OFFICE OF COMMUNICATIONS

Spectrum Commons Classes for Licence-Exemption

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

Statement

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Contents

Section 1

Executive Summary

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

1.2 We will not introduce the proposals in our regulations immediately. These ideas are for future licence-exempt decisions and we are not planning to implement them in the UK in the short term. It is our intention to bring these ideas to inform debate within the international bodies such as the relevant European entities considering licence-exempt issues.

1.3 We propose a scheme based on the division of licence-exempt applications according to their interference characteristics. These are evaluated by means of an Interference Indicator. Its value is calculated according to the likelihood of an application in causing interference and based on its parameters of bandwidth, duty cycle, range and expected deployment density. A Spectrum Commons Class is defined as a range of Indicator values. Applications with similar Indicator values will belong to the same class, and only applications in a class will be allowed in a particular band. As a result, only applications with like interference potential would share spectrum. Within a 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 preference for a market-based approach. It also outlines, at a high level, our understanding on 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.

[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/

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 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 Commission 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 statement contains 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. The proposals would be applicable to bands allocated to licence exempt use, except when such use arises from a "network uplink", i.e. an operator has been granted a licence for a network consisting of a downlink and an uplink and the use of terminals transmitting on the uplink is exempted from licensing (but remains under the control of the operator).

1.11 We do not intend 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 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. Therefore, a key element of the class-based spectrum commons is how the Interference Indicator is defined and calculated. The Indicator represents the

[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

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. It must be noted that the Indicator simply allows us to compare the interference potential of applications: it does not have absolute meaning.

Specification of the Interference Indicator

1.15 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.

1.16 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

1.17 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: $BW_{Interferer} / BW_{SharedBand}$. A particular technology will not have a single Interference Indicator, but one that will vary depending on the frequency band where it is used.

Time domain

1.18 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

1.19 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 will need to determine a typical threshold. This threshold will be expressed in terms of a power flux density, i.e. $dBm/m^2/MHz$, and its value will be calculated for each band, based on factors such as the propagation characteristics and typical receiver performance at the frequencies of the band.

- **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 level 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

1.20 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

1.21 As an example of how the Indicator can be calculated in real life, we have looked at four existing licence-exempt technologies and 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.

Table 1: The Interference Indicator of existing technologies

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

Politeness rules and protocols

1.22 Although the application of classes will ensure that dissimilar applications are in different bands, there is still a possibility of interference between the similar applications using a band. 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.

1.23 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 users in the band. However, for low-interference devices we do not believe that a requirement for sensing would be justified.

1.24 We propose that in order to share equitably, technologies 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.

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

Spectrum Commons Classes

1.26 A class will be defined for each band dedicated to licence-exempt use. A class is determined by an upper and lower threshold of Interference Indicator values. Applications with Indicator higher than the upper threshold will be deemed to generate too much interference and kept out of the band. Applications between the two bounds will be allowed in the band provided that they implement polite rules. An Indicator value below the lower bound will signal that the application makes little use of the resources and therefore is allowed to share without the need of polite techniques. The choice of threshold values will be based on the economic value of the applications that are likely to occupy the band.

1.27 Prior to assigning a new band for licence-exempt use, Ofcom will evaluate whether the band has higher economic value under licensed or licence-exempt conditions, taking into account its wider duties regarding spectrum. In addition, consideration must be given to any existing – primary – users that might require protection from licence-exempt new entrants.

Impact on stakeholders

1.28 These proposals will increase the flexibility of use of licence-exempt spectrum while reducing the potential for interference between devices and increasing the overall capacity of the band. These benefits should result in increased utility for end-users. The requirements for polite protocols may add a small amount of complexity to devices but we do not believe this will make a material difference to their price.

1.29 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

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

1.31 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.

1.32 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

1.33 The proposals in this consultation cannot be applied immediately. Policy in this area is normally harmonized at European level and there is ongoing work in Europe on these issues. We intend that our proposals will inform this debate. We believe that they are well aligned with the work on Collective Use of Spectrum, and that they are a possible way to implement the concept.

Section 2

Overview

2.1 The Spectrum Framework Review (SFR) describes Ofcom's strategy for the management of spectrum. This consists of a market-led 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 with spectrum commons because this avoids separate allocations for each application, some of which will be underused. In addition, 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 A device should operate in a fair manner. In section 7 we explain that this means that 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.

2.7 The question of defining the classes is addressed in section 8. For each band dedicated to licence exempt use, a class is defined as a range of Interference Indicators. Applications with Indicator value lower than the upper bound of the range will be allowed in the band. In addition, applications with Indicator value higher than the lower bound of the range will be required to implement polite rules.

Section 3

Background

3.1 In this section we introduce 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 technology-neutral licensing conditions;
- 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 appropriate licensing conditions.

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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.

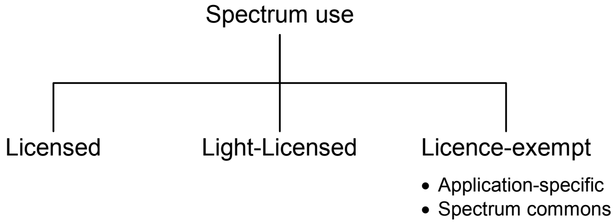
3.6 In the medium to longer term we expect the effect of this to be that Ofcom increasingly withdraws from managing the radio spectrum through regulatory intervention. Inevitably, there will be circumstances when we cannot fully achieve this aim. In these cases we will explicitly explain why we have 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 addressed 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). A particular occurrence of application-specific licence-exempt use is that of the network uplink. In this case an operator has been granted a licence for a network consisting of a downlink and an uplink. Use of terminals transmitting on the uplink is then often exempted from licensing (but remains under the control of the operator). This case of licence-exemption is out of the scope of this document.

3.10 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.

3.11 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

3.12 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.

3.13 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.

3.14 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.

3.15 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

3.16 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.

3.17 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

3.18 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.

3.19 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.

3.20 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)

3.21 The European Commission commissioned several studies during the last year 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).

3.22 The Commission has sought advice from the RSPG[7] on a European approach to Collective Use of Spectrum. RSPG has produced a draft opinion which has gone through the public consultation process and is now being revised by the group[8]. This draft defines CUS as:

> Collective Use of Spectrum allows an undetermined number of independent users and/or devices to access spectrum in the same range of frequencies at the same time and in a particular geographic area under a well-defined set of conditions.

3.23 The draft opinion reflects on the benefits and disadvantages of the CUS model at EU level, and on 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.

3.24 In its draft opinion, the RSPG considers that regulators should seek to remove constraints on spectrum use wherever technology allows. In the case of CUS, this means that allocations and associated regulations should generally be made as generic as possible and should not impose unnecessary constraints on the technologies deployed in the band.

3.25 In cases where co-existence between different types of usage would be difficult (for example low and high power applications), the draft opinion notes that one potential solution may be to consider various multiple classes of collective use whereby each class would be associated with a particular piece of spectrum and be managed by a specific set of rules defined by the regulator. The rules could be determined in such a way so as to ensure that the applications permitted in each CUS band would have broadly similar interference generating characteristics.

Other European activities in the licence-exemption area

3.26 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 revised regularly 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.

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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/rspg16/rspg08227_draftopinion_cus_final.pdf

3.27 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 statement

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

3.29 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 statement does not address all the issues in the discussion on Collective Use of Spectrum, it does present a possible way to implement CUS.

3.30 In reality most spectrum is already assigned and underlay is the usual situation for the vast majority of LE Apparatus. RSPG has acknowledged this situation and it is exploring the increased potential for sharing between licensed and licence-exempt devices. The proposals in this statement are primarily intended for new allocations to licence-exempt use, but we do allow for the situation where there exists a higher power licensed service by requiring LE technologies to detect and yield to licensed services.

3.31 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 believe 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 a relatively coordinated way. This document is therefore intended to add a framework to help establish a method to authorise differing classes of LE apparatus.

3.32 We intend to discuss with our European colleagues the feasibility of these proposals, which we believe are well aligned with the opinion on Collective Use of Spectrum, and may be a way to bring the concepts in the opinion one step closer to implementation. We also intend to take advantage of the debate on CUS to bring these ideas to the attention of the European Commission.

3.33 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].

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[9] Decision 2006/771/EC: Commission Decision of 9 November 2006 on harmonisation of the radio spectrum for use by short-range devices

[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 will tend to minimise 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 the 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 to allow 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 now present a proposal for a profile that we call the 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 A relevant point is whether the Indicator should take into account the ability of applications to share spectrum with their own kind and with others. For example, if an application is able to sense and yield to other users, this clearly reduces the interference it creates. In principle, it seems fair to take all capabilities of an application into account to evaluate its Interference Indicator. However, our preference is to leave the sharing methods out of the Indicator. We see two reasons for this:

- We think that regardless of how good a sharing technique is, there is always the possibility of a hidden node problem. This problem can be overcome with RTS/CTS[12] technique, but only if nodes can decode each other's transmissions, i.e. they have the same technology. We believe that the hidden node problem will remain since we cannot mandate a single technology. In practice, systems will operate in presence of other systems that they are not aware of. In such case, the interference they inflict will only be linked to their physical characteristics, even if they have very capable sharing methods. We believe that a worst case situation, where a system operates on the belief that there is no one else around it could interfere with, gives us common grounds for comparison.

- Second, we believe it will be difficult to measure the effect of sharing techniques in a fair manner. Different polite protocols improve different aspects of overall spectrum efficiency, making it difficult to compare. In particular, we would need to specify a precise scenario, including the deployment of alternative technologies, in order to test the sharing capabilities of the applications. We think it will be very difficult to define and agree on such scenario.

4.15 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 Indicators of other systems.

4.16 A possible implementation of the Indicator could be a single numerical figure. 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 that contribute to it, 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.

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

- **Lack of bias**. The Indicator should not bias manufacturers 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.

[12] RTS/CTS: Request To Send / Clear To Send

This is particularly challenging given the great diversity of radio uses, and forces us to look for a truly generic technique.

4.18 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 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.

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

4.20 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 an Interference Indicator. We think that this Indicator should be derived the 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.

