TV white spaces: approach to coexistence

Technical analysis

Technical report

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Section 1

Introduction

1.1 On 4 September 2013 we published a consultation on the coexistence of white space devices (WSDs) operating in the UHF TV band (470-790 MHz) with other users of the spectrum. In this, we described our proposals for database assisted access to TV white spaces (TVWSs) and our approach for ensuring a low probability of harmful interference from WSDs to existing services.

1.2 This technical report sets out full details of the technical analysis and modelling that we have undertaken to inform our proposals. This includes an explanation of the methodology and parameters we have used and the results of our modelling of TVWS availability.

1.3 This report is structured as follows:

- In Section 2, we present the background to our framework for access to TVWSs in the UK, and describe elements of the framework which are particularly relevant to coexistence analysis;
- In Section 3, we present a high level description of the calculations which need to be performed by Ofcom and providers of white space databases (WSDBs);
- In Section 4, we present our analysis of coexistence in relation to digital terrestrial broadcasting (DTT) use of the spectrum in the UK;
- In Section 5, we present our analysis of coexistence in relation to programme making and special events (PMSE) use of the spectrum;
- In Section 6, we present our analysis of coexistence in relation to mobile network use of the spectrum above the UHF TV band;
- In Section 7, we present our analysis of coexistence in relation to services below the UHF TV band;
- In Section 8, we describe our analysis of coexistence in relation to DTT use of the spectrum in our neighbouring countries.

Section 2

Background

2.1 In this section we describe the framework for database-assisted access to TV white spaces in the UK, with special emphasis on the elements of the framework most relevant to the issue of coexistence with existing users of the spectrum inside and outside the UHF TV band (470-790 MHz).

Database-assisted access to TVWS

2.2 WSDs operating in the UHF TV band will be licence exempt equipment that share the spectrum with the DTT and PMSE services. These two licensed services are the primary users of the band, and as such, Ofcom must ensure a low probability of harmful interference to these services.

2.3 A low probability of harmful interference also extends to services outside the UHF TV band. These include mobile networks above the band (791-860 MHz), and a range of uses such as emergency services, PMSE, scanning telemetry, short range devices, business radio, and maritime radio below the band (450-470 MHz).

2.4 The frequency allocations for the above services are illustrated below. Note that channels 31 to 37 are currently cleared of DTT transmissions, but are in use by PMSE.

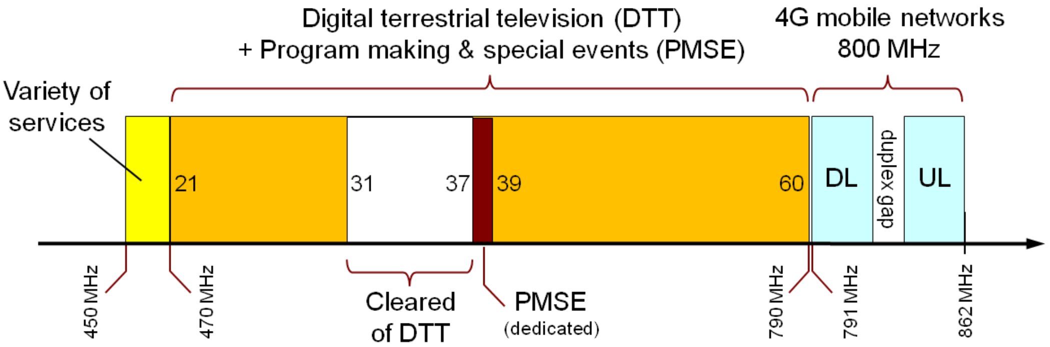

Figure 2.1 – The UHF TV band (470-790 MHz) and its users.

2.5 By itself, a WSD does not have access to the requisite information about DTT and PMSE usage of the band to be able to transmit without there being a substantial risk of causing harmful interference to existing users. Therefore, a WSD must contact an appropriate repository – a WSDB – and communicate information about itself and its geographic location.

2.6 The WSDB will respond to the WSD with a set of operational parameters including the frequencies and maximum powers at which the WSD can transmit in order to ensure a low probability of harmful interference to the primary users.

2.7 The following are some of the key elements of our adopted regulatory framework:

- WSDs will be permitted to transmit in the UHF TV band provided that there is a low probability that they will cause harmful interference to incumbent licensed users within the band (DTT and PMSE) as well as users outside the band.

- Compliance with the licence exemption regulations will require that WSDs operate according to the frequency/power parameters (restrictions) that they receive from a WSDB. They will be required to obtain such parameters from a qualifying WSDB. The qualifying WSDB will generate the frequency/power parameters for WSDs on the basis of information relating to the incumbent users that Ofcom will regularly make available.

- WSDs will be able to identify qualifying WSDBs by consulting a list on a website maintained by Ofcom, and select a preferred WSDB from that list. This is the so-called “database discovery”. The choice of preferred WSDB will be for the master WSD to determine itself.

- WSDs are categorised as masters and slaves. A master WSD is required to have a communications link to access Ofcom’s list of qualifying WSDBs, and a communications link to query one of the qualifying WSDBs. A slave WSD, on the other hand, does not have a direct connection to Ofcom or a WSDB; it will obtain its frequency/power parameters from a WSDB through a master WSD.

- Ofcom will calculate the frequency/power restrictions which apply in relation to interference from WSDs to DTT (both in the UK and across borders). The results of these calculations will be communicated to the WSDBs. These will also include any additional *location agnostic* frequency/power restrictions that may apply in relation to interference to services inside or outside the UHF TV band. Ofcom will provide scheduled updates to the above data whenever there is a relevant change to the planning of DTT or other services. We expect that these updates will occur once or twice a year. On certain occasions, there may be unscheduled updates to the above data. These may be triggered by an interference management process or by fine-tuning of Ofcom’s coexistence modelling parameters,

- Ofcom will also provide to WSDBs information on PMSE assignments throughout the UK. This information will be updated on a scheduled three-hourly basis. WSDBs will use this information to calculate frequency/power restrictions in relation to interference from WSDs to PMSE. On certain occasions, there may be unscheduled updates to the above data. These may be triggered by an interference management process.

- The WSDBs will combine the frequency/power restrictions calculated by Ofcom with those they calculate themselves, and convey these to the relevant WSDs.

2.8 The above elements are illustrated in Figure 2.2. For the purposes of this document, we use the terms *frequency/power restrictions*, *WSD emission limits*, and *TVWS availability data* interchangeably.

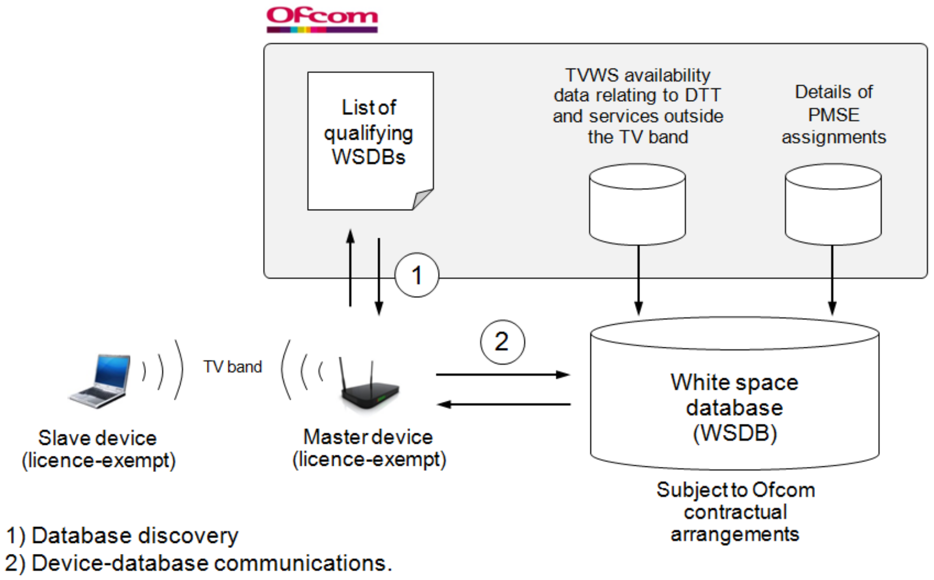

Figure 2.2 – Adopted framework for authorising the use of TV white spaces.

Interactions between WSDBs and WSDs

2.9 In November 2012 we published "A consultation on white space device requirements" where we outlined our proposals for the operation of WSDs and the nature of the data exchanged between WSDs and WSDBs. Our proposals (among others) were subsequently incorporated into the draft European harmonised standard EN 301 598 which is currently subject to public consultation[1]. Here we summarise the key elements of the WSDB-WSD interactions implied by EN 301 598.

2.10 As noted before, the first operation of a master WSD is database discovery. This is where the device consults a web listing of qualifying WSDBs (maintained by Ofcom). Master WSDs must repeat database discovery with a given minimum regularity as specified by Ofcom (as the list may be occasionally updated by Ofcom).

2.11 Having selected a WSDB from the web list, the master WSD will then initiate communications with that WSDB. WSDBs and WSDs are required to exchange the following parameters:

- Device parameters (DPs) – These are communicated from a WSD to a WSDB, and identify specific characteristics of the WSD (including its location).

- Operational Parameters (OPs) – These are generated by a WSDB and communicated to WSDs. They specify the radio frequency (RF) frequency/power restrictions (as well as other instructions) which WSDs must comply with when transmitting in the UHF TV band. There are two types of operational parameters:

    a) Specific Operation Parameters (SOPs) account for the DPs of a specific WSD.

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[1] Draft ETSI EN 301 598 V1.0.0 (2013-07), "White space devices (WSD); Wireless access systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

b) Generic Operational Parameters (GOPs) are intended for slave WSDs whose DPs are not known. A WSDB will communicate GOPs to a master WSD, which in turn will broadcast these to all slave WSDs in its coverage area. GOPs account for certain characteristics of the serving master WSD (e.g., location, power, and hence coverage area), but assume default values for the DPs of the slave WSDs.

- Channel Usage Parameters (CUPs) – These are reported by a WSD to inform a WSDB of the *actual* radio resources that will be used by the WSDs.

2.12 The interactions between master WSDs, slave WSDs and WSDBs may be described in terms of four separate phases A to D as presented next, and illustrated in Figure 2.3.

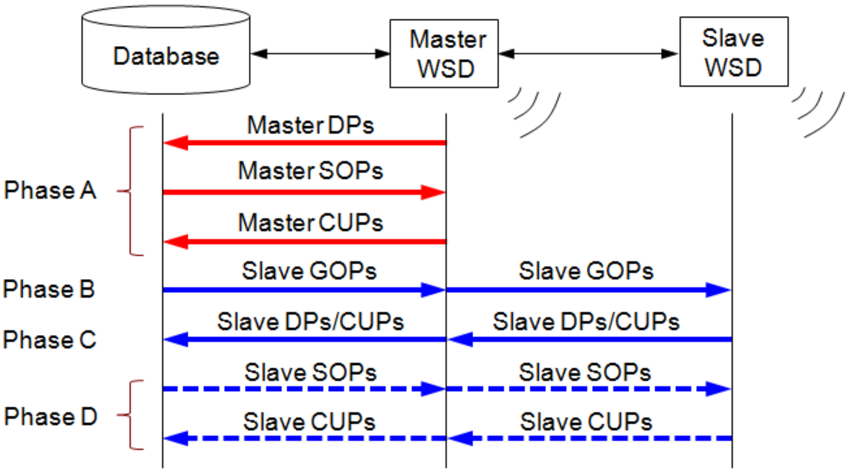

Figure 2.3 – Operational phases.

Phase A: Specific operational parameters for a master WSD

2.13 Phase A relates to the generation and communication of SOPs for master WSDs, and involves the following steps:

- The master WSD must request from a WSDB the SOPs for its own transmissions. In this process, the master WSD must first communicate its DPs to the WSDB.

- The WSDB will then generate the SOPs that the master WSD must comply with for its transmissions. For this, the WSDB will use TVWS availability data[2] and the DPs provided by the master WSD. The WSDB will communicate the SOPs to the master WSD.

- The master WSD must respond to the WSDB with its CUPs (the channel(s) and radiated power(s) that it intends to use) if its total EIRP exceeds 0 dBm. The channels used will be a subset of those included in the SOPs.

- The master WSD can then start transmissions in the UHF TV band according to its reported CUPs.

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[2] These are a combination of the frequency/power restrictions provided by Ofcom and those calculated by the WSDB itself.

Phase B: Generic operational parameters for slave WSDs

2.14 Phase B relates to the generation and communication of GOPs for slave WSDs in the coverage area of a particular master WSD. A master WSD that supports association of slave WSDs over the UHF TV band[3] must undertake phase B. We use the term “association” to refer to the process whereby a slave WSD initially identifies itself to its serving master WSD. Phase B involves the following steps:

- The master WSD must contact the serving WSDB and request GOPs for the transmissions of those slave WSDs within its coverage area.
- The WSDB will then use the information that it holds about the master WSD (see Phase A) to calculate the master’s coverage area. The WSDB will calculate the GOPs by assuming a) that slaves may be at any location within the master’s coverage area, and b) default conservative values for the DPs of the slaves. Note that at this stage no slave WSD DPs are available at the master WSD or at the WSDB, since no slave WSDs will have yet associated with the master WSD. The WSDB will send the GOPs to the master WSD.
- The master WSD must then broadcast the GOPs to slave WSDs within its coverage area. The GOPs will correspond to the full set (or a subset[4]) of the channels identified and communicated by the WSDB.
- Slave WSDs must comply with the broadcast GOPs when they transmit in the UHF TV band for purposes of association with the master WSD.

Phase C: Association of a slave WSD with a serving master WSD

2.15 Phase C relates to the association of slave WSDs with master WSDs. Any slave WSD wishing to radiate over the UHF TV band, irrespective of whether or not association is performed over the UHF TV band, must undertake the following steps:

- A slave WSD must associate with a master WSD by identifying itself to the master (it may submit a subset of its DPs for this purpose).
- Where association is performed over the UHF TV band, the slave WSD will transmit according to the GOPs broadcasted by the master WSD.
- The master WSD must forward the identities, or the full set of DPs, of its associated slave WSDs to the WSDB.
- Slave WSDs which have already associated with a master WSD may continue to use GOPs for subsequent transmissions. Alternatively, they may request SOPs in order to benefit from increased TVWS availability (see Phase D).

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[3] There may be circumstances where the WSD wireless technology supports the association of slave WSDs via media other than the UHF TV band, e.g., via wireless access in other frequency bands, or wire-line access. In such cases “specific” (Phase D) rather than “generic” (Phase B) operational parameters apply.

[4] The master may not be able to, or may not be willing to, receive transmissions from slave WSDs in all channels identified by the WSDB.

Specific operational parameters for a slave WSD

2.16 Phase D relates to the generation and communication of SOPs for individual slave WSDs. A slave WSD which associates with a master WSD over a medium other than the UHF TV band must also undertake the steps described below. This is because GOPs do not apply in such circumstances, and SOPs are necessary. Phase D involves the following steps:

- A slave WSD may contact its serving master WSD and request SOPs for its transmissions. In such a case, the master WSD must forward this request to the WSDB. Alternatively, a master WSD may itself request SOPs from the WSDB for the transmissions of the slave WSD.

- The WSDB will then generate SOPs using the slave DPs provided by the master WSD and the TVWS availability data.

- The WSDB will communicate the SOPs for a slave WSD to the master WSD. The master WSD must then communicate the SOPs to the associated slave WSD.

- The slave WSD must respond to the master WSD with its CUPs (the channel(s) and radiated power(s) that it intends to use) if its total EIRP exceeds 0 dBm. This is mandatory unless the slave WSD CUPs have been chosen by the master WSD.

- The master WSD must forward the CUPs to the WSDB.

Exchanged data between WSDs and WSDBs

Device parameters

2.17 The details of the various device parameters communicated by WSDs are presented below. The device antenna location, technology identifier, type, and spectrum emission class are of particular relevance to the coexistence studies.

Table 2.1. Device parameters.

Parameter	Description
Antenna location	Latitude, longitude, and altitude (x, y, h). Antenna height above ground may be reported as an alternative to altitude.
Antenna location uncertainty	Latitude, longitude, and altitude uncertainties ($\pm\Delta x$, $\pm\Delta y$, $\pm\Delta h$).
Device type	Type A or type B.
Device category	Master or slave.
Unique device identifier	The unique device identifier is composed of three parts: the manufacturer identifier, which is unique to the manufacturer; the model identifier; the serial number.
Technology identifier	This may include the name of the organisation responsible for the technology specifications, the number, the version and issue date of the specifications.
Device spectrum emission class	Class 1, 2, 3, 4 or 5 (see later for definitions).
Spectral mask improvement	Improvements in adjacent frequency leakage ratio.
Reverse intermodulation product improvement	Improvements in the reverse intermodulation performance.

WSD location

2.18 The antenna location (horizontal and vertical) of a WSD is one of the most important device parameters. Horizontal location is described as latitude and longitude coordinates. Vertical location is described as altitude/height. Unless otherwise stated, in this document we use the term “height” to refer to height above ground level. We reserve the term “altitude” to refer to height above sea level.

2.19 Master WSDs must communicate their latitude and longitude coordinates to WSDBs. Reporting of altitude/height is optional for master WSDs. If altitude/height is not reported, a default value specified by Ofcom will be used for purposes of coexistence calculations.

2.20 Reporting of location (horizontal or vertical) is optional for slave WSDs. If not reported, the horizontal location of a slave WSD will be inferred by WSDBs from the coverage area of the serving master WSD. If altitude/height is not reported, a default value specified by Ofcom will be used for purposes of coexistence calculations.

Device type

2.21 A Type A WSD is a master or slave device that is intended for fixed use only. This type of equipment can have integral, dedicated or external antennas. Type A devices will typically be network base stations or consumer premises equipment. See Figure 2.4.

2.22 A Type B WSD is a master or slave device that is not intended for fixed use and which has an integral antenna or a dedicated antenna. The equipment and the antenna must be designed to ensure that no antenna other than that furnished by the responsible party can be used with the device. In the case of dedicated antennas, the manufacturer has to specify the antennas that have been assessed together with the equipment against the requirements of EN 301 598. This information must be included in the user documentation. The use of other antennas is prohibited.

2.23 Note that the device type does not identify devices as indoor or outdoor.

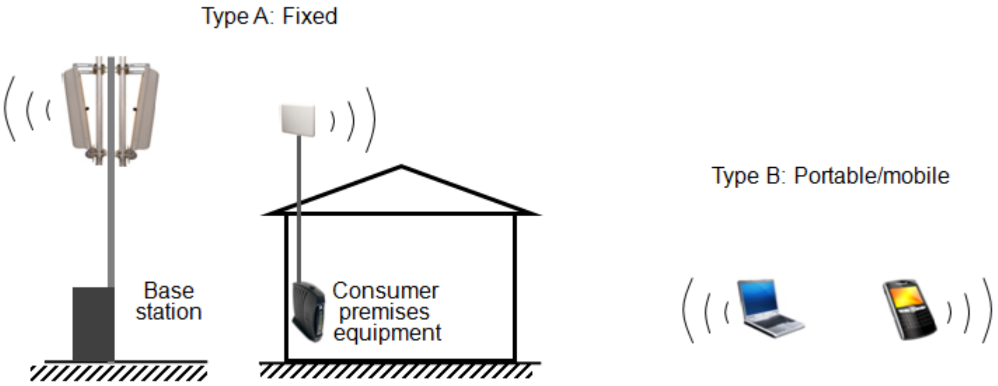

Figure 2.4 – Device types.

Technology identifier

2.24 Measurements have indicated that the susceptibility of DTT receivers to adjacent channel interferers varies widely depending on the time-frequency structure of the interferer’s signal, and hence its wireless technology. This is the case even if the different technologies result in the same amount of out-of-block spectral leakage.

2.25 The WSD technology identifier would therefore allow Ofcom and the WSDBs to account (where applicable) for the time-frequency structure of WSD technologies in calculating the frequency/power restrictions. See discussions on protection ratio categories in Section 4.

Spectrum emission class

2.26 The spectrum emission class defines the limits on out-of-block emissions (spectral leakage) of a WSD. See Figure 2.5.

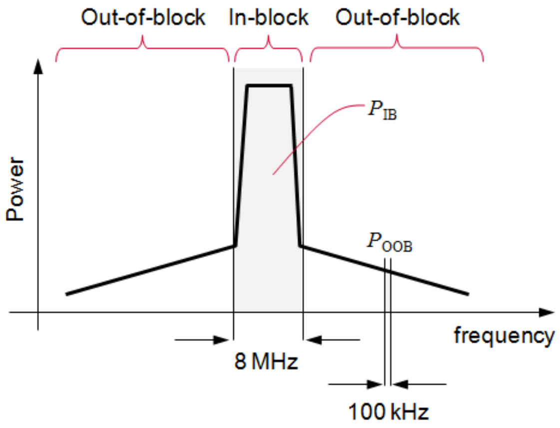

Figure 2.5 – Out-of-block emissions.

2.27 Specifically, the out-of-block EIRP spectral density, P_{OOB}, of a WSD must satisfy

$$P_{\text{OOB (dBm/(100 kHz))}} \leq \max\{P_{\text{IB (dBm/(8 MHz))}} - \text{AFLR}_{\text{ (dB)}}, -84\}, \tag{2.1}$$

where P_{IB} is the in-block EIRP over 8 MHz, and AFLR is the adjacent frequency leakage ratio outlined in the Table 2.2 for different spectrum emission classes. Each out-of-block EIRP spectral density is examined in relation to P_{IB} in the nearest (in frequency) DTT channel used by the WSD. Where there are two nearest (in frequency) DTT channels used, the one with the lower P_{IB} must be considered.

Table 2.2 – Adjacent frequency leakage ratios (AFLR) for different device classes.

Where P_{OOB} falls within the ΔF^{th} adjacent 8 MHz DTT channel	AFLR (dB)				
	Class 1	Class 2	Class 3	Class 4	Class 5
$\Delta F = \pm 1$	74	74	64	54	43
$\Delta F = \pm 2$	79	74	74	64	53
$\Delta F \geq +3$ or $\Delta F \leq -3$	84	74	84	74	64

2.28 The principle here is that WSDs with stringent spectrum emission masks (e.g. class 1) are afforded greater TVWS availability than those with more relaxed masks (e.g. class 5), due to their lower propensity for causing interference.

2.29 Finally, note that the emission limits in Table 2.2 apply within the 470-790 MHz band. Different requirements apply outside the band. Specifically, the emissions outside the band must not exceed -36 dBm/(100 KHz) and -54 dBm/(100 kHz) over 230-470 MHz and 790-862 MHz, respectively. See discussions on emission limits above and below the band in Sections 6 and 7.

Operational parameters

2.30 The details of the various operational parameters communicated by WSDBs are presented in Table 2.3. The maximum permitted in-block EIRP, $P_1(F)$, and EIRP spectral density, $P_0(F)$, are of particular relevance to the coexistence studies. These describe the EIRP in dBm that must not be exceeded in any 8 MHz or 100 kHz bandwidth, respectively.

Channel usage parameters

2.31 The details of the various channel usage parameters communicated by WSDs are presented in Table 2.4. Master WSDs must report their channel usage parameters, if their total EIRP exceeds 0 dBm. Slave WSDs must report their channel usage parameters if their total EIRP exceeds 0 dBm, unless their channel usage parameters have been chosen by their serving master WSD.

Table 2.3. Operational parameters.

Parameters	Description
Lists of available DTT channels	This is the list of DTT channels in which the WSD is allowed to transmit. DTT channels are indexed as $F = 21\ldots60$.
Maximum in-block RF EIRP spectral density for each DTT channel	$P_0(F)$ dBm/(0.1 MHz) in DTT channel F. This EIRP limit is calculated based on the protection requirements of both DTT and PMSE users.
Maximum in-block RF EIRP for each DTT channel	$P_1(F)$ dBm over 8 MHz in DTT channel F. This EIRP limit is calculated based on the protection requirements of DTT users, and users outside the band.
Maximum nominal channel bandwidth	Contiguous bandwidth (in Hz).
Maximum total bandwidth	Total bandwidth (in Hz), contiguous or non-contiguous.
Time validity start (T_{ValStart})	Time when the operational parameters start being valid.
Time validity end (T_{ValEnd})	Time when the operational parameters stop being valid.
Location validity (L_{Val})	Radius (in metres) of the circle centred on the reported location of the WSD, outside of which the operational parameters are not valid
Update timer (T_{Update})	This timer indicates how often (in seconds) the master WSD will check with the WSDB that the operational parameters are still valid.

Table 2.4. Channel usage parameters.

Parameters	Description
List of DTT channels within which a WSD intends to transmit	DTT channels indexed as $F = 21\ldots60$.
In-block RF EIRP spectral density which a WSD intends to use within each DTT channel	Specified as $p_0(F)$ (dBm/0.1 MHz).
In-block RF EIRP which a WSD intends to use within each DTT channel	Specified as $p_1(F)$ (dBm over 8 MHz).

Summary

2.32 We have described the UK framework for database-assisted access to TV white spaces, and presented the details of the data exchanged between WSDBs and WSDs, as specified in the draft ETSI harmonised standard EN 301 598.

2.33 The exchanged data consist of device parameters communicated from WSDs to WSDBs, operational parameters communicated from WSDBs to WSDs, and channel usage parameters reported from WSDs back to WSDBs.

2.34 The operational parameters include frequency and power restrictions which will apply to WSDs in order to ensure a low probability of harmful interference to incumbent services inside and outside the UHF TV band. The coexistence studies presented in the subsequent sections describe our proposals for these restrictions.

Section 3

TVWS calculations

3.1 As described in the previous section, the operational parameters which a WSDB communicates to WSDs include TVWS availability data in the form of location-specific and frequency-specific regulatory emission limits; i.e., maximum permitted in-block[5] EIRPs. These limits will be calculated subject to the requirement of a low probability of harmful interference to:

- DTT use in the UK within the UHF TV band;
- PMSE use within the UHF TV band (in the form of licensed assignments);
- DTT use by the UK’s international neighbours in the UHF TV band; and
- uses above and below the UHF TV band.

3.2 The framework which we have developed for access to TV white spaces in the UK[6] is based on the premise that the impact of harmful interference on a DTT receiver is a function of the quality of the DTT coverage in the geographical area where the DTT receiver is located.

3.3 The implication is that the regulatory emission limits for a WSD can be significantly increased in areas where the DTT signal-to-interference-plus-noise ratio (SINR) is high in the absence of WSDs. In other words, where the DTT coverage quality is good, WSDs can operate at higher powers. Information on the DTT SINR at different locations in the UK is available via the DTT UK planning model (UKPM).

3.4 Our approach regarding PMSE is somewhat different. Here, absent information on the details of equipment deployments, we consider the quality of PMSE reception to be the same at every venue. However, the regulatory emission limits for a WSD can be significantly increased the further the WSD is located geographically from a PMSE receiver.

3.5 In this section we present a high-level description of the calculations necessary to derive the WSD regulatory emission limits in relation to other uses of the spectrum, and explain how and where these limits are combined. Figure 3.1 illustrates the various emission limits, and the entities responsible for their calculation.

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[5] Note that the unknown independent variable is the in-block (rather than out-of-block) EIRP. This is because in the draft European harmonised standard EN 301 598 the out-of-block EIRP is already pre-defined relative to the in-block EIRP for five different WSD spectrum emission classes. The out-of-block EIRP is accounted for implicitly in the interference calculations via the protection ratios.

[6] Note that this framework is somewhat different from that adopted by the FCC in the US, where the operation of WSDs in specific frequencies is subject to the WSDs being located outside specified contours derived from the coverage areas of DTT transmitters.

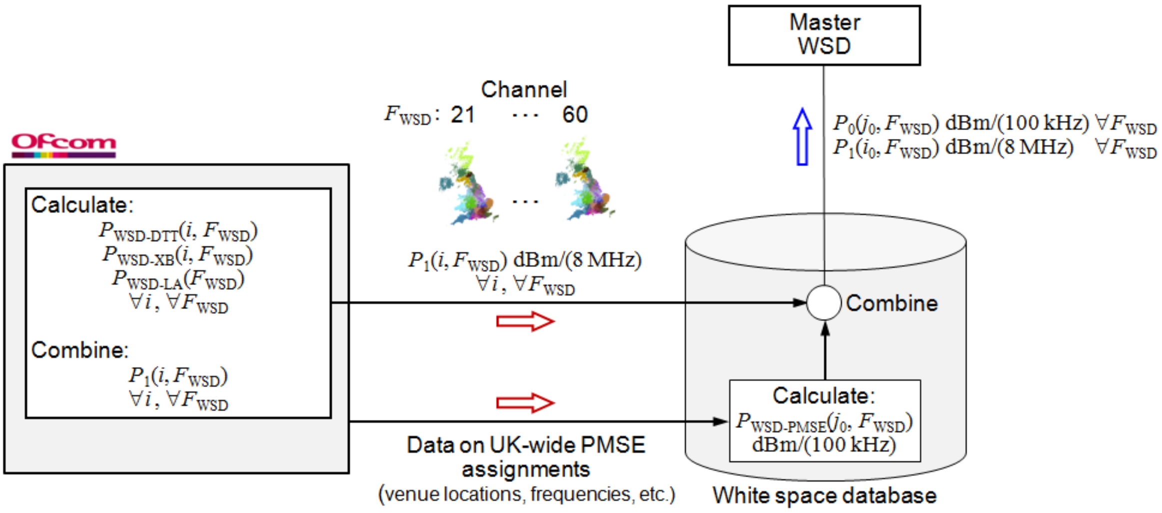

Figure 3.1 – WSD emission limits, their notation, and their calculations.

Calculation of emission limits relating to DTT in the UK

3.6 In relation to DTT, the derivation of location-specific TVWS availability can be formulated as the following problem:

> Calculate the maximum permitted WSD in-block EIRP, $P_{\text{WSD-DTT}}(i, F_{\text{WSD}})$, for a WSD located in a geographic pixel indexed as i, and radiating in channel F_{WSD}, subject to a given probability of a target reduction in DTT signal-to-interference-plus-noise ratio in any channel F_{DTT} = 21 to 60.

3.7 The unit of $P_{\text{WSD-DTT}}(i, F_{\text{WSD}})$ is chosen as dBm/(8 MHz), since DTT operates in 8 MHz channels. Also, in line with DTT planning in the UK, we use a spatial resolution that is based on 100 metre × 100 metre geographic pixels ("pixels"). The area of the UK is covered by over 20 million pixels.

3.8 The above problem can (in principle) be solved via the following procedure.

Table 3.1. DTT calculations for a WSD in pixel i and channel F_{WSD}.

1) Identify all K populated victim pixels which receive the DTT service in a given channel F_{DTT}. Index these pixels as $k = 1 \ldots K$.

2) Calculate the maximum permitted WSD in-block EIRPs, $P_{\text{WSD-DTT}}(i, k, F_{\text{WSD}}, F_{\text{DTT}})$ $k = 1 \ldots K$, in relation to DTT in the K victim pixels identified in step (1).

3) Select the smallest of the K values calculated in step (2):

$$P_{\text{WSD-DTT}}(i, F_{\text{WSD}}, F_{\text{DTT}}) = \min_{k}\{P_{\text{WSD-DTT}}(i, k, F_{\text{WSD}}, F_{\text{DTT}})\}.$$

4) Repeat (1)-(3) for all victim channels F_{DTT} = 21 to 60. Then,

$$P_{\text{WSD-DTT}}(i, F_{\text{WSD}}) = \min_{F_{\text{DTT}}} P_{\text{WSD-DTT}}(i, F_{\text{WSD}}, F_{\text{DTT}}).$$

3.9 For a UK-wide picture, the above would need to be repeated for each WSD pixel (indexed as i) in the UK and for each WSD channel (F_{WSD} = 21 to 60). This can be interpreted as 40 maps of the UK with the maximum permitted WSD EIRP depicted in each pixel.

3.10 The outlined procedure need only consider victim pixels which are actually served by DTT[7]. Furthermore, strictly speaking, the outlined procedure need only be performed for the *most susceptible* victim pixels which receive DTT. This is because the less susceptible victim pixels do not affect the outcome of the calculations. As a result, identification of the most susceptible pixels at an early stage in the calculations can reduce computational complexity significantly.

3.11 Ofcom will be responsible for generating UK-wide TVWS availability datasets in relation to DTT and will communicate these to WSDBs. Ofcom will generate a unique TVWS availability dataset for each combination of WSD spectrum emission class, WSD technology (protection ratio) category, and a number of representative WSD antenna heights, all for type A WSDs. TVWS availability for type B devices will be inferred by WSDBs from availability for type A devices. See Section 4 for further details.

Calculation of emission limits relating to PMSE

3.12 In relation to PMSE, the derivation of location-specific TVWS availability can be formulated as the following problem:

> Calculate the maximum permitted WSD in-block EIRP, $P_{\mathrm{WSD\text{-}PMSE}}(j, F_{\mathrm{WSD}})$, for a WSD located in a geographic location indexed as j, and radiating in channel F_{WSD}, subject to a given PMSE wanted-to-unwanted power ratio in any channel F_{DTT} = 21 to 60.

3.13 The unit of $P_{\mathrm{WSD\text{-}PMSE}}(j, F_{\mathrm{WSD}})$ is chosen as dBm/(100 kHz), since the vast majority of PMSE equipment operate in bandwidths of 200 kHz or less, and so a finer resolution than 8 MHz is required.

3.14 Also note that for PMSE calculations we propose to use “geographic location” rather than “geographic pixel” as used for DTT. This is because the coordinates of PMSE equipment will be known with a spatial resolution that will in many cases be better than the coarse 100 metre resolution of the pixels used in DTT planning. In this way we can take better account of the more precise information on the locations of PMSE use and allow more efficient use of white spaces.

3.15 The above problem can (in principle) be solved via the following procedure.

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[7] In line with the planning of the DTT network in the UK, served pixels are defined as those where the DTT location probability is 70% or greater in 1%-time DTT self-interference conditions (also known as ducting).

Table 3.2. PMSE calculations for a WSD at location j and channel F_{WSD}.

1) Identify all L PMSE assignments in a given channel F_{DTT}.
   Index their locations as $l = 1 \ldots L$.

2) Calculate the maximum permitted WSD in-block EIRPs, $P_{\mathrm{WSD\text{-}PMSE}}(j, l, F_{\mathrm{WSD}}, F_{\mathrm{DTT}})$ $l = 1 \ldots L$, for protection of PMSE in the L assignments identified in step (1).

3) Select the smallest of the L values calculated in step (2):

$$P_{\mathrm{WSD\text{-}PMSE}}(j, F_{\mathrm{WSD}}, F_{\mathrm{DTT}}) = \min_{l}\{P_{\mathrm{WSD\text{-}PMSE}}(j, l, F_{\mathrm{WSD}}, F_{\mathrm{DTT}})\}.$$

4) Repeat (1)-(3) for all victim channels F_{DTT} = 21 to 60. Then,

$$P_{\mathrm{DTT\text{-}PMSE}}(j, F_{\mathrm{WSD}}) = \min_{F_{\mathrm{DTT}}} P_{\mathrm{DTT\text{-}PMSE}}(j, F_{\mathrm{WSD}}, F_{\mathrm{DTT}}).$$

3.16 For a UK-wide picture, the above would need to be repeated for each WSD location (indexed as j) in the UK and for each WSD channel (F_{WSD} = 21 to 60).

3.17 WSDBs will be responsible for performing the above calculations. The WSDBs will need to account for WSD spectrum emission class, reported WSD antenna height, and WSD type (A/B) in performing the calculations. See Section 5 for further details.

3.18 In practice, it is not necessary for the WSDBs to develop a UK-wide picture, as the calculations can be performed in real time by WSDBs in response to queries by individual WSDs[8].

3.19 Once again, the outlined procedure need only consider the *most susceptible* PMSE assignments. This is because the less susceptible assignments do not affect the outcome of the calculations. As a result, identification of the most susceptible assignments at an early stage in the calculations can reduce computational complexity significantly.

Calculation of emission limits relating to cross border DTT

3.20 In the relation to cross border DTT, the derivation of location-specific TVWS availability can be formulated as the following problem:

> Calculate the maximum permitted WSD in-block EIRP, $P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}})$, for a WSD located in a geographic pixel indexed as i, and radiating in channel F_{WSD}, subject to the received field strength in neighbouring countries not exceeding relevant international coordination trigger threshold in channel F_{WSD}.

3.21 The unit of $P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}})$ is chosen as dBm/(8 MHz), since DTT operates in 8 MHz channels. Again, in line with DTT planning in the UK, we use a spatial resolution that is based on 100 metre × 100 metre geographic pixels (“pixels”).

3.22 The above problem can (in principle) be solved via the following procedure.

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[8] As described earlier, this is different from the case of DTT, where Ofcom pre-calculates TVWS availability across the UK.

Table 3.3. Cross border DTT calculations for a WSD in pixel i and channel F_{WSD}.

1) Identify all M victim pixels within the UK's neighbouring countries. Index these pixels as $m = 1 \ldots M$.

2) Calculate the maximum permitted WSD in-block EIRPs, $P_{\mathrm{WSD\text{-}XB}}(i, m, F_{\mathrm{WSD}})$ $m = 1 \ldots M$, such that a specific power threshold is not exceeded in any of the M victim pixels identified in step (1).

3) Select the smallest of the M values calculated in step (2):

$$P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}}) = \min_{m} P_{\mathrm{WSD\text{-}XB}}(i, m, F_{\mathrm{WSD}}).$$

3.23 For a UK-wide picture, the above would need to be repeated for each WSD pixel (indexed as i) in the UK and for each WSD channel (F_{WSD} = 21 to 60). This can be interpreted as 40 maps of the UK with the maximum permitted WSD EIRP depicted in each pixel.

3.24 In practice, only WSD pixels near the UK coastlines or land borders need to be examined since pixels in land are unlikely to be subject to any cross-border restrictions.

3.25 Furthermore, the outlined procedure need only consider the *most susceptible* victim pixels within the UK's neighbouring countries (likely to be near the borders). This is because the less susceptible victim pixels do not affect the outcome of the calculations. As a result, identification of the most susceptible pixels at an early stage in the calculations can reduce computational complexity significantly.

3.26 Ofcom will be responsible for generating UK-wide TVWS availability datasets in relation to cross border DTT. A unique TVWS availability dataset will be generated for each of a number of representative type A WSD antenna heights. TVWS availability for type B devices will be inferred by Ofcom from availability for type A devices. See Section 8 for further details. Ofcom will combine cross border restrictions with other EIRP limits which might apply, and will communicate these to WSDBs.

Calculation of location-agnostic emission limits

3.27 Location-agnostic WSD emission limits will apply in the context of seeking to ensure a low probability of harmful interference to uses above and below the UHF TV band, as well as PMSE usage in channel 38.

3.28 These limits are not location-specific because information on the locations of the above uses is not available and therefore cannot be exploited in our database-assisted framework for access to TV white spaces. As a result, the WSD emission limits are simply specified by Ofcom as location-agnostic limits, $P_{\mathrm{LA}}(F_{\mathrm{WSD}})$, in each channel $F_{\mathrm{WSD}} = 21 \ldots 60$.

3.29 The unit of $P_{\mathrm{WSD\text{-}LA}}(F_{\mathrm{WSD}})$ is chosen as dBm/(8 MHz).

Combining of emission limits by Ofcom

3.30 As described in Section 2, Ofcom will calculate the limits $P_{\mathrm{WSD\text{-}DTT}}(i, F_{\mathrm{WSD}})$, $P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}})$, and $P_{\mathrm{WSD\text{-}LA}}(F_{\mathrm{WSD}})$, all in dBm/(8 MHz), in the context of interference to UK DTT, cross border DTT, and PMSE use in channel 38 (as well as uses outside the UHF TV band), respectively.

3.31 Then, for a WSD located in geographic pixel i, and radiating in channel F_{WSD}, Ofcom will calculate the overall EIRP limit as

$$P_1(i, F_{\mathrm{WSD}}) = \min\left\{ P_{\mathrm{WSD\text{-}DTT}}(i, F_{\mathrm{WSD}}),\ P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}}),\ P_{\mathrm{WSD\text{-}LA}}(F_{\mathrm{WSD}}) \right\} \qquad (3.1)$$

in dBm/(8 MHz). That is to say, the restrictions relating to cross border DTT, uses in channel 38, and outside the UHF TV band, will be applied as an *overlay* on the restrictions relating to DTT in the UK. Ofcom will then communicate the values of $P_1(i, F_{\mathrm{WSD}})$ to the WSDBs.

3.32 Note that Ofcom will calculate a unique set of combined limits for each combination of WSD spectrum emission class, WSD technology (protection ratio) category, and WSD antenna height, all for type A WSDs. A number of representative antenna heights will be used for this purpose. Limits for type B devices will be inferred by WSDBs from the limits for type A devices.

Combining of emission limits by WSDBs

3.33 As well as receiving the limits $P_1(i, F_{\mathrm{WSD}})$ in dBm/(8 MHz) from Ofcom, WSDBs will calculate the limits $P_{\mathrm{WSD\text{-}PMSE}}(j, F_{\mathrm{WSD}})$ in dBm/(100 kHz) in of the context of interference to PMSE.

3.34 Then, for a WSD at geographic location j (which falls within pixel i), and radiating in channel F_{WSD} , a WSDB will calculate the overall EIRP spectral density limit as

$$P_0(j, F_{\mathrm{WSD}}) = \min\left\{ P_1(i, F_{\mathrm{WSD}}) - 10\log_{10}(80),\ P_{\mathrm{WSD\text{-}PMSE}}(j, F_{\mathrm{WSD}}) \right\} \qquad (3.2)$$

in dBm/(100 kHz), where the logarithm converts the measurement bandwidth from 8 MHz to 100 kHz. That is to say, the EIRP spectral density limit is the most stringent of the values calculated in relation to each of the existing uses of the spectrum.

The values of $P_0(j, F_{\mathrm{WSD}})$ dBm/(100 kHz) and $P_1(i, F_{\mathrm{WSD}})$ dBm/(8 MHz) will form the basis of the operational parameters which WSDBs communicate to WSDs (see Section 2).

3.35 Note that a unique set of combined limits will be calculated for each combination of WSD spectrum emission class, WSD technology (protection ratio) category, WSD type (A/B), and WSD antenna height. A number of representative antenna heights will be used for this purpose. Limits for type B devices will be inferred by WSDBs from the limits for type A devices.

Power adjustments by Ofcom (volume dial)

3.36 It may be necessary for Ofcom to adjust the regulatory emission limits $P_1(i, F_{\mathrm{WSD}})$ and $P_0(i, F_{\mathrm{WSD}})$ that are communicated to WSDBs and calculated by WSDBs, respectively. Such adjustments might be on a location-specific and/or channel-specific basis, and may be triggered by an interference management process or by fine tuning of Ofcom's coexistence modelling parameters.

3.37 The adjustments, $\Delta(i, F_{\mathrm{WSD}})$, will be communicated by Ofcom to the WSDBs, which will then apply the adjustments as

$$P_0(j, F_{\mathrm{WSD}}) \leftarrow P_0(j, F_{\mathrm{WSD}}) + \Delta(i, F_{\mathrm{WSD}}) \qquad (3.3a)$$

$$P_1(i, F_{\mathrm{WSD}}) \leftarrow P_1(i, F_{\mathrm{WSD}}) + \Delta(i, F_{\mathrm{WSD}}) \qquad (3.3b)$$

for a WSD at geographic location j (which falls within pixel i).

3.38 A unique set of adjustments may be specified by Ofcom for each combination of WSD spectrum emission class, WSD technology (protection ratio) category, WSD type (A/B), and representative WSD antenna height.

Multiple WSDs and interference aggregation

3.39 In the framework which we have presented for the calculation of WSD emission limits, we have implicitly assumed that at any one time only one WSD radiates per pixel/location and per DTT channel[9].

3.40 In practice, a WSDB or multiple WSDBs may provide services (information on available channels and permitted powers) to multiple WSDs in the same geographic area and the same DTT channels. This may result in an aggregation of interferer signal powers and an increased probability of harmful interference to the existing services in the area.

3.41 We believe that such aggregation of interference is unlikely to be problematic in the short term, for the following reasons:

- Our approach for the calculation of WSD emission limits is cautious. The emission limits include implicit margins which will provide some *ex ante* mitigation of interference aggregation.

- Received power reduces rapidly with increasing geographic separation from a transmitter, and as such, experienced interference tends to be dominated by the nearest interferer (which will have been accounted for in the calculations of the WSD emission limits).

- In order for WSDs to coexist, many will implement polite protocols, such as listen-before talk collision avoidance (CSMA/CA) used in Wi-Fi, or frequency hopping used in Bluetooth. In such cases, it is unlikely that WSDs will transmit at the same time and at the same frequencies when in close proximity.

- Received interference reduces rapidly with increasing frequency separation from the interferer. It is likely that as part of their service provision, WSDBs will perform radio resource management for congestion avoidance, and instruct WSDs to

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[9] Note that if a WSD radiates a narrowband signal with a bandwidth that is a fraction, α, of 8 MHz, then the WSD must radiate at a lower (by the same factor α or lower) EIRP. This is because the WSD emission limits are specified both as EIRP (dBm/(8 MHz)) and EIRP spectral density (dBm/(100 kHz)). Furthermore, a WSD which transmits simultaneously over multiple DTT channels must a) comply with the maximum permitted in-block EIRP spectral densities in each of the DTT channels used; and b) radiate with a total in-block EIRP (measured over the total number of DTT channels to be used) which does not exceed the smallest of the maximum permitted in-block EIRPs specified over each of the DTT channels used.

avoid congregation in the same channels when operating in the same geographic area (centralised coordination to assist distributed polite protocols).

- If WSDs did transmit simultaneously and at the same frequencies, the composite signal would increasingly appear noise-like and this would render the time-frequency structure of the composite signal more benign in the context of interference to existing services.

3.42 As such, we do not believe that there is a need to address interference aggregation in the short term. Also note that the final four items above imply that interference is unlikely to aggregate in linear proportion to the number of WSDs.

3.43 In the longer term, we foresee three high-level options for mitigating harmful interference to existing services in the event that interference aggregation were to become a problem:

a) Direct reductions in WSD emission limits

In this approach, Ofcom would specify reductions in the WSD emission limits and communicate these to the WSDBs. These reductions might be calculated because of a change in our modelling assumptions about the number of WSDs radiating in a given location. The reductions might be communicated to WSDBs in the form of explicit power adjustments, or through changes in the parameters specified for both the Ofcom and WSDB calculations.

The reductions might be location-specific and frequency-specific, they might be *ex ante* in light of a predicted risk of interference aggregation, or *ex post* in response to observed/reported cases of harmful interference aggregation.

b) Rule-based reductions in WSD emission limits

Here, Ofcom would specify rules which relate the maximum permitted WSD EIRP at a given location and frequency to the number of WSDs which a WSDB already serves in the proximity of that location. Although not perfect (because other WSDBs might also be serving WSDs in the same location), this has the advantage over option (a) in that a WSDB would be able to use the latest data on the WSD use of the radio resource at a given location (as reported by the WSD channel usage parameters) to manage interference aggregation more efficiently.

There may be cases where the rules might not permit additional WSDs to use the spectrum until existing WSDs ceased transmission, or used the spectrum at lower EIRPs. In this sense, the operation of a WSDB would be similar to the process of call admission control as performed by base stations in a mobile network.

c) Rule-based reductions with inter-WSDB communications

This is an expansion of option (b), whereby WSDBs would develop a mechanism for collecting and aggregating information on the numbers and radio resource usage of WSDs that each WSDB supported at any given location. The WSDBs would then be required to adjust the WSD emission limits based on the aggregated information and according to specific rules defined by Ofcom.

3.44 Each of the options raises different issues which we would need to consider further before making any decisions as to which to pursue. Given that we do not at this stage consider a need to address interference aggregation, we do not propose to consult on them at this stage, but will develop more detailed proposals if and when a need to address interference aggregation arises in the future. However, if stakeholders have views on the high level options discussed above, we would be happy to consider them.

Enhanced mode

3.45 In the framework which we have described, we need to account for a very wide range of WSD use cases and deployment scenarios. For this reason, we need to make certain generic cautious assumptions in our modelling which may not be representative of all cases and scenarios. For example, we have little choice but to be agnostic in relation to factors such as the directionality/polarisation of WSD emissions, or the specificities of interferer victim geometries.

3.46 We refer to this as our *baseline* framework.

3.47 In practice, there will be cases where WSDs might employ directional antennas pointing in benign directions, or where WSDs radiate with a polarity that is orthogonal to that of the victim’s receiver antenna, or where the WSD is far away (or effectively shielded) from the most susceptible victims. It might be possible to exploit such information, where it could be provided to WSDBs, to allow increased TVWS availability in the form of more relaxed WSD emission limits.

3.48 We refer to this an *enhanced* framework. This framework relies on appropriate mechanisms being developed to enable the installer of a WSD to convey certain specified information (such as the examples given above) to a WSDB.

3.49 We may in due course consider the implementation of the enhanced framework. The current consultation, however, relates exclusively to the baseline framework.

Summary

3.50 We have summarised at a high level our approach for calculating the WSD emission limits in relation to the various existing uses of the spectrum inside and outside the UHF TV band.

3.51 We have also explained how the various limits must be reconciled to derive location-specific and frequency-specific in-block EIRP limits P_0 dBm/(100 kHz) and P_1 dBm/(8 MHz) which form the basis of operational parameters which WSDBs communicate to WSDs.

3.52 In the following five sections, we describe details of our coexistence studies, and present our proposals for the various WSD emission limits $P_{\text{WSD-DTT}}$, $P_{\text{WSD-PMSE}}$, $P_{\text{WSD-LA}}$ and $P_{\text{WSD-XB}}$.

Section 4

WSD emission limits in relation to DTT

4.1 In this section we present our proposed *baseline* framework for calculating the maximum permitted in-block EIRP $P_{\mathrm{WSD\text{-}DTT}}(i, F_{\mathrm{WSD}})$ of a WSD which operates at a given geographic location i and in a specific DTT channel F_{WSD}. This emission limit is specified to ensure a low probability of harmful interference to the reception of the DTT service via roof-top aerials.

4.2 As explained in Section 3, Ofcom will calculate the above EIRP limits for all locations in the UK and all DTT channels 21 to 60, accounting for the five WSD spectrum emission classes, three technology (protection ratio) categories, and a number of representative WSD antenna heights, all for type A WSDs. Ofcom will then communicate these to the WSDB providers. The EIRP limits for type B WSDs will be inferred by WSDBs from the limits for type A WSDs.

4.3 Here, we first explain how the DTT network is planned in the UK, and the way in which the UK Planning Model (UKPM) estimates the quality of DTT coverage at different locations in terms of a quantity known as *location probability*.

4.4 We then describe how the EIRP of a WSD relates to a reduction in DTT signal-to-interference-plus-noise-ratio (SINR) and location probability. We show how parameters such as coupling gain (separation between WSD and DTT receiver) and protection ratio (DTT receiver selectivity and WSD spectral leakage) influence this relationship.

4.5 Subsequently, we set out our proposals for the parameter values to be used in calculating the maximum permitted WSD in-block EIRPs. Specifically, we specify values for the:

- probability of a target reduction in DTT SINR;
- WSD-DTT coupling gains; and
- WSD-DTT protection ratios.

4.6 Finally, we present the implications of our proposals on TVWS availability via several numerical examples across the UK and in Central London and Glasgow.

4.7 Note that where we use the term “height”, we mean height above ground level. We reserve the term “altitude” to refer to height above sea level.

4.8 Ideally, given an accurate characterisation of DTT coverage, and information regarding the detailed specifics of individual interference scenarios, we would be able to calculate WSD emission limits which would maximise TVWS availability whilst seeking to ensure a low probability of harmful interference to DTT.

4.9 In practice, our knowledge of the quality of DTT coverage is based on the results of the UKPM. While the UKPM is a sophisticated model, and its output has been calibrated extensively over the years in the context of estimating gross DTT coverage, the UKPM was not designed for purposes of analysing coexistence between DTT and other services. Furthermore, it is not possible to account for the conditions in individual interference scenarios (separations between WSD and DTT receiver, effects of local terrain, etc.), since information at such level of granularity is not available under our baseline framework.

4.10 Consequently, we need to adopt a balanced approach in specifying parameter values for the calculation of WSD emission limits. We believe that the parameter values that we have set out in our proposals account for a broad range of scenarios, and that in combination with our proposed modelling methodology, result in a low probability of harmful interference to DTT.

The modelling of the DTT network in the UK

4.11 The DTT service in the UK is delivered via a multi-frequency network of 80 high power transmitters, complemented by 1076 low power relays.

4.12 The DTT network is planned via the UKPM. This is a modeling tool developed by the broadcasters, and which estimates the extent of DTT coverage by calculating a parameter called the location probability at every 100 m × 100 m geographic pixel across the UK.

4.13 The DTT location probability is defined as the probability with which a DTT receiver would operate correctly at a specific location; i.e., the probability with which the median wanted signal level is appropriately greater than a minimum required value.

4.14 Consider a pixel where the DTT location probability is q_1 in the absence of interference from systems other than DTT. Then we can write (in the linear domain)

$$q_1 = \Pr\left\{ P_\mathrm{S} \ge P_{\mathrm{S},\min} + \sum_{k=1}^{K} r_{U,k} P_{U,k} \right\} = \Pr\{ P_\mathrm{S} \ge P_{\mathrm{S},\min} + V \} = \Pr\{ P_\mathrm{S} \ge U \} \tag{4.1}$$

where $\Pr\{A\}$ is the probability of event A, P_S is the received power of the wanted DTT signal, $P_{\mathrm{S,min}}$ is the DTT receiver's (noise-limited) reference sensitivity level[10], $P_{U,k}$ is the received power of the k^{th} unwanted DTT signal, and $r_{U,k}$ is the DTT-DTT protection ratio (co-channel or adjacent-channel) for the k^{th} DTT interferer.

4.15 The UKPM models both P_S and U as log-normal random variables, i.e., $P_{\mathrm{S}\,(\mathrm{dBm})} \sim \mathrm{N}(m_\mathrm{S}, \sigma_\mathrm{S}^2)$ and $U_{(\mathrm{dBm})} \sim \mathrm{N}(m_U, \sigma_U^2)$, for each pixel in the UK. Then, naturally,

$$q_1 = \Pr\left\{ \frac{P_\mathrm{S}}{U} \ge 1 \right\} = \Pr\left\{ P_{\mathrm{S}\,(\mathrm{dBm})} - U_{(\mathrm{dBm})} \ge 0 \right\} = 1 - \frac{1}{2}\,\mathrm{erfc}\left\{ \frac{1}{\sqrt{2}} \frac{m_\mathrm{S} - m_U}{\sqrt{\sigma_\mathrm{S}^2 + \sigma_U^2}} \right\}. \tag{4.2}$$

4.16 A pixel is considered served by DTT if the location probability for that pixel exceeds 70%. In other words, the location probability is 70% at the edge of DTT coverage.

4.17 It is worth noting that the UKPM calculates location probability with the DTT wanted and unwanted powers modelled at the *50% time* and *1% time* levels, respectively. That is, the DTT unwanted interferer levels correspond to those which might be experienced during nominally 1% of the time over the period of a year as a result of atmospheric phenomena (so-called *ducting*) which cause a significant increase in the received levels of interference. Under normal propagation conditions, the location probability is likely to be considerably greater than predicted by the UKPM.

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[10] $P_{\mathrm{S,min}\,(\mathrm{dBm})} = -75.42 + 20 \log_{10}(f_{(\mathrm{MHz})}/500)$. If $F_{\mathrm{DTT}} \ge 39$, then $P_{\mathrm{S,min}\,(\mathrm{dBm})} \leftarrow P_{\mathrm{S,min}\,(\mathrm{dBm})} + 1$.

4.18 The presence of any interferer naturally results in a reduction of the DTT location probability. Such a reduction is a suitable metric for specifying regulatory emission limits for WSDs operating at DTT frequencies.

Proposed approach for calculation of WSD emission limits

4.19 In the approach adopted by the FCC, WSDs are permitted to radiate at up to a fixed maximum power[11] so long as they are located outside pre-defined geographic exclusion zones. The exclusion zones correspond to areas where the received DTT field strength exceeds a FCC-defined threshold based on FCC-defined propagation models.

4.20 In the approach proposed by Ofcom, there are no explicit exclusion zones. Here, it is the in-block EIRP of the WSDs (rather than their geographic location) that is explicitly restricted. The approach permits WSDs to communicate at greater EIRPs in areas where DTT field strength is greater; i.e., where DTT is more robust to interference.

4.21 The maximum permitted in-block EIRP for a WSD at a given location and in a given channel must be calculated by accounting for the likelihood of harmful interference to DTT reception in all channels 21…60 in the 470-790 MHz band. As illustrated in Figure 4.1, interference to DTT might be co-channel or adjacent channel.

