Access to white spaces in the UHF band: Protection of digital terrestrial television and calculation of TV white space availability

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20 October 2011

(last modified 20 July 2012)

Outline

Introduction

- In this discussion document we describe our approach for calculating the amount of available white space radio resource in the UHF TV band[1]; also known as TV white space (TVWS).
- We quantify TVWS availability as the location-specific maximum permitted EIRPs for white space devices (WSDs) radiating in any particular TV channel, subject to the protection of the digital terrestrial TV (DTT) services[2] in the UK. The amount of TVWS availability will be calculated by Ofcom, and shared with white space database (WSDB) providers, who in turn relay this information to WSDs.
- We begin in Section (2), with a description of the eco-system of the database-assisted framework for access to TVWSs. This includes a description of the data exchange between Ofcom, WSDB providers, communications providers (CPs), and WSDs.
- In Section (3), we present a high-level description of our approach for the calculation of TVWS availability, subject to the appropriate protection of the DTT service.
- In Section (4), we describe the various heuristic rules which we have defined in order to characterise WSD-TV geometries, given the uncertainties in the locations of both the WSD interferers and the victim DTT receivers.

1 For the purposes of this document, this is defined as the frequency band 470 – 790 MHz (channels 21-60), but excluding 606 – 614 MHz (channel 38). Channels 31-37 comprise the so-called 600 MHz band, and have been cleared in the UK. The use of the 600 MHz band is the subject of a current Ofcom consultation. Channel 38 is used for shared (uncoordinated) licensed programme making and special events (PMSE) usage in the UK.

2 Protection of PMSE is addressed in a separate document.

Introduction

- In Section (5), we describe the approach used in the planning of the DTT network in the UK, and define our criteria for the protection of the DTT service. We then present detailed algorithms for the calculation of a) the maximum permitted WSD EIRP originating from any given pixel and in any DTT channel, and b) the maximum permitted interferer power received at any given pixel and in any DTT channel.

- Default parameter values are presented in Section (6).

Outline

Overview

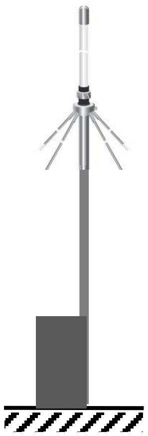
- In this section, we describe the interactions among the various entities involved in the UK framework for access to TVWS spectrum; namely Ofcom, WSDBs, and WSDs.
- We first define *vanilla* and *enhanced* TVWS availability, and describe the roles played by Ofcom and WSDBs with regards to their calculation.
- We then briefly describe the requirement for WSDs to discover Ofcom-approved WSDBs, and summarise the requirements for communications between WSDs and discovered WSDBs. For further details, see *“Regulatory requirements for white space devices in the UHF TV band,” Ofcom, 4 July 2012.*

Definitions

- In defining TVWS availability, we identify two flavours:
  - Vanilla — The term *vanilla* refers to TVWS availability calculations that are based on *default* (cautious) WSD antenna characteristics.
  - Enhanced — The term *enhanced* refers to TVWS availability calculations that are based on specific WSD antenna characteristics, either reported automatically by a WSD, or reported by a communications provider.
- Examples of WSD antenna characteristics include:
  - longitude and lattitude[1],
  - directional antenna pattern,
  - pointing angle,
  - height,
  - polarization,
  - position (indoor/outdoor).

Omni-directional

Omni-directional



Directional

[1] For the case of slave WSDs, the reporting of longitude and latitude coordinates is optional. For the case of master WSDs, the reporting of longitude and latitude coordinates is mandatory, and will therefore be incorporated in the vanilla TVWS availability calculations.

Ofcom calculation of TVWS availability

- In the UK framework, Ofcom will calculate the amount of vanilla TVWS availability, and will forward this information to WSDB providers. We believe that this is the most appropriate approach for the following two reasons:
  - The output of the DTT UK planning model (UKPM) is essential for characterising DTT coverage, and hence, for the calculation of TVWS availability. However, there exist commercial obstacles in making the output of the UKPM available to WSDB providers. Resolving these obstacles can result in long delays in enabling access to TVWSs.
  - We have concerns with regards to the ability of WSDB providers to (at least in the short term) accurately and consistently calculate TVWS availability for the protection of DTT. We have a preference for a unique set of calculations, under the control of Ofcom[1,2].
- It is possible that with the passage of time — and with growing confidence in the ability of WSDBs to mitigate interference to the DTT service — the task of calculating TVWS availability might eventually be delegated to the WSDB providers.
- Enhanced TVWS availability can, however, be calculated by WSDB providers. As will be seen in later sections, these calculations are relatively simple and do not require explicit access to the output of the UKPM. The calculations may be offered by WSDBs as a value-added service.

1 We acknowledge that in the US the calculation of TVWS availability is performed by the WSDB providers. However, we note that the calculations proposed by Ofcom are more involved than those defined by the FCC, and require detailed knowledge of the DPP planning, including the effects of DTT self-interference, TV aerial pointing options (known as digital preferred service area (DPSA) layers), and incoming cross-border interference.

2 We note that the calculation of TVWS availability for the protection of PMSE is simpler than that for the protection of DTT. It is plausible that this could be performed by WSDB providers rather than Ofcom.

Output of Ofcom calculations

- The output of Ofcom's TVWS calculations (forwarded to WSDBs) will include the following for each pixel in the UK:

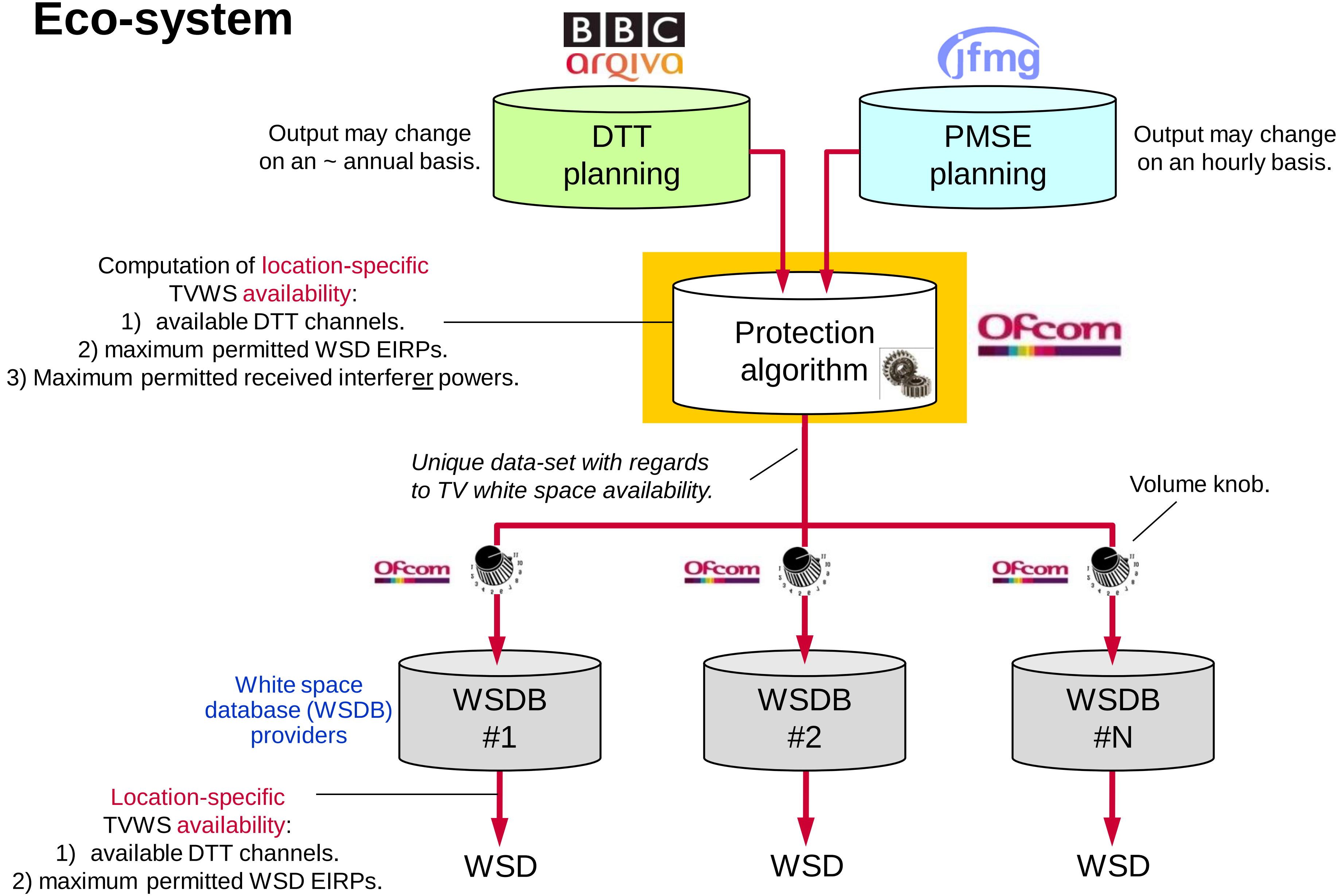
  a) A list of available DTT channels.
  b) Maximum permitted WSD EIRP in each channel (vanilla calculations).
  c) Maximum permitted received WSD interferer power from each channel (agnostic of WSD antenna parameters).

