Digital dividend: cognitive access

Statement on licence-exempting cognitive devices using interleaved spectrum

Statement

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Section 1

Executive summary

Background

1.1 Since its launch in 2005, our Digital Dividend Review (DDR) has considered how to make the spectrum freed up by digital switchover (DSO) available for new uses.[1] This includes the capacity available within the spectrum that will be retained to carry the six digital terrestrial television (DTT) multiplexes after DSO. This is known as interleaved spectrum because not all this spectrum in any particular location will be used for DTT and so is available for other services on a shared (or interleaved) basis.

1.2 In our statement of 13 December 2007 on our approach to awarding the digital dividend,[2] we considered the use of interleaved spectrum by licence-exempt applications (i.e. those exempted from the need to be licensed under the Wireless Telegraphy Act 2006[3]). We concluded that we should allow cognitive access as long as we were satisfied that it would not cause harmful interference to licensed uses, including DTT and programme-making and special events (PMSE). This could potentially bring substantial benefits to citizens and consumers in the form of new devices and services.

1.3 Cognitive devices should detect spectrum that is otherwise unused and transmit without causing harmful interference. They have the potential to support a wide range of uses, including high-speed always-on broadband.

1.4 In a consultation published on 16 February 2009,[4] we proposed a number of technical parameters that we suggested would prevent harmful interference while enabling licence-exempt cognitive use of interleaved spectrum. This statement concludes on some of the issues raised but notes that further work is needed on others.

Key conclusions

1.5 The cognitive consultation noted that there were three main approaches to determining whether spectrum was unused – detection, geolocation and beacons. It suggested that beacons were the least appropriate and did not merit further investigation and this was widely agreed by respondees. It asked whether detection and geolocation should both be enabled as alternatives. Some respondees agreed to this while others felt that geolocation was essential or that both approaches needed to be used together. Many noted that in any case, detection alone was very difficult to implement and unlikely to be used for the foreseeable future. Overall, existing licence holders of interleaved spectrum generally accepted the level of protection offered by geolocation although some in the PMSE community were concerned about the speed of database update and saw the use of detection in addition to geolocation as a way to resolve this issue.

[1] See www.ofcom.org.uk/radiocomms/ddr/ for more information about the DDR, including previous publications.
[2] www.ofcom.org.uk/consult/condocs/ddr/statement/statement.pdf.
[3] www.opsi.gov.uk/acts/acts2006/pdf/ukpga_20060036_en.pdf.
[4] www.ofcom.org.uk/consult/condocs/cognitive/cognitive.pdf.

1.6 If detection alone is used then the likelihood of interference occurring depends on the parameter values selected. The proponents of cognitive access argued that we had been too cautious in our selection of parameters and levels more favourable to cognitive devices should be selected, while licence holders and other affected stakeholders argued that we had been insufficiently cautious and that parameters should be modified to provide greater levels of protection. For the most part, these arguments rested on the identification of certain situations where cognitive devices might be in proximity to licensed devices but unable to detect them.

1.7 We conclude from the responses that the most important mechanism in the short to medium term will be geolocation. While we set out some ideas about how this might operate in the cognitive consultation we did not cover all aspects in detail and hence believe that further work, possibly leading to consultation specifically on geolocation, is appropriate. Hence, this statement does not conclude our work on cognitive access. Instead it sets out those aspects where we consider we can draw a conclusion such that we can concentrate on the remaining issues.

1.8 Our view on detection is that it should be allowed but with sensing levels and transmit levels lower than we had originally proposed. In the cognitive consultation we presented detailed analysis to show how these levels were derived. This was generally supported but some respondees suggested other deployment scenarios and showed how these levels would not afford sufficient protection under these scenarios. We accept that greater levels of protection might be needed in these scenarios but consider them sufficient unlikely that to afford such protection would place an excessive additional burden on cognitive devices. We do not have data to substantiate this view – and indeed until the likely uses of cognitive devices are known it would not be possible to assemble this data. Hence, this decision is based on a subjective assessment of the likely risks. In addition, with the reduction in levels mentioned above, we have gone some way to affording additional protection to all licence holders.

1.9 As a result we propose to allow detection alone as well as geolocation. However, we note that implementation of detection-only devices is likely many years away and hence there is little advantage in rapidly making the necessary regulations to licence-exempt such devices. Given that there may be benefits in European harmonisation and that more evidence may emerge we have elected to set out our chosen parameters in this statement but will not take any further action at least until we have concluded on geolocation parameters. If further evidence comes to light before we make regulations, we would reconsider the parameters set out here as appropriate.

1.10 We welcome the Government's support for our establishing the parameters for successful cognitive access in the UK and achieving the international harmonisation that is required, as set out in its Digital Britain Final Report[5].

Key device parameters

1.11 Table 1 sets out the parameters we have concluded on if cognitive devices are to use detection alone. Transmit powers here and throughout this document are effective isotropic radiated power (EIRP) into an 8 MHz bandwidth.

[5] www.culture.gov.uk/what_we_do/broadcasting/6216.aspx

Table 1. Key parameters for detection

Cognitive parameter	Value
Sensitivity assuming a 0 dBi antenna	-120 dBm in 8 MHz channel (DTT) -126 dBm in 200 kHz channel (wireless microphones)
Transmit power	4 dBm (adjacent channels) to 17 dBm
Transmit-power control	Required
Bandwidth	Unlimited
Out-of-band performance	< -46 dBm
Time between sensing	< 1 second

1.12 Table 2 sets out the key parameters for geolocation that we are able to conclude upon at this point.

Table 2. Key parameters for geolocation

Cognitive parameter	Value
Locational accuracy	Nominally 100 metres
Transmit power	As specified by the database
Transmit-power control	Required
Bandwidth	Unlimited
Out-of-band performance	< -46 dBm

Next steps

1.13 We will now work with stakeholders to further develop the concepts and algorithms necessary for geolocation and expect to consult further on geolocation later in 2009.

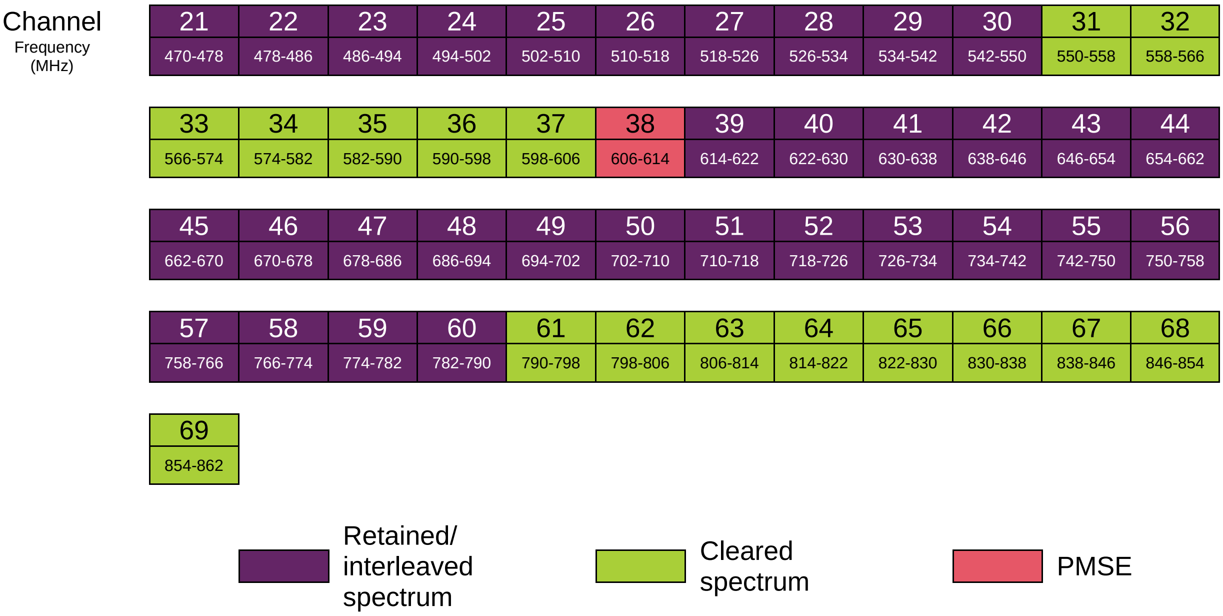
Section 2

Introduction

The DDR and interleaved spectrum

2.1 The configuration of UHF Bands IV and V after DSO, the subject of the DDR, remains subject to change, particularly in the light of our decision to clear the 800 MHz band (channels 61-69) to align the upper band of the UK's digital dividend with the spectrum being released in an increasing number of other European countries. Figure 1 shows where interleaved spectrum will be located as a consequence of this decision.

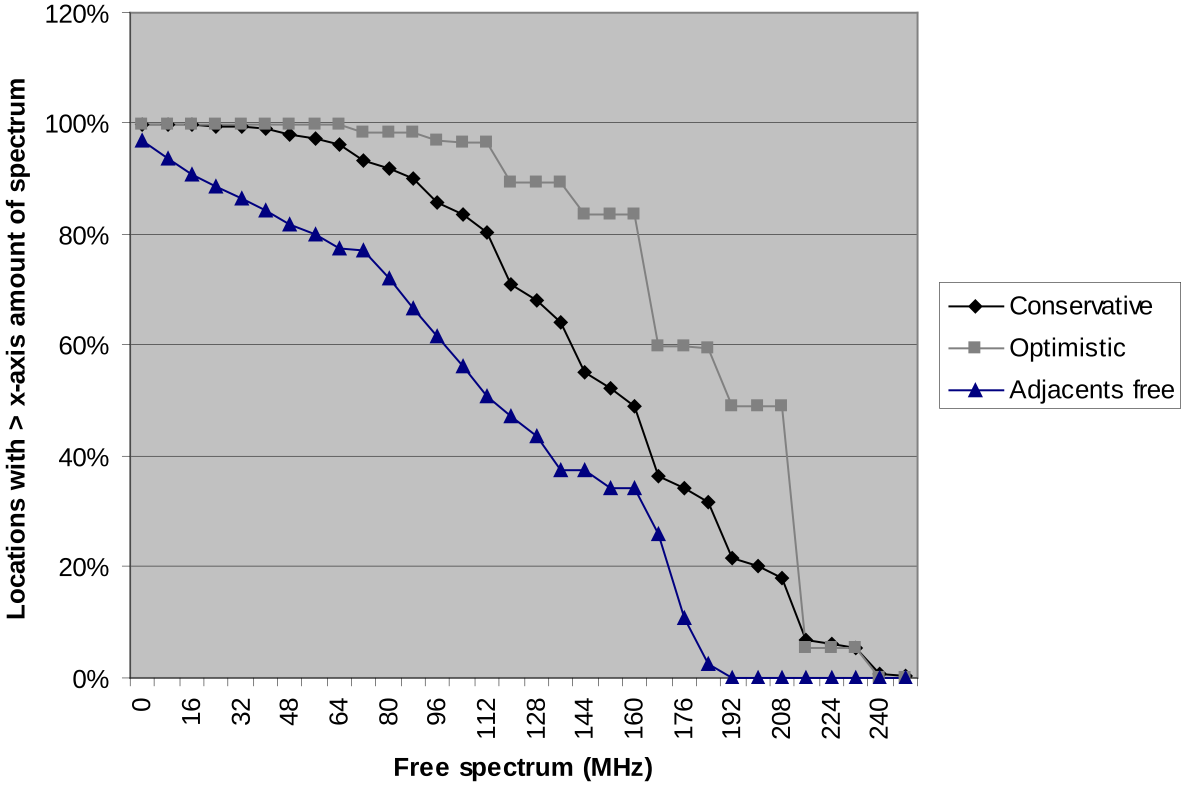
Figure 1. UHF Bands IV and V after DSO and 800 MHz clearance



2.2 Modelling shows that there is a substantial amount of interleaved spectrum. This is often termed "white space" because, when plotting a geographic map of DTT coverage and using colours to denote received signal strength, those areas without signal (and hence where the spectrum is unused) are left uncoloured and so appear white. Figure 2 gives a high-level estimate of the amount of interleaved spectrum in any given location. The two lines labelled "conservative" and "optimistic" assume that all free channels can be used, including those with use in adjacent channels. The two lines form a bound depending on assumptions about television antenna orientation. They show that over 50% of locations are likely to have more than 150 MHz of interleaved spectrum and that even at 90% of locations around 100 MHz of interleaved spectrum might be available. This is a substantial amount, even after allowing for use by PMSE and other low-power services (e.g. local television). By way of comparison, around 80 MHz of spectrum is available in the 2.4 GHz band used for Wi-Fi and 140 MHz was auctioned for 3G use in 2000. Hence, making this spectrum available for use could bring substantial value to citizens and consumers.