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[13]; 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 victim 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. As we explained in the previous section, the purpose of the interference profile is to assess a technology on the basis of its RF and deployment

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

characteristics. We will discuss the use of sharing techniques 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 usage is busy, yet realistic. For example, for Wi-Fi this might 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

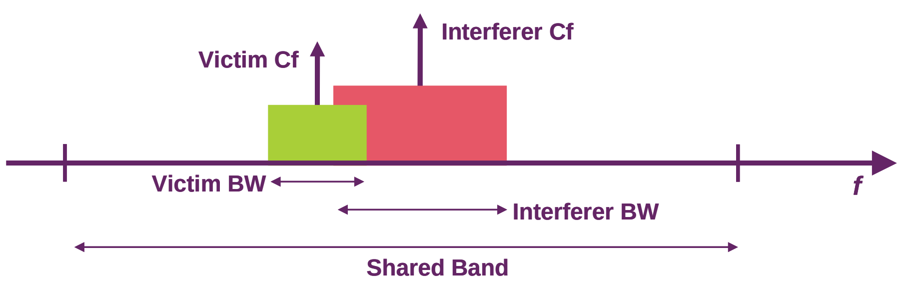
5.9 We focus here on the situation where collisions occurs in the frequency domain, i.e. the probability that the victim receiver channel and the interferer transmission channel overlap, and on the interference due to that overlap. We assume that the interferer power levels are high enough to affect 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 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 In this scenario where the interferer carrier 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 bandwidth 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. A precise definition of the bandwidth used will be required to ensure that it covers the spectrum actually occupied and not only the data-carrying portion. One suitable option could be the bandwidth containing 90% of total radiated power. However, we do not propose a specific measurement here; this will be agreed as part of the regulations for each particular band.

5.14 A technology may support different channel bandwidths (this is the case of WiMAX, which can be operated with 5 MHz, 10 MHz and 20 MHz). The different bandwidths should be considered when calculating the ratio, leading to different Indicator values for each bandwidth. A special case that one may envisage is a technology that dynamically changes its bandwidth. For this, it will make more sense to agree on an average, or typical bandwidth and have a single Indicator value. A third particular situation is that of a technology that 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 also tends to increase. Hence for a given technology and throughput, the interference potential is usually lower in high frequency bands than in lower band. 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.

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 Under these assumptions, 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 therefore as an indicator of the interfering potential. A precise definition of duty cycle is needed. We do not propose to do it in this document but in the regulations specific to each band. This definition should consider effects such as power ramp-up and short transmission gaps, and formalise parameters such as the maximum duration of a short interruption that would be ignored so that transmission is considered continuous.

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.

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 to 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.

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 a 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. Empirical and theoretical models are available to approximate common scenarios, and hence we propose to use these models where applicable[14].

5.27 The effect of directional 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 directional 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 which may not always be the case but we do not believe this approximation will unduly affect the results.

Threshold level

5.29 A key parameter in the range calculation is the threshold level. A 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. In the following paragraphs, we look at how the threshold should be expressed and then at what its value should be.

[14] 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.

5.30 We think that the threshold should be independent of the channel bandwidth of the technology under test. This was also the view of a majority of the responses to our consultation. We would therefore prefer a threshold in terms of power density (dBm/MHz) and not power (dBm). Still, for the power density to be measured in practice we need make assumptions on the receiver antenna. To avoid this additional requirement, we will define the power flux density, in dBm/m^2/MHz. This aligns with our approach to Spectrum Usage Rights[15]. Finally, we note that in certain frequency bands Megahertz wide bandwidths are rare. Either a narrower measure (dBm/m^2/kHz) or a simpler, power density measurement would be preferred.

5.31 We looked at several options in our consultation with regards to the threshold value. We considered the noise floor, which would form the lowest bound; the co-channel interference requirements of existing systems such as Bluetooth; and the channel busy indication threshold of Listen-Before-Transmit specifications. We averaged the values we found and concluded proposing a generic threshold level of -80 dBm/MHz, although we acknowledged that this is a somewhat arbitrary selection.

5.32 The responses that we received were not supportive of this generic value. As a result we have decided that the level will be determined independently for each frequency band under consideration, since factors such as propagation conditions, band noise or technology capabilities vary significantly from one band to another.

5.33 In any case, one must remember that as long as the same threshold is used in evaluating all devices to be put in the band, it does not matter unduly if it is set somewhat too high or low – the effect will be the same across all devices.

Density

5.34 The second measure of interference potential in the geographic domain 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 suffering interference 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.

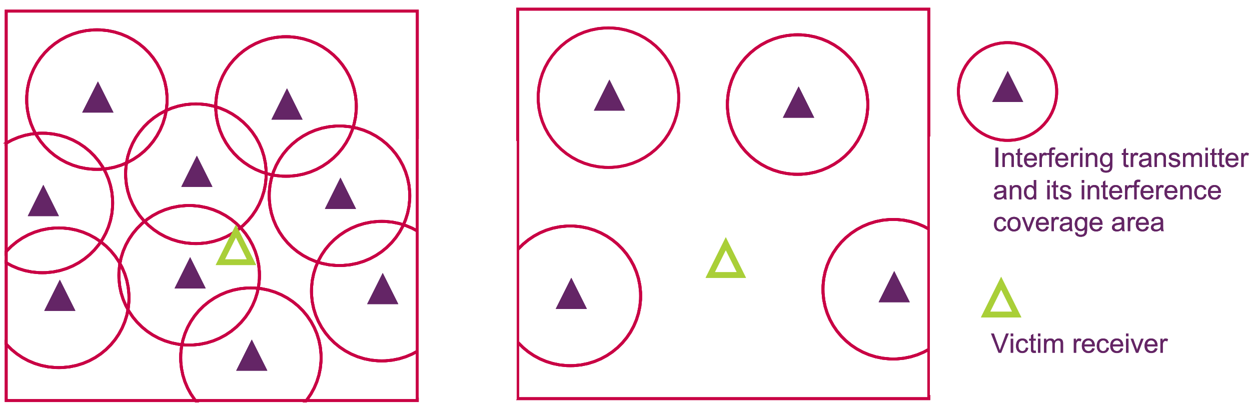


Figure 4: Density of interferers

[15] http://www.ofcom.org.uk/radiocomms/isu/sursguide/

5.35 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 spatial resource. For two technologies with the same coverage area per transmitter, the more ubiquitous one will result in a higher value of interference.

5.36 We introduced the concept of *usage scenarios* when looking at the time domain. The choice of scenario will directly determine the density factor and, to a lesser extent, the time domain factor. Hence, getting the scenario right will be the key element when evaluating the Indicator of a technology. The key elements for the scenario definition are the following:

- 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 transmitters. A technology can be very popular in certain busy areas while absent in others. Hence we propose to estimate density in the scenario where the technology is deployed.

- We introduced the busy hour concept in the time domain section above: the scenario will specify the time of day and the duration of the busy hour. Also, it 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.

- 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 computer and its mouse. Our view is that we should continue thinking in terms of technology, but in certain cases we should estimate application use 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.
  We propose that our busy scenarios account for this; 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.

- Depending on the technology, we could assess individual transmitters, bi-directional radio-links or whole systems. Examples of each could be an RFID reader, a Bluetooth phone and its headset, and a network of home automation nodes. The high level methodology is to consider technologies as systems, and to evaluate them in scenarios where we may have more than one system. The particular scenario and technology will determine the best split of a system. On occasions, it may make more sense to consider a scenario with a single system made up of several transmitters, which would have very low density but high time domain usage; while in other occasions it is preferable to set a scenario with a high population of single transmitters, i.e. high density but low duty cycle. We have taken the latter approach in our examples, but it could be equally possible, for example, to analyze a home automation scenario as a single synchronized system with a high occupancy of the time domain.

5.37 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. Furthermore, 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 the interference potential of any technology. Typically, we would work with interested parties to reach a consensus on the density figure.

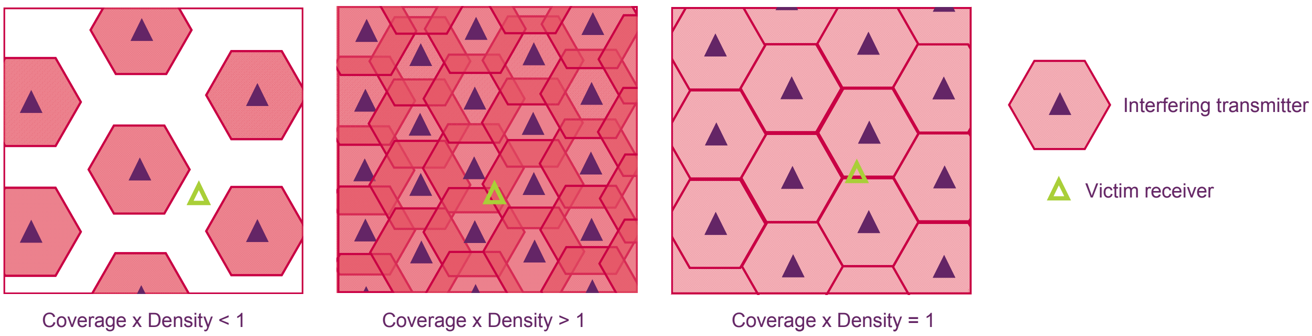
Construction of the Indicator

5.38 The Indicator, then, should be based on the frequency factor, the time factor, the number of devices and the 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.

5.39 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.

5.40 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 a 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



5.41 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 the distribution is uniform, we face the worst case scenario of no 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.

5.42 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 the entire space domain resource, and we will mark it as impolite in the space domain.

5.43 The example here is an idealization, licence exempt devices will not be uniformly deployed and will not have a 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.

5.44 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. An alternative could be to weight each component differently, i.e. to multiply them by different indexes. This would imply that we give more (or less) importance to usage in one resource over the others. We see no evidence at this point to do so. Furthermore, it would be very difficult to agree on the extent to which use of one resource is more important than use of another, and hence on the weighting indexes. Therefore, we propose that the Interference Indicator is calculated as follows:

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

5.45 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 product *Coverage x Density* does not have an upper bound.