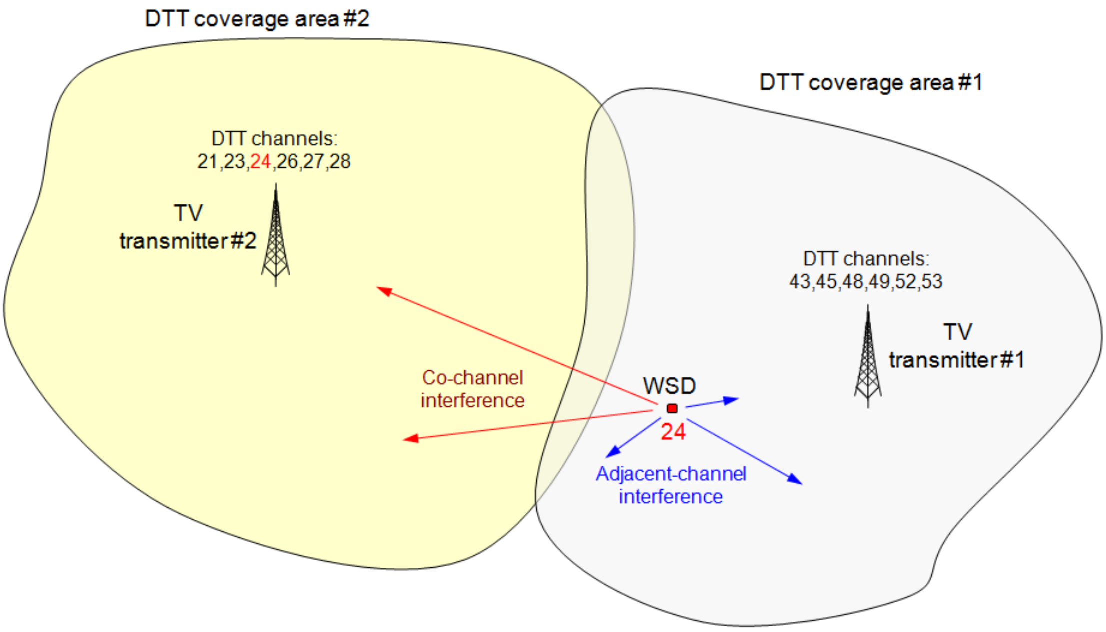

Figure 4.1 – Examples of co-channel and adjacent channel interference to DTT. A WSD has the potential to cause interference to DTT in a number of different pixels.

4.22 The WSD EIRP limits will be constrained by what we refer to as the *most susceptible* DTT pixel. In most cases, this pixel is one that is in the close proximity of the WSD and is subject to co-channel or adjacent channel interference. However, in some circumstances, the most susceptible pixel is far from the WSD and is subject to co-channel interference.

4.23 Under our framework for calculating WSD emission limits, we propose to treat co-channel and adjacent channel interference in the same way. Consequently, we

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[11] This is 36 dBm EIRP for fixed devices.

propose to allow WSDs to operate co-channel with DTT within the coverage area of a DTT transmitter subject to stringent WSD emission limits defined to ensure a low probability of harmful interference. In practice WSDs which operate co-channel with DTT within the coverage area of a DTT transmitter may themselves be exposed to significant levels of interference from DTT and may therefore seek to avoid operating in these channels if possible.

4.24 Furthermore, we propose to cap the maximum in-block EIRP of all WSDs at 36 dBm/(8 MHz) under the baseline framework. We consider that such a cap on the maximum permitted power is important in avoiding the overloading of nearby DTT receivers. This value is also in line with the FCC limit for fixed devices, and is in our view a sensible value which caters for most of the envisaged TVWS use cases.

Question T1: Do you have any comments on our proposal to cap the maximum in-block EIRP of all WSDs at 36 dBm/(8 MHz)?

What happens when a WSD radiates

4.25 Consider a WSD which operates in DTT channel $F_{WSD} = F_{DTT} + \Delta F$, where F_{DTT} is the index of the DTT channel where the DTT service is received with location probability q_1. This is illustrated in Figure 4.2 below.

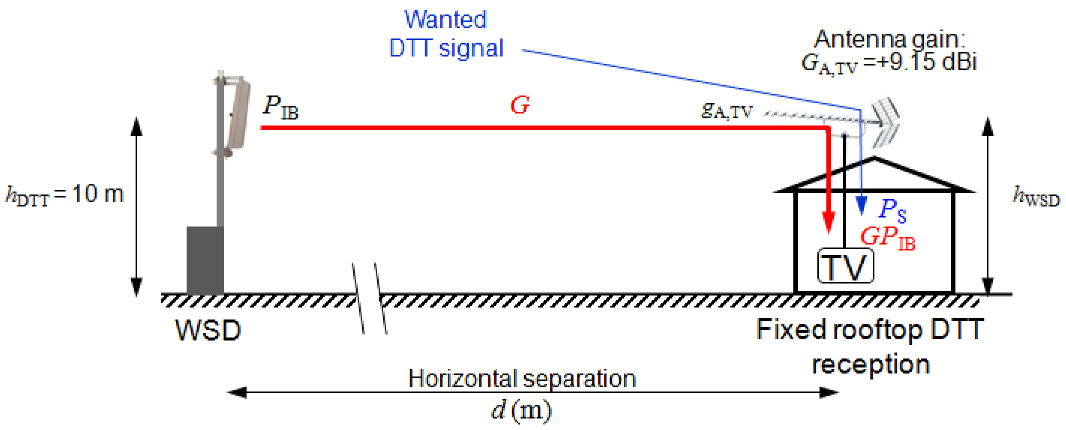

Figure 4.2 – Illustration of interference from a WSD to a DTT receiver.

4.26 Also assume that the WSD radiates with an in-block EIRP of P_{IB} over a channel bandwidth of 8 MHz. The presence of the WSD interferer reduces the DTT location probability from q_1 to q_2.

4.27 Assuming a coupling gain, G, between the WSD and the victim DTT receiver, the WSD interferer power at the DTT receiver is given by the product GP_{IB}. Following the framework of Equation (4.1), we may write (again in the linear domain)

$$q_2 = q_1 - \Delta q = \Pr\left\{ P_S \geq U + r(\Delta F, m_S)\, G\, P_{IB} \right\} \tag{4.3}$$

4.28 The coupling gain, G, includes the WSD transmitter's antenna angular discrimination, propagation/path gain, and the DTT receiver's antenna gain, angular discrimination, and polarization discrimination. The coupling gain accounts for the heights of the interferer and victim, and clutter conditions. The coupling gain may be modelled as a log-normal random variable; i.e., $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$, or simply as a deterministic variable m_G ($\sigma_G = 0$).

4.29 The protection ratio, $r(\Delta F, m_S)$, is defined as the ratio of the received wanted DTT signal power to the received WSD interferer power at the point of failure of the DTT receiver. For the special case of co-channel operation ($\Delta F = 0$) the protection ratio is effectively the signal-to-interference ratio at the point of failure. For $\Delta F \neq 0$, the protection ratio is a function of the spectral *leakage* of the WSD signal into adjacent DTT channels, as well as the *adjacent channel selectivity* (ACS) of the DTT receiver.

4.30 The ACS characterises the overall behaviour of the receiver in response to the adjacent channel interferer, and captures effects ranging from frequency discrimination (i.e., various stages of filtering) to receiver susceptibility to the interferer's signal structure (e.g., inability of the receiver's automatic gain control to respond to large fluctuations in the interferer's power).

4.31 The protection ratio broadly decreases with increasing frequency separation, ΔF, between the WSD and DTT signals. This is with the exception of the so-called "N+9" effect characteristic of superheterodyne receivers where the protection ratio exhibits an increase for a frequency separation of 72 MHz between the wanted and unwanted signals.

4.32 We also model protection ratios as a function of the received median wanted DTT signal power m_S. This dependence implicitly characterises the non-linear behaviour (including hard overload) of the DTT receiver.

Calculation of maximum permitted WSD EIRP

4.33 The objective here is to calculate the maximum permitted WSD in-block EIRP, P_{IB}, such that the reduction in DTT location probability in a given victim pixel does not exceed a pre-defined target value, Δq_{T}.

4.34 A number of approaches exist for solving this problem.

4.35 One approach uses Monte Carlo techniques to generate numerous realisations of the variables P_S, U, r and G in Equation (4.3), and searching for a value of P_{IB} which results in a location probability count of $q_2 = q_{\mathrm{T}} = q_1 - \Delta q_{\mathrm{T}}$. The main advantage of this approach is that it makes no assumptions regarding the distribution of the sums of log-normal random variables. A disadvantage is the potentially large computational complexity, absent efficient rules for selecting a minimum yet sufficient number of Monte Carlo trials.

4.36 Alternatively, a semi-analytical solution can be derived by re-formulating Equation (4.3) in a specific way and using numerical techniques such as Schwartz-Yeh (or its enhanced variants) to characterise the sums of log-normal random variables[12]. This approach is described in Annex 1 and uses an iterative algorithm to calculate P_{IB} in Equation (4.3).

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[12] V.Petrini, H.R.Karimi, "TV white space databases: Algorithms for the calculation of maximum permitted radiated power levels," in *Proc. Dynamic Spectrum Access Networks* (DySPAN), Oct. 2012, Washington – USA.

4.37 Note that the resulting solution to P_{IB} is the maximum permitted WSD in-block EIRP, $P_{\mathrm{WSD\text{-}DTT}}(i, F_{\mathrm{WSD}})$ for a given pixel i and channel $F_{\mathrm{WSD}} = F_{\mathrm{DTT}} + \Delta F$, and will be calculated by Ofcom as discussed in Section 3.

Question T2: Do you have any comments on our approach for calculating WSD emission limits, as expressed in Equation (4.3), in relation to DTT coexistence calculations?

Uncertainty in the locations of DTT receivers

4.38 Here we describe how the WSD-DTT geometries (and hence coupling gains) can be modelled given the inherent uncertainties in the locations of the DTT receivers in relation to a WSD.

4.39 Note that even if the location of a WSD is known precisely, the locations of the DTT receivers are typically not known (at least not as part of our baseline framework). All that is typically known is that a specific number of households are located *somewhere* within a 100 m × 100 m pixel. This uncertainty means that the coupling gains cannot be calculated based on actual separations between WSDs and DTT receivers, but need to be calculated based on pragmatic assumptions.

4.40 Note that the coupling gains used in the TVWS calculations in relation to DTT will be explicitly specified by Ofcom.

Same-pixel geometries

4.41 Here, the DTT pixel of interest is the same as the pixel within which the WSD is located. This is shown in Figure 4.3. Given the uncertainty in the locations of the DTT receiver antennas within the pixel, and the fact that the horizontal coordinates of the WSD itself are only accounted for with a 100 m resolution, we propose to make use of a *reference coupling gain*, G_0.

4.42 A reference coupling gain might be derived from a *reference geometry* which depicts a specific likely geometry between a WSD and a DTT receiver. Alternatively, the reference coupling gain might be derived from the statistical distribution of WSD and DTT receiver antenna locations, heights, and other characteristics. The value of the same-pixel reference coupling gai*n is quite importa*nt, as it represents the highest WSD-DTT coupling gain considered for any WSD location.

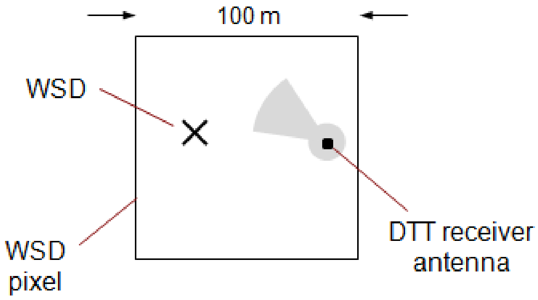

Figure 4.3 – Same-pixel scenarios. A reference coupling gain is proposed.

1^{st} tier pixel geometries

4.43 Here, the DTT pixel of interest is among the 1^{st} tier of eight pixels that surround the pixel within which the WSD is located. This is shown in Figure 4.4. Again, given that the actual locations of the DTT receiver antennas within the pixel are not known, and the fact that the horizontal coordinates of the WSD itself are only accounted for with a 100 m resolution, we propose to make use of the same reference coupling gain, G_0, as for the same-pixel case.

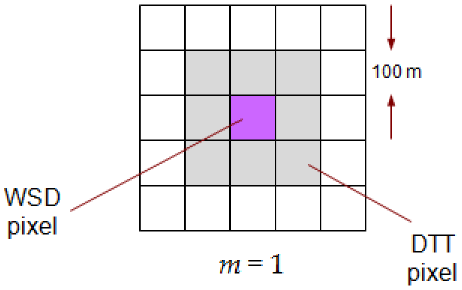

Figure 4.4 – Tier 1 pixel scenarios. A reference coupling gain is proposed.

4.44 This is a pragmatic solution, but one which over-estimates the coupling gain. We propose to partially resolve this over-estimation by calculating the average (rather than the minimum) of the values of $P_{\text{WSD-DTT}}(i, k, F_{\text{WSD}}, F_{\text{DTT}})$ over k, where k is the index of the DTT pixel and in this example covers the WSD pixel and the eight surrounding tier 1 pixels. This is then somewhat akin to thinking of the 9 coloured pixels of Figure 4.4 as one large 300 m × 300 m pixel.

2^{nd} tier pixel ($m \geq 2$) geometries

4.45 Here, the DTT pixel of interest is among the 2^{nd} tier of pixels that surround the pixel within which the WSD is located. This is shown in Figure 4.5. As can be seen, sixteen distinct coupling gains $G_{2,n}$ $n = 1\ldots16$ apply in such cases.

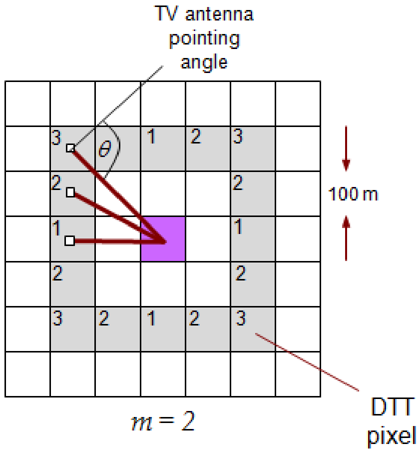

Figure 4.5 – Tier 2 pixel scenarios, with three types of WSD/DTT pixel geometries. The coupling gains (excluding antenna angular discrimination) to pixels 1, 2, and 3 are specified as $G'_{2,1}$, $G'_{2,2}$ and $G'_{2,3}$, respectively.

4.46 Crucially, the increased separation between the WSD and examined DTT pixels means that the angular discrimination which results from the horizontal orientation of the DTT receiver antennas (pointing at the relevant TV transmitter) can make a substantial contribution to the values of the coupling gain.

4.47 We propose to generate the 16 values based on three unique reference coupling gains $G'_{2,n}$ $n = 1\ldots3$ which purely account for the geometries (including pixel separations and transmitter/receiver heights), and then complement these with additional gain terms to account for the horizontal orientation of the DTT receiver antennas (these orientations will be available from the DTT network plan).

mth tier pixel (m ≥ 3) geometries

4.48 Here, the DTT pixel of interest is among the m^{th} tier ($m \geq 3$) of pixels that surround the pixel within which the WSD is located. With growing separation between the WSD and victim pixels, the uncertainty in the locations of the DTT receivers plays an increasingly lesser role. In other words, the pixel separations become better proxies for the actual interferer-victim separations, and so reference geometries are no longer required.

4.49 As such, the coupling gains can be derived via path loss models which account for the pixel separations. As in the case of 2nd tier pixels, these are then complemented with additional gain terms to account for the horizontal orientation of the DTT receiver antennas. This is illustrated in Figure 4.6.

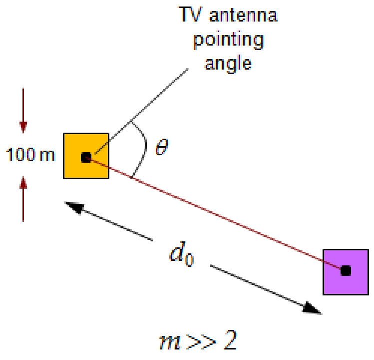

Figure 4.6 – Tier 3 pixels and beyond.

Question T3: Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of DTT receivers in relation to DTT calculations?

Proposed parameter values

4.50 We refer back to Equation (4.3) which identifies the relationship between WSD in-block EIRP, P_{IB}, and the reduction in location probability, Δq, where

$$q_2 = q_1 - \Delta q = \Pr\left\{ P_{\text{S}} \geq U + r\,G\,P_{\text{IB}} \right\}. \qquad (4.4)$$

4.51 The parameter values to be specified are as follows:

- A maximum (target) reduction in location probability, Δq_T
- The protection ratio, r_T
- The coupling gain, G_T

4.52 In defining the above parameter values, it is important to account for another key parameter. This is the likelihood, L, that the reduction in location probability exceeds the target Δq_T, given the selected values G_T and r_T for the protection ratio and coupling gain, respectively. In short,

$$L = \Pr\{\,\Delta q > \Delta q_T\,\} = \Pr\left\{r\,G > r_T G_T\right\} = \Pr\left\{r > r_T\right\}\Pr\left\{G > G_T\right\} \tag{4.5}$$

where the coupling gain and protection ratio are assumed to be independent random variables.

4.53 We propose a likelihood of $L = 0.1$ (or 10%). That is to say, once a WSD radiates, we expect a 10% likelihood that the resulting reduction in location probability, Δq, at a DTT receiver exceeds the intended target, Δq_T.

4.54 We further propose to split this likelihood equally into exceedance likelihoods of roughly 30% for each of the protection ratio and coupling gain, i.e.,

$$\Pr\left\{r > r_T\right\} = \Pr\left\{G > G_T\right\} = 0.3. \tag{4.6}$$

4.55 An exceedance likelihood of 10% might appear too high in the context of ensuring a low probability of harmful interference from licence exempt WSDs to licensed services. However, the 10% figure needs to be considered in conjunction with the target reduction in location probability (see below).

Proposed target reduction in DTT location probability

4.56 We propose a target reduction in signal-to-noise-plus-interference ratio (SINR) of 1 dB at the edge of coverage of a DTT transmitter. This is equivalent to a 1 dB rise in the noise-plus-interference floor (also known as desensitisation).

4.57 A 1 dB desensitisation corresponds to an interference-to-noise ratio (INR) of roughly -6 dB, where noise refers to both thermal noise and self-interference within a radio system. Coexistence studies typically assume an INR of somewhere between -10 dB to +0 dB (and sometimes even greater).

4.58 A 1 dB rise in the noise-plus-interference floor at the edge of coverage is a common technical assumption in coexistence studies. This is because wireless systems are usually engineered to operate at a safe margin above expected levels of noise-plus-interference, and as a result, a 1 dB rise is not considered to result in perceptible interference in practice.

4.59 We consider, therefore, that a 1 dB desensitisation is a reasonable criterion in the context of our model-based framework and a 10% likelihood that this might be exceeded.

4.60 Furthermore, in practice, the actual desensitisation is likely to be lower than the assumed 1 dB, due to the presence of existing man-made interference.

4.61 According to the principles of DTT network planning in the UK, the edge of DTT coverage is defined as a location where the location probability is 70% as estimated by the UKPM; i.e., where $q_1 = 0.7$. Here, a 1 dB desensitisation corresponds to a 7 percentage point reduction in location probability; i.e., $\Delta q_T = 0.07$. This is illustrated in the left hand chart of Figure 4.7 for a noise-limited scenario ($V = 0$). Here, the wanted signal is modelled as $P_S \sim N(m_S, \sigma_S^2)$, where for $P_{S,min}$ = -75.9 dBm/(8 MHz) at 474 MHz and σ_S = 5.5 dB (as assumed by the UKPM), m_S is set to -73 dBm/(8 MHz) for a starting location probability of $q_1 = 0.7$.

4.62 As described earlier, we propose to allow greater WSD emission limits in areas where the received DTT signal strength is greater (where DTT reception is more robust to interference). This can be achieved by maintaining a fixed reduction in location probability at all locations within the coverage area of a DTT transmitter.

4.63 The above principle is illustrated in Figure 4.8, which shows the rise in the noise-plus-interference floor (desensitisation) and interference-to-noise-ratio (INR) as a function of received DTT signal strength for a 7 percentage point reduction in location probability. The rise in the interference floor directly relates to the increased WSD emission limits.

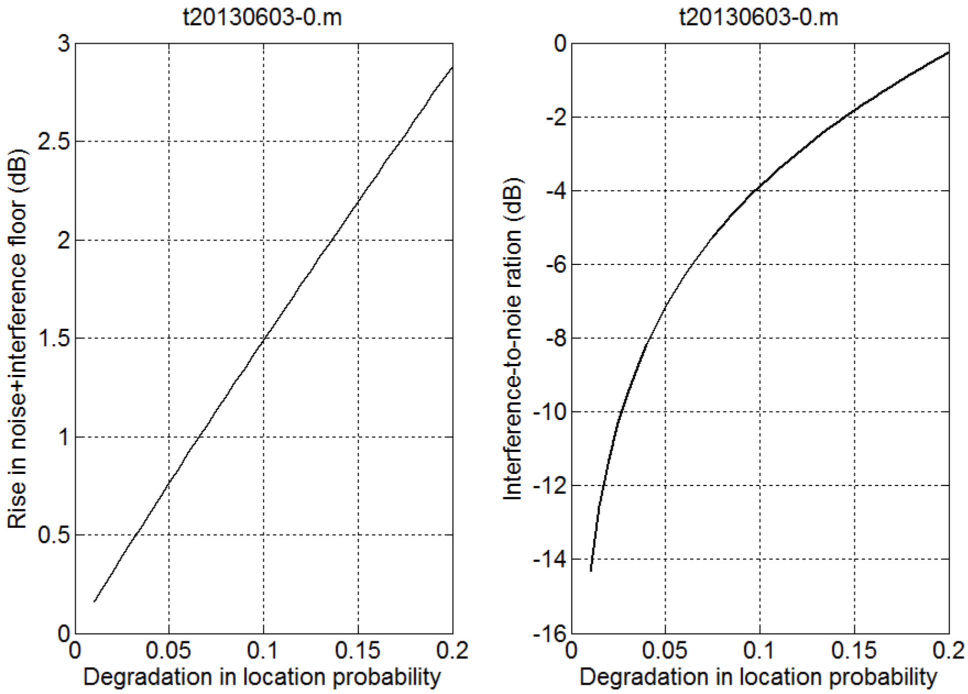

Figure 4.7 – Rise in the noise floor (desensitisation) and interference-to-noise ratio (INR) as a function of reduction in location probability from a starting value of 70%.

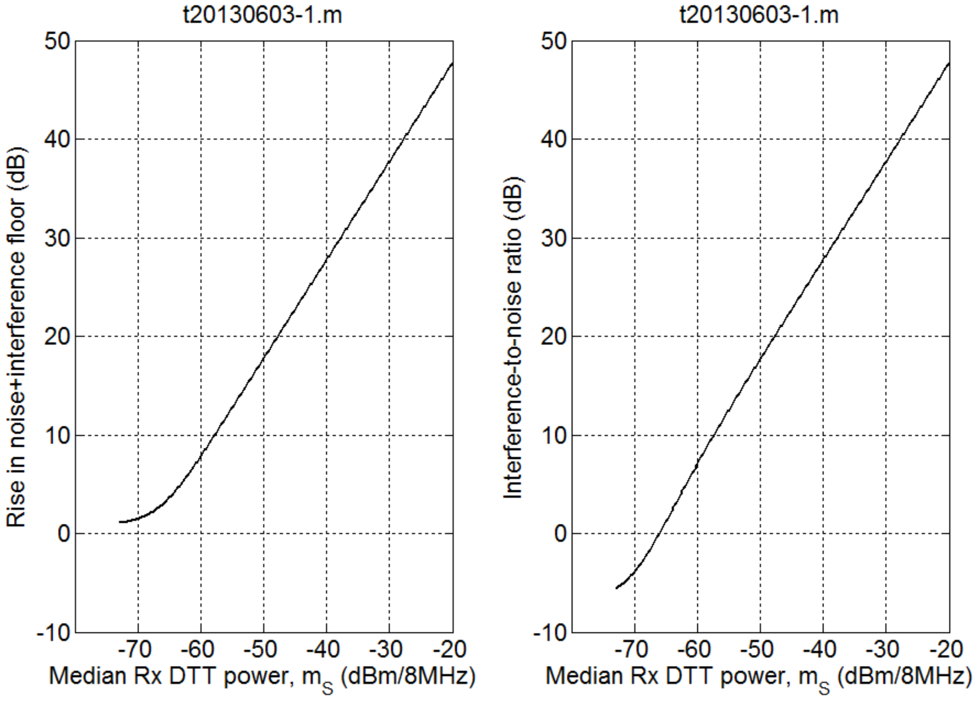

Figure 4.8 – Rise in the noise floor (desensitisation) and interference-to-noise ratio (INR) as a function of received DTT signal power.

4.64 Taken together, we believe that a 10% probability of a 1 dB rise in the edge of coverage noise-plus-interference floor (or a 7 percentage point reduction in location probability), implies a low probability of harmful interference to DTT in practice. In reaching this conclusion, we have given due consideration to recent evidence from LTE base station deployments in the 800 MHz band. These indicate that the observed cases of interference to DTT are substantially fewer than predicted by a similar modelling of the impact of interference on DTT location probability.

Question T4: Do you have any comments on our proposed target of a 10% likelihood of a 1 dB rise in the noise-plus-interference floor at the edge of DTT coverage?

Proposed coupling gains

4.65 The coupling gain, G, is defined as the ratio of the WSD power arriving at the input to a DTT receiver divided by the power radiated by the WSD. The coupling gain is a function of the locations of the WSD antenna and DTT receiver antenna, antenna directionalities, antenna polarisations, and the DTT receiver antenna gain. Specifically, the coupling gain may be written (in the linear domain) as

$$G = g_{\mathrm{A,WSD}}(\alpha) \times G_{\mathrm{P}} \times G_{\mathrm{A,TV}} \times g_{\mathrm{A,TV}}(\beta) \times g_{\mathrm{Polar,TV}}(\beta), \quad (4.7)$$

where

$g_{\mathrm{A,WSD}}(\alpha)$	is the WSD antenna angular discrimination, along the relevant *cone* angle α w.r.t. antenna boresight,
G_{P}	is the propagation/path gain,
$G_{\mathrm{A,TV}}$	is the DTT receiver antenna gain,
$g_{\mathrm{A,TV}}(\beta)$	is the DTT receiver antenna angular discrimination,

along the relevant *cone* angle β w.r.t. antenna boresight,

$g_{\mathrm{Polar,TV}}(\beta)$ is the DTT receiver antenna polarisation discrimination, along the relevant *cone* angle β w.r.t. antenna boresight.

4.66 In short, if a WSD radiates with power, P, then the power received at the input to a TV receiver is given by the product GP, *where* $G < 1$. Note that the coupling gain does not include the WSD antenna gain, since the reference is radiated (post antenna) power rather than conducted (pre-antenna) transmit power.

4.67 In our calculations of TVWS availability, we do not account for the WSD antenna angular discrimination or the DTT receiver antenna polarisation discrimination; i.e., we assume that $g_{\mathrm{A,WSD}} = g_{\mathrm{Polar,TV}} = 1$. This is because information on the orientation and polarisation of the WSD antenna will not be available under our baseline framework.

4.68 Ofcom will generate TVWS availability datasets for WSD heights of 1.5, 5, 10, 15, 20, and 30 metres (based on corresponding coupling gains) and will communicate these to WSDBs.

4.69 Where the height of the WSD is reported, we propose that WSDBs select the TVWS availability dataset corresponding to the nearest height among the above list. Where the height of the WSD is not reported, we propose that WSDBs select the dataset calculated by Ofcom based on specific default heights (see later).

Type A devices

4.70 We now describe the modelling of coupling gains for type A (fixed) WSDs.

a) Same-pixel and tier 1 pixel scenarios

4.71 This refers to cases where the WSD and DTT receiver are located in the same pixel or immediately adjacent pixels (see Figure 4.4).

4.72 To derive an appropriate coupling gain for such cases, we have used the UK-wide statistics of *nearest neighbour* household address separations provided by Digital UK, as a proxy for the statistics of nearest neighbour WSD-DTT antenna separations. We acknowledge that such statistics are not a perfect proxy for the wide range of WSD installations in specific locations, but we believe they capture the type of antenna separations one might expect. The nearest neighbour separation statistics are shown in Figure 4.9.

4.73 Note that the statistics include a minimum separation of 2 metres. We understand that this is an artefact of the source of the data which uses a variety of locations ranging from somewhere in the dwelling through to the precise location of the postal delivery point. We believe that a separation of 2 metres is too small a value in the context of coexistence studies.

4.74 We consider that minimum values of 5, 10, and 20 metres are more representative of nearest neighbour line-of-sight WSD-DTT antenna separations in urban, suburban, and rural environments[13]. We believe that these are reasonable assumptions given the wide variety of possible WSD installations.

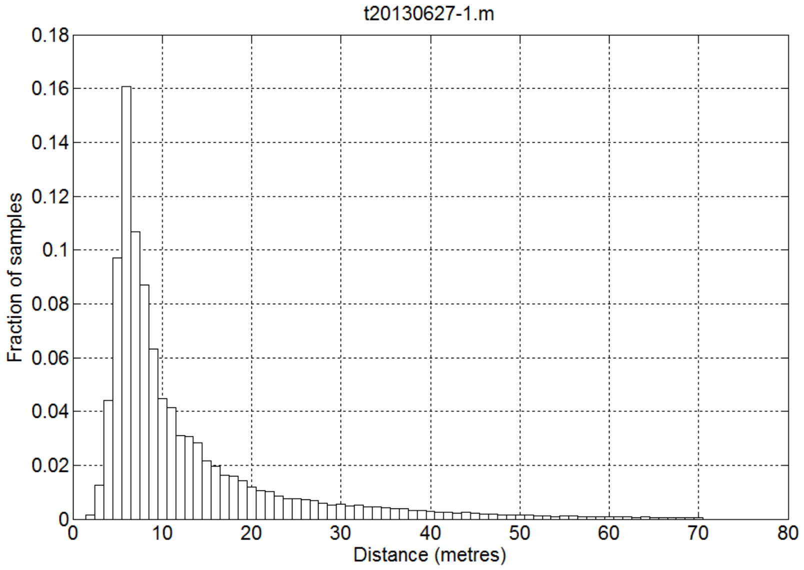

Figure 4.9 – Nearest neighbour household separations. Source: Digital UK.

4.75 Figures 4.10(a)-(c) illustrate the coupling gain statistics which results from the nearest neighbour statistics for minimum separations of 5, 10, and 20 metres. The path gain G_{P} is modelled via the SEAMCAT extended Hata propagation model's urban, suburban, and open profiles[14]. To model the angular discrimination $g_{\mathrm{A,TV}}$ of the DTT receiver antenna, we have assumed a uniformly distributed random horizontal angle between the WSD and DTT transmitter as observed at the DTT receiver antenna. We have accounted for vertical angular discrimination at the DTT receiver antenna according to the WSD-DTT antenna separations and heights. Finally, we have assumed that the DTT antenna's directional pattern $g_{\mathrm{A,TV}}$ follows the ITU-R BT.419-3 specification, with a gain $G_{\mathrm{A,TV}}$ of 9.15 dBi (including cable loss).

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[13] In cases where both the WSD and DTT antennas are installed on the rooftop of the same house, the installer can take appropriate measures to avoid large coupling gains.

[14] See the SEAMCAT manual at http://tractool.seamcat.org/wiki/Manual.

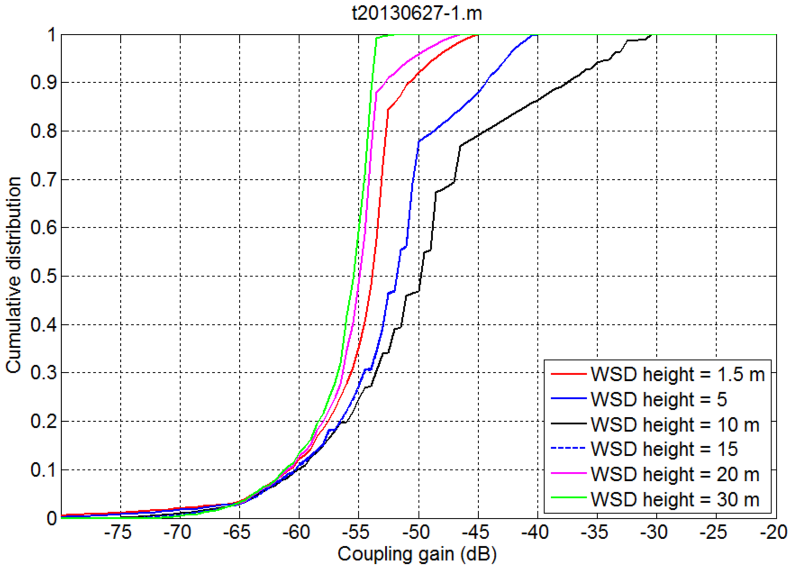

Figure 4.10(a) – Coupling gain statistics at 474 MHz for same-pixel and tier 1 pixel scenarios. These account for DTT receiver antenna discrimination.
Minimum nearest neighbour separation is set to 5 metres.
The curves for heights of 5 and 15 metres overlap.

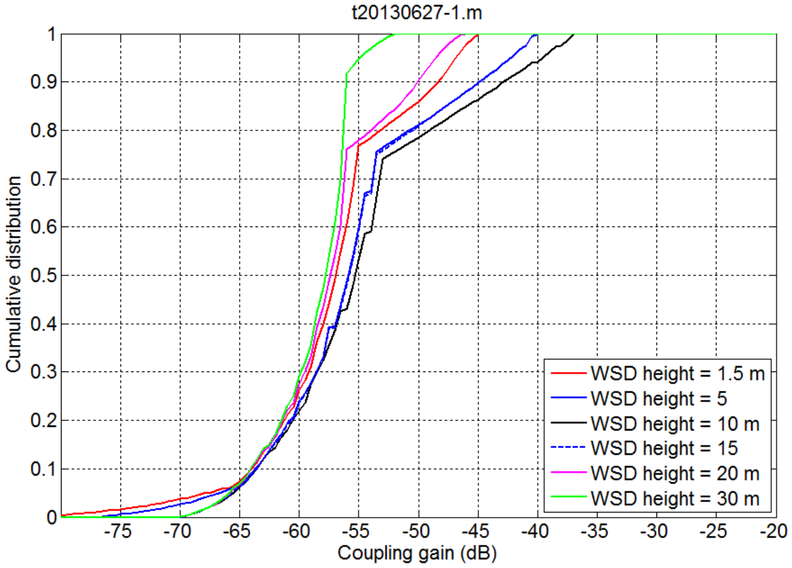

Figure 4.10(b) – Coupling gain statistics at 474 MHz for same-pixel and tier 1 pixel scenarios. These account for DTT receiver antenna discrimination.
Minimum nearest neighbour separation is set to 10 metres.
The curves for heights of 5 and 15 metres overlap.

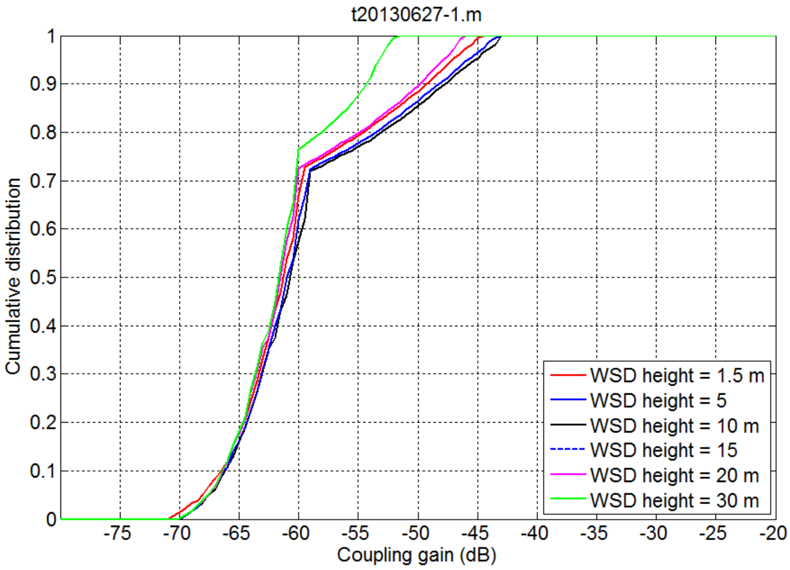

Figure 4.10(c) – Coupling gain statistics at 474 MHz for same-pixel and tier 1 pixel scenarios. These account for DTT receiver antenna discrimination. Minimum nearest neighbour separation is set to 20 metres. The curves for heights of 5 and 15 metres overlap.

4.76 As explained before, we propose to use coupling gain values which correspond to a 30% exceedance probability (70th percentile). With reference to Figures 4.10(a)-(c), the proposed reference coupling gains, G_0, for same-pixel or tier 1 pixel geometries are presented in Table 4.1 for a number of WSD antenna heights (above ground). Note that the maximum coupling gain occurs at a WSD antenna height of 10 metres, which is the same as the assumed height of the DTT receiver rooftop antennas.

Table 4.1(a). Proposed 70th percentile coupling gains at 474 MHz for same-pixel and tier 1 pixel scenarios. These account for DTT receiver antenna angular discrimination. Minimum nearest neighbour separation is set to 20, 10, and 5 metres for open, suburban, and urban environments.

WSD antenna height	Coupling gain, G_0 (dB) (open, suburban, urban)
1.5 metres	-60, -55, -53
5 metres	-59, -54, -51
10 metres	-59, -53, -47
15 metres	-59, -54, -51
20 metres	-60, -56, -54
30 metres	-60, -57, -55

4.77 Where the WSD height is not reported, we propose to use a cautious default height of h_{WSD} = 10 metres to derive the relevant TVWS availability dataset.

4.78 The values of G_0 in the above table are quoted at 474 MHz. These will be translated to a frequency of f MHz by adding a term $20\ \log_{10}(474/f)$.

b) Tier 2 pixel scenarios

4.79 This refers to cases where the DTT pixel of interest is in the second tier of pixels which surround the WSD pixel (see Figure 4.5).

4.80 Here it is the pixel separation, rather than the nearest neighbour antenna separation, which is more relevant in calculating the coupling gains. For this reason, we propose to model the coupling gains based on the statistics of WSD-DTT antenna separations, assuming uniform spatial distributions of WSDs and DTT antennas in their respective pixels. We again propose to model the path gain G_P via the SEAMCAT extended Hata propagation model using the urban, suburban, and open profiles. A DTT receiver antenna gain $G_\mathrm{A,TV}$ of 9.15 dB is assumed (including cable loss). Note that at this point, the angular discrimination $g_\mathrm{A,TV}$ of the DTT antenna is not yet accounted for, and will be addressed separately. Figure 4.11 shows an example of the resulting coupling gain statistics.

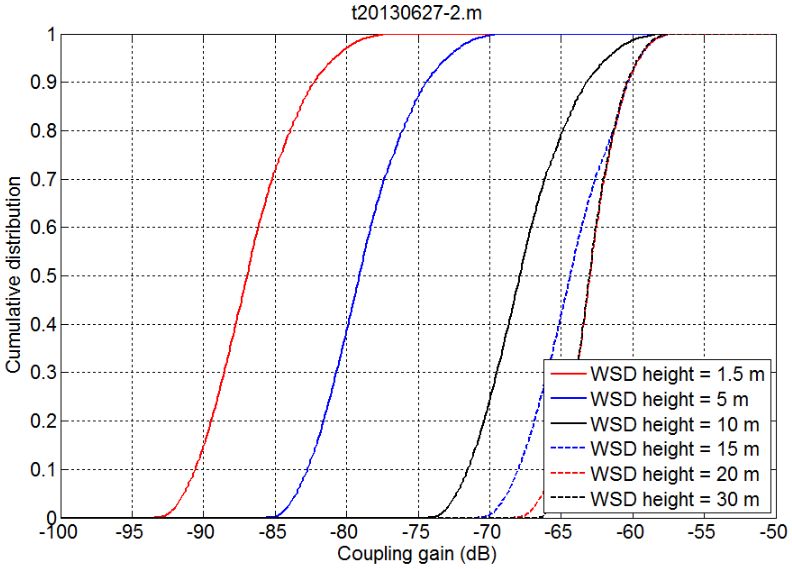

Figure 4.11 – Coupling gain ($G'_{2,1}$) statistics for a tier 2 pixel scenario (suburban). These do not account for DTT receiver antenna angular discrimination.

4.81 Again, we propose to use coupling gain values corresponding to a 30% exceedence probability (70th percentile). The proposed reference coupling gains $G'_{2,i}$ are presented in Table 4.2 for a number of WSD antenna heights (above ground).

Table 4.2. Proposed 70th percentile coupling gains for tier 2 pixel scenarios. These do not account for DTT receiver antenna angular discrimination.

	Tier 2: Coupling gain (open, suburban, urban)		
	Type 1 pixel	Type 2 pixel	Type 3 pixel
WSD antenna height	$G'_{2,1}$ (dB)	$G'_{2,2}$ (dB)	$G'_{2,3}$ (dB)
1.5 metres	-68, -85, -94	-69, -87, -96	-73, -91, -99
5 metres	-62, -77, -86	-63, -79, -88	-65, -83, -92
10 metres	-62, -66, -75	-63, -68, -76	-65, -72, -80
15 metres	-62, -63, -71	-63, -65, -73	-65, -68, -77
20 metres	-62, -62, -69	-63, -63, -70	-65, -66, -74
30 metres	-62, -62, -65	-63, -63, -67	-65, -65, -71

4.82 Where the WSD height is not reported, we propose to use a cautious default height of h_{WSD} = 30 metres to derive the relevant TVWS availability dataset.

4.83 The values of $G'_{2,i}$ in the above table are quoted at 474 MHz. These will be translated to a frequency of f MHz by adding a term $20 \log_{10}(474/f)$.

4.84 For each tier 2 pixel, we propose to explicitly account for horizontal angular discrimination $g_{\mathrm{A,TV}}(\theta)$ at the DTT receiver antenna by calculating the horizontal angle, θ, between the bore-sight of the DTT receiver antenna (“preferred service area” pointing angle) and the line joining the WSD and DTT pixel centres (see Figure 4.5). The overall coupling gain will then be given as $G_{2,i\ (\mathrm{dB})} = G'_{2,i\ (\mathrm{dB})} + g_{\mathrm{A,TV}}(\theta)_{(\mathrm{dB})}$. We assume that the DTT receiver antenna’s directional pattern $g_{\mathrm{A,TV}}$ follows the ITU-R BT.419-3 specification.

c) Tier 3 pixel scenarios (and beyond)

4.85 This refers to cases where the DTT receiver pixel of interest is in the third tier of pixels which surround the WSD pixel (see Figure 4.6).

4.86 For tier 3 and beyond, the uncertainty in the locations of the DTT receiver antenna becomes increasingly less relevant. This is because the propagation loss becomes increasingly dictated by the much larger separations between the WSD pixel and the DTT receiver pixel. However, the prediction of propagation loss also becomes more difficult as factors such as terrain features and man-made obstacles begin to play a greater role.

4.87 We propose to calculate the coupling gain, G, using the extended Hata path loss model. This will be a function of centre-to-centre horizontal separation between the WSD and DTT pixels, the WSD antenna height (DTT antenna height of 10 metres), the clutter type (urban/suburban/open) of the DTT pixel, and the pointing angle of the DTT antenna.

4.88 Where the WSD height is not reported, we propose to use a cautious default height of h_{WSD} = 30 metres to derive the relevant TVWS availability dataset.

4.89 We propose to account for horizontal angular discrimination $g_{\mathrm{A,TV}}(\theta)$ at the DTT receiver antenna by calculating the horizontal angle, θ, between the bore-sight of the DTT receiver antenna (“preferred service area” pointing angle) and the line joining the WSD and DTT pixel centres (see Figure 4.6).

4.90 As usual, we assume that the DTT receiver antenna's directional pattern $g_{\mathrm{A,TV}}$ follows the ITU-R BT.419-3 specification, with a gain $G_{\mathrm{A,TV}}$ of 9.15 dBi (including cable loss).

4.91 It is customary to model the coupling gain G as a log-normal random variable where $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$, with median m_G derived via an empirical propagation model. The standard deviation, σ_G , then captures the uncertainty around the median. This is the approach we adopted in the co-existence studies at 800 MHz, where m_{G} was derived from (suburban) extended Hata, and σ_G was set to a value of 5.5 dB.

4.92 Given our framework of working with the 70th percentile of coupling gain, we might model $G_{(\mathrm{dB})}$ as $m_G + 0.52\sigma_G$. Here, however, here propose to derive m_{G} from the extended Hata model, but we propose to use $\sigma_G = 0$ dB. This is because the Hata model tends to over-estimate path gain as compared to many of the more sophisticated models (such as 1546), and as such, we consider that the addition of an additional extra margin to the median coupling gain is too cautious. However, in order to capture the range of different propagation environments, we propose to use the open, suburban, and urban profiles of the extended Hata model depending on the clutter type of the DTT receiver's pixel.

4.93 Examples of the path loss given by the extended Hata model for a number of antenna heights are presented in Annex 2.

Type B devices

4.94 The modelling of coupling gains for type B (portable/mobile) WSDs are described next. These are modelled in the same way as for type A WSDs, but subject to the following conditions:

a) Where the WSD height is reported, and this is greater than 2 metres, the WSD will be assumed to be located indoors. Here a nominal building penetration loss of 7 dB will be subtracted from the type A coupling gains (added to the WSD emission limits).

b) Where the WSD height is not reported, we propose that a default height of $h_{\mathrm{WSD}} = 1.5$ metres (outdoor) be used in all cases.

Question T5: Do you have any comments on our proposed approach for calculating coupling gains in relation to DTT calculations?

Proposed WSD-DTT protection ratios

Protection ratio measurements

4.95 As noted earlier, the WSD-DTT protection ratio is defined as the ratio of wanted DTT signal power (in 8 MHz) over unwanted WSD signal power (in 8 MHz) at the point of DTT receiver failure.

4.96 We recently commissioned the Digital TV Group (DTG) to undertake a series of measurements of WSD-DTT protection ratios. The measurements involved a WSD based on the Weightless technology standard[15], and fifty of the top-selling DVB-T

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[15] http://www.weightless.org/about/what-is-weightless

receivers on the UK market. The details of the measurement procedures and the post processing of the results are presented in Annex 4.

4.97 The Weightless WSD was a base station transmitting a QPSK modulated wideband (8 MHz) signal, consisting of bursts of duration 3.5 ms repeating every 10 ms. The signal was filtered to improve its adjacent channel leakage ratio (ACLR) prior to its application to the DTT receivers.

4.98 For each wanted signal power C = {-70,-60, -50,-30} dBm at the input of the DTT receivers, the interferer (unwanted) power I at the point of receiver failure was recorded at a number of channel offsets ΔF. The point of failure was defined as the point of picture break-up, observed in the form of blocking or pixelation. The ratio C over I (each in units of mW) is the measured protection ratio $r_{\mathrm{M}}(C, \Delta F)$.

4.99 These measurements were subsequently post processed to derive the adjacent channel selectivity, $\mathrm{ACS}(C, \Delta F)$, of the DTT receivers. Then the adjacent channel leakage ratios, $\mathrm{ACLR}(\Delta F)$, for the five WSD spectrum emission masks of EN 301 598 (see Section 2) were combined with the derived selectivity values, to calculate *class-specific* protection ratios $r(C, \Delta F)$ for each of the fifty DTT receivers.

4.100 Finally, for each value of $C = C_0$ and $\Delta F = \Delta F_0$ the cumulative distribution of the fifty protection ratios $r(C_0, \Delta F_0)$ (scaled by the market sales figures for each DTT receiver) was calculated and the 70th percentile value was recorded.

4.101 Figure (4.12) shows an example of the resulting C and I values for $r(C, \Delta F)$ at ΔF = +1 (immediate adjacency) and a class 1 WSD spectrum emission mask. Figure (4.13) shows the cumulative distribution of the protection ratios r for C = -60 dBm.

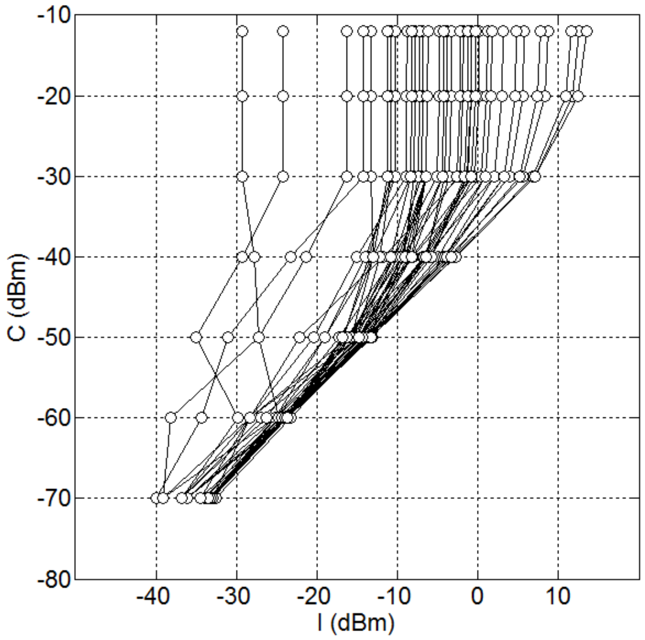

Figure 4.12 – Post processed class-specific protection ratios (C vs. I) for immediate channel adjacency (ΔF = +1) and WSDs with class 1 spectrum emission mask.

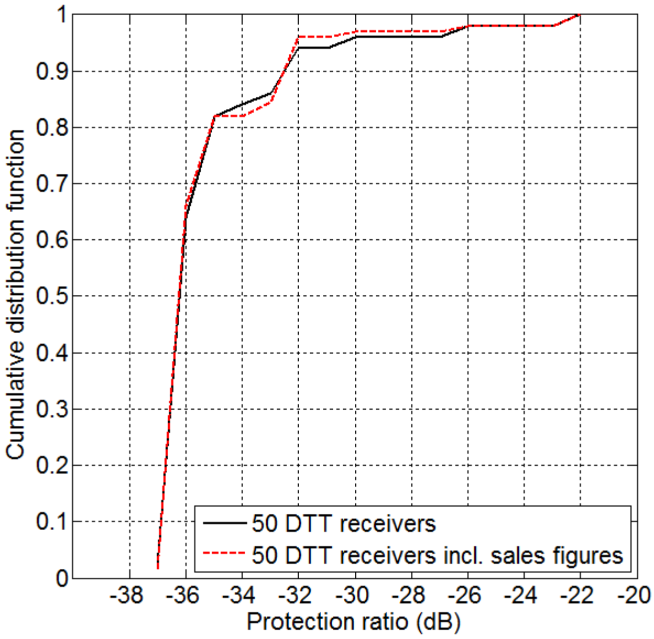

Figure 4.13 – Cumulative distribution of class-specific protection ratios for immediate channel adjacency ($\Delta F = +1$), $C = -60$ dBm, and WSDs with class 1 spectrum emission mask.

4.102 The protection ratios at the 70th percentile level for a number of C and ΔF values are presented in Tables 4.3(a)-(e). For $\Delta F = 0$, the co-channel protection ratio is 17 dB. We propose to use these protection ratios for the calculation of WSD emission limits in relation to DTT in the Ofcom pilot.

Table 4.3(a). Proposed protection ratios for class 1 WSDs.

$r(C, \Delta F)$ (dB)	C (dBm/8MHz)						
Channel separation	≤ -70	-60	-50	-40	-30	-20	-12
$\Delta F = \pm 1$	-36	-36	-35	-30	-24	-14	-6
$\Delta F = \pm 2$	-42	-41	-39	-33	-26	-16	-8
$\Delta F = \pm 3$	-45	-40	-40	-34	-28	-18	-10
$\Delta F = \pm 4$	-55	-49	-44	-37	-29	-19	-11
$\Delta F = \pm 8$	-58	-57	-47	-39	-30	-20	-12
$\Delta F = +9$	-47	-43	-39	-35	-28	-18	-10
$\Delta F = -9$	-60	-58	-48	-39	-30	-20	-12
$\lvert\Delta F\rvert \geq \pm 10$	-62	-58	-48	-39	-29	-19	-11

Table 4.3(b). Proposed protection ratios for class 2 WSDs.

$r(C, \Delta F)$ (dB)	C (dBm/8MHz)						
Channel separation	≤ -70	-60	-50	-40	-30	-20	-12
$\Delta F = \pm 1$	-36	-36	-35	-30	-24	-14	-6
$\Delta F = \pm 2$	-38	-37	-36	-31	-25	-16	-8
$\Delta F = \pm 3$	-38	-36	-36	-32	-27	-18	-10
$\Delta F = \pm 4$	-47	-45	-42	-36	-29	-19	-11
$\Delta F = \pm 8$	-55	-54	-47	-39	-30	-20	-12
$\Delta F = +9$	-47	-43	-39	-35	-28	-18	-10
$\Delta F = -9$	-59	-56	-48	-39	-30	-20	-12
$\|\Delta F\| \geq \pm 10$	-62	-58	-48	-39	-29	-19	-11

Table 4.3(c). Proposed protection ratios for class 3 WSDs.

$r(C, \Delta F)$ (dB)	C (dBm/8MHz)						
Channel separation	≤ -70	-60	-50	-40	-30	-20	-12
$\Delta F = \pm 1$	-28	-27	-27	-25	-23	-14	-6
$\Delta F = \pm 2$	-38	-37	-36	-31	-25	-16	-8
$\Delta F = \pm 3$	-45	-40	-40	-34	-28	-18	-10
$\Delta F = \pm 4$	-55	-49	-44	-37	-29	-19	-11
$\Delta F = \pm 8$	-58	-57	-47	-39	-30	-20	-12
$\Delta F = +9$	-47	-43	-39	-35	-28	-18	-10
$\Delta F = -9$	-60	-58	-48	-39	-30	-20	-12
$\|\Delta F\| \geq \pm 10$	-62	-58	-48	-39	-29	-19	-11

Table 4.3(d). Proposed protection ratios for class 4 WSDs.

$r(C, \Delta F)$ (dB)	C (dBm/8MHz)						
Channel separation	≤ -70	-60	-50	-40	-30	-20	-12
$\Delta F = \pm 1$	-18	-17	-17	-17	-17	-13	-7
$\Delta F = \pm 2$	-28	-27	-27	-26	-24	-15	-8
$\Delta F = \pm 3$	-38	-36	-36	-32	-27	-18	-10
$\Delta F = \pm 4$	-47	-45	-42	-36	-29	-19	-11
$\Delta F = \pm 8$	-55	-54	-47	-39	-30	-20	-12
$\Delta F = +9$	-47	-43	-39	-35	-28	-18	-10
$\Delta F = -9$	-59	-56	-48	-39	-30	-20	-12
$\|\Delta F\| \geq \pm 10$	-62	-58	-48	-39	-29	-19	-11

Table 4.3(e). Proposed protection ratios for class 5 WSDs.