- WSDBs can relay (a) and (b) to those WSDs which do not report any information regarding their antenna characteristics. This represents vanilla TVWS availability.

- WSDBs can use (a) and (c), in conjunction with any reported WSD antenna characteristics, to calculate[1] increased maximum permitted WSD EIRPs in each channel, and relay these to the relevant WSDs. This represents enhanced TVWS availability.

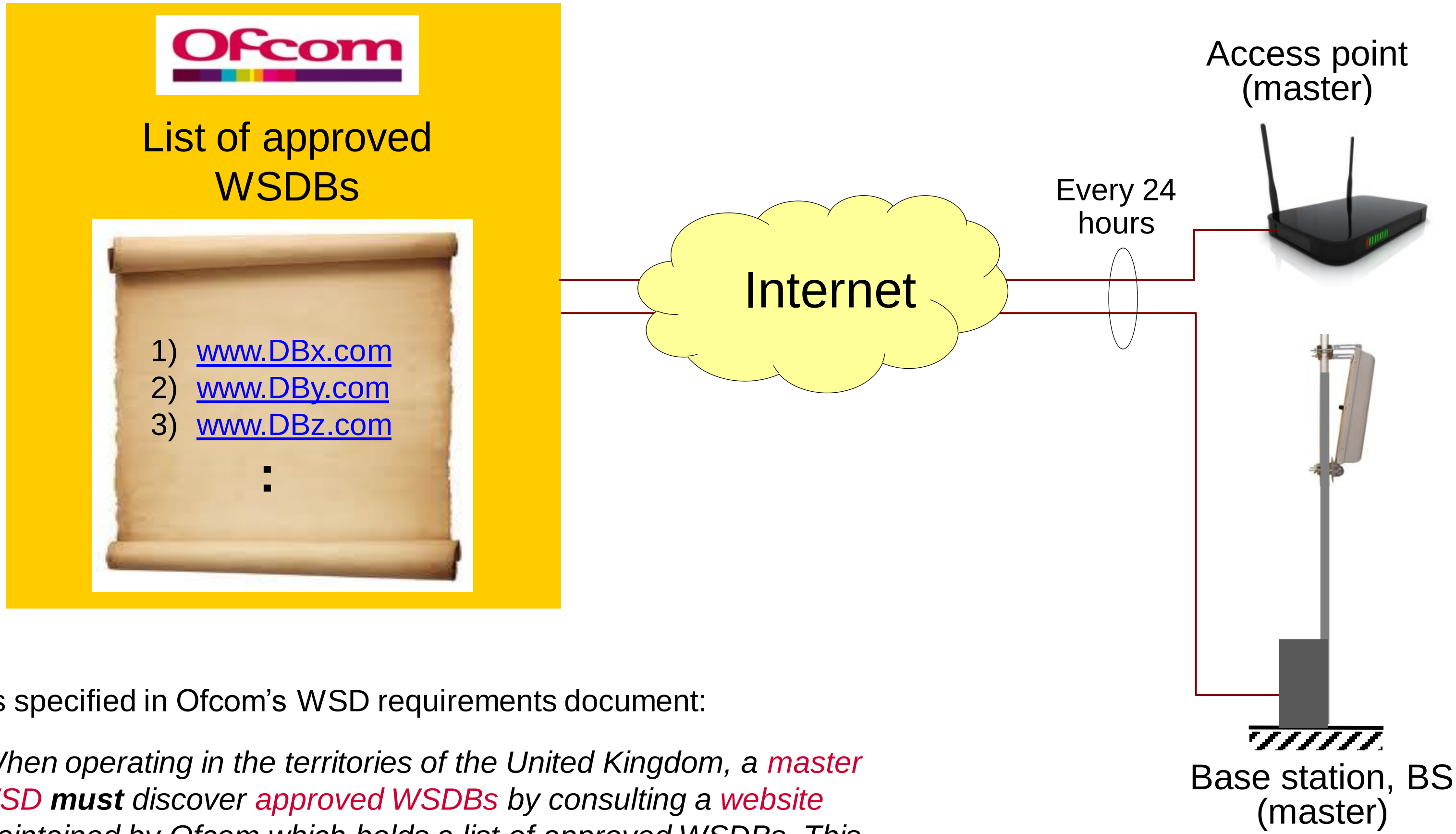
[1] See also Section (5.3).

Eco-system



BBC arqiva
jfmg
Output may change on an ~ annual basis.
DTT planning
PMSE planning
Output may change on an hourly basis.
Computation of location-specific TVWS availability:
1) available DTT channels.
2) maximum permitted WSD EIRPs.
3) Maximum permitted received interferer powers.
Protection algorithm
Ofcom
Unique data-set with regards to TV white space availability.
Volume knob.
Ofcom
Ofcom
Ofcom
White space database (WSDB) providers
WSDB #1
WSDB #2
WSDB #N
Location-specific TVWS availability:
1) available DTT channels.
2) maximum permitted WSD EIRPs.
WSD
WSD
WSD

Database "discovery"