5.46 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.
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.

5.47 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:

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

5.48 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.

5.49 It must be noted that current requirements in ECC Rec. 70-03[16] for Short Range Devices take a similar approach, albeit not specified as explicitly as an interference

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

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 listen-before-talk functionality are allowed.

5.50 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 more structured manner.

5.51 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.

Section 6

The Interference Indicator of existing technologies

6.1 In order to show how the indicator could be used and the range of values that could be expected, we have applied the Interference Indicator formula to a variety of technologies that operate, or will operate in the near future, in bands with licence exempt use.

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 would require consultation with users and industry so that the parameters are accurate and widely agreed. Finally, we must remember that these are busy scenarios, normal use will see lower levels of occupancy and interference.

6.3 We have looked at the following cases. The assumptions and detailed calculations are in Annex 2.

- **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, Wireless HD & IEEE 802.15.3c.** Residential scenario in a block of flats, wireless link between a HDTV source and a HDTV screen. Cable replacement is an 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.

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

	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[17]	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**

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, but the scenario coverage areas are never that large. This means that a 1 km^2 area supporting the number of units reported in the table will 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, where the area is smaller than the technology's interference coverage area will have a number of units 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 3362 m^2, the interference coverage area. 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.

6.8 One can note from table 2 that the frequency factor is normally low, few technologies will have a channel bandwidth similar to 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 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 technologies are proposed to use it.

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.

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

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

	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**

6.11 In table 3 we have only modified I_f . The propagation range and coverage will also change with a 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[18]. 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 in 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 look at how we can set requirements for polite rules and sharing mechanisms. Finally, section 8 brings together the indicator and the polite rules to propose a scheme of spectrum commons classes.

[18] Note that 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

Politeness rules and protocols

7.1 We have defined a method to categorize wireless systems according to their interference characteristics. Systems with similar characteristics will be allowed to operate in the same frequency band. However, this does not mean that they will not interfere with each other and that interference limitation measures are not needed.

7.2 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

7.3 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 interference, the regulator imposes limits for transmitted power or duty cycle, or techniques known as spectrum etiquette or polite protocols.

7.4 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.

7.5 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 Ofcom's remit 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[19] and hinder innovation. Instead, we will require a fair use of the resources and a few high level rules.

7.6 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 will be up to the developers and the standardization bodies to produce protocols according to our requirement.

7.7 There is considerable academic work on the subject of fair allocation in telecommunications networks. The seminal paper by Kelly[20] addresses the issue of charging, rate control and routing on a fixed packet network. In a more recent paper, Briscoe[21] 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, Nandagopal et al.[22] propose a contention based protocol that achieves fairness at the MAC layer.

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

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

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

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

7.8 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.

7.9 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 wait until it becomes available or move to another channel. 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.

7.10 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.

7.11 We see this definition of fairness as a matter of principle, not as a precise regulatory policy. We acknowledge it is open to interpretation but would expect system designers to show that they were abiding by the spirit of this principle.

Interference situations and mitigation rules

7.12 We look now in more detail at the situations when interference might arise. We can think of two distinct cases when a system can be harmful to others:

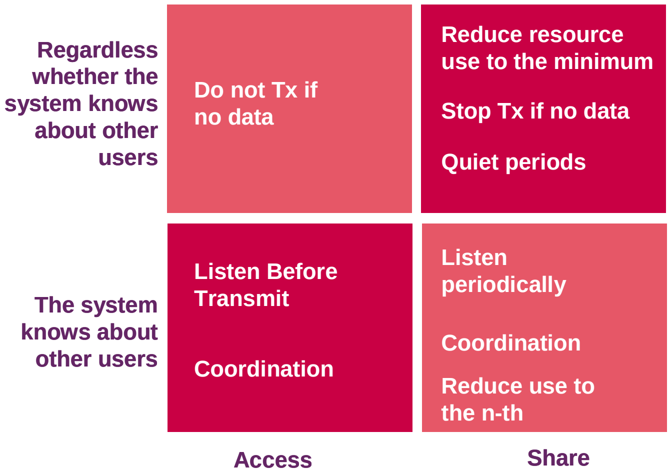
- When **accessing** the resources, if they are already taken.
- When **using** the resources, if others need access.

7.13 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.

7.14 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.

7.15 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.

Figure 6: Politeness rules



7.16 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.

7.17 Current technologies already implement a variety of the techniques in figure 6. 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 with other users.

Looking at the interference mitigation rules in detail

7.18 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. We cannot expect that this is 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.

7.19 We now consider the rules placed in the lower quadrants of figure 6.

- **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 RTS/CTS techniques that partly overcome the "hidden node" problem[23].
  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 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, it 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.

- **Listen periodically.** The current user lets other systems access the channel. It 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 become free again or move to another channel. As in the case of the quiet periods, unless a system knows the characteristics of other technologies in the band, it would not know how long to hold. 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. If any user does not wish to take up all of its 1/n allocation then the "spare" resource should be equally divided among the remaining users. 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, 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

[23] 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.

not able to participate in the scheme. A further enhancement would be to introduce the concepts of equitable and proportional share. Note that these rules require sophisticated coordination or channel sensing mechanisms and would work well only if all participants follow them.

Proposal for regulatory requirements

7.20 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, 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 alone.

7.21 For high-interference devices 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[24], or that widely different technologies can communicate over the air.

7.22 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).

7.23 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 %.

7.24 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.

7.25 In addition, the following polite rules will be required for technologies not qualified as low interferers:

- 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).

7.26 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.

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

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

7.27 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.

7.28 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.

7.29 Item (iii) requires late comers to detect and coordinate with users of a pre-authorized licence-exempt technology. Coordination, in this case, might simply require yielding to primary users. 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. However, this requires that the technical specifications of the primary users are publicly available. 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.

Section 8

A proposal for Classes

8.1 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. In the previous section, we suggest that technologies should implement measures to ensure that they exploit the resources in a fair manner, and we proposed high level politeness rules based on this objective. We observed that these rules would apply to technologies that are not low interferers, but we did not elaborate on what we consider a low interferer. For this, we use the concept of Spectrum Commons Class.

8.2 Ultimately, our objective is to be able to decide whether certain technology is allowed in a band. We propose to define a class for each band allocated to license exempt use. The class will be specified in terms of a lower and upper bounds of Interference Indicator values. Technologies whose Interference Indicator is below the upper bound will be allowed in the band.

8.3 Before introducing how the class is defined, we must note the two policy issues that precede the definition of the class. However, we will not delve into these:

i) **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[25].

ii) **Are there primary users in the new band?** This is the case in most new allocations for licence-exempt use and Ofcom has to make a policy decision regarding protection of primary users from the licence exempt entrants. If this is the case, specific politeness rules would be imposed on the new entrants, or the range of licence exempt technologies could be reduced.

Deciding on a class for a new licence exempt band

8.4 Once that the policy decision to reserve a band for licence-exempt use has been made, the question is what class, or classes, should be allowed in the band. We propose that the decision is made fundamentally on the basis of economic value.

8.5 Technologies likely to use the band can be sorted according to their Interference Indicator. We would predict the economic value to be derived from these technologies. The optimum class for the band will be one covering the range of Interference Indicators that would provide highest economic value.

8.6 We showed in the LEFR that having technologies with very different interference potential decreases the economic value obtained from the band. For high value technologies to operate under acceptable conditions, technologies that interfere with them, i.e. with high interference potential, must be kept out of the band. The upper bound will ensure this. Its value will be a trade-off to maximize the economic value: it

[25] Wireless Telegraphy Act 2006, Section 3

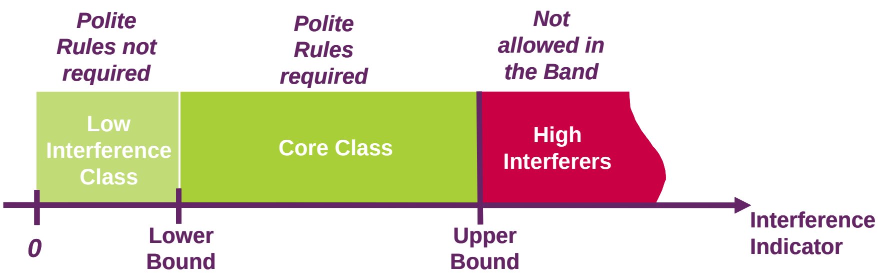
should be low enough to keep interfering technologies out but high enough to allow potentially valuable applications.

8.7 Applications below the lower bound will be deemed very low interferers; their usage of the resources is so low that they are not required to implement the polite rules in previous section.

8.8 The value of the lower bound will also be a compromise. On one side, we will not want to let technologies use the bands without polite protocols if their resource usage is similar to that of the core technologies of the band. On the other side, we will not want to charge low profile technologies with the burden of implementing polite rules if their use of resources is so low that core technologies are unaffected.

8.9 Figure 7 displays the three classes that arise from this approach: First, a high interferer class[26], covering applications that are not allowed in the band. Second, a core class formed by those applications with an Indicator between the two thresholds. Applications in the core class are required to implement the polite rules. Finally, a low interference class, covering those applications that are allowed in the band without the requirement to implement polite rules.

Figure 7: Spectrum Commons Classes



8.10 In practice, we will evaluate economic value of candidate applications for each band and then decide on which brings the best use. It can be argued that this is not a truly spectrum commons approach, since we are restricting use of the band. In fairness, it is not possible to be completely technology neutral in any spectrum allocation. For example, we conduct research of the most likely applications before our spectrum awards. We then devise the terms of the award (spectrum usage rights, spectrum packaging) according to the characteristics of the likely applications but without mandating a specific technology. We face a similar situation with the Spectrum Commons Classes. Since we need to define a class for the band, we might as well base it on the most likely or most valuable application. We are not technology specific, since we only specify the class boundaries.

8.11 There are other aspects aside from the indicator value and implementation of polite rules that need to be considered when authorising technologies to use a band. Services in the adjacent band are an example: it is very difficult to isolate two technologies that are collocated in the same device, so ideally they should be allocated bands as far apart as possible. Another aspect is whether they would be sufficiently immune from interference from the already approved technologies.