$r(C, \Delta F)$ (dB)	C (dBm/8MHz)						
Channel separation	$\leq$ -70	-60	-50	-40	-30	-20	-12
$\Delta F = \pm 1$	-7	-6	-6	-7	-7	-6	-4
$\Delta F = \pm 2$	-17	-16	-16	-16	-16	-13	-7
$\Delta F = \pm 3$	-28	-27	-27	-26	-25	-17	-10
$\Delta F = \pm 4$	-38	-37	-36	-32	-28	-19	-11
$\Delta F = \pm 8$	-48	-47	-44	-37	-30	-20	-12
$\Delta F = +9$	-46	-43	-39	-35	-28	-18	-10
$\Delta F = -9$	-55	-53	-46	-38	-30	-20	-12
$\lvert\Delta F\rvert \geq \pm 10$	-61	-58	-48	-39	-29	-19	-11

4.103 We note the following points in relation to the measured protection ratios r_M and the calculated class-specific protection ratios r:

a) Protection ratios r_M were not measured for values of C below -70 dBm. For these values of C we have assumed that r_M and r remain unchanged from their value at C = -70 dBm. This is a reasonable assumption given the linear operation of receivers for these values of C.

b) Protection ratios r_M were not measured for values of C above -30 dBm. For these values of C we have assumed hard overload of the receiver; i.e., r_M in dB increases proportionally with C in dBm (vertical C vs. I curves). This over-estimates the protection ratios, particularly at small frequency separations. However, WSD emission limits at such high values of C are more likely to be restricted by the 36 dBm cap, rather than by the protection ratios.

c) Protection ratios r_M were not measured at C = -40 dBm. The protection ratios at this level were derived via linear interpolation of the protection ratios measured at C = -50 and -30. We propose to use similar interpolation of the class-specific protection ratios r for values of C which do not appear in Tables 4.3(a)-(e). This is common practice for purposes of modelling.

d) Protection ratios r_M were not measured at negative frequency separations ($F_{WSD} < F_{DTT}$). We propose to use the class-specific protection ratios r at positive frequency separations as a proxy for negative frequency separations. This is with the exception of the case of $\Delta F = -9$, where the use of r at $\Delta F = +9$ is not appropriate[16]. Instead, we propose to use the linear interpolation of the protection ratios r at $\Delta F = +8$ and $+10$ as proxies for protection ratios at $\Delta F = -9$.

e) The assumed WSD ACLR values are based on the five spectrum emission masks of EN 301 598 (see Table 2.2) for channel separations $\Delta F = \pm 1$, ± 2 and ± 3. The masks extend at a fixed level (independent of frequency separation) for $\lvert\Delta F\rvert > 3$. In practice, however, the emissions of radio devices roll off with frequency separations beyond the first few adjacent channels. To account for this, we have assumed a roll off (increase in ACLR) of 10 dB per 8 MHz in the

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[16] This is because the large protection ratios that occur at ΔF =+9” (the so-called “N+9” effect characteristic of superheterodyne receivers) do not occur at negative frequency offsets.

calculation of the class-specific protection ratios. This roll-off is in line with the slopes of the class 3, 4, and 5 masks over the first three adjacent channels. This means that at large frequency separations the protection ratios are lower bounded due to the selectivity of the DTT receiver (rather than the spectral leakage of the WSD transmitter).

f) We have assumed that the protection ratios for frequency separations of greater than 10 channels are the same as those for a frequency separation of 10 channels. We have tested the protection ratios of four DTT receivers at frequency separations of 20 and 40 channels. The results[17] indicate that the protection ratios for certain receivers do reduce significantly at large frequency separations; however this is not universally the case for all receivers. Furthermore, it is difficult to know whether protection ratio measurements at large frequency offsets are lower bounded the by the limited ACLR of the test WSD signal, as the measurement of the latter is often well beyond the dynamic range of measurement equipment. In short, our assumption that protection ratios for $|\Delta F| \geq 10$ are independent of ΔF is a cautious one, and most likely over-estimates the extent of harmful interference.

Protection ratio categories

4.104 We acknowledge that the proposed protection ratios in Tables 4.3(a)-(e) for use in the Ofcom pilot are based on the measurements of only a single WSD technology. We are also aware that other radio technologies can have in-block time-frequency signal structures which may be more or less disruptive to the operation of DTT receivers[18].

4.105 For the purposes of our framework for access to TV white spaces, we propose to generate TVWS availability datasets corresponding to three categories of “high”, “medium” and “low” protection ratios, which characterise the propensity of different WSD radio technologies to cause harmful interference to DTT. We expect that the protection ratios in Tables 4.3(a)-(e) are likely to belong to the “low” category.

4.106 The organisations responsible for the specification of various WSD radio technologies would be required to present Ofcom with evidence in the form of protection ratio measurements against a pre-specified group of DTT receivers. Upon examining such evidence, Ofcom would assign each radio technology to one of the three technology categories. This information would be shared with the WSDBs, so that they could select the appropriate TVWS availability dataset in accordance with the reported technology ID of individual WSDs.

4.107 Absent such evidence, a WSD radio technology would be assigned, by default, to the “high” protection ratio category (namely that which corresponded to the greatest propensity for causing harmful interference).

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[17] As might be expected, the reductions in protection ratios with frequency separation are less pronounced for high values of C. This is because the receivers begin to overload, and exhibit less frequency discrimination. One of the tested receivers exhibited (for all values of C) protection ratios that were around 10 dB lower at ΔF = 20 than at ΔF = 10, but interestingly only 3-4 dB lower at ΔF = 40 than at ΔF = 10. Another receiver exhibited (at C = -70 dBm) protection ratios that were 8 and 17 dB lower at ΔF = 20 and ΔF = 40 respectively, than at ΔF = 10, but showed little improvements at C = -50 dBm. The remaining two receivers exhibited little improvements in protection ratios at ΔF = 20 or ΔF = 40.

[18] Note that this issue does not arise in relation to PMSE equipment, which as a result of their narrowband nature appear to be insensitive to the in-block time-frequency structure of a WSD signal, and are primarily susceptible to the out-of-block emissions of a WSD.

4.108 We welcome measurements of protection ratios (and out-of-block emissions) of various WSD technologies to inform our decision regarding the three protection ratio categories. However, we must emphasise that the measurement of protection ratios is a complex procedure, and we strongly recommend that any such measurements be performed according to Ofcom's specifications (see Annex 4) and with actual WSDs (as opposed to recorded signals) transmitting in a normal mode of operation.

Question T6: Do you have any comments on our proposed protection ratios in relation to DTT calculations?

Uncertainty in the location of WSDs

4.109 In the above sections we described our proposals for dealing with the uncertainty in the location of the DTT receivers and the calculation of WSD-DTT coupling gains. Here, we present our proposals for dealing with the uncertainty in the location of the WSDs themselves. These proposals are for use by WSDBs when interpreting the TVWS availability datasets $P_1(i, F_{\mathrm{WSD}})$ communicated to them by Ofcom.

Uncertainty in the location of master WSDs

4.110 In some cases, the horizontal location uncertainty reported by the master WSD is nominally zero. This might be the case, for example, where the master WSD is a fixed outdoor installation, and it is accurately geolocated. In such cases, the master WSD would simply be associated with the pixel within whose boundaries it is located. Given that the location of the master WSD pixel is known, it is possible to extract the maximum permitted WSD in-block EIRP for the said pixel from the dataset $P_1(i, F_{\mathrm{WSD}})$ of UK-wide EIRP limits provided by Ofcom. WSDBs need take no further action.

4.111 In other cases, the horizontal location uncertainty reported by the master WSD may be non-zero. To account for this uncertainty, the WSDB may need to associate the master WSD with a number of pixels (as opposed to a single pixel). The area covered by these pixels will be a superset of the area within which the master WSD might be located; i.e., the master's "area of potential locations.

4.112 For a master WSD with reported nominal horizontal coordinates (x_0, y_0), and reported horizontal location uncertainties $(\pm\Delta x, \pm\Delta y)$, the area of potential locations will be modelled as a rectangle centred on (x_0, y_0), and with sides of length $2\Delta x$ and $2\Delta y$ aligned with the North-South/East-West directions.

4.113 If the area of potential locations extends over N surrounding pixels, then the WSDB will associate the master WSD with those same N pixels. This is illustrated in Figure 4.14 below.

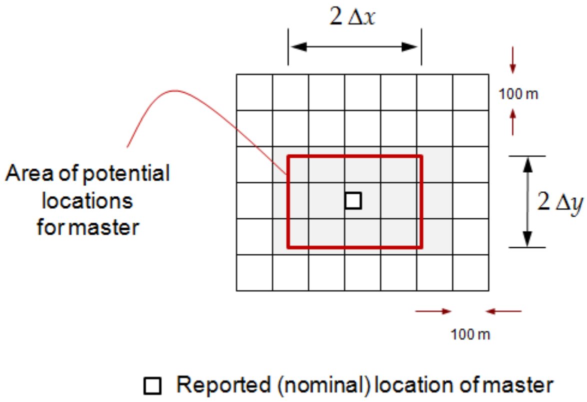

Figure 4.14 – Accounting for location uncertainty of a master WSD.

4.114 Specifically, assume that the area of potential locations of a master WSD overlaps (fully or partially) with N pixels, where the pixel indices are $n = 1 \ldots N$. Also assume the availability (provided by Ofcom) of pre-computed maximum permitted in-block EIRPs, $P_1(n, F_{\mathrm{WSD}})$, for a WSD located within the n^{th} pixel. The maximum permitted in-block EIRP for the master WSD can then be derived by a WSDB as the smallest of the N pre-computed values, $\min_n P_1(n, F_{\mathrm{WSD}})$.

4.115 In practice, the horizontal location uncertainty of a master WSD is unlikely to extend over many pixels. So N is very unlikely to be greater than 4.

Uncertainty in the location of slave WSDs

4.116 The location of a slave WSD may be significantly different from the location of its serving master WSD. It is then very likely that the maximum permitted EIRP for a slave WSD is also different from the maximum permitted EIRP for its master WSD.

4.117 In any case, in order to calculate the TVWS availability for a slave WSD, we require some indication of the range of coordinates within which the slave WSD might be located; i.e., the slave's area of potential locations.

4.118 In cases where the slave WSD is geolocated, its location uncertainty can be accounted for in precisely the same way as it is for a master WSD (see above and Figure 4.14).

4.119 If the slave is not geolocated, the WSDB will need to calculate the coverage area of its serving master WSD; i.e., the area within which the master WSD can communicate with the slave WSD. The calculated coverage area of the master WSD (also incorporating the location uncertainty of the master WSD itself) then acts a proxy for the area of potential locations for the slave WSD.

4.120 For a serving master WSD with reported nominal horizontal coordinates (x_0, y_0), and reported horizontal location uncertainties $(\pm\Delta x, \pm\Delta y)$, the coverage area will be modelled as a circle centred on (x_0, y_0), and with radius $d_0 + \sqrt{(\Delta x^2 + \Delta y^2)}$. Here, d_0 is the coverage range of the master WSD (see Annex 3). In short, the area of potential locations for slave WSDs is the area of potential locations for the master WSD, extended by d_0.

4.121 If the area of potential locations for the slave WSD extends over N surrounding pixels, then the WSDB will associate the slave WSD with those same N pixels. This is illustrated in Figure 4.15 below.

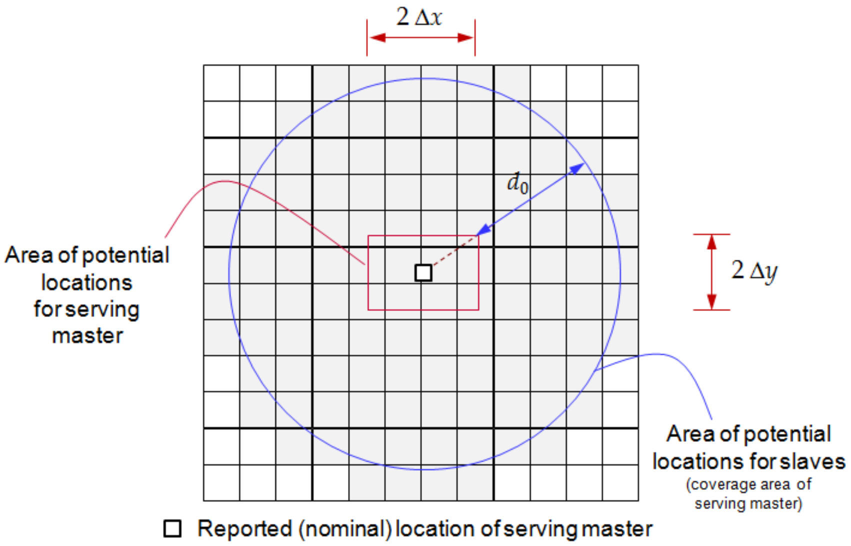

Figure 4.15 – Accounting for location uncertainty of a non-geolocated slave WSD.

4.122 Specifically, assume that the area of potential locations of a slave WSD overlaps (fully or partially) with N pixels, where the pixel indices are $n = 1 \ldots N$. Also assume the availability (provided by Ofcom) of pre-computed maximum permitted in-block EIRPs, $P_1(n, F_{\mathrm{WSD}})$, for a slave WSD located within the n^{th} pixel. The maximum permitted in-block EIRP for the slave WSD can then be derived by a WSDB as the smallest of the N pre-computed values, $\min_n P_1(n, F_{\mathrm{WSD}})$.

4.123 The approach for calculating the coverage radius of a master WSD is presented in Annex 3.

Question T7: Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of WSDs in relation to DTT calculations?

Numerical examples of TVWS availability in relation to DTT

Illustrative examples of WSD emission limits

4.124 Figures 4.16(a)-(g) illustrate the maximum permitted type A WSD EIRPs as a function of received median DTT signal power in channel, 40 for a number of frequency separations ΔF, and for a WSD antenna height of 10 metres in a suburban environment.

4.125 These results are for same-pixel or tier-1 pixel scenarios, and for a L = 10% likelihood that the reduction Δq in location probability exceeds 7 percentage points. They also correspond to a noise-limited DTT coverage; i.e., where the DTT self-interference term V in Equation (4.1) is zero. The coupling gain and protection ratio values are as proposed earlier in this section.

4.126 We can make the following observations:

- For ΔF = +1 (N+1 adjacency), even a class 1 WSD is highly restricted in the maximum EIRP levels it is permitted to use. At the very edge of DTT coverage (m_S ~ -70 dBm/(8 MHz)), the maximum permitted EIRP is around 11 dBm/(8 MHz) for a class 1 devices, and -7 dBm/(8 MHz) for a class 4 device. However, a level of 36 dBm is permitted deep into the coverage area of the DTT transmitter (m_S > -40 dBm/(8 MHz)).

- The emission limits increase with increasing frequency separations. At $\Delta F = +8$ (N+8 adjacency), there is very little restriction on the EIRP of a class 1 WSD.
- At $\Delta F = +9$ (N+9 adjacency), the emission limits become more stringent. This is due to the so-called "N+9" effect, where certain DTT receivers become particularly susceptible to adjacent channel interference. The reduced ACS of the DTT receiver becomes the bottleneck and increases the protection ratios for this adjacency. This is why all five WSD emission classes are penalised similarly.
- At $\Delta F = +10$ (N+10 adjacency) and beyond, all WSD classes are permitted to transmit at a maximum EIRP of 36 dBm/(8 MHz).

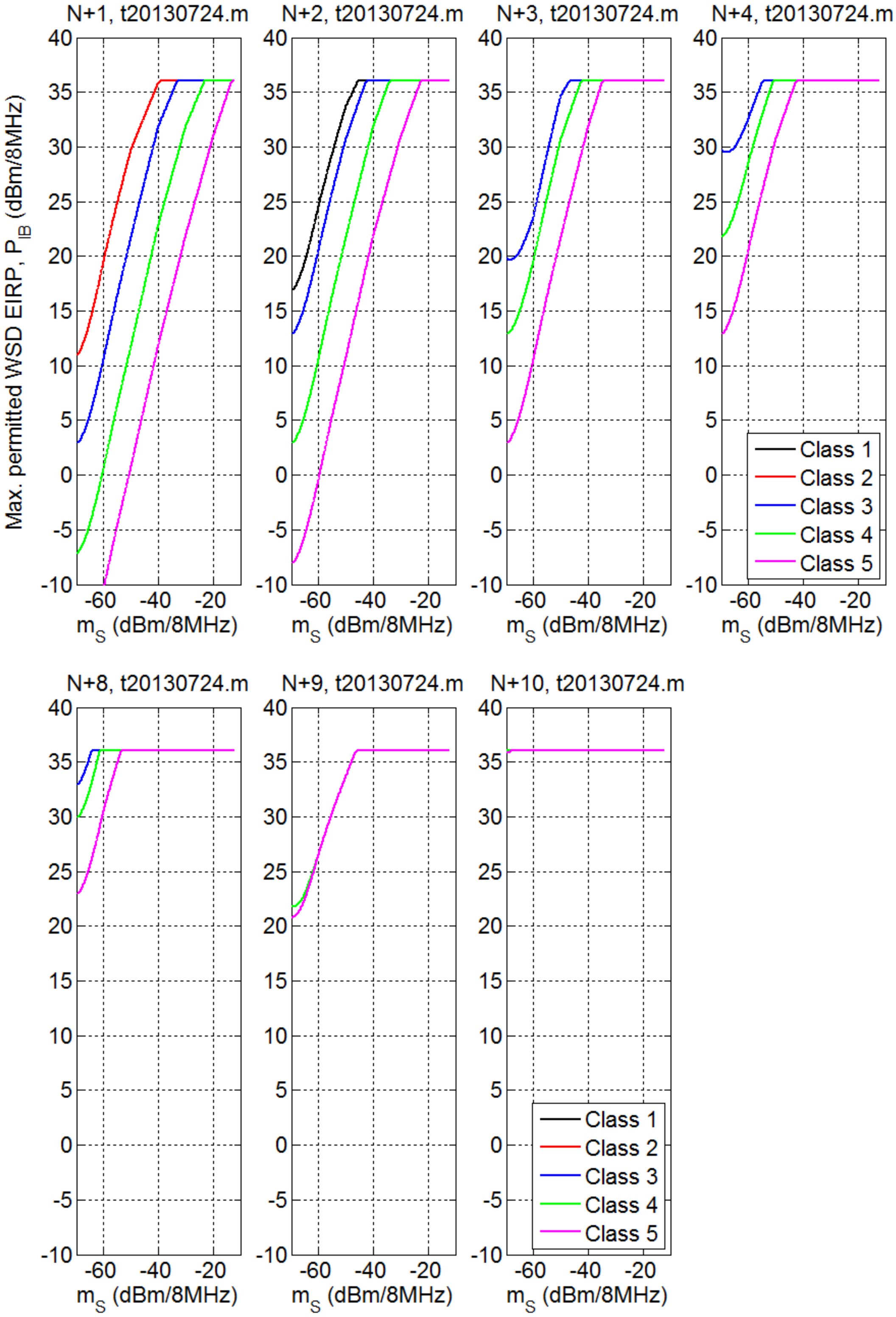

Figure 4.13(a)-(g) – Variation of maximum permitted WSD EIRP as a function of received DTT median signal power.

UK-wide TVWS availability

4.127 Here we present the results of our modelling of UK-wide TVWS availability in relation to co-existence with DTT. We also intend to shortly publish a series of geographic maps of white space availability.

4.128 The following results correspond to the geolocated WSD deployment scenarios described in Table 4.4 below. All modelling parameter values are as proposed in this section.

4.129 It should be noted that the presented results apply to geolocated WSDs only. If a WSD is not geolocated (e.g. a slave WSD which has not yet attached to a master) then the uncertainty in its location will mean lower TVWS availability.

Table 4.4. Scenarios examined for UK-wide TVWS availability.

Scenario	WSD type	WSD class	WSD antenna height (metres)	Use case (master WSD)
1	A	1	15	Base station
2	A	4	10	CPE with roof-top antenna
3	A/B	4	1.5	Access point
4	A/B	5	1.5	Portable/mobile device

4.130 The presented UK-wide TVWS availability has been derived according to WSD emission limits calculated in relation to the following DTT services:

- The Public Service Broadcasting (PSB) multiplexes;
- Commercial (6COM) multiplexes;
- Nations multiplexes;
- The 600 MHz multiplexes; and
- Local TV multiplexes.

4.131 This means that the DTT receiver antennas in each pixel have been assumed to be pointing towards the relevant TV transmitter(s) which provide the above services[19].

4.132 Figures 4.14(a)-(d) show the percentages of households where a given minimum number of DTT channels are available for use by a WSD when it transmits at a specific EIRP level. The WSD EIRPs are in dBm over 8 MHz. Note that the maximum permitted power of a WSD is capped at 36 dBm over 8 MHz.

4.133 We have calculated TVWS availability at every 100 metre × 100 metre pixel in the UK. We have considered all 40 DTT channels as available for WSD use, with the exception of channels 38, 60. The results do not include location-specific restrictions in relation to DTT across borders or PMSE.

4.134 The results for scenarios 1 and 2 can be extended to type B WSDs by relaxing the emission limits by a nominal building penetration loss of 7 dB (type B WSDs at a reported height of 2 metres or more will be assumed to be located indoors). The results for scenarios 3 and 4 apply to both type A and type B WSDs.

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[19] Note that the information on the 600 MHz and local TV multiplexes are based on current plans and are subject to change.

4.135 With the current version of the modelling tool that we have used to derive these estimates, we have not been able to account for the particularly high susceptibility of TV receivers when WSDs radiate nine channels above the DTT service. As a consequence, the results that we have presented in the figures below are likely to overstate the TVWS availability by up to one channel for any given power level. Taking account of this over-estimation, the results indicate that:

- TVWS availability reduces considerably where the WSD exhibits large amounts of out-of-block spectral leakage (higher classes).

- In scenario 1, where the WSD spectral leakage is low, around 90% of household locations will have access to 3 or more 8 MHz channels at a power of 35 dBm/(8 MHz).

- In scenario 4, where the WSD spectral leakage is high, only just under 70% of household locations will have access to 3 or more 8 MHz channels at a power of 35 dBm/(8 MHz). However, this availability rises to just under 90% at a power of 25 dBm/(8 MHz). For comparison, LTE mobile phone handsets use 23 dBm.

- A comparison of scenarios 2 and 3 indicates the impact of WSD antenna height on TVWS availability. As can be seen, TVWS availability is somewhat lower for a WSD antenna height of 10 metres since it is equal to the planned DTT receiver antenna height and so creates a greater potential for interference. However the difference in maximum permitted emission limit is only 2 to 3 dB.

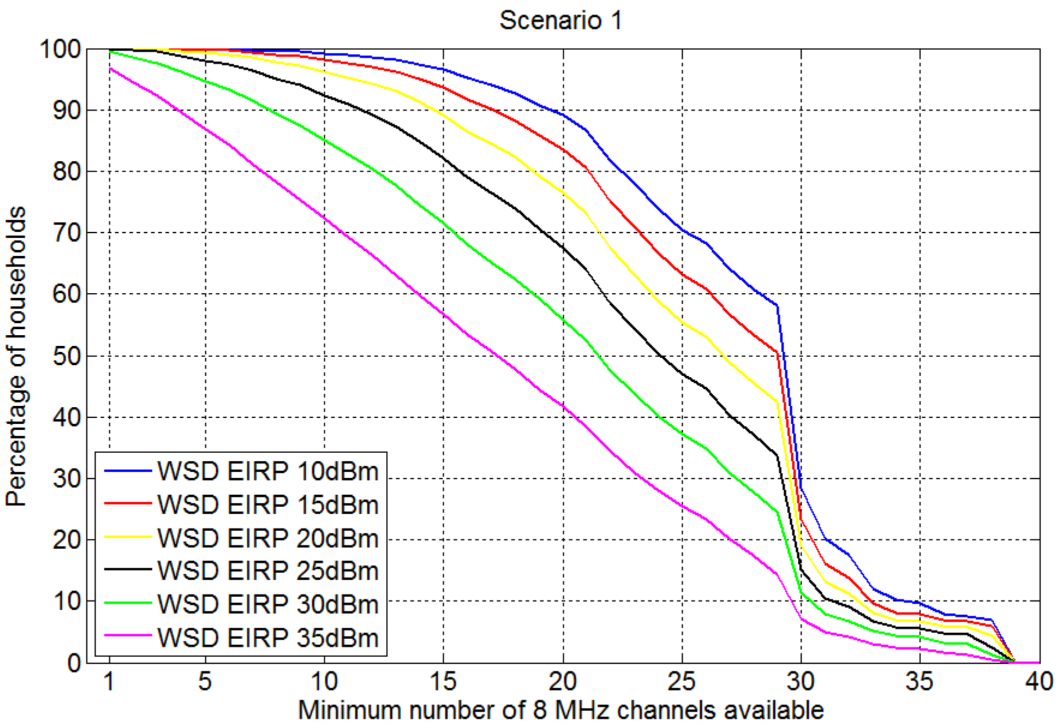

Figure 4.14(a) – UK-wide TVWS availability for scenario 1.
Class 1 WSD with an antenna height of 15 metres.

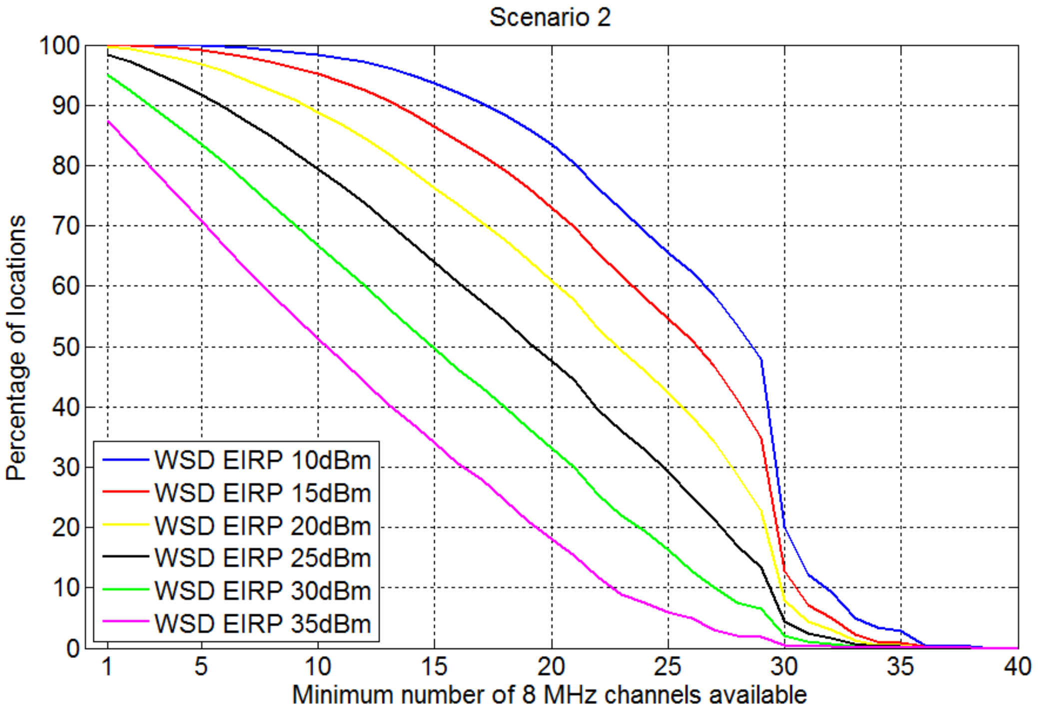

Figure 4.14(b) – UK-wide TVWS availability for scenario 2.
Class 4 WSD with an antenna height of 10 metres.

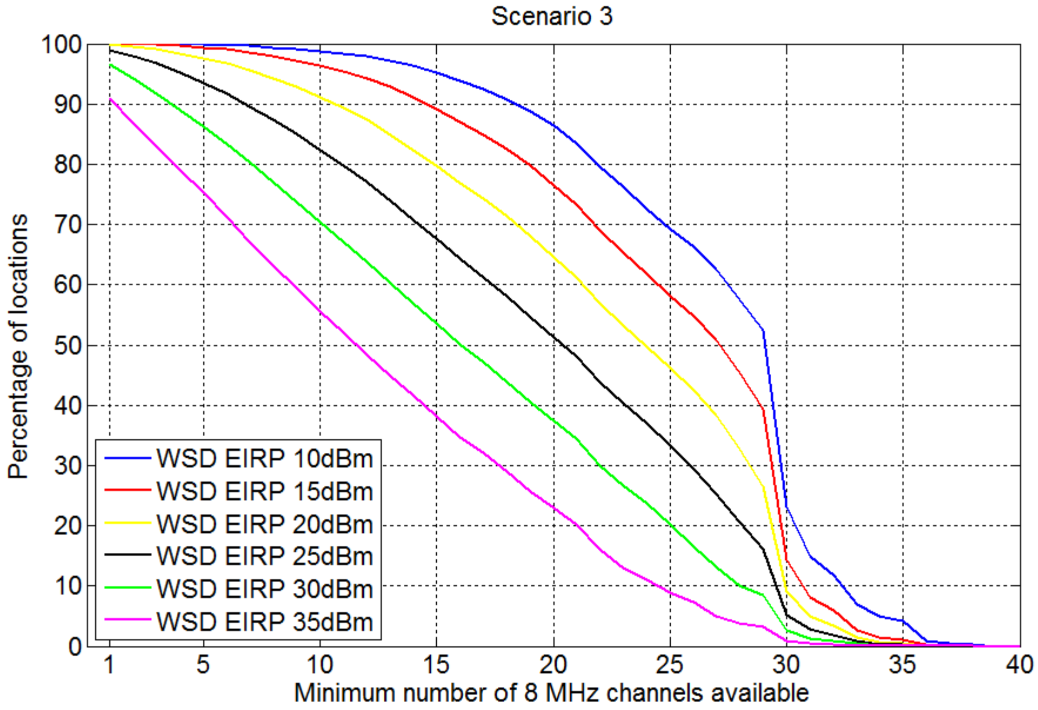

Figure 4.14(c) – UK-wide TVWS availability for scenario 3.
Class 4 WSD with an antenna height of 1.5 metres.

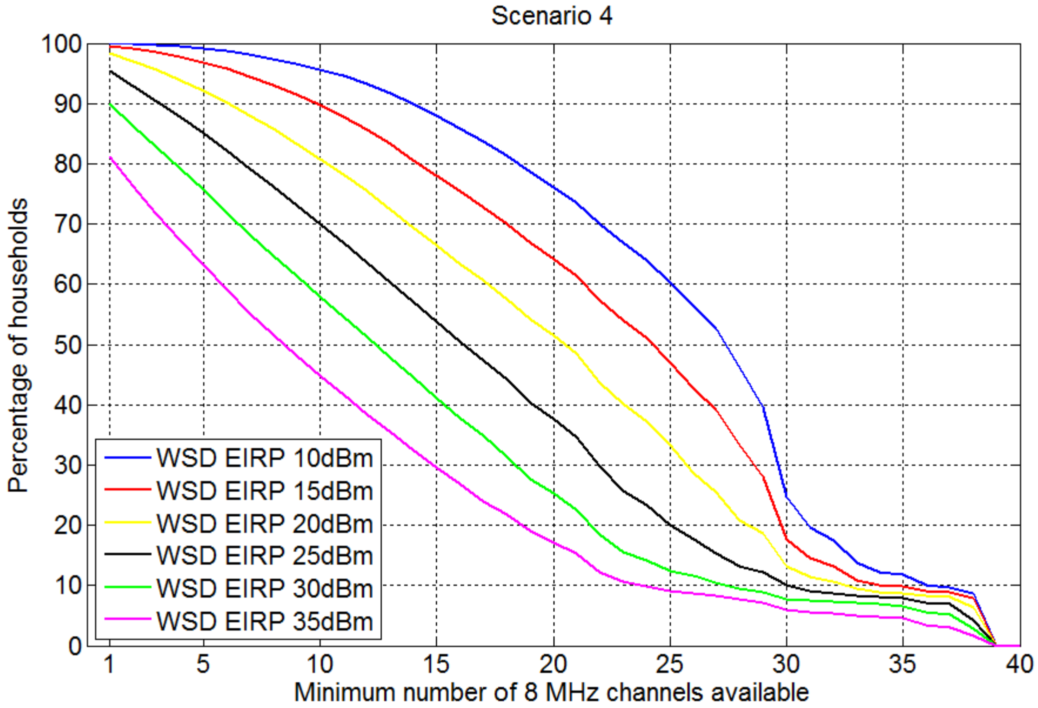

Figure 4.14(d) – UK-wide TVWS availability for scenario 4.
Class 5 WSD with an antenna height of 1.5 metres.

TVWS availability in London and Glasgow

4.136 Figures 4.15 and 4.16 show the statistics of TVWS availability in 10 km × 10 km areas of London and Glasgow for scenarios 1 to 4. The vertical axes here are in percentage of locations rather than households for purposes of comparison with the PMSE results of Section 5.

4.137 As noted earlier, our modelling in relation to DTT over-estimates TVWS availability by up to one channel.

4.138 The area examined in London is centred on National Grid Reference TQ 300 800 and includes Camden and Islington to the North, Paddington and Kensington to the West, Clapham and Brixton to the South, and Bermondsey to the East. The area examined in Glasgow is centred on National Grid Reference NS 590 650 (Glasgow Central Station).

4.139 The results show that there is significantly less TVWS available in Glasgow than in Central London in relation to DTT.

4.140 In London, there is a main DTT transmitter station (Crystal Palace) close to the city, with no alternative main stations of any significance, though there are some small 3PSB relays. This means that the DTT coverage is quite robust and so large WSD powers are possible.

4.141 In Glasgow, the main DTT transmitter station (Black Hill) is further away to the East of the city. Some pixels in Glasgow are better served by another main station, Darvel which is some way to the South of the city. There are also some 3PSB relays in Glasgow centre, which probably cover more of Glasgow than the relays in London do. As a result, the permitted WSD powers are more restricted in Glasgow than they are in London.

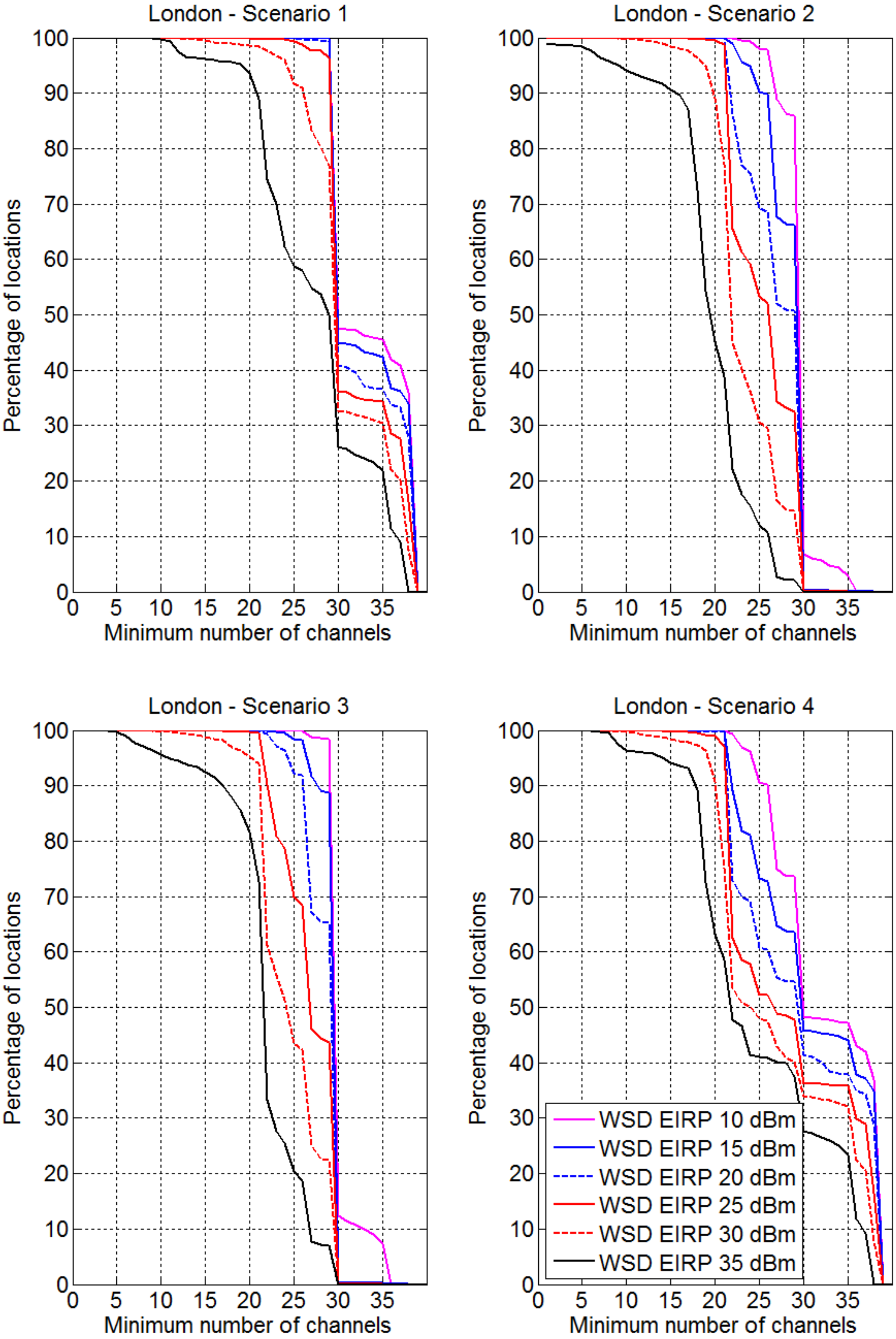

Figure 4.15 – Availability of 8 MHz channels in Central London in relation to DTT.

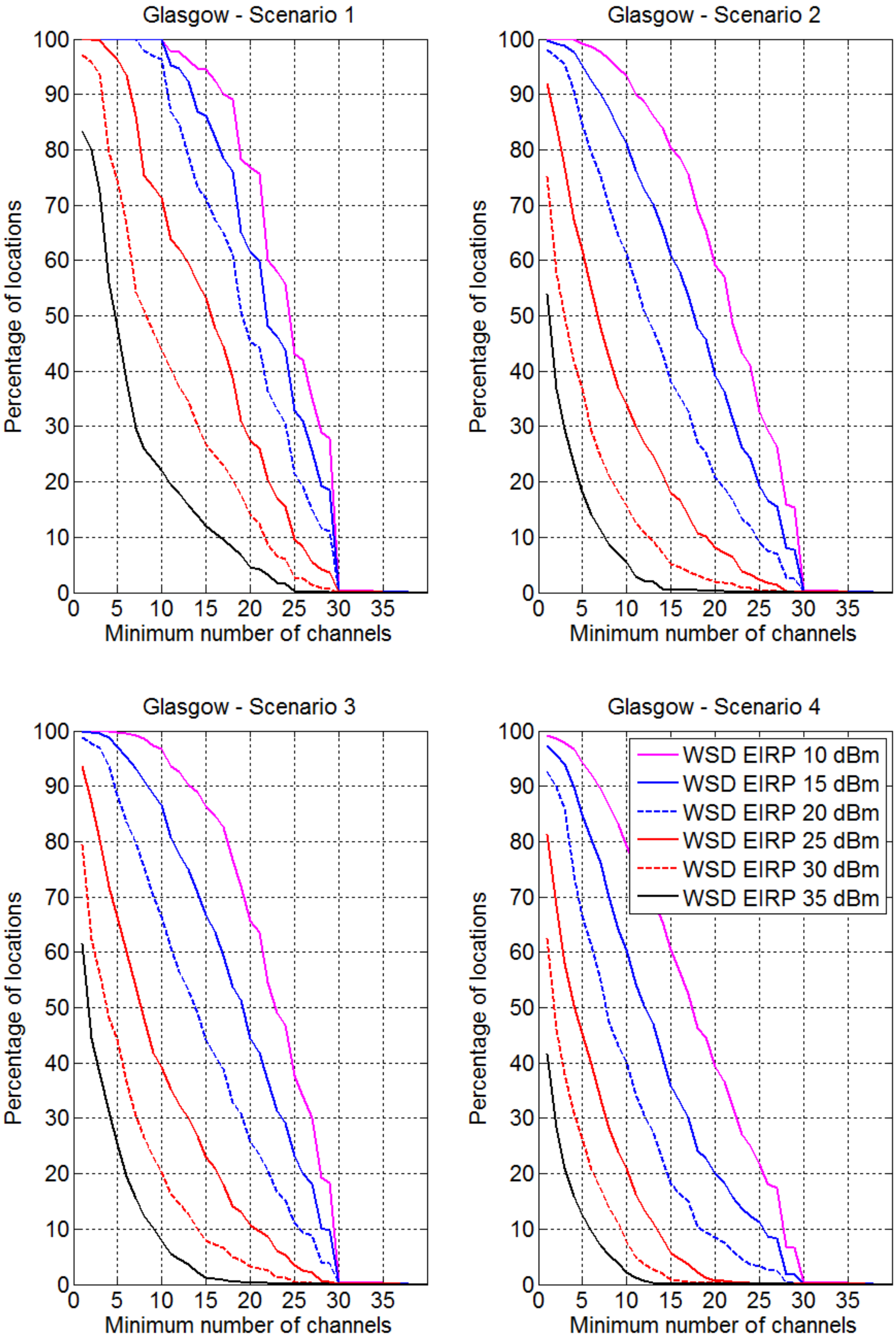

Figure 4.16 – Availability of 8 MHz channels in Glasgow in relation to DTT.

Summary and conclusions

4.142 We have presented our proposed framework for calculating location-specific and channel-specific maximum permitted WSD in-block EIRP levels in the context of ensuring a low probability of harmful interference to DTT use in the 470-790 MHz band.

4.143 Ofcom will perform the proposed calculations and will reconcile the derived WSD emission limits with EIRP restrictions which may apply in relation to other services (namely PMSE use in channel 38, cross border DTT use, and services outside the UHF TV band). Ofcom will then communicate the resulting limits to the WSDBs.

4.144 We have also proposed various technical parameter values for the calculation of the WSD emission limits. These relate to the probability of a target reduction in DTT signal-to-interference-plus noise (SINR) ratio, the coupling gain (including propagation loss) between the WSD transmitter and DTT receiver, and the WSD-DTT protection ratios (ratios of wanted to unwanted powers at the point of DTT receiver failure).

4.145 Specifically, our proposals include the following:

- The proposed WSD emission limits are calculated subject to a 10% probability that the radiations by a WSD would result in a rise in the noise-plus-interference floor which exceeds 1 dB at the edge of DTT coverage in any given channel. The approach permits increasing WSD emission levels in accordance with increasing DTT received power levels deep within the coverage area of a DTT transmitter.

- The proposed short range WSD-DTT coupling gains are based on the statistics of nearest-neighbour household separations, subject to minimum separations of 5, 10, and 20 metres in urban, suburban, and rural areas, respectively. Such a statistical approach is proposed to account for the uncertainty in the locations of the DTT receivers in relation to a WSD. The extended Hata model is proposed for the calculation of path loss. Where height is not reported by the WSD, we propose to use default heights of 10 and 1.5 metres for type A and B WSDs, respectively.

- The proposed longer range WSD-DTT coupling gains are based on the median path loss between WSD and DTT pixels derived via the extended Hata model, and explicitly account for the orientation of the DTT receiver antennas in different pixels. Where height is not reported by the WSD, we propose to use default heights of 30 and 1.5 metres for type A and B WSDs, respectively.

- The proposed WSD-DTT protection ratios are based on the results of our measurements of a WSD signal (Weightless standard) and fifty of the top-selling DTT receivers in the UK.

4.146 Ofcom will calculate a unique set of WSD emission limits for each combination of five WSD spectrum emission classes (as defined in the draft European harmonised standard EN 301 598) and six representative WSD antenna heights of 1.5, 5, 10, 15, 20 and 30 metres (as well as for the default heights).

4.147 We also propose to generate TVWS availability datasets corresponding to three categories of “high”, “medium” and “low” protection ratios (one of which will correspond to the protection ratios presented in this report). These will characterise the varying propensities of different WSD radio technologies to cause harmful interference to DTT receivers.

4.148 We believe that the proposed emission limits will result in a low probability of harmful interference to DTT in practice. We plan to test the implications of the calculated WSD emission limits during the forthcoming Ofcom TVWS pilot programme, and will continue to gather evidence from real-world measurements to further inform our decisions.

Section 5

WSD emission limits in relation to PMSE

5.1 In this section we present our detailed proposed framework for calculating the maximum permitted in-block EIRP spectral density $P_{\text{WSD-PMSE}}(j, F_{\text{WSD}})$ of a WSD operating at a given geographic location j and in a specific DTT channel F_{WSD}. This emission limit is specified to ensure a low probability of harmful interference to PMSE use of the spectrum.

5.2 As explained in Section 3, the above EIRP values will be calculated by the WSDBs, reconciled with other power restrictions which may apply, and communicated to the WSDs.

5.3 Here, we first explain the nature of PMSE use of the 470-790 MHz band in the UK. We then describe the information that is available in relation to PMSE use in individual assignments, and which can be utilised in the coexistence calculations.

5.4 Subsequently, we set out our proposed approach and parameter values for the coexistence calculations. These parameters include the wanted received signal power at the PMSE receiver, the WSD-PMSE coupling gains, and the WSD-PMSE protection ratios.

5.5 We then present our proposals in relation to PMSE use in channel 38.

5.6 Finally, we present the implications of our proposed parameter values via a number of examples of TVWS availability (powers and channels) for ensuring a low probability of harmful interference to PMSE use.

5.7 Note that where we use the term “height”, we mean height above ground level. We reserve the term “altitude” to refer to height above sea level.

The PMSE services in the UHF TV band

5.8 The following are the five main PMSE services[20] which operate in the UHF TV band subject to licences issued on behalf of Ofcom by Arqiva Limited (as JFMG) to whom Ofcom has contracted out PMSE licensing services:

- Wireless microphones;
- In-ear monitors;
- Talkback;
- Programme audio links; and
- Data links.

5.9 The licences issued by JFMG are location specific; i.e., they authorise the use of the spectrum at specific venues. This is with the exception of UK-wide licences that are issued for use of channel 38 (606 – 614 MHz).

5.10 Wireless microphones, in-ear monitors and talkback account for the vast majority of assignments.

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[20] Note that if other PMSE services are used in the TV band 470-790 MHz, appropriate coexistence criteria will be developed and applied.

5.11 Wireless microphones and in-ear monitors typically have a nominal channel bandwidth of 200 kHz. Both types of devices can move during use, with the in-ear monitors providing a customised audio link back to the performer.

5.12 Talkback[21] typically has nominal channel bandwidths of 12.5 kHz, 25 kHz, 100 kHz or 200 kHz, and is designed for the purpose of communicating instructions to the programme-making team including presenters, interviewers, and equipment operators/engineers.

5.13 Programme audio links typically have a nominal channel bandwidth of 200 kHz and comprise studio transmitter links and outside broadcast links. Programme audio links are used for the purpose of carrying broadcast-quality monophonic or stereophonic music and speech signals.

5.14 Data links are used for remote control of cameras and other equipment and also for signalling. They use the same type of technology as talkback and will be treated as such for the purposes of coexistence calculations.

5.15 The number of PMSE channels authorised for use depends on the nature of the PMSE event. This can range from a single channel in a small event, up to 40 or more for wireless microphones and IEMs in a major production. The channel frequencies authorised are not based on any specific raster, and are selected to minimise the impact of inter-modulation products and to interleave with other PMSE users. Where multiple PMSE channels are authorised for use, these may span a single 8 MHz DTT channel, or multiple (contiguous or non-contiguous) DTT channels.

5.16 PMSE use can occur at various locations both indoor and outdoor. Use can be permanent or ongoing (such as in a West End theatre), or it can be temporary, running from a few hours for a concert, to a few days for a sports event (e.g. the Open Golf Championship) or festival (e.g. Glastonbury).

Information on usage of spectrum by PMSE

5.17 For the purposes of licensing, the location of the PMSE transmitter is required and is recorded in the JFMG licensing database. This has historically been specified as the location of the venue, with the PMSE user being free to deploy equipment anywhere within the venue in order to achieve the best system performance.

5.18 For coexistence studies, however, it is the location and height of the PMSE receiver (rather than transmitter) antenna that is relevant. The PMSE receiver antenna location and height will be provided by Ofcom to the WSDBs.

5.19 Receiver antenna height is currently not recorded and we are working with JFMG to ensure that the licence application process contains the specific requirement to provide the PMSE receiver antenna height. Where this is not provided, a default antenna height will be used by the WSDBs.

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[21] Various technologies fall under the talkback category, including professional mobile radio (PMR), in-studio belt-pack systems (both of 12.5 kHz or 25 kHz bandwidth) and intercom systems (200 kHz bandwidth). We consider that intercom systems are likely to be the most vulnerable of these types and we have accordingly adopted the wireless microphone protection ratios to ensure a low probability of harmful interference to the talkback usage type.

5.20 Receiver horizontal location is already provided via the licensing process for some PMSE applications such as audio links where the receiver location could be several kilometres away from the transmitter. For low power applications (microphones, IEMs etc.) the receiver location is considered to be the location of the transmitter as provided by the licensee. However, we do recognise that for microphones, IEMs and talkback the receiver antenna could be located anywhere within the venue and we address this later in this section.

5.21 Table 5.1 describes the information on PMSE assignments that will be supplied by JFMG and which will form the basis of PMSE usage data that Ofcom will provide to the WSDBs.

Table 5.1 – Parameters recorded in the JFMG licensing database.

Parameter	Description
Assignment_ID	Unique identifier for the assignment.
Equipment_Type_ID	Type of equipment/service used in the assignment, encoded as follows: 1 – Talkback 2 – Wireless microphone 4 – Programme audio link 16 – Data link 64 – In ear monitor 1, 2 and 64 make up the vast majority of assignments.
X_Coord_metres	Eastings of the PMSE receiver antenna (expressed to a precision of one metre) referenced to the Ordnance Survey National Grid.
Y_Coord_metres	Northings of the PMSE receiver antenna (expressed to a precision of one metre) referenced to the Ordnance Survey National Grid.
Antenna_Height_metres	Height above ground level of PMSE receiver antenna in metres. A default value of 5 metres will be assumed in the absence of available information.
Frequency_MHz	Centre frequency of the PMSE assignment in MHz. This is used to determine the DTT channel index of the assignment. The DTT channel index is given by (see also footnote): $F = 21 + \text{floor}\{(\text{Frequency\_MHz} - 470)/8\}$.
Bandwidth_MHz	Bandwidth of the assignment in MHz. This will usually be the nominal bandwidth of the relevant usage type, for example 200 kHz for wireless microphones.
Start	Start date and time of the assignment.
Finish	Finish date and time of the assignment.
Situation_ID	I - Internal (outdoor) E - External (indoor) A - Airborne

5.22 We do not propose to account for the specific numbers and frequencies of PMSE channels authorised for use within a given DTT channel. This is because we do not know precisely which frequencies within the DTT channel will be used by WSDs.

Therefore, if PMSE equipment and WSDs occupy the same DTT channel, they will be considered co-channel in the context of coexistence calculations[22].

5.23 We are exploring the possibility of identifying and recording the boundaries of PMSE venues, in order to derive multiple candidate PMSE antenna receiver locations. These candidate locations would be provided by Ofcom to the WSDBs, and would capture the uncertainty in the locations of the PMSE receiver antenna within a venue (see later this section). This is particularly relevant in the context of PMSE venues which cover large geographic areas (e.g. a Golf course).

5.24 We note that the accurate reporting of PMSE usage data (particularly PMSE receiver antenna locations and heights) is key to implementing the coexistence criteria to ensure a low probability of harmful interference.

Proposed approach for the calculation of WSD emission limits

5.25 Figure 5.1 illustrates an example of interference from a fixed WSD to a PMSE receiver. A WSDB calculates a value for the maximum permitted WSD in-block EIRP spectral density $P_{\text{WSD-PMSE}}$ in dBm/(100 kHz) in each DTT channel. These limits are calculated to ensure a low probability of harmful interference to the PMSE receiver.

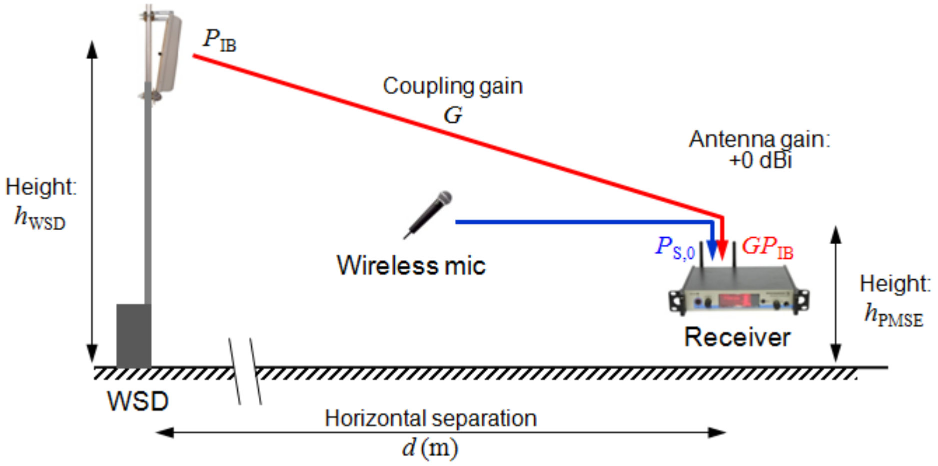

Figure 5.1 – Illustration of interference from a WSD to a PMSE receiver. A building penetration loss will be included in the coupling gain G where appropriate.

5.26 Specifically, a WSDB will use the reported horizontal location (indexed with j) and location uncertainty of the WSD to define a number, N, of *candidate* locations (indexed with n) at which the WSD might be located (see later in this section).

5.27 Then for each candidate location, $n = 1 \ldots N$, and each available DTT channel, $F =$ 21…60, the WSDB will calculate the maximum permitted in-block EIRP spectral density $P_{\text{WSD-PMSE}}(j, n, F)$ in dBm/(100 kHz) according to the procedures described in this section. The following WSD parameters will be used for the calculations:

- The WSD spectrum emission class;

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[22] An exception is where a PMSE assignment straddles two DTT channels, in which case we propose to treat PMSE as adjacent-channel to WSDs which occupy either of the two DTT channels. We consider this to be a reasonable approach given that PMSE channel bandwidths are much less than 8 MHz, and WSD signals tend to use internal guard bands in order to meet out-of-block emission limits.

- WSD antenna height above ground level. This will be derived from the WSD antenna altitude. If altitude is not reported by the WSD, this will be assumed to be “undetermined”, and a default value for the WSD antenna height (specified by Ofcom) be used.

5.28 The WSDB will then derive the maximum permitted EIRP spectral density $P_{\text{WSD-PMSE}}(j, F)$ in dBm/(100 kHz). This will be the smallest of the $P_{\text{WSD-PMSE}}(j, n, F)$ values over the candidate WSD locations, i.e.,

$$P_{\text{WSD-PMSE}}(j,F) = \min_{n} P_{\text{WSD-PMSE}}(j,n,F) \qquad (5.1)$$

5.29 Finally, the WSDB will calculate the maximum permitted in-block EIRP spectral density $P_0(j, F)$ in dBm/(100 kHz) – to be communicated to WSDs as operational parameters – as the smaller of the two values $P_{\text{WSD-PMSE}}(j, F)$ and $P_1(i, F) - 10\log_{10}(80)$. We defined the latter term in Section 3, and this accounts for the likelihood of interference to DTT, and any other restrictions which might apply in relation to services outside the UHF TV band or across borders.

5.30 The expressions for the calculation of $P_{\text{WSD-PMSE}}(j, n, F)$ are described next, where for brevity we refer to it as P_{IB}.

Expression for the maximum permitted WSD EIRP spectral density

5.31 We propose to calculate the maximum permitted WSD in-block spectral density based on the typical levels of wanted signal power at the PMSE receiver. We have adopted this approach as an alternative to an interferer-to-noise approach[23], because PMSE equipment in practice operates in the presence of levels of background interference that are significantly greater than the thermal noise level. The interferer-to-noise approach, where the target levels of WSD interference are assessed with reference to the thermal noise floor (rather than the existing interference-plus-noise floor), is therefore not appropriate in relation to assessing the probability of harmful interference to PMSE.

5.32 The maximum permitted WSD in-block EIRP spectral density, P_{IB} in dBm/(100 kHz), in a specific DTT channel can be calculated according to

$$P_{\text{IB (dBm/100 kHz)}} = P_{\text{S,0 (dBm/}B\text{)}} - r(\Delta F)_{\text{(dB)}} - m_{G\,\text{(dB)}} - \gamma_{\text{(dB)}} - 10\log_{10}(80), \qquad (5.2)$$

where

$P_{\text{S,0}}$	is the received wanted PMSE signal power (over bandwidth B),
B	is the nominal channel bandwidth of the PMSE device in kHz,
m_G	is the WSD-PMSE median coupling gain,
$r(\Delta F)$	is the WSD-PMSE protection ratio defined as the ratio of received wanted PMSE signal power (in bandwidth B) over received unwanted WSD signal power (in 8 MHz) at the point of PMSE receiver failure,

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[23] ECC Report 185, “Complementary Report to ECC Report 159: Further definition of technical and operational requirements for the operation of white space devices in the band 470-790 MHz,” January 2013, http://www.erodocdb.dk/docs/doc98/official/Pdf/ECCRep185.pdf.

ΔF is the WSD-PMSE DTT channel separation[24] (in units of 8 MHz), and
γ is a margin (≥ 0 dB).

5.33 The logarithm simply converts the calculated EIRP from a bandwidth of 8 MHz to a bandwidth of 100 kHz.

5.34 Equation (5.2) effectively states that the ratio between the received wanted signal power, $P_{\mathrm{S},0}$, and the received unwanted signal power, $m_G P_{\mathrm{IB}}$, must exceed the protection ratio, $r(\Delta F)$, multiplied by a margin γ.

Question T8: Do you have any comments on our approach for calculating WSD emission limits , as expressed in Equation (5.2), in relation to PMSE coexistence calculations?

5.35 The values of the PMSE parameters to be used in Equation (5.2) must correspond to the *most susceptible* PMSE assignment; i.e. the PMSE assignment whose protection results in the smallest value of P_{IB}.

5.36 The proposed values for the parameters in Equation (5.2) are presented next. Note that information on PMSE parameters will be provided by Ofcom to the WSDBs, whereas information on WSD parameters will be reported (where applicable) by the WSDs to the WSDBs.