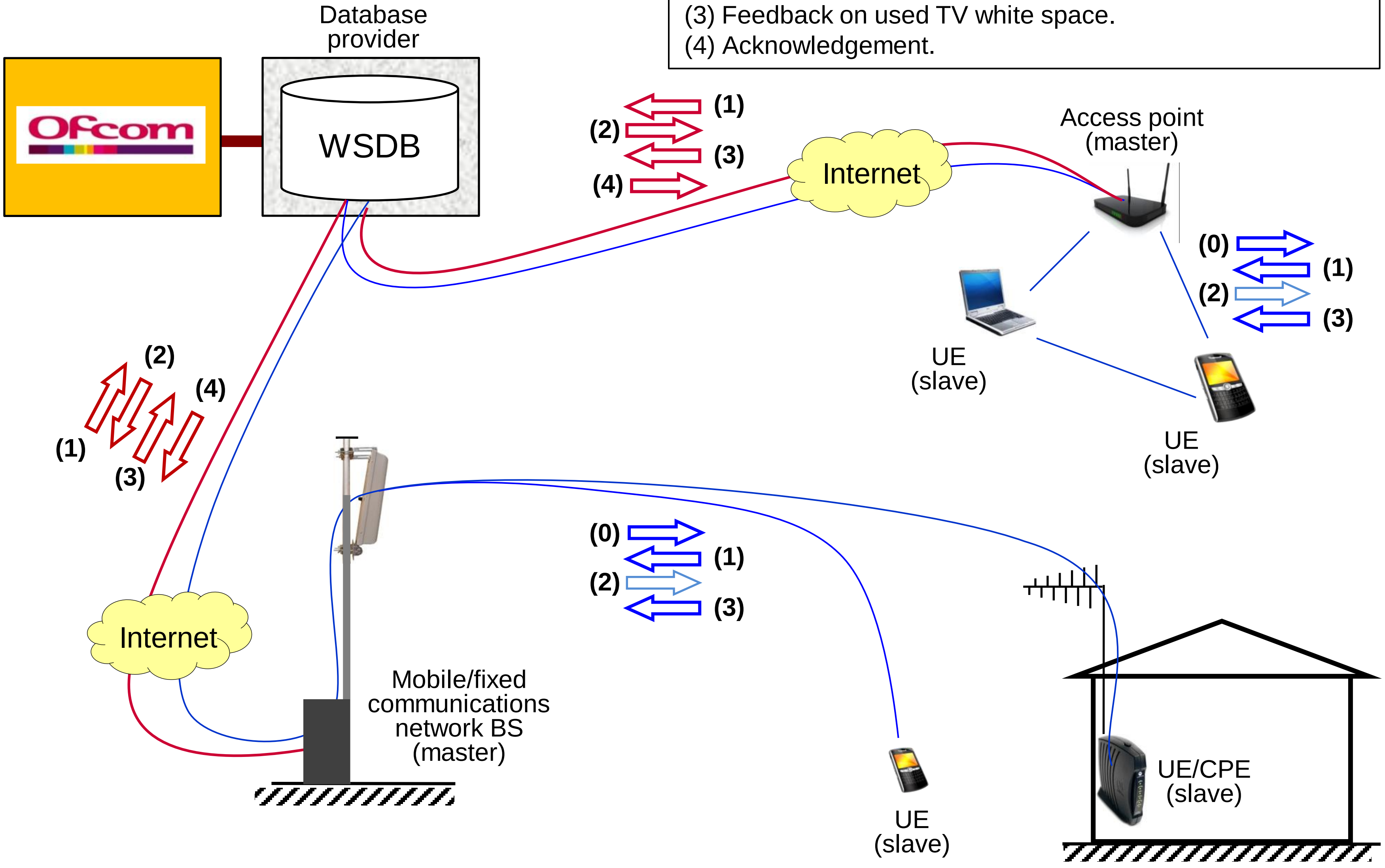
- As specified in Ofcom's WSD requirements document:

  "*When operating in the territories of the United Kingdom, a master WSD* ***must*** *discover approved WSDBs by consulting a website maintained by Ofcom which holds a list of approved WSDBs. This requirement applies unless the master WSD has consulted the website within the last 24 hours.*"

- White space databases which fail to comply with Ofcom's requirements will be removed from the Ofcom list.

Data exchange

(0) Broadcast info on TV white space availability.
(1) Report device attributes (e.g., location, device class).
(2) Communicate device-specific TV white space availability.
(3) Feedback on used TV white space.
(4) Acknowledgement.



Data transfer between WSDs and WSDB

<u>(1) Master to database</u>

- Mandatory: Device ID, device class. technology ID.
- Mandatory: Antenna coordinates (x, y).
- Optional[1]: Antenna height.
- Optional: (Fixed) antenna angular discrimination.
- Optional: (Fixed) antenna polarisation.
- Optional: (Fixed) antenna indoor/outdoor.

<u>(2) Database to master</u>

- Channel/power pairs: $(f_i, P_i)_1$.
- Time validity.

<u>(3) Master to database</u>

- Used channel/power pairs: $(f_i, P_i)_2$.

<u>(4) Acknowledgement</u>

- Acknowledgement of receipt of information on used channel/power pairs.

<u>(0) Slave to master ($\rightarrow$ database)</u>

- Channel/power pairs: $(f_i, P_i)_3$.
- Time validity.

<u>(1) Slave to master ($\rightarrow$ database)</u>

- Mandatory: Device ID, device class, technology ID.
- Optional: Antenna coordinates (x, y).
- Optional[1]: Antenna height.
- Optional[2]: (Fixed) antenna angular discrimination.
- Optional[2]: (Fixed) antenna polarisation.
- Optional[2]: (Fixed) antenna indoor/outdoor.

<u>(2) Database to master ($\rightarrow$ slave)</u>

- Channel/power pairs: $(f_i, P_i)_4$.
- Time validity.

<u>(3) Slave to master ($\rightarrow$ database)</u>

- Used frequency-power pairs: $(f_i, P_i)_5$.

[1] Mandatory (rather than optional) if the antenna coordinates of a fixed WSD are determined by a communications provider.
[2] Applies only where the latitude and longitude coordinates of a fixed slave WSD are communicated to a WSDB.

Enhanced vs. vanilla, continued…

- As seen in the previous slides, the reporting of WSD antenna characteristics is only optional. Where these characteristics are not reported, the TVWS availability for WSDs is calculated based on cautious *default* parameter values; e.g., omni-directional WSD emissions, or WSD emissions that are co-polar with the DTT signal (see other examples in Section 5). We refer to the results of these calculations as *vanilla* TVWS availability.

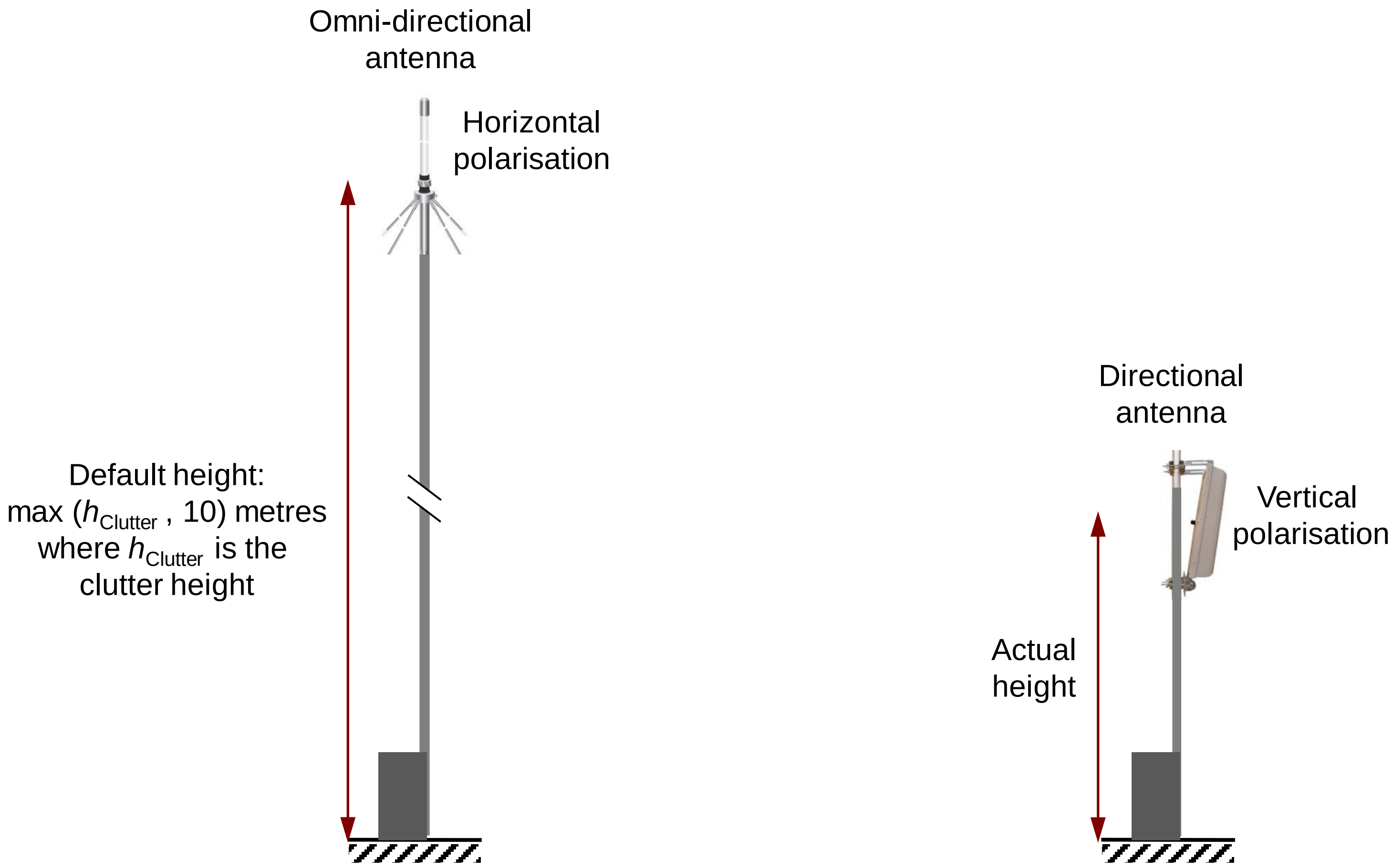
- Note that there will be a unique TVWS availability for

  - each of four device classes (corresponding to a unique spectral emission mask), and
  - each WSD technology (where technology-specific protection ratios are available).