2.3 The third line on the chart, labelled "adjacents free," assumes that a channel can only be used if the adjacent channels on either side are also free. Some have suggested that practical realisations of cognitive devices will need to have free adjacent channels to meet the necessary device specifications. Obviously, there will be less spectrum available when free adjacents are needed. The figure shows that this reduces the amount of spectrum available in 50% of locations from around 150 MHz to 100 MHz. Importantly, it also results in no spectrum being available in some 5% of locations.

Figure 2. Estimated amount of interleaved spectrum



Source: Arqiva.

2.4 The white space appears to be a substantial amount of spectrum which is unused and could be valuably employed by cognitive devices. It is effectively set aside from high power broadcast use to avoid interference with other nearby transmitters using the same frequencies. It is therefore only available for low power usage otherwise harmful interference will result.

2.5 In our statement on awarding the digital dividend, we decided that we would treat the interleaved spectrum in four different ways:

- We would include the capacity in channels 61 and 62 in the cleared award. This has been superseded by our decision to clear the 800 MHz band, which will see channels 61 and 62 cleared in their entirety for award and the DTT services deployed in those channels moved to channels 39 and 40 instead.

- We would award geographic packages of one or two 8 MHz channels, suitable but not reserved for local television, wherever there was credible evidence of demand. We consulted on the detailed design of these awards on 12 June 2008.[6] We published a statement on the first two geographic-interleaved awards, covering the Manchester and Cardiff areas, on 29 October 2008.[7] We concluded

[6] www.ofcom.org.uk/consult/condocs/ddrinterleaved/interleaved.pdf.
[7] www.ofcom.org.uk/consult/condocs/notice524/statement/statement.pdf.

the award for the Manchester area in February 2009 and that for the Cardiff area in March 2009.

- We would award a single package of most of the remaining interleaved spectrum by beauty contest to a band manager with obligations to PMSE users. We consulted on the detailed design of this award on 31 July 2008[8] and again on 22 June 2009.[9]

- We would allow licence-exempt cognitive access to interleaved spectrum (then excluding channels 61 and 62) provided this would not result in harmful interference to licensed users. This reflected our duty under section 8(4) of the Wireless Telegraphy Act to exempt from licensing any use of wireless-telegraphy apparatus that we consider is not likely to cause harmful interference.

2.6 This statement focuses on the last of these approaches to the interleaved spectrum and sets out some of the details of how cognitive devices will be allowed to use it on a licence-exempt basis.

Cognitive access

2.7 We consider cognitive devices – sometimes known as white-space devices – to be those that assess the available spectrum, determine which parts of it are currently unused and make use of this spectrum when they have information to transmit. They are often described as being particularly suited for high-bandwidth services such as home and business networks, community and campus networks and municipal Wi-Fi.

2.8 In allowing cognitive access to interleaved spectrum, it is important first to determine the method used to assess whether spectrum is vacant and then to set appropriate parameters for each method selected. For example, if the method selected is spectrum sensing, key parameters are the sensitivity of the cognitive device to detecting signals from other uses and the power levels at which it is allowed to transmit if it concludes that the spectrum is empty.

2.9 It is generally not possible to design a cognitive device to be able to detect and avoid every technology that might be deployed in the spectrum in the future. Hence, there is a risk that cognitive access to interleaved spectrum might reduce the value of subsequently deploying different technologies. If it became clear in due course that a valuable new licensed use could not be deployed as a result of cognitive access, we would review the situation and determine whether to modify the parameters relating to cognitive devices.

Structure of this document

2.10 This document is structured as follows:

- Section 3 considers deliberations about licence-exempt cognitive access to interleaved spectrum in the US and the EU.

- Section 4 discusses in overview three approaches to determining whether spectrum is free for use by a cognitive device and considers how the appropriate transmission parameters should be set.

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[8] www.ofcom.org.uk/consult/condocs/bandmngr/condoc.pdf.
[9] www.ofcom.org.uk/consult/condocs/bandmanager09/bandmanager09.pdf.

- Section 5 considers the detection parameters necessary for a cognitive device to operate successfully through spectrum sensing.

- Section 6 considers some of the issues associated with using a database of which frequencies a cognitive device is allowed to use at any location.

- Section 7 considers the transmission from some appropriate infrastructure of a beacon – a signal providing information on which frequencies are available for cognitive use in the vicinity.

- Section 8 considers the three different approaches proposed to enable a cognitive device to determine which spectrum it can transmit in.

- Section 9 considers other parameters that need to be set appropriately.

- Section 10 outlines the path we plan to follow to maximise the probability of achieving international harmonisation around an acceptable standard.

- Section 11 summarises our conclusions and next steps.

Section 3

International developments

Introduction

3.1 Many other countries are engaged in the process of DSO and hence are also considering whether and how to realise a digital dividend. This section considers deliberations about licence-exempt cognitive access to interleaved spectrum in the US and Europe.

Developments in the US

3.2 On 4 November 2008, the Federal Communications Commission (FCC) adopted a report setting out rules allowing licence-exempt cognitive devices to operate in interleaved spectrum.[10] These rules are complex but in outline require cognitive devices to use both spectrum sensing and geolocation. The devices must sense both television signals and wireless microphones down to -114 dBm. They must also locate their position to within 50 metres and then consult a database that will inform them about available spectrum in that location. Mobile devices may then transmit at up to 100 mW unless they are using a channel adjacent to terrestrial television, in which case their transmission power can only be 40 mW. Out-of-band emissions must be 55 dB below the in-band levels. Different rules apply to fixed devices (assumed to be base stations, likely providing a rural-coverage service). Detailed rules associated with the frequency of database access and sensing are provided.

3.3 Devices that use sensing alone are allowed in principle. Their output power is restricted to 50 mW, and they must be submitted in advance to the FCC for laboratory and field testing so the FCC can determine whether they are likely to cause harmful interference. The exact process that the FCC will use to determine this has not been specified.

3.4 Devices without geolocation capabilities are also allowed if they are transmitting to a device that has determined its location. In this case, one device would be acting as a "master" for a network and the other "slave" devices would operate broadly under its control in terms of the spectrum they would use.

3.5 The FCC has set aside two channels in each location for wireless-microphone use alone and therefore not available to cognitive devices.[11] These "safe-harbour" channels are intended to provide wireless microphones with spectrum in which it is guaranteed that cognitive devices will not operate.

3.6 The FCC report includes a detailed discussion about whether cognitive access should be licensed, licence-exempt or subject to light licensing. It concludes that the best way to facilitate innovative new applications is via licence-exemption and that licensing would not be practicable for many of the new applications envisaged. It also notes that any licenses would be difficult to define and subject to change (e.g. if television coverage was re-planned), so the rights awarded would be rather tenuous.

3.7 The key implication that might be drawn from the US work is that the technology needed for sensing alone is currently insufficiently well developed to be used for

[10] http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.doc.

[11] Television channels in the US are 6 MHz rather than the 8 MHz European standard.

cognitive devices. This was particularly the case when detecting wireless microphones but also true in some cases when detecting television signals. Given the broad similarities between the licensed use in the US and the UK this suggests that devices that rely on sensing alone may not be readily implementable at present.

Developments in Europe

3.8 Work on a pan-European specification for cognitive devices is taking place within a newly formed working group, SE43, of the European Conference of Postal and Telecommunications Administrations (CEPT). This work is currently at an early stage. It is not clear how any results will be promulgated. We will continue to contribute to this work, looking for the least intrusive way to achieve effective international harmonisation (see section 10).

Section 4

Determining free spectrum and setting transmission levels

Introduction

4.1 A cognitive device needs to determine that spectrum is free and then only transmit according to an appropriate range of parameters such as power levels and out-of-band emissions. This section discusses in overview three approaches to determining whether spectrum is free: detection, geolocation databases and beacon reception. It goes on to consider how the appropriate transmission parameters should be set.

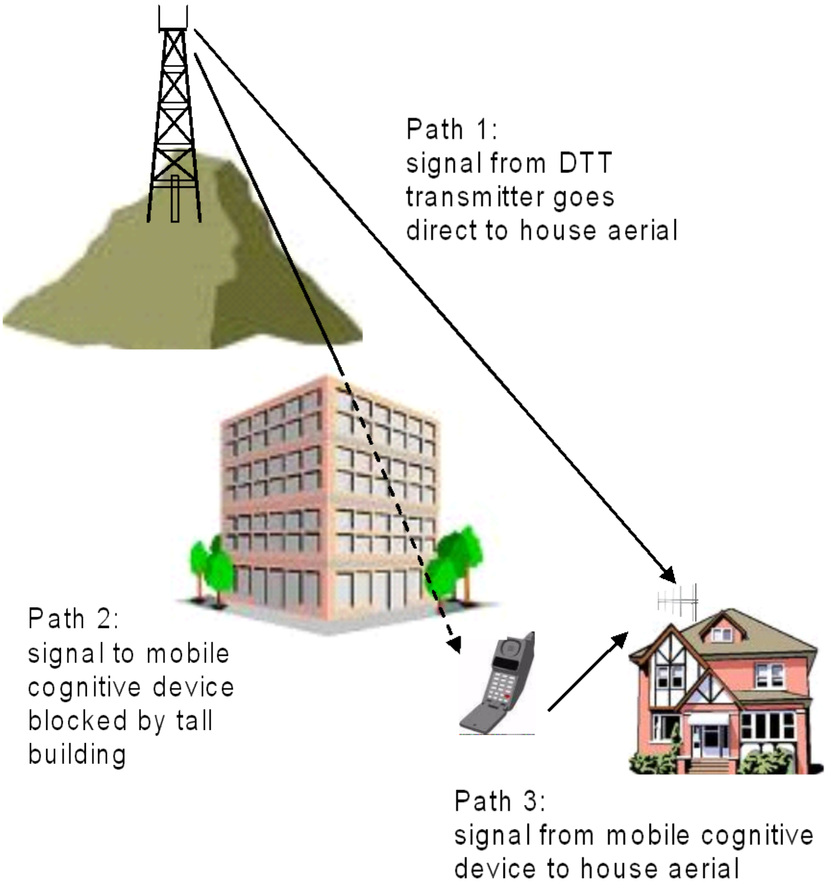
Detection

4.2 If a cognitive device transmits near the receiver of a licensed use of interleaved spectrum it might cause harmful interference. If detection is used, the device seeks to avoid causing harmful interference by monitoring the spectrum for transmissions. It deduces that there are no nearby active receivers in that spectrum if it cannot detect any transmissions because there would be nothing for them to receive.

4.3 However, there is a problem with this approach often termed the “hidden-terminal” issue. This arises when the receiver of a licensed use is better able to receive the transmission than the cognitive device. Figure 3 illustrates this.

4.4 A house receives a DTT signal using a rooftop directional aerial mounted clear of surrounding buildings (path 1). Nearby is a mobile cognitive device attempting to detect the same signal at street level, but it is blocked by surrounding buildings (path 2) and therefore much reduced in strength. The cognitive device might erroneously conclude that there are no transmissions and hence no active nearby receivers, transmit and cause harmful interference to the rooftop aerial (path 3). A similar situation can be envisaged with respect to PMSE applications, including wireless microphones.

Figure 3. The hidden-terminal issue



4.5 The approach suggested to solving this problem is to determine two parameters. The first is the minimum signal level, or "sensitivity" at which the receiver from the existing service is able to deliver that service or the minimum level that it is likely to experience in practice. For a DTT receiver this would either be the minimum level at which an acceptable picture can be displayed or the minimum signal strength within "protected coverage regions". The second parameter, termed the "additional margin" is an estimate of the difference in signal level that might be caused by the hidden terminal problem. For example, this might be based on an estimate of the maximum difference between signal levels at rooftop level and at street level. The addition of the sensitivity and the additional margin becomes the "sensing level". If a cognitive device does not detect a signal above the sensing level it can consider the channel to be unused in its vicinity.