Wanted signal power at PMSE receiver

5.37 Here we present the proposed values of the received wanted PMSE signal power, $P_{\mathrm{S},0}$, for the different use cases in the UHF TV band. WSDBs will use these values in Equation (5.2).

5.38 In determining the received wanted PMSE signal power, we refer to the default PMSE field strengths to be protected as presented in the Geneva ’06 Agreement[25] and/or Annex 5 of The Chester Agreement[26] (“Chester ’97 Annex 5”).

Wireless microphones

5.39 The proposed received wanted signal power, $P_{\mathrm{S},0}$, for wireless microphones is -65 dBm/(200 kHz). This figure is calculated from Chester ’97 Annex 5 with reference to the radio microphone tables in which the default field strength to be protected is specified as 68 dBµV/m at 650 MHz. The nominal channel bandwidth is 200 kHz and an antenna gain of 0 dBi has been used in the conversion from field strength to power.

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[24] For example, if a WSD uses DTT channel $n+m$, and a PMSE device uses DTT channel n, then $\Delta F = m$. If both the WSD and PMSE device operate in the same DTT channel, then ΔF = 0, and the WSD is considered to be operating co-channel with the PMSE device (even if the WSD and PMSE device don’t use exactly the same frequencies). This is because the extent to which a WSD signal occupies an 8 MHz DTT channel will not generally be known.

[25] “FINAL ACTS of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06),” ITU, Geneva 2006.

[26] “The Chester 1997 Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the introduction of Terrestrial Digital Video Broadcasting (DVB-T),” Chester, 25 July 1997, http://www.archive.ero.dk/132D67A4-8815-48CB-B482-903844887DE3?frames=no&.

5.40 The proposed -65 dBm/(200 kHz) is broadly in line with the received wireless microphone wanted signal powers reported in various trials[27, 28] and is considerably higher than the typical wireless microphone minimum sensitivity of around -95 dBm/(200 kHz).

In-ear monitor

5.41 The proposed received wanted signal power, $P_{S,0}$, for in-ear monitors is -65 dBm/(200 kHz), and is the same as for wireless microphones.

Talkback

5.42 The proposed received wanted signal power, $P_{S,0}$, for talkback is -65 dBm/(200 kHz), and is the same as for wireless microphones.

Programme audio links

5.43 The proposed received wanted signal power, $P_{S,0}$, is -73 dBm/(200 kHz) for programme audio links. This figure is calculated from Chester '97 Annex 5 with reference to the studio transmitter link and Outside Broadcast (OB) link tables. We have chosen the lower default field strength to be protected of 60.5 dBµV/m @ 650 MHz[29]. The nominal channel bandwidth is 200 kHz and an antenna gain of 0 dBi has been used in the conversion from field strength to power.

Data links

5.44 We treat data links in the same manner as talkback since they use similar equipment.

Summary of proposed values

5.45 In summary, we propose to use the values of received wanted PMSE signal power, $P_{S,0}$, described in Table 5.2 for the purposes of Equation (5.2). These are given for the various PMSE use cases.

Table 5.2 – Wanted signal power at the PMSE receiver.

PMSE use case	$P_{S,0}$ (dBm/B)	PMSE channel bandwidth, B
Wireless microphones	-65	200 kHz
In-ear monitors	-65	200 kHz
Talkback	-65	200 kHz
Programme audio links	-73	200 kHz
Data links	-65	200 kHz

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[27] SE43(11)82AP1, "Wise-Project Measurement Report: PMSE Measurements in Helsinki City Theatre," December 2011, http://wise.turkuamk.fi/?page=documents.

[28] Cambridge Silicon Radio Limited, "Cambridge TV White Spaces Trial: PMSE Trial Report," 2012. http://docbox.etsi.org/Etsi_Cenelec/PUBLIC%20FOLDER%20on%20DD/White%20Space/White%20Space%20Cambridge%20PMSE%20Trial.pdf.

[29] The Chester '97 Annex 5 tables also show 66 dBµV/m (studio transmitter link) and 86 dBµV/m (OB link).

Question T9: Do you have any comments on the PMSE wanted signal power levels that we propose in relation to coexistence calculations?

WSD transmitter to PMSE receiver coupling gains

Median coupling gain

The median coupling gain between the WSD transmitter and PMSE receiver in Equation (5.2) will be calculated according to

$$m_{G\,(\mathrm{dB})} = m_{\mathrm{P}\,(\mathrm{dB})} + G_{\mathrm{W}\,(\mathrm{dB})} + G_{\mathrm{A,PMSE}\,(\mathrm{dB})}\,, \tag{5.3}$$

where

m_{P}	is the median path gain (< 0 dB),
G_{W}	is the building penetration (wall) gain (≤ 0 dB), and
$G_{\mathrm{A,PMSE}}$	is the PMSE receiver antenna gain (≥ 0 dB).

5.46 In deriving Equation (5.3) we have not accounted for any angular or polarisation discrimination at the transmitter or receiver antennas. This is because information regarding the orientations of the WSD and PMSE antennas will typically not be available. We acknowledge that ignoring antenna discrimination results in an over-estimation of the extent of interference. In practice, judicial positioning of PMSE receiver antennas can boost the PMSE signal by around 10 dB, while simultaneously suppressing the WSD signal by around 10 dB.

5.47 We propose that WSDBs use the parameter values in Table 5.3 for calculations of median coupling gain in Equation (5.3).

Table 5.3 – Parameter values for calculating WSD-PMSE median coupling gain.

Parameter	Value
m_{P}	Median path gain. For terrestrial PMSE services (those categorised as indoor or outdoor), the median path gain will be based on the SEAMCAT extended Hata path loss model[30]. See Annex 2 for numerical examples. For airborne services, the free space path loss model will be used. Note that path gain is the negative of path loss (both in dB).
G_{W}	Building penetration gain. We propose to use 0 dB for outdoor PMSE assignments / outdoor WSD, –7 dB for indoor PMSE assignments / outdoor WSD, –7 dB for outdoor PMSE assignments / indoor WSD, and –14 dB for indoor PMSE assignments / indoor WSD[31]. Type A WSDs will be assumed to be outdoors.

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[30] See the SEAMCAT manual at http://tractool.seamcat.org/wiki/Manual.

[31] Cases where both the WSD and PMSE are indoors and in the same venue will be dealt with via candidate locations so that WSDs will not be allowed to operate inside a PMSE venue. This is because the candidate locations of a PMSE receiver will extend outside the boundaries of the PMSE venue, and the candidate locations of a WSD will extend outside its area of location uncertainty (see later this section).

	Type B WSDs will be assumed to be outdoors, unless they report a height that is greater than 2 metres in which case they will be assumed to be indoors. Ofrom will provide WSDBs with information on the indoor/outdoor/airborne nature of PMSE usage for each PMSE assignment as indicated in Table 5.1.
$G_{\mathrm{A,PMSE}}$	PMSE antenna gain. We propose 0 dBi for all PMSE usage types.

5.48 We have proposed a building penetration loss that is considered typical for the UHF band[32]. We generally have no information regarding the indoor/outdoor nature of a WSD. This is why we propose that all type A WSDs be treated as outdoor. We consider that a type B WSD with a height that is greater than 2 metres is likely to be indoor and should benefit from more relaxed emission limits through an added building penetration gain.

5.49 The assumed value of the PMSE antenna gain is consistent with the value used for deriving the received wanted PMSE signal power.

Median path gain

5.50 The median path gain is a function of transmitter antenna height h_{WSD}, receiver antenna height h_{PMSE}, horizontal separation d between transmitter and receiver antennas, frequency f, and clutter type (for Extended Hata).

5.51 The antenna height h_{WSD} is a key element in the calculation of median propagation gain. The draft European harmonised standard EN 301 598 specifies that WSDs may automatically report their altitude h (above sea level) or height h_{WSD} (above ground) to the WSDBs. Where it is altitude that is reported, WSDBs will need to convert this to height using the method described in Annex 2.

5.52 We propose that WSDBs use the parameter values in Table 5.4 for calculation of median path gain.

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[32] ETSI TR 101 190 V1.3.2 (2011-05), "Digital Video Broadcasting (DVB); Implementation guidelines for DVB terrestrial services; Transmission aspects".

Table 5.4 – Parameter for calculating WSD-PMSE path gain.

Parameter	Value
h_{WSD}	Height of WSD antenna. A WSD may report this directly to a WSDB. If it is the altitude, h, that is reported, then the WSD antenna height above ground will be calculated as $h_{\mathrm{WSD}} = \max(h - h_T , 1.5)$ metres where h_T is the local terrain height derived from a terrain database (see Annex 2). The max operator avoids negative values of h_{WSD} which might arise as a result of inaccuracies in h or h_T. The height h_{WSD} will then be rounded to the nearest value of 1.5, 5, 10, 15, 20, or 30 metres. If the altitude or height are not reported, then the following default values will be used: Type A: $h_{\mathrm{WSD}} = 30$ metres, Type B: $h_{\mathrm{WSD}} = 1.5$ metres.
h_{PMSE}	Height of PMSE receiver antenna. This will be provided by Ofcom to the WSDBs for each PMSE assignment. A default value of 5 metres will be assumed in the absence of available information.
d	Horizontal separation between WSD and the PMSE receiver antennas. For geo-located master or slave WSDs, these will be calculated as the horizontal separations between the candidate location(s) of the WSD and the candidate location(s) of the receiver in a PMSE assignment. See later for the definitions of candidate locations. For the special case of non-geolocated slave WSDs, d will be lower-bounded to a value of 10 metres (see later).
f	Centre frequency of the DTT channel used by PMSE. This will be derived from the frequency of the PMSE assignment as provided by Ofcom to the WSDBs.
Clutter type	This will be determined by the WSDBs based on the location of the PMSE usage. This will be either urban, suburban, or open and will be identified according to a clutter database (see Annex 2).

Default WSD antenna heights

5.53 Where a WSD does not report its antenna altitude or height, we propose to use cautious rules to characterise antenna height:

- For type A WSDs, we propose to use a default outdoor height of 30 metres. We acknowledge that the majority of outdoor deployments are likely to be at heights of 20 metres or less (as is the case for base stations in mobile networks). However, we believe that such a default value will serve to incentivise the reporting of type A WSD antenna altitude/height.

- For type B WSDs, we propose to use a default outdoor height of 1.5 metres. This is broadly equivalent to an indoor height of 5 metres for a building penetration loss of 7 to 10 dB). This will account for the vast majority of type B use cases.

Question T10: Do you have any comments on our proposed approach for calculating coupling gains in relation to PMSE calculations

Uncertainty in the location of WSDs

5.54 In Table 5.4 we refer to the candidate horizontal location(s) of a WSD. Such candidate locations are necessary to account for uncertainty in the location of a WSD and will be derived by the WSDBs according to the definitions in this section. The use of candidate locations also facilitates the pre-calculation of coupling gains by the WSDBs.

5.55 All candidate locations must be considered in relation to calculating the maximum permitted WSD EIRP spectral density P_{IB}.

5.56 Candidate locations will be derived from an *area of potential locations* associated with a WSD. The area of potential locations is a geographical region within which a WSD might be located.

5.57 For a geolocated (master or slave) WSD with reported *nominal horizontal coordinates* (x_0, y_0), and reported horizontal location uncertainties $(\pm\Delta x, \pm\Delta y)$, the area of potential locations will be modelled as a rectangle centred on (x_0, y_0), and with sides of length $2\Delta x$ and $2\Delta y$ aligned with the North-South/East-West directions. This is shown in Figure 5.2 below.

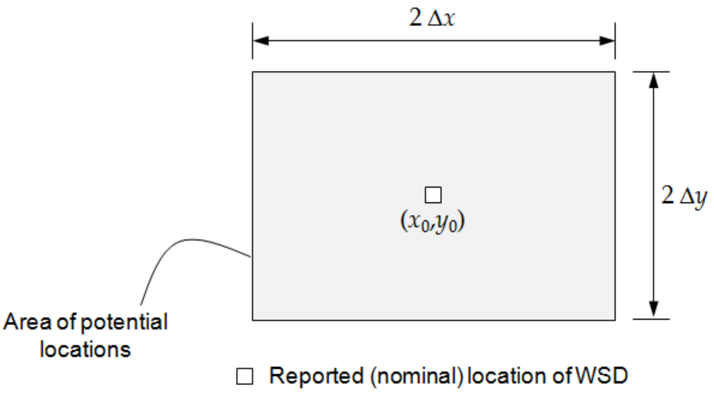

Figure 5.2 – Area of potential locations for a horizontally geolocated WSD.

5.58 For a slave WSD whose horizontal location is unknown (is not geolocated), the area of potential locations is the coverage area of its serving master WSD. For a serving master WSD with reported nominal horizontal coordinates (x_0, y_0), and reported horizontal location uncertainties $(\pm\Delta x, \pm\Delta y)$, the coverage area will be modelled as a circle centred on (x_0, y_0), and with radius $d_0 + \sqrt{(\Delta x^2 + \Delta y^2)}$. Here, d_0 is the coverage range of the master WSD (see Annex 3). In short, the area of potential locations for slave WSDs is the area of potential locations for the master WSD, extended by d_0. This is shown in Figure 5.3 below.

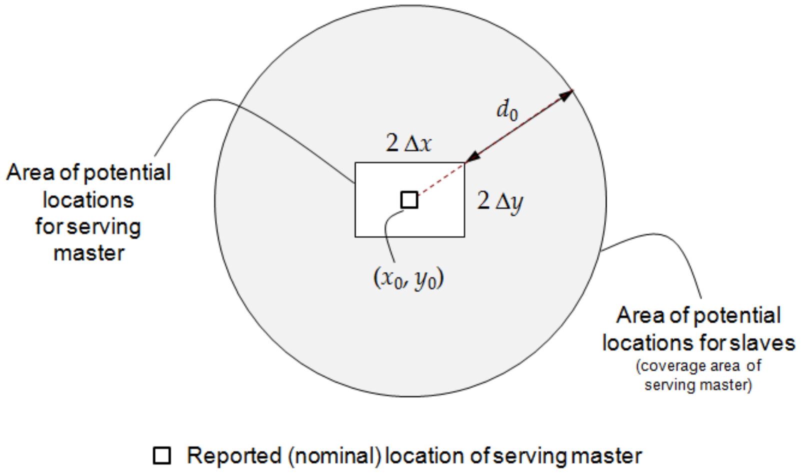

Figure 5.3 – Area of potential locations for a slave WSD whose horizontal location is not known (non-geolocated).

5.59 The candidate locations of a WSD will then be selected so as to coincide with locations of grid points which fall inside – or are less than 5 metres outside – the boundary of the area of potential locations of the WSD. The grid itself will be aligned with the NGR[33] grid and will have a resolution of 10 metres. This is shown in Figure 5.4 below.

5.60 If the area of potential locations does not contain any grid points, then the four corners of the grid square which contains the reported nominal horizontal location of the WSD (or its serving master WSD) will be considered as candidate locations.

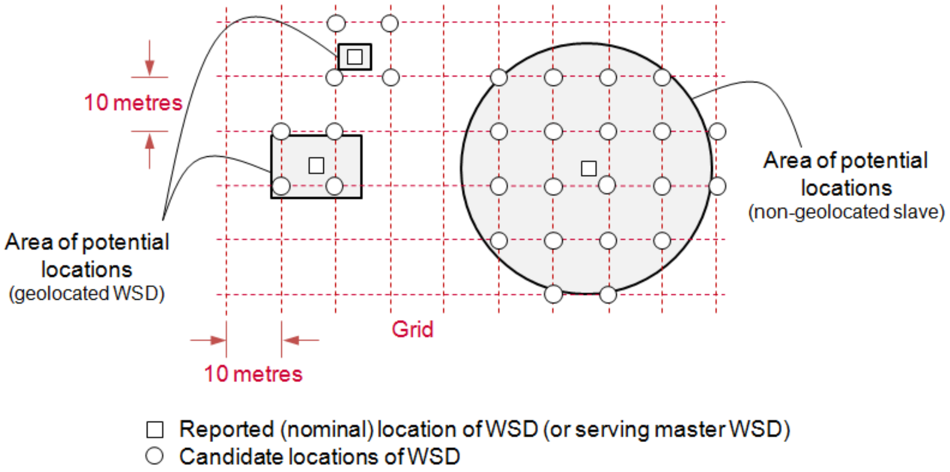

Figure 5.4 – Candidate locations for a WSD.

Question T11: Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of WSDs in relation to PMSE calculations?

Uncertainty in the horizontal location of PMSE receivers

5.61 In Table 5.4 we refer to the horizontal location(s) of PMSE receiver antennas associated with a PMSE assignment. We are exploring the possibility of identifying

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[33] Ordnance Survey National Grid Reference.

and recording multiple candidate PMSE receiver antenna locations for certain assignments in order to address the issue of uncertainty in the location of PMSE receivers within a venue. For this reason, the PMSE usage data provided by Ofcom *may* contain multiple candidate horizontal locations for certain PMSE assignments.

5.62 All such candidate horizontal locations must be considered in relation to calculating the maximum permitted WSD EIRP spectral density P_{IB}.

5.63 Ofcom will select the candidate locations so that they coincide with locations of grid points which fall within the boundary of the PMSE venue, or whose associated grid squares overlap with the boundary of the PMSE venue. The boundary of the venue may be provisionally approximated as a circle. The grid itself will again be aligned with the NGR grid and will have a resolution of 10 metres. This is illustrated below in Figure 5.5.

5.64 Where the candidate locations are for an indoor assignment, and they fall inside/outside the PMSE venue, Ofcom will label them as indoor/outdoor respectively.

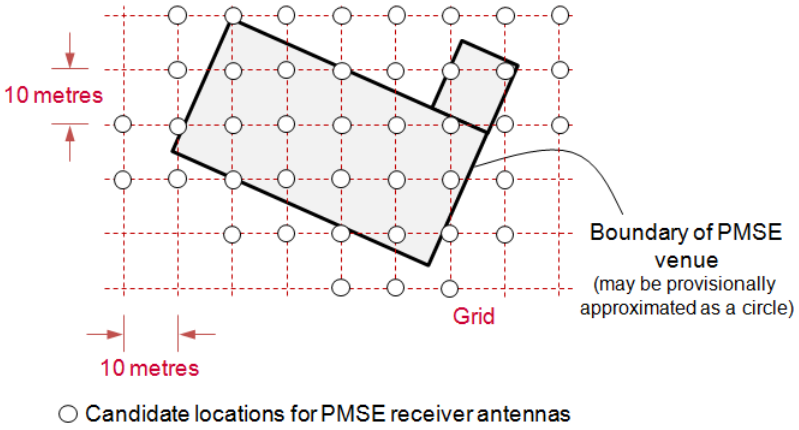


Figure 5.5 – Candidate receiver antenna locations for a PMSE assignment.

Question T12: Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of PMSE receivers in relation to PMSE calculations?

WSD-PMSE separations for non-geolocated slave WSDs

5.65 The calculation of horizontal separation, d, for non-geolocated slave WSDs will need to be treated in a special way.

5.66 As described in Section 2 and above, slave WSDs are not required to report their (horizontal or vertical) location to WSDBs. If not reported, WSDBs will infer the horizontal location of a slave WSD from the coverage area of its serving master WSD. In other words, the slave WSD will be assumed to be located at candidate locations defined by the coverage area of its master WSD.

5.67 The separation between a non-geolocated slave WSD and PMSE receivers can then be calculated from the horizontal separation between the slave WSD candidate locations and PMSE receiver candidate locations (as is the case for geolocated WSDs).

5.68 However, it is possible that certain slave WSD candidate locations might coincide with certain PMSE receiver candidate locations. This means that the WSD-PMSE separation d might be calculated as zero, implying a zero maximum permitted in-block EIRP spectral density P_{IB} in every channel (since $m_{\mathrm{G}} = +\infty$). Consequently, the coverage area of the master WSD would be completely sterilised and non-geolocated slave WSDs therein would not be permitted to radiate at all. In practice, the probability of such co-location is vanishingly small, as the slave WSD could be located anywhere within the coverage area of the master.

5.69 In order to rectify the above issue, we propose that if a candidate location of a non-geolocated slave coincides with the candidate location of a PMSE receiver, then WSDBs use a default WSD-PMSE horizontal separation of 10 metres and assume a 0 dB building penetration gain. We propose no building penetration gain because no information will be available on the indoor/outdoor nature of non-geolocated slave WSDs.

5.70 A useful way to interpret the above requirements is as follows: If the coverage area of a serving master WSD overlaps with the location of a PMSE receiver, we assume that irrespective of the location of a slave WSD, it is always a distance of 10 metres away from the said PMSE receiver. Although this means that non-geolocated slave WSDs will be subject to stringent emission limits in such circumstances, nonetheless they will still be able to operate (particularly for larger WSD-PMSE channel separations).

Question T13: Do you have any comments on our proposed approach for the derivation of WSD-PMSE coupling gains for non-geolocated slaves in relation to PMSE calculations?

WSD-PMSE protection ratios

5.71 As noted earlier, the WSD-PMSE protection ratio is defined as the ratio of wanted PMSE signal power (in bandwidth B) over unwanted WSD signal power (in 8 MHz) at the point of PMSE receiver failure.

5.72 We have undertaken a number of measurements to quantify the protection ratios relevant to different PMSE use cases. We have used a WSD signal based on the WiMAX standard for this purpose. The details of the measurement procedures and the post processing of the results are presented in Annex 5. We have characterised PMSE receiver failure as a 6 dB reduction in signal-to-noise and distortion ratio (SINAD).

5.73 The resulting values of protection ratio $r(\Delta F)$ are presented in Tables 5.5 to 5.7 for use in Equation (5.2). These are given for various PMSE use cases, different WSD spectrum emission classes, and the PMSE received wanted signal powers which were presented in Table 5.2.

5.74 The assumed WSD spectral leakage is based on the five spectrum emission masks of EN 301 598 (see Section 2) for channel separations $\Delta F = \pm1, \pm2$ and ±3. At increasing frequency separations, or low in-block EIRPs, WSDs will readily meet and exceed the EN 301 598 spectrum emission masks. As for the case of the WSD-DTT protection ratios, we have assumed a roll off in the emission masks (increase in AFLR) of 10 dB per 8 MHz beyond the third adjacent channel for the calculation of the WSD-PMSE protection ratios.

5.75 Due to their narrowband nature, PMSE equipment have high adjacent channel selectivity, to the extent that the WSD-PMSE protection ratios are primarily lower bounded by the limited ACLR (non-zero out-of-block emissions) of the WSDs at low frequency separations. As such, the spectrum emission class of the WSD has a strong bearing on the values of the protection ratios.

5.76 We propose not to address adjacencies beyond the 10th adjacent channel in relation to coexistence calculations; because we consider that the risk of harmful interference at these adjacencies is very small.

Table 5.5 – WSD-PMSE protection ratios: Wireless microphones.

$r(\Delta F)$ (dB)	Wireless microphones				
Frequency adjacency	WSD Class 1	WSD Class 2	WSD Class 3	WSD Class 4	WSD Class 5
$\Delta F = 0$	-4				
$\Delta F = \pm 1$	-52	-52	-48	-39	-28
$\Delta F = \pm 2$	-61	-58	-58	-49	-38
$\Delta F = \pm 3$	-62	-58	-62	-58	-49
$\Delta F = \pm 4$	-60	-60	-60	-60	-56
$\Delta F = \pm 5$	-69	-69	-69	-69	-66
$\Delta F = \pm 6$	-72	-72	-72	-72	-71
$\Delta F = \pm 7$	-73	-73	-73	-73	-73
$\Delta F = \pm 8$	-74	-74	-74	-74	-74
$\Delta F = \pm 9$	-75	-75	-75	-75	-75
$\lvert\Delta F\rvert = 10$	-78	-78	-78	-78	-78

Table 5.6 – WSD-PMSE protection ratios: In-ear monitors.

$r(\Delta F)$ (dB)	In-ear monitors				
Frequency adjacency	WSD Class 1	WSD Class 2	WSD Class 3	WSD Class 4	WSD Class 5
$\Delta F = 0$	-2				
$\Delta F = \pm 1$	-54	-54	-47	-37	-26
$\Delta F = \pm 2$	-61	-57	-57	-47	-36
$\Delta F = \pm 3$	-64	-57	-64	-57	-47
$\Delta F = \pm 4$	-60	-59	-60	-59	-55
$\Delta F = \pm 5$	-64	-64	-64	-64	-62
$\Delta F = \pm 6$	-64	-64	-64	-64	-64
$\Delta F = \pm 7$	-65	-65	-65	-65	-65
$\Delta F = \pm 8$	-66	-66	-66	-66	-66
$\Delta F = \pm 9$	-67	-67	-67	-67	-67
$\lvert\Delta F\rvert = 10$	-68	-68	-68	-68	-68

Table 5.7 – WSD-PMSE protection ratios: Programme audio links.

$r(\Delta F)$ (dB)	Programme audio links				
Frequency adjacency	WSD Class 1	WSD Class 2	WSD Class 3	WSD Class 4	WSD Class 5
$\Delta F = 0$	2				
$\Delta F = \pm 1$	-50	-50	-42	-33	-22
$\Delta F = \pm 2$	-57	-53	-53	-43	-32
$\Delta F = \pm 3$	-61	-53	-61	-53	-43
$\Delta F = \pm 4$	-67	-62	-67	-62	-53
$\Delta F = \pm 5$	-69	-67	-69	-67	-62
$\Delta F = \pm 6$	-69	-69	-69	-69	-67
$\Delta F = \pm 7$	-69	-69	-69	-69	-69
$\Delta F = \pm 8$	-69	-69	-69	-69	-69
$\Delta F = \pm 9$	-69	-69	-69	-69	-69
$\lvert\Delta F\rvert = 10$	-69	-69	-69	-69	-69

5.77 Note that the protection ratio measurements for programme audio links were only performed for channel separations of up to $\Delta F = \pm 4$. Absent additional data, we have assumed that the adjacent channel selectivity of the PMSE receiver remains at the same level for greater channel separations. It is for this reason that for large channel separations, the proposed protection ratios are increasingly limited by the ACS of the PMSE receiver.

5.78 The protection ratios for wireless microphones are also proposed to be used for talkback and data link equipment.

Question T14: Do you have any comments on our proposed protection ratios in relation to PMSE calculations?

Margin

5.79 It is common practice to model propagation gain as a log-normal random variable; i.e., $G_P \sim N(m_P, \sigma_P^2)$. The median, m_P , is typically based on a propagation model (e.g. extended Hata), with the standard deviation, σ_P, accounting for the variation of the propagation model around the median. The margin $\gamma_{(dB)}$ in Equation (5.2) would be typically set to a value $k\,\sigma_P$ to account for uncertainties in radio propagation.

5.80 We note that we have already made cautious (protective) assumptions regarding the median coupling gain, as we have not accounted for angular and polarisation discrimination at the WSD transmitter and PMSE receiver antennas. For this reason, we believe that the addition of a further margin is not necessary, and so propose to use a value of $\gamma_{(dB)} = 0$ in Equation (5.2). Instead, in order to capture the range of different propagation environments, we propose to use the open, suburban, and urban profiles of the extended Hata model depending on the clutter type of the PMSE receiver's location (as derived from a clutter database).

Question T15: Do you have any comments on our assessment that a margin for uncertainties in radio propagation is not necessary given the proposed parameters for derivation of coupling gains in relation to PMSE coexistence calculations?

Examples of EIRP restrictions and separation

5.81 Figures 5.6 to 5.9 show the variation of maximum permitted WSD in-block EIRP spectral density, P_{IB}, as a function of separation between a WSD and a wireless microphone assignment. We have used the parameter values proposed in this section to calculate emission the limits.

5.82 These are presented for channel 38 (610 MHz), assuming a wireless microphone height of 10 metres, a WSD height of 10 metres, a wireless microphone receiver antenna gain of 0 dBi, and the protection ratios of Table 5.5. We have assumed equal PMSE and WSD heights to illustrate challenging interference geometries. We have used a building penetration gain of 0 dB. Note that P_{IB} is capped at 17 dBm/(100 kHz) which scales to 36 dBm/(8 MHz).

5.83 Figure 5.6 indicates that P_{IB} will be restricted by the WSDBs when a WSD is less than roughly 400 and 700 metres away from a co-channel wireless microphone assignment in suburban and urban environments, respectively.

5.84 Figure 5.7 indicates that the restriction distances drop to below 200 metres for 1st adjacent channel wireless microphone assignments. Also note that different restrictions apply to the five spectrum emission classes. As mentioned earlier, the protection ratios are typically lower bounded by the limited ACLR (spectral leakage) of the WSD. For this reason, class 1 and class 5 WSDs (compliant with the most stringent and most relaxed spectrum emission masks) are subject to the least and greatest EIRP restrictions, respectively.

5.85 Figure 5.8 shows that the restriction distances further reduce to below 100 metres for 2nd adjacent channel wireless microphone assignments.

5.86 Figure 5.9 shows that for the 3rd channel adjacencies, power restrictions apply to class 1 to 4 WSDs for separations of less than 10 metres, and to class 5 WSDs for separations of less than 20 metres. There is very little difference here between the restrictions in suburban and urban environments (extended Hata path loss is effectively the same as free space at these separations).

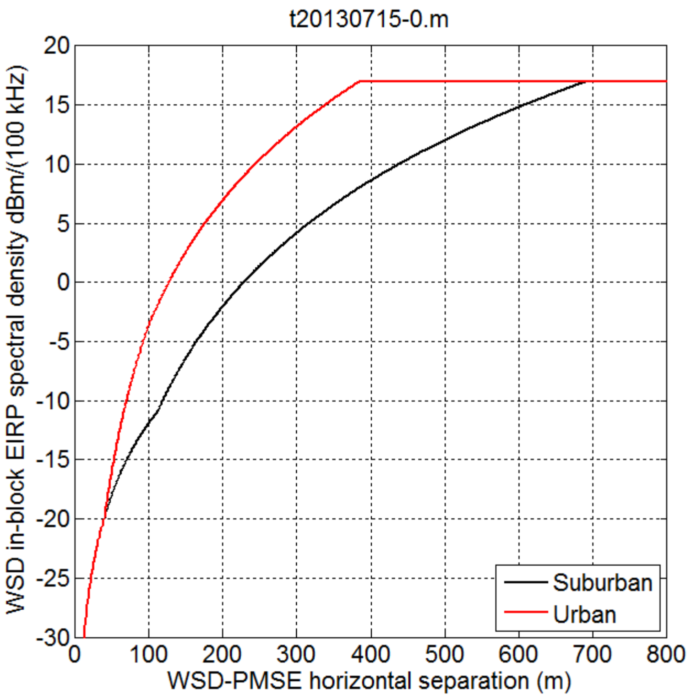
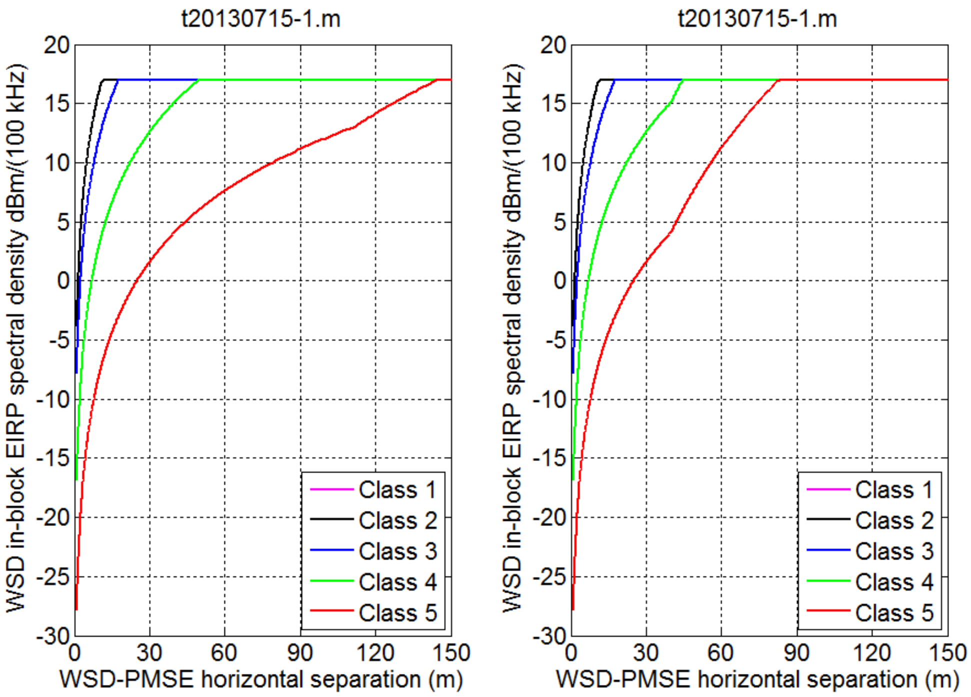
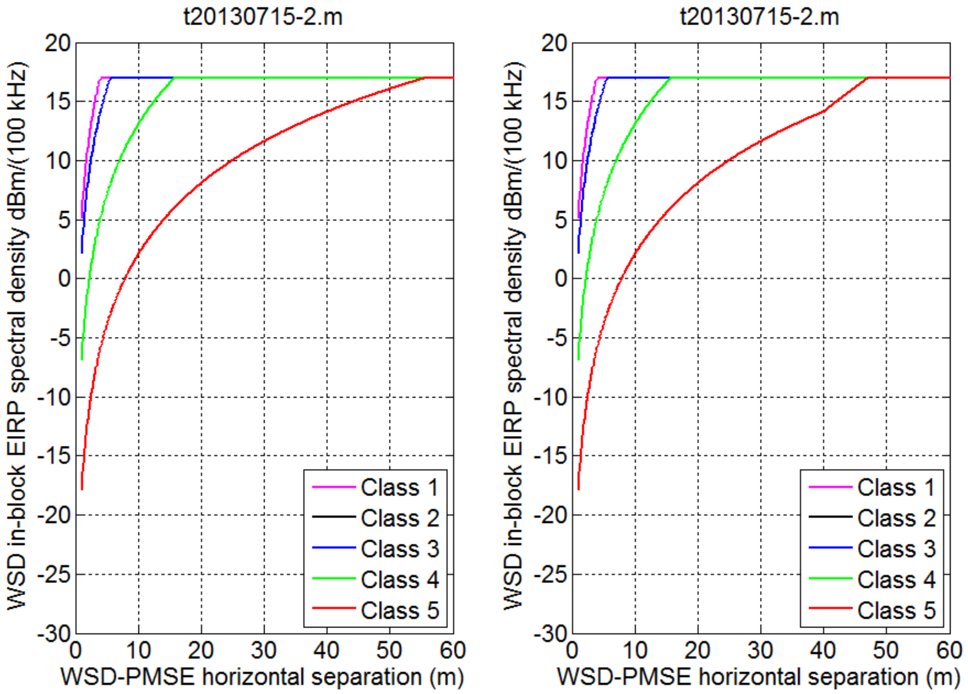


Figure 5.6 – WSD EIRP restrictions when co-channel with wireless microphone PMSE assignments.



a) Suburban b) Urban

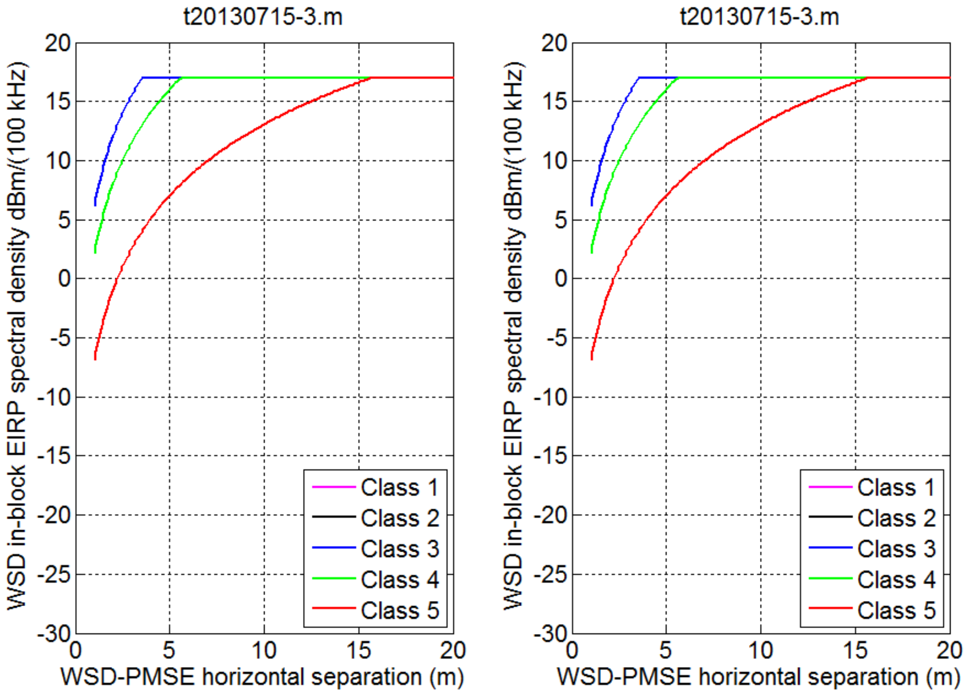
Figure 5.7 – WSD EIRP restrictions in the 1st adjacent channel with respect to wireless microphone PMSE assignments.



a) Suburban

b) Urban

Figure 5.8 – WSD EIRP restrictions in the 2nd adjacent channel with respect to wireless microphone PMSE assignments.



a) Suburban

b) Urban

Figure 5.9 – WSD EIRP restrictions in the 3rd adjacent channel with respect to wireless microphone PMSE assignments.

PMSE in channel 38

Background

5.87 In the UK, channel 38[34] is allocated exclusively to PMSE primarily for use by radio wireless microphones and there are two 200 kHz channels available for audio link applications.

5.88 PMSE usage in channel 38 is subject to “shared licences” issued by JFMG. The licences are typically annual/bi-annual and provide spectrum access rights at any location in the UK, and at any time, in an uncoordinated fashion. This means that the locations of the PMSE equipment in channel 38 are generally not known[35].

5.89 The licensing regime in channel 38 is particularly useful for PMSE use cases which are not location specific. Examples of such use cases include news gathering, and touring bands.

Proposed restrictions

5.90 We propose to treat PMSE use in channel 38 in the same way as PMSE use in all other channels in terms of the technical parameters.

5.91 However, absent data on the locations of PMSE use in channel 38, we propose to use a “reference” or “default” separation between a WSD and the PMSE receiver. In other words, we assume that irrespective of the location of the WSD, there is always a PMSE use of channel 38 at a distance of 10 metres away. We consider that this is a reasonable separation, given that in line with our approach for the other channels, we do not account for any antenna angular discrimination. We also propose to use a building penetration gain of 0 dB.

5.92 Figure 5.6 indicates that protection distances of hundreds of metres are required between an outdoor PMSE assignment and an outdoor co-channel WSD radiating at 17 dBm/(100 kHz) or 36 dBm/(8 MHz). For a reference separation of 10 metres, harmful interference to PMSE can only be mitigated subject to extremely stringent WSD emission limits (in-block EIRP of less than -10 dBm/(8 MHz)).

5.93 Consequently, given the risk of harmful interference and the very stringent emission limits, we believe it would be prudent not to allow WSD operation in channel 38.

5.94 With regards to WSD emission limits in channels adjacent to channel 38, and with reference to the results of Figures 5.7 to 5.9 for a default separation of 10 metres, we propose that the in-block EIRP spectral density, P_0, and EIRP, P_1, of WSDs be restricted such that

$$P_0 \leq 17 - x \quad \text{dBm/(100 kHz)} \tag{5.4}$$

$$P_1 \leq 36 - x \quad \text{dBm/(8 MHz)} \tag{5.5}$$

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[34] Channel 38 is used for radio astronomy by our European neighbours. For this reason, channel 38 is not suitable for very high-power use cases such a main DTT transmitters.

[35] This is with the exception of two specific 200 kHz channels available for higher power (10 W maximum ERP) PMSE usage. Examples of such use are in major sports events. The locations of these PMSE equipments is known and can, if needed, be accounted for by a TVWS database.

where the reduction, x, is as per outlined in Table 5.8 below for different WSD spectrum emission classes and DTT channels.

Table 5.8 – WSD radiate power must not exceed
($17 - x$) dBm/(100 kHz) or ($36 - x$) dBm/(8 MHz)
in relation to PMSE usage in channel 38.

x (dB)	Channel		
	38 ± 1	38 ± 2	38 ± 3
Class 1	0	0	0
Class 2	0	0	0
Class 3	5	0	0
Class 4	15	5	0
Class 5	25	15	5

5.95 That is to say, WSDs with class 1 and 2 spectrum emission masks may operate in channels adjacent to channel 38 without any restriction in relation to PMSE usage in channel 38. However, WSDs with class 3, 4, or 5 emission classes are subject to certain power caps in channels adjacent to channel 38. No restrictions are deemed necessary for channels lower than 35 or higher than 41.

Question T16: Do you have any comments on our proposed WSD emission limits in relation to PMSE use in channel 38?

Examples of TVWS availability in relation to PMSE

5.96 Here we present illustrative examples of TVWS availability in relation to PMSE usage in selected areas of Central London and Glasgow. We also intend to shortly publish a series of geographic maps of white space availability.

5.97 The results account for all WSD emission limits in relation to PMSE. This includes all location agnostic restrictions in relation to PMSE use in channel 38, namely no operation in channel 38, and reduced maximum in-block EIRPs in channels 35-37 and 39-41. The results are presented both with and without restrictions which apply in relation to DTT. Note that no cross border restrictions apply in London or Glasgow (see Section 8). We have also assumed no operation in channel 60 in relation to 4G use above the band (see Section 6).

5.98 Finally, we have made the following simplifying assumptions:

- The by far most dominant PMSE usage type is wireless microphone, and we have modelled all PMSE assignments as such.
- We have used a frequency of 626 MHz in calculating the median path gain (centre frequency of DTT channel 40). There is approximately a 2 dB difference between the median path gain in channel 40 and in either of channels 21 or 59.

5.99 It should be noted that the presented results apply to geolocated WSDs only. If a WSD is not geolocated (e.g. a slave WSD which has not yet attached to a master) then the uncertainty in its location will mean lower TVWS availability.

WSD emission limits in London in relation to PMSE

5.100 London has a considerably higher geographic concentration of PMSE deployments than in any other UK city. We have conducted our study in a 10 km × 10 km area centred on National Grid Reference TQ 300 800. This area includes Camden and Islington to the North, Paddington and Kensington to the West, Clapham and Brixton to the South, and Bermondsey to the East.

5.101 We have used PMSE assignments live at any time on 25th May 2013 as a snapshot of PMSE activity in the area[36]. The calculated restrictions account for a total of 5003 PMSE frequency assignments. Note that there are often multiple assignments at the same location.

5.102 We have calculated the WSD emission limits at the centre of every 100 m × 100 m pixel in the examined area. We have considered all 40 DTT channels as available for WSD use, with the exception of channels 38, 60.

5.103 As implied by Figures 5.6 to 5.9, there are restriction zones in the vicinity of each PMSE assignment within which WSDs are limited in the maximum EIRP they can use. The limits are a function of WSD antenna height, spectrum emission class, and frequency separation from the PMSE assignments.

5.104 We quantify TVWS availability at any particular WSD location as the maximum number of DTT channels which are available for use by a WSD when it transmits at a given WSD in-block EIRP spectral density $P_{\text{WSD-PMSE}}$.

5.105 Figure 5.10 shows the percentage of WSD locations (test points) in the examined area where a minimum number of DTT channels are available for use by a WSD when it transmits at a given EIRP. Results are given for WSD antenna heights of 1.5, 5, 10, 15 and 20 metres and WSD EIRP spectral densities of -4, +6, and +16 dBm/(100 kHz). The latter correspond to 15, 25, and 35 dBm/(8 MHz), respectively.

5.106 The curves with the same colour correspond to the various WSD spectrum emission classes: the upper curve of the set corresponds to class 1 and the lower curve of the set corresponds to class 5.

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[36] 25 May 2013 was a Saturday and part of a Bank Holiday weekend. This date was chosen as it was considered to be representative of a relatively high period of PMSE use.

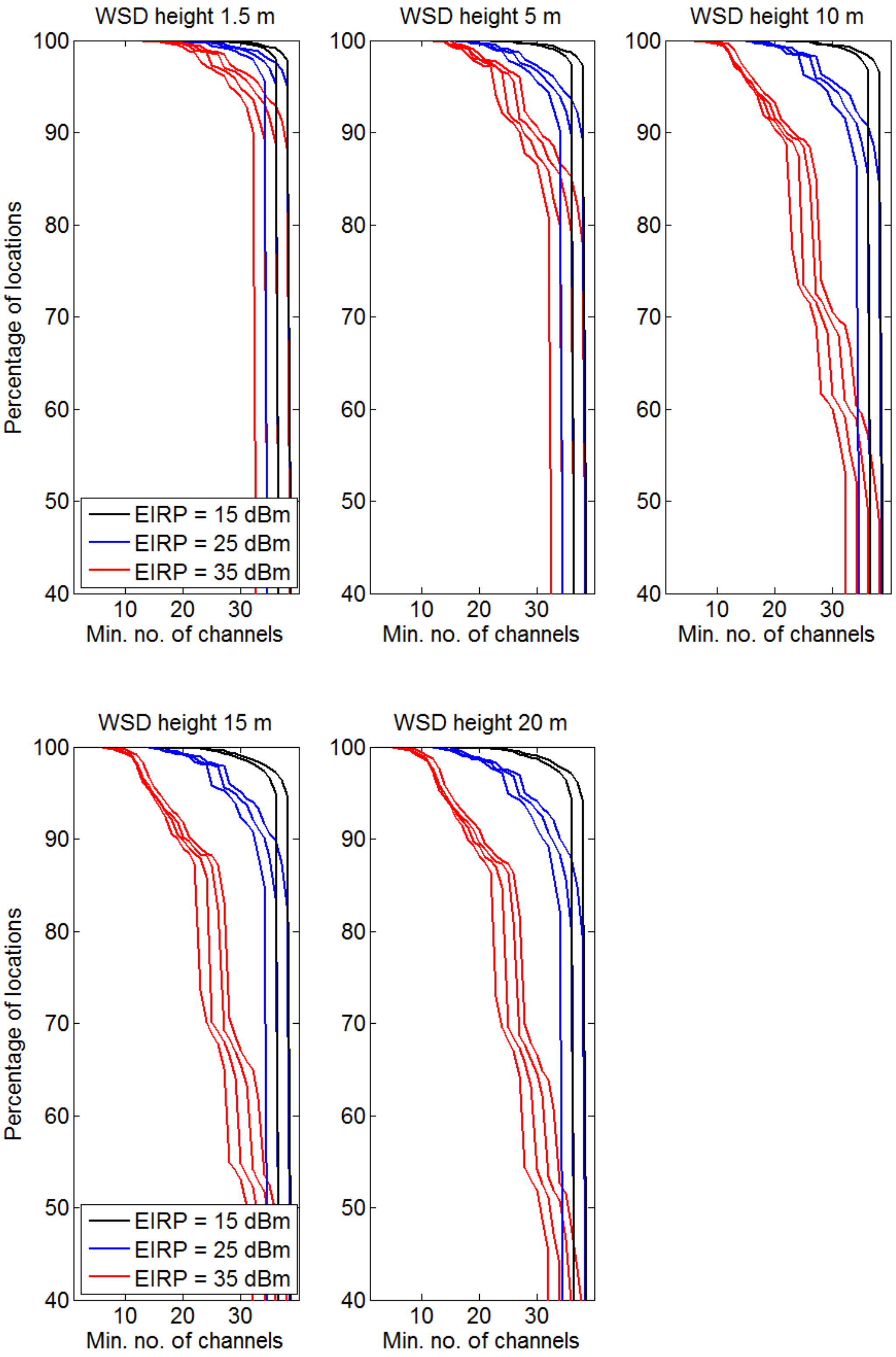

Figure 5.10 – Availability of 8 MHz channels in London in relation to PMSE. The EIRP values represent $P_{\mathrm{WSD\text{-}PMSE}}$ = -4, +6, +16 of dBm/(100 kHz) equivalent to 15, 25, and 35 dBm/(8 MHz). Curves of similar colour apply to different WSD spectrum emission classes.

5.107 We can deduce the following from Figure 5.10:

- Around 99% of WSD locations examined have access to 10 channels or more. While around 90% of WSD locations examined have access to 18 channels or more.
- Low-power WSDs at 15 dBm/(8 MHz) can access 30 channels or more at 99% of locations. In contrast, high-power WSDs at 35 dBm/(8 MHz) can only access 21 channels or more at 99% of locations if the antenna height is low, at 1.5 m.
- The impact of restrictions we have imposed in relation to PMSE use in DTT channel 38 and neighbouring channels is evident. As set out earlier WSDs are not permitted to operate in channels 38 and 60, so at best only 38 channels are available. The restrictions on the maximum in-block EIRP (Table 5.8) in channels 35-37 and 39-41 imply that for an EIRP level of 35 dBm/(8 MHz) no more than 32 channels are available for a class 5 WSD at any given location. Similarly, at an EIRP of 15 dBm/(8 MHz) no more than 36 channels are available for a class 5 WSD at any location.

5.108 A key conclusion is the importance of keeping WSD antenna heights to the minimum necessary in order to benefit from maximum TVWS availability.

5.109 Figure 5.11 shows the TVWS availability in London for the four scenarios we considered in Section 4.

5.110 As can be seen, TVWS availability is considerable greater in the low-height scenarios 3 and 4 (height of 1.5 metres) even though the WSD in these scenarios have relaxed spectrum emission masks (class 4 and 5). In these scenarios, around 99% of locations have access to 21 channels or more at a power of 35 dBm/(8 MHz).

5.111 Even in scenarios 1 and 2 (heights of 15 and 10 metres, classes 1 and 4), around 99% of locations have access to 12-13 channels or more at a power of 35 dBm/(8 MHz).

5.112 Since there are two channels where WSDs are not permitted to operate, the maximum number of available channels is 38. Depending on their emission class and their intended transmit power, WSDs may be prohibited from using some or all of the three channels on either side of channel 38. For example, for a class 5 device at 35 dBm/(8 MHz), the maximum number of available channels is 32.

5.113 Figure 5.12 shows the overall TVWS availability in relation to both DTT[37] and PMSE. This means that the more stringent of the WSD emission limits in relation to DTT and PMSE apply. The results indicate that in scenario 1 around 97% of locations have access to 3 channels or more at a power of 35 dBm/(8 MHz). In scenario 4, around 97% of locations have access to 7 or more channels.

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[37] Note that our modelling in relation to DTT over-estimates TVWS availability by up to one channel.

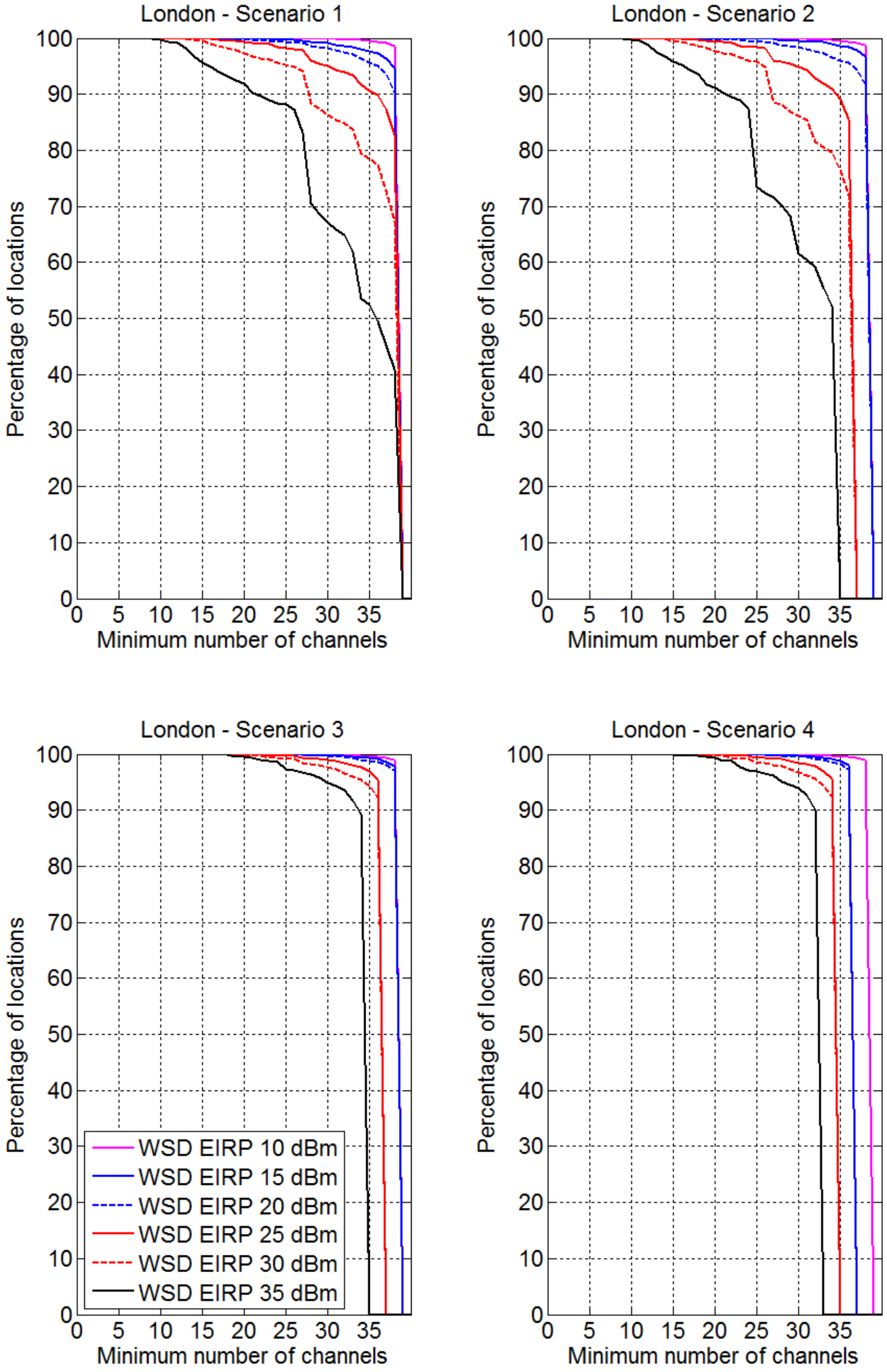

Figure 5.11 – Availability of 8 MHz channels in London in relation to PMSE.
Scenario 1: Class 1 at 15 metres. Scenario 2: Class 4 at 10 metres.
Scenario 3: Class 4 at 1.5 metres. Scenario 4: Class 5 at 1.5 metres.

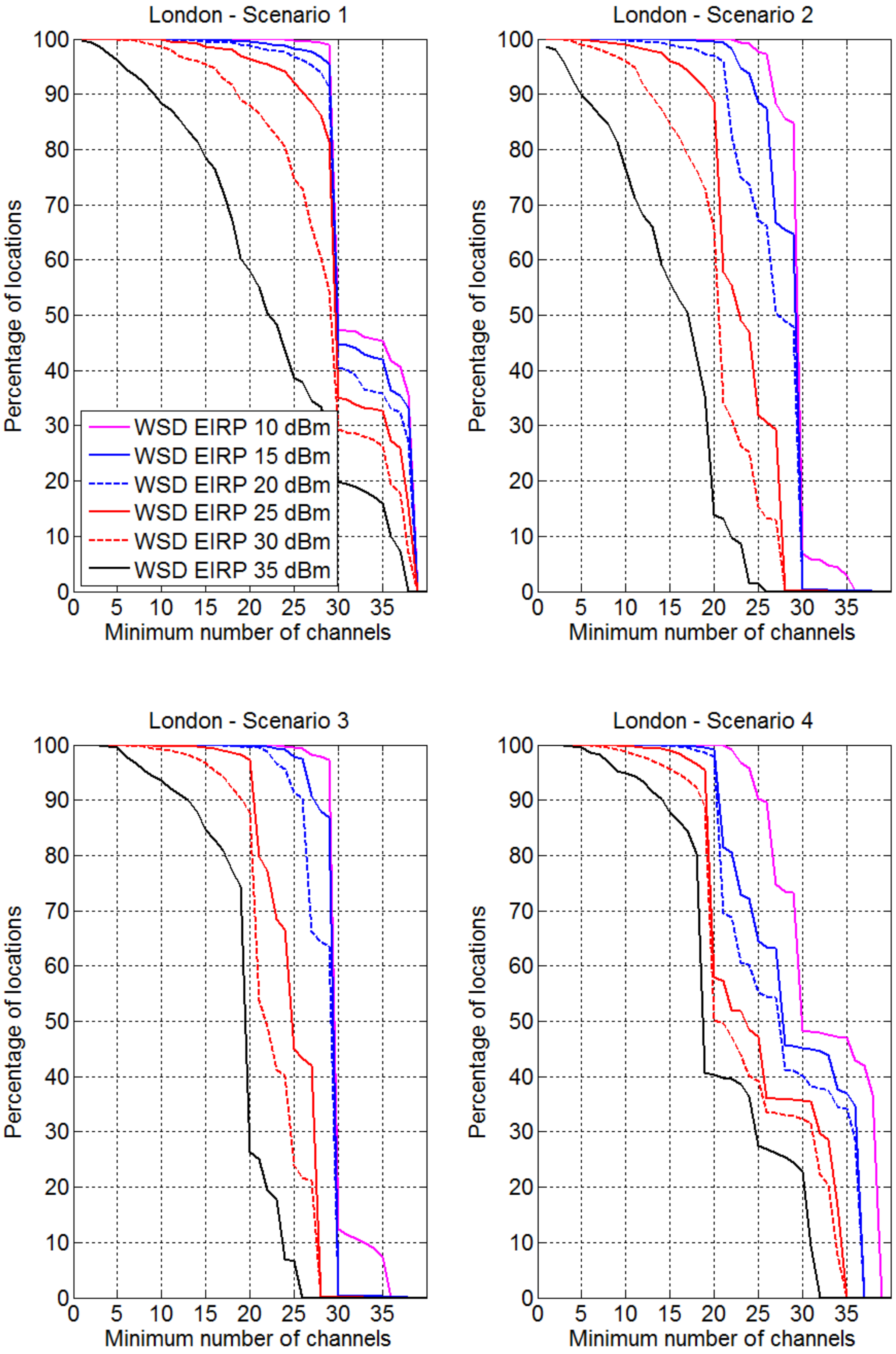

Figure 5.12 – Availability of 8 MHz channels in London in relation to DTT and PMSE. Scenario 1: Class 1 at 15 metres. Scenario 2: Class 4 at 10 metres. Scenario 3: Class 4 at 1.5 metres. Scenario 4: Class 5 at 1.5 metres.