- Where WSD antenna characteristics are reported, these can be accounted for in the calculations, resulting in what we refer to as *enhanced* TVWS availability.

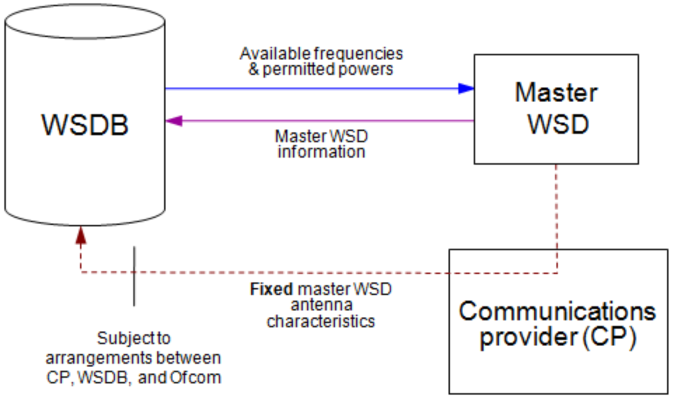
[1] Each of the four device classes that we have defined corresponds to a unique spectral emission mask.

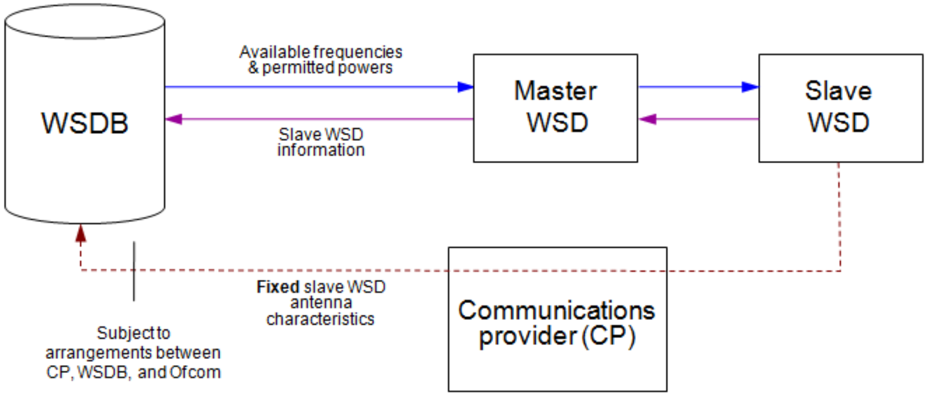
Default vs. specific antenna characteristics



Communications providers and fixed WSDs

- The WSD antenna characteristics referred to in the previous slides can be either determined automatically by the WSD, or, in special circumstances, be determined by a communications provider (CP). These special circumstances apply to fixed WSDs which, in order to benefit from enhanced TVWS availability, are geo-located by a CP (for increased geo-location accuracy), or use judicious antenna characteristics to mitigate interference to DTT and PMSE services.
- Where the WSD characteristics are determined by a CP, it is the responsibility of the CP (and not the master WSD) to communicate this information to approved WSDBs. This will be subject to special arrangements between the CP, the WSDB provider, and Ofcom.
- Information determined by a CP shall not be input into the master WSD itself. This is to mitigate the risk of inaccurate information being manually input into devices by users (whether unintentionally, or in an attempt to benefit from enhanced TVWS availability).





Outline

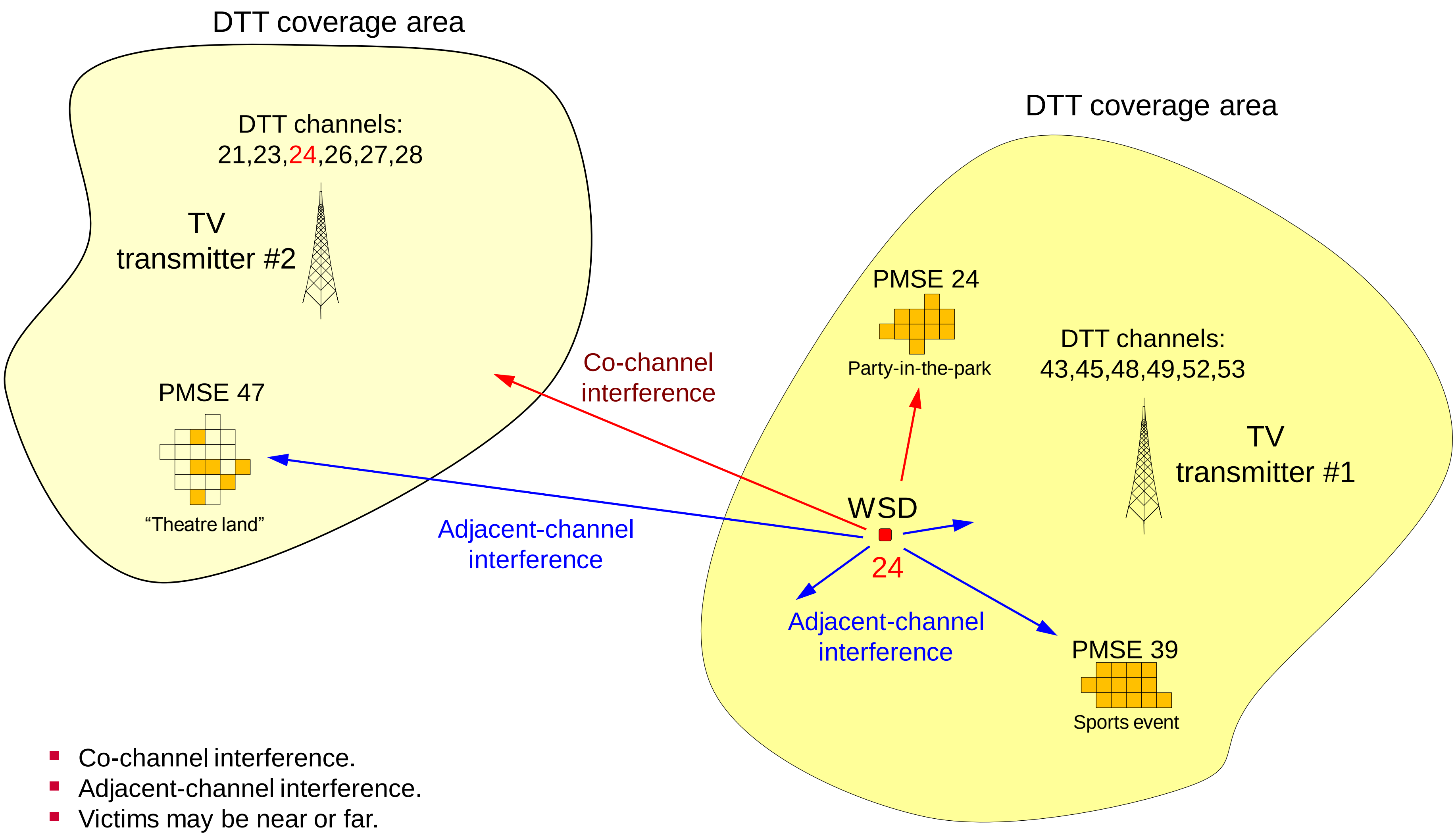
Overview

- In the FCC's approach, WSDs are allowed to radiate at up to a fixed maximum power, so long as they are located outside specific geographic exclusion zones. The exclusion zones correspond to areas where the received DTT field strength exceeds a FCC-defined value as quantified via FCC-defined propagation models.
- 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 limits on in-block EIRP are calculated by Ofcom and communicated to WSDs by the WSDBs.
- The approach permits WSDs to communicate at greater EIRPs in areas where DTT field strength is greater[1]; i.e., where DTT is more robust to interference.
- The maximum permitted in-block EIRP for a WSD to communicate in a specific channel is calculated so as to simultaneously protect DTT (and PMSE) reception in all of channels 21…30,39…60.
- In this section we formulate the approach at a high level. Details of the assumptions regarding interferer-victim geometries and the various co-existence calculations are presented in Sections (4) and (5).