4.6 Determining the sensitivity of a device is relatively straightforward. It is often quoted in device specifications and can readily be confirmed in laboratory trials. For example, a number of DTT receivers could be procured, a test signal inserted into their aerial socket and the strength of this signal reduced until the picture quality visibly deteriorates.

4.7 Determining the additional margin is much more problematic. The difference in signal level caused by the hidden-terminal problem will vary substantially with geometry according to the composition of nearby buildings, street width, distance from the transmitter, height of the rooftop aerial and so on. It is impossible to measure all situations. The best that can be achieved is to either model or measure a set of representative locations selected as carefully as possible. The measurements themselves will be probabilistic in that they will show that, for example, in 90% of cases the margin needed is less than, say, 20 dB and in 99% less than 25 dB. These values may also have substantial error bars associated with them. Interpretation is then needed as to which level of probability to adopt.

4.8 There is a further problem due to use of adjacent channels. For many devices, including most DTT receivers, a strong signal on a channel adjacent to the one to which they are tuned can also cause harmful interference. Hence, a cognitive device that has discovered an empty channel may need to check the adjacent channels (termed the “n±1” channels) and modify its transmissions if it discovers that these channels are in use. Indeed, for some receivers, it may be necessary to scan more widely, perhaps including n±2, n±3 etc.

4.9 Detection is discussed in more detail in section 5.

Geolocation databases

4.10 An alternative to sensing is for a cognitive device to know its location and to have available a database of which frequencies it is allowed to use at which location. This overcomes most of the problems associated with sensing but leads to other issues such as:

- How will the device know its location?
- Who will maintain the database? Will there be one provider for all bands or a separate database per band? What will the commercial arrangements be? Will there be competition concerns?
- What availability is needed for the database? Is it acceptable for it to be offline for substantial periods?
- How will devices download updated versions of the database? How frequently should they do so? What will the loading on the spectrum be as a result?

4.11 Geolocation databases are discussed in more detail in section 6.

Beacon reception

4.12 This approach requires the transmission from some appropriate infrastructure of a signal providing information on which frequencies are available for cognitive use in the vicinity. Cognitive devices tune to this channel and then use the information provided to select their preferred frequency. They may still need to sense whether these frequencies are in use by other cognitive devices, but this is far less onerous since there is often a lesser need to ensure that cognitive devices do not interfere with each other. If the cognitive device is unable to find a beacon it is safest for it not to transmit, since it may be within the area covered by the beacon but shielded from receiving it. If it were to transmit on a randomly selected channel it could cause harmful interference.

4.13 While this resolves the sensing problem at the cognitive device it raises many other problems:

- Who provides the beacon signal? What are the commercial arrangements and if there is only one provider are there competition concerns?

- How is the beacon information kept up to date, especially where licensed services are changing rapidly?
- What spectrum is used for the beacon?
- What technical parameters and protocols are used by the beacon transmitter?
- How can reception of the beacon signal be prevented outside of its intended coverage area, where it will be incorrect?
- Should there be separate beacons for separate frequency bands or one beacon for all the bands to which cognitive access is allowed?
- Is it acceptable for use of cognitive devices to be denied access to the spectrum if the beacon fails or is taken off-air for any reason?

4.14 Beacon reception is discussed in more detail in section 7.

Transmission parameters

4.15 Once a cognitive device has determined that it can use spectrum, there must be some restrictions on its transmissions. The most important of these parameters is the power level. As the power a cognitive device is allowed to transmit increases, so the range of its transmissions will grow. This means it has the potential to interfere with receivers further away. The further away the receiver, the greater the potential for the hidden-terminal issue to occur due to the increasing differences in the geometry of the signal reception that are possible. Another way to look at this would be that measurements of the additional margin needed would generally exhibit a higher probability of a larger margin as the range increases.

4.16 However, as discussed above, the additional margin can only be estimated, and understanding how it changes with transmit power adds a further variable in that the additional range achieved by a higher-power cognitive device is itself highly variable according to local topography. Hence, any correlation between cognitive transmit power and the additional margin can only be approximate.

4.17 Another restriction on power levels is the ability of existing devices such as DTT receivers to reject signals in adjacent or near-adjacent channels. If a cognitive device detected a free channel and transmitted in this channel, an existing device tuned to a nearby channel might not be able to adequately filter out the cognitive transmission, resulting in harmful interference. As shown later, this is likely to be a more significant limit on transmit power than consideration of the additional margin.

4.18 In any case, it seems sensible to require the cognitive device to use transmit-power control (TPC) such that if it requires less power at a particular moment because the device it is communicating with is nearby, it reduces its power level to the minimum needed for successful communication. TPC is widely adopted in many wireless devices and has the additional benefit of increasing battery life. The effect of TPC is difficult to quantify because it is unclear how often devices will operate below full power, but it can only reduce the interference caused to other devices.

Section 5

Detection

Introduction

5.1 The concept of detection as a mechanism for determining free channels was introduced in section 4. This section considers the device parameters needed to ensure that a cognitive device that relied on detection or sensing (these two terms are used interchangeably in this document) alone did not cause harmful interference to licensed spectrum users. It deals separately with the technical issues associated with protecting DTT, PMSE (specifically wireless microphones) and mobile television which are considered to be the most likely licensed uses of the interleaved spectrum. At present we do not believe other uses of the interleaved spectrum, such as wireless broadband, are sufficiently likely to merit specific protection from cognitive devices but if this were to change we would consider modifying our parameters as appropriate.

Protecting DTT

Introduction

5.2 Based on the discussion in earlier sections, for DTT we need to determine the sensitivity, the additional margin, the adjacent channel performance and then set the power levels accordingly. Note that all figures for the cognitive device assume a 0 dBi antenna.

Sensitivity

5.3 We commissioned a range of measurements of available DTT receivers. These have been performed on our behalf by ERA. One such study analysed the potential for harmful interference to 15 digital set-top boxes commonly available on the UK market.[12] ERA's measurements indicated that -84 dBm is the threshold of DTT visibility (i.e. the minimum useable signal level before the observed picture starts to degrade). This value is consistent with the figure suggested by the White Spaces Coalition in the US and by other studies.[13]

5.4 We have also looked in detail at the expected post-DSO signal levels for viewers around the UK. DTT networks are planned for viewers to receive a minimum signal level of approximately -70 dBm. In the cognitive consultation we set out an assessment, based on detailed modelling work, that typically around 99.8% of those within coverage areas will receive a signal above -70 dBm and 99.9% above -72 dBm. Subsequently, we have discovered two discrepancies with the conversion we performed from field strength to signal level. The first was an inconsistent use of feeder loss – we used 3 dB here but 5 dB in subsequent analysis. The second was the selection of the frequency at which to perform the conversion. We used a frequency near the bottom of UHF Band IV, but if a frequency at the top of UHF Band V were used this would subtract up to 4 dB from the signal level. The result of this is that in the worst case where the cognitive device is operating at the top of UHF Band

[12] www.ofcom.org.uk/research/technology/ctc/era05-07/2007-0631.pdf.
[13] See, for example, Technical Parameters and Planning Algorithms, JPP/MB/1, Joint Frequency Planning Project, July 2003.

V, the signal level is 6 dB lower than we originally presented, while in the best case it is some 2 dB lower.

5.5 As a result, we have revised our assessment of this worst case. Figure 4 shows the range of signal levels experienced averaged across three representative channels (channels 23, 43 and 54). Figure 5 shows a small section of figure 4 focusing on the low signal levels.

Figure 4. Distribution of received signal strength across channels 23, 43 and 54

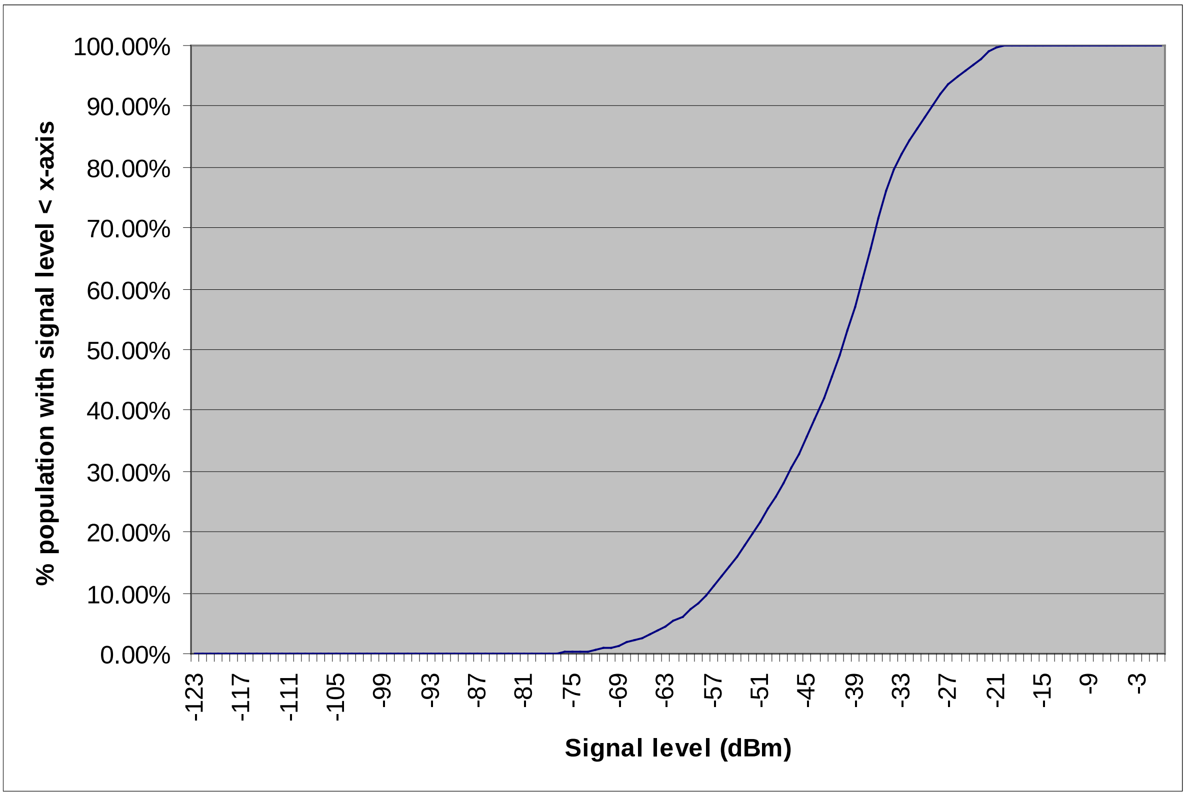
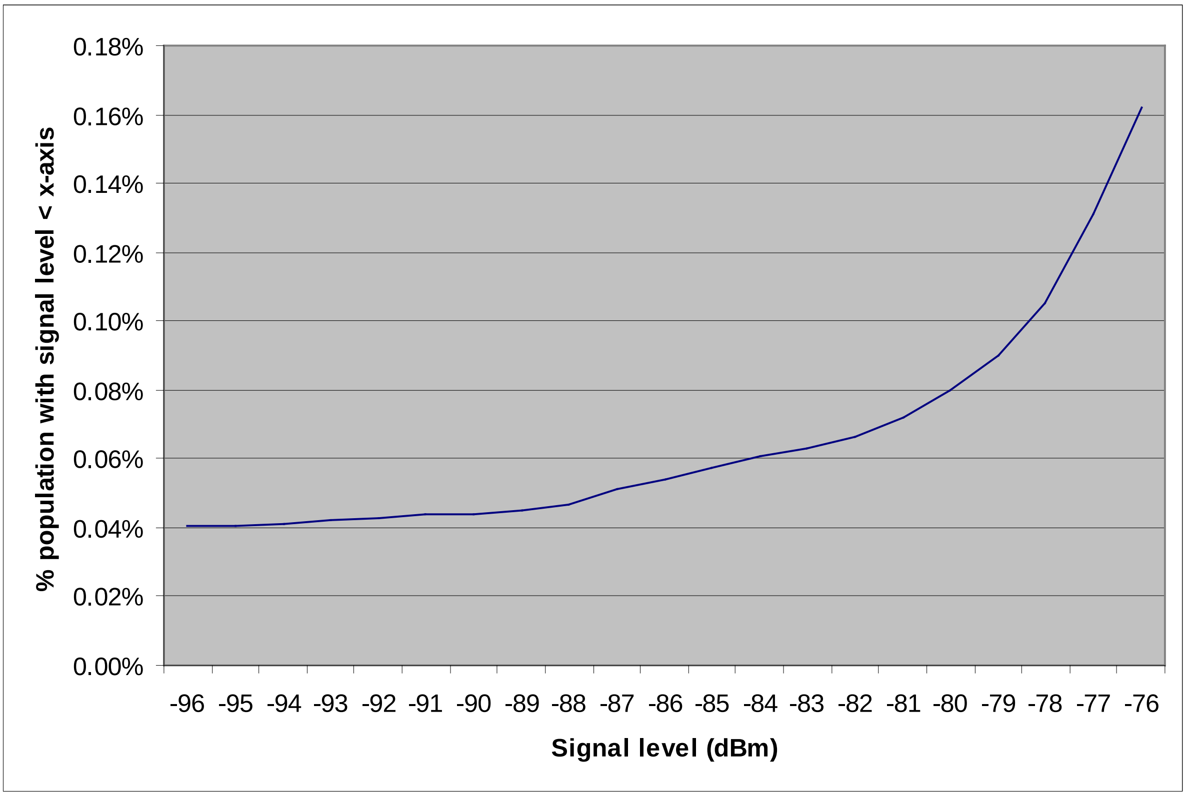