WSD emission limits in Glasgow in relation to PMSE

5.114 We have conducted our study in a 10 km × 10 km area in Glasgow centred on National Grid Reference NS 590 650 (Glasgow Central Station).

5.115 We have used PMSE assignments live at any time on 25th May 2013 as a snapshot of PMSE activity in the area. The calculated restrictions account for a total of 201 PMSE frequency assignments. Note that there are often multiple assignments at the same location.

5.116 We have calculated the WSD emission limits at the centre of every 100 m × 100 m pixel in the examined area. We have considered all 40 DTT channels as available for WSD use, with the exception of channels 38, 60.

5.117 Figure 5.13 shows the percentage of WSD locations (test points) in the examined area where a minimum number of DTT channels are available for use by a WSD when it transmits at a given EIRP. Results are given for WSD antenna heights of 1.5, 5, 10, 15 and 20 metres and WSD EIRP spectral densities of -4, +6, and +16 dBm/(100 kHz). The latter correspond to 15, 25, and 35 dBm/(8 MHz), respectively.

5.118 The results are consistent with those for London, but reflect the lower prevalence of PMSE use in Glasgow. Nevertheless, we can see that WSDs have access to 19 or more channels in 99% of test locations. The impact of restrictions associated with PMSE use in DTT channel 38 is again visible.

5.119 Figure 5.14 shows the TVWS availability in Glasgow for the four deployment scenarios we considered in Section 4. Under all four scenarios, more than 99% of locations would have access to 21 or more channels at a power of 35 dBm/(8 MHz).

5.120 Figure 5.15 shows the overall TVWS availability in relation to both DTT[38] and PMSE. This means that the more stringent of the WSD emission limits in relation to DTT and PMSE apply.

5.121 The results indicate that in scenario 1 around 97% of locations have access to 3 or more channels at a power of 35 dBm/(8 MHz). In scenario 4, around 97% of locations have access to 7 or more channels.

5.122 The Figure shows that availability in Glasgow is mainly constrained by DTT use. In scenario 1 only around 55% of locations have access to 3 or more channels at a power of 35 dBm/(8 MHz). In scenario 4, only 16% of locations have access to 3 or more channels.

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[38] Note that our modelling in relation to DTT over-estimates TVWS availability by up to one channel.

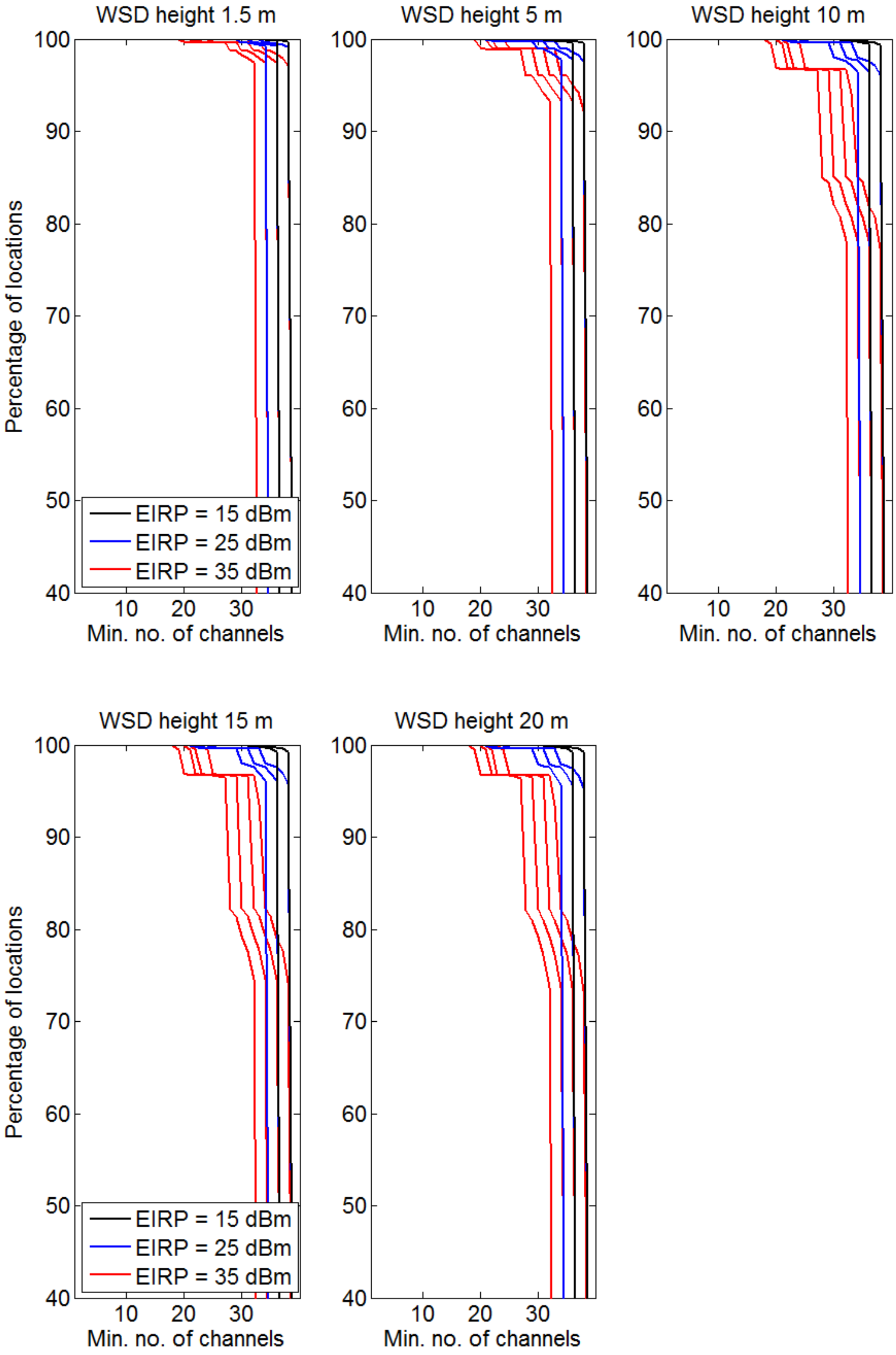

Figure 5.13 – Availability of 8 MHz channels in Glasgow in relation to PMSE. The EIRP values represent $P_{\text{WSD-PMSE}}$ = -4, +6, +16 of dBm/(100 kHz) equivalent to 15, 25, and 35 dBm/(8 MHz). Curves of similar colour apply to different WSD spectrum emission classes.

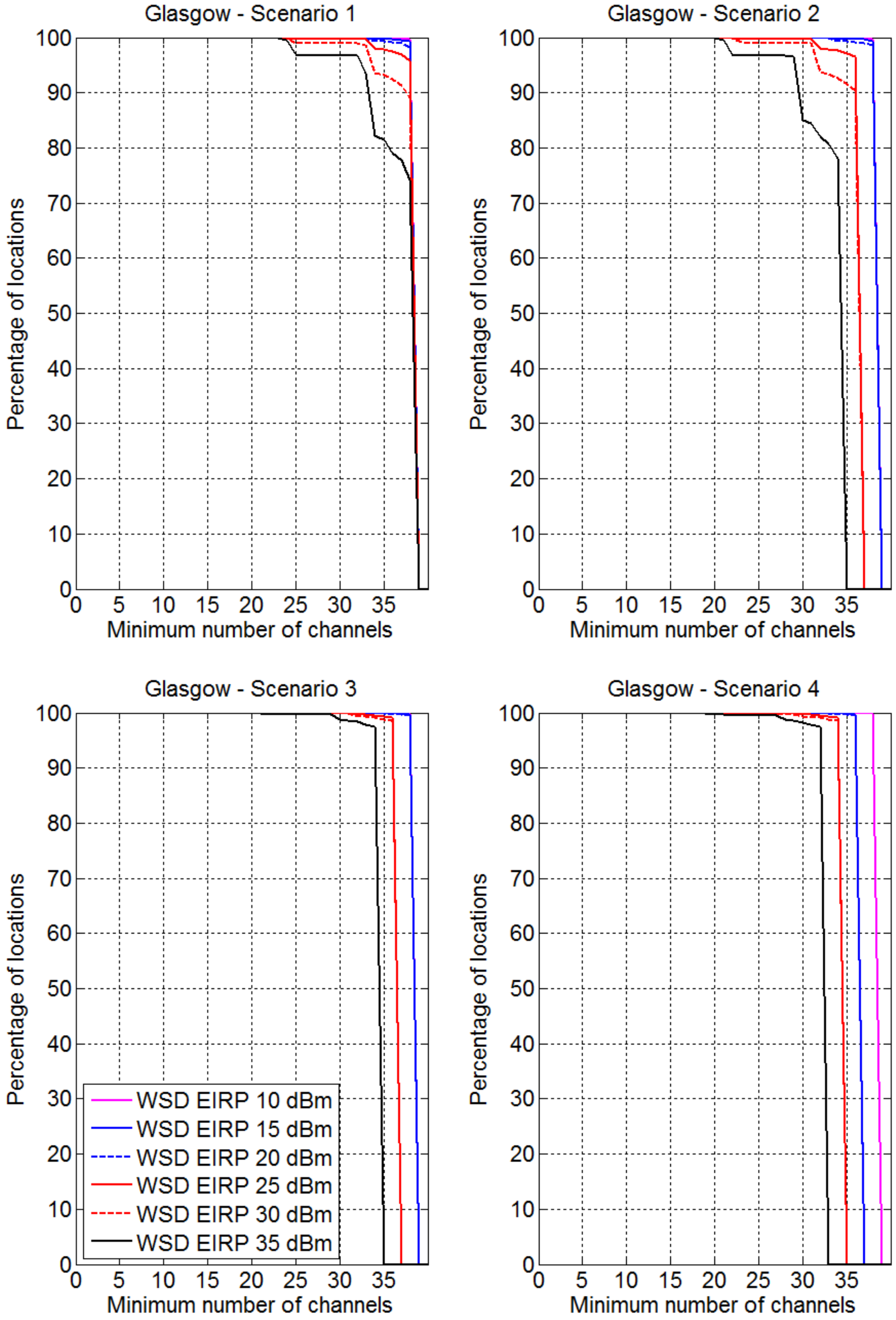

Figure 5.14 – Availability of 8 MHz channels in Glasgow in relation to PMSE. Scenario 1: Class 1 at 15 metres. Scenario 2: Class 4 at 10 metres. Scenario 3: Class 4 at 1.5 metres. Scenario 4: Class 5 at 1.5 metres.

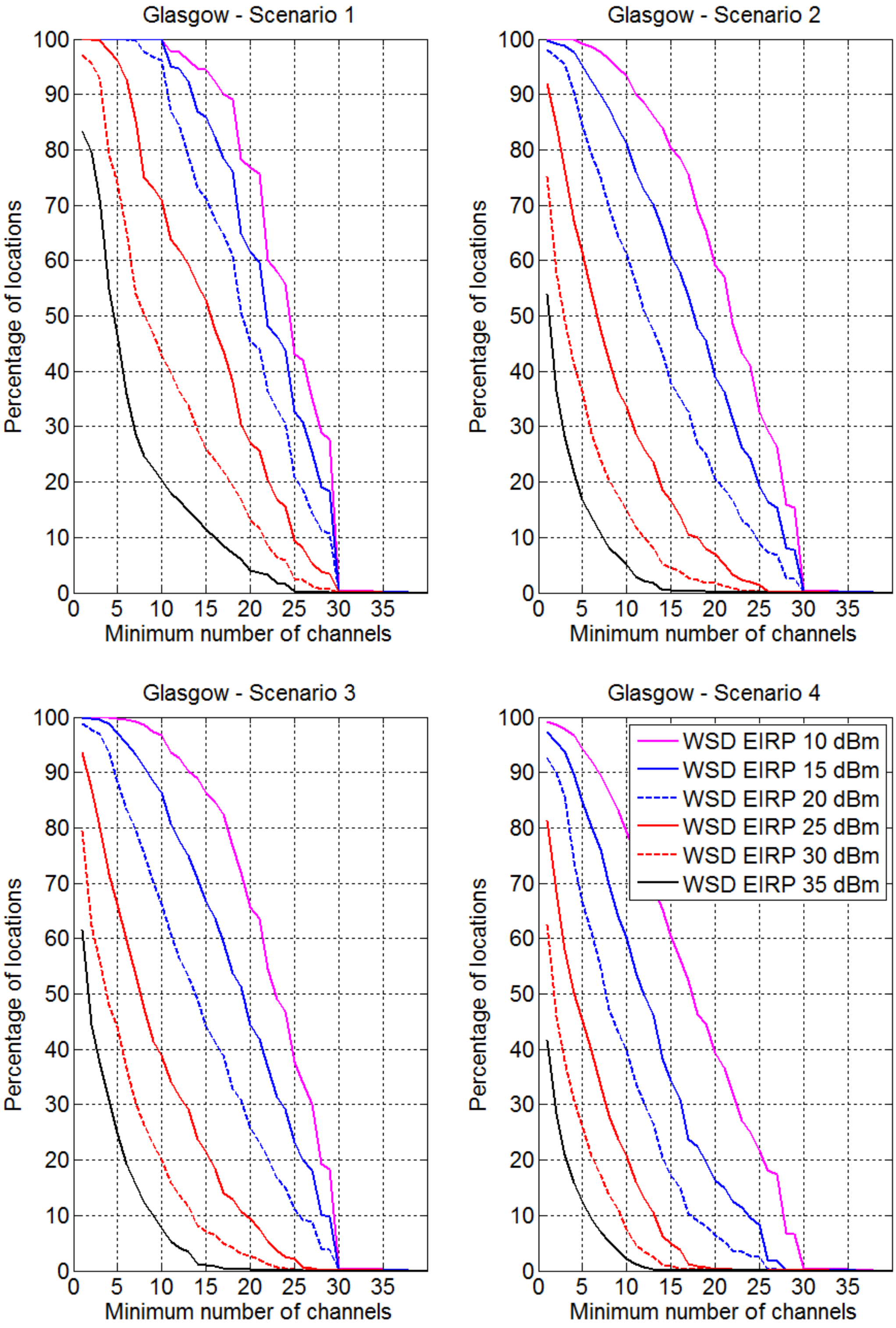

Figure 5.15 – Availability of 8 MHz channels in Glasgow in relation to DTT and PMSE.
Scenario 1: Class 1 at 15 metres. Scenario 2: Class 4 at 10 metres.
Scenario 3: Class 4 at 1.5 metres. Scenario 4: Class 5 at 1.5 metres.

Summary and conclusions

5.123 We have described our proposed approach for calculating location-specific and channel-specific maximum permitted WSD in-block EIRP spectral density levels in the context of seeking to ensure a low probability of harmful interference to PMSE usage in the 470-790 MHz band.

5.124 These calculations will be performed by the WSDBs based on relevant information on individual PMSE assignments in the UK as provided by Ofcom. The calculated WSD emission limits will be reconciled with any other EIRP restrictions which may apply (as communicated to the WSDBs by Ofcom). The resulting limits will then be communicated by the WSDBs to the WSDs.

5.125 We have also proposed various technical parameter values for the calculation of the WSD emission limits. These relate to the wanted signal power levels at the PMSE receivers, the coupling gain (including path loss) between the WSD transmitter and PMSE receiver, and the WSD-PMSE protection ratios (ratio of wanted to unwanted powers at the point of PMSE receiver failure).

5.126 Specifically, our proposals include the following:

- The maximum permitted in-block EIRP of a WSD in relation to PMSE use increases in accordance with its increasing geographic separation from (co-channel or adjacent-channel) PMSE assignments. As described in Section 4, the maximum in-block EIRP will be capped at 36 dBm in an 8 MHz channel.

- The proposed WSD-PMSE coupling gains are based on the median path loss derived via the extended Hata model, and explicitly account for the heights of the transmitters and receivers, as well as the indoor/outdoor nature of the WSD and the PMSE assignments. The coupling gains do not account for any angular discrimination at the antennas (in practice these will further contribute to mitigation of interference).

- Where a WSD reports its height, it will be rounded to the nearest value of 1.5, 5, 10, 20, or 30 metres. Type A WSDs will be assumed to be outdoor. Type B WSDs will be assumed to be outdoor, unless their reported height is greater than 2 metres in which case they will be assumed to be indoor. Where height is not reported by the WSD, default heights of 30 and 1.5 metres are proposed for type A and type B WSDs, respectively. A default height of 5 metres is proposed for the PMSE receiver, where height information is not available.

- We propose to use candidate locations to account for the uncertainty in the locations of WSDs and PMSE receivers. In cases where the candidate locations of a non-geolocated slave WSD coincide with the candidate locations of a PMSE receiver, we propose to use a default WSD-PMSE separation of 10 metres. No building penetration loss will be considered in these cases.

- The proposed WSD-PMSE protection ratios are based on the results of our measurements of a WSD signal (WiMAX standard) and a number of PMSE devices.

- The case of PMSE usage in channel 38 is treated differently, since the assignments are UK-wide. In order to reduce the probability of harmful interference to PMSE usage in channel 38, we propose that WSDs do not operate in channel 38, and that the in-block EIRP spectral density of class 3, 4, and 5 WSDs be appropriately capped in channels 35-37 and 39-41.

Section 6

WSD emission limits in relation to mobile services above the UHF TV band

6.1 In this section we examine the potential for harmful interference from WSDs to mobile networks operating in the 800 MHz band (791 to 860 MHz) and how to ensure that the probability of any such harmful interference is low.

6.2 In our consultation of November 2010 *Implementing geolocation* we stated:

> "…*we propose not to allow white space operation in channel 60 both to protect licensed operation in channels above 60 and also because there may be additional interference experienced in channel 60 as a result of use in channels 61 and above. We will also give consideration as to whether lower power levels should be adopted in channels 58 and 59*."

6.3 Here we review and further elaborate on our proposals. Specifically, we examine the potential for harmful interference to mobile stations receiving in the 791 – 821 MHz (downlink) band and assess the need for any restrictions on the operation of WSDs in order to mitigate any such interference.

6.4 We consider interference to mobile stations (rather than base stations) due to the "reverse duplex" nature of the 800 MHz band plan, which places the mobile network downlinks immediately above the UHF TV band.

6.5 The material in this section is organised as follows:

- We first present the UK band plan for the operation of mobile networks in the 800 MHz band;

- We next examine the existing levels of intra-band adjacent channel interference which mobile stations experience in the course of their normal operation in a mobile network and in the absence of WSD transmissions; and

- We then assess the potential for harmful interference from WSDs in the context of the existing levels of intra-band adjacent channel interference. We examine the need for any restrictions on the WSD operating EIRPs and frequencies for appropriately reducing the likelihood of harmful interference.

6.6 Note that the geographic locations of LTE mobile stations will not be known by Ofcom or WSDB providers. As such, any restrictions on the operation of WSDs for mitigating interference to LTE mobile stations would, by definition, need to be location-agnostic.

Band plan for mobile services in the 800 MHz band

6.7 The European preferred harmonised frequency arrangement for mobile/fixed communication networks (MFCNs) is specified by Annex 1 of ECC/DEC/(09)03. This consists of a frequency division duplex (FDD) channelling arrangements of 2×30MHz, based on a block size of 5MHz, a duplex gap of 11 MHz, and a duplex spacing of 41 MHz. The downlink starts at 791 MHz and the uplink starts at 832 MHz (reverse duplex). This implies a 1 MHz guard band between MFCNs and UHF DTT services. Figure 6.1 shows the UK band allocation following the 4G auction of the 800 MHz band[39].

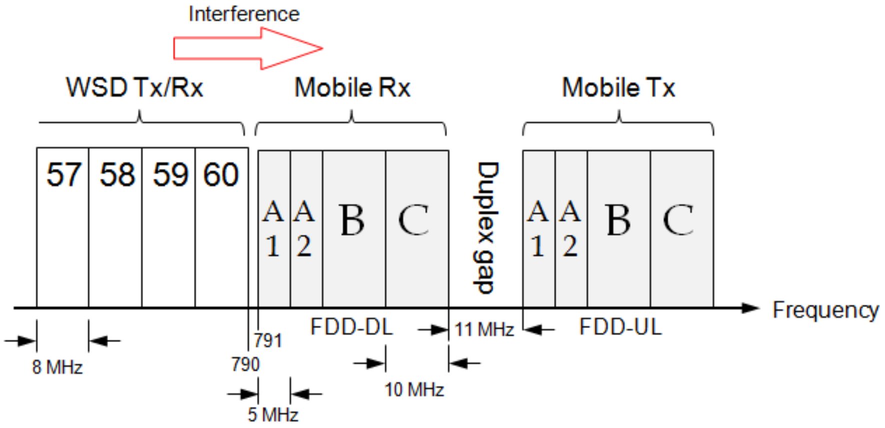

Figure 6.1 – The UK 800 MHz band plan.

6.8 Note that one of the primary purposes of the duplex gap is to facilitate the mitigation of mobile self-interference and mobile-to-mobile interference through the use of duplex filtering at the mobile station. The duplex gap is essentially a guard band which allows a duplex filter in a mobile station to achieve sufficient levels of stop-band attenuation given a transition-band roll-off that is not prohibitive.

Existing interference to mobile stations

6.9 A mobile station experiences intra-band adjacent channel interference in the course of its normal operation in a mobile network. This consists of the following:

- Interference from adjacent channel base stations; and
- Interference from other mobile stations as well as itself.

6.10 This is illustrated below in Figure 6.2, where we contrast mobile-to-mobile interference from uplink blocks A_1, A_2 , B and C, against base-to-mobile interference from downlink blocks A_1, A_2 and B.

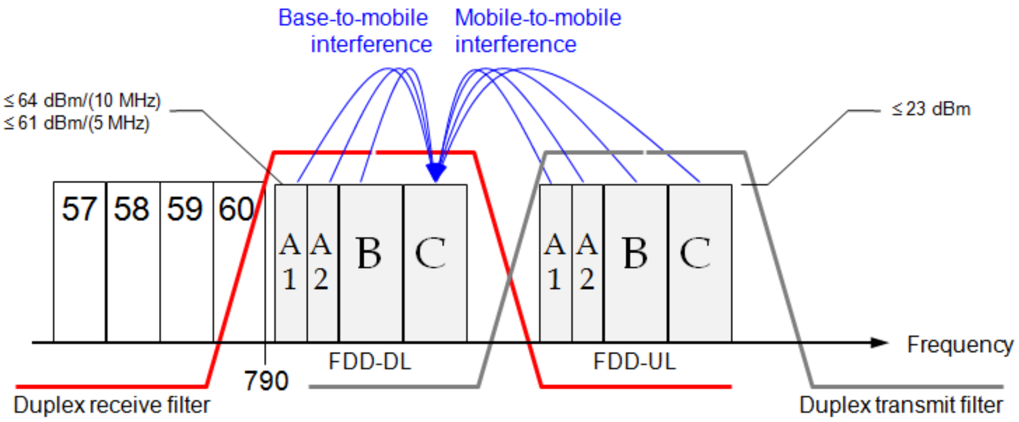

Figure 6.2 – Base-to-mobile and mobile-to-mobile interference.

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[39] http://media.ofcom.org.uk/2013/02/20/ofcom-announces-winners-of-the-4g-mobile-auction/.

6.11 In comparing the impact of base-to-mobile and mobile-to-mobile interference, we note the following:

a) In the UK, LTE base stations operating in blocks A_1 and A_2 may transmit at an in-block EIRP up to 61 dBm/(5MHz). LTE base stations operating in blocks B and C may transmit at an in-block EIRP of up to 64 dBm/(10MHz). LTE mobile stations, on the other hand, may transmit at an in-block EIRP of up to 23 dBm. See Table 6.1.

b) The adjacent channel leakage ratios (ACLRs)[40] of LTE mobile stations and base stations are summarised in Tables 6.2 and 6.3 for the relevant adjacencies. Note that the ACLRs of the mobile stations are considerably greater than those of base stations. This is due to the stop-band attenuation of the duplex filter at the mobile station transmitter, which suppresses a mobile's out-of-block emissions by roughly an additional 50 dB as compared to the ACLRs defined in the 3GPP specifications. No base station duplex filtering applies for these adjacencies.

c) The adjacent channel selectivities (ACSs)[41] of LTE mobile stations are also summarised in Tables 6.2 and 6.3 for the relevant adjacencies. Note that the ACS values in relation to mobile interferers transmitting in blocks A_1, A_2, B, and C are considerably greater than those in relation to base station interferers transmitting in blocks A_1, A_2 and B. This is because of the stop-band attenuation of the duplex filter at the mobile station receiver, which suppresses the interferers from the uplink blocks by roughly an additional 50 dB as compared to the ACSs defined in the 3GPP specifications.

6.12 Tables 6.2 and 6.3 also show the resulting adjacent channel interference ratios (ACIRs)[42] for the relevant adjacencies, as well as the term $P_{(\mathrm{dBm})} - \mathrm{ACIR}_{(\mathrm{dB})}$, where P is the interferer in-block EIRP. Once added to a transmitter-receiver coupling gain, this term is representative of the adjacent channel interference experienced by the receiver.

Table 6.1. Maximum in-block EIRP of LTE base stations and mobile stations.

	LTE BS (10 MHz)	LTE BS (5 MHz)	LTE MS
P (dBm)	64	61	23

Table 6.2. Mobile-to-mobile interference.

MS-MS	ACLR (dB)	ACS (dB)	ACIR (dB)	P – ACIR (dBm)
$C \leftarrow A_1$	88^+	95^+	87	-64
$C \leftarrow A_2$				
$C \leftarrow B$				
$C \leftarrow C$				

+ Includes 50 dB of added discrimination due to duplex filtering.

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[40] The ACLRs of mobile stations are derived from the specifications in 3GPP TS 36.101. The ACLRs of base stations are derived from the block edge masks in ECC Decision ECC/DEC/(09)03 (and EC Decision 2010/267/EU). These masks were in turn derived from the 3GPP specifications TS 36.105 subject to a 15 dBi antenna gain for comparison with in-block EIRPs.

[41] The ACSs of mobile stations are derived from the selectivity and blocking specifications in 3GPP TS 36.101. In the latter case, a noise figure of 10 dB is assumed.

[42] The ACIR is given (in the linear domain) as $\mathrm{ACIR}^{-1} = \mathrm{ACLR}^{-1} + \mathrm{ACS}^{-1}$.

Table 6.3. Base-to-mobile interference.

BS-MS	ACLR (dB)	ACS (dB)	ACIR (dB)	P-ACIR (dBm)
$A_1 \rightarrow C$	40	45	39	22
$A_2 \rightarrow C$	40	45	39	22
$B \rightarrow C$	39	33	32	32

6.13 Due to the impact of both transmit and receive duplex filtering in the LTE mobile station, the above results indicate that the ACIR values for mobile-to-mobile interference are considerably greater than those for base-to-mobile interference. In addition, the typical EIRP of a LTE base station (61-64 dBm) is 38-41 dB higher than that of a LTE mobile station (23 dBm). That is to say, for similar geometries (or coupling gains), mobile-to-mobile interference (as represented by $P_{(\mathrm{dBm})} - \mathrm{ACIR}_{(\mathrm{dB})}$) can be around 90-100 dB less than base-to-mobile interference.

6.14 Even accounting for the high coupling gains that might arise when two mobiles are in each other's close proximity, the implication is that the interference that a mobile station experiences from adjacent channel base stations is more substantial than the interference it experiences from other mobile stations (including itself).

6.15 Given the above, we will next examine the potential for harmful interference from WSDs in the context of base-to-mobile interference.

Potential for interference from WSDs

6.16 Here we use the base-to-mobile interference as a benchmark for assessing the impact of interference from WSDs to mobile stations. Again, note that the interfering base station transmissions fall within the downlink band, and as such are not subject to the stop-band attenuation of a mobile station's duplex filter. This is illustrated below in Figure 6.3, where we contrast base-to-mobile interference from downlink blocks A_2, B and C, against WSD-to-mobile interference from DTT channels 60, 59 and 58.

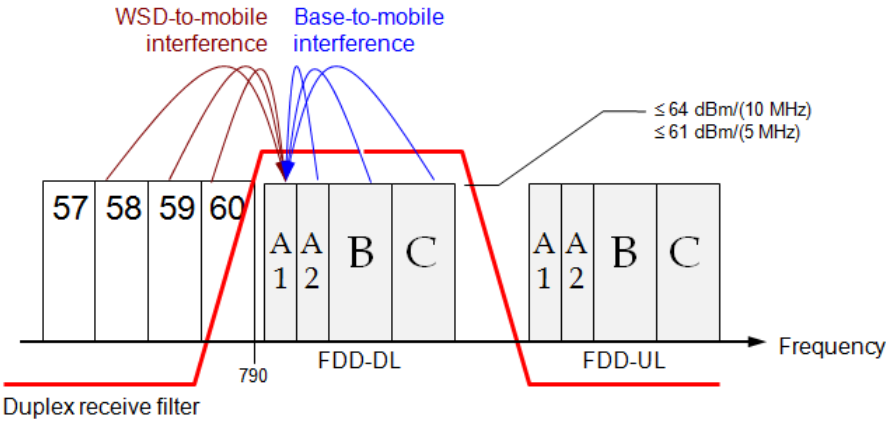

Figure 6.3 – Interference from WSDs contrasted with base-to-mobile interference.

6.17 In deriving appropriate restrictions on the operation of WSDs, we note the following:

- LTE base stations operating in block A_1 and A_2 may transmit at an in-block EIRP of up to 61 dBm/(5MHz). LTE base stations operating in blocks B and C may transmit at an in-block EIRP of up to 64dBm/(10 MHz). WSDs may transmit (subject to permission from a WSDB) at an in-block EIRP of up to 36 dBm/(8 MHz). See Table 6.4.

- The ACLRs of WSDs with respect to the 800 MHz band (derived[43] from ETSI EN 301 598) are similar or more stringent than those of LTE base stations (ECC/DEC/(09)03). See Table 6.5.

- The WSD in-block emissions in channels 59 and below[44] will be suppressed roughly by an additional 50 dB due to the stop-band attenuation of the duplex filter at the mobile station receiver (while the LTE base station emissions will not). Table 6.5 below shows the LTE mobile station adjacent channel selectivity (3GPP TS 36.101) for the relevant adjacencies but also accounting for the duplex filtering where appropriate.

6.18 Table 6.5 also shows the resulting adjacent channel interference ratios (ACIRs) and the term $P_{(\mathrm{dBm})} - \mathrm{ACIR}_{(\mathrm{dB})}$ for the relevant adjacencies.

6.19 The results indicate that the ACIR for a WSD in channel 60 is broadly similar to that for a LTE base station in block A_2. That is to say – for similar geometries and similar in-block EIRPs – the interference from a WSD in channel 60 is similar to the interference from a LTE base station in block A_2.

6.20 In practice, however, the maximum EIRP (36 dBm/(8 MHz)) of a WSD is 25 dB lower than the maximum EIRP (61 dBm/10MHz) of a LTE base station in block A_2. This means that, for similar geometries (or coupling gains) the interference (as represented by $P_{(\mathrm{dBm})} - \mathrm{ACIR}_{(\mathrm{dB})}$) from a WSD in channel 60 is some 26 dB lower than the interference from a LTE base station in block A_2.

Table 6.4. Maximum in-block EIRP of LTE base stations and WSD.

	LTE BS (10MHz)	LTE BS (5MHz)	WSD
P (dBm)	64	61	36

Table 6.5. WSD-to-mobile and base-to-mobile interference.

Adjacency	ACLR (dB)	ACS (dB)	ACIR (dB)	P – ACIR
$60 \rightarrow A_1$	73	33	33	3
$59 \rightarrow A_1$		98[+]	73	-37
$58 \rightarrow A_1$				
$57 \rightarrow A_1$				
$A_1 \leftarrow A_2$	39	33	32	29
$A_1 \leftarrow B$	46	36	36	28
$A_1 \leftarrow C$	46	48	44	20

+ Includes 50 dB of added discrimination due to duplex filtering.

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[43] The WSD emission limit over the band 790-862 MHz is specified at -54 dBm/(100 kHz) in ETSI EN 301 598. For an in-block EIRP of 36 dBm, this corresponds to an ACLR of 36 – (–54+17)= 73 dB.

[44] The WSD in-block emissions in channels 60 would partially fall within the transition band of mobile station duplex filters, and so would not be suppressed as much as those in channels 59 and below.

6.21 The values of $P - \mathrm{ACIR}$ imply that the levels of interference that a mobile station would receive when in the proximity of a WSD in channel 60 are significantly lower than the levels of interference that the mobile station would receive when it is in the *same proximity* of an adjacent channel base station.

6.22 However, a mobile station is more likely to be in the close proximity (say, tens of metres) of a WSD than an adjacent channel base station. This is due to the expected proliferation and use cases of WSDs as fixed low-power base stations and CPEs, or portable/mobile equipment. As a result, a mobile station might occasionally receive significant levels of interference from a WSD in channel 60.

6.23 Furthermore, base-to-mobile interference is an issue which affects all mobile network operators (MNOs). For this reason, MNOs have an incentive to coordinate and to mitigate such interference, for example, though a judicious selection of base station sites. Such coordination is not possible between a MNO and users of WSDs.

6.24 Given the above, we believe that it would be prudent at this stage to prohibit WSDs from operating in channel 60.

6.25 Interference levels from WSDs in channels 59 and below are expected to be three orders of magnitude lower than those in channel 60. As such, we do not believe that any restrictions are required for the operation of WSDs in channels 59 and below.

6.26 We intend to review our position in light of further studies and evidence in this area, and to explore the possibility of relaxing the proposed restrictions.

Question T17: Do you have any comments on our proposal not to permit WSDs to operate in channel 60?

Summary and conclusions

6.27 We have examined the potential for harmful interference from WSDs to mobile stations operating in the 800 MHz band, and assessed the need for any restrictions on the operation of WSDs in order to mitigate such interference.

6.28 In performing this analysis, we have accounted for the levels of intra-band mobile-to-mobile, and base-to-mobile interference which mobile stations might experience in the course of normal operation and in the absence of WSD transmissions.

6.29 Having examined the potential for harmful interference, we propose not to permit WSDs to operate in channel 60.

Section 7

WSD emission limits in relation to services below the UHF TV band

7.1 In this section we examine the issue of interference from WSDs to a range of different services operating below the UHF TV band.

7.2 Specifically, we present proposed WSD emission limits to ensure a low likelihood of harmful interference to breathing apparatus (BA) telemetry equipment as used by the UK Fire and Rescue Service. This service is due to migrate to the sub-band 469.850-470 MHz by end of 2015 and we consider this to be one of the most vulnerable services for the purpose of establishing WSD emission restrictions in relation to spectrum use below 470 MHz. This is because of the safety of life use of BA telemetry equipment as well as the challenging interference geometries it presents. As such, we consider BA telemetry equipment to be an appropriate representative service for our calculations.

7.3 The material in this section is organised as follows:

- We first present an overview of the various types of services in the UHF 2 band (450-470 MHz).
- We then assess the potential for interference from WSDs to BA telemetry equipment in the context of previous studies which examined the planned migration of the equipment from 862.9625 MHz to 869.5 MHz. The assessment is based on estimated levels of interference which BA telemetry equipment are expected to experience at 869.5 MHz from 800 MHz LTE uplink transmissions.

7.4 We note that the geographic locations of services below the UHF TV band will not typically be known, and our proposed restrictions are therefore location-agnostic.

Services in the 450-470 MHz band

7.5 There are a range of different services below the UHF TV band. Of prime interest are those occupying the band 450-470 MHz (see Figure 7.1), which include emergency services (ES), PMSE, scanning telemetry (ST), short range devices (SRD), business radio (BR) and maritime radio (MR).

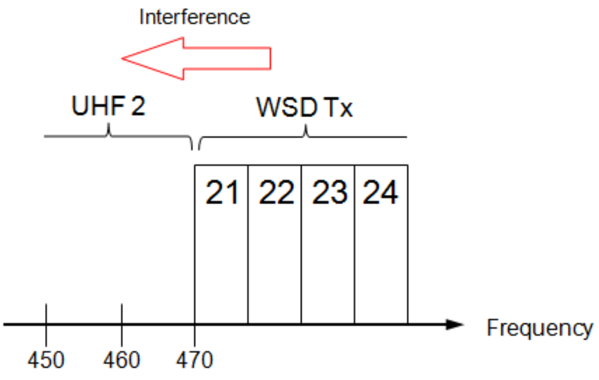

Figure 7.1 – The lower edge of the UHF TV band.

7.6 The frequency allocations in the band are complex with many small portions of the spectrum used by different services. Table 7.1 shows an approximate distribution of spectrum allocation by service based on a previous study undertaken in 2008 by Ofcom on the configuration of the UHF 2 band[45].

Table 7.1 – The UHF 2 band allocations.

Service	Spectrum allocation
Business and maritime radio	33%
Emergency services	32%
PMSE	20%
Scanning telemetry	10%
Short range devices	5%

7.7 The spectrum allocated to emergency services in this band supports a number of services. These are generally PMR (Private Mobile Radio, sometimes called Professional Mobile Radio) applications. The HM Prison Service is in the process of replacing all its current assignments with a TETRA network with 20 × 25 kHz duplex channel pairs.

7.8 Among the spectrum allocated for emergency services, a special case of governmental telemetry operations is a breathing apparatus equipment (BA Telemetry) used by the Fire and Rescue Services (FRS). These systems were operating at 862.9625 MHz and have been be relocated to 869.5 MHz in order to avoid interference from the deployment of mobile services below 862 MHz. In the longer term a plan is in place to move to a frequency between 469.850-470 MHz by end of 2015.

7.9 There is 3.5875 MHz of fragmented spectrum allocated to PMSE users in the UHF 2 band. The majority of the assignments for PMSE services in this band are licensed to talkback applications, others include data and programme audio links. Most of the services operate in a 12.5 kHz bandwidth. The characteristics of these applications are the same as those explained in Section 5.

7.10 The service provided by scanning telemetry (ST) allows the monitoring of critical national fuel and power, water and non-utility services. These services operate in the frequency band 457.5 to 458.5 MHz paired with 464.0 to 465.0 MHz. The duplex split for scanning telemetry provides a suitable arrangement for the deployment of services on a national basis.

7.11 Short range devices (SRDs) in the UHF 2 band operate on a licence-exempt basis. The applications include telemetry and tele-command, medical and biological applications, vehicle paging alarm, fixed alarms and model control. The channel bandwidth is either 12.5 kHz or 25 kHz. The maximum ERP varies between 10 mW up to 500 mW.

7.12 There are a large number of different users and types of usage within the UHF 2 band for business radio services and they are based on analogue or digital PMR technologies. Roughly 60% of the business radio services are analogue and the rest

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[45] Mott MacDonald, "Final report: Study to review the configuration of the 450-470MHz band in the UK," Dec 2008, http://licensing.ofcom.org.uk/binaries/spectrum/business-radio/technical-information/UHF2_realignment_study.pdf .

are digital. Business radio extends into many areas of business use, such as rail networks, logistics and service industry, utilities, private security services, media, sport and recreation. The spectrum assigned for business radio services in UHF 2 is particularly for use in conurbations where the majority of systems occupy a coverage radius of less than one kilometre.

7.13 Maritime on board radio shares the spectrum with business radio and scanning telemetry services in the UHF 2 band. These frequencies are not assigned to Business Radio or scanning telemetry licensees near coasts or navigational inland waterways. There are four channels available for use only with a bandwidth of 12.5 kHz and these are interleaved with a further six channels that may be used for 12.5 kHz or 25 kHz working. IR2035 refers to the ITU Recommendation[46] for power limits. The maximum power permitted by the Recommendation is 2 Watts ERP. Apparatus must also be fitted with a device to allow the power to be reduced by 10 dB.

7.14 In reality, operators generally select the high output setting. Furthermore, in many cases, we believe that ships simply use general purpose UHF handheld equipment that is tuneable over the frequency range allocated to on-board communications. This equipment may not be limited to 2 W ERP (35 dBm) and, in practice, may typically be 5 W ERP (39 dBm). While we have direct control over UK-flagged ships, via the UK ship radio licence, it is important to remember that these frequencies are allocated globally, so will be used by ships of any flag. Their use may also not be limited to coastal areas but may extend to inland waterways, such as the rivers Humber or Severn, the Manchester Ship Canal or Firths of Clyde or Forth.

7.15 The services in the UHF 2 band typically use narrowband channels (ranging from 6.25 to 200 kHz, but mostly 12.5 and 25 kHz), and EIRPs range from 12 dBm for short range devices up to 52 dBm for business radio and 54 dBm for scanning telemetry. Table 7.2 shows the EIRPs of these services.

Table 7.2 – The EIRPs and bandwidths of the services in UHF 2 band.

Services	Maximum EIRP
Emergency services	Range from 35 dBm to 46 dBm for prison services, 27 dBm for breathing apparatus telemetry.
Business Radio	Base station: 52 dBm (25kHz), 49 dBm (12.5 kHz). 46 dBm (6.25 kHz). Mobile station: 46 dBm (6.25, 12.5, 25 kHz).
Programme making and special events	32 dBm / 39 dBm for talk back (12.5 kHz, 25 kHz). 46 dBm for programme audio links (50 kHz). 32 dBm for data links (12.5 kHz).
Scanning telemetry	54 dBm (12.5 kHz).
Short range devices	12 dBm to 29 dBm (12.5, 25 kHz).
Maritime (for on-board ships)	Recommended up to 35 dBm but in practice up to 5 W ERP (12.5, 25 kHz).

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[46] ITU-R M.1174-2, http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1174-2-200405-I!!PDF-E.pdf .

Potential for harmful interference from WSDs

7.17 The UHF 2 band is predominantly used by narrowband applications. According to the previous study[45] undertaken by Thales on behalf of Ofcom, there are approximately 16,500 duplex assignments and 7,000 simplex assignments. Due to the variety of different services and assignments, we will not perform co-existence studies for each individual service.

7.18 Among the spectrum allocated for emergency services, of particular interest is a special case of governmental telemetry operations: breathing apparatus equipment (BA Telemetry) used by the Fire and Rescue Services (FRS).

7.19 BA telemetry generally operates in 25 kHz narrowband channels. These systems previously operated at 862.9625 MHz, and they have been relocated to 869.5 MHz to mitigate the potential interference from LTE. In the long term, the FRS is planning to move the BA telemetry to below 470 MHz, and the allocation is likely to be within 469.850-470 MHz.

7.20 The FRS have long used self-contained breathing apparatus to undertake operations in hazardous areas such as those filled with smoke or toxic vapour. BA telemetry is essential and provided for safety of life purposes. The potential risk caused by interference from WSDs to BA telemetry equipment is the highest compared to the other services in the UHF 2 band. Furthermore, BA telemetry can pose challenging interference geometries, with the possibility of low separations between the telemetry equipment and WSDs.

7.21 For these reasons, we consider BA telemetry to be an appropriate representative of the services in the UHF 2 band for deriving WSD emission limits which ensure a low probability of harmful interference to services below the UHF TV band.

7.22 Previous studies carried out on behalf of Ofcom by Thales and Aegis[47,48] considered the impact of LTE mobile stations in the 800 MHz uplink band (832-862 MHz) on the BA telemetry equipment at 862.9625 MHz and 869.5 MHz.

7.23 We describe below how the potential for interference from WSDs to planned BA telemetry operating in 469.875-470 MHz can be compared with the levels of interference which the BA telemetry experience in their current allocation at 869.5 MHz from LTE uplink block C. This is illustrated in Figure 7.2.

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[47] Thales Research and Technology (UK), “862-863MHz breathing apparatus telemetry system interference study,” 15 Dec 2010, http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/thales-report.pdf.

[48] Aegis System Limited, “Breathing apparatus telemetry system interference study,” 19 Mar 2012, http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/spectrum-clearance/Aegis_Report.pdf .

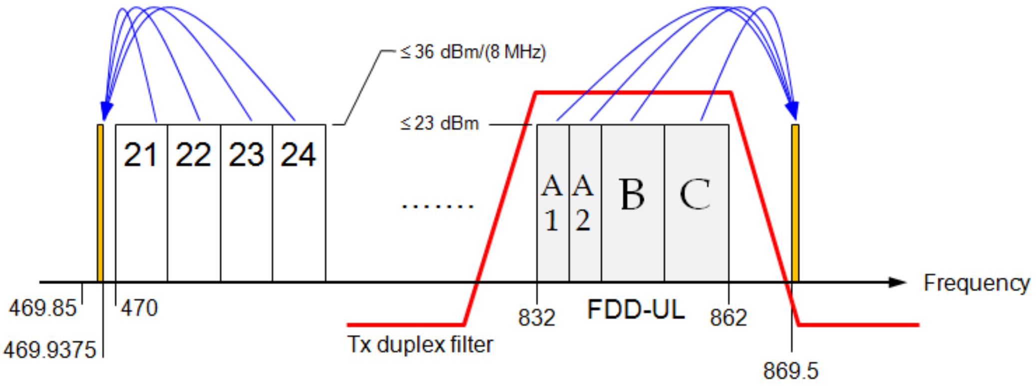

Figure 7.2 – Interference from WSDs contrasted with interference from LTE mobile stations.

7.24 In comparing the impact of interference from WSDs and LTE mobile stations to BA telemetry, we note the following:

- LTE mobile stations may transmit at an in-block EIRP of up to 23 dBm/(10 MHz), whereas WSDs may transmit (subject to permission from a WSDB) at an in-block EIRP of up to 36 dBm/(8 MHz). See Table 7.3.

- The services in the UHF 2 band (including BA telemetry) are narrowband, so the dominant mechanism for interference is spectrum leakage from a potential WSD interferer rather than the receiver selectivity.

- We present the out-of-band emissions of WSDs and LTE mobile stations in Table 7.4 over the relevant BA telemetry bands at 469.9375 MHz and 869.5 MHz, respectively. Here we have assumed that the devices radiate at maximum in-block EIRP of 36 dBm/(8 MHz). The WSD out-of-band emission levels are derived from the more stringent of the class-specific AFLR values[49] (see Section 2) and the absolute emission limit of -36 dBm/100kHz (-42 dBm/25kHz) over the 230-470 MHz band (all as specified in ETSI EN 301 598). We have also assumed a 10 dB/(8 MHz) roll-off of out-of-band emissions with increasing frequency separation from the band edge.

- We also present in Table 7.4 the measured out-of-band emission levels for three commercial LTE mobile stations subject to different resource block utilisations[50] (UE 1, 2 and 3), as well as the levels specified in 3GPP TS 36.101. In practice, LTE mobile stations have tighter spectrum emission masks than specified in the 3GPP specifications due to the stop-band attenuation of the duplex filter.

Table 7.3. Maximum in-block EIRP of WSDs and LTE mobile stations.

	WSD (8 MHz)	LTE MS
P_{IB} (dBm)	36	23

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[49] Specifically, $P_{\mathrm{OOB\ (dBm)}} = P_{\mathrm{IB\ (dBm)}} - \mathrm{AFLR}_{\mathrm{(dB)}}$ where $P_{\mathrm{OOB\ (dBm)}}$ and $P_{\mathrm{IB\ (dBm)}}$ are out-of-band and in-block EIRPs over 100 kHz and 8 MHz, respectively.

[50] LTE UE 1 refers to the out-of-band emissions of a commercial LTE UE where all LTE resource blocks are utilised, as described in the Thales report[47]. LTE UE 2 and 3 refer to the ‘profile 2’ and ‘profile 3’ out-of-band emissions for a commercial LTE UE as described in the Aegis report[48]. In the Aegis report, it is stated that the results for LTE UE 2 are directly comparable with those for LTE UE 1 in the Thales report as the emission levels of the two are similar at 862.9625 MHz.

Table 7.4. Out-of-band emissions from WSDs below 470 MHz in compliance with the class-specific adjacent frequency leakage ratio or the unwanted emissions limits over 230-470 MHz, whichever is more stringent. Also shown are out-of-band emissions levels from LTE mobile stations above 860 MHz.

P_{OOB} (dBm/25 kHz)	WSD					LTE MS
Adjacency	Class 1	Class 2	Class 3	Class 4	Class 5	
469.9375 ← 21	-44	-44	-42	-42	-42	N/A
469.9375 ← 22	-49	-44	-44	-42	-42	
469.9375 ← 23	-54	-44	-54	-44	-42	
469.9375 ← 24	-64	-54	-64	-54	-44	
C → 862.9625 (3GPP)	N/A					-19
C → 862.9625 (LTE UE 1)						-26
C → 862.9625 (LTE UE 2)						-27
C → 862.9625 (LTE UE 3)						-31
C → 869.5 (3GPP)						-29
C → 869.5 (LTE UE 1)						-45
C → 869.5 (LTE UE 2)						-50
C → 869.5 (LTE UE 3)						-57

7.25 The findings from the study by Aegis (UE 2 and 3) suggest that by moving BA telemetry from 862.9625 MHz to 869.5 MHz (increasing the minimum frequency separation from the LTE band to 7.5 MHz), and given the spectral leakage of practical LTE mobile stations, "…the probability of interference from LTE handsets to BA telemetry at 869.5 MHz is so low as to be insignificant in the operation of the telemetry system."

7.26 A similar conclusion is drawn by the Thales study (UE 1) which states that "Apart from the rare case of UEs with a clear view down over the incident in a rural area, [a move from 862.9625 MHz to 869.5 MHz] would in practice render most other interference extremely unlikely.".

7.27 Based on the conclusions of the above studies, we propose to use the out-of-block emission level, -45 dBm/(25 kHz), of LTE UE 1 at 869.5 MHz as a benchmark for assessing the impact of interference from WSDs to BA telemetry below 470 MHz. Accordingly, and accounting for a frequency squared dependency of path loss, the out-of-band emission levels of WSDs must not exceed -45 + 5 = -40 dBm/(25 kHz) or -44 dBm (100 kHz) at 469.9375 MHz[51].

7.28 The draft harmonised standard ETSI EN 301 598[52] for WSDs specifies that the level of unwanted emissions from WSD over the 230-470 MHz band must not exceed

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[51] 469.9375 MHz is the centre of the potential BA telemetry operating band 469.875-470 MHz.

[52] Draft ETSI EN 301 598, v 1.0.0 (2013-07), "White space devices (WSD); Wireless access systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

-36 dBm/(100kHz). However, the above analysis indicates that to mitigate the interference from WSDs to the BA telemetry, the unwanted emission level below 470 MHz would need to be -44dBm/(100kHz); i.e., 8 dB more stringent.

7.29 As a result, we intend to propose an 8 dB reduction of the WSD unwanted out-of-band emissions limit specified over 230-470 MHz in the draft EN 301 598, from the current value of -36 dBm/(100 kHz) down to -44 dBm/(100 kHz). This is illustrated below in Figure 7.3.

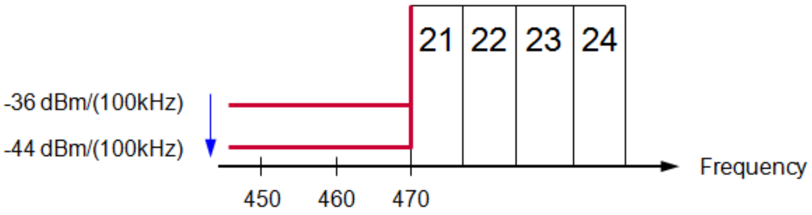

Figure 7.3 – Proposed tightening of the unwanted emission limit over 230-470 MHz in draft EN 301 598.

7.30 We will submit our proposal as part of our response to the public consultation on the draft EN 301 598 (closing date 26 September 2013). If this is accepted, we propose no further restrictions on the operation of WSDs in relation to services below the UHF TV band.

Question T18: Do you have any comments on our proposal that, if the unwanted emissions limit (over 230-470 MHz) in the draft ETSI standard (EN 301 598) is tightened by 8 dB, there should be no further restrictions on the operation of WSDs in relation to services below the UHF TV band?

7.31 An alternative to the reduction of the out-of-band emission limit in EN 301 598 – should this not be accepted – is to specify class-specific restrictions in the maximum permitted in-block EIRP of WSDs in a number of DTT channels above the 470 MHz band edge. These restrictions would have the effect of reducing the out-of-band emissions below 470 MHz (Table 7.4) to the required level of -44 dBm/(100 kHz).

7.32 The in-block EIRP spectral density, P_0, and EIRP, P_1, of WSDs would then be restricted such that

$$P_0 \leq 17 - x \quad \text{dBm/(100 kHz)} \tag{7.1}$$

$$P_1 \leq 36 - x \quad \text{dBm/(8 MHz)} \tag{7.2}$$

where the reduction, x, is as per outlined in Table 7.5 below for different WSD spectrum emission classes and DTT channels. No restrictions would apply above channel 24.

Table 7.5. Alternative to proposed revision to the out-of-band emission limit in EN 301 598: WSD in-block EIRP must not exceed
$(17 - x)$ dBm/(100 kHz) or $(36 - x)$ dBm/(8 MHz)
in relation to services below 470 MHz.

x (dB)	DTT channel			
	21	22	23	24
Class 1	6	1	0	0
Class 2	6	6	6	0
Class 3	8	6	0	0
Class 4	8	8	6	0
Class 5	8	8	8	6

7.33 In summary (as an alternative to our proposed revision of the unwanted emissions limit in EN 301 598),

- WSDs with class 1 and 3 spectrum emission masks may operate without restriction in channel 23 and above.
- WSDs with class 2 and 4 spectrum emission masks may operate without restriction in channel 24 and above.
- WSDs with class 5 spectrum emission mask may operate without restriction in channel 25 and above.

Question T19: Do you have any comments on our proposal that, if the unwanted emissions limit (over 230-470 MHz) in the ETSI standard (EN 301 598) is not changed, there should be restrictions on the in-block powers of WSDs in channels 21 to 24.

Summary and conclusions

7.34 We have described the wide variety of services operating below the UHF TV band. The breathing apparatus (BA) telemetry used by the UK Fire and Rescue Services is due to migrate to the sub-band 469.850-470 MHz by the end of 2015. As BA telemetry is a life-critical system and can present challenging interference scenarios, we have considered it as representative of other services in the UHF 2 band.

7.35 In deriving WSD emission limits to ensure a low probability of harmful interference to the BA telemetry service below 470 MHz, we have made reference to previous studies which examined the planned migration of the service from 862.9625 MHz to 869.5 MHz to mitigate interference from the 800 MHz LTE uplink transmissions.

7.36 Having examined the out-of-block emission levels of WSDs, we believe that interference from WSDs to BA telemetry and other services below 470 MHz can be mitigated by restricting the level of unwanted WSD emissions below 470 MHz to -44dBm/(100 kHz). We therefore intend to propose an 8 dB reduction of the WSD unwanted emissions limit specified over 230-470 MHz in the draft EN 301 598, from the current value of -36 dBm/(100 kHz) down to -44 dBm/(100 kHz).

7.37 As an alternative to the above revision of EN 301 598, we propose class-specific restrictions on the in-block EIRPs of WSDs in channels 21 to 24.