[1] It should be noted that in areas where the DTT field strength is high, the white spaces are not *clean*, and the DTT signals themselves can cause interference to WSD communications.

Interference: An illustration

- Spatial resolution: 100 m × 100 m pixels.
- Frequency resolution: 8 MHz.



- Co-channel interference.
- Adjacent-channel interference.
- Victims may be near or far.

WSDB calculations: High-level

- The calculation of location-specific TVWS availability can be formulated as the following problem:

Calculate the maximum permitted EIRP, $P_{\max}(l_i,\ f_{\mathrm{WSD},n})$,
for a WSD to radiate inside a pixel of location l_i, and in DTT channel $f_{\mathrm{WSD},n}$,
while simultaneously protecting UK-wide DTT reception in all channels, $f_{\mathrm{DTT},m}\ \ m=1\ldots M$.

- The above can be solved via the following procedure:

Procedure

1) Identify all[1] K populated victim pixels which receive DTT service in channel m.

2) For each of the K interferer-victim pixel pairs, calculate[2] the maximum EIRP which a WSD may radiate subject to the protection of DTT reception in channel $f_{\mathrm{DTT},m}$. Denote these K EIRPs as $p_k(l_i, f_{\mathrm{WSD},n},\ f_{\mathrm{DTT},m})$ with $k=1\ldots K$. The smallest of these K EIRPs is then the maximum permitted WSD EIRP for the protection of DTT reception in channel $f_{\mathrm{DTT},m}$; i.e.,

$$p(l_i, f_{\mathrm{WSD},n}, f_{\mathrm{DTT},m}) = \min_k \left\{ p_k(l_i\ , f_{\mathrm{WSD},n}\ , f_{\mathrm{DTT},m}) \right\}.$$

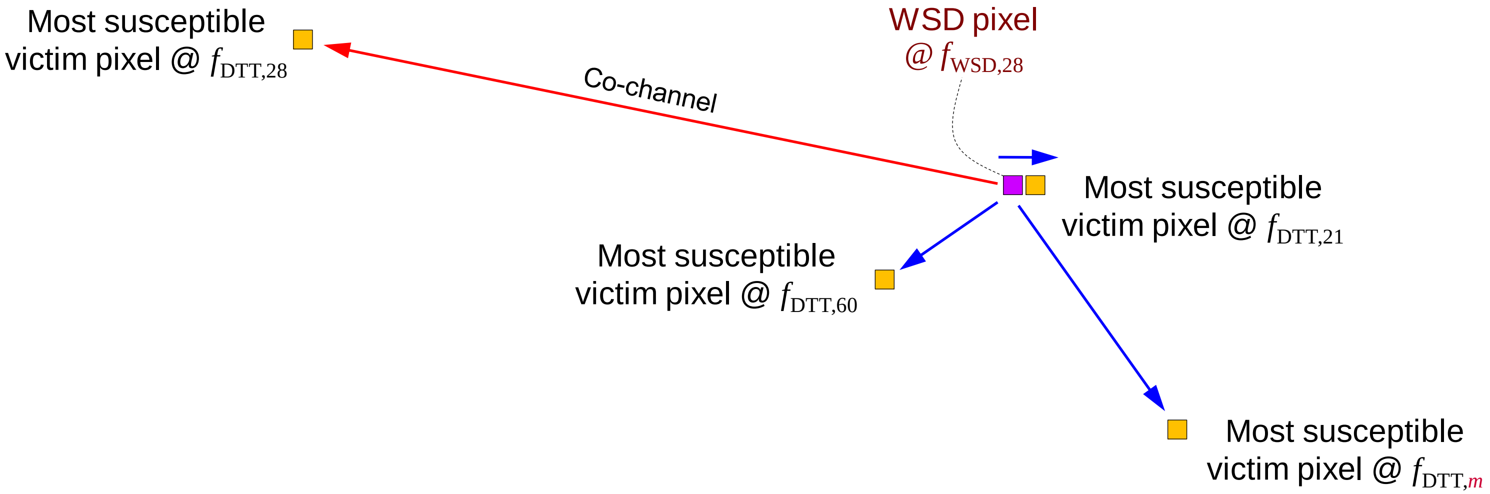
3) Repeat steps (2) and (3) for each of the DTT channels $f_{\mathrm{DTT},m}\ \ m=1\ldots M$. The smallest of these M EIRPs is then the maximum permitted WSD EIRP for the simultaneous protection of DTT reception in all channels, $f_{\mathrm{DTT},m}\ \ m=1\ldots M$; i.e.,

$$P_{\max}(l_i, f_{\mathrm{WSD},n}) = \min_m \left\{ p(l_i\ , f_{\mathrm{WSD},n}\ , f_{\mathrm{WSD},m}) \right\}.$$

1 See next slide.
2 See Section (5) for details.

Discussion

- The above algorithm quantifies TVWS availability in DTT channel $f_{\mathrm{WSD},n}$ and in a specific pixel at location l_i. For a UK-wide picture, the algorithm would need to be repeated for each DTT channel and for each pixel in the UK. The UK consists of roughly 20 million pixels.
- Note that the above algorithm need only consider victim pixels which are served by DTT. By definition, this represents pixels where the DTT location probability is 70% or greater.
- Also note that the above algorithm need only consider populated victim pixels. The logic here is that DTT reception in an unpopulated pixel need not be protected.
- Strictly speaking, steps (1) and (2) in the above algorithm need only be performed for the *most susceptible* populated victim pixel which receives DTT service in channel m (as opposed to all K populated victim pixels which receive DTT service in channel m). This would reduce computational complexity significantly.



Outline

Overview

- In this section, we address issues relating to the derivation of WSD-to-TV coupling gains.
- We first define the coupling gain and describe its importance in quantifying the impact of interference from WSDs to the DTT service.
- We then describe how the coupling gain between a WSD and a DTT receiver can be calculated and incorporated into Ofcom's calculations of TVWS availability, given the inherent uncertainties in the locations of the potential DTT receiver victims.
- We finally explain how WSDBs will need to account for the uncertainty in the reported location of WSDs, when interpreting the TVWS availability information provided by Ofcom.

Coupling gain: definition

- The coupling gain between a WSD and a DTT receiver is defined as a function of their antenna locations, antenna gains, antenna directionalities, and antenna polarisations. Specifically, the coupling gain may be written (in the linear domain) as

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

  where

$g_{\mathrm{A,WSD}}(\alpha)$	= WSD antenna angular discrimination, along the relevant *cone* angle α w.r.t. antenna boresight,
G_{Prop}	= propagation gain (path loss),
$G_{\mathrm{A,TV}}$	= TV aerial gain,
$g_{\mathrm{A,TV}}(\beta)$	= TV aerial angular discrimination, along the relevant *cone* angle β w.r.t. antenna boresight,
$g_{\mathrm{Polar,TV}}(\beta)$	= TV aerial polarisation discrimination, along the relevant *cone* angle β w.r.t. antenna boresight.