Figure 5. Detailed view of part of figure 4



5.6 From figure 5 it can be seen that only 0.1% of the population receive a DTT signal below -78 dBm. These levels are reasonably consistent across rural, suburban and urban areas, with less than a 2 dB variation between them.

5.7 So, although DTT receivers are capable of receiving signals to a level as low as -84 dBm, less than 0.1% of households who are considered to be in an area covered by DTT will actually experience a level below -78 dBm. We think it appropriate to protect DTT down to -78 dBm. Note that this does not mean that the remaining 0.1% will experience harmful interference, but that there will be some low probability that they might, which we discuss further below.

5.8 In responding to the consultation, many agreed that this level we had proposed of -72 dBm was appropriate, or even too low (i.e. too conservative). However, broadcasters were concerned that it was too high (i.e. not conservative enough). Some noted we had not taken into account commercial multiplexes that often transmitted on lower powers. Others suggested as a matter of principle that DTT receivers should be protected to their minimum sensitivity level (around -82 to -84 dBm) or that a 9 dB fade margin should be allowed. Digital UK suggested as a result that a level of -80 dBm was more appropriate while Qualcomm recommended -77 dBm. Our revised level of -78 dBm aligns reasonably well with most of these suggestions. While an even lower level, such as -84 dBm, would afford greater protection to DTT reception outside of the protected service area it would also further inhibit cognitive access. On balance we do not believe this is necessary or appropriate.

5.9 Hence, we conclude that -78 dBm is the sensitivity level for DTT. This is 6 dB lower (more conservative) than the level we set out in the cognitive consultation.

Additional margin

5.10 It is possible to consider a very wide range of different scenarios for the position of the cognitive device and the DTT receiver, each of which could have differing requirements for an additional margin. It is not practical to consider every possible situation that might arise, but here we examine a range of situations that we consider to represent likely worst cases. By this we mean situations that might happen with reasonable frequency and appear to us to be likely to lead to worst-case interference probabilities. We exclude situations that we consider to be highly unlikely on the basis that including these would likely result in excessively cautious margins, unduly reducing the value that could be derived from cognitive access.

5.11 The scenarios can be divided into the two discrete cases of external antennas (typically rooftop mounted) and internal aerials (typically mounted on top of the television set). Protection of internal/set-top aerial reception is not conferred under our current interference policy or any decisions we have made in relation to DSO, but given their widespread use – approximately 5% of households use them for reception on their primary television set and around 45% on additional sets – we believe it appropriate to provide some degree of protection for them in practice in this case.

External antennas

5.12 We consider the likely worst case to be that illustrated in figure 3, above. We asked a consulting company, ERA, to undertake both a measurement and modelling campaign to determine the additional margin needed. After extensive measurements and modelling activities they reported the margins shown in table 3 below.

Table 3. Summary of hidden node margins for different area types

Environment	Hidden node margin (dB) for % of locations		
	90%	95%	99%
Densely urban	18.5	22.4	29.2
Urban	28.1	30.2	32.5
Suburban	30.5	31.4	32.9
Rural	14.9	15.6	16.6

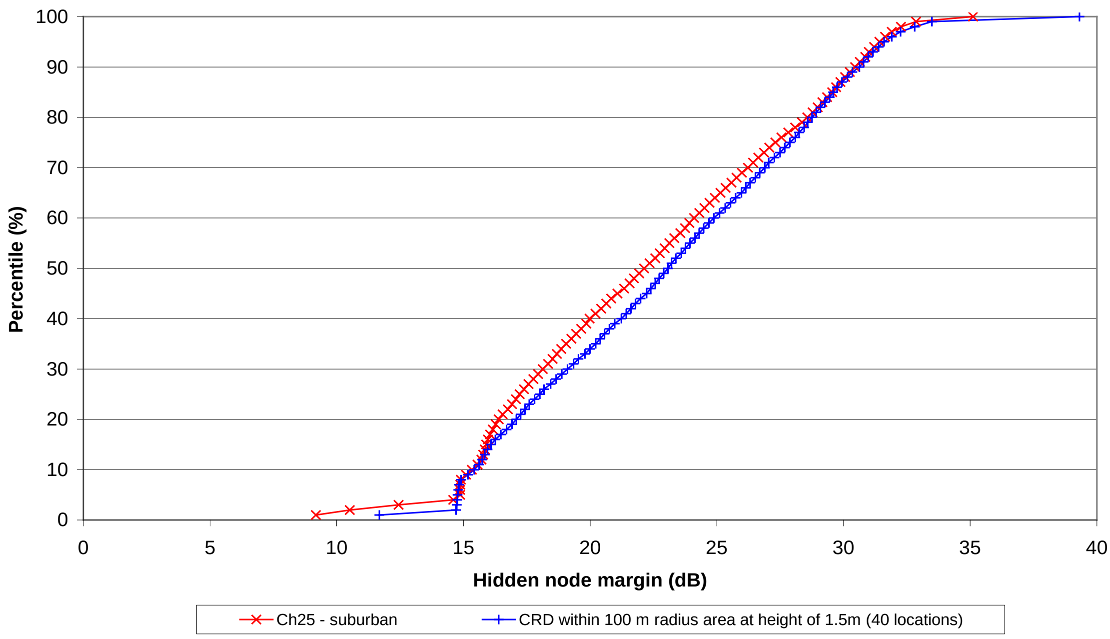
5.13 We consider it important to offer protection in all areas and so take the worst case, namely the suburban results. We note that the public-service broadcasting (PSB) multiplexes have an obligation to match current analogue coverage levels (98.5% of households), and this should not be changed by cognitive access. ERA's results show that the absolute worst-case margin covering virtually 100% of locations is around 35 dB. This also includes allowance for misalignment of antennas (where the cognitive device's antenna is oriented in a different plane from the polarisation of the DTT transmitter's antenna).

5.14 The responses to the cognitive consultation on this parameter were mixed. Some felt we were being too conservative and that the location where we had performed the measurements was likely to lead to greater margin values than would generally be experienced[14]. Others suggested that our measurements were insufficient because

[14] We had to conduct the measurements in locations with high received DTT signals at rooftop level in order that we could accurately detect the street level signals even when there was a 30-40 dB difference. In practice, this meant measuring in locations where there was often line-of-sight from a rooftop antenna to the TV mast. There is a plausible argument that this environment will maximise the difference between rooftop and street level signals because where line-of-sight is not available the

they had neglected to take into account the fact that a cognitive device could interfere with DTT reception up to a few hundred metres away and hence we should establish the difference between rooftop reception and street level reception not only in a given location but in locations where the rooftop location was 100 metres or more away from the street location. They conjectured that this would lead to a greater margin, or a higher probability of the higher margin levels occurring. We accept that our measurements did not assess this situation and as a result commissioned a further short study. The results of this are shown in figure 6 below where the red line represents the original distribution of the margin and the blue line the revised distribution when considering the difference not only between the cognitive device and the nearest house but the cognitive device and all homes within 100 metres[15].

Figure 6. Revised margin taking houses within 100 metres into account



5.15 The simulations show that at a percentile point of 99% the two measurements are almost identical – increasing from 32.9 dB to 33.5 dB. However, the 100% point increases by around 4 dB from 35 dB to 39 dB. As before we have combined these results with the distribution probability for signal strength to determine the overall likelihood of interference (for which there needs to be both a large margin and low received signal strength). We found that for the sensitivity levels we are proposing the revised margin distribution made no material change, increasing the probability of interference from 0.0451% to 0.0457%. We therefore conclude that taking the range of a cognitive device into account when calculating the margin does not make any material difference and does not require our margin figure or proposed sensitivity to be modified.

5.16 The BBC noted that if a cognitive device was in a loft in a terraced row of houses and a neighbour had their antenna in an adjacent loft then substantially more margin

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rooftop signal might undergo similar reflections and refractions to the street level signal and so have a more similar level (i.e. a smaller margin). Because of the limitations of measurement equipment we are unable to confirm this argument.

[15] It is quite possible that the signal from a cognitive device might extend further than 100 metres but we do not believe extending the distance used in this analysis would materially change these results.

would be required. We accept this analysis but think this situation sufficiently unlikely to merit full protection – few if any of the current scenarios for the use of cognitive devices would result in loft mounting of transmitters. The BBC also suggested that greater margins might be needed in some indoor situations although did not provide full analysis of what these might be.

5.17 Overall, then, we select a margin of 35 dB, assuming a 0 dBi antenna at the cognitive device[16]. A typical DTT antenna will have a gain of around 12 dB and cable losses of around 5 dB. Hence, we can calculate the level that a cognitive device needs to sense to as:

-78 dBm - 35 dB (margin) - 12 dB (antenna gain) + 5 dB (television feeder loss)

5.18 This implies that the cognitive device fitted with a 0 dBi antenna would need to sense to -120 dBm to ensure an acceptably low probability of harmful interference. This is 6dB lower than proposed in the cognitive consultation as a result of the modified DTT sensitivity level set out above. As discussed earlier, this results in a probability of harmful interference of 0.045%. That is, when a cognitive device decides to transmit, there is a 0.045% probability that it will cause harmful interference to a DTT receiver. In practice, its transmission will be intermittent and there may not be a DTT receiver in the vicinity that is turned on and tuned to a channel close to that selected by the cognitive device, so the probability of harmful interference will be lower than this.

5.19 We expect proponents of cognitive access will find our detection threshold of -120 dBm too low and will argue that it prevents the design of low-cost devices. Equally, we expect that some existing DTT providers will feel that we have not afforded them complete protection across all possible scenarios. Clearly, there is a balance to be struck which can be informed by evidence, such as the modelling activities reported here, but which will also rely on subjective judgement as to the relevance and likelihood of particular scenarios. In making our judgement, we believe we have generally been cautious, taking worst case numbers in many cases. We acknowledge that we have not accepted all arguments put forwards for even lower sensing levels as our judgement is that these scenarios are highly unlikely and even in these cases good protection will generally be afforded by having taken worst case numbers at most stages of the work.

Adjacent channel issues and transmit power

5.20 To understand how a device should behave with respect to adjacent-channel use in interleaved spectrum, we need to consider the geometry shown in figure 3. Here, a cognitive device transmits near a house receiving a DTT signal. Based on the adjacent-channel selectivity of the DTT receiver and the likely path loss between the cognitive device and the receiver, we can determine the maximum transmit power that can be allowed.