Section 8

WSD emission limits in relation to cross border issues

8.1 The United Kingdom and its neighbouring countries use the UHF band for DTT broadcasting classed as a primary service under the ITU Radio Regulations. Cross border co-ordination is an important factor to consider in the context of the use of the UHF TV band by WSDs.

8.2 The UK has international obligations with respect to the development of any services requiring new frequency use, and this includes WSD deployments. Under Article 5 of the ITU Radio Regulations, the primary service allocation in the UHF band (470-790MHz) in Region 1 is broadcasting. The UK considers WSDs to fall within the scope of land mobile services and therefore these would be considered as a secondary service as recognised in the ITU Radio Regulations under Article 5.296.

8.3 Our technical analysis suggests that unrestricted operation of WSDs near the UK coast line and/or land borders might cause harmful interference to DTT reception in the neighbouring countries. We therefore consider that co-ordination with our neighbouring countries would be appropriate to determine and agree technical parameters that would allow WSDs in the UK to coexist with cross border primary service DTT networks.

8.4 In this section we present our proposals for the calculation of location-specific and frequency-specific WSD emission limits in order to mitigate the risk of harmful interference to our neighbours. These limits will be combined by Ofcom with other WSD emission limits in relation to spectrum use by other services in the UK (including DTT) and communicated to WSDBs.

DTT cross border co-ordination in the UHF TV band

8.5 Countries can develop spectrum usage as long as it does not cause any harmful interference to neighbouring countries. Administrations signed up to the Geneva 2006 (GE06) digital broadcasting agreement can request additional DTT requirements to those registered in the GE06 plan. Any such request can operate below a specific co-ordination trigger threshold field strength level if desired to proceed without co-ordination agreement. If the trigger threshold field strength level is exceeded, international co-ordination agreement is required to protect existing GE06 (primary) broadcasting services.

8.6 In a DTT-DTT environment, the co-ordination trigger threshold field strength levels[53] of Table 8.1 are used for the protection of broadcasting services given an addition/ modification of the GE06 Plan affecting neighbouring administrations.

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[53] "Annex 4 - Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz," RRC-06, Geneva, 15 May - 16 June 2006.

Table 8.1 – Thresholds which trigger international co-ordination.

Broadcasting system modifying the plan	Trigger field strength $E_T(F)$ (dB(µV/m))		
	Band IV - CHs 21-34 (F = 470-582 MHz)	Band V - CHs 35-51 (F = 582-718 MHz)	Band V - CHs 52-69 (F = 718-862 MHz)
DVB-T	21 dBµV/m	23 dBµV/m	25 dBµV/m

8.7 If received DTT emissions exceed these threshold levels, official co-ordination is required. Affected administrations analyse each case to determine any incompatibility with registered services and in most cases the bilateral negotiation results in acceptable levels of outgoing/incoming field strengths between both parties.

Proposed approach for calculation of WSD emission limits

8.8 WSDs have no official internationally recognised frequency plan or treaty to govern their registration, deployment, interference potential or a requirement for co-ordination. However, the UK is internationally bound by the GE06 Treaties to ensure that neighbouring countries' primary DTT services are not affected by harmful interference from UK secondary services, which as noted above, we consider to include WSDs.

8.9 If a "new" DTT allocation was requested near the UK's coast lines or land borders, then co-ordination agreements would be required to operate the DTT transmitter if the resulting field strength received at the neighbouring countries exceeded the GE06 co-ordination trigger threshold levels presented in Table 8.1.

8.10 While the trigger levels of Table 8.1 were created for managing DTT to DTT interference, we believe that they provide a good starting point for determining WSD emission limits to ensure a low probability of harmful interference to other countries.

8.11 We consider this to be a sensible approach because fixed WSDs are similar to DTT relays in terms of bandwidth and deployment, and portable/mobile WSDs are unlikely to cause cross-border interference due to their low height.

Calculation methodology

8.12 The objective here is to calculate the maximum permitted WSD in-block EIRP, $P_{\text{WSD-XB}}(i, F_{\text{WSD}})$, at a given location i and DTT channel F_{WSD} in the UK subject to the requirement that the resulting field strength received at the neighbouring countries does not exceed the GE06 co-ordination trigger threshold levels.

8.13 In performing these calculations, we assume that the maximum permitted WSD in-block EIRP is capped at 36 dBm/(8 MHz) as proposed in Section 4.

8.14 We propose to characterise the locations of WSDs as points in the centres of 1 km × 1 km pixels across the UK. These locations will be based on the gridlines contained in the British Ordnance survey map, which provide the co-ordinates of any location in the UK at different resolutions. For example, a pixel near Dover would have the X co-ordinates (Eastings) 629500 and Y co-ordinates (Northings) 140500.

8.15 We note that it is not strictly necessary to examine every pixel across the UK for the purposed of calculating the WSD emission limits. Our analysis indicates, for example, that the emissions of a WSD radiating at 36 dBm/(8 MHz) and at a height (above ground) of 10 metres would not be restricted (thresholds would not be exceeded) if the WSD operated more than 20 km in-land from the coast.

8.16 For this reason we propose only to consider WSD pixels which are within a buffer zone along the UK land borders and coastline, and including the Isle of Wight, Isles of Scilly, as well as any islands near the coast.

8.17 An example is illustrated in Figure 8.1, where we show a buffer zone of around 25 km width along the UK coastline for a WSD height of 10 metres. A wider buffer zone would be used for the land border between Northern Ireland and the Republic of Ireland.

Figure 8.1 – Buffer zone within which calculations are performed.

8.18 For each WSD location within the buffer zone, the resulting received field strength will be calculated at a set of M *test points* along the coastlines of France, Belgium, the Netherlands, and the Republic of Ireland, as well as the area inside the Republic of Ireland near the land border with Northern Ireland.

8.19 Figure 8.2 shows a specific WSD pixel in Dover with its centre at coordinates (629500, 140500) and with lines connecting it to the examined test points along the coasts and borders of neighbouring countries.

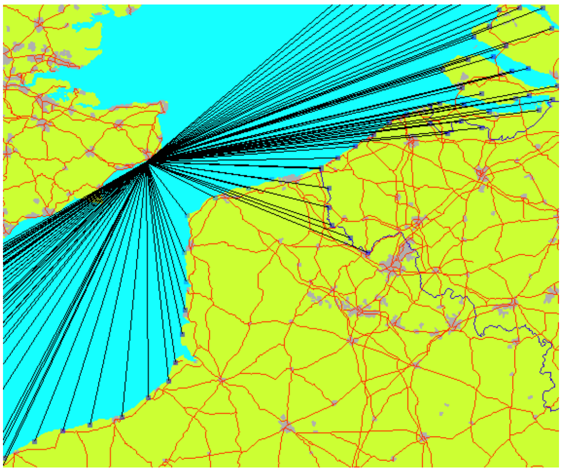

Figure 8.2 – A WSD pixel in Dover and test point locations in neighbouring countries.

8.20 We propose to use ITU Recommendation1546-4[54] to model radio propagation from each WSD pixel location to each test point location. Specifically, the propagation will be modelled at the three Rec.1546 reference frequencies of 100, 600 and 2000 MHz. The propagation at intermediate frequencies of DTT channels 21 to 60 will then be derived via the interpolation formula defined in Rec.1546.

8.21 Given a WSD pixel location i, the field strengths received at each of the M test point locations in the neighbouring countries and each DTT channel will be calculated as $E_m(i, F_{\mathrm{WSD}})$, where $m = 1\ldots M$ and $F_{\mathrm{WSD}} = 21\ldots60$. We assume that the WSD radiates at 36 dBm/(8 MHz). Let $E(i, F_{\mathrm{WSD}})$ denote the largest received field strength over the test points at any given channel, i.e.,

$$E(i, F_{\mathrm{WSD}}) = \max_m E_m(i, F_{\mathrm{WSD}}). \tag{8.1}$$

8.22 These maximum values will then be compared to the relevant GE06 co-ordination trigger threshold levels $E_{\mathrm{T}}(F_{\mathrm{WSD}})$ in Table 8.1.

8.23 If a WSD at a given pixel location i results in received field strengths that do not exceed the GE06 co-ordination trigger thresholds, i.e., $E(i, F_{\mathrm{WSD}}) \le E_{\mathrm{T}}(F_{\mathrm{WSD}})$, then it will not be subject to restrictions in its emission levels.

8.24 If a WSD at a given pixel location i results in received field strengths that do exceed the GE06 co-ordination trigger thresholds, i.e., $E(i, F_{\mathrm{WSD}}) > E_{\mathrm{T}}(F_{\mathrm{WSD}})$, then it will be subject to restrictions in its emission levels. Specifically, if

$$E(i, F_{\mathrm{WSD}})_{(\mathrm{dB\mu v/m})} = E_{\mathrm{T}}(F_{\mathrm{WSD}})_{(\mathrm{dB\mu v/m})} + x(i, F_{\mathrm{WSD}})_{(\mathrm{dB})}, \tag{8.2}$$

where $x > 0$, then the maximum permitted in-block EIRP for that WSD would be restricted to

$$P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}}) = 36 - x(i, F_{\mathrm{WSD}}) \quad \mathrm{dBm/(8\ MHz)}. \tag{8.3}$$

8.25 Table 8.2 below shown illustrative examples of the various parameter values for a given channel, with one WSD pixel location and four test points. Based on this example, the maximum permitted WSD EIRP is 36 – 4.9 = 31.1 dBm/(8 MHz).

Table 8.2 – Example of received field strengths and WSD EIRP restriction.

WSD pixel location, i	Test point index, m	Received field strength at test point $E_m(i,F_{\mathrm{WSD}})$ dBμV/m	$E(i,F_{\mathrm{WSD}})$ dBμV/m	Threshold $E_{\mathrm{T}}(F_{\mathrm{WSD}})$ dBμV/m	Restriction x (dB)
629500 140500	F54	25.9	25.9	21	4.9
	F55	23.2			
	F53	21.4			
	F56	20.2			

8.26 Ofcom will calculate the emission limits $P_{\mathrm{WSD\text{-}XB}}(i, F_{\mathrm{WSD}})$ for all relevant locations i in the UK, all DTT channels F_{WSD} = 21 … 60, and representative type A WSD antenna heights of 1.5, 5, 10, 15, 20, and 30 metres. Emission limits for type B WSDs can be inferred from the limits for type B WSDs. The limits for type A and type B devices will

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[54] http://www.itu.int/rec/R-REC-P.1546/en.

be the same except for type B WSDs with antenna heights of greater than 2 metres in which case the WSDs will be considered to be indoors and subject to a 7 dB relaxation of the emission limits. Ofcom will then combine the resulting limits with any other limits which might apply (see Section 3) and communicated these to WSDBs.

Numerical examples of TVWS availability in relation to cross border DTT

8.27 Here we present the results of our modelling of UK-wide TVWS availability subject to the requirement that the GE06 co-ordination trigger thresholds in neighbouring countries are not exceeded.

8.28 Figures 8.3 and 8.4 show the WSD emission limits in channel 21 in the areas near the Isle of Wight and Dover based on a 1 km × 1 km pixel raster. We have assumed a WSD antenna height of 10 metres. These results do not account for any restrictions which might apply in relation to DTT, PMSE, and other services above and below the UHF TV band in the UK.

8.29 The coloured pixels are the locations where restrictions apply. The colour code scale indicates the range of maximum permitted WSD in-block EIRPs, $P_{\text{WSD-XB}}$, at any pixel location.

8.30 We also intend to shortly publish a series of geographic maps of UK-wide TVWS availability in relation to cross-border constraints in channels 21 to 59 (excluding channel 38) and for a WSD antenna height of 10 metres.

8.31 The results indicate that the restrictions are only severe near Dover and the land border between Northern Ireland and the Republic of Ireland.

Summary and conclusions

8.32 We recognise the requirement to correspond and/or meet with our neighbouring administrations to discuss our proposals for enabling access to the TV white spaces in the UK, and to ensure that the risk of harmful interference to cross border primary DTT services is appropriately mitigated.

8.33 In the absence of any specific threshold levels for secondary services, we propose to initiate discussions on the basis of the GE06 trigger threshold levels used for DTT co-ordination.

8.34 We have calculated the corresponding location-specific and frequency-specific WSD emission limits subject to the requirement that the relevant GE06 co-ordination trigger threshold levels are not exceeded in our neighbouring countries. These limits will be combined with other WSD limits calculated by Ofcom (e.g., in relation to DTT in the UK) and communicated to the WSDBs.

8.35 We would also like to explore alternative threshold levels or approaches to enable more efficient use of TV white spaces in the UK. For example, we may only select test points at specific frequencies where the relevant DTT channel is actually used by our neighbouring country.

8.36 We believe that engaging with neighbouring countries at an early stage should provide the opportunity to present our technical proposals for discussion and feedback.

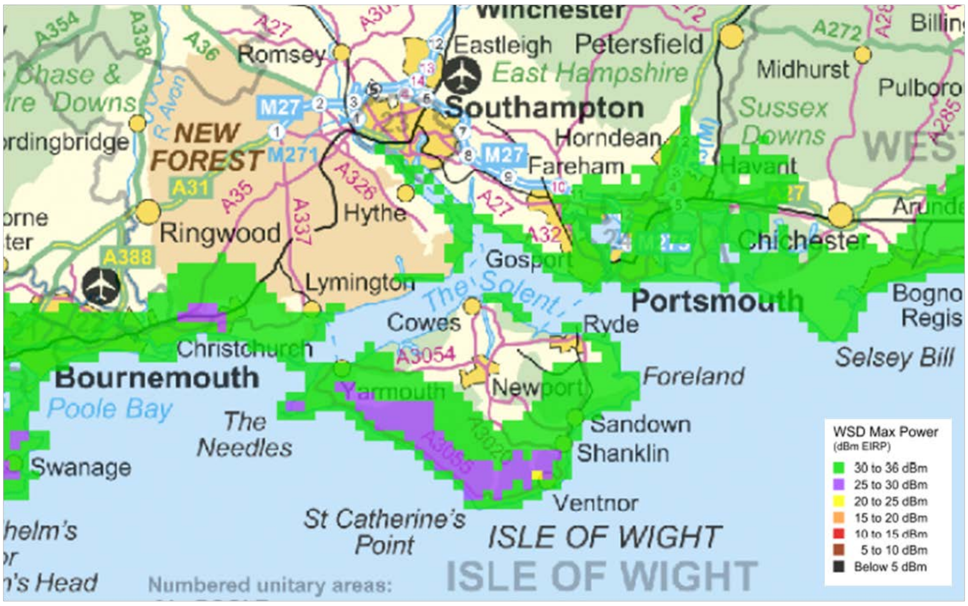


Figure 8.3 – TVWS availability on the Isle of Wight in channel 21, subject to the requirement that the GE06 co-ordination trigger thresholds are not exceeded.

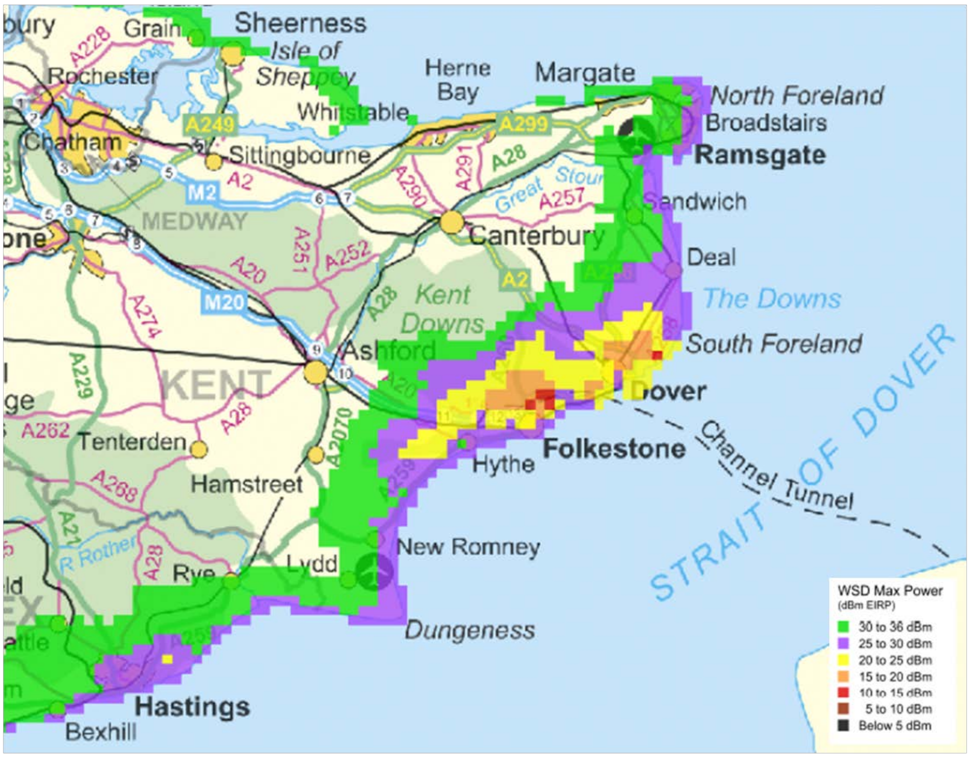


Figure 8.4 – TVWS availability near Folkestone and Dover in channel 21, subject to the requirement that the GE06 co-ordination trigger thresholds are not exceeded.

Annex 1

Algorithm for calculation of WSD emission limits in relation to DTT

A1.1 As we explained in Section 4, the calculation of the maximum permitted WSD in-block EIRP can be formulated as finding the value of P_{IB} which satisfies (in the linear domain)

$$q_2 = q_1 - \Delta q = \Pr\left\{ P_{\mathrm{S}} \geq U + r(\Delta F, m_{\mathrm{S}})\, G\, P_{\mathrm{IB}} \right\}, \tag{A1.1}$$

where $\Pr\{A\}$ is the probability of event A, P_{S} is the received power of the wanted DTT signal, U represents the impact of noise and DTT self-interference, $r(\Delta F, m_{\mathrm{S}})$ is the WSD-DTT protection ratio, and G is the WSD-DTT coupling gain. Then q_1 and q_2 are the DTT location probabilities in the absence and presence of WSD transmissions, respectively.

A1.2 The UKPM models both P_{S} and U as log-normal random variables, i.e., $P_{\mathrm{S\,(dBm)}} \sim \mathrm{N}(m_{\mathrm{S}}, \sigma_{\mathrm{S}}^2)$ and $U_{\mathrm{(dBm)}} \sim \mathrm{N}(m_U, \sigma_U^2)$.

A1.3 A semi-analytical solution can be derived by re-formulating the above problem as

$$\begin{aligned} q_2 &= q_{\mathrm{T}} = q_1 - \Delta q_{\mathrm{T}} \\ &= \Pr\left\{ P_{\mathrm{S}} \geq U + r(\Delta F, m_{\mathrm{S}})\ G\ P_{\mathrm{IB}} \right\} \\ &= \Pr\left\{ 1 \geq \frac{U}{P_{\mathrm{S}}} + \frac{G\, r(\Delta F, m_{\mathrm{S}})\, P_{\mathrm{IB}}}{P_{\mathrm{S}}} \right\} = \Pr\left\{ 1 \geq \frac{U}{P_{\mathrm{S}}} + \frac{Z}{P_{\mathrm{S}}} \right\} \\ &= \Pr\left\{ 1 \geq A + B \right\} = \Pr\left\{ 1 \geq Y \right\} = \Pr\left\{ 0 \geq Y_{\mathrm{(dB)}} \right\}, \end{aligned} \tag{A1.2}$$

where q_{T} is a target reduced location probability and Δq_{T} is the target reduction.

A1.4 The following features can then be exploited:

- Since U and P_{S} are uncorrelated log-normal random variables, it follows that $A_{\mathrm{(dB)}}$ is also Gaussian, with median and standard deviation $m_A = m_U - m_{\mathrm{S}}$, and $\sigma_A = (\sigma_U^2 + \sigma_{\mathrm{S}}^2)^{1/2}$, respectively.

- Since Z and P_{S} are uncorrelated log-normal random variables, it follows that $B_{\mathrm{(dB)}}$ is also Gaussian, with median and standard deviation $m_B = m_Z - m_{\mathrm{S}}$, and $\sigma_B = (\sigma_Z^2 + \sigma_{\mathrm{S}}^2)^{1/2}$, respectively.

- Finally, since A and B are log-normal random variables, $Y_{\mathrm{(dB)}}$ can be modelled as a Gaussian random variable, whose median, m_Y, and standard deviation, σ_Y, can be calculated via algorithms such as Schwartz-Yeh. Note that since P_{S}, U, and Z are independent, it follows that $A_{\mathrm{(dB)}}$ and $B_{\mathrm{(dB)}}$ are uncorrelated.

8.37 The objective is then to calculate the WSD in-block EIRP, P_{IB}, such that

$$\Pr\left\{0 \geq Y(P_{\mathrm{IB}})_{(\mathrm{dB})}\right\} = q_{\mathrm{T}}, \tag{A1.3}$$

A1.5 Since Y is log-normal, we have $q_{\mathrm{T}} = (1/2)\,\mathrm{erfc}\{(1/\sqrt{2})\,m_Y/\sigma_Y\}$. The calculation of P_{IB} is therefore a non-linear problem. Also, note that the random variable Y is itself a function of P_{IB} (the unknown). For this reason, we propose to use the following iterative algorithm to to search for the solutions P_{IB}.

Initialization: Select an initial value, P, for P_{IB} .

1) Calculate $m_Z = r(\Delta f, m_{\mathrm{S}})_{(\mathrm{dB})} + m_{\mathrm{G}} + P$.

2) Use Schwartz-Yeh (or enhanced variant) to derive m_Y and σ_Y .

3) Calculate the reduced location probability as
$q_2 = (1/2)\,\mathrm{erfc}\{(1/\sqrt{2})\,m_Y/\sigma_Y\}$.

4) If q_2 is suitably close to q_{T}, then STOP,
otherwise appropriately increment/decrement P
and go to (1).

Termination: The maximum permitted WSD EIRP, P_{IB} ,
is the value of P when the loop is existed at step (4).

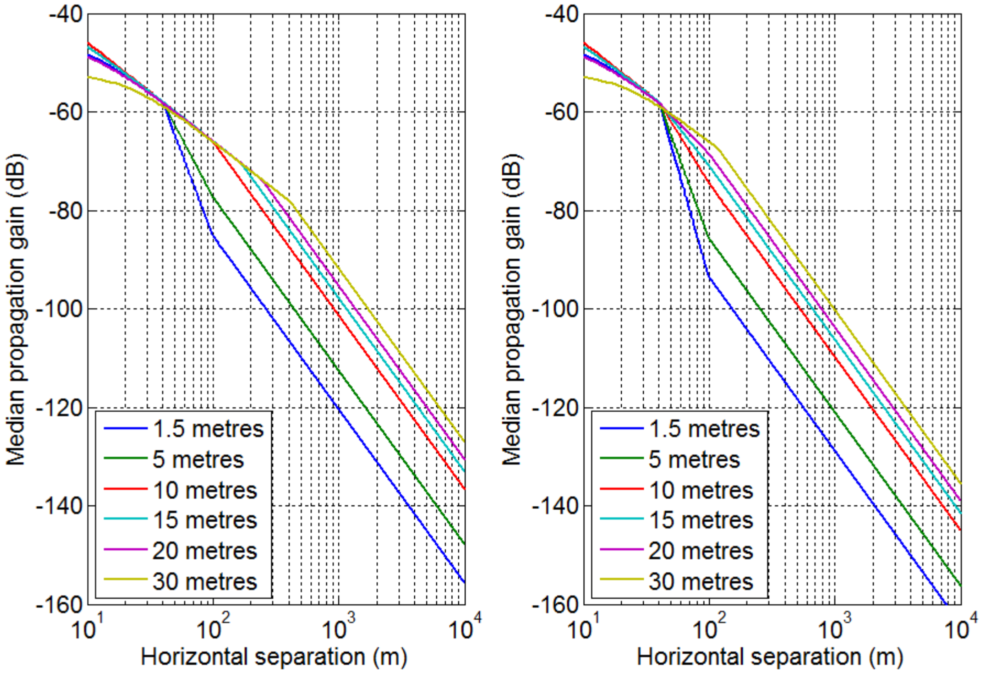
A1.6 We acknowledge that alternative formulations and search criteria exist with different trade-offs between complexity and accuracy.

Annex 2

Propagation models, height and clutter

Propagation model

A2.1 In this document we have repeatedly referred to the SEAMCAT extended Hata propagation model[55]. Here we present numerical examples of path gain as calculated by extended Hata in urban, suburban, and rural environments and for a range of antenna heights. We also compare extended Hata with free space path loss and the two-ray model (reflection coefficient of -1).



(Suburban) (Urban)

Figure A2.1 – Median propagation gain as a function of transmitter-receiver horizontal separation. Receiver height is 10 m. Frequency is 474 MHz. WSD height, h_{WSD} , is 1.5, 5, 10, 15, 20 or 30 metres.

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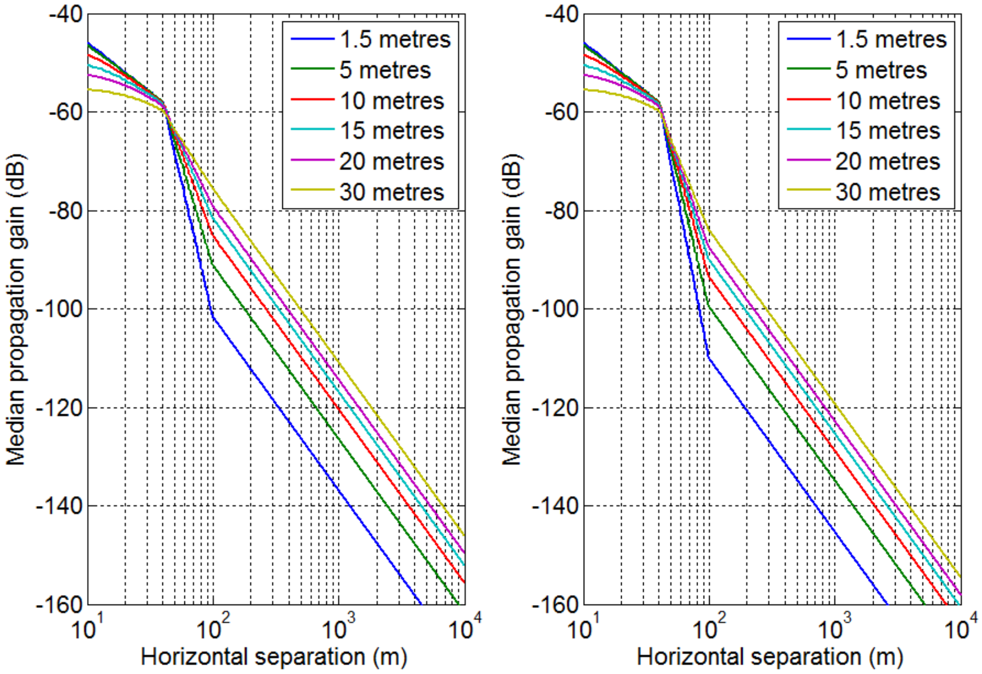
[55] See the SEAMCAT manual at http://tractool.seamcat.org/wiki/Manual.



(Suburban)

(Urban)

Figure A2.2 – Median propagation gain as a function of transmitter-receiver horizontal separation. Receiver height is 1.5 m. Frequency is 474 MHz. WSD height, h_{WSD} , is 1.5, 5, 10, 15, 20 or 30 metres.

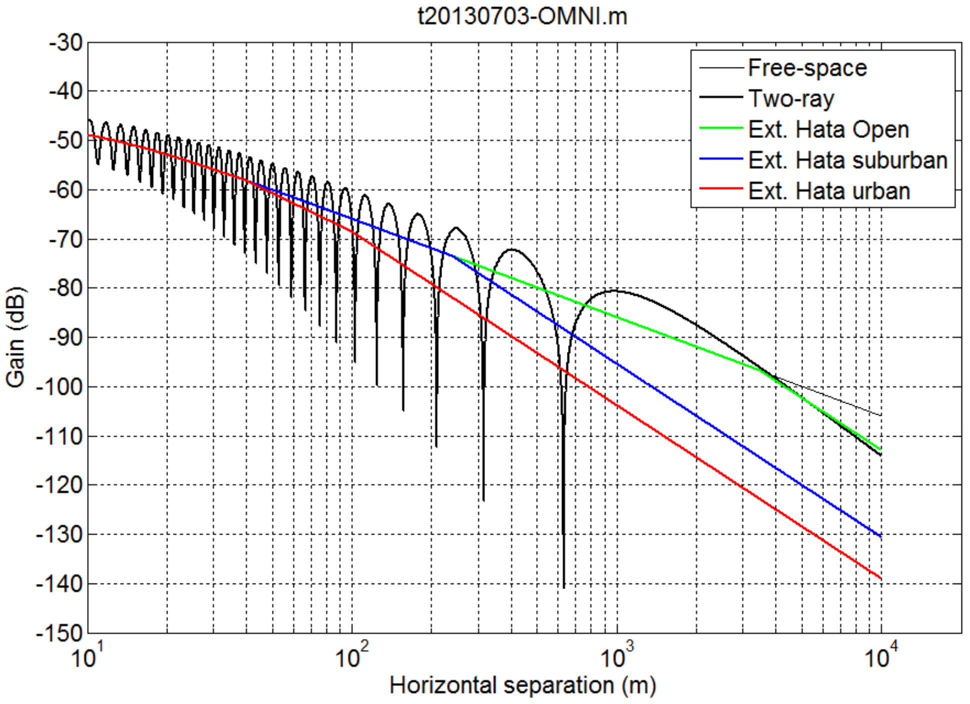


Figure A2.3 – Median propagation gain as a function of transmitter-receiver horizontal separation. Transmitter/receiver heights: 20/10 m. Frequency is 474 MHz.

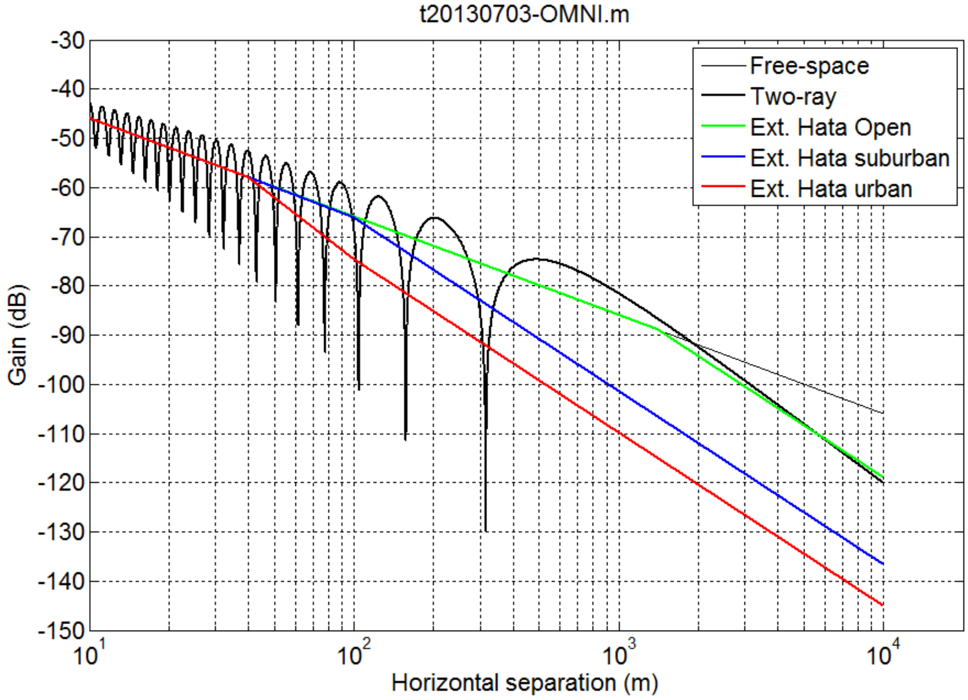


Figure A2.4 – Median propagation gain as a function of transmitter-receiver horizontal separation. Transmitter/receiver heights: 10/10 m. Frequency is 474 MHz.

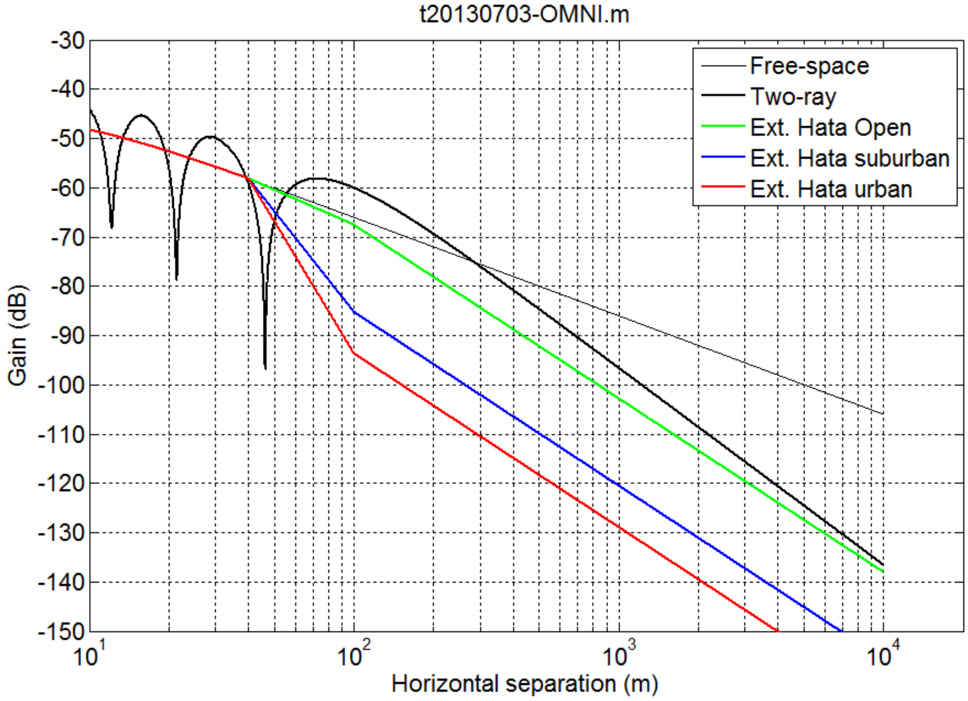


Figure A2.5 – Median propagation gain as a function of transmitter-receiver horizontal separation. Transmitter/receiver heights: 1.5/10 m. Frequency is 474 MHz.

Determination of height of WSD above ground level

A2.2 As outlined in Section 5, the WSD height, h_{WSD}, above ground level is required for the calculation of the median propagation gain. WSDBs will determined this from the reported WSD altitude, h, as

$$h_{\mathrm{WSD}} = \min(h - h_{\mathrm{T}}\,,\, 1.5) \ \ \text{metres}$$

A2.3 where h_{T} is the local terrain height. There is the possibility that the result of the subtraction might be negative or a very small positive number. To mitigate this, the result is adjusted via the “min” operator to ensure that h_{WSD} is not less than 1.5 metres.

A2.4 WSDBs will calculate the local terrain height by using the bi-linear interpolation method described in Rec. ITU-R P.1144[56]. WSDBs will use data from a common digital terrain map for this purpose.

Clutter types

A2.5 As outlined in Sections 4 and 5, we propose to use the urban, suburban, and open profiles of the SEAMCAT extended Hata model for purposes of coexistence calculations in relation to DTT and PMSE.

A2.6 The actual Hata profile used will be based on the clutter type at the location of the DTT or PMSE receiver.

A2.7 WSDBs will use a common clutter database (50 metre resolution) to determine the clutter type. Specifically, the clutter type at the location of the receiver antenna will be established by using the dataset at the nearest (50 metre resolution) grid point. The dataset will be mapped on to urban, suburban, and open clutter designations as defined by Ofcom. An illustrative example is outlined in Table A2.1.

Table A2.1. Illustrative clutter code mapping.

Clutter description in a clutter database	Extended Hata clutter profile
Dense Urban	Urban
Urban	Urban
Industry	Suburban
Suburban	Suburban
Village	Suburban
Parks/Recreation	Open
Open	Open
Open in Urban	Open
Forest	Open
Water	Open

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[56] http://www.itu.int/rec/R- REC-P.1144/en

Annex 3

Calculation of the coverage area of a master WSD

A3.1 In this section we describe the WSDB calculations used to derive the coverage area of a master WSD.

A3.2 Master WSDs are required to report their geographic location to WSDBs, and their location will be typically known to a high degree of accuracy. Slave WSDs, on the other hand, are not required to report their location. Even if a slave WSD has geolocation capability, its location may not be known[57] by a master WSD prior to commencement of master-slave communications (and hence association) over the UHF TV band, and therefore cannot be known by a WSDB.

A3.3 In these instances, WSDBs will use the estimated coverage area of a master WSD as an indication of the area of potential locations of slave WSDs whose location is not known.

A3.4 As described in Sections 4 and 5, for a serving master WSD with reported nominal horizontal coordinates (x_0, y_0), and reported horizontal location uncertainties $(\pm\Delta x, \pm\Delta y)$, the coverage area will be modelled as a circle centred on (x_0, y_0), and with radius $d_0 + \surd((\Delta x^2 + \Delta y^2)$. Here, d_0 is the coverage range of the master WSD. In short, the area of potential locations for slave WSDs is the area of potential locations for the master WSD, extended by d_0. This is repeated Figure A3.1 below.

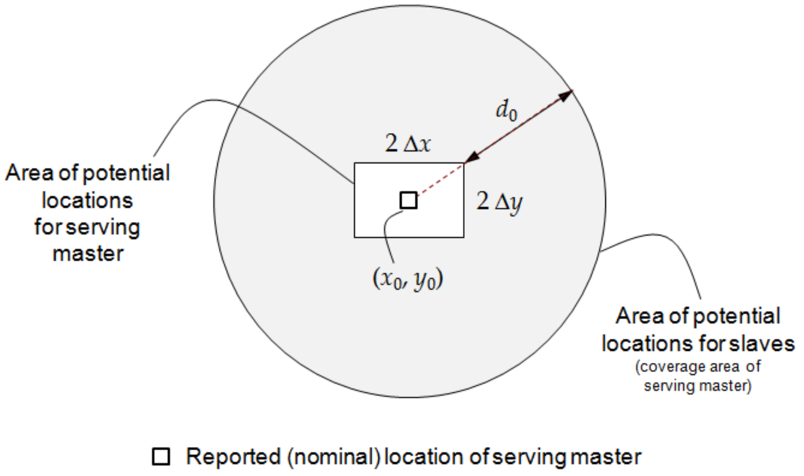

Figure A3.1 – Area of potential locations for a slave WSD whose horizontal location is not known (non-geolocated).

A3.5 A WSDB will calculate the coverage range, d_0 , of a master WSD by first estimating the minimum coupling gain between the master and its slaves, and then using a path loss model to estimate the range.

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[57] It is possible that a geolocated slave reports its location to a master WSD through means other than wireless communications over the UHF TV band (e.g. wireless communications in other bands). In such cases the location of the slave may be known by the master prior to master-slave communications over the UHF TV band.

Minimum coupling gain

A3.6 A WSDB will calculate the minimum coupling gain, m_G , as

$$m_G(d_0)_{(\mathrm{dB})} = P_{\mathrm{REFSENS}\ (\mathrm{dBm/100\,kHz})} - P_{(\mathrm{dBm/100\,kHz})} \tag{A3.1}$$

where

P	is the EIRP spectral density of the master WSD, and
P_{REFSENS}	is the minimum receiver (reference) sensitivity at the antenna connector of the slave WSD, defined by the equipment technology specifications.

A3.7 Note that the median coupling gain, m_G, is a function of the (unknown) coverage range, d_0, of the master WSD. We next present the proposed values for the various parameters to be used in Equation (A3.1).

Proposed parameter values

Master WSD EIRP spectral density

A3.8 Consider the case where a master WSD reports multiple channel usage parameters, $p_0(F)$, where p_0 is the EIRP spectral density in DTT channel F (see Section 2). Let f be the centre frequency of the DTT channel F. The WSDB will use as P the reported EIRP spectral density $p_0(F)$ which corresponds to the maximum value of

$$p_0(F) - 20\log_{10}(f)$$

i.e., that which results in the largest coverage range accounting for a square-law frequency dependence of radio propagation.

A3.9 Note that a master WSD is only required to report channel usage parameters to the WSDB if its total EIRP is above 0 dBm. For a master WSD that does not report channel usage parameters, the WSDB will use a value of P = -19 dBm/(100 kHz).

Slave WSD reference sensitivity

A3.10 The WSDB will use the reference sensitivity level of the slave WSD as quoted in the specifications of the WSD technology. Where multiple reference sensitivity levels are quoted for different modulation and coding schemes, the WSDB will select the minimum value quoted. The WSDB will identify the WSD technology through the reported technology ID of the master WSD.

Median coupling gain

A3.11 The median path gain m_P between the master WSD and slave WSD will be calculated according to

$$m_P(d_0)_{(\mathrm{dB})} = m_{G\,(\mathrm{dB})} - G_{\mathrm{A,Slave}\ (\mathrm{dBi})} \tag{A3.2}$$

where

m_G	is the coupling loss from Equation (A3.1), and
$G_{\mathrm{A,Slave}}$	is the slave WSD receiver antenna gain (≥ 0 dBi).

A3.12 We propose that WSDBs use the values in Table A3.1 in Equation (A3.1).

Table A3.1 – Parameter values for calculating master WSD coverage range.

Parameter	Value
m_P	Median path gain. This will be based on the SEAMCAT extended Hata path loss model[58]. See Annex 2 for numerical examples. Note that path gain is the negative of path loss (both in dB).
$G_{A,Slave}$	Slave WSD receiver anenna gain. WSDBs will use the following default values: Type A: $G_{A,Slave} = 10$ dBi, Type B: $G_{A,Slave} = 0$ dBi.

A3.13 Note that the propagation gain given by the extended Hata model is a function of transmitter height h_{Master} in metres, receiver height h_{Slave} in metres, horizontal separation d_0 in metres between transmitter and receiver, frequency f in MHz, and clutter type. We propose that WSDBs use the values in the Table A3.2 in the SEAMCAT extended Hata model.

Table A3.2 – Parameter values for calculating path gain.

Parameter	Value
h_{Master}	Height of the master WSD. A master WSD may report its height to a WSDB. If the height is not reported, then WSDBs will use the following default values: Type A: $h_{WSD} = 30$ metres, Type B: $h_{WSD} = 1.5$ metres.
h_{Slave}	Height of the slave WSD. WSDBs will use the following default values: Type A: $h_{WSD} = 10$ metres, Type B: $h_{WSD} = 1.5$ metres.
d_0	This radius of the master WSD coverage area. This is the unknown to be determined.
f	Centre frequency of the DTT channel, F, associated with the channel usage parameter p_0, which results in the largest value of $p_0(F) - 20\log_{10}(f)$.
Clutter type	This will be determined by the WSDBs based on the location of the master WSD. This will be either urban, suburban, or open and will be identified according to a clutter database (see Annex 2).

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[58] See the SEAMCAT manual at http://tractool.seamcat.org/wiki/Manual.

Annex 4

WSD-DTT protection ratios

A4.1 The protection ratio – sometimes referred to as the "C-to-I ratio" – is the ratio of the wanted signal power over the unwanted (co-channel or adjacent-channel) signal power at the point of failure of a receiver. The higher the protection ratio, the more susceptible the receiver is to interference. In the context of DTT, we have used degradation in video quality (in the form of pixilation or loss) as a measured of receiver failure.

A4.2 In this annex we describe the procedures for deriving WSD-DTT protection ratios corresponding to five WSD spectrum emission classes as defined in the draft ETSI harmonised European standard EN 301 598[59].

A4.3 These protection ratios are for use by Ofcom for purposes of calculating the maximum permitted WSD in-block EIRPs in relation to DTT use.

A4.4 We have derived these protection ratios by first measuring the co-channel and adjacent-channel protection ratios of DTT receivers in the presence of a *test* WSD signal. The test WSD signal was generated from a Weightless WSD base station provided by a UK based wireless communication company. We commissioned the Digital TV Group (DTG) to perform the measurements for fifty DTT (DVB-T) receivers. .

A4.5 We have used these measurements to derive the adjacent channel selectivity (ACS) of the DTT receivers. The derived ACS values were then combined with the adjacent channel leakage ratios (ACLRs) for the five WSD spectrum emission classes to calculate the class-specific WSD-DTT protection ratios. Finally, we have used the sales data for the fifty tested receivers to generate the cumulative distribution of the class-specific protection ratios and their 60th, 70th, 80th, and 90th percentile values.

A4.6 Unless otherwise stated, we use the term channel to refer to an 8 MHz DTT channel, and DTT receivers to refer DTT DVB-T receivers Furthermore, we use P_S and C, and P_X and I interchangeably to refer to wanted DTT and unwanted WSD in-block powers, respectively. Finally, we use the subscript "M" to denote measured parameters.

Certain results are produced to one decimal place. This is for purposes of transparency in the calculations, and do not reflect measurement accuracy.

Measurement set up

A4.7 The DTG performed measurements on a total of fifty DTT receivers, with eight receivers tested at a time. The test set up for the WSD-DTT protection ratio measurements is shown in Figure A4.1 followed by an illustration of the wanted and unwanted spectrum emissions masks in Figure A4.2.

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[59] Draft ETSI EN 301 598 V1.0.0 (2013-07), "White space devices (WSD); Wireless access systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

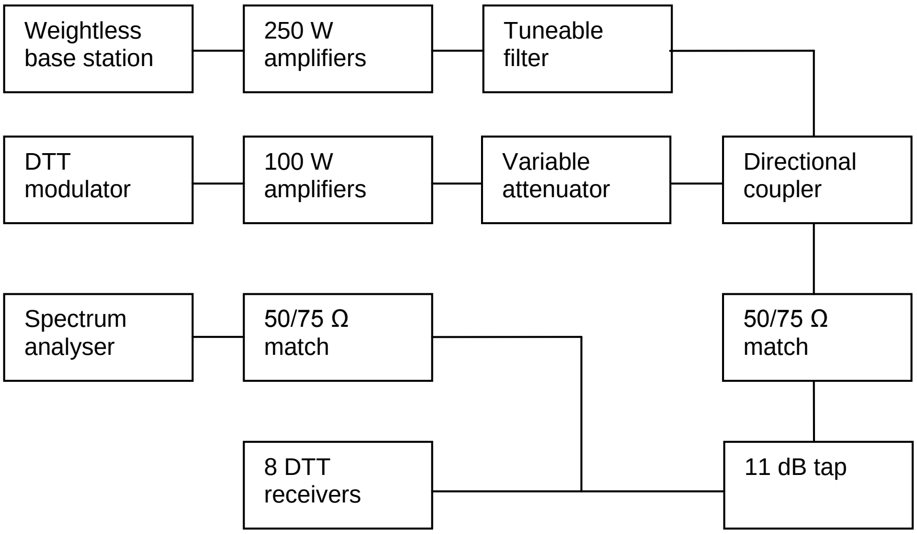

Figure A4.1- Test setup for DTT receiver measurements.

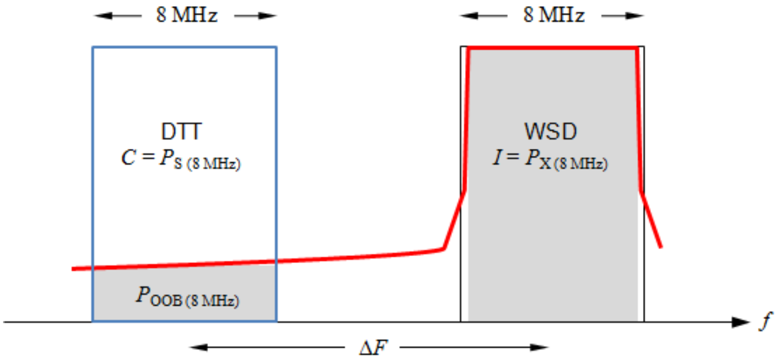

Figure A4.2- Wanted and unwanted signals.

A4.8 The wanted DTT signal and unwanted WSD signal were combined using a 10 dB directional coupler, then distributed to the DTT receivers through a distribution system made up of 11 dB taps (8 output) connected via quad shielded coaxial cable. Impedance matching circuits (50/75 Ω Match) were used where necessary.

A4.9 Note that the spectrum analyser has a connector which introduces an extra 6 dB loss. Consequently, 6 dB has to be added to the recorded single level from the spectrum analyser in order to represent the level at the input to the DTT receivers.

DTT signal

A4.10 The wanted DTT signal was generated using Alitronika modulators and PC stream Xpress software, which is a DTT modulator system that allows multiple test streams to be set up. The DVB-T signal parameters were set as shown in Table A4.1 below. The DTT signal level was controlled using a 100 W amplifier then a second smaller DTT pre-amplifier via a variable attenuator.

Table A4.1 – DVB-T signal parameters.

Parameter	DVB-T
Multiple access	COFDM
Modulation	64-QAM
Forward error correction	2/3
FFT points	8k
Guard Interval (µs)	7
Data rate (Mbit/s)	24.1
Channel bandwidth (MHz)	8

WSD signal

A4.11 The unwanted WSD test signal was generated by a Weightless base station transmitting a wideband 8 MHz QPSK modulated signal. The base station was connected directly to the test setup. The signal was made up of pulses of duration 3.5 ms with a 10 ms spacing. The measured spectrum emission mask (centre frequency 786 MHz) at the input to the DTT receivers is shown in Figure A4.3 below.

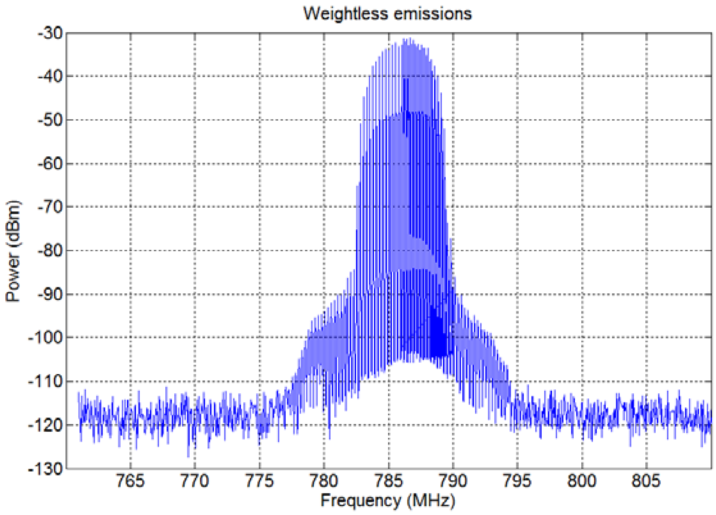

Figure A4.3 - Example of spectrum emission mask of the tested Weightless WSD signal.

A4.12 The spectrum emission mask of the Weightless signal in Figure A4.3 was captured with a 50 kHz resolution. The power level on the Y axis represents dBm/50 kHz. In this case, the total in-block power over 8 MHz is around -19 dBm.

A4.13 The adjacent channel leakage ratio (ACLR) of the WSD test signal is a key element in the derivation of the DTT receiver selectivity. The ACLR is measured as

$$\mathrm{ACLR}_{\mathrm{M}} = \frac{P_{\mathrm{X}\,(8\,\mathrm{MHz})}}{P_{\mathrm{OOB}\,(8\,\mathrm{MHz})}} \tag{A4.1}$$

where P_X is the in-block power over 8 MHz, and P_{OOB} is the out-of-block power over 8 MHz. Note that the out-of-block power is measured over 8 MHz to reflect the bandwidth of the DTT receiver.

A4.14 Table A4.2 shows the measured ACLR values of the Weightless test signal. The ACLR of the Weightless signal was increased by using a tuneable band pass filter. This was to ensure that the receiver selectivity can be derived from the protection ratios in a reliable way (see derivation of adjacent channel selectivity).

Table A4.2 – Measured ACLR values of the Weightless test signal.

Channel separation, ΔF	ACLR_M (dB)
±1	63
±2	82
$\lvert\Delta F\rvert \geq 3$	90

A4.15 As we can see from the spectrum emission mask of Figure A4.1, the spectrum analyser's trace is limited by the analyser noise floor. As such, it is difficult to measure the out-of-block powers P_{OOB} after the 3rd adjacent channel, especially in the presence of a high in-block power. For this reason, we have assumed that the ACLR remains constant at 90 dB for the fourth adjacent channel and beyond.

Measurement of protection ratios

A4.16 The following is the procedure used to measure the WSD-DTT protection ratios for the tested DTT receivers:

1) The DTT receiver was tuned to an appropriate channel in an interference-free environment with sufficient DTT signal power to verify video operation.

2) The wanted DTT signal power was adjusted via the variable attenuator. The power level at the input to the DTT receiver was recorded as $C_{(\mathrm{dBm})}$.

3) The DTT signal was then switched off, and the unwanted WSD signal was applied to the DTT receiver with its carrier frequency adjusted for the required channel separation. The WSD signal was filtered to remove any wideband noise produced within the amplifier.

4) The DTT signal was reapplied to the DTT receiver, and the WSD signal power was set to maximum. This resulted in picture failure (blocking or pixelation).

5) The WSD signal power was reduced until the DTT picture returned and no errors were observed. The average RMS power level was monitored and recorded.

6) The interferer power, $I_{(\mathrm{dBm})}$ at the input to the DTT receiver was then calculated by adding a 6 dB match pad loss and a 3.5 dB correction factor, u, to the recorded average RMS power.

7) The difference $C_{(\mathrm{dBm})} - I_{(\mathrm{dBm})}$ was recorded as the protection (or C-to-I) ratio $r_M(C, \Delta F)$ in dB.

A4.17 The maximum permitted EIRP levels which a WSDB reports to a WSD represent maximum RMS power. For signals that contain time discontinuities (e.g., signals with low radio resource utilisation or time division duplex signals), there will be marked difference between the maximum RMS power and the measured average RMS power. For this reason a correction factor of u = 3.5 dB was used to convert the measured average RMS power to the required maximum RMS power.

A4.18 To measure the correction factor, the spectrum analyser was set to time domain mode, with settings adapted from ETSI EN 301 598 V1.0.0 in order to capture the maximum RMS power. The resolution bandwidth was adjusted to 8 MHz to capture all of power within the identified DTT channel. The used settings are shown in Table A4.3.

Table A4.3 – Spectrum analyser settings.

Centre frequency	Frequency of emission identified during the pre-scan
Resolution bandwidth	8 MHz
Video bandwidth	Auto
Frequency span	N/A
Sweep mode	Continuous
Sweep time	Auto
Trigger	Free Run
Detector	RMS
Trace mode	Max Hold

A4.19 The DTT receivers were tested at wanted power levels of C = -70, -60, -50 and -30 dBm, and channel separations ΔF = 1, 2, 3, 4, 8, 9 and 10. A positive channel separation means that the WSD signal is at the higher frequency. In order to quantify protection ratios at larger frequency offsets, four DTT receivers were also tested at channel separations of ΔF = 20 and 40.

A4.20 Figures A4.4 to A4.7 illustrate the measured protection ratios $r_M(C, \Delta F)$ for the fifty tested DTT receivers at various channel separations, ΔF, and wanted DTT signal powers, C. These protection ratios are also presented in Tables A4.7 to A4.10 in the end of this annex.

Large channel separations

Table A4.4 shows the measured protection ratios at ΔF = +10, +20 and +40 for four tested DTT receivers. Receiver 29 exhibits a significant reduction in protection ratio for large channel separations, but this is only for small C. For larger C, receiver overload means that protection ratios are broadly insensitive to channel separation. The protection ratios for receiver 43 show little variation with channel separation, while for receiver 30 the protection ratios at ΔF = 20 are smaller than those at ΔF = 40. In summary, the measurements show that the selected DTT receivers behave very differently, and the measured protection ratios do not always decrease with increasing channel separation.

Table A4.4 – Measured protection ratios at large channel separations.