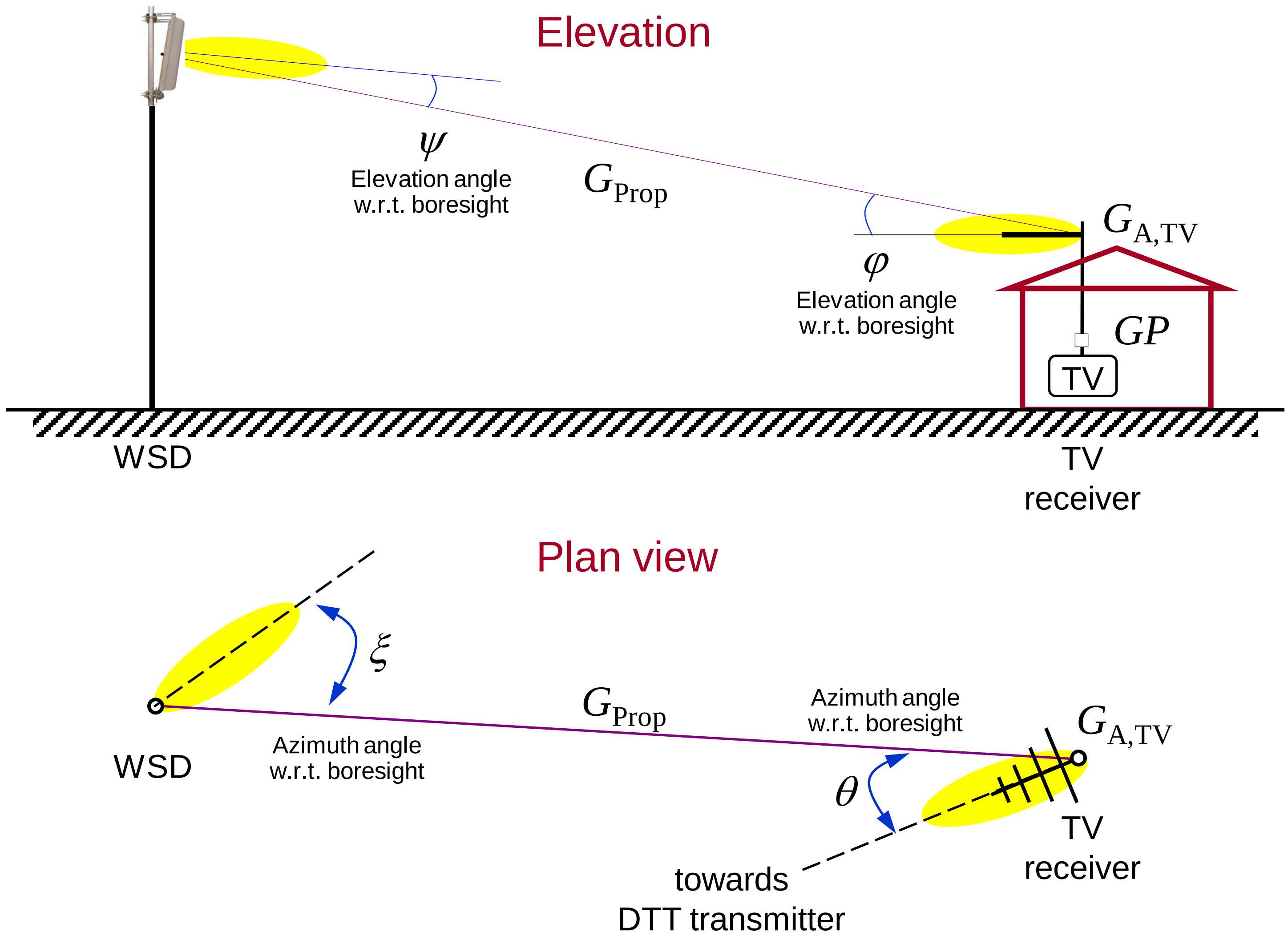
- In short, if a WSD radiates with power, P, then the power received at the input to a TV receiver is given by the product $G \times P$.

- Note that the coupling gain does not include the WSD antenna gain, since the regulations deal with radiated power rather than conducted power.

- We model coupling gain, G, as a log-normal random variable; i.e., $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$.

Coupling gain: definition

$$\cos(\alpha) = \cos(\xi)\cos(\psi)$$
$$\cos(\beta) = \cos(\theta)\cos(\varphi)$$



Outline

Problem formulation

- Even if the location of a WSD is known[1,2] precisely by a WSDB, the precise locations of the DTT receivers are typically not known.
- All that is typically known is that a specific number of households are located *somewhere* within a 100 m × 100 m pixel.
- The above uncertainty means that in most circumstances the coupling gains cannot be calculated based on actual[3] interferer-victim separations, but need to be calculated based on specific heuristic rules.
- These rules are described next, and will be used by Ofcom for the calculation of vanilla TVWS availability.

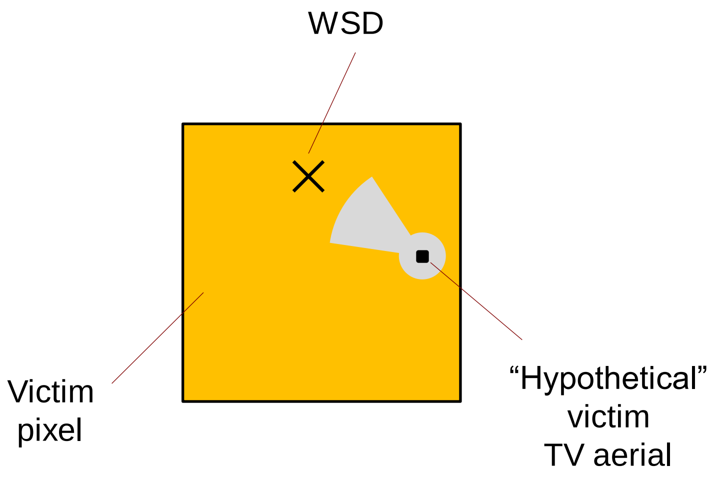
1 We will address uncertainties in WSD locations in Sections (4.2) and (4.3).
2 Either determined and reported automatically by the WSD, or determined and reported by a CP.
3 It is plausible that in some special circumstances (e.g., those involving fixed WSDs in sparsely populated areas), the location of nearby households can be determined, reported, and incorporated into the enhanced TVWS calculations performed by a WSDB.

Same-pixel
Reference geometry

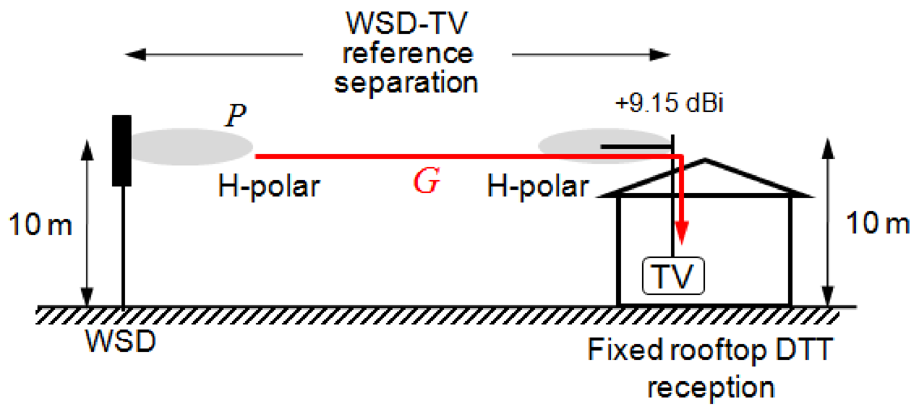
- Here, the most susceptible *victim* pixel is the same as the pixel within which the WSD is located. Given that the actual locations of the TV aerials within the most susceptible pixel are not known, we calculate the WSD-to-TV coupling gain based on a *reference geometry*.