8.12 In addition to the indicator upper threshold and the need to implement polite rules, there will always be a maximum limit for transmitted power. This is for two reasons:

[26] 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.

- The Interference Indicator approach is intended to allow developers to trade off resource usage in the three domains. However, it could have the undesired effect of allowing an excessively high transmit power, sufficient to cause blocking of neighbouring devices, to be balanced with a very low utilization in the frequency and time domains.

- There are health and safety requirements that devices need to comply with, and these normally include a maximum radiated power.

The class of a technology also depends on the applications

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

8.14 We think that 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.

Section 9

Conclusions

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, we propose to 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.
- 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.
- Proposing a structure with three classes corresponding to core, low interferer and high interferer.

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 frequency and time resources exploited, we define the frequency factor as the channel bandwidth divided by the total bandwidth, and the time factor as 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 these factors. We believe that such Indicator gives a fair estimation of the interference a technology will cause to other users of the band.

Behavioural requirements

9.4 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.

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

9.6 Most licence-exempt allocations have a primary user. Our proposals give it adequate protection, since the polite rules will require technologies to detect and yield to the primary user.

Establishment of classes

9.7 A class will be defined for each band dedicated to licence-exempt use. A class is determined by an upper and lower threshold of Interference Indicator values. Applications with Indicator higher than the upper threshold will be deemed to generate too much interference and kept out of the band. Applications between the two bounds will be allowed in the band provided that they implement polite rules. Applications with an Indicator value below the lower bound make little use of the resources, and are allowed in the band without the need of polite techniques. The choice of threshold values will be based on the economic value of the applications that are likely to occupy the band.

Next steps

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. The work in this area is normally harmonized at European level and there is ongoing work in Europe on these issues. We intend that our proposals will inform this debate. In particular, we believe that they are well aligned with the RSPG work on Collective Use of Spectrum, and that they are a possible way to implement the concepts in their draft opinion. We also intend to take advantage of the debate on CUS to bring these ideas to the attention of the European Commission.

Annex 1

Impact Assessment

Introduction

A1.1 The analysis presented in this annex represents an impact assessment, as defined in section 7 of the Communications Act 2003 (the Act).

A1.2 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

A1.3 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.

A1.4 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.

A1.5 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.

A1.6 Ensuring these goals would promote innovation and stimulate competition in the provision of new radio communication services.

Ofcom's policy objective

A1.7 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.

A1.8 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 high interfering technologies to follow a number of polite rules.

A1.9 This consultation supplements the LEFR and other work undertaken by Ofcom to introduce a generic approach to the regulations of licence exempt bands. The objective of this statement 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.

A1.10 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.

A1.11 Ofcom hopes that this statement, 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.

A1.12 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

A1.13 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 some 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.

A1.14 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.

A1.15 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.

A1.16 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

A1.17 Ofcom believes that systems should be categorized according to their potential to interfere with others. There is not a widely agreed definition of this potential, but Ofcom thinks it should be a measure of the use of the common resources; the more a technology occupies a resource, the higher its interference potential. In addition, it should be fair, comprehensive, i.e. take all factors into account, applicable to any system, and independent of the interference victim.

A1.18 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.

A1.19 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 remains open to proposals on how to better this Indicator.

A1.20 Hence, Ofcom prefers to agree on a common method to measure interference, and to use it for all future licence-exempt allocations.

Requirement for technologies to follow polite rules

A1.21 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.

A1.22 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, an 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.

A1.23 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

A1.24 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.

A1.25 The spectrum commons model is Ofcom's preferred strategy for future authorisations of licence-exempt usage of unused spectrum. Since the spectrum commons approach is expected to result in the liberalisation of spectrum for licence-exempt use, it should be easier for diverse applications to emerge and for the set of applications active in a band to change over time without Ofcom's intervention. This is expected to encourage the emergence of innovative services and hence to stimulate competition.

A1.26 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 2

Calculating the Interference Indicator of existing technologies

A2.1 This annex presents 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.

A2.2 In these examples we use the parameter labelled **target level at coverage boundary** with a value of -80 dBm/MHz. This is the interference threshold level discussed in section 5. We noted in that section that the threshold value would be set for each band separately, and according to the capabilities of technology at that frequency. Therefore, the -80 dBm/MHz value used here must be understood as an example. In addition, we decided in section 5 that this threshold would be defined as a power flux density (dBm/m^2/MHz) and not as power density (dBm/MHz). These are related by the effective aperture of the receiver antenna. We have are taking a simplified approach here and combining power flux density and antenna aperture into a single assumption for the power density value.

2.1 RFID in the UHF band

A2.3 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.

Table 4: RFID technology parameters

	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 5: RFID operation assumptions

	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 6: RFID propagation model

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

Table 7: RFID interference coverage area

	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 8: RFID Interference Indicator

	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]

2.2 IEEE 802.11b

A2.4 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.

Table 9: IEEE802.11b technology parameters

	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 10: IEEE802.11b operation assumptions per user

	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 11: IEEE802.11b propagation model

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 12: IEEE802.11b interference coverage area

	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 13: IEEE802.11b channel occupancy (1 unit)

	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 14: IEEE802.11b unit density in scenario

	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 15: IEEE 802.11b Interference Indicator

	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]

2.3 Bluetooth

A2.5 Office scenario with Bluetooth enabled cell phones and Bluetooth enabled computers.

Table 16: Bluetooth Technology Parameters

	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 17: Bluetooth operation assumptions

	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 18: Bluetooth propagation model

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 19: Bluetooth interference coverage area

	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 20: Bluetooth channel occupancy in the busy hour

	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 21: Bluetooth unit density

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

Table 22: Bluetooth Interference Indicator

	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]

2.4 60 GHz WPAN

A2.6 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.

Table 23: WPAN Technology Parameters

	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 24: WPAN operation assumptions

	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 25: WPAN propagation model

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 26: WPAN interference coverage area

	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 27: WPAN channel occupancy and unit density

	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 28: WPAN Interference Indicator

	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]

2.5 Home Automation

A2.7 Home Automation Devices operating in the 868 Band. Technology parameters from the Konnex[27] standard. The scenario models a 2000 m^2 residential property with 40 nodes.

Table 29: Home Automation technology parameters

	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 30: Home Automation propagation model

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

Table 31: Home Automation operation assumptions

	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 32: Home Automation interference coverage area

	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)

[27] http://www.knx.org/

Table 33: Home Automation Interference Indicator

	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]

Annex 3

Summary of responses to the Consultation and Ofcom's views on the issues raised

A3.1 Introduction

A3.1 This annex provides a summary of the stakeholder responses to the Spectrum Commons Classes Consultation Document (published in May 2008). All non-confidential responses are available in full on Ofcom website[28].

A3.2 Section A3.2 provides a general overview of stakeholder responses. This is followed by a section summarising the responses to each of the questions that were asked in the Consultation Document, along with a discussion of Ofcom's views on the issues raised. The final section in this annex deals with stakeholder responses which are not directly related to the specific questions asked in the Consultation Document.

A3.3 We have not listed every response here, but have singled out those which we believe raise important issues or which are not in full agreement with our proposals. In some cases, we agree with the issues raised and as a result have made changes to the proposals that were in the Consultation. In other cases, we are not persuaded to change our views and we discuss in this annex why this is the case.

A3.2 General overview of responses

A3.4 We received 11 responses to the Consultation Document. These were from a range of stakeholders including equipment manufacturers, IC manufacturers, network operators, application providers and organisations representing various users of spectrum. While many were strongly supportive of the whole set of proposals, a few were critical. The key issues raised are summarised below, along with some discussion of how we understand them.

Interference characteristics as the basis of the spectrum commons classification

A3.5 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". The indicator represents the interference potential of a technology, and it is calculated from the factors that contribute to interference: bandwidth, duty cycle and use of geographic resources.

A3.6 A majority of responses supported a classification based on interference potential, defined as a function of the usage of these resources. However, some thought that these factors were insufficient to capture the effective occupation of resources.

[28] http://www.ofcom.org.uk/consult/condocs/scc/

They felt that the characteristics of the victim receiver and the sharing capabilities of a technology, i.e. polite protocols, should also be factored in.

A3.7 We do not think that specific victim receiver characteristics should be considered when evaluating the interference potential of the transmitter of a technology. We acknowledged in section 5 that the receiver performance is a key element in an interference situation, but this performance is very much dependent on the victim device: certain technologies would support high levels of unwanted signal better than others. And different implementations of the same technology may be better than others at decoding the desired signal in presence of noise or interference. Hence, the effect of an interfering transmitter on decoding performance will vary strongly across receiver applications, technologies and even implementations. We think that it is not fair to evaluate a technology on the basis of the receiver characteristics of another technology.

A3.8 One could consider a hypothetical band with an incumbent technology whose receiver performance requirements are available and well specified. In such case, a newcomer technology could be tested for interference on the basis of its own characteristics plus the receiver characteristics of the incumbent. However, we aim at a generic approach where we cannot make the assumption of a single incumbent, and where we do not know which other victim receivers could appear in the future. For this reason, we do not think it is possible to consider receivers in the indicator calculation, other than in the most generic way.

A3.9 Some stakeholders argued that sharing methods (i.e. polite protocols) should be considered in the indicator, and not only pure physical characteristics (bandwidth, power and duty cycle). It seems fair to take all capabilities of a technology into account to evaluate its interference potential. For example, if it is able to sense and yield to other users, this clearly reduces the interference it creates.

A3.10 However, our preference is to leave the sharing methods out of the indicator. We think that regardless of how good a sharing technique is, there is always the possibility of a hidden node problem. This problem can be overcome with RTS/CTS technique, but only if nodes can decode each other's transmissions, i.e. they have the same technology. We believe that the hidden node problem will always persist since we cannot mandate a single technology. In practice, systems will operate in presence of other systems that they are not aware of. In such cases, the level of interference they produce will only be linked to their physical characteristics, even if they have very capable sharing methods. We believe that a worst case situation, where a system operates on the belief that there is no one else around it could interfere with, gives us common grounds for comparison.