$r_M(C, \Delta F)$ (dB)	C = -70 dBm			C = -60 dBm		
Receiver ID	ΔF = +10	ΔF = +20	ΔF = +40	ΔF = +10	ΔF = +20	ΔF = +40
22	-72	-77	-77	-66	-70	-66
29	-57	-65	-74	-63	-65	-71
30	-59	-71	-62	-50	-59	-53
43	-69	-71	-68	-59	-59	-58

$r_M(C, \Delta F)$ (dB)	C = -50 dBm			C = -30 dBm		
Receiver ID	ΔF = +10	ΔF = +20	RX ID	ΔF = +10	ΔF = +20	RX ID
22	-58	-59	-65	-40	-41	-39
29	-62	-63	-65	-42	-44	-44
30	-39	-51	-43	-21	-31	-24
43	-54	-50	-49	-32	-31	-30

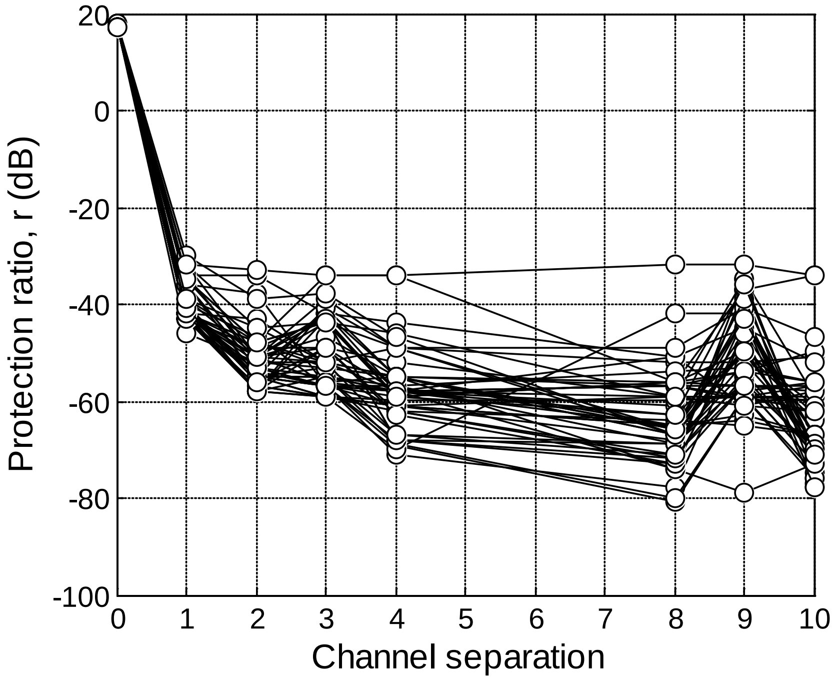

Figure A4.4 – Measured protection ratios of 50 DTT receivers, C = -70 dBm.

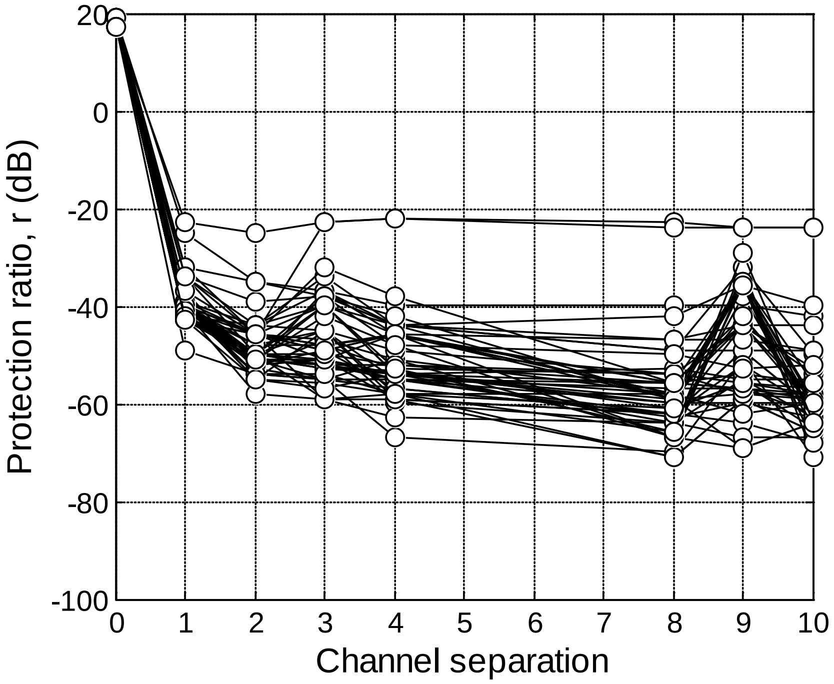

Figure A4.5 – Measured protection ratios of 50 DTT receivers, *C* = -60 dBm.

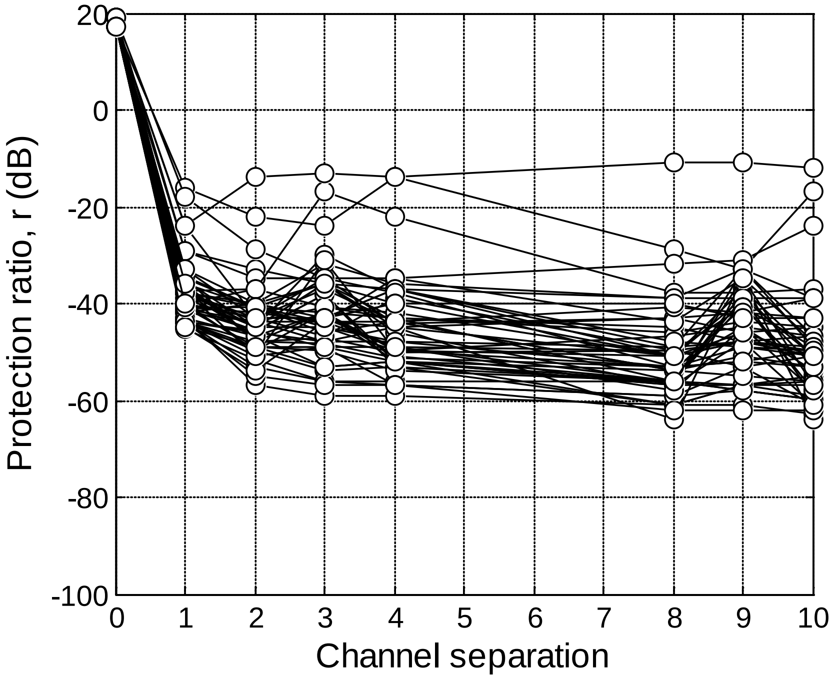

Figure A4.6 – Measured protection ratios of 50 DTT receivers, *C* = -50 dBm.

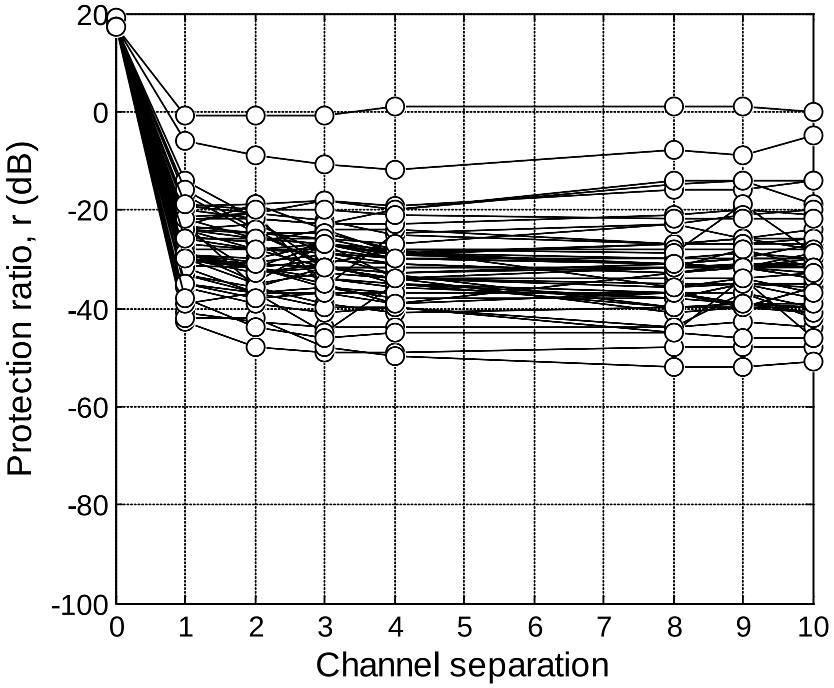

Figure A4.7 – Measured protection ratios of 50 DTT receivers, *C* = -30 dBm.

Derivation of adjacent channel selectivity

A4.21 In this subsection, we describe the derivation of the adjacent channel selectivity of a DTT receiver.

A4.22 The adjacent channel selectivity $\mathrm{ACS}(C, \Delta F)$ of a tested DTT receiver can be derived from the measured co-channel and adjacent-channel protection ratios. From the definition of ACS we have (in the linear domain),

$$P_{\mathrm{I\,(8\,MHz)}} = P_{\mathrm{OOB\,(8\,MHz)}} + \frac{P_{\mathrm{X\,(8\,MHz)}}}{\mathrm{ACS}(C, \Delta F)}, \qquad \text{(A4.2)}$$

where P_{X} is the in-block power of the unwanted signal, P_{OOB} is the out-of-block power of the unwanted signal, and P_{I} is the experienced interference power (see also Figure A4.2).

A4.23 From the definition of adjacent-channel interference ratio (ACIR) we also have (in the linear domain),

$$\mathrm{ACIR_M}(C, \Delta F) = \frac{P_{\mathrm{X\,(8\,MHz)}}}{P_{\mathrm{I\,(8\,MHz)}}}, \qquad \text{(A4.3)}$$

at the point of receiver failure. Combining (A4.2) and (A4.3) we have

$$\begin{aligned}\frac{1}{\mathrm{ACIR}_{\mathrm{M}}(C,\Delta F)} &= \frac{P_{\mathrm{OOB\,(8\,MHz)}}}{P_{\mathrm{X\,(8\,MHz)}}} + \frac{1}{\mathrm{ACS}(C,\Delta F)} \\ &= \frac{1}{\mathrm{ACLR}_{\mathrm{M}}(\Delta F)} + \frac{1}{\mathrm{ACS}(C,\Delta F)},\end{aligned} \tag{A4.4}$$

or

$$\mathrm{ACS}(C,\Delta F) = \left\{ \mathrm{ACIR}_{\mathrm{M}}^{-1}(C,\Delta F) - \mathrm{ACLR}_{\mathrm{M}}^{-1}(\Delta F) \right\}^{-1}, \tag{A4.5}$$

where $\mathrm{ACLR}_{\mathrm{M}}(\Delta F)$ is the measured adjacent channel leakage ratio[60] of the 8 MHz WSD test signal with spectral leakage over the 8 MHz DTT channel (see Table A4.2).

A4.24 Finally, from the definition of ACIR we have (in the linear domain),

$$\begin{aligned}\mathrm{ACIR}_{\mathrm{M}}(C,\Delta F) &= \frac{P_{\mathrm{X\,(8\,MHz)}}}{P_{\mathrm{I\,(8\,MHz)}}} = \frac{P_{\mathrm{X\,(8\,MHz)}}}{P_{\mathrm{S\,(8\,MHz)}}} \times \frac{P_{\mathrm{S\,(8\,MHz)}}}{P_{\mathrm{I\,(8\,MHz)}}} \\ &= \frac{1}{r_{\mathrm{M}}(C,\Delta F)} \times \mathrm{SIR} \equiv \frac{1}{r_{\mathrm{M}}(C,\Delta F)} \times r_{\mathrm{M}}(0),\end{aligned} \tag{A4.6}$$

where $r_{\mathrm{M}}(C, \Delta F)$ is the measured adjacent channel protection ratio, SIR is the signal-to-interference ratio at the point of failure, and $r_{\mathrm{M}}(0)$ is the measured co-channel protection ratio. Note that we use $r_{\mathrm{M}}(0)$ as a proxy for the signal-to-interference ratio at the point of receiver failure. Specifically, if P_{X} is the power of a co-channel unwanted signal over 8 MHz,

$$r_{\mathrm{M}}(0) = \frac{P_{\mathrm{S\,(8\,MHz)}}}{P_{\mathrm{X\,(8\,MHz)}}} \equiv \frac{P_{\mathrm{S\,(8\,MHz)}}}{P_{\mathrm{I\,(8\,MHz)}}}. \tag{A4.7}$$

A4.25 Combining Equations (A4.5) and (A4.6) we have

$$\mathrm{ACS}(C,\Delta F) = \left\{ \frac{r_{\mathrm{M}}(C,\Delta F)}{r_{\mathrm{M}}(0)} - \mathrm{ACLR}_{\mathrm{M}}^{-1}(\Delta F) \right\}^{-1}. \tag{A4.8}$$

A4.26 Figures A4.8 to A4.11 illustrate the derived values of $\mathrm{ACS}(C, \Delta F)$ for the fifty tested DTT receivers at various channel separations, ΔF, and wanted DTT signal powers, C.

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[60] By definition, ACLR is greater than ACIR (ASC being a positive number). Occasionally, the measured test $\mathrm{ACLR}_{\mathrm{M}}$ is lower than $\mathrm{ACIR}_{\mathrm{M}}$ as derived from the measured protection ratios $r_{\mathrm{M}}(\mathrm{C}, \Delta F)$ and $r_{\mathrm{M}}(0)$. This is a result of model/measurement error and it is not possible to derive a valid ACS in such circumstances. At other times, $\mathrm{ACLR}_{\mathrm{M}}$ is too close to $\mathrm{ACIR}_{\mathrm{M}}$. This makes the derivation of ACS very sensitive to measurement errors (resulting in potentially very large/unreliable values of ACS). To mitigate this (and absent other data), one might set $\mathrm{ACLR}_{\mathrm{M\,(dB)}}$ to $\mathrm{ACIR}_{\mathrm{M\,(dB)}}$ + 3. This implies that $\mathrm{ACS} = \mathrm{ACLR}_{\mathrm{M}}$. If $\mathrm{ACLR}_{\mathrm{M}}$ is in fact greater, then we will have over-estimated ACS by at most 3 dB. If $\mathrm{ACLR}_{\mathrm{M}}$ is in fact smaller, then there is a possibility that we will have hugely under-estimated ACS. The latter in unavoidable, and is precisely why it is important for the WSD test signal to have as large an ACLR as possible. The ACLR of the Weightless test signal was large enough (through additional filtering) to avoid the above problems.

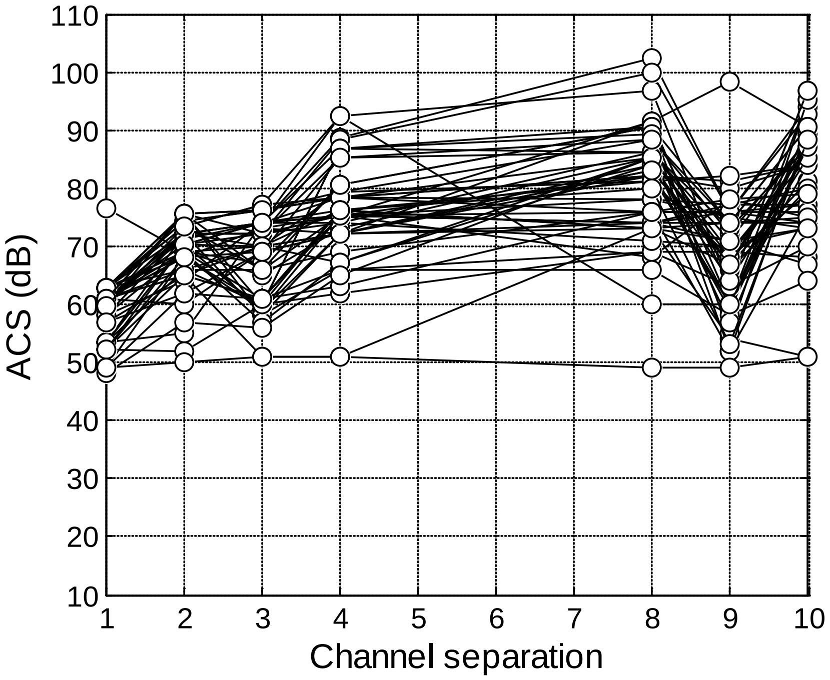

Figure A4.8 – Derived ACS for 50 DTT receivers, *C* = -70 dBm.

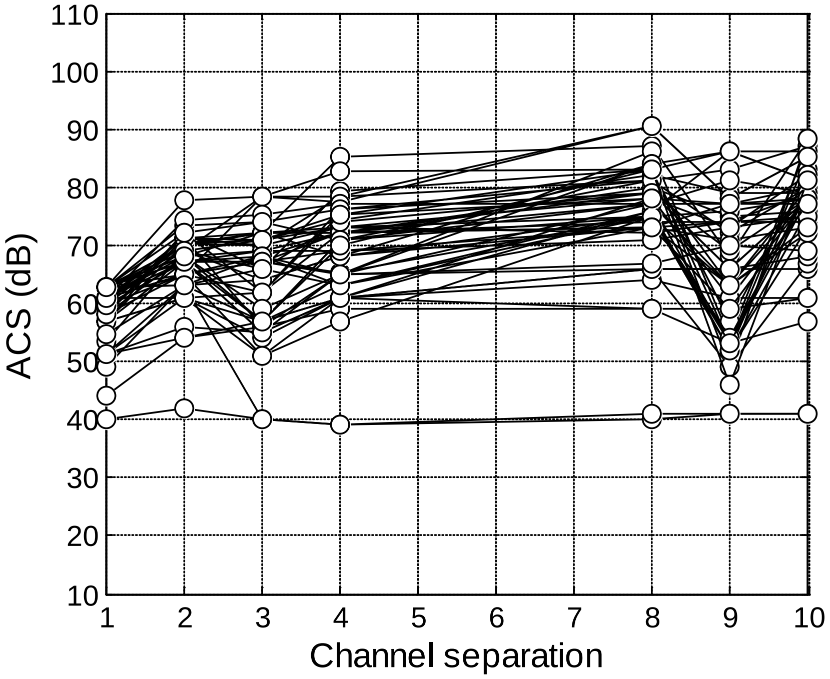

Figure A4.9 – Derived ACS for 50 DTT receivers, *C* = -60 dBm

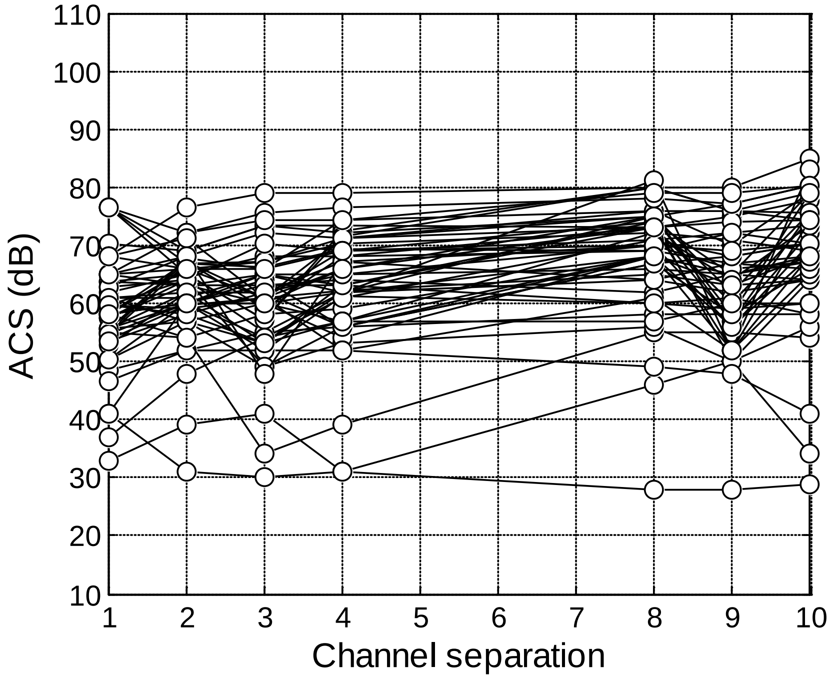

Figure A4.10 – Derived ACS for 50 DTT receivers, *C* = -50 dBm.

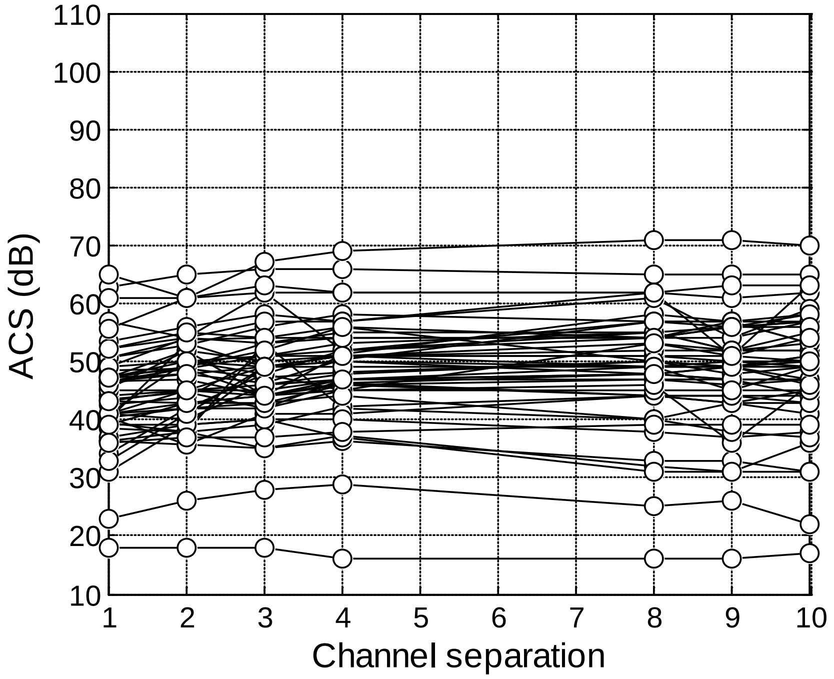

Figure A4.11 – Derived ACS for 50 DTT receivers, *C* = -30 dBm.

Calculation of class-specific protection ratios

A4.27 In this subsection, we describe the calculation of protection ratios for the fifty tested DTT receivers, and for each of the five WSD spectrum emission classes.

A4.28 A class-specific protection ratio, $r(C, \Delta F)$, at a particular wanted signal power C, and channel separation ΔF, can be calculated by taking account of derived DTT receiver selectivity $\mathrm{ACS}(C, \Delta F)$, and the class-specific WSD $\mathrm{ACLR}(\Delta F)$ as defined in EN 301 598.

A4.29 Note that we derive class-specific protection ratios by using the class-specific ACLR of a WSD with an in-block bandwidth of 8 MHz.

A4.30 By definition (in the linear domain),

$$\begin{aligned} r(C,\Delta F) &= \frac{P_{\mathrm{S}\,(8\,\mathrm{MHz})}}{P_{\mathrm{X}\,(8\,\mathrm{MHz})}} = \frac{P_{\mathrm{S}\,(8\,\mathrm{MHz})}}{P_{\mathrm{I}\,(8\,\mathrm{MHz})}} \times \frac{P_{\mathrm{I}\,(8\,\mathrm{MHz})}}{P_{\mathrm{X}\,(8\,\mathrm{MHz})}} \\ &= r_{\mathrm{M}}(0) \times \frac{1}{\mathrm{ACIR}(C,\Delta F)} \\ &= r_{\mathrm{M}}(0) \times \left(\mathrm{ACLR}^{-1}(\Delta F) + \mathrm{ACS}^{-1}(C,\Delta F) \right), \end{aligned} \tag{A4.9}$$

where P_{S} is the in-block power of the wanted signal, P_{X} is the in-block power of the unwanted signal, and P_{I} is the experienced interference power. We have used the definition of ACIR to derive the last line which describes the relationship with the class-specific ACLR and the derived ACS.

A4.31 So class-specific protection ratios can be calculated via Equation (A4.9) from the measured co-channel protection ratio, the derived ACS, and the WSD class-specific ACLR.

A4.32 Recall that by definition

$$\mathrm{ACLR} = \frac{P_{\mathrm{IB}\,(8\,\mathrm{MHz})}}{P_{\mathrm{OOB}\,(8\,\mathrm{MHz})}} = \frac{P_{\mathrm{IB}\,(8\,\mathrm{MHz})}}{80\ P_{\mathrm{OOB}\,(100\,\mathrm{kHz})}} = \frac{1}{80}\mathrm{AFLR}, \tag{A4.10}$$

where AFLR for different WSD classes is defined in EN301 598 (see Section 2). In other words,

$$\mathrm{ACLR}_{(\mathrm{dB})} = \mathrm{AFLR}_{(\mathrm{dB})} - 19. \tag{A4.11}$$

A4.33 Table A4.5 shows the values of $\mathrm{ACLR}(\Delta F)$ for the five WSD spectrum emission classes. For channel separations $\Delta F = \pm1$, ±2 and ±3, the values of $\mathrm{ACLR}(\Delta F)$ are as defined in ETSI EN 301 598 (for greater channel separations the limits in EN 301 598 remain at their values for $\Delta F = \pm3$). To account for practical spectrum masks, we have assumed a roll off (increase in ACLR) of 10 dB per 8 MHz for $|\Delta F| > 3$.

Table A4.5 – Class-specific ACLRs.

ACLR(ΔF)	WSD spectrum emission class				
Channel separation, ΔF	Class 1	Class 2	Class 3	Class 4	Class 5
±1	71	71	61	51	40
±2	76	71	71	61	50
±3	81	71	81	71	61
± 4	91	81	91	81	71
± 5	101	91	101	91	81
± 6	111	101	111	101	91
± 7	121	111	121	111	101
± 8	131	121	131	121	111
± 9	141	131	141	131	121
± 10	151	141	151	141	131

A4.34 As mentioned earlier, protection ratios were measured for C = -70, -60, -50, and -30 dBm. In order to derive protection ratios for C = -40, -20, and -12 dBm for use in the coexistence studies, we have used interpolation and extrapolation as follows:

a) Protection ratios for C = -40 dBm were derived via linear interpolation of the protection ratios at C = -50 and -30 dBm.

b) Protection ratios for C =-20 and -12 dBm were derived by assuming that the receivers suffer from hard overload for C > -30 dBm from antenna overload, (i.e., C vs. I curves are vertical).

A4.35 Figure A4.12 shows the measured protection ratios for the fifty receivers with ΔF = 1, where the values with square markers are derived via interpolation and extrapolation. Figure A4.13 shows the resulting protections ratios for the class 1 spectrum emission mask.

A4.36 Note that negative channel separations ($F_{\mathrm{WSD}} < F_{\mathrm{DTT}}$) were not examined. We propose to use the protection ratios at positive channel separations as a proxy for negative channel separations. This is with the exception of the case of ΔF = –9, where the use of the protection ratio at ΔF = +9 is not appropriate[61]. Instead, we propose to use the linear interpolation of the protection ratios at ΔF = +8 and +10 as proxies for protection ratios at ΔF = –9.

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[61] This is because the large protection ratios that occur at ΔF =+9. This so-called “N+9” effect characteristic of super heterodyne receivers does not occur at negative frequency offsets.

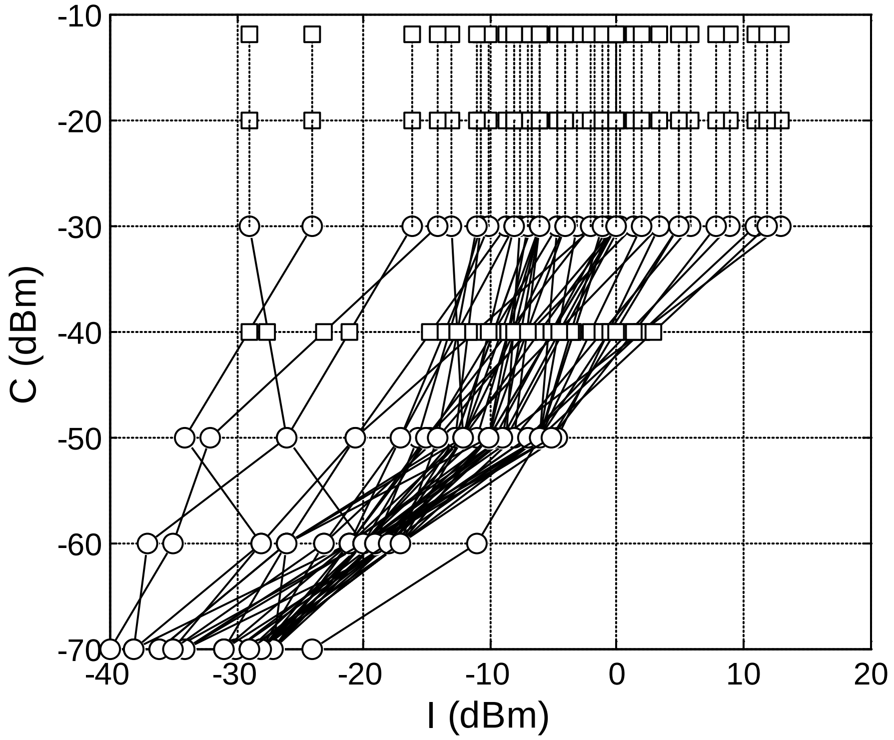

Figure A4.12 – Interpolation and extrapolation of measured protection ratios, ΔF = 1, WSD class 1.

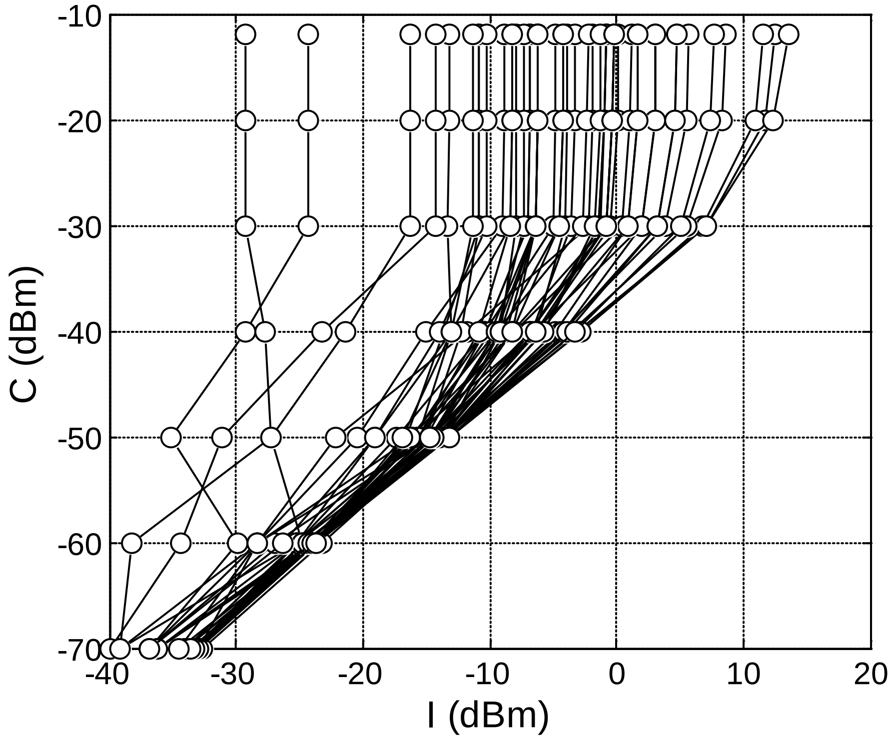

Figure A4.13 – Calculated class-specific protection ratios, ΔF = 1, WSD class 1.

Statistics of protection ratios based on sales figures

A4.37 In this subsection, we describe the calculation of the 60th, 70th, 80th and 90th percentile values of class-specific protection ratios. We do this by generating cumulative distribution functions of $r(C, \Delta F)$, based on the sales figures of the fifty receivers tested.

A4.38 The fifty tested DTT receivers were chosen according to retailers' sales data (exclude online sales) as the top selling 50 receivers in the UK (set top boxes and TVs) between 2007 and 2013. The sales figure grouped by the receiver chassis as shown in Table A4.6. Note that DVB-T2 receivers also support DVB-T, but DVB-T receivers do not support DVB-T2.

A4.39 The tested receivers represent different receiver types, e.g., Silicon or "Can" tuners that support either DVB-T or DVB-T2 transmission modes. Different models of receiver are classed as having the same chassis if they have:

- the same tuner and demodulator; and
- the same SI/PSI middleware software (including active format descriptor and subtitle selection); and
- the same multimedia and hypermedia experts group (MHEG-5) engine; and
- at least the same amount of memory for the MHEG-5 engine and other applications.

A4.40 For each combination of $C, \Delta F$, and WSD spectrum emission class, we compile the fifty calculated protection ratios $r(C, \Delta F)$ for the fifty receivers, and count them according to their respective sales figures. We then generate the cumulative distribution function of the protection ratios. This results in a unique distribution for each combination of $C, \Delta F$, and WSD class. The *n*th percentile protection ratio can then be read off the distributions.

A4.41 Figures A4.14 and A4.15 illustrate the probability density function and cumulative distribution of $r(C, \Delta F)$ for C = -60 dBm, ΔF = +1, and a class 1 WSD.

Table A4.6 – DTT receiver sales figures between 2007 and 2011.

Receiver ID	Receiver type	Total chassis sales units	Receiver ID	Receiver type	Total chassis sales units
1	DVB-T	144813	26	DVB-T	428375
2	DVB-T2	581205	27	DVB-T	238895
3	DVB-T2	254999	28	DVB-T	776829
4	DVB-T2	159294	29	DVB-T	428375
5	DVB-T2	159294	30	DVB-T	215857
6	DVB-T2	86549	31	DVB-T	238895
7	DVB-T2	428375	32	DVB-T	18874
8	DVB-T2	192715	33	DVB-T	380008
9	DVB-T2	159164	34	DVB-T	729580
10	DVB-T2	159294	35	DVB-T	195181
11	DVB-T2	444020	36	DVB-T	151509
12	DVB-T2	697392	37	DVB-T	287103
13	DVB-T2	159164	38	DVB-T	250346
14	DVB-T2	254999	39	DVB-T	171010
15	DVB-T2	1121372	40	DVB-T	195894
16	DVB-T2	159294	41	DVB-T	326406
17	DVB-T2	192715	42	DVB-T	159355
18	DVB-T2	159164	43	DVB-T	171010
19	DVB-T2	178317	44	DVB-T	420270
20	DVB-T	374381	45	DVB-T	234734
21	DVB-T	685527	46	DVB-T	505502
22	DVB-T	238895	47	DVB-T	118
23	DVB-T	350855	48	DVB-T	343881
24	DVB-T	994048	49	DVB-T	556304
25	DVB-T	138662	50	DVB-T	638567

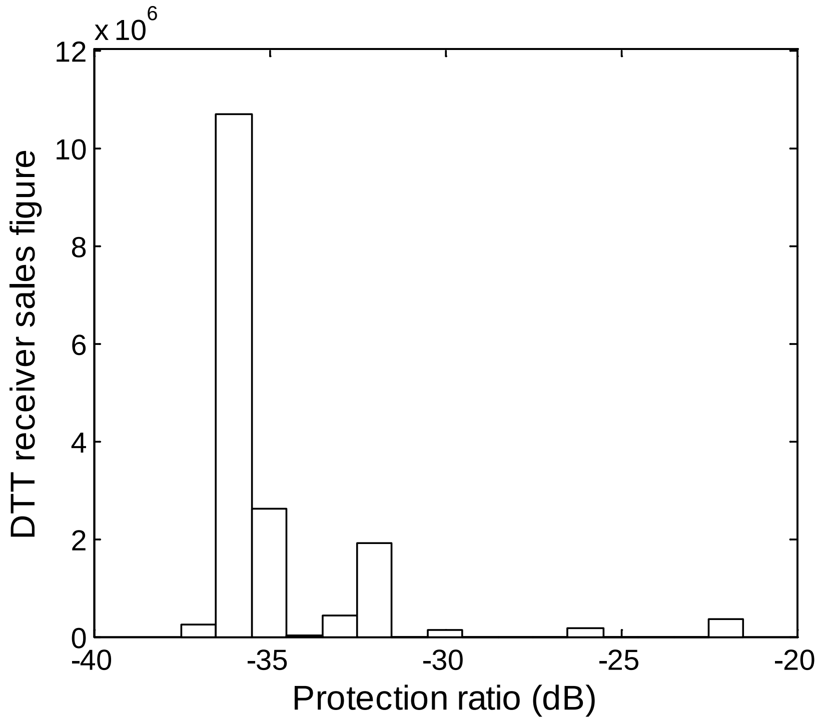

Figure A4.14 – Probability density function of class-specific protection ratios for *C* = -60 dBm, ΔF = +1 and WSD class 1 spectrum emission mask.

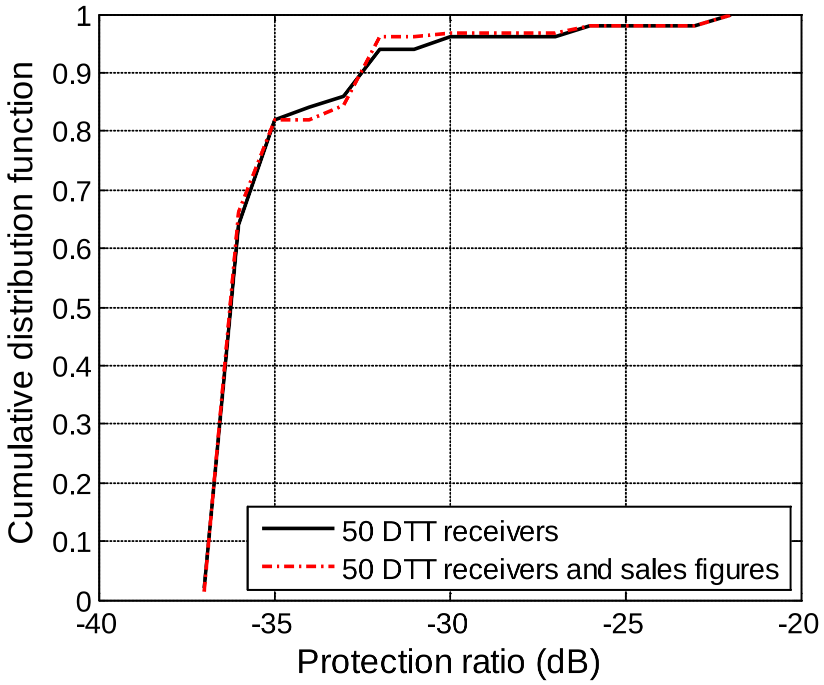

Figure A4.15 – Cumulative distribution function of class-specific protection ratios for *C* = -60 dBm, ΔF = +1 and WSD class 1 spectrum emission mask.

Results of measurements and calculations

A4.42 Tables A4.7 to A4.10 show the raw measured protection ratios $r_M(C, \Delta F)$ for C = -70, -60, -50 and -30 dBm, and ΔF = 0, 1, 2, 3, 4, 8, 9 and 10.

A4.43 Tables A4.11 to A4.14 show the derived adjacent channel selectivities $\mathrm{ACS}(C, \Delta F)$ for C = -70, -60, -50 and -30 dBm, and ΔF = 0, 1, 2, 3, 4, 8, 9 and 10.

A4.44 Tables A4.15 to A4.18 show the calculated class-specific protection ratios $r\ (C, \Delta F)$ for C = -70, -60, -50, -40, -30, -20 and -12 dBm, and ΔF = 0, 1, 2, 3, 4, 8, 9 and 10 at the 60th, 70th, 80th and 90th percentiles. As stated in paragraph 4.31, we use linear interpolation of the protection ratios at ΔF = +8 and +10 as proxies for protection ratios at $\Delta F = -9$. Protection ratios at ΔF = +9 are derived from raw measured data.

A4.45 In these tables $\Delta F = i$ is labelled as $N + i$.

Table A4.7 – Full set of measured protection ratios for C = -70 dBm.

$r(\Delta F)$	Measured protection ratios for C = -70 dBm							
RXID	N+0	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	17.1	-39.9	-46.9	-56.9	-70.9	-77.9	-45.9	-77.9
2	17.1	-41.9	-50.9	-55.9	-57.9	-50.9	-60.9	-57.9
3	17.1	-42.9	-54.9	-56.9	-57.9	-60.9	-57.9	-55.9
4	17.1	-39.9	-54.9	-56.9	-69.1	-80.9	-58.9	-75.9
5	17.1	-41.9	-42.9	-51.9	-54.9	-66.9	-48.9	-62.9
6	17.1	-31.9	-44.9	-43.9	-48.9	-51.9	-51.9	-50.9
7	17.1	-41.9	-54.9	-54.9	-57.9	-56.9	-53.9	-49.9
8	17.1	-42.9	-48.9	-48.9	-51.9	-58.9	-58.9	-58.9
9	17.1	-35.9	-52.9	-41.9	-54.9	-73.9	-42.9	-76.9
10	17.1	-42.9	-50.9	-42.9	-58.9	-55.9	-49.9	-63.9
11	17.1	-42.9	-57.9	-58.9	-60.9	-64.9	-63.9	-66.9
12	17.1	-42.9	-56.9	-58.9	-60.9	-64.9	-62.9	-66.9
13	17.1	-31.9	-50.9	-41.9	-57.9	-73.9	-78.9	-72.9
14	17.1	-45.9	-51.9	-52.9	-54.9	-56.9	-58.9	-59.9
15	17.1	-35.9	-37.9	-56.9	-56.9	-68.9	-51.9	-67.9
16	17.1	-42.9	-54.9	-54.9	-68.9	-79.9	-58.9	-74.9
17	17.1	-40.9	-54.9	-56.9	-57.9	-56.9	-56.9	-56.9
18	18.1	-41.9	-54.9	-58.9	-69.9	-41.9	-41.9	-71.9
19	17.1	-42.9	-56.9	-58.9	-61.9	-63.9	-64.9	-66.9
20	17.1	-41.9	-54.9	-54.9	-57.9	-56.9	-59.9	-59.9
21	17.1	-41.9	-48.9	-42.9	-67.9	-68.9	-53.9	-70.9
22	17.1	-41.9	-51.9	-43.9	-57.9	-64.9	-42.9	-71.9
23	17.1	-41.9	-47.9	-52.9	-61.9	-70.9	-54.9	-70.9
24	18.1	-33.9	-33.9	-41.9	-43.9	-50.9	-44.9	-51.9
25	17.1	-34.9	-47.9	-33.9	-33.9	-55.9	-36.9	-33.9
26	18.1	-41.9	-54.9	-58.9	-59.9	-59.9	-58.9	-61.9
27	17.1	-35.9	-52.9	-56.9	-60.9	-67.9	-42.9	-66.9
28	18.1	-41.9	-50.9	-48.9	-61.9	-71.9	-36.9	-75.9
29	17.1	-41.9	-57.9	-58.9	-60.9	-58.9	-58.9	-56.9
30	17.1	-41.9	-47.9	-43.9	-45.9	-58.9	-34.9	-58.9
31	17.1	-41.9	-54.9	-40.9	-54.9	-65.9	-41.9	-69.9
32	17.1	-41.9	-52.9	-54.9	-56.9	-53.9	-52.9	-55.9
33	17.1	-42.9	-57.9	-54.9	-66.9	-68.9	-55.9	-69.9
34	18.1	-38.9	-50.9	-46.9	-54.9	-66.9	-48.9	-70.9
35	17.1	-40.9	-57.9	-40.9	-48.9	-48.9	-40.9	-46.9
36	17.1	-42.9	-57.9	-48.9	-62.9	-72.9	-56.9	-72.9
37	17.1	-41.9	-53.9	-56.9	-67.9	-72.9	-45.9	-77.9
38	18.1	-41.9	-50.9	-38.9	-48.9	-66.9	-38.9	-69.9
39	18.1	-34.9	-47.9	-51.9	-48.9	-65.9	-45.9	-66.9
40	17.1	-35.9	-54.9	-52.9	-54.9	-64.9	-42.9	-69.9
41	17.1	-41.9	-57.9	-42.9	-67.9	-71.9	-34.9	-71.9
42	17.1	-41.9	-50.9	-55.9	-54.9	-55.9	-56.9	-57.9
43	18.1	-29.9	-38.9	-37.9	-46.9	-66.9	-49.9	-68.9
44	18.1	-33.9	-51.9	-51.9	-57.9	-62.9	-49.9	-60.9
45	17.1	-41.9	-52.9	-56.9	-58.9	-55.9	-53.9	-55.9
46	17.1	-38.9	-44.9	-51.9	-66.9	-70.9	-56.9	-72.9
47	17.1	-34.9	-50.9	-51.9	-54.9	-65.9	-49.9	-69.9
48	17.1	-31.9	-32.9	-33.9	-33.9	-31.9	-31.9	-33.9
49	17.1	-40.9	-55.9	-48.9	-57.9	-58.9	-60.9	-61.9
50	17.1	-38.9	-47.9	-43.9	-58.9	-62.9	-35.9	-70.9

Table A4.8 – Full set of measured protection ratios for C = -60 dBm.

$r(\Delta F)$	Measured protection ratios for C = -60 dBm							
RXID	N+0	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	17.1	-41.9	-50.9	-54.9	-66.9	-69.9	-50.9	-70.9
2	19.1	-39.9	-49.9	-51.9	-53.9	-52.9	-54.9	-54.9
3	19.1	-40.9	-50.7	-52.9	-53.9	-58.9	-57.9	-58.9
4	19.1	-40.9	-49.9	-59.1	-58.1	-70.9	-58.9	-65.9
5	19.1	-40.9	-50.7	-52.9	-53.1	-60.9	-55.9	-56.9
6	19.1	-31.9	-34.9	-36.9	-39.9	-39.9	-39.9	-41.9
7	17.1	-42.9	-50.9	-51.9	-54.9	-59.9	-59.9	-62.9
8	17.1	-33.9	-38.9	-37.9	-43.9	-48.9	-48.9	-48.9
9	19.1	-39.9	-51.9	-36.9	-45.9	-66.9	-34.9	-67.9
10	19.1	-40.9	-47.9	-47.9	-46.1	-55.9	-43.9	-53.9
11	19.1	-39.9	-51.9	-50.9	-53.9	-55.9	-56.9	-58.9
12	19.1	-40.9	-53.9	-54.9	-56.9	-61.9	-63.9	-67.9
13	17.1	-38.9	-49.9	-37.9	-47.9	-66.9	-68.9	-63.9
14	17.1	-48.9	-53.9	-54.9	-54.9	-56.9	-56.9	-57.9
15	19.1	-38.9	-50.9	-51.9	-55.1	-62.9	-59.9	-59.9
16	19.1	-38.9	-45.9	-59.1	-59.1	-70.9	-58.9	-65.9
17	19.1	-39.9	-45.9	-47.9	-52.9	-53.9	-57.9	-57.9
18	19.1	-36.9	-52.9	-46.9	-59.9	-63.9	-37.9	-62.9
19	19.1	-40.9	-57.9	-58.9	-62.9	-63.9	-66.9	-66.9
20	17.1	-41.9	-49.9	-50.9	-54.9	-55.9	-56.9	-61.9
21	19.1	-39.9	-50.9	-50.9	-58.9	-61.9	-43.9	-60.9
22	17.1	-42.9	-50.9	-39.9	-53.9	-57.9	-34.9	-65.9
23	17.1	-39.9	-47.9	-44.9	-54.9	-61.9	-48.9	-60.9
24	17.1	-33.9	-43.9	-36.9	-43.9	-46.9	-43.9	-43.9
25	17.1	-31.9	-45.9	-22.9	-21.9	-22.9	-23.9	-23.9
26	19.1	-39.9	-54.9	-55.9	-57.9	-57.9	-61.9	-59.9
27	17.1	-38.9	-52.9	-54.9	-50.9	-57.9	-34.9	-55.9
28	17.1	-42.9	-45.9	-46.9	-50.9	-66.9	-31.9	-70.9
29	17.1	-42.9	-54.9	-56.9	-53.9	-59.9	-35.9	-62.9
30	17.1	-38.9	-43.9	-33.9	-43.9	-48.9	-31.9	-49.9
31	17.1	-42.9	-49.9	-37.9	-43.9	-58.9	-34.9	-58.9
32	17.1	-40.9	-49.9	-51.9	-51.9	-53.9	-55.9	-57.9
33	17.1	-41.9	-51.9	-48.9	-56.9	-61.9	-48.9	-60.9
34	17.1	-38.9	-43.9	-39.9	-45.9	-58.9	-68.9	-63.9
35	17.1	-41.9	-49.9	-39.9	-43.9	-41.9	-35.9	-39.9
36	17.1	-39.9	-50.9	-39.9	-53.9	-63.9	-54.9	-62.9
37	17.1	-39.9	-53.9	-53.9	-57.9	-65.9	-35.9	-67.9
38	19.1	-39.9	-45.9	-31.9	-37.9	-55.9	-34.9	-59.9
39	19.1	-39.9	-45.9	-48.9	-45.9	-57.9	-43.9	-58.9
40	17.1	-42.9	-45.9	-50.9	-45.9	-57.9	-35.9	-60.9
41	17.1	-39.9	-54.9	-44.9	-58.9	-61.9	-51.9	-60.9
42	19.1	-40.9	-45.9	-47.9	-45.9	-46.9	-46.9	-48.9
43	19.1	-24.9	-34.9	-37.9	-41.9	-58.9	-41.9	-58.9
44	19.1	-33.9	-49.9	-44.9	-48.9	-53.9	-43.9	-52.9
45	17.1	-40.9	-49.9	-49.9	-51.9	-55.9	-53.9	-55.9
46	17.1	-41.9	-43.9	-44.9	-57.9	-60.9	-55.9	-64.9
47	17.1	-36.9	-45.9	-48.9	-45.9	-55.9	-41.9	-59.9
48	17.1	-22.9	-24.9	-22.9	-21.9	-23.9	-23.9	-23.9
49	17.1	-42.9	-50.9	-41.9	-47.9	-49.9	-52.9	-51.9
50	17.1	-33.9	-45.9	-39.9	-52.9	-65.9	-28.9	-63.9

Table A4.9 – Full set of measured protection ratios for C = -50 dBm.

$r(\Delta F)$	Measured protection ratios for C = -50 dBm							
RXID	N+0	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	17.1	-37.3	-50.7	-48.9	-56.9	-58.9	-52.9	-60.9
2	19.1	-41.3	-43.9	-43.9	-44.9	-42.9	-45.9	-44.9
3	19.1	-43.9	-45.7	-48.9	-48.9	-49.9	-52.9	-50.9
4	19.1	-41.3	-45.7	-38.1	-53.1	-60.9	-56.9	-55.9
5	19.1	-43.9	-47.7	-47.1	-50.1	-49.9	-47.9	-46.9
6	19.1	-29.3	-32.9	-35.9	-36.9	-38.9	-38.9	-38.9
7	17.1	-45.3	-51.7	-55.9	-55.9	-55.9	-57.9	-59.9
8	17.1	-29.3	-34.9	-34.9	-44.1	-42.9	-41.9	-42.9
9	19.1	-37.3	-44.9	-35.9	-42.9	-55.9	-38.9	-58.9
10	19.1	-34.3	-40.7	-41.9	-43.1	-45.9	-43.9	-44.9
11	19.1	-37.3	-43.9	-40.9	-42.9	-44.9	-47.9	-48.9
12	19.1	-43.9	-49.7	-53.9	-52.9	-55.9	-57.9	-59.9
13	17.1	-35.3	-44.7	-35.9	-45.9	-56.9	-32.9	-46.9
14	17.1	-43.9	-45.9	-47.9	-47.9	-48.9	-47.9	-49.9
15	19.1	-34.9	-47.7	-48.1	-51.1	-52.9	-51.9	-49.9
16	19.1	-40.3	-45.7	-38.1	-52.1	-60.9	-56.9	-54.9
17	19.1	-40.9	-48.9	-52.9	-51.9	-56.9	-56.9	-58.9
18	19.1	-35.9	-47.9	-41.9	-51.9	-55.9	-37.9	-52.9
19	19.1	-42.9	-56.9	-58.9	-58.9	-60.9	-60.9	-62.9
20	17.1	-43.9	-48.9	-49.9	-53.9	-55.9	-56.9	-56.9
21	19.1	-37.9	-46.9	-41.9	-49.9	-50.9	-36.9	-50.9
22	17.1	-39.9	-49.9	-41.9	-50.9	-55.9	-39.9	-57.9
23	17.1	-41.9	-39.9	-35.9	-44.9	-50.9	-47.9	-50.9
24	17.1	-37.3	-36.9	-16.9	-21.9	-37.9	-37.9	-36.9
25	17.1	-15.9	-21.9	-23.9	-13.9	-28.9	-32.9	-16.9
26	19.1	-43.9	-52.9	-55.9	-56.9	-58.9	-57.9	-59.9
27	17.1	-37.9	-44.9	-44.9	-49.9	-46.9	-44.9	-46.9
28	17.1	-41.9	-43.9	-47.9	-44.9	-63.9	-34.9	-63.9
29	17.1	-43.9	-54.9	-56.9	-56.9	-61.9	-61.9	-61.9
30	17.1	-32.9	-39.9	-31.9	-35.9	-38.9	-32.9	-38.9
31	17.1	-37.9	-39.9	-42.9	-36.9	-50.9	-38.9	-50.9
32	17.1	-42.9	-46.9	-52.9	-51.9	-56.9	-47.9	-60.9
33	17.1	-39.9	-36.9	-40.9	-41.9	-50.9	-47.9	-50.9
34	17.1	-40.9	-41.9	-43.9	-34.9	-43.9	-34.9	-47.9
35	17.1	-37.9	-42.9	-34.9	-34.9	-31.9	-30.9	-23.9
36	17.1	-23.9	-42.9	-36.9	-43.9	-53.9	-50.9	-52.9
37	17.1	-44.9	-53.9	-43.9	-48.9	-57.9	-44.9	-57.9
38	19.1	-38.9	-44.9	-29.9	-36.9	-48.9	-32.9	-48.9
39	19.1	-34.9	-40.9	-45.9	-43.9	-53.9	-40.9	-54.9
40	17.1	-39.9	-42.9	-46.9	-38.9	-49.9	-40.9	-48.9
41	17.1	-43.9	-50.9	-30.9	-49.9	-52.9	-48.9	-49.9
42	19.1	-39.9	-42.9	-42.9	-36.9	-47.9	-48.9	-50.9
43	19.1	-17.9	-28.9	-34.9	-37.9	-52.9	-44.9	-53.9
44	19.1	-37.9	-40.9	-43.9	-43.9	-40.9	-41.9	-38.9
45	17.1	-44.9	-48.9	-48.9	-51.9	-53.9	-54.9	-55.9
46	17.1	-40.9	-40.9	-44.9	-47.9	-52.9	-51.9	-52.9
47	17.1	-32.9	-42.9	-42.9	-39.9	-50.9	-45.9	-50.9
48	17.1	-23.9	-13.9	-12.9	-13.9	-10.9	-10.9	-11.9
49	17.1	-35.9	-40.9	-35.9	-39.9	-39.9	-42.9	-42.9
50	17.1	-39.9	-42.9	-42.9	-48.9	-55.9	-34.9	-56.9

Table A4.10 – Full set of measured protection ratios for C = -30 dBm.