- The figure below illustrates the *default* reference geometry for the calculation of *vanilla* TVWS availability. In short, we assume that irrespective of the actual location of the WSD, a victim TV aerial always exists at a fixed reference distance from the WSD, and points in azimuth towards the interfering WSD. In this default scenario, the interferer and victim are both assumed to be at the same height, and with similarly polarised antennas.

- The WSD-to-TV coupling gain, G, is modelled as a log-normal random variable; i.e., $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$. The proposed default median and standard deviation values are presented in Section (6). Specific WSD antenna heights (above sea level) reported automatically or by a communications provider (CP) can be incorporated by a WSDB into the reference geometries and the calculation of *enhanced* TWVS availability.



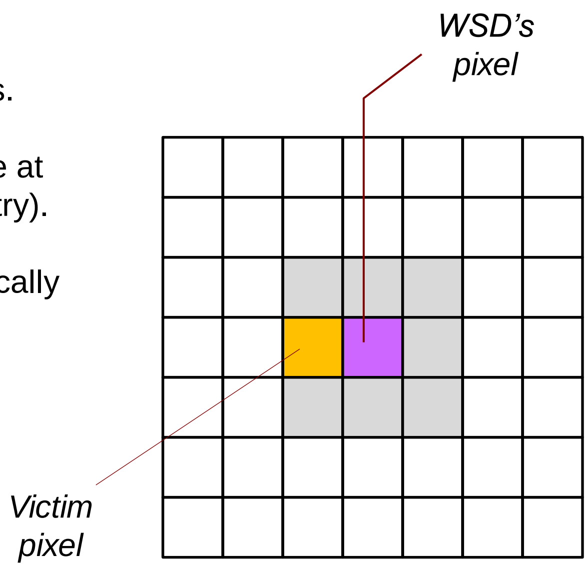
Default reference geometry



1st tier pixel

Reference geometry

- Here, the most susceptible *victim* pixel is among the 1st tier of pixels surrounding the pixel within which the WSD is located.
- Given that the actual locations of the TV aerials within the most susceptible pixel are not known, we calculate the WSD-to-TV coupling gain based on the same default reference geometry as for the same-pixel scenario. As before, G is modelled as a log-normal random variable; i.e., $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$.
- This is an over-cautious approach, because it typically under-estimates the interferer-victim separation. However, this is a pragmatic approach, and will over-estimate the WSD-to-TV coupling gain in only a relatively small proportion of pixels.
- The result can be interpreted as the introduction of a 1-pixel wide "soft buffer zone" between WSDs and potential victim TV aerials at the edge of DTT coverage.
- Unlike the case of reference geometries in "same pixel" scenarios, here we <u>can</u> account for the angular discrimination and pointing angle of the TV aerials. We explain our approach in the next slide. Note that this is limited to azimuth (horizontal) angles only, since the interferer and victim are both assumed to be at the same height in 1st tier scenarios (see same-pixel default reference geometry).
- As before, specific WSD antenna heights (above sea level) reported automatically or by a communications provider (CP) can be incorporated by a WSDB into the reference geometries and the calculation of *enhanced* TWVS availability.

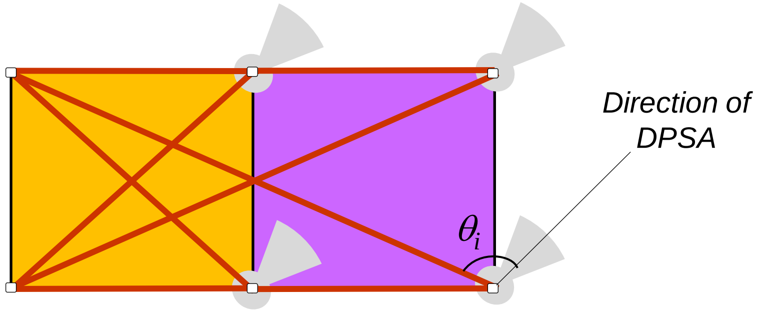


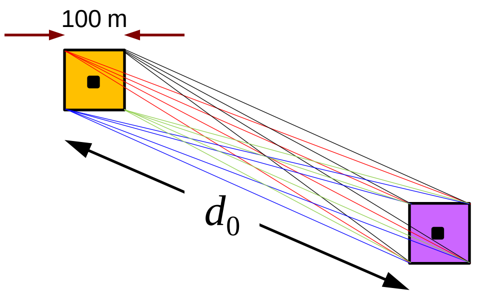
1st tier pixel
Angular discrimination

- In the case of 1st tier scenarios, we account for the horizontal angular discrimination of the TV aerials.
- Once again, given the uncertainty in the location of the victim TV aerials, we adopt a pragmatic approach. Specifically, we propose to use an approach suggested by Kostas Tsioumparakis (BBC), for the calculation of the angular discrimination. We summarise this in terms of the following steps:

1) Assume that the WSD is located at (or just inside) one of the 4 corners of its pixel.
2) Assume that the victim TV aerial is also located at (or just inside) one of the 4 corners of its pixel.
3) Assuming that the TV aerial points at the relevant DPSA-defined DTT transmitter, and based on the assumptions in steps (1) and (2), record the 16 azimuth angles, θ_i i = 1…16, of the WSD w.r.t. the TV aerial's boresight.
4) Use the ITU-R BT.419-3 pattern to calculate the corresponding 16 values, $g_{\mathrm{A,TV}}(\theta_i) \le 1$ i = 1…16, of TV aerial angular discrimination gain.
5) Select $\max_i \{g_{\mathrm{A,TV}}(\theta_i)\}$, as the prevailing TV aerial angular discrimination gain.

- The same approach can be applied to *m*th tier scenarios. As the interferer-victim separation increases, the output of steps (1-5) becomes an increasingly accurate representation of the TV aerial angular discrimination gain.



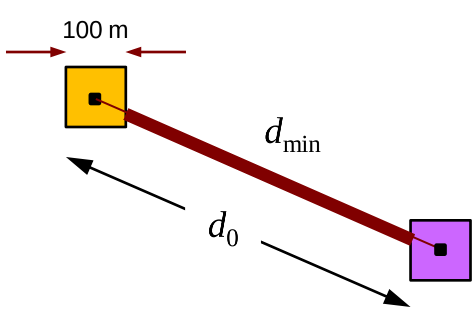


m^{th} tier pixel ($m \geq 2$)
Non-reference geometry

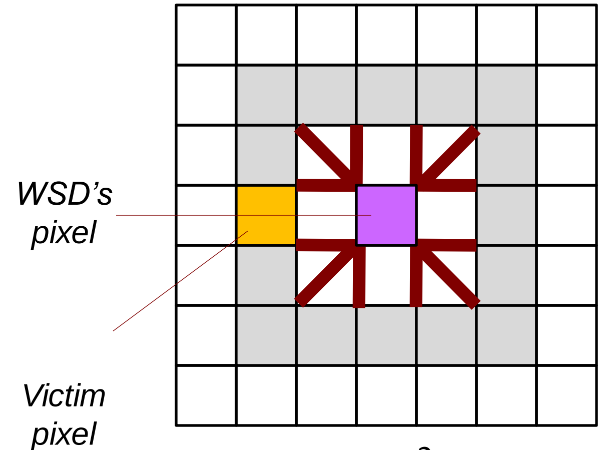
- Here, the most susceptible *victim* pixel is among the m^{th} tier ($m \geq 2$) of pixels surrounding the pixel within which the WSD is located (see figure below for $m = 2$).
- To circumvent the uncertainty in the victim's location, and adopting a cautious approach, we work based on the *minimum* possible horizontal separation, d_{min} , between the WSD antenna and the victim TV aerial. Following an approach again suggested by Kostas Tsioumparakis (BBC), We approximate this as

$$d_{\min} \approx \max\left\{ d_0 - 100\sqrt{2}, 100 \right\}$$

  where d_0 is the distance between the centres of the pixels wherein the WSD antenna and the TV aerial are located.
- This approximation under-estimates the interferer-victim separation (see thick lines in the figure for $m = 2$). However, the approximation error increasingly reduces (as a fraction of d_0) as we move to the higher-order tiers (i.e., as m increases).