A3.11 In addition, we believe it will be difficult to measure the effect of sharing techniques in a fair manner. Different polite protocols improve different aspects of overall spectrum efficiency, making it difficult to compare. In particular, we would need to specify a scenario including the deployment of alternative technologies in order to test the sharing capabilities of the technology under evaluation.

Definitions of the usage of frequency, time and geographic domain resources

A3.12 The consultation proposed to calculate the resource usage as follows:

- In the frequency domain, we take the ratio of channel bandwidth to shared bandwidth: $BW_{Interferer} / BW_{SharedBand}$

- In the time domain, we consider the duty cycle at the busy hour. We acknowledge that it depends on the traffic for a majority of technologies. Usage scenarios, defining the most common application of the technology, will allow us to derive the traffic.
- The geographic domain usage is derived from two factors, the interference coverage of the transmitter and the density of transmitters.

A3.13 Stakeholder generally agreed that the procedures for measuring interference potential in the domains are correct. However, many argued that the definitions of how the ratios are calculated are imprecise, and proposed refinements to these definitions. We generally agree with the proposed corrections and we comment on these in detail in the section below. We must note however that the intention of the consultation was not to define in detail how the factors will be calculated – that will be done in each specific consultation on particular frequency bands – but to present the basis of the calculation. We do not think that a definition that is at the same time precise and generic to all future licence exempt allocations is possible.

Geographic domain

A3.14 We define the interference coverage as the area where the power level of the signal from the transmitter is higher than a certain threshold. We proposed a threshold level of -80dB/MHz, and debated whether this threshold should be expressed in power (dBm) or power density (dBm/MHz).

A3.15 Some stakeholders noted that the coverage factor should include the effects of beamforming, steerable antennas and other advanced antenna techniques. We think that these techniques can easily be incorporated to the calculations. The proposed coverage factor accounts for beamwidth. Sweeping or steerable antennas produce an interference area of constant size but moving around the transmitter – since we are only interested in the size of the area where interference occurs we can ignore the movement of the antenna beam. Adaptive antennas that may change their bandwidth can be modelled with a typical or nominal beam.

A3.16 We got mixed views on the -80dBm/MHz threshold. Some stakeholders considered it a good starting point, while others thought it is too high a value. Based on the feedback, we will not propose any particular value at this stage, leaving the precise definition for individual consultations. A majority of responses preferred to have a threshold in terms of power density (dBm/MHz). One stakeholder suggested neither power nor power density, but power flux density (dBm/MHz/m^2). We think this is a better approach and have incorporated it into our statement.

A3.17 The proposal to incorporate a factor based on transmitter density in the interference evaluation was well received by a majority of stakeholders. Some were concerned that subjective assumptions will be required, and that it will be difficult to make realistic estimations. We agree that density calculation for licence-exempt devices can only be speculative. But we also think that it is a key element in evaluating interference. The fact that it is difficult and subject to high margin of error should not stop us from using it.

Interference Indicator defined as a product of the factors

A3.18 The consultation proposes to calculate the Indicator as a simple product of four factors: frequency ratio, duty cycle, interference coverage and transmitter density. A majority of stakeholders supported this approach. Some argued that further thought should be given to the weight of the components, which for example could be raised to different indexes.

A3.19 We do not see a reason to do this. The proposed approach (all indexes equal to one) gives the same weight to all three domains, hence it equally measures exploitation of each domain. Different indexes would imply that we give more (or less) importance to usage in one resource. We see no evidence at this point to do so. Even if it was the case, it would be very difficult to agree on the extent to which use of one resource is more important than use of another, and hence agree on the weighting indexes.

Number of classes and boundaries

A3.20 We did not receive unanimous support for our proposal of 3 classes limited by boundary values of 0.01 and 1. Some stakeholders would prefer to decide on this on a case-by-case basis. They suggest that boundaries could be different for each band, and should be based on the potential technologies in each band and our general spectrum policy.

A3.21 Based on this feedback, we have reviewed our position on the class count and the boundaries. We will not propose any fixed number of classes or boundary values at this stage. In addition, one of the responses presented an approach to the selection of class boundaries that aligns with our intentions better than our own text:

A3.22 The thresholds for a given band can be understood as a split of technologies into

i) those that are forbidden from the band due to their interference potential being too high,

ii) those allowed to use the band subject to appropriate polite protocols, and

iii) those that are allowed to use the band without restriction due to their interference potential being significantly lower.

A3.23 The respondent suggested that the upper threshold should be selected to maximize the economic value, while the lower threshold would be such that technologies below it would not affect those above. We also agree with this approach.

A3.24 We note that this is not in contradiction with our proposal. We suggested that there would be 3 classes, from low to high interference potential. For a new band, the economic value of potential technologies would determine which of these classes would apply to the band. If a medium interference class is selected, the thresholds would split technologies as explained above. A high interference class is equivalent to an upper threshold brought up to infinity, and a low interference class could be implemented with a low value for the upper threshold and no requirement for polite protocols.

Fairness

A3.25 We defined a fair system as one that

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

A3.26 Most of responses agree with this definition to some extent, although many observed that it is to a high degree open to interpretation and difficult to articulate in a regulatory requirement.

A3.27 Our intention with this definition is to establish a common understanding of what fairness implies which can then be used as a basis for the drafting of specific regulations. We acknowledge that it is difficult to capture the general view in an enforceable requirement.

Polite Rules

A3.28 The consultation proposes that technologies belonging to medium and high interference class should follow these polite rules:

- 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.

A3.29 In general, our proposal for polite rules was supported by a majority of respondents. Some noted that more thought needs to be given before they can be implemented in practice. We agree with this, and we expect to further elaborate on the rules in our future work.

A3.30 We sought to investigate if and what sensing mechanisms could be required in the polite rules. Our understanding was that 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. We specifically asked stakeholders for their opinion on the effectiveness of blind detection compared to signal specific techniques. The feedback we have received does not substantially change our views, and we will maintain our requirements as expressed in the polite rules in the consultation.

A3.3 Question by question review of stakeholder responses

A3.31 In the text below, for clarity we have repeated the consultation questions on grey background text, stakeholders' comments are given in italics and Ofcom's responses and comments are presented in plain text.

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

A3.32 A majority of stakeholders agreed without comments. A few argued that although interference should be the basis of the classification, two other aspects should be taken into account: receiver characteristics and sharing methods. We have presented our views on this in the previous section. Stakeholders also raised the following points:

Yes, however we believe that in some cases it is appropriate to take account of the victims' characteristics, for example if these can be reliably predicted.
This is a good but not entirely complete basis. The proposed interference indicator is purely transmission based. Whilst this eases calculation it overlooks other factors […]

Ofcom's view

A3.33 We agree that a better picture of the interference situation can be achieved if we take the victim's characteristics into account. However, as we explain in the previous section, we do not think the class of a technology should depend on the characteristics of its victims.

We feel that implementing spectrum commons classes would hinder the realisation of the economic benefits which licence exemption can unlock. Spectrum classes are intuitively attractive, but implementing them represents an enormous step that we feel is not yet supported sufficiently well by analysis.

Ofcom's view

A3.34 We do not agree. The economic benefits of spectrum commons were evaluated in our Licence Exemption Framework Review consultation of 2007 and the following statement. The response seems to favour a pure spectrum commons model, where applications with widely different technical parameters share the same spectrum. We believe that such model will suffer interference issues. We showed in the LEFR 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.

The concept of classes and interference characteristics seems open to a huge variation of interpretations. Were this approach to be adopted and then promoted to the EU it seems likely that a very wide range of interpretations would be created by the Member States leading to market fragmentation, inefficient use of the spectrum and consequential loss of user value.
Considering the variety of uses and devices that already exist and are most likely to come into existence in the future, it is not clear how a classification approach can be sustained. It is further unclear how any such regime could be imposed without giving preference to some technologies over others.

Ofcom's view

A3.35 We agree that there is a risk of varying interpretations and market fragmentation. For this reason, we propose to introduce the concept at European level and if applied, there will be a common European interpretation.

A3.36 We do not think that a wide variety of uses and devices is a concern to maintain a classification, provided that the rules are clear and applicable to any technology. We agree that there is a risk that the classification regime, if poorly defined, gives advantage to certain technologies over others. However, regulators will take utmost care when defining the regime.

Spectrum sharing is more than dealing with interference and involves the broad ability of wireless systems to function in the presence of others. A better method of spectrum commons classification would take into account the ability of different wireless systems to share spectrum with their own kind and with others. In today's marketplace, there are various ways in which unlicensed devices share spectrum, from the most primitive (e.g., low power) to highly sophisticated (e.g., DFS).

Ofcom's view

A3.37 As explained above, we think that sharing techniques should not be a factor of the classification.

Dissimilar sharing methods are likely to prevent efficient spectrum sharing. But over time, new and improved cognitive technologies could make efficient spectrum sharing easier. For example, software defined radio transmitters can be modified by uploading new software versions. In some cases, future technologies may employ radio beacon technology to control subservient base stations within a geographic area. Improved sensing technologies could well emerge.

Ofcom's view

A3.38 We agree that better sharing efficiency is obtained when the same, or similar, sharing techniques are employed. However, we do not think this can be guaranteed nor promoted by a regulatory body. As a means to ensure regulatory neutrality, we think that we need to consider in our regulations the case where independently developed technologies share the spectrum.

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?

A3.39 A majority of stakeholders agreed. Some commented that a precise definition is needed, notably regarding the sidebands and the effect of frequency hopping. We agree with most of the comments, but we do not consider that we should precisely define at this stage of the work how the ratios are calculated. The following comments were also raised:

A victim system will suffer interference if it receives energy (above its blocking threshold) within its receiver bandwidth at any time during reception of a packet. Hence, the effective channel bandwidth of a frequency hopping system should be based on the overall spectral occupancy over a time period similar to that of typical packet duration for other systems. To avoid making the metric specific to a particular technology, a nominal period such as 1 second should be picked.