$r(\Delta F)$	Measured protection ratios for C = -30 dBm							
RXID	N+0	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	17.1	-33.3	-35.7	-38.9	-40.9	-39.9	-39.9	-39.9
2	17.1	-22.3	-20.7	-35.9	-24.9	-22.9	-25.9	-25.9
3	18.1	-25.3	-26.7	-23.9	-28.9	-30.9	-31.9	-30.9
4	17.1	-30.3	-31.7	-27.1	-34.1	-40.9	-39.9	-35.9
5	17.1	-29.3	-29.7	-27.1	-29.1	-30.9	-29.9	-26.9
6	17.1	-21.3	-20.7	-18.1	-20.1	-14.9	-13.9	-18.9
7	17.1	-33.3	-36.7	-36.9	-38.9	-36.9	-38.9	-39.9
8	17.1	-28.3	-34.7	-27.1	-29.1	-26.9	-25.9	-27.9
9	17.1	-23.3	-24.7	-30.9	-34.9	-37.9	-34.9	-37.9
10	17.1	-19.3	-20.7	-22.1	-25.1	-26.9	-25.9	-23.9
11	17.1	-19.3	-18.7	-23.9	-23.9	-26.9	-26.9	-26.9
12	17.1	-29.3	-31.7	-33.9	-34.9	-36.9	-36.9	-39.9
13	17.1	-25.3	-26.7	-33.9	-35.9	-37.9	-34.9	-34.9
14	17.1	-26.9	-27.9	-26.9	-28.9	-29.9	-28.9	-29.9
15	17.1	-31.3	-31.7	-30.1	-31.1	-32.9	-31.9	-28.9
16	17.1	-29.3	-30.7	-29.1	-33.1	-39.9	-39.9	-35.9
17	17.1	-42.9	-47.9	-48.9	-48.9	-47.9	-47.9	-47.9
18	17.1	-29.9	-34.9	-32.9	-33.9	-33.9	-33.9	-32.9
19	18.1	-40.9	-42.9	-43.9	-43.9	-43.9	-42.9	-43.9
20	17.1	-31.9	-36.9	-35.9	-36.9	-36.9	-39.9	-40.9
21	19.1	-29.9	-30.9	-31.9	-31.9	-31.9	-30.9	-30.9
22	17.1	-29.9	-31.9	-35.9	-37.9	-37.9	-38.9	-39.9
23	17.1	-23.9	-22.9	-28.9	-30.9	-32.9	-30.9	-31.9
24	17.1	-23.3	-18.7	-18.1	-19.1	-15.9	-15.9	-13.9
25	17.1	-5.9	-8.9	-10.9	-11.9	-7.9	-8.9	-4.9
26	19.1	-41.9	-41.9	-47.9	-49.9	-51.9	-51.9	-50.9
27	17.1	-16.9	-24.9	-25.9	-28.9	-26.9	-26.9	-25.9
28	17.1	-35.9	-38.9	-40.9	-39.9	-44.9	-33.9	-45.9
29	17.1	-34.9	-36.9	-39.9	-39.9	-43.9	-36.9	-41.9
30	17.1	-19.9	-21.9	-22.9	-22.9	-20.9	-19.9	-20.9
31	17.1	-23.9	-27.9	-27.9	-29.9	-30.9	-29.9	-29.9
32	17.1	-38.9	-36.9	-44.9	-34.9	-39.9	-38.9	-40.9
33	17.1	-22.9	-35.9	-31.9	-32.9	-31.9	-31.9	-29.9
34	17.1	-23.9	-32.9	-30.9	-27.9	-35.9	-34.9	-34.9
35	17.1	-21.9	-21.9	-22.9	-19.9	-13.9	-13.9	-13.9
36	17.1	-13.9	-21.9	-31.9	-33.9	-34.9	-34.9	-35.9
37	17.1	-34.9	-37.9	-36.9	-36.9	-36.9	-38.9	-38.9
38	17.1	-23.9	-25.9	-26.9	-27.9	-27.9	-27.9	-27.9
39	17.1	-27.9	-27.9	-28.9	-29.9	-29.9	-29.9	-29.9
40	17.1	-23.9	-24.9	-24.9	-27.9	-28.9	-18.9	-28.9
41	17.1	-28.9	-31.9	-34.9	-38.9	-32.9	-31.9	-31.9
42	17.1	-29.9	-32.9	-31.9	-32.9	-30.9	-31.9	-33.9
43	17.1	-15.9	-23.9	-31.9	-33.9	-31.9	-27.9	-31.9
44	17.1	-25.9	-25.9	-25.9	-26.9	-22.9	-20.9	-19.9
45	17.1	-37.9	-43.9	-45.9	-44.9	-44.9	-45.9	-45.9
46	17.1	-29.9	-30.9	-31.9	-31.9	-31.9	-31.9	-33.9
47	17.1	-21.9	-25.9	-26.9	-29.9	-30.9	-31.9	-32.9
48	17.1	-0.9	-0.9	-0.9	1.1	1.1	1.1	0.1
49	17.1	-18.9	-19.9	-19.9	-20.9	-21.9	-21.9	-21.9
50	17.1	-25.9	-27.9	-31.9	-33.9	-35.9	-33.9	-36.9

Table A4.11 – Full set of derived ACS, C = -70 dBm.

ACS(ΔF)	Measured ACS for C = -70 dBm						
RXID	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	58.2	64.0	74.1	92.3	96.7	63.0	96.7
2	61.1	68.1	73.1	75.1	68.0	78.0	75.0
3	62.8	72.2	74.1	75.1	78.0	75.0	73.0
4	58.2	72.2	74.1	88.5	102.3	76.0	94.0
5	61.1	60.0	69.0	72.1	84.1	66.0	80.0
6	49.2	62.0	61.0	66.0	69.0	69.0	68.0
7	61.1	72.2	72.1	75.1	74.0	71.0	67.0
8	62.8	66.1	66.0	69.0	76.0	76.0	76.0
9	53.4	70.1	59.0	72.1	91.6	60.0	95.3
10	62.8	68.1	60.0	76.2	73.0	67.0	81.1
11	62.8	75.5	76.2	78.3	82.1	81.1	84.1
12	62.8	74.4	76.2	78.3	82.1	80.0	84.1
13	49.2	68.1	59.0	75.1	91.6	98.2	90.5
14	76.5	69.1	70.0	72.1	74.0	76.0	77.0
15	53.4	55.0	74.1	74.1	86.2	69.0	85.1
16	62.8	72.2	72.1	88.2	100.0	76.0	92.7
17	59.6	72.2	74.1	75.1	74.0	74.0	74.0
18	62.8	73.3	77.2	92.3	60.0	60.0	90.5
19	62.8	74.4	76.2	79.4	81.1	82.1	84.1
20	61.1	72.2	72.1	75.1	74.0	77.0	77.0
21	61.1	66.1	60.0	86.7	86.2	71.0	88.3
22	61.1	69.1	61.0	75.1	82.1	60.0	89.4
23	61.1	65.0	70.0	79.4	88.3	72.0	88.3
24	52.3	52.0	60.0	62.0	69.0	63.0	70.0
25	52.3	65.0	51.0	51.0	73.0	54.0	51.0
26	62.8	73.3	77.2	78.3	78.0	77.0	80.0
27	53.4	70.1	74.1	78.3	85.1	60.0	84.1
28	62.8	69.1	67.0	80.5	90.5	55.0	95.3
29	61.1	75.5	76.2	78.3	76.0	76.0	74.0
30	61.1	65.0	61.0	63.0	76.0	52.0	76.0
31	61.1	72.2	58.0	72.1	83.1	59.0	87.2
32	61.1	70.1	72.1	74.1	71.0	70.0	73.0
33	62.8	75.5	72.1	85.3	86.2	73.0	87.2
34	58.2	69.1	65.0	73.1	85.1	67.0	89.4
35	59.6	75.5	58.0	66.0	66.0	58.0	64.0
36	62.8	75.5	66.0	80.5	90.5	74.0	90.5
37	61.1	71.2	74.1	86.7	90.5	63.0	96.7
38	62.8	69.1	57.0	67.0	85.1	57.0	88.3
39	53.4	66.1	70.0	67.0	84.1	64.0	85.1
40	53.4	72.2	70.0	72.1	82.1	60.0	87.2
41	61.1	75.5	60.0	86.7	89.4	52.0	89.4
42	61.1	68.1	73.1	72.1	73.0	74.0	75.0
43	48.1	57.0	56.0	65.0	85.1	68.0	87.2
44	52.3	70.1	70.0	76.2	81.1	68.0	79.0
45	61.1	70.1	74.1	76.2	73.0	71.0	73.0
46	56.9	62.0	69.0	85.3	88.3	74.0	90.5
47	52.3	68.1	69.0	72.1	83.1	67.0	87.2
48	49.2	50.0	51.0	51.0	49.0	49.0	51.0
49	59.6	73.3	66.0	75.1	76.0	78.0	79.0
50	56.9	65.0	61.0	76.2	80.0	53.0	88.3

Table A4.12 – Full set of derived ACS, C = -60 dBm.

ACS(ΔF)	Measured ACS for C = -60 dBm						
RXID	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	61.1	68.1	72.1	85.3	87.2	68.0	88.3
2	61.1	69.1	71.1	73.1	72.0	74.0	74.0
3	62.8	69.9	72.1	73.1	78.0	77.0	78.0
4	62.8	69.1	78.5	77.4	90.5	78.0	85.1
5	62.8	69.9	72.1	72.3	80.0	75.0	76.0
6	51.3	54.0	56.0	59.0	59.0	59.0	61.0
7	62.8	68.1	69.0	72.1	77.0	77.0	80.0
8	51.3	56.0	55.0	61.0	66.0	66.0	66.0
9	61.1	71.2	56.0	65.0	86.2	54.0	87.2
10	62.8	67.1	67.0	65.2	75.0	63.0	73.0
11	61.1	71.2	70.0	73.1	75.0	76.0	78.0
12	62.8	73.3	74.1	76.2	81.1	83.1	87.2
13	56.9	67.1	55.0	65.0	84.1	86.2	81.1
14	NaN	71.2	72.1	72.1	74.0	74.0	75.0
15	59.6	70.1	71.1	74.3	82.1	79.0	79.0
16	59.6	65.0	78.5	78.5	90.5	78.0	85.1
17	61.1	65.0	67.0	72.1	73.0	77.0	77.0
18	56.9	72.2	66.0	79.4	83.1	57.0	82.1
19	62.8	77.7	78.3	82.7	83.1	86.2	86.2
20	61.1	67.1	68.0	72.1	73.0	74.0	79.0
21	61.1	70.1	70.0	78.3	81.1	63.0	80.0
22	62.8	68.1	57.0	71.1	75.0	52.0	83.1
23	58.2	65.0	62.0	72.1	79.0	66.0	78.0
24	51.3	61.0	54.0	61.0	64.0	61.0	61.0
25	49.2	63.0	40.0	39.0	40.0	41.0	41.0
26	61.1	74.4	75.1	77.2	77.0	81.1	79.0
27	56.9	70.1	72.1	68.0	75.0	52.0	73.0
28	62.8	63.0	64.0	68.0	84.1	49.0	88.3
29	62.8	72.2	74.1	71.1	77.0	53.0	80.0
30	56.9	61.0	51.0	61.0	66.0	49.0	67.0
31	62.8	67.1	55.0	61.0	76.0	52.0	76.0
32	59.6	67.1	69.0	69.0	71.0	73.0	75.0
33	61.1	69.1	66.0	74.1	79.0	66.0	78.0
34	56.9	61.0	57.0	63.0	76.0	86.2	81.1
35	61.1	67.1	57.0	61.0	59.0	53.0	57.0
36	58.2	68.1	57.0	71.1	81.1	72.0	80.0
37	58.2	71.2	71.1	75.1	83.1	53.0	85.1
38	61.1	65.0	51.0	57.0	75.0	54.0	79.0
39	61.1	65.0	68.0	65.0	77.0	63.0	78.0
40	62.8	63.0	68.0	63.0	75.0	53.0	78.0
41	58.2	72.2	62.0	76.2	79.0	69.0	78.0
42	62.8	65.0	67.0	65.0	66.0	66.0	68.0
43	44.1	54.0	57.0	61.0	78.0	61.0	78.0
44	53.4	69.1	64.0	68.0	73.0	63.0	72.0
45	59.6	67.1	67.0	69.0	73.0	71.0	73.0
46	61.1	61.0	62.0	75.1	78.0	73.0	82.1
47	54.6	63.0	66.0	63.0	73.0	59.0	77.0
48	40.0	42.0	40.0	39.0	41.0	41.0	41.0
49	62.8	68.1	59.0	65.0	67.0	70.0	69.0
50	51.3	63.0	57.0	70.0	83.1	46.0	81.1

Table A4.13 – Full set of derived ACS, C = -50 dBm.

ACS(ΔF)	Measured ACS for C = -50 dBm						
RXID	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	55.0	67.9	66.1	74.4	76.0	70.0	79.0
2	63.6	63.0	63.0	64.0	62.0	65.0	64.0
3	76.5	64.8	68.1	68.1	69.0	72.0	70.1
4	63.6	64.8	57.2	72.4	80.0	76.0	75.5
5	76.5	66.9	66.3	69.3	69.0	67.0	66.1
6	48.5	52.0	55.0	56.0	58.0	58.0	58.0
7	70.1	68.9	73.3	73.3	73.0	75.0	77.7
8	46.5	52.0	52.0	61.2	60.0	59.0	60.0
9	57.4	64.0	55.0	62.0	75.0	58.0	79.0
10	53.9	59.8	61.0	62.2	65.0	63.0	64.0
11	57.4	63.0	60.0	62.0	64.0	67.0	68.1
12	76.5	68.9	73.3	72.2	75.0	77.0	80.3
13	52.8	61.8	53.0	63.0	74.0	50.0	64.0
14	65.0	63.0	65.0	65.0	66.0	65.0	67.1
15	54.6	66.9	67.3	70.3	72.0	71.0	69.1
16	61.7	64.8	57.2	71.4	80.0	76.0	74.4
17	62.8	68.1	72.2	71.2	76.0	76.0	79.0
18	55.7	67.1	61.0	71.2	75.0	57.0	72.2
19	68.2	76.6	79.0	79.0	80.0	80.0	85.0
20	65.0	66.1	67.1	71.2	73.0	74.0	74.4
21	58.2	66.1	61.0	69.1	70.0	56.0	70.1
22	58.2	67.1	59.0	68.1	73.0	57.0	75.5
23	61.1	57.0	53.0	62.0	68.0	65.0	68.1
24	55.0	54.0	34.0	39.0	55.0	55.0	54.0
25	33.0	39.0	41.0	31.0	46.0	50.0	34.0
26	76.5	72.2	75.5	76.6	78.0	77.0	80.3
27	55.7	62.0	62.0	67.1	64.0	62.0	64.0
28	61.1	61.0	65.0	62.0	81.1	52.0	83.2
29	65.0	72.2	74.4	74.4	79.0	79.0	80.3
30	50.2	57.0	49.0	53.0	56.0	50.0	56.0
31	55.7	57.0	60.0	54.0	68.0	56.0	68.1
32	62.8	64.0	70.1	69.1	74.0	65.0	79.0
33	58.2	54.0	58.0	59.0	68.0	65.0	68.1
34	59.6	59.0	61.0	52.0	61.0	52.0	65.0
35	55.7	60.0	52.0	52.0	49.0	48.0	41.0
36	41.0	60.0	54.0	61.0	71.0	68.0	70.1
37	68.2	71.2	61.0	66.1	75.0	62.0	75.5
38	59.6	64.0	49.0	56.0	68.0	52.0	68.1
39	54.6	60.0	65.0	63.0	73.0	60.0	74.4
40	58.2	60.0	64.0	56.0	67.0	58.0	66.1
41	65.0	68.1	48.0	67.1	70.0	66.0	67.1
42	61.1	62.0	62.0	56.0	67.0	68.0	70.1
43	37.0	48.0	54.0	57.0	72.0	64.0	73.3
44	58.2	60.0	63.0	63.0	60.0	61.0	58.0
45	68.2	66.1	66.1	69.1	71.0	72.0	73.3
46	59.6	58.0	62.0	65.0	70.0	69.0	70.1
47	50.2	60.0	60.0	57.0	68.0	63.0	68.1
48	41.0	31.0	30.0	31.0	28.0	28.0	29.0
49	53.4	58.0	53.0	57.0	57.0	60.0	60.0
50	58.2	60.0	60.0	66.1	73.0	52.0	74.4

Table A4.14 – Full set of derived ACS, C = -30 dBm.

ACS(ΔF)	Measured ACS for C = -30 dBm						
RXID	N+1	N+2	N+3	N+4	N+8	N+9	N+10
1	50.6	52.8	56.0	58.0	57.0	57.0	57.0
2	39.4	37.8	53.0	42.0	40.0	43.0	43.0
3	43.4	44.8	42.0	47.0	49.0	50.0	49.0
4	47.5	48.8	44.2	51.2	58.0	57.0	53.0
5	46.5	46.8	44.2	46.2	48.0	47.0	44.0
6	38.4	37.8	35.2	37.2	32.0	31.0	36.0
7	50.6	53.8	54.0	56.0	54.0	56.0	57.0
8	45.5	51.8	44.2	46.2	44.0	43.0	45.0
9	40.4	41.8	48.0	52.0	55.0	52.0	55.0
10	36.4	37.8	39.2	42.2	44.0	43.0	41.0
11	36.4	35.8	41.0	41.0	44.0	44.0	44.0
12	46.5	48.8	51.0	52.0	54.0	54.0	57.0
13	42.4	43.8	51.0	53.0	55.0	52.0	52.0
14	44.1	45.0	44.0	46.0	47.0	46.0	47.0
15	48.5	48.8	47.2	48.2	50.0	49.0	46.0
16	46.5	47.8	46.2	50.2	57.0	57.0	53.0
17	62.8	65.0	66.0	66.0	65.0	65.0	65.0
18	47.1	52.0	50.0	51.0	51.0	51.0	50.0
19	61.1	61.0	62.0	62.0	62.0	61.0	62.0
20	49.2	54.0	53.0	54.0	54.0	57.0	58.0
21	49.2	50.0	51.0	51.0	51.0	50.0	50.0
22	47.1	49.0	53.0	55.0	55.0	56.0	57.0
23	41.0	40.0	46.0	48.0	50.0	48.0	49.0
24	40.4	35.8	35.2	36.2	33.0	33.0	31.0
25	23.0	26.0	28.0	29.0	25.0	26.0	22.0
26	65.0	61.0	67.0	69.0	71.0	71.0	70.0
27	34.0	42.0	43.0	46.0	44.0	44.0	43.0
28	53.4	56.0	58.0	57.0	62.0	51.0	63.0
29	52.3	54.0	57.0	57.0	61.0	54.0	59.0
30	37.0	39.0	40.0	40.0	38.0	37.0	38.0
31	41.0	45.0	45.0	47.0	48.0	47.0	47.0
32	56.9	54.0	62.0	52.0	57.0	56.0	58.0
33	40.0	53.0	49.0	50.0	49.0	49.0	47.0
34	41.0	50.0	48.0	45.0	53.0	52.0	52.0
35	39.0	39.0	40.0	37.0	31.0	31.0	31.0
36	31.0	39.0	49.0	51.0	52.0	52.0	53.0
37	52.3	55.0	54.0	54.0	54.0	56.0	56.0
38	41.0	43.0	44.0	45.0	45.0	45.0	45.0
39	45.1	45.0	46.0	47.0	47.0	47.0	47.0
40	41.0	42.0	42.0	45.0	46.0	36.0	46.0
41	46.1	49.0	52.0	56.0	50.0	49.0	49.0
42	47.1	50.0	49.0	50.0	48.0	49.0	51.0
43	33.0	41.0	49.0	51.0	49.0	45.0	49.0
44	43.0	43.0	43.0	44.0	40.0	38.0	37.0
45	55.7	61.0	63.0	62.0	62.0	63.0	63.0
46	47.1	48.0	49.0	49.0	49.0	49.0	51.0
47	39.0	43.0	44.0	47.0	48.0	49.0	50.0
48	18.0	18.0	18.0	16.0	16.0	16.0	17.0
49	36.0	37.0	37.0	38.0	39.0	39.0	39.0
50	43.0	45.0	49.0	51.0	53.0	51.0	54.0

Table A4.15 – 60th percentile protection ratios (dB) for WSD classes 1 to 5.

Class 1, 60%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-37	-36	-35	-30	-25	-15	-7
N±2	-42	-41	-40	-34	-28	-20	-12
N±3	-46	-43	-41	-36	-30	-20	-12
N±4	-55	-50	-45	-38	-31	-21	-13
N±8	-62	-58	-51	-42	-32	-22	-14
N+9	-51	-48	-42	-36	-32	-22	-14
N–9	-63	-60	-51	-41	-31	-21	-13
N±10	-64	-61	-50	-40	-30	-20	-12

Class 2, 60%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-37	-36	-35	-30	-25	-15	-7
N±2	-38	-37	-36	-33	-29	-19	-12
N±3	-38	-36	-36	-33	-29	-20	-12
N±4	-48	-46	-43	-37	-31	-21	-13
N±8	-57	-55	-50	-41	-32	-22	-14
N+9	-51	-48	-42	-36	-32	-22	-14
N–9	-61	-58	-50	-41	-31	-21	-13
N±10	-64	-61	-50	-40	-30	-20	-12

Class 3, 60%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-28	-27	-27	-25	-23	-15	-7
N±2	-38	-37	-36	-33	-29	-19	-12
N±3	-46	-43	-41	-36	-30	-20	-12
N±4	-55	-50	-45	-38	-31	-21	-13
N±8	-62	-58	-51	-42	-32	-22	-14
N+9	-51	-48	-42	-36	-32	-22	-14
N–9	-63	-60	-51	-41	-31	-21	-13
N±10	-64	-61	-50	-40	-30	-20	-12

Class 4, 60%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-18	-17	-17	-17	-17	-13	-7
N±2	-28	-27	-27	-27	-26	-19	-10
N±3	-38	-36	-36	-33	-29	-20	-12
N±4	-48	-46	-43	-37	-31	-21	-13
N±8	-57	-55	-50	-41	-32	-22	-14
N+9	-51	-48	-42	-36	-32	-22	-14
N–9	-61	-58	-50	-41	-31	-21	-13
N±10	-64	-61	-50	-40	-30	-20	-12

Class 5, 60%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-7	-6	-6	-7	-7	-7	-4
N±2	-17	-16	-16	-17	-17	-15	-10
N±3	-28	-27	-27	-27	-26	-19	-12
N±4	-38	-37	-37	-34	-30	-21	-13
N±8	-48	-47	-46	-39	-32	-22	-14
N+9	-50	-47	-42	-36	-32	-22	-14
N–9	-56	-54	-48	-40	-31	-21	-13
N±10	-63	-60	-50	-40	-30	-20	-12

Table A4.16 – 70th percentile protection ratios (dB) for WSD classes 1 to 5.

Class 1, 70%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-36	-36	-35	-30	-24	-14	-6
N±2	-42	-41	-39	-33	-26	-16	-8
N±3	-45	-40	-40	-34	-28	-18	-10
N±4	-55	-49	-44	-37	-29	-19	-11
N±8	-58	-57	-47	-39	-30	-20	-12
N+9	-47	-43	-39	-35	-28	-18	-10
N–9	-60	-58	-48	-39	-30	-20	-12
N±10	-62	-58	-48	-39	-29	-19	-11

Class 2, 70%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-36	-36	-35	-30	-24	-14	-6
N±2	-38	-37	-36	-31	-25	-16	-8
N±3	-38	-36	-36	-32	-27	-18	-10
N±4	-47	-45	-42	-36	-29	-19	-11
N±8	-55	-54	-47	-39	-30	-20	-12
N+9	-47	-43	-39	-35	-28	-18	-10
N–9	-59	-56	-48	-39	-30	-20	-12
N±10	-62	-58	-48	-39	-29	-19	-11

Class 3, 70%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-28	-27	-27	-25	-23	-14	-6
N±2	-38	-37	-36	-31	-25	-16	-8
N±3	-45	-40	-40	-34	-28	-18	-10
N±4	-55	-49	-44	-37	-29	-19	-11
N±8	-58	-57	-47	-39	-30	-20	-12
N+9	-47	-43	-39	-35	-28	-18	-10
N–9	-60	-58	-48	-39	-30	-20	-12
N±10	-62	-58	-48	-39	-29	-19	-11

Class 4, 70%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-18	-17	-17	-17	-17	-13	-7
N±2	-28	-27	-27	-26	-24	-15	-8
N±3	-38	-36	-36	-32	-27	-18	-10
N±4	-47	-45	-42	-36	-29	-19	-11
N±8	-55	-54	-47	-39	-30	-20	-12
N+9	-47	-43	-39	-35	-28	-18	-10
N–9	-59	-56	-48	-39	-30	-20	-12
N±10	-62	-58	-48	-39	-29	-19	-11

Class 5, 70%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-7	-6	-6	-7	-7	-6	-4
N±2	-17	-16	-16	-16	-16	-13	-7
N±3	-28	-27	-27	-26	-25	-17	-10
N±4	-38	-37	-36	-32	-28	-19	-11
N±8	-48	-47	-44	-37	-30	-20	-12
N+9	-46	-43	-39	-35	-28	-18	-10
N–9	-55	-53	-46	-38	-30	-20	-12
N±10	-61	-58	-48	-39	-29	-19	-11

Table A4.17 – 80th percentile protection ratios (dB) for WSD classes 1 to 5.

Class 1, 80%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-36	-35	-34	-29	-23	-13	-5
N±2	-42	-40	-38	-30	-22	-12	-4
N±3	-42	-38	-36	-31	-25	-15	-7
N±4	-53	-47	-39	-32	-25	-15	-7
N±8	-56	-55	-43	-35	-27	-17	-9
N+9	-43	-35	-37	-34	-26	-16	-8
N–9	-57	-55	-45	-36	-27	-17	-9
N±10	-58	-55	-46	-36	-26	-16	-8

Class 2, 80%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-36	-35	-34	-29	-23	-13	-5
N±2	-37	-37	-35	-29	-22	-12	-4
N±3	-37	-35	-33	-29	-25	-15	-7
N±4	-47	-44	-38	-32	-25	-15	-7
N±8	-54	-53	-43	-35	-27	-17	-9
N+9	-43	-35	-37	-34	-26	-16	-8
N–9	-56	-54	-45	-36	-27	-17	-9
N±10	-58	-55	-46	-36	-26	-16	-8

Class 3, 80%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-28	-27	-27	-25	-22	-13	-5
N±2	-37	-37	-35	-29	-22	-12	-4
N±3	-42	-38	-36	-31	-25	-15	-7
N±4	-53	-47	-39	-32	-25	-15	-7
N±8	-56	-55	-43	-35	-27	-17	-9
N+9	-43	-35	-37	-34	-26	-16	-8
N–9	-57	-55	-45	-36	-27	-17	-9
N±10	-58	-55	-46	-36	-26	-16	-8

Class 4, 80%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-18	-17	-17	-17	-17	-12	-5
N±2	-28	-27	-27	-24	-21	-12	-4
N±3	-37	-35	-33	-29	-25	-15	-7
N±4	-47	-44	-38	-32	-25	-15	-7
N±8	-54	-53	-43	-35	-27	-17	-9
N+9	-43	-35	-37	-34	-26	-16	-8
N–9	-56	-54	-45	-36	-27	-17	-9
N±10	-58	-55	-46	-36	-26	-16	-8

Class 5, 80%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-7	-6	-6	-7	-7	-6	-3
N±2	-17	-16	-16	-16	-16	-11	-4
N±3	-28	-27	-27	-25	-23	-15	-7
N±4	-38	-37	-35	-30	-25	-15	-7
N±8	-47	-46	-42	-35	-27	-17	-9
N+9	-43	-35	-37	-34	-26	-16	-8
N–9	-52	-51	-44	-36	-27	-17	-9
N±10	-57	-55	-46	-36	-26	-16	-8

Table A4.18 – 90th percentile protection ratios (dB) for WSD classes 1 to 5.

Class 1, 90%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-34	-33	-33	-27	-20	-10	-2
N±2	-37	-39	-37	-29	-20	-10	-2
N±3	-42	-37	-31	-26	-20	-10	-2
N±4	-47	-43	-34	-28	-21	-11	-3
N±8	-52	-48	-38	-30	-21	-11	-3
N+9	-38	-34	-34	-30	-19	-9	-1
N–9	-53	-48	-38	-29	-20	-10	-2
N±10	-53	-48	-38	-29	-19	-9	-1

Class 2, 90%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-34	-33	-33	-27	-20	-10	-2
N±2	-35	-36	-35	-28	-20	-10	-2
N±3	-37	-34	-30	-25	-20	-10	-2
N±4	-45	-41	-34	-28	-21	-11	-3
N±8	-51	-47	-38	-30	-21	-11	-3
N+9	-38	-34	-34	-30	-19	-9	-1
N–9	-52	-48	-38	-29	-20	-10	-2
N±10	-53	-48	-38	-29	-19	-9	-1

Class 3, 90%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-27	-26	-26	-23	-19	-10	-2
N±2	-35	-36	-35	-28	-20	-10	-2
N±3	-42	-37	-31	-26	-20	-10	-2
N±4	-47	-43	-34	-28	-21	-11	-3
N±8	-52	-48	-38	-30	-21	-11	-3
N+9	-38	-34	-34	-30	-19	-9	-1
N–9	-53	-48	-38	-29	-20	-10	-2
N±10	-53	-48	-38	-29	-19	-9	-1

Class 4, 90%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-18	-17	-17	-17	-16	-9	-2
N±2	-28	-27	-27	-23	-19	-10	-2
N±3	-37	-34	-30	-25	-20	-10	-2
N±4	-45	-41	-34	-28	-21	-11	-3
N±8	-51	-47	-38	-30	-21	-11	-3
N+9	-38	-34	-34	-30	-19	-9	-1
N–9	-52	-48	-38	-29	-20	-10	-2
N±10	-53	-48	-38	-29	-19	-9	-1

Class 5, 90%	C (dBm/8 MHz)						
Adjacencies	≤-70	-60	-50	-40	-30	-20	-12
N±1	-7	-6	-6	-7	-7	-5	-1
N±2	-17	-16	-16	-16	-15	-9	-2
N±3	-28	-27	-25	-22	-19	-10	-2
N±4	-38	-36	-32	-27	-21	-11	-3
N±8	-47	-44	-38	-30	-21	-11	-3
N+9	-38	-34	-34	-30	-19	-9	-1
N–9	-50	-46	-38	-29	-20	-10	-2
N±10	-53	-48	-38	-29	-19	-9	-1

Annex 5

WSD-PMSE protection ratios

A5.1 The protection ratio – sometimes referred to as the “C-to-I ratio” – is the ratio of the wanted signal power over the unwanted (co-channel or adjacent-channel) signal power at the point of failure of a receiver. The higher the protection ratio, the more susceptible the receiver is to interference. In the context of PMSE, we have used degradation in audio signal-to-noise and distortion ratio (SINAD) as a measure of receiver failure.

A5.2 In this annex we describe the procedures for deriving WSD-PMSE protection ratios corresponding to five WSD spectrum emission classes as defined in the draft ETSI harmonised European standard EN 301 598[62].

A5.3 These protection ratios are intended for use by WSDBs for purposes of calculating the maximum permitted WSD in-block EIRPs in relation to PMSE use.

A5.4 We have derived these protection ratios by first measuring the co-channel and adjacent-channel protection ratios of the PMSE receivers in the presence of a *test* WSD signal. The test WSD signal was a recorded WiMAX base station signal.

A5.5 We have used these measurements to derive the adjacent channel selectivity (ACS) of the PMSE receivers. The derived ACS values were then combined with the adjacent channel leakage ratios (ACLRs) for the five WSD spectrum emission classes to calculate the class-specific WSD-PMSE protection ratios.

A5.6 We used PMSE licensing data to select the most likely used PMSE equipment types. As such the devices under test consisted of two wireless microphones, an in-ear monitor, and a programme audio link device.

A5.7 Unless otherwise stated, we use the term channel to refer to an 8 MHz DTT channel. Furthermore, we use P_S and C, and P_X and I interchangeably to refer to wanted PMSE and unwanted WSD in-block powers, respectively. Finally, we use the subscript “M” to denote measured parameters.

A5.8 Note that certain results are presented to one decimal place. This is for purposes of transparency in the calculations, and do not reflect measurement accuracy.

Measurement set up

A5.9 We performed measurements on four selected PMSE receivers: two wireless microphones, one in-ear monitor, and a device for programme audio links. The test set up for the WSD-PMSE protection ratio measurements is shown in Figure A5.1 followed by an illustration of the wanted and unwanted signal emissions masks in Figure A5.2.

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[62] Draft ETSI EN 301 598 V1.0.0 (2013-07), “White space devices (WSD); Wireless access systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive”.

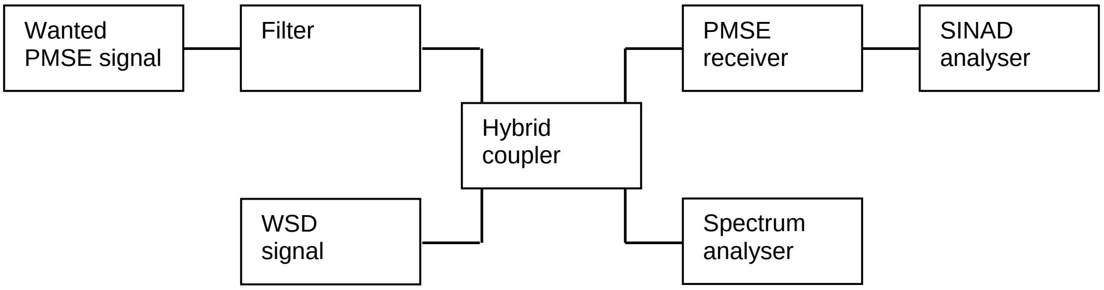

Figure A5.1 – Test setup for PMSE receiver measurements.

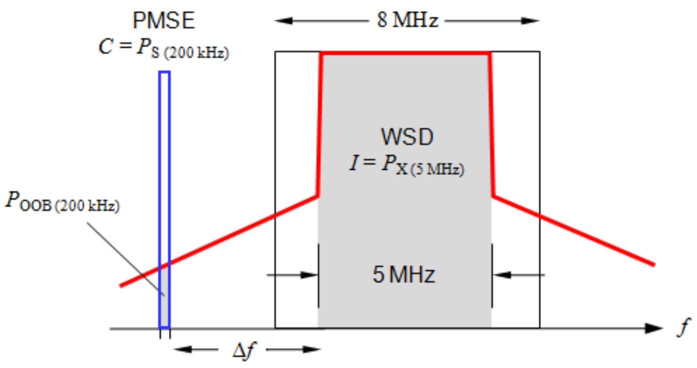

Figure A5.2 – Wanted and unwanted signals.

A5.10 The wanted PMSE signal and unwanted WSD signal were combined using a 10 dB directional hybrid coupler. The outputs of the coupler were connected to the PMSE receiver and a spectrum analyser. In this way we could monitor both the wanted and unwanted signals at the input port of the PMSE receiver. Cross calibration between the hybrid coupler's output ports was made at regular intervals.

PMSE signal

A5.11 The wanted PMSE signal was produced by a signal generator. This was a RF carrier at the appropriate frequency modulated by a 1 kHz tone. The tone was produced via the signal generator's internal function generator and where necessary an external function generator was used to produce the tone lock. The FM deviation was set according to the PMSE receiver manufacturers' specifications.

A5.12 The PMSE signal parameters were taken from the UK Interface Requirement 2038 – Programme making and special events (PMSE)[63]. The relevant operational parameters are summarised in Table A5.1. Since no standard operational parameters were found for in-ear monitor device, we used the same parameters as for wireless microphones.

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[63] "UK Interface Requirement 2038 – Programme making and special events (PMSE)", February, 2006, http://www.ofcom.org.uk/radiocomms/ifi/licensing/classes/pmse/

Table A5.1 – Operational parameters of tested PMSE receivers.

PMSE receiver	Frequency band (MHz)	Service bandwidth	Operating power (dBm/200 kHz)	Reference standard
Wireless microphone 1	470 to 854	200 kHz	-65	EN 300 422
Wireless microphone 2	470 to 854	200 kHz	-65	EN 300 422
In ear monitor (IEM)	Same as wireless microphones			
Programme audio link	470 to 590 598 to 606 614 to 854	200 kHz	-71.6	EN 300 454

WSD signal

A5.13 For the unwanted WSD test signal, we used the recording of a WiMAX base station’s transmissions for a 6 Mbits/s traffic load and a bandwidth of 5 MHz. This was played back through the arbitrary function waveform generator of an Agilent E4438C signal generator. The output of the signal generator was filtered to remove any wideband signal generator noise. The measured spectrum emission mask (centre frequency 740 MHz) at the input to PMSE receivers is shown in Figure A5.3 below.

A5.14 Considering that the tested PMSE devices have a 200 kHz bandwidth, the spectrum emission mask of the WiMAX signal was captured with a 1 kHz resolution. The power level on the Y axis represents dBm/1 kHz. In this case, the total in-block power over 5 MHz is around 4 dBm.

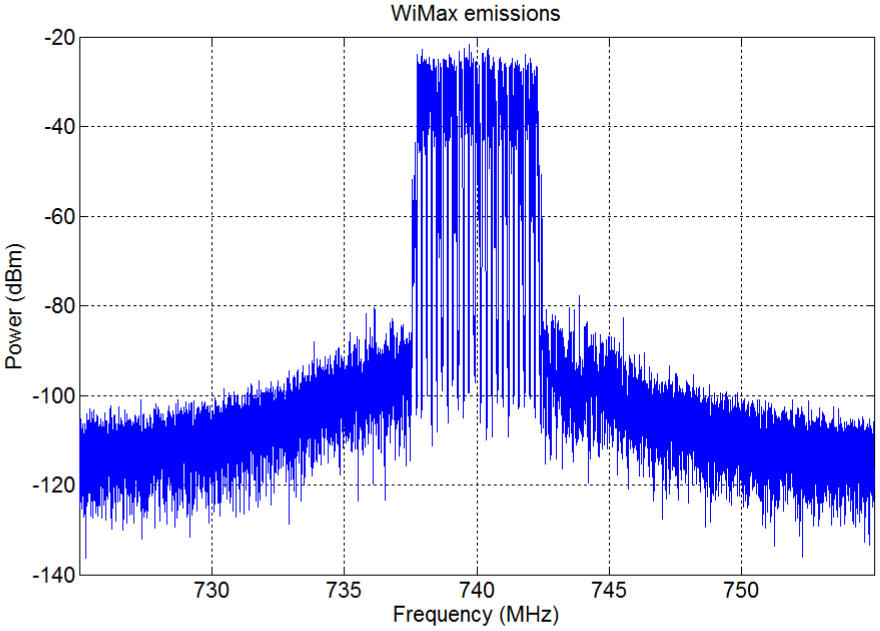

Figure A5.3 – Example of Spectrum emission mask of the tested WiMAX WSD signal.

A5.15 The adjacent channel leakage ratio (ACLR) of the WSD test signal is a key element in the derivation of the PMSE receiver selectivity. The ACLR is measured as

$$\mathrm{ACLR_M} = \frac{P_{\mathrm{X\,(5\,MHz)}}}{P_{\mathrm{OOB\,(200\ kHz)}}}, \tag{A5.1}$$

where P_X is in-block power over 5 MHz, and P_{OOB} is the out-of-block power over 200 kHz. Note that the out-of-block power is measured over 200 kHz to reflect the bandwidth of the PMSE receiver.

A5.16 Table A5.2 shows the measured ACLR values of the WiMAX test signal. These are presented for two frequency separations at each channel separation.

Table A5.2 – Measured ACLR values of the WiMAX test signal.

Channel separation, ΔF	Edge-to-edge frequency separation, Δf (MHz)	$\mathrm{ACLR_M}$ (dB)
±1	0.2	74
±1	4	83
±2	8.2	90
±2	12	93
$\lvert\Delta F\rvert \geq 3$	16.2	94

A5.17 As we can see from the spectrum emission mask of Figure A5.3, the spectrum analyser’s trace is limited by the analyser noise floor. As such, it is difficult to measure the out-of-block powers P_{OOB} after the 3rd adjacent channel, especially in the presence of a high in-block power. For this reason, we have assumed that the ACLR remains constant at 94 dB for the fourth adjacent channel and beyond.

Measurement of protection ratios

A5.18 The following is the procedure we used to measure to the WSD-PMSE protection ratios for the tested PMSE receivers:

1) The PMSE receiver was tuned to an appropriate channel.

2) The wanted PMSE signal power was adjusted via the level control of the signal generator. The power level at the input to the PMSE receiver was recorded as $C_{(\mathrm{dBm})}$.

3) The audio SINAD was measured and recorded in an interference-free environment.

4) The unwanted WSD signal was applied to the PMSE receiver and its carrier frequency adjusted for the required frequency separation.

5) The WSD signal power was increased to the point that a 6 dB reduction in the SINAD was observed. The maximum RMS power level was monitored and recorded as $I_{(\mathrm{dBm})}$ at the input to the PMSE receiver.

6) The difference $C_{(\mathrm{dBm})} - I_{(\mathrm{dBm})}$ was recorded as the protection (or C-to-I) ratio $r_{\mathrm{M}}(C, \Delta F)$ in dB.

A5.19 Unlike the case of WSD-DTT measurements, we do not use a correction factor for measurements of PMSE receivers, this is because we directly measure the maximum RMS power I of the interferer signal.

A5.20 To do this, the spectrum analyser was set to time domain mode, with settings adapted from ETSI EN 301 598 V1.0.0 in order to capture the maximum RMS power. The resolution bandwidth was adjusted to 8 MHz to capture all of power within the identified 8 MHz channel. The used settings are shown in Table A5.3.

Table A5.3 – Spectrum analyser settings.

Centre frequency	Frequency of emission identified during the pre-scan
Resolution bandwidth	8 MHz
Video bandwidth	Auto
Frequency span	N/A
Sweep mode	Continuous
Sweep time	Auto
Trigger	Free Run
Detector	RMS
Trace mode	Max Hold

A5.21 We measured protection ratios for WSD-PMSE channel separations of ΔF = 0, 1, 2, 3, 4, 5, 10 and 40. A positive channel separation means that the WSD signal is at the higher frequency. We assumed similar protection ratios for negative channel separations.

A5.22 Since the bandwidth of a PMSE signal is much smaller than 8 MHz, we examined two frequency separations Δf for each channel separation ΔF. This allows us to assess the sensitivity of protection ratios to the position of the PMSE signal within a DTT channel.

A5.23 Table A5.4 shows the measured protection ratios $r_{\mathrm{M}}(C, \Delta F)$ of the four PMSE receivers at specific PMSE wanted signal powers and a range of WSD-PMSE channel separations. Where protection ratios values are not shown, this is either because measurements were not attempted or because we were not able to generate sufficiently large I levels to cause a 6 dB degradation in SINAD.

Table A5.4 – Measured protection ratios.

$r_{\mathrm{M}}(C, \Delta F)$ (dB)					
Channel separation, ΔF	Edge-to-edge frequency separation, Δf (MHz)	C = -65 dBm			C = -71.3 dBm
		Wireless microphone 1	Wireless microphone 2	IEM	Programme audio link
0	N/A	2	-6	0	4
±1	0.2	-49	-56	-56	-52
±1	4	-56	-62	-62	-57
±2	8.2	-60	-66	-66	-64
±2	12	-60	-66	-67	-66
±3	16.2	-58	-68	-67	-65
±3	20	-59	-69	-66	-67
±4	24.2	-61	-60	-60	-68
±4	28	-63	-70	-65	-60
±5	32.2	-66	-73	-64	-
±5	36	-68	-74	-63	-
±10	77.4	-	-78	-68	-
±40	317.4	-	-	-65	-

Derivation of adjacent channel selectivity

A5.24 In this subsection, we describe the derivation of the adjacent channel selectivity of a PMSE receiver.

A5.25 The adjacent channel selectivity, $\mathrm{ACS}(C, \Delta F)$ of a tested PMSE receiver can be derived from the measured co-channel and adjacent-channel protection ratios, and the measured adjacent channel leakage ratio of the tested unwanted signal. From the definition of ACS we have (in the linear domain),

$$P_{\mathrm{I}\,(200\ \mathrm{kHz})} = P_{\mathrm{OOB}\,(200\ \mathrm{kHz})} + \frac{P_{\mathrm{X}\,(5\ \mathrm{MHz})}}{\mathrm{ACS}(C, \Delta F)}, \tag{A5.2}$$

where P_{X} is the in-block power of the unwanted signal, P_{OOB} is the out-of-block power of the unwanted signal, and P_{I} is the experienced interference power (see also Figure A5.2).

A5.26 From the definition of adjacent-channel interference ratio (ACIR) we also have (in the linear domain),

$$\mathrm{ACIR}_{\mathrm{M}}(C,\Delta F)=\frac{P_{\mathrm{X\,(5\,MHz)}}}{P_{\mathrm{I\,(200\,kHz)}}}, \qquad \text{(A5.3)}$$

at the point of receiver failure. Combining (A5.2) and (A5.3) we have

$$\begin{aligned}\frac{1}{\mathrm{ACIR}_{\mathrm{M}}(C,\Delta F)}&=\frac{P_{\mathrm{OOB\,(200\,kHz)}}}{P_{\mathrm{X\,(5\,MHz)}}}+\frac{1}{\mathrm{ACS}(C,\Delta F)}\\&=\frac{1}{\mathrm{ACLR}_{\mathrm{M}}(\Delta F)}+\frac{1}{\mathrm{ACS}(C,\Delta F)},\end{aligned} \qquad \text{(A5.4)}$$

or

$$\mathrm{ACS}(C,\Delta F)=\left\{\mathrm{ACIR}_{\mathrm{M}}^{-1}(C,\Delta F)-\mathrm{ACLR}_{\mathrm{M}}^{-1}(\Delta F)\right\}^{-1}, \qquad \text{(A5.5)}$$

where $\mathrm{ACLR}_{\mathrm{M}}(\Delta F)$ is the measured adjacent channel leakage ratio[64] of the 5 MHz WSD test signal with spectral leakage over the 200 kHz PMSE channel (see Table A5.2).

A5.27 Finally, from the definition of ACIR we have (in the linear domain),

$$\begin{aligned}\mathrm{ACIR}_{\mathrm{M}}(C,\Delta F)&=\frac{P_{\mathrm{X\,(5\,MHz)}}}{P_{\mathrm{I\,(200\,kHz)}}}=\frac{P_{\mathrm{X\,(5\,MHz)}}}{P_{\mathrm{S\,(200\,kHz)}}}\times\frac{P_{\mathrm{S\,(200\,kHz)}}}{P_{\mathrm{I\,(200\,kHz)}}}\\&=\frac{1}{r_{\mathrm{M}}(C,\Delta F)}\times\mathrm{SIR}\equiv\frac{1}{r_{\mathrm{M}}(C,\Delta F)}\times r'_{\mathrm{M}}(0)\ ,\end{aligned} \qquad \text{(A5.6)}$$

where $r_{\mathrm{M}}(C, \Delta F)$ is the measured adjacent channel protection ratio, and SIR is the signal-to-interference ratio at the point of failure. Note that $r'_{\mathrm{M}}(0)$ is the measured bandwidth adjusted co-channel protection ratio over the 200 kHz PMSE channel. We can derive its value from the measured co-channel protection ratio $r(0)$. Specifically, if P_{X} is the power of a co-channel unwanted signal over 5 MHz,

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[64] By definition, ACLR is greater than ACIR (ASC being a positive number). Occasionally, the measured test $\mathrm{ACLR}_{\mathrm{M}}$ is lower than $\mathrm{ACIR}_{\mathrm{M}}$ as derived from the measured protection ratios $r_{\mathrm{M}}(\mathrm{C}, \Delta F)$ and $r_{\mathrm{M}}(0)$. This is a result of model/measurement error and it is not possible to derive a valid ACS in such circumstances. At other times, $\mathrm{ACLR}_{\mathrm{M}}$ is too close to $\mathrm{ACIR}_{\mathrm{M}}$. This makes the derivation of ACS very sensitive to measurement errors (resulting in potentially very large/unreliable values of ACS). To mitigate this (and absent other data), one might set $\mathrm{ACLR}_{\mathrm{M\,(dB)}}$ to $\mathrm{ACIR}_{\mathrm{M\,(dB)}} + 3$. This implies that $\mathrm{ACS} = \mathrm{ACLR}_{\mathrm{M}}$. If $\mathrm{ACLR}_{\mathrm{M}}$ is in fact greater, then we will have over-estimated ACS by at most 3 dB. If $\mathrm{ACLR}_{\mathrm{M}}$ is in fact smaller, then there is a possibility that we will have hugely under-estimated ACS. The latter in unavoidable, and is precisely why it is important for the WSD test signal to have as large an ACLR as possible. The ACLR of our WiMAX test signal was large enough (through additional filtering) to avoid the above problems.

$$r'_{\mathrm{M}}(0) = \frac{P_{\mathrm{S}\,(200\,\mathrm{kHz})}}{P_{\mathrm{X}\,(200\,\mathrm{kHz})}} \equiv \frac{P_{\mathrm{S}\,(200\,\mathrm{kHz})}}{P_{\mathrm{I}\,(200\,\mathrm{kHz})}} = \frac{P_{\mathrm{S}\,(200\,\mathrm{kHz})}}{\frac{0.2}{5}P_{\mathrm{X}\,(5\,\mathrm{MHz})}} = \frac{5}{0.2}\frac{P_{\mathrm{S}\,(200\,\mathrm{kHz})}}{P_{\mathrm{X}\,(5\,\mathrm{MHz})}} = \frac{5}{0.2}r_{\mathrm{M}}(0). \tag{A5.7}$$

A5.28 Combining Equations (A5.5) to (A5.7) we have

$$\mathrm{ACS}(C,\Delta F) = \left\{\frac{0.2}{5}\frac{r_{\mathrm{M}}(C,\Delta F)}{r_{\mathrm{M}}(0)} - \mathrm{ACLR}_{\mathrm{M}}^{-1}(\Delta F)\right\}^{-1}. \tag{A5.8}$$

A5.29 Table A5.5 shows the measured co-channel protection ratio $r_{\mathrm{M}}(0)$, and the bandwidth adjusted co-channel protection ratio $r'_{\mathrm{M}}(0)$, for the four tested PMSE receivers. Table A5.6 shows the derived values of $\mathrm{ACS}(C, \Delta F)$ for the four PMSE receivers.

Table A5.5 – Measured and bandwidth adjusted co-channel protection ratios.

Co-channel protection ratio (dB)	Wireless microphone 1	Wireless microphone 2	In-ear monitor	Programme audio link
$r(0)$	2	-6	0	4
$r'(0)$	16	8	14	18

Table A5.6 – Derived values of ACS.

ACS (C, ΔF) (dB)					
Channel separation, ΔF	Edge-to-edge frequency separation, Δf (MHz)	C = -65 dBm			C = -71.3 dBm
		Wireless microphone 1	Wireless microphone 2	IEM	Programme audio link
±1	0.2	65	64	72	72
±1	4	72	70	77	76
±2	8.2	76	74	81	83
±2	12	75	73	81	85
±3	16.2	74	76	81	83
±3	20	74	77	80	86
±4	24.2	76	68	73	87
±4	28	79	78	79	78
±5	32.2	81	81	78	-
±5	36	84	82	77	-
±10	77.4	-	86	82	-
±40	317.4	-	-	79	-

Calculating class-specific protection ratios

A5.30 In this subsection, we describe the calculation of protection ratios for the four tested PMSE devices, and for each of the five WSD spectrum emission classes.

A5.31 A class-specific protection ratio, $r(C, \Delta F)$, at a particular wanted signal power C, and channel separation ΔF, can be calculated by taking account of derived PMSE receiver selectivity $\mathrm{ACS}(C, \Delta F)$, and the class-specific WSD $\mathrm{ACLR}(\Delta F)$ as defined in ETSI EN 301 598.

A5.32 Note that we derive class-specific protection ratios by using the class-specific ACLR of a WSD with an in-block bandwidth of 8 MHz.

A5.33 By definition (in the linear domain),

$$\begin{aligned} r(C,\Delta F) &= \frac{P_{\mathrm{S}\,(200\ \mathrm{kHz})}}{P_{\mathrm{X}\,(8\ \mathrm{MHz})}} = \frac{P_{\mathrm{S}\,(200\ \mathrm{kHz})}}{P_{\mathrm{I}\,(200\ \mathrm{kHz})}} \times \frac{P_{\mathrm{I}\,(200\ \mathrm{kHz})}}{P_{\mathrm{X}\,(8\ \mathrm{MHz})}} \\ &= r'_{\mathrm{M}}(0) \times \frac{1}{\mathrm{ACIR}(C,\Delta F)} \\ &= r'_{\mathrm{M}}(0) \times \left(\mathrm{ACLR}^{-1}(\Delta F) + \mathrm{ACS}^{-1}(C,\Delta F) \right), \end{aligned} \tag{A5.9}$$

where P_{S} is the in-block power of the wanted signal, P_{X} is the in-block power of the unwanted signal, and P_{I} is the experienced interference power. We have used the definition of ACIR to derive the last line which describes the relationship with the class-specific ACLR, and the derived ACS. Note that $r'_{\mathrm{M}}(0)$ is the bandwidth adjusted co-channel protection ratio. We can derive its value from the measured co-channel protection ratio $r_{\mathrm{M}}(0)$ as described earlier. Specifically,

$$r'_{\mathrm{M}}(0) = \frac{5}{0.2} \times r_{\mathrm{M}}(0). \tag{A5.10}$$

A5.34 So class-specific protection ratios can be calculated via Equation (A5.9) from the measured co-channel protection ratio, the measured ACS, and the WSD class-specific ACLR.

A5.35 Recall that by definition

$$\mathrm{ACLR} = \frac{P_{\mathrm{IB}\,(8\,\mathrm{MHz})}}{P_{\mathrm{OOB}\,(200\,\mathrm{kHz})}} = \frac{P_{\mathrm{IB}\,(8\,\mathrm{MHz})}}{2\,P_{\mathrm{OOB}\,(100\,\mathrm{kHz})}} = \frac{1}{2}\mathrm{AFLR} \tag{A5.11}$$

where AFLR for different WSD classes is defined in EN301 598 (see Section 2). In other words,

$$\mathrm{ACLR}_{(\mathrm{dB})} = \mathrm{AFLR}_{(\mathrm{dB})} - 3. \tag{A5.12}$$

A5.36 Table A5.7 shows the values of $\mathrm{ACLR}(\Delta F)$ for the five WSD spectrum emission classes. For channel separations $\Delta F = \pm 1$, ± 2 and ± 3, the values of $\mathrm{ACLR}(\Delta F)$ are as defined in EN 301 598 (for greater channel separations the limits in EN 301 598 remain at their values for $\Delta F = \pm 3$). To account for practical spectrum masks, we have assumed a roll off (increase in ACLR) of 10 dB per 8 MHz for $|\Delta F| > 3$.

A5.37 Tables A5.8 to A5.11 show the calculated values of $r(C, \Delta F)$ as described in Equation A5.9.

Table A5.7 – Class-specific ACLRs.

ACLR(ΔF)	WSD spectrum emission class				
Channel separation, ΔF	Class 1	Class 2	Class 3	Class 4	Class 5
±1	71	71	61	51	40
±2	76	71	71	61	50
±3	81	71	81	71	61
± 4	91	81	91	81	71
± 5	101	91	101	91	81
± 6	111	101	111	101	91
± 7	121	111	121	111	101
± 8	131	121	131	121	111
± 9	141	131	141	131	121
± 10	151	141	151	141	131

Table A5.8 – Class-specific protection ratios (wireless microphone 1).

$r(C,\Delta F)$, C = -65 dBm		Wireless microphones 1				
Channel separation, ΔF	Edge-to-edge separation, Δf (MHz)	WSD class 1	WSD class 2	WSD class 3	WSD class 4	WSD class 5
±1	0.2	-55	-55	-52	-43	-32
±1	4	-60	-60	-53	-43	-32
±2	8.2	-64	-62	-62	-53	-42
±2	12	-64	-62	-62	-53	-42
±3	16.2	-67	-62	-67	-62	-53
±3	20	-68	-62	-68	-62	-53
±4	24.2	-60	-60	-60	-60	-58
±4	28	-70	-69	-70	-69	-63
±5	32.2	-73	-73	-73	-73	-70
±5	36	-74	-74	-74	-74	-71
±10	77.4	-78	-78	-78	-78	-78
±40	317.4	-	-	-	-	-

Table A5.9 – Class-specific protection ratios (wireless microphone 2).

$r(C,\Delta F)$, C = -65 dBm		Wireless microphones 2				
Channel separation, ΔF	Edge-to-edge separation, Δf (MHz)	WSD class 1	WSD class 2	WSD class 3	WSD class 4	WSD class 5
±1	0.2	-48	-48	-44	-35	-25
±1	4	-53	-53	-45	-36	-25
±2	8.2	-57	-54	-54	-45	-35
±2	12	-57	-54	-54	-45	-35
±3	16.2	-57	-54	-57	-54	-45
±3	20	-58	-54	-58	-54	-45
±4	24.2	-61	-60	-61	-60	-54
±4	28	-63	-61	-63	-61	-55
±5	32.2	-66	-65	-66	-65	-63
±5	36	-68	-68	-68	-68	-64
±10	77.4	-	-	-	-	-
±40	317.4	-	-	-	-	-

Table A5.10 – Class-specific protection ratios (programme audio link).

$r(C,\Delta F)$, C = -65 dBm		Programme audio link				
Channel separation, ΔF	Edge-to-edge separation, Δf (MHz)	WSD class 1	WSD class 2	WSD class 3	WSD class 4	WSD class 5
±1	0.2	-50	-50	-43	-33	-22
±1	4	-52	-52	-43	-33	-22
±2	8.2	-57	-53	-53	-43	-32
±2	12	-57	-53	-53	-43	-32
±3	16.2	-61	-53	-61	-53	-43
±3	20	-62	-53	-62	-53	-43
±4	24.2	-67	-62	-67	-62	-53
±4	28	-60	-58	-60	-58	-52
±5	32.2	-	-	-	-	-
±5	36	-	-	-	-	-
±10	77.4	-	-	-	-	-
±40	317.4	-	-	-	-	-

Table A5.11 – Class-specific protection ratios (in-ear monitor).

$r(C,\Delta F)$, C = -71.3 dBm		In-ear monitor (IEM)				
Channel separation, ΔF	Edge-to-edge separation, Δf (MHz)	WSD class 1	WSD class 2	WSD class 3	WSD class 4	WSD class 5
±1	0.2	-55	-55	-47	-37	-26
±1	4	-56	-56	-47	-37	-26
±2	8.2	-61	-57	-57	-47	-36
±2	12	-61	-57	-57	-47	-36
±3	16.2	-64	-57	-64	-57	-47
±3	20	-64	-57	-64	-57	-47
±4	24.2	-60	-59	-60	-59	-55
±4	28	-65	-63	-65	-63	-57
±5	32.2	-64	-64	-64	-64	-62
±5	36	-63	-63	-63	-63	-62
±10	77.4	-68	-68	-68	-68	-68
±40	317.4	-63	-57	-63	-57	-47