5.21 While there are many different variations of path loss, we consider a worst-case but likely situation is that the cognitive device is in the street outside the house, the antenna on the rooftop and the cognitive device in the main beam of the receiver antenna. In this case, the distance between the cognitive device and the antenna is typically at least 10 metres. This leads to a free-space path loss of approximately 50 dB assuming free-space propagation. We assume that the path is approximately 45° from horizontal. The gain of a typical omni-directional antenna at 45° elevation is

[16] One respondee informed us that a typical handheld device might have an antenna with gain of -7dBi. This would result in a need to sense to a signal power 7dB lower than that set out here.

around 4 dB less than the 0° gain, hence around -2 dBi, while that of a typical Yagi-type UHF antenna is around 10 dB lower than the 0° elevation, which is typically around 12 dB, hence around 2 dBi. In addition, we expect cable losses from the television aerial of around 5 dB. This leads to a total path loss in the region of 50 + 2 - 2 + 5 = 55 dB.

5.22 The worst case would be a DTT receiver operating at the margin of planned coverage, receiving -78 dBm wanted signal. ERA noted that, on an adjacent channel (n±1), most receivers needed a carrier-to-interference (C/I) ratio of around -30 to -40 dB depending on the technology generating the interference and factors such as the number of Quadrature Amplitude Modulation levels used in DTT transmission. Of these, the vast majority fell below -30 dB. Taking 30 dB as appropriately cautious, the adjacent-channel signal should not exceed -78 + 30 = -48 dBm. Hence, the maximum transmitted signal level would be around -48 + 55 = 7 dBm EIRP (5mW). Note that this is 6dB lower than we proposed in the cognitive consultation as a result of the reduced DTT sensitivity level.

5.23 In the n±2 and subsequent adjacent channels, DTT receivers have much better filtering. The same measurements showed that they have a rejection figure on average 13-16 dB better in these channels than in the n±1 channel. This allows around 20 dBm (100 mW) if not operating in immediately-adjacent channels.

5.24 There was a mixed response to these proposals. Some noted correctly they need not apply to geolocation (see later). Others suggested they were overly cautious and that 100 mW could be used on the adjacent channel. Some suggested that the minimum path loss of 50 dB we had assumed was insufficiently low and that 46 dB should be used reducing power levels by 4 dB. The BBC again noted the loft-installation case and suggested powers below 0 dBm would be needed to account for this.

5.25 In addition to these comments we have noted our previous assumptions treated in-band and out-of-band interference to DTT detection separately. In practice, the DTT receiver will see both of these modes of interference simultaneously. We therefore conclude that we need to reduce the powers calculated separately by 3 dB such that when the effects of both modes of interference are combined they are no worse than a single mode of interference. Hence, we further reduce the transmit powers to 4 dBm EIRP in adjacent channels and 17 dBm EIRP in non-adjacent channels.

5.26 Because of the changes we have made to DTT sensitivity and combined effects we have actually reduced adjacent channel power levels by 9 dB from our original proposal. As with the discussion earlier we need to exercise judgement when faced with arguments as to why power levels should be reduced still further and assess whether these would be overly cautious or relate to scenarios that are very unlikely. For example, we accept that path loss levels of less than 50 dB can occur in some situations but judge these situations to be relatively rare. In almost all cases path losses will actually be well above 50 dB particularly when taking into account factors such as the likely misalignment of antenna polarisation, body losses of the person using the cognitive device and so on.

5.27 We note that there is ongoing work in CEPT groups SE42 and SE43 which is relevant to the transmission parameters and discuss this further in section 10.

Improved receiver parameters

5.28 Some of the transmit restrictions on cognitive devices come about because of the receiver performance of DTT equipment. If receiver specifications were improved to have greater adjacent channel selectivity then the need to use reduced power levels in adjacent channels could be removed. We asked whether there was anything we could do to improve this. Respondees suggested that it was inappropriate to assume that standards would improve over time but that it would be appropriate for us to work with standards bodies to ensure future specifications took full account of the likely use of the spectrum. One respondee suggested that we could instigate a quality mark on equipment similar to the energy efficiency markings used on white goods. While an interesting idea this is beyond our remit.

5.29 We therefore conclude that we cannot assume that receiver specifications will improve over time but that we should work with standards bodies in future such that we can input into the specification process.

Protecting wireless microphones

Sensitivity

5.30 In the same piece of work reported above, ERA also measured the sensitivity of a range of wireless microphones and concluded that the average sensitivity was -91.5 dBm[17] at the input of wireless microphone receiver. However, when making measurements in a range of venues they noted that the receivers were typically operated at signal levels above -67 dBm in order to ensure a high quality link.

5.31 Respondees to the consultation agreed that microphones were generally operated at these levels but some suggested that they could be operated at lower levels and that signal levels as low as -95 dBm should be used in our calculations. However, all respondees except the BBC, felt that the overall conclusions we came to when taking into account the additional margin (see below) were adequate to offer protection to wireless microphones and hence we have not changed this reference level.

Additional margin

5.32 The additional margin geometry for a wireless microphone is quite different from that for DTT. For wireless microphones the worst case would likely be a cognitive device immediately outside of a theatre.

5.33 As with the DTT case, ERA conducted some very detailed measurement and modeling work across a range of venues including a TV production studio, a concert arena and a West End theatre. This involved 3D modeling of the venue and computer prediction of signal levels via ray-tracing, coupled with measurements to validate a subset of the modeled results. This work suggested that in all cases considered the margin would be below 39 dB.

5.34 However, in addition to this margin there is a possibility of “body loss” caused when a person wearing a wireless microphone is oriented such that their body is between the transmitter and the cognitive device. This factor was not taken into account in the modeling work and needs to be added to the margin. Measurements made in a controlled anechoic chamber suggest that the worst case body loss is in the region of 20 dB. As a result, the total margin becomes 59 dB.

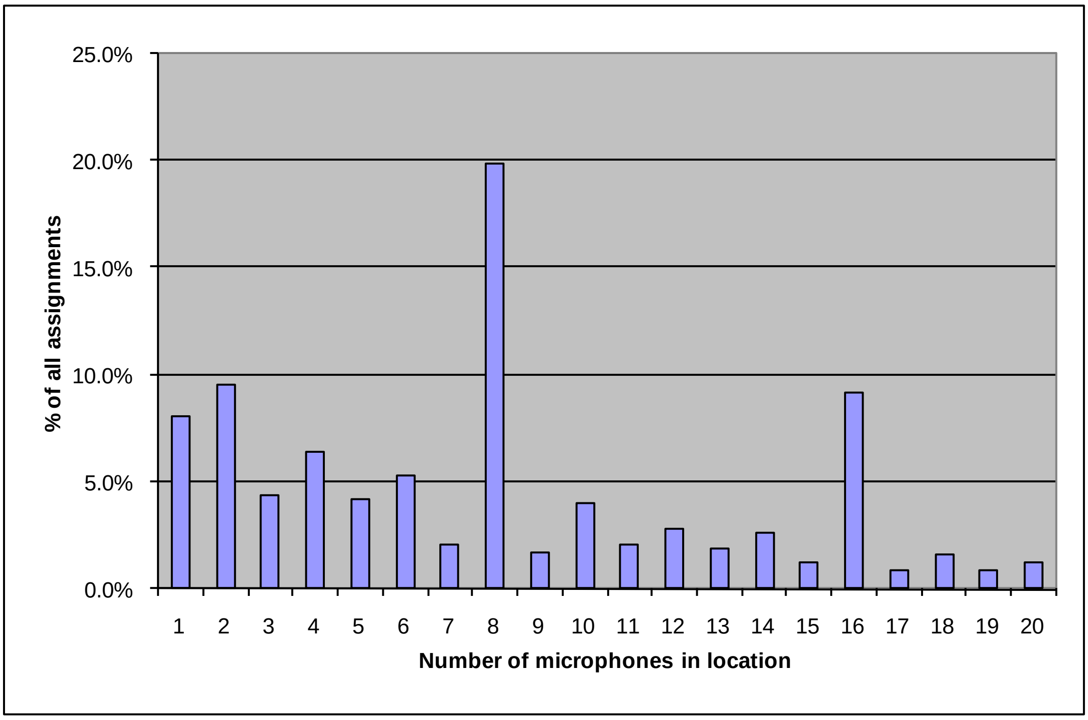
5.35 Some respondees felt this was much too conservative and that, for example, reflections within the theatre would ensure that maximum body loss never occurred. They also suggested that multiple wireless microphones typically operate within an 8

[17] For wireless microphones all power levels are quoted for 200 kHz channels.

MHz channel and the chances of all microphones being in the worst case simultaneously was very low. This would enable a much lower margin to be used. Others felt that the combination of the sensitivity and the margin led to a result that was about right albeit that the sensitivity might be too high and the margin too large.

5.36 The band manager for the PMSE industry, JFMG, provided us some approximate data on the number of microphones typically operating in a channel, shown in figure 7 below.

Figure 7. Number of wireless microphones in any given location[18]



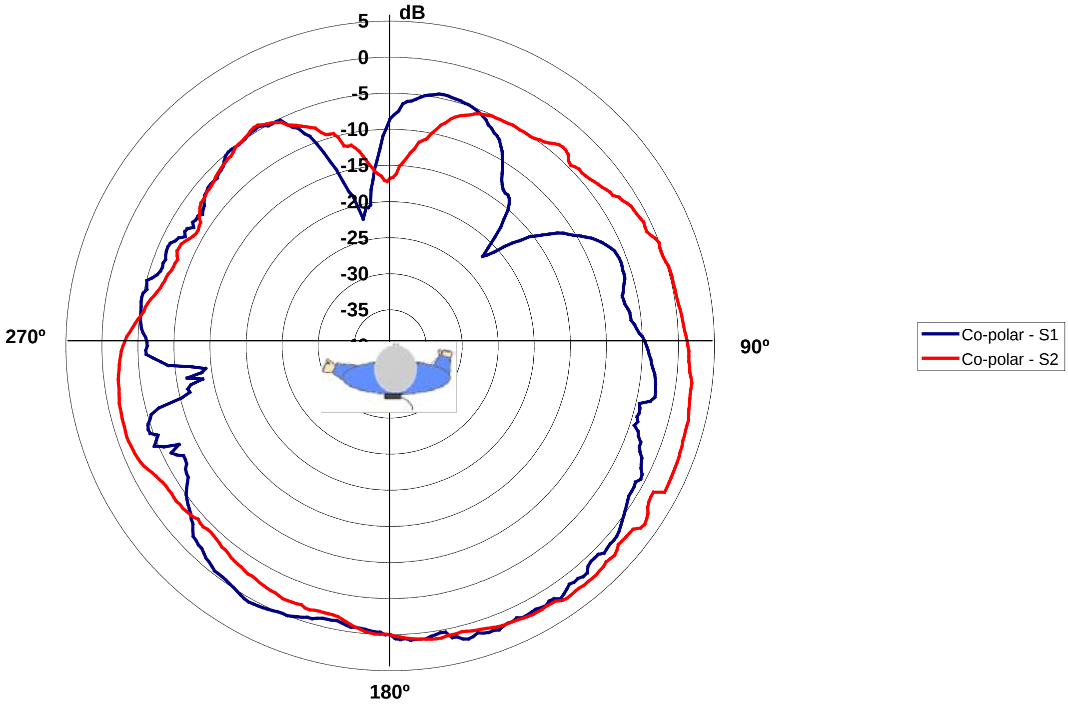
Source: JFMG

5.37 This data is rather approximate since numbers are not always recorded accurately but suggests that around 8% of assignments are for a single microphone, with many having 4 or more. Hence, there is a high chance that a cognitive device would be able to detect one or more microphones, even if others were shadowed to the worst possible extent. However, to rely on this might result in interference in 8% of cases which would be very problematic for licence holders so we do not propose to alter our sensing levels as a result, merely to note that in more than 90% of cases the presence of multiple microphones provides further margin of safety.

5.38 In order to investigate the body loss further we commissioned some measurements of body loss as a person wearing a microphone was rotated on a platform in some representative venues. An example of the results obtained is shown in figure 8 below.