Ofcom's view

A3.40 We can consider frequency hopping systems as narrowband with high power, or as wideband with power integrated over the wider bandwidth and hence lower power density. The proposal here goes along the second approach. We do not have a preference at this time, and we will consider this as part of the future work towards detailed requirements.

The channel bandwidth should be a measure of the actual transmission spectrum, not just the data-carrying portion of the signal. A suitable measure that is independent of technology would be the B90 bandwidth, i.e. with an upper frequency limit and lower frequency limit such that each of the mean powers radiated above the upper frequency limit and below the lower frequency limit is equal to 5% of the total mean power radiated.

Ofcom's view

A3.41 Agreed. This bandwidth measurement can be retained when drafting specific regulations.

No. The relative amount of spectrum used is a very primitive and therefore a very inaccurate measure of interference potential. A single powerful narrow band source can easily prevent the operation of wideband systems over a very large area whereas the narrowband system will hardly be affected by the wideband systems. Therefore, a measure is needed that takes this asymmetry into account, e.g. power density – the higher the power density, the larger the victim area.

Ofcom's view

A3.42 A powerful narrowband source will have a low frequency domain factor but a high interference coverage area, yielding a high overall Interference Indicator. The asymmetry mentioned is covered by the fact that the Indicator is built upon contributions from the usage of the three resources: spectrum, time domain, geographic domain.

WiMAX standard supports a number of different channel bandwidths (5 MHz, 10 MHz and 20 MHz) to make the best use of the available spectrum. The implication of using the ratio, as proposed, does not take account of the technology's flexibility of supporting a number of different bandwidths. Therefore, we would like this factor taken into consideration.

Ofcom's view

A3.43 Agreed. The different channel bandwidths should be considered when calculating the ratio, leading to different Indicator values for each bandwidth.

A3.44 Technologies may appear in the future that can dynamically change their bandwidth. Today, many systems vary their duty cycle according to the traffic requirements from the upper layers. We can speculate that future technologies, based for example on OFDM techniques, may also vary their spectrum usage according to the traffic. In such case, it will make sense to define the most common scenario of spectrum usage, or to average spectrum usage, to result in a unique Indicator for the technology.

Even though it might represent the use of the frequency domain resource, the proposed ratio could be raised to any index without loss of generality. In the present proposal, the index has been set to one, which appears the obvious place to start. However, since different values of the index divide up applications in different ways, the choice of index has real-world, potentially dampening impact on innovators' flexibility.

Ofcom's view

A3.45 We agree that different values will rate applications in different ways and have an impact on innovators' choice. Raising the index of the frequency ratio will change the weight we put on usage of frequency domain resources against usage in the other domains (time and geographic). However, we think that the fairest way to value usage across domains is to set all indexes to one.

Such approaches appear not to adequately cater for new technologies such as spread spectrum modulation. These are significant interferers when deployed in close proximity to other devices. It can be expected that close proximity will be a very common deployment scenario in residential situations and that the desired data rates will be higher than today.

Ofcom's view

A3.46 We disagree. There is no reason why the ratio cannot be applied to spread spectrum technologies. Close proximity interference is an issue that can only be tackled by regulations to some extent. There will always be a risk of interference when uncoordinated devices share a band, regardless of the modulation technique.

In relation to the general principle that one only uses the needed bandwidth at any time, the proposals seem to indicate that the worst case (i.e. the maximum) bandwidth will be used to assess the interference potential. As this usage may be quite rare it seems unnecessarily pessimistic and not an efficient representation of the behaviour typically.

Ofcom's view

A3.47 This seems to address the case of technologies that support different channel bandwidths, in line with the WiMAX comment above. Our proposal is not to take the worst case here, but an average of the varying bandwidth or a different classification for each different bandwidth.

Q3.1: 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?

A3.48 A majority of stakeholders agreed. Some commented that a more detailed definition is needed and provided guidance, others raised the concerns below:

No. Duty cycle is only relevant for systems with low duty cycles and therefore it can not be used as a generic indicator or as a component of a composite indicator.

Ofcom's view

A3.49 We disagree, we do not see arguments that reduce the validity of the duty cycle concept in case of high duty cycle systems.

An integral approach to assessing the time dimension of spectrum sharing should take into account frequency of access, duration of access and probability of access. If the latter is adaptively determined by a system, its ability to share the time dimension determines its overall potential of efficient spectrum sharing.

Ofcom's view

A3.50 Agree, we define the scenario and assume that the system does not see any other system, we then measure the duty cycle.

We expect the duty cycle for modern and future devices to be extremely variable, depending on the service being carried at any one time. So in a converged service deployment, the device would be delivering entertainment one time and simple status messages another. Again, taking the worst case might lead to significant divergence between the assessment of bandwidth for regulatory purposes and the experience seen in the field.

Ofcom's view

A3.51 Agree. This was already recognized in the consultation. We propose to deal with this aspect through the definition of usage scenarios, where the services are specified and, based on these, the time domain usage is derived.

Duty cycle is easily understood but, again, a more careful definition is needed to capture worst-case or 'busy' scenarios – particularly where several devices (or nodes) may need to be combined to support a single application.

…. Take for example a building sensor/security network where individual nodes may be only at 0.1% use but a few dozen sensors still add up in the local vicinity...

Ofcom's view

A3.52 We agree with these views. We consider technologies as systems, and we measure them in scenarios where we may have more than one individual system. Depending on the technology and the scenario, the system may be a single transmitter (for example an RFID reader), a transmitter-receiver pair (a Bluetooth phone and its headset), or several devices (a network of synchronized sensor nodes). The scenario will determine the density of devices. In the RFID case, we may have many readers, i.e. systems, in a warehouse, while the case of home automation can be seen as one network of sensor nodes. Time domain usage is partly conveyed in the duty cycle and partly in the density factor. However, the results should be similar regardless of how we define the system/scenario. This should be agreed with stakeholders.

Most radio systems ramp up their transmit power before a packet, ramp it down again afterwards, and leave a gap between packets. The example assessments in the consultation document suggest that this is assessed as a continuous activity, which is probably the right approach, but this is not made clear in the definition text. The metric should be formalised, e.g. by defining the transmission as lasting for the period at which the output power is above 10% of the peak power, and defining a minimum gap duration such that shorter interruptions to the transmission are ignored and the transmission is considered to be continuous.
The minimum gap duration cannot be entirely technology agnostic; it should ideally be similar to the typical packet length. Since higher frequency bands generally support higher bandwidths and hence shorter packets, the duration should range from around 10ms for lower bands through to around 1ms for higher bands.

Ofcom's view

A3.53 Agreed. We think that proposals are valid and will be an input when we consider specific frequency bands.

The proposal is also not clear as to whether the metrics are assessing individual transmitters, a bidirectional radio link, or whole systems. The example assessments appear to mix the latter two approaches - treating Wi-Fi and Bluetooth as systems, but RFID and home automation as a separate radio links. To a first approximation the difference is not important providing the same approach is used consistently for all of the metrics that contribute to the interference indicator. However, for systems that are strictly time division duplexed (whether within a particular network or on a particular channel) this can have a significant effect on how the interference potential scales with increasing density of transmitters.

Ofcom's view

A3.54 As explained above, we do not propose to have a clear-cut approach to this. Applications and technologies are widely different, in some cases it makes sense to evaluate time usage per individual link (a WiFi access point streaming video to a laptop) while in others are better suited to a whole system approach (a Bluetooth master with several slaves). The time domain factor will be complemented by the scenario definition to give the full picture of the technology usage of the time resources in a given scenario.

Q3.2: Do you agree that the duty cycle should be evaluated at the busy hour?

A3.55 A majority of comments were supportive. Again, some of these stakeholders would like to see a detailed definition of busy hour. Some responses were concerned with the use of the busy hour concept. These are presented below:

Adding "busy hour" to the duty cycle measure compounds the inaccuracy of the latter by adding a highly subjective factor – one based on fear at the victim side and one based on wishful thinking on the part of a proponent of a technology.

Ofcom's view

A3.56 We disagree with this view. Busy hour is not an alien concept in telecommunications. It is commonly used for dimensioning systems. Usage of any system, including those using licence exempt bands, will vary during the day. When we define in our scenario a precise time of the day and period over which we average, we focus on a situation where interference is likely to arise. We remove from the scenario the less relevant periods of the day when the system is more lightly used. The busy hour factor is a time domain effect, but it is in fact more closely linked to the selection of scenario than to the duty cycle.

It also is unclear whether 'busy hour' is a still a meaningful concept. With the increasing prevalence of storage in end-user devices and the growth in peer-to-peer distribution technologies, quiet periods might become scarcer, or at least more random, and therefore the busy hour(s) would be less distinct.

Ofcom's view

A3.57 We agree that trends seem to indicate a reduction of variability in usage of certain technologies along the day. However, we do not think this invalidates the "busy hour" concept, which we see as a reference. In any case, a time and period must be used to evaluate scenarios, and the "busy hour" is the industry most widely used agreement.

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?

A3.58 Most of responses agreed with the concept. However, many also emphasized the difficulty of properly evaluating density of transmitters. One respondent observed that only surveys after the devices are placed in the market would yield useful transmitter density estimations.

A3.59 We agree that density calculation for licence-exempt devices can only be speculative. This is more the case for devices that are not yet in the market. However, we think that industry and regulatory bodies should not give up looking for estimations just because it is difficult and with a high margin of error. Estimations of market penetration and usage scenarios are important in the development of technologies, and industry regularly engages in these activities. For example, when requiring new spectrum allocations at European level, stakeholders are requested to produce a System Reference Document in ETSI which includes a market analysis.

A3.60 The points below were also raised:

Many radio technologies incorporate mechanisms that coordinate the activity of multiple transmitters, such as Bluetooth's master scheduling activity of multiple slaves, or Wi-Fi's arbitration of access to a shared channel. These mechanisms result in the interference potential of those technologies not scaling linearly with either increasing coverage or density. Taking the example of Wi-Fi, a particular channel will not (significantly) exceed 100% utilisation regardless of how many devices are within range of each other.

