HDTV1080i Compressed to 1.75 Gbps			IEEE 802.15-06/0055r22
[10]	Application bit rate UM2	1750	Mbps	
	Bearer: OFDM HRP mode 1, 1.88 Gbps payload data rate			IEEE 802.15-07/942r2
[11]	HRP mode 1 offered bitrate	1880	Mbps	

Table 23. WPAN operation assumptions

Parameter	Value	Notes
Pathloss	$PL = PL_{10} + 10\,N \log_{10}(d/d_0)$	IEEE802.15.3c model IEEE802.15-07/0584r1
PL0 = 86 , n = 2.44 for residential, NLOS environments @ 60 GHz		
d in metres, d0 =1 metre		

Table 24. WPAN propagation model

	Parameter	Value		Notes
[12]	Target level at coverage boundary	-80	dBm/MHz	
[13]	WPAN level at coverage boundary	-46.65	dB	[12] + 10*LOG10([3])
	Required pathloss	71.65	dBm	[1]-[13]
	Required distance	1.52	m	From the propagation model
[14]	Interference coverage range	1.52	m	
[15]	Interference coverage area	7.284	m2	=π*[14]^2*([6]/360)

Table 25. WPAN interference coverage area

	Parameter	Value		Notes
[16]	Duty cycle at the PHY	0.93		[10]/[11]
[17]	Channel occupancy per unit	0.931	erl	[9]*[16]
[18]	Unit density	6250	units/km2	[7]*[8]

Table 26. WPAN channel occupancy and unit density

	Parameter	Value		Notes
[19]	Frequency factor	0.308		[3]/[4]
[20]	Time factor	0.931	erl	[17]
[21]	Coverage	7.284	m2	[15]
[22]	Density	6250	erl/km2	[18]
	Coverage * density	0.045		[21]*[22]
	Interference Indicator	**0.013**		[19]*[20]* [21]*[22]

Table 27. WPAN Interference Indicator

6.4 Home Automation

A6.6 Home Automation Devices operating in the 868 Band. Technology parameters from the Konnex standard. The scenario models a 2000 m2 residential property with 40 nodes.

	Parameter	Value		Notes
[1]	EIRP	16.1	dBm	ECC Rec. 70-03, 25mW ERP
[2]	Operating Frequency	868.3	MHz	ECC Rec. 70-03
[3]	Channel BW	0.1	MHz	Konnex specification
[4]	Band Width	0.6	MHz	ECC Rec. 70-03
[5]	Max Duty Cycle	100%		LBT
[6]	Antenna Beamwidth	360	degrees	Konnex specification

Table 28. Home Automation technology parameters

Parameter	Value	Notes
Pathloss breakpoint: d=10m	$PL = 51.2 + 35 \log_{10}(d/10)$	ECC Report 37, deterministic method

Table 29. Home Automation propagation model

	Parameter	Value		Notes
	Residential scenario: detached house, 150m2 built on a 2000 m2 plot			
[7]	Plot area	2000	m2	
[8]	Nodes per house hold	40		All devices on the same channel
	Transmissions per day per node	10		Approx. one transmission / 2 hours
[9]	Burst length	1	sec	Busy hour: all nodes transmit 1 burst
[10]	Duty cycle / node in the busy hour	0.014%		[9]/(2*3600)
[11]	Density in scenario	20000	units/km2	[8]*10^6/[7]

Table 30. Home Automation operation assumptions

	Parameter	Value		Notes
[12]	Target level at coverage boundary	-80	dBm/MHz	
[13]	Level at coverage boundary	-90	dB	[12] + 10*LOG10([3])
	Required Pathloss	106.1	dBm	[1]-[13]
	Required distance	371.5	m	From the propagation model
[14]	Interference coverage range	371.5	m	
[15]	Interference coverage area	0.433	km2	=π*[14]^2*([6]/360)

Table 31. Home Automation interference coverage area

	Parameter	Value		Notes
[16]	Frequency factor	0.1667		[3]/[4]
[17]	Time factor	0.0001	erl	[10]
[18]	Coverage	0.433	m2	[15]
[19]	Density	20000	erl/km2	[11]
	Coverage * density	8673.2		[18]*[19]
	Interference Indicator	**0.2008**		[16]*[17]* [18]*[19]

Table 32. Home Automation Interference Indicator

Annex 7

Glossary

BER	Bit Error Ratio
Bluetooth	A technical standard for short-range wireless communications between devices such as mobile phones and headsets.
Broadband fixed wireless access (BWFA)	A means of connecting to homes and offices using wireless, as opposed to copper wires or fibre optics.
Channel bandwidth	The difference between the upper and lower cutoff frequencies of the transmitted or received signal
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.
Collective Use of Spectrum	A spectrum management approach which allows more than one user to occupy the same range of frequencies at the same time without the need for individual licensing.
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.
Duty cycle	The percentage of time a transmitter keeps the channel busy
EC	The European Commission. The executive body of the European Union (EU).
ECC	European Communications Committee. An Europe-wide organization that develop policies on electronic communications, notably in the area of spectrum, and reports to the CEPT. http://www.ero.dk/
EIRP	Equivalent Isotropic Radiated Power. The amount of power that would have to be emitted by an isotropic antenna (one that evenly distributes power in all directions) to produce the power density observed in the direction of maximum antenna gain
ETSI	European Telecommunications Standards Institute
GSM	The Global System for Mobile Communications. The existing (second generation) cellular technology widely deployed around the world.
HDTV	High-definition television.

IEEE	Institute of Electrical and Electronics Engineers
ISM band	Radio band originally reserved internationally for the use of RF electromagnetic fields for industrial, scientific and medical purposes other than communications
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.
LBT	Listen Before Transmit. An interference mitigation technique where the transmitter checks that the channel is not busy before initiating a transmission
LEFR	Licence-Exemption Framework Review
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.
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.
RFID	Radio Frequency Identification. An wireless identification method that stores and retrieves data from tags or transponders
RSPG	Radio Spectrum Policy Group
Spectrum	The set of all radio frequencies.
Spectrum commons	Co-existence of licence-exempt devices for different applications and with different technologies within a band

Spectrum commons classes	An implementation of spectrum commons where only technologies with similar interference characteristics are allowed in the band
Spectrum liberalisation	Allowing licence holders to change the use to which they put their spectrum, within constraints to prevent interference.
Spectrum trading	The ability of users to buy and sell spectrum licences without prior approval from the regulator.
SRD	Short Range Device. A radio transmitter that has low capability of causing interference to other radio equipment, generally due to its low power and low range.
Under-lay	A licence situation where new users are allowed in a band where there is a primary user, provided that they observe the necessary requirements to avoid disturbing the primary user
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.