[18] Note this chart is truncated so that assignments with more than 20 microphones are not shown and is only indicative.

Figure 8. Typical body loss plot made in a West End Theatre



5.39 This plot suggests that a difference between the signal received when the body is not blocking the transmission path (at 180^{o}) to that when the greatest blocking occurs (at around 350^{o}) can be 20dB or more even in a theatre. Hence, we believe the choice of 20dB body margin remains appropriate.

5.40 Using these figures results in a sensing level of -67 - 59 = -126 dBm, 6 dB lower than for DTT. However, wireless microphone signals operate within a bandwidth of 200 kHz while DTT signals have a bandwidth of 8MHz. The narrower bandwidth reduces the noise detected by 16 dB. Hence, although the level is lower, the detection task may be less onerous for the device than DTT detection.

5.41 Proponents of cognitive devices generally felt this level was too low (ie too conservative) for reasons set out above. However, the PMSE community generally agreed with this level subject to a number of additional constraints and assurances. These included high levels of care in the testing and type approval process. They also suggested that sensing from both cognitive devices making either end of a communications link be required. This would prevent master-slave operation (see later). No quantitative reasoning was provided as to why such dual-sensing was needed although it would tend to result in a lower risk of interference. For reasons discussed later we are not proposing master-slave operation when detection only is used and hence conclude that dual-sensing would occur as a result of normal cognitive operation.

5.42 Only the BBC sought a greater level of protection with a sensitivity of -136dBm to accommodate certain outdoor sporting events. We believe that while wireless microphones might be operated at lower signal levels at these events (the BBC suggested 10dB lower at -77dBm) in general the margin needed will also be lower due to the reduced blocking in the area and hence that there is no need to reduce the detection level further.

5.43 Given the responses and further analysis we have concluded that a level of -126dBm (in a 200kHz channel) is appropriate for wireless microphone detection.

Protecting mobile television

5.44 Most respondees concluded that there was very little chance that mobile TV would be deployed within the interleaved spectrum and hence that it would be inappropriate to offer protection. Further, many noted that if a geolocation approach were adopted it would be possible to modify device parameters were mobile TV or other similar services to subsequently be deployed. We agree with this and as a result are not setting cognitive parameters to specifically offer protection to mobile TV.

Cooperative detection

5.45 A further possibility currently being considered at a research level is for multiple cognitive devices to share information on signal detection. This would improve the probability of detection since if one device were in a shadow of the wanted signal it might receive a signal from another nearby device which was not shadowed warning that the frequency was in use. By this process, researchers suggest that a lower value for the additional margin could be adopted.

5.46 Respondees noted that as this remains a research topic it would be inappropriate to take it into account in setting specifications. Many were sceptical that it could ever be relied upon sufficiently that device specification could be modified as a result. We agree and so are not taking this into account in setting key cognitive parameters.

5.47 Some respondees did note that when two cognitive devices communicated there would be some cooperative detection taking place since both would generally sense the channel prior to selecting it. We have not taken this into account in our calculation which as a result will tend to be conservative. Indeed, in almost all cases, such dual-sensing will offer substantially greater protection to existing licence holders than we have assumed.

"Real world" device performance

5.48 We have above determined a set of sensitivity levels that cognitive devices must be able to achieve to ensure that harmful interference does not occur. This sensitivity needs to be achieved in "real-world" scenarios. In particular, the devices must be able to sense in the presence of strong signals in adjacent channels (or they must choose not to use channels where strong signals are present in adjacent channels). They must also be able to sense adequately in the presence of other cognitive devices using nearby channels.

5.49 Hence, as part of the specification and resulting type-approval verification, cognitive devices must be tested to ensure that they do not incorrectly declare a channel to be unused regardless of the level of signal in adjacent channels.

Implications for cognitive device design

5.50 With these levels for sensitivity and additional margin, cognitive devices will need to detect a transmission at very low levels, all in the presence of signals in adjacent channels and fluctuating signal levels. This is an extremely challenging task and will likely require the cognitive device to process repetitive elements of the signals in order to recover them from below the noise. Many respondees noted the extreme difficulties in designing consumer devices and suggested as a result that detection alone was unlikely to be used for many years, if ever. In reducing the sensitivity level for DTT by another 6 dB from the level in the cognitive consultation, we have made this even more challenging.

5.51 Given this assessment it does not currently seem appropriate to move ahead rapidly in developing licence-exemption regulations that are unlikely to be exploited. As discussed later, we will await further input on geolocation and then decide how to move ahead on detection.

Section 6

Geolocation databases

Introduction

6.1 As mentioned in section 4, an alternative to sensing is for a cognitive device to know its location and to consult a database of which frequencies it is allowed to use at that location. In this section we consider some of the issues associated with such an approach.

6.2 A geolocation-database approach might work well for avoiding DTT transmissions. Transmitter locations and transmission frequencies change relatively infrequently. Moreover, the location of transmitters is well known and the resulting coverage carefully predicted. It would be possible to provide an up-to-date UK-wide database showing which channels were in use for DTT in any given location.

6.3 With wireless-microphone use, the position is less clear. Some use is relatively static over long periods (e.g. in studios or theatres). These locations and the spectrum used could relatively easily be entered into a database. However, other use is shorter term, ranging from sporting events such as the British Formula 1 Grand Prix, which can be predicted, to electronic newsgathering (ENG), which is unpredictable and may see use occurring with an hour's notice or less. The latter application is likely to be most problematic for a database approach, requiring very frequent updates and devices to check the database frequently. Data from JFMG suggests that nearly 30% of all PMSE applications need to be fulfilled within less than 16 hours.

6.4 Many options could be considered. These include:

- The database approach could be adopted with short timescales for updating to accommodate ENG.
- In every location one or more available channels could be marked in the database as "in use", effectively reserving them for ENG applications.
- The database approach could be coupled with a requirement for sensing such that wireless microphone use (or indeed any other use) not registered in the database would generally be detected by a cognitive device and the channel avoided[19].

6.5 Most respondees favoured the idea of marking a small number of channels in each location as "in use" to offer protection to ENG and other applications that needed access more quickly than a 24 hour period. Few thought that requiring more rapid database access than this was practical. However, the PMSE community noted that some wireless devices might not be able to work over all channels and hence might not be able to use the channels that were "reserved" for them, or that even if they could the resulting lack of flexibility might be problematic in some situations. However, it was not clear whether this problem was associated more with larger events where typically there would be sufficient notice to populate the database 24 hours in advance. The PMSE respondees instead preferred the use of detection as well as geolocation to avoid microphones that were not registered in the database.

[19] This is the approach that the FCC advocated in 2008 for use in the US.

6.6 This is an area on which we do not yet have sufficient information and guidance to make a decision and intend to discuss further with stakeholders and, if appropriate, consult again in due course.

Determining location

6.7 Clearly, for this approach to work, a cognitive device will need to know its location. How it does so is not a matter of concern to us as regulator, although this will potentially add cost to the handset and may reduce battery life. Most proposals suggest the use of the Global Positioning System, although alternative approaches based on the reception of known transmissions (e.g. from Wi-Fi networks) could be adopted.

6.8 What is of regulatory concern is the accuracy of position information. If the cognitive device determines its position with substantial error, it may not be able to use spectrum available in the area in which it has concluded it is located. Equally, specifying too precise a requirement for position information could impose unnecessary cost or complexity on the terminal. Most respondees agreed with our suggestion for 100 metre accuracy. Some PMSE respondees suggested much less, in the region of 1-3 metres including indoors but did not make a clear case as to why this was needed.

6.9 One respondee suggested that locational accuracy did not need to be specified but that the locational database could respond according to the accuracy with which the device knew its location. We agree with this point in principle, but are concerned with overly complicating the database approach by requiring additional parameters such as locational accuracy to be provided. As a result we have concluded that 100 metre be the default accuracy and that devices which are using a lesser accuracy be required to indicate this to the database or process the database information accordingly.

Database ownership

6.10 For this approach to work there must be a single "master" database containing the spectrum that can be used in each location in the UK. Licensed spectrum users will need to provide information to the database about the spectrum that they are using in each location, and cognitive devices will need to access this information. There could be multiple copies of the master database located on "mirror" sites and maintained by different organisations, but they will need to ensure that their copies are accurate and up-to-date versions of the original.

6.11 Licensed users (e.g. DTT and PMSE, at least initially in the form of the band manager being created through the DDR) will need to take ownership of providing data concerning the spectrum that they are using in each location. For DTT, this information may be relatively static. For PMSE, it might need updating daily or even more frequently.

6.12 The actual ownership of the servers on which the database resides is less relevant. However, the owner of these servers will need to ensure that:

- The database is updated rapidly upon the provision of information from licence holders, perhaps within 1 hour.
- The database is available for most of the time. We would suggest a minimum of 99.99% availability.

- Database enquiries and downloads use appropriate protocols. We suggest Internet-based protocols and standard enquiry languages.

6.13 Respondees agreed with this analysis but suggested that the regulator should intervene to the minimum level possible and leave many of these details to industry unless there was evidence that they were not being addressed.

Use of the database for spectrum management purposes

6.14 The use of a database would appear to bring spectrum management benefits. For example, all cognitive devices could be deactivated by fully populating the database with "all channels in use in this location". Alternatively, individual channels could be "turned off" either UK-wide or in particular geographic areas.

6.15 We would not want to make use of such capabilities lightly because they would disadvantage existing users, manufacturers and possibly others. However, there might be good reasons for deploying them, for example, to enable the introduction of a new and significantly more valuable licensed service or alternatively in restricting usage in bands or geographies where harmful interference to licensed services had occurred. Respondees agreed with this approach, although they cautioned us against making changes without careful consideration.

Transmitter parameters

6.16 An intelligent database could return to the device not only the spectrum it could use but also the transmit powers that could be used in each channel. These powers could be calculated depending on how far away the spectrum was in licensed use and, if appropriate, how far away adjacent channels were also used. This might allow higher power levels than those suggested for the sensing approach.

Fixed base stations

6.17 Using a database could potentially allow for fixed base stations operating at relatively high power levels compared to those allowed using detection alone. If a channel was not in use for some distance from the location of the base station, the location database could return a relatively high allowed power level enabling base-station operation.

6.18 Because a base station would typically be at a higher height than a terminal, and hence its signal would propagate further, it might be that the database should return a different power level for base-station operation. Alternatively, the base station itself might be required to reduce the allowed power level as returned by the database according to its height. As a result, we do not see any need to treat fixed base stations differently from other cognitive users.

6.19 However, a fixed base station would still need to check the database regularly, and it might be that the spectrum it was using became unavailable on occasions, perhaps due to PMSE activity in the area. There could also be harmful interference from other cognitive devices or base stations in the area.

Probability of harmful interference

6.20 A geolocation-database approach has the potential to avoid harmful interference altogether assuming it is appropriately specified. As a result, it would appear to offer a higher level of protection to licensed users than detection, albeit at the cost of increased administrative effort.

Further work required

6.21 Enabling the database approach requires the database to be populated and devices to be able to interact with the database in a prescribed manner. In overview, we expect cognitive devices to send a request to the database which includes their current location and for the database to respond with details of channels that are available in the vicinity and associated power levels that are allowed. The devices might indicate the radius around them for which they require information – for example a small radius such as 100 metres would return only information about channels in that specific location whereas a larger radius such as 10 km would allow the device to download a portion of the database such that if it moved, or had poor locational accuracy, it would not need to re-consult the database.

6.22 Populating the database requires an analysis for every “pixel” in the UK as to what power levels could be used by a cognitive device on each channel such that it does not cause interference both on the channel itself and on adjacent channels. This analysis would need to be re-run each time an assignment changed, such as a new PMSE assignment, although with intelligent design the re-run could be restricted to only those areas affected and substantial elements pre-calculated and stored.

6.23 In order to perform this analysis the database will need to have details of all the licensed transmitters in the spectrum including information such as transmitter height, power levels and for PMSE information such as whether the devices are located indoors. It will then need to use agreed propagation algorithms coupled with mapping and terrain databases to perform the predictions. Further discussion and consultation is required in areas such as:

- What information should be provided by the licence holders?
- What propagation algorithms should be used?
- What parameters should be assumed for device sensitivity and selectivity?