Ofcom's view

A3.61 System characteristics can be looked at from different perspectives, depending on the scenario. As the comment suggests, a Bluetooth master controlling several slaves is evaluated more accurately as a single interfering entity than a collection of transmitters. We have addressed this issue under comments to question Q3.1.

There seems to be an ambiguity in the definition of transmitter density, as it is not clear if it refers to physical devices in the market or to the "active" ones. For instance, many devices can have Bluetooth capabilities, but few may actually be turned on. Also the determination of the area over which the density is computed, although required, may prove highly controversial.

Ofcom's view

A3.62 This is another aspect of the difficulty in assessing density. As shown in the examples given in the consultation, we evaluate how many devices are present and what proportion is active when we define the scenario. These will always be a matter of guesswork and subject to debate.

Q5.1: Do you agree with our method to calculate the interference coverage area of a transmitter?

A3.63 A majority of stakeholders broadly agreed with the method, several did not comment on this question and others raised the following concerns.

No. While power density is a better parameter than total power on which to evaluate interference probability, a "reference receiver approach", although simple, is not justifiable

Ofcom's view

A3.64 We understand the concern about a "reference receiver approach" as a rejection of a single threshold value. We have argued that victim receiver characteristics should not be part of the evaluation of the Interference Indicator of an aggressor technology. This leads us to consider an interference threshold level that is generic. However, we have revisited our position on the particular value and concluded that we will not set a generic value across bands. Instead, the level will be determined for each band under consideration according to existing and potential technologies.

No. The method and level chosen appear to have been derived from some ETSI specifications for certain limited low-frequency applications having a listen-before-transmit requirement and it thus technology specific and unlikely to meet the wider future needs.

In reality, the interference range will vary over a wide range depending on the propagation conditions, the frequency and of course, the ability of the victim receiver to reject the signal.

Ofcom's view

A3.65 We disagree with these objections. We note that the method proposed has not been derived from ETSI deliverables. It is based on transmitted power, propagation losses and antenna characteristics hence we think it is generic and applicable to any technology. It does take propagation conditions and frequency into account but, as we explain in section A3.2, we do not consider that the victim receiver characteristics should be part of the indicator calculation.

There appears to be an implicit assumption that all of the radios for a particular radio system will be close together compared to their interference range. This is unlikely to be the case for technologies such as Bluetooth that implement power control to minimise their output power based on the signal level at the peer's receiver. The geographic location of the different transmitters will not significantly affect the interference indicator, but the power control mechanisms should be taken into consideration.

Ofcom's view

A3.66 Power Control mechanisms raise an interesting challenge. Under good reception conditions, a system will reduce its transmitted power from the nominal EIRP and hence interfere less. The question is how to evaluate this reduction in the interference generated in a simple way. An option is to assume that the system operates in isolation and hence suffers no interference itself, leading to a low transmitted power. But this will give a misleading indication of its behaviour in presence of other systems, a situation where it would increase its power and hence be more interfering itself. To properly account for power control we will need to specify the reception conditions of the system evaluated. This needs to include the interference it suffers from other systems. We do not believe it is possible to do this in a technology neutral way.

A3.67 Although we agree that Power Control should ideally be accounted for when calculating interference coverage, we prefer at this point to consider it as a higher layer sharing mechanism and to base this coverage on a simple parameter such as EIRP.

An increasing number of radio systems are using multiple transmit antennas, e.g. IEEE 802.11n MIMO, but there appears to be an implicit assumption in the consultation document of a single antenna. It would make sense to consider all of the antennas of a single transmitter together as a single (directional) antenna. However, steerable antennas probably need to be treated specially, considering the total area swept during a nominal period, say 1 second.

A3.68 We agree that antenna arrays can be treated as a single directional antenna. We do not think that a special consideration is needed for steerable antennas. A device whose beam is swept maintains the size of the interference coverage area. The fact that this area "moves" around the transmitter does not mean that the amount of generated interference changes.

Q5.2: What is your view on a threshold level of -80 dBm/MHz to determine the interference range?

A3.69 There was no majority view on this point. A few stakeholders found the value too high, while others thought it was a good starting point. Several argued that it should be dependent on the frequency range under study, since propagation conditions and receiver technology are very different at high and low frequencies.

A3.70 Following these comments we do not propose a single threshold value at this stage, and we remark that -80dBm/MHz is only an example for discussion. We propose that the threshold value should be calculated for each band independently, and based on propagation considerations and on input from industry on receiver technology.

A3.71 However, we must put the threshold in context. It is a reference value that has no practical meaning. High or low, it will affect all technologies opting for a band to the same extent. If chosen very low for example, it will result in large interference coverage areas for all technologies.

Q5.3: Do you think the threshold level should be expressed as power density (dBm/MHz) or as power (dBm)?

A3.72 A majority of respondents preferred a threshold in terms of power density (dBm/MHz) over power (dBm). However, one stakeholder argued that a power density requirement favours narrowband systems because a wideband device would detect a single narrow band device while the same is not true the other way around. Another stakeholder proposed to use power flux density (dBm/MHz/m^2), which we think it is in fact the best way to express the threshold level. The responses are reviewed below:

…a threshold set in dBm/MHz favours narrowband systems: a wideband device would detect a single narrow band device but the same is not true the other way around. Only a fraction of the power of the wideband device is received by the narrow band device.

Ofcom's view

A3.73 We do not agree with this comment; we think that the specification of the threshold one way or the other will not change this effect.

In lower frequency bands where MHz bandwidths are rarer, either a narrower spectral density measure (dBm/10kHz or 100kHz) or a just a simpler dBm-only measure should be considered.

Ofcom's view

A3.74 Agreed. Just as the actual value should be consistent with the frequency range under study, we think that the units should be in line with bandwidths commonly used in the range. We agree that for lower frequency bands, a simple power level specification of the threshold could be preferred over the power density.

The definition however, may not be "technology neutral" since the capture area of the receive antenna is not accounted for in the definition. To accommodate the antennas, the definition must relate to a defined capture area e.g. -100dBm/MHz/cm2 or -60dBW/MHz/m2.

By defining the interference levels in dB/MHz/m2, those with systems with a larger capture area will therefore receive a higher noise at the receiver input but will be protected at the same level of performance at the receiver input.

Ofcom's view

A3.75 We agree with this comment. By defining the threshold in dB/MHz/m^2, we make it independent of the receiver antenna used to measure it. We must note also that these are the units used for the specification of Spectrum Usage Rights, which is the preferred Ofcom approach to the technical requirements in licenses.

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

A3.76 A majority of stakeholders, agreed with this approach. Comments here align with those raised under Q4, notably with regards to the difficulty to assess density.

Yes, where "busy yet realistic" is the stakeholder consensus.

Ofcom's view

A3.77 Agreed. The usage scenario can only be the result of consensus among technology proponents, regulatory bodies and other interested parties.

We have some concerns that were there is less dense deployment of devices then the use of a fixed value may have some adverse implications. In particular where there is a lower density of devices could the power density be increased.

Ofcom's view

A3.78 We agree with this view but we do not see a reason for concern. The point of having an indicator that compounds the different effects is precisely to allow technologies that have a low interference profile in one domain to increase their profiles in another.

The interference indicator is determined during the development phase so could it be subsequently changed if numbers deployed are significantly different.

Ofcom's view

A3.79 We do not think it is feasible to change the indicator after deployment has commenced. We acknowledge that it can be very difficult to get all interested parties to agree on density figures and the likely scenario of a technology. Once this is agreed the Interference Indicator can be calculated. A technology could be extremely successful and be deployed in much higher numbers than expected. This would also mean that it generates more interference than expected. A re-calculated indicator would have a higher value, potentially placing the technology out of the class it was designed for. In conclusion, a very successful technology could be thrown out of its band. We do not think this is acceptable. We expect developers to present usage scenarios as accurately as possible, and regulators and industry to find a different way to cope with very successful, very interfering technologies.

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?

A3.80 A majority of stakeholders supported this approach. Some argued that further thought should be given to the weight of the components, which could be for example raised to different indexes. We have addressed this comment in the summary section. The current weighting values all factors equal, which has the advantage of simplicity. Any alternative needs be well justified and this may be difficult. We comment on other points below:

Each of the factors that make up the interference indicator fail to convey the ability of the technology to share spectrum with other transmitters of its type and with other technologies. As a result, the interference indicator concept will fail to deliver benefits of efficient spectrum use and continued innovation. As designed, the interference indicator does not capture improvements in cognitive radio technologies, and therefore, fails to provide incentives to develop them.

Ofcom's view

A3.81 Our purpose for the indicator is not to measure the ability of a technology to share spectrum, but the level of interference that it might cause to other users. We have explained above why we believe that the Indicator should be based on physical characteristics and not account for sharing techniques. We deal with these under the polite rules section, where we set up a number of high level requirements.

The inclusion of politeness in the interference assessment would thus incentivise the adoption of polite protocols since a lower class categorisation would give access to more spectrum

Ofcom's view

A3.82 Again, we see the merit of this view. However, we think it would be very difficult to evaluate polite protocols as part of the interference assessment. We propose instead to incentivise higher layer techniques through the polite rules.

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?

A3.83 Some stakeholders agreed with three classes and others preferred to split the middle class in two, as suggested in the consultation. Only a few stakeholders commented on the boundary values, and the preference is to look at a wide selection of existing devices and to study the boundaries specifically for each new band where a class would be applied.

A3.84 From the responses, we think that we cannot present a definite answer to the number of classes and the boundary values. We think that this is an issue that cannot be addressed properly at a generic level, only when deciding on a particular band. As introduced in section A3.2, one stakeholder presented an approach to the selection of class boundaries that aligns with our thinking better than our own text. This proposal is briefly reviewed below, followed by other concerns raised:

Rather than picking one of several predefined classes it would be better to select optimum thresholds for the band under consideration to split technologies into (i) those that are forbidden from the band due to their interference potential being too high, (ii) those allowed to use the band subject to appropriate polite protocols, and (iii) those that are allowed to use the band without restriction due to their interference potential being significantly lower. The upper threshold should be picked to maximise the economic value criteria proposed within the consultation document. The lower threshold should then be selected such that technologies below that threshold would not be expected to adversely affect those above it to any significant degree. Approval of technologies to use the band should additionally *consider whether they would be sufficiently immune from interference from the already approved technologies.*

Ofcom's view

A3.85 We think that this interpretation of the classes aligns with our intentions. It presents the methodology towards a class definition in a way that is easier to understand. We develop on these arguments in this statement.