6.24 The devices will need to use a pre-determined protocol to report their location and required radius of information to the database and to understand the response from the database. This may be better standardised by industry than the regulator.

6.25 We intend to discuss these issues with affected stakeholders and then consult on them.

Section 7

Beacon reception

7.1 Beacon reception requires the transmission from some appropriate infrastructure of a signal providing information about which spectrum is available for cognitive use in the vicinity. Cognitive devices tune to this beacon and then use the information provided to select their preferred frequency. They may still need to sense whether these frequencies are in use by other cognitive devices, but this is far less onerous since there is often a lesser need to ensure that cognitive devices do not interfere with each other. If the cognitive device is unable to find a beacon, it is safest for it not to transmit since it may be within the area covered by the beacon but shielded from receiving it. If it were to transmit on a random channel, it could cause harmful interference.

7.2 No respondee indicated a preference for the beacon approach and our assessment (see later) is that it is inferior to the other approaches. Hence, we do not discuss it further here.

Section 8

Comparing the different approaches

Introduction

8.1 This section considers the three different approaches to enable a cognitive device to determine spectrum in which it can transmit. From a regulatory viewpoint, the key parameters of interest are the potential to cause harmful interference and the efficiency of spectrum use. However, we also recognise that it will be important to select an approach that can be practically implemented at the lowest possible cost in order to maximise the benefits to citizens and consumers.

Potential for harmful interference

8.2 We have discussed the interference potential of each of the approaches in sections 5 through 7. In outline we concluded that:

- Detection might result in a very small risk of harmful interference due to the possibility that the cognitive device is shadowed from the signal that it is trying to detect. It is difficult to determine precisely what this probability is, although we have made some estimates based on propagation modelling and shown the inherent trade-off between sensing performance and probability of harmful interference.

- An approach based on geolocation databases is unlikely to result in harmful interference as long as the database is appropriately specified and maintained. The only areas of risk are where licensed users change location unexpectedly and there is possible harmful interference until the database is updated.

- An approach based on beacons has some possibility for harmful interference if the beacon is detected outside the area for which it is intended. The probability of this occurring can be reduced but at the expense of preventing cognitive access altogether in certain areas.

8.3 Hence, an approach based on geolocation databases appears to offer the lowest potential for harmful interference.

Efficiency of spectrum use

8.4 By efficiency of use, we mean the ability of cognitive devices to use as much unused spectrum as possible in any given location. Considering each of the approaches:

- Detection would generally be able to make efficient use of the spectrum as long as the devices did not generate “false positives” (i.e. conclude that spectrum was used when it was not). This might occur if they detected noise or spurious emissions within the spectrum and could not distinguish this from an intentional signal. As the sensing level is reduced to reduce the potential for harmful interference, the likelihood of false positives increases. However, advances in technology or novel approaches to detection might improve this over time.

- An approach based on geolocation databases is likely to make efficient use of the spectrum. Since the cognitive device is accurately informed of all available spectrum, there should be no inefficient operation.

- An approach based on beacons may be inefficient for various reasons. If the cell size of the beacon is larger than the area of licensed use, cognitive access will be sterilised unnecessarily. As described above, reducing the probability of harmful interference is also likely to result in inefficient use of spectrum.

8.5 Hence, an approach based on geolocation databases would appear to offer the most efficient use of the spectrum and does not require any trade-off between harmful interference and efficiency, unlike the other two approaches.

Practicality

8.6 It is generally more appropriate for stakeholders to provide insight on the practicality of different approaches as they will have more information available to them than we do. Our initial assessment is that:

- Detection requires neither standardisation nor any coordinated activity (e.g. to build a database). No funding is needed to establish databases or beacons. Hence, this approach could likely be implemented most quickly. However, sensing reliably at the levels we have determined has so far proved to be difficult, and it is not yet clear whether it can be practically achieved in consumer devices.

- The geolocation-database approach does require coordinated activity to build and maintain the database, to specify its parameters and to ensure appropriate availability. It also requires cognitive devices to be able to determine their position and communicate with the database regularly, perhaps via alternative wireless mechanisms. All of this can be achieved with current technology but will add cost to cognitive devices and both cost and administrative burdens to licensed users.

- Beacons require substantial activity to build and maintain a network. Access to spectrum must be achieved and standards developed, likely on an international basis. It is unclear how a network of beacons would be funded or who would build and maintain them. It seems likely that it would take many years to design and deploy such a network.

8.7 Hence, detection is likely to be the most practical approach to implement, providing compliant devices can be economically developed, while beacons could be expensive and time-consuming to deploy.

Conclusions

8.8 Of the three approaches considered, we conclude that beacons are unlikely to be deployed in the medium term and do not have any compelling advantages over the other two approaches. Hence, we do not see the need to proceed with the regulatory activity necessary to enable them at present.

8.9 We see advantages and disadvantages to both detection and geolocation databases. From a spectrum-management viewpoint, geolocation databases appear to bring some advantages in terms of reducing the probability of harmful interference while enabling efficient use of spectrum, but we fully recognise the practical difficulties associated with this approach. Hence, at this point, our inclination is to enable both detection and geolocation databases and allow stakeholders to determine which approach they prefer. Indeed, both approaches could even be amalgamated.

8.10 Some respondees agreed to this while others felt that geolocation was essential or that both approaches needed to be used together. Many noted that in any case, detection alone was very difficult to implement and unlikely to be used for the foreseeable future. In particular, the PMSE respondees felt that the geolocation database was unlikely to be updated sufficiently rapidly for all use and that detection was needed as well to accommodate these cases. One respondee felt geolocation should be mandated as it was the only way that spectrum could be cleared of cognitive devices should this become necessary. Some of the stakeholders were concerned that detection resulted in too high a risk of harmful interference and therefore should not be used alone.

8.11 We conclude from this that the most important mechanism in the short to medium term will be geolocation. We will investigate further the speed at which the database can be updated and hence whether detection will also be required in addition to geolocation. Given the current problems in implementing detection we would prefer not to require detection to be used alongside geolocation unless there is a strong need for this.

8.12 We are not convinced by the arguments that suggest that detection alone cannot offer adequate protection. This would only be the case if the detection levels we have determined were incorrect. As discussed earlier, with modifications to the parameters that we proposed (the additional 6 dB) adequate protection will be achieved in all situations that are likely to occur. Hence, we will allow detection alone as well as geolocation. However, we note that implementation of detection-only devices is likely many years away and hence there is little advantage in rapidly making the necessary regulations to exempt such devices while there may be advantages in awaiting international developments to align where appropriate.

Section 9

Other important parameters

Introduction

9.1 In addition to sensitivity and transmit power there are other parameters that need to be set appropriately. These include bandwidth, time between sensing, out-of-band performance and politeness of use. Each of these is considered separately below.

Spectrum available

9.2 Given our decision to clear the 800 MHz band, the available interleaved spectrum will be at 470-550 MHz and 614-790 MHz. There might be some merit in excluding cognitive access at the edge of these bands to provide additional protection to licensed services operating in the adjacent spectrum.

9.3 Most respondees noted that any band edge restrictions necessary would only become apparent after the cleared spectrum had been awarded and the use of the spectrum became clear. This could then be accommodated via a change to the geolocation database in the case that geolocation was being used. Proponents generally concluded that no further restrictions were necessary. PMSE respondees requested that sufficient protection be provided to channel 38 and one cellular respondee suggested that channel 60 be avoided.

9.4 We agree that the geolocation approach can be used to avoid any band-edge problems and this is a further reason to prefer this approach. In the case that detection alone is used we conclude that channels adjacent to the band edge (channels 30, 39 and 60) should not be used by cognitive devices as a precaution, at least until the usage of the cleared spectrum becomes apparent.

Bandwidth

9.5 We see no need to place any particular restrictions on device bandwidth other than that the emissions must fit within the spectrum identified above (a maximum of 176 MHz). While there is a default bandwidth of 8 MHz in use by DTT transmissions in the interleaved spectrum, there seems no reason why a cognitive device should not transmit across more than one channel as long as it correctly measures all the channels used and any appropriate adjacent channels as empty. Equally, there is no reason why devices should not transmit with a bandwidth less than 8 MHz.

9.6 Most respondees agreed with this. Some expressed concern that there should be a minimum bandwidth. One respondee felt that without this there could be multiple cognitive interferers on a single PMSE or DTT channel and the combined effect of their interference problematic. We do not agree with this. Our experience, for example when analysing the effect of multiple interferers for ultra-wideband (UWB) usage, shows that the nearest interferer dominates to the extent that other interferers make little difference. Other respondees felt that a minimum bandwidth somewhat greater than the 200 kHz used by wireless microphones was needed so that cognitive devices could distinguish wireless microphones from other cognitive devices. However, they did not explain why they felt this ability to distinguish sources of signal important.

9.7 Overall, we conclude that there need be no restriction on bandwidth.

Time between checking for channel usage (where sensing is used)

9.8 Cognitive devices which use sensing to determine whether a channel is available should periodically check to detect whether, perhaps as a result of their movement or a change in the licensed use, the channel they previously identified as usable is no longer available to them. The time between checking is a trade off – too long and they could move into a materially different situation before changing channel, too short and they could spend so much time checking that there is little opportunity for them to transmit.

9.9 We envisage that cognitive devices will be relatively slow-moving or stationary. This is because the low power levels we are proposing will likely only allow a range of a few hundred metres. A fast-moving device would move out of communications range with another device too quickly to be able to handover or perform useful data transfer.

9.10 We expect DTT signals to be relatively static. The transmitters will not rapidly turn on or off nor change their transmit powers. The received signal level at a cognitive device will not fluctuate substantively under most usage scenarios.

9.11 Wireless microphone signals are less likely to be static over a period of minutes. Microphones can be switched on and off in a venue as an actor enters or leaves the stage and the signal level at a cognitive device could fluctuate, for example, as the device was moved along a street adjacent to a theatre.

9.12 One case might be a device moving at a slow walking pace past a theatre. Simple modelling suggests that the signal strength will vary by 10 dB in about 100m distance when directly approaching the theatre. At 2m/s this would take around 50s. However, a more demanding case would be when an actor turned on their microphone and then moved onto the stage. This might happen in just a few seconds resulting in a channel suddenly coming into licensed use.

9.13 Hence, it seems appropriate that the rescan time on the channel that the cognitive device is using should be of the order of a second or two. We proposed 1 second in order to be conservative. Most respondees agreed with this. Some felt it to be too conservative because wireless microphones would typically remain on even when an actor was off stage but supplied no evidence to show that this was generally the case. Most noted that it was not relevant when geolocation was used. As a result we have decided to leave this parameter at 1 second.

Out-of-band performance

9.14 We can understand the required out-of-band performance using the same argument as for adjacent channel performance. From the ERA report we have that a DTT receiver needs about 20 dB C/I ratio co-channel. Hence, for a DTT receiver on the edge of coverage, any in-band signals need to be below -98 dBm if they are not to degrade performance. With a 55 dB path loss the maximum transmitted signal would be -98 + 55 = -43 dBm. (For example, with a 20 dBm transmitter power this corresponds to a filtering requirement of 63 dB.) As mentioned earlier we then need to reduce this figure by 3dB in order to account for both in-band and out-of-band interference occurring together. This lowers the level to -46dBm. Note that this result differs from that set out in the cognitive consultation as a result of the changes to receiver signal levels discussed earlier and taking into account both in-band and out-of-band interference combined.

9.15 For a wireless microphone operating at 67 dBm there is a requirement for 25 dB C/I. This means any interfering signal must be below -67 - 25 = -92 dBm. With a 32 dB minimum path loss this results in a transmitter level of -60 dBm in a 200 kHz bandwidth and taking a further 3dB into account to allow for combined in-band and out of band effects this falls to -63 dBm. This is equivalent to -47 dBm in an 8MHz bandwidth. Hence, this is very similar to the levels for DTT.

9.16 Respondees provided a mixed response. Some felt that the level we initially proposed was too conservative as a result of overly short separation distances assumed for PMSE. However, with the change to DTT levels relaxing the PMSE result would now only change the level by 1dB. Others suggested that wireless microphones should be protected to -95dBm resulting in substantially lower signal levels. However, this would likely make cognitive devices very difficult to manufacture and we do not believe that the risk of both a microphone receiver operating at its lower limit and a cognitive device being at the shortest possible separation distance simultaneously is such that this reduced level would be merited. The BBC argued that the loft-deployment case for DTT would require -58dBm in an 8 MHz bandwidth, but as stated earlier we believe this case to be unlikely. Given the arguments on both sides of the limit and the lack of additional evidence we conclude our proposed level of -46dBm is the best way ahead.

9.17 We note that there is ongoing work in CEPT groups SE42 and SE43 which is relevant to the transmission parameters and discuss this further in Section 10.

Politeness

9.18 As we set out in our statement on the Licence-Exemption Framework Review (LEFR), published on 4 December 2007,[20] licence-exempt devices should behave in a polite manner. By this we mean that the available resource should be shared fairly between all those attempting to use it.

9.19 In the case of cognitive access there will inherently be an element of fairness in that when a cognitive device scans spectrum to see whether it is in use, it will automatically detect another nearby cognitive device already using that spectrum and so refrain from using it itself. By this means, we expect that one device will not force another out of spectrum that it is already using.

9.20 However, this raises the possibility of a device acquiring spectrum that is free and then staying in that spectrum for a prolonged period, preventing others having an opportunity to access it. This would be unfair. In the cognitive consultation we set out one mechanism to prevent this: requiring cognitive devices to cease transmitting periodically. However, respondees generally felt this was too prescriptive and that politeness should be left to the industry to resolve. We accept these arguments and no longer suggest any parameters required to ensure polite usage. However, we do expect standards bodies and device manufacturers to develop their technologies such that they will operate in a “polite” manner.

Making use of sensing or location in other devices

9.21 If a cognitive device (termed the “slave”) communicates with another nearby cognitive device (termed the “master”) that has already established that the spectrum is free using sensing or location, it might not be necessary for the slave to also establish that the spectrum is free. It could simply make use of the searching

[20] www.ofcom.org.uk/consult/condocs/lefr/lefr_statement/lefr_statement.pdf.

performed by the master. This could allow much simpler cognitive devices working in, say, a home environment where the home hub had undertaken the necessary spectrum checks. Alternatively, it could allow simpler devices communicating with base stations.

9.22 However, there is a risk of harmful interference if the slave is some distance from the master and possibly in a location where the spectrum is in licensed use. This risk clearly increases with the range of the slave. For the home application, there would appear to be little risk, whereas for the base-station application, the risk is much greater. Quantifying the degree of risk is difficult. A number of respondees were concerned about this risk pointing out, for example, that the master could be sufficiently far from a wireless microphone not to detect it, but the slave could be close enough to cause harmful interference. Others felt that in a PMSE environment the combined sensing of both devices was necessary (see earlier).

9.23 Given that the geolocation database tends to offer a higher level of protection than sensing, we proposed that the use of slave-device operation only be allowed where the master has performed database location. The responses suggest this is an appropriate way ahead, so this is the basis on which we will proceed.

Future-proofing

9.24 It is generally not possible to design a cognitive device to be able to detect and avoid any technology that might be deployed in the spectrum in the future. Indeed, as explained in the cognitive consultation, parameters typically need to be set depending on the technologies and services that the cognitive device is trying to detect. Hence, there is a risk that cognitive access to the interleaved spectrum might reduce the value of subsequent licensed deployment of different technologies.

9.25 We considered this in our statement on awarding the digital dividend and concluded that the likelihood of the introduction of such technologies in this spectrum was low in the foreseeable future given its likely continued use for DTT and PMSE. This is consistent with Analysys Mason's report to us on opportunity cost and Administered Incentive Pricing calculations for spectrum proposed for award to a band manager with obligations to PMSE.[21] If it became clear, in due course, that there was a valuable new licensed use of the spectrum that could not be deployed as a result of cognitive use, we would carefully review the situation, taking all relevant factors into account, including the expected economic value of continued cognitive use and the predicted value of the new licensed use.

9.26 If we came to the view that there was good reason to take action, we might require all cognitive devices sold after some future date to be able to detect and avoid this new licensed use. It is typically not possible (nor necessarily desirable) to require devices already sold to be recalled or for their use to be prevented. However, over time, the number of such devices, and hence their potential for harmful interference, will fall. It often takes more than five years to introduce a new technology from the time that it is first identified. Many consumer electronics products have a lifetime of this order, and hence we might expect that many of the existing cognitive devices would have been replaced by the time that the new technology was deployed.

9.27 If a geolocation-database approach is adopted, this substantially eases the future-proofing problem. If it were judged appropriate and proportionate, all devices could be "turned off" simply by ensuring the database registers all spectrum as in use. A

[21] www.ofcom.org.uk/consult/condocs/bandmanager09/report2.pdf.

transition period can be implemented by gradually increasing the spectrum registered as in use in the database. This is a significant advantage of utilising databases.

Section 10

International harmonisation

Introduction

10.1 This section outlines the path we plan to follow to maximise the probability of achieving international harmonisation around an acceptable standard.

10.2 In our LEFR statement, we set out the reasons why regulators have a role to play in ensuring harmonisation of the terms of spectrum access for licence-exempt devices. These include the greater economies of scale in equipment manufacture that can be achieved with international harmonisation, benefiting citizens and consumers. Moreover, cognitive devices may be small and easily transported across borders and so may cause harmful interference in different countries if key parameters differ substantively.

Harmonisation in Europe

10.3 European alignment can occur through informal, semi-formal or mandatory processes. An informal route would entail all countries individually selecting the same standard. A semi-formal route might be via a CEPT recommendation that was widely adopted. A mandatory process might be via European Union (EU) legislation, such as was adopted for UWB.

10.4 Technical work is now taking place within CEPT group SE43 on cognitive access, although this is at an early stage. There is also relevant work taking place in SE42 considering interference from mobile services to DTT which is applicable to interference from cognitive devices to DTT. We are engaging actively in this work and will consider modifying the parameters we have determined as results emerge.

10.5 We have already noted some differences between the SE42 work and the analysis presented in this statement on cognitive devices, although the changes we have made in our proposals following consultation go some way to removing these differences. The key remaining difference that we currently perceive is that the SE42 work has suggested that any interference should result in no more than a 1 dB degradation to the noise floor for DTT receivers. In the cognitive work we have noted that DTT receivers are operated above -78 dBm while if operated at the noise floor they could work down to around -82 dBm. Hence, the noise floor could be degraded by up to 4 dB before material impact on DTT reception is experienced. This explains the differences in our analysis at present. Another key difference is that SE42's decisions will protect indoor portable DTT reception while we chose not to explicitly do so in the cognitive consultation, nor are UK broadcasting networks planned to provide indoor portable coverage. This adds a further difference to the results.

10.6 We will discuss these differences within SE42 and SE43 as relevant and re-examine the assumptions we have made here in due course once these bodies have deliberated further.

Harmonisation with the US

10.7 There are no formal mechanisms for ensuring alignment with the US. The FCC has developed its own views on an appropriate set of device parameters, as we have done in this statement. Nevertheless, there are many informal opportunities to work together, sharing evidence and thinking, and we will make the most of these opportunities.

10.8 As we noted in the cognitive consultation, there is good agreement between the parameters put forward in the US and those that we proposed and have subsequently determined here. Equally, there are some differences. The channel plan for television transmissions in the US differs from the UK, being based around 6 MHz rather than 8 MHz channels. Also, the technical standard for DTT transmission is different, with the result that sensing mechanisms designed to allow cognitive devices to detect DTT signals at low levels in the US may not work in the UK. As a result, it seems unlikely that a device made for the US market would be able to work in the UK even with alignment of parameters. However, it may be that manufacturers are able to make devices that can detect which environment they are in, perhaps based on characteristics of local television signals, and modify their behaviour accordingly. Even if this is not possible, relatively similar parameter values might allow economies of scale for some components and chipsets.

10.9 The key point of difference between our approach and the FCC's is that we suggest that sensing alone could be allowed without detailed device tests (although devices would have to operate in conformity with the Radio and Telecommunications Terminal Equipment Directive[22]).

10.10 Table 4 provides a comparison of some of the key parameters we have determined and those put forward by the FCC.

Table 4. Comparison of UK and US parameters

Parameter	UK value	US value
DTT sensing	-120 dBm	-114 dBm
Wireless-microphone sensing	-126 dBm	-114 dBm
Location accuracy	100 metres	50 metres
Transmit power – adjacent channels	2.5 mW	40 mW
Transmit power – non-adjacent channels	50 mW	100 mW
Out-of-band powers	< -46 dBm	55 dBc[23]
Time between sensing	1 second	1 minute

10.11 As we did with UWB, we will seek to influence international specifications, notably those in Europe, on the basis of an evidence-based and widely supported position derived from consultation, dialogue and consideration in the UK. Our hope is that harmonisation in Europe and the US will be on as similar a basis as possible. However, we will not support any form of harmonisation unless we are satisfied that it will not result in harmful interference to licensed users of the interleaved spectrum in the UK. Also, different DTT standards (e.g. between the US and Europe) make full worldwide harmonisation unlikely.

[22] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:091:0010:0028:EN:PDF.
[23] For a transmit power of 100 mW, this corresponds to 20 - 55 = -35 dBm.

Section 11

Conclusions and next steps

Conclusions

11.1 This statement has concluded on a number of parameters relevant to licence-exempt cognitive access to interleaved spectrum while noting that further work and consultation will be necessary on issues predominantly related to geolocation.

11.2 If sensing is to be used, the key parameters we have determined are as set out in table 5.

Table 5. Key parameters for sensing

Cognitive parameter	Value
Sensitivity assuming a 0 dBi antenna	-120 dBm in 8 MHz channel (DTT) -126 dBm in 200 kHz channel (wireless microphones)
Transmit power	4 dBm (adjacent channels) to 17 dBm
Transmit-power control	Required
Bandwidth	Unlimited
Out-of-band performance	< -46 dBm
Time between sensing	< 1 second

11.3 If geolocation is to be used, the key parameters we have determined are as set out in table 6.

Table 6. Key parameters for geolocation

Cognitive parameter	Value
Locational accuracy	Nominally 100 metres
Frequency of database access	(to be determined)
Transmit power	As specified by the database
Transmit-power control	Required
Bandwidth	Unlimited
Out-of-band performance	< -46 dBm

Next steps

11.4 We have already commenced work on possible details of the geolocation solution and intend to consult on these later in 2009. This may lead to a subsequent statement at which point we will decide whether to make the necessary regulations in the UK or to await international harmonisation.

11.5 If we decide to work internationally to achieve harmonisation, it may take some time, perhaps years, for all the necessary processes to be concluded. At present, the key points of interaction are with the FCC and the White Spaces Coalition in the US and within CEPT and the EU in Europe. Because we do not yet know whether and in what form international harmonisation might be achieved, we cannot give guidance as to how long it might take to reach this stage.

11.6 During this process it is possible that more evidence will become available or that circumstances will change – for example the probability of different services being deployed in the interleaved spectrum might increase. Were this to happen we would reconsider the appropriateness of the parameter values we have concluded on prior to moving to publish necessary legislation.

Annex 1

Glossary of abbreviations

3G	Third-generation mobile-phone standards and technology
CEPT	European Conference of Postal and Telecommunications Administrations
C/I	Carrier to interference
dB	Decibel
dBc	Decibels relative to carrier
dBi	Decibels relative to an isotropic antenna
dBm	Decibels relative to milliwatts
DDR	Digital Dividend Review
DSO	Digital switchover
DTT	Digital terrestrial television
EIRP	Effective isotropic radiated power
ENG	Electronic newsgathering
EU	European Union
FCC	Federal Communications Commission
GHz	Gigahertz
kHz	Kilohertz
LEFR	Licence-Exemption Framework Review
MHz	Megahertz
mW	Milliwatt
PMSE	Programme-making and special events
PSB	Public-service broadcasting
TPC	Transmit-power control
UHF	Ultra-High Frequency
UWB	Ultra-wideband