Our concern is with the whole principle of dividing up licence-exempt spectrum and thus excluding potentially valuable, innovative applications from accessing the capacity that their market success warrants.

Ofcom's view

A3.86 We do not share this concern. As explained in the Licence Exemption Framework Review, we think it is suboptimal to let all applications, high and low interferers, access the same licence-exempt band. We believe a better outcome is achieved if only technologies with similar interference characteristics are allowed in a band. The decision as to which band to allow would be based on economic benefits, so it would inherently favour, rather than exclude, potentially valuable applications.

The choice of thresholds within a particular band may be adjusted after the initial allocation of the band, but only to the extent that the classification of already approved technologies remain unchanged by the new thresholds.

Ofcom's view

A3.87 We are not convinced that changing the thresholds after band release is advisable. Such change represents a modification of the regulatory requirements, and should not be taken lightly. We do not think that the choice of thresholds should be made on the assumption that they may be readjusted later.

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

A3.88 All but one responses agreed with the definition of fairness to some extent, although many observed that it is open to interpretation and difficult to articulate in a regulatory requirement. The following points were raised:

However, there should be an explicit exception for technologies that are not expected to be a significant source of interference. It would be an inappropriate burden for such systems to have to implement active monitoring for other systems.

Ofcom's view

A3.89 We agree with this view. Such technologies would be classified as low interferers, and exempt from implementing sharing techniques. For devices to be allowed in bands allocated to a low interference class, technology developers will have to show that their Interference Indicator is lower than the threshold.

The proposals discussed in section 8 favour short, "bursty" traffic over other forms of communication and thus limit the types of services that can be sustained. Future VoIP users *(for example) could thus be at an unfair disadvantage in terms of access and maintenance of the call where currently they are able to have a good service.*

Ofcom's view

A3.90 We do not think that this inference is entirely correct; we do not think that the proposal favours bursty traffic. Our view is that users should be able to use as much resources they need but also to monitor these resources and share if other users are detected.

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

A3.91 A majority of stakeholders agreed that signal specific detection has benefits over blind detection, but there was no consensus on this point. One response noted that none of these techniques deals with the hidden terminal problem. Another expressed preference for blind techniques from a regulatory point of view, arguing that regulations should avoid being technology specific. We address below a concern raised under this question with regards to the situation of incumbents:

If in the future some spectrum were to come available for licence-exempt deployment without the requirement of re-locating the incumbent, the situation would be different. In this case, the incumbent may well have rights that need to be maintained. In order to obtain the maximum benefit from the spectrum for all users, it may be necessary to carefully coordinate usage with knowledge of the current technologies employed by the incumbent. When the incumbent migrates to new services the analysis may have to be repeated and there may even be limitations on what the incumbent can migrate to. This is a very difficult situation and it may be better to seek alternative solutions to avoid incumbents and licence-exempt services sharing the same band.

Ofcom's view

A3.92 We would like to point out that there is little/no spectrum that remains unused. Future allocations of bands to licence exempt usage are likely to have a primary user, and licence exempt technologies will have to yield to it. An example of this is the licence exempt bands at 5GHz, where wideband data systems in the 5GHz band are required to detect and avoid co-channel operation with incumbent radar systems.

A3.93 The feedback from stakeholders does not change substantially our views on detection techniques. While signal specific techniques are undoubtedly more effective when the characteristics are known, this is not always the case. We maintain our requirements for the polite rules as expressed in the consultation, and we acknowledge that both blind detection and signal specific have a place in licence exempt regulations.

Q11: Do you agree with the proposed polite rules?

A3.94 A majority of stakeholders agreed with the basis of the proposals without major concerns. The following points were also raised:

In addition to the politeness rules being proposed, we are of the opinion that a clear safeguard limit should be imposed on the transmitter eirp. In fact, with the proposed approach, an excessively high transmit power, sufficient to cause blocking of neighboring devices, could be balanced by other factors in the computation of the interference indicator and be therefore otherwise be allowed.

Ofcom's view

A3.95 We agree with this comment. A maximum EIRP requirement will always be present.

The 1/n or 1/(n+1) (±X%) requirement is likely to be both unworkable and undesirable. With multiple technologies sharing a band it is unreasonable to expect all devices to be able to count the number of different transmitters (or systems) that are operating within their locality. Even within a single technology this would generally be very tricky and inefficient. This requirement also makes the assumption that all transmitters need to use their full share of resources, but in general this is unlikely to be the case, which will result in other systems throttling their usage unnecessarily.

Ofcom's view

A3.96 We agree with these observations to some extent. We do not expect technologies to be able to detect and account for every transmitter in their neighbourhood. We understand that this requirement is unlikely to be completely achievable in practice. In addition, we do not expect transmitters to occupy their share of resources unnecessarily. However, we think that, in presence of other transmitters, a transmitter should target a use of resources of not more than 1/n or 1/(n+1). We see this as a guiding principle rather than a specific requirement.

The requirement to coordinate with existing users of the band is unnecessary; as an alternative it should be sufficient for new technologies to yield to existing ones. Any requirement for detection and/or coordination with other technologies must be accompanied by a requirement for (the medium access portion of) the specifications for those technologies to be made public. Such detection techniques should not need to be perfect, e.g. it should be sufficient to implement energy detection rather than needing to synchronise to particular modulation schemes or decode packet headers.

Ofcom's view

A3.97 We agree with this comment. Newcomers should detect and yield to incumbents.

The energy detect requirement needs to be clarified. Is this a one-off measurement before using the band, or does it need to be repeated periodically or even before every transmission? A one-off assessment would not take account of changing environments, which are particularly likely with mobile equipment. However, a 1 second measurement period would be excessive if required before every transmission. The definition of typical bands would give be encouraging technologies with similar characteristics, which is counter to the stated aims.

Ofcom's view

A3.98 We agree that these issues merit further study. We will consider them when looking at specific bands.

Other considerations raised by respondents

Light licensing and coordination protocols

A3.99 One stakeholder commented on the similarities between light licensed and unlicensed spectrum. Light-licensing resides somewhere between the licensing and licence-exempt models, and is particularly useful for fixed services. Under a light-licence regime, radio devices are registered and their locations and transmission characteristics maintained in a database. This lets multiple operators coordinate, and affords protection to existing users.

A3.100 We do not think that spectrum commons classes are needed for bands where light licensing is in place. The ultimate goal in all cases is to let devices share spectrum. In a light licence scenario, this is achieved through the registration and coordination mechanisms which seem to function well. We do not see a need to introduce another regulatory mechanism such as Spectrum Classes, and hence we think that light licensing is out of the scope of this proposal which is specific to licence exemption.

A3.101 The same response argued that coordination is the sharing mechanism that results in most efficient use of spectrum. Coordination mechanisms let systems in the same band and geographic area exchange information about the resources they occupy. Systems can coordinate over the air if they have common technology or via a database where the location and characteristics of each system are stored. The light licensed bands are an example of the latter.

A3.102 We agree that coordination could in theory provide an interference free environment and hence be the most efficient sharing method. In practice, coordination is rarely applicable to licence exempt bands because 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.

A3.103 A coordination mechanism used on a licence exempt band may in fact have the undesirable effect of making the band technology-specific. One can imagine a few systems located in the same area, all using the same technology which is able to coordinate them. This “network” will ensure that its members do not interfere with each other, but will not avoid them interfering with other systems using a different technology. Worse still, it may occupy all resources with the effect that other, more polite, technologies cannot operate and only systems that implement the coordination technology will be able to function properly.

Inefficiency risks of partitioning licence-exempt spectrum

A3.104 One stakeholder was concerned about partitioning bands where licence-exempt use is allowed. It feared this would introduce inefficiencies, such as an administration that choosing the wrong application for which to reserve spectrum, or different administrations choosing different classes in the same band and thus fragmenting the market. The stakeholder suggests that the market is better able to determine the share of spectrum which applications and technologies require.

A3.105 We think there is always a risk of inefficiency. In the case of licensed spectrum, we reduce this risk allowing licences to be traded. In the case of licence exempt use, we propose to introduce spectrum commons classes. These impose little constraint on applications, since the class only requires that technologies have a similar interference profile. We do not have here the problem of a wrongly chosen application, since other applications could use the band provided that they have similar interference characteristics. Note that “similar interference characteristics” means that the Interference Indicator is within the class range. We think this is closer to a pure spectrum commons allocation than to an application specific allocation, because we do not impose a particular technology, bandwidth, power or timing requirements. Therefore, the risk of inefficient use of spectrum is greatly reduced.

A3.106 We agree that there is risk of market fragmentation if different administrations choose different classes, or more generally, different approaches to licence exemption. For this reason, we intend to present our concepts to our colleagues from regulatory bodies in Europe. The goal is a common, European wide approach to licence exemption.

Spectrum Classes are not needed, developers already have incentives to implement mechanisms that limit the impact of interference.

A3.107 It is argued that being resilient to interference is a competitive advantage in the licence-exempt environment. In addition, it is noted that many of these devices are portable, hence energy consumption is a key factor that drives transmission power down.

A3.108 We agree with these arguments. However, we note that a technology that is resilient to interference does not necessarily produce less interference itself. Spectrum classes and polite rules will not remove the incentives to implement better receivers. The incentives remain because in a licence-exempt environment devices will always have to deal with interference. Classes and rules impose requirements on the transmitters so that devices interfere less.

A3.109 Secondly, we note that developers of portable devices strive to make them as energy efficient as possible. But not all uses that one can envisage for licence-exempt spectrum will be portable.

Annex 4

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
RTS/CTS	Request To Send / Clear To Send. Clearing exchange between a transmitter and receiver to prevent interference to and from nodes hidden from the transmitter.
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.