$m >> 2$



$m = 2$

m^{th} tier pixel ($m \geq 2$)
Non-reference geometry

- The WSD-to-TV coupling gain, G, is modelled as a log-normal random variable; i.e., $G_{(\text{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$. See also Section (6) for further description of the parameter values.

- The median m_G will incorporate the Extended Hata model for median propagation gain, m_{Prop}, as a function of horizontal separation, $d_{\min}$, and the heights (above sea leve) of the WSD and TV aerials. Depending on the clutter characteristics of the victim pixel, the urban or suburban profiles of the extended Hata model will be used.

- The height, h_{WSD}, of the WSD will be accounted for in the default non-reference geometries. Specifically, we will use the default value

$$h_{\text{WSD}} = \max(h_{\text{Clutter}}, 10) \quad \text{metres}$$

  where h_{Clutter} is the clutter height (in metres) in the WSD's pixel.

- Specific WSD antenna heights (above seal level) reported automatically or by a communications provider (CP) can be incorporated by a WSDB into the non-reference geometries and the calculation of enhanced TWVS availability.

- Terrain data <u>will not</u> be included in the calculations of vanilla TVWS availability. This is due to the excessive complexity involved in computing and storing terrain propagation gains for all[1] interferer-victim pixel pairs in the UK. However, terrain data can be incorporated by a WSDB into its calculations of enhanced TVWS availability.

[1] We are considering the possibility of using terrain data at a low spatial resolution (e.g., 1 km x 1 km) as a means of reducing the computational and storage requirements.

Outline

Location uncertainty: Master

- In the previous section we examined the heuristic rules which will be used by Ofcom to circumvent issues caused by the uncertainty in the location of the victim TV receivers. Here, we address rules to circumvent issues caused by the uncertainty in the location of the master WSD. These rules are for use by WSDBs.

Zero uncertainty

- In some cases, the location uncertainty reported by the master WSD is nominally zero. This might be the case, for example, where the master WSD is a fixed installation, and it is geo-located by a CP.
- In such cases, the master WSD would be associated with the pixel within whose boundaries the WSD is located.
- Given that the location of the master WSD is known, it is possible to calculate the relevant WSD-to-TV coupling gains[1], and so derive the corresponding maximum permitted WSD EIRP. WSDBs need take no further action.

[1] See previous section on how to deal with the uncertainty in victim locations.

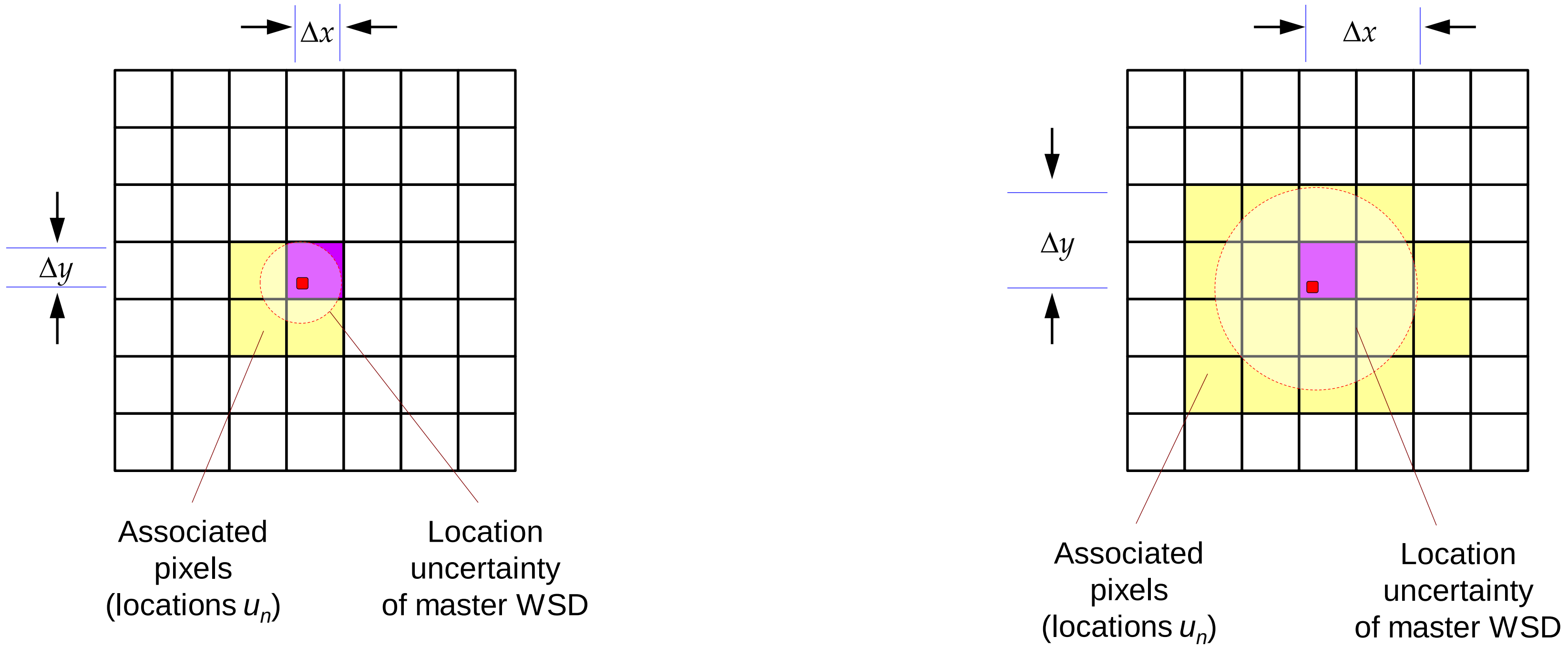
Location uncertainty: Master

Non-zero uncertainty

- In some cases, the location uncertainty reported by the master WSD is non-zero. This might be the case, for example, where the master WSD is portable/mobile and/or indoor[1].
- To account for the uncertainty in location, the WSDB will 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 (as identified by the reported location uncertainty).
- Specifically, if the location uncertainty extends over a N surrounding pixels, then the master WSD will be associated with (assumed to be located within) those same N pixels. See illustrations in the next slide.

[1] Here the location of the master WSD is not fixed. Therefore, the master WSD has to estimate its location via technologies such as GPS, with inevitable geo-location inaccuracies as a function of local clutter and obstacles.

Examples: Pixels associated with master WSD



- Assume that in the calculations the WSDB associates a master WSD with N pixels, where the nominal pixel locations are $u_n \;\; n = 1 \ldots N$.

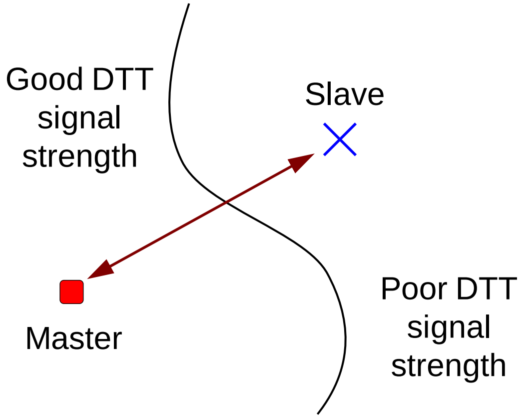
- Ofcom will have pre-computed the maximum permitted WSD EIRP, $P(u_n)$, assuming that the master WSD is located within the i^{th} pixel, and using the reference and non-reference geometries outlined in Section (4.1). The maximum permitted in-block EIRP for the master WSD is then derived by a WSDB as the smallest of the N calculated values; i.e.,

$$P_{\max} = \min_n P(u_n).$$

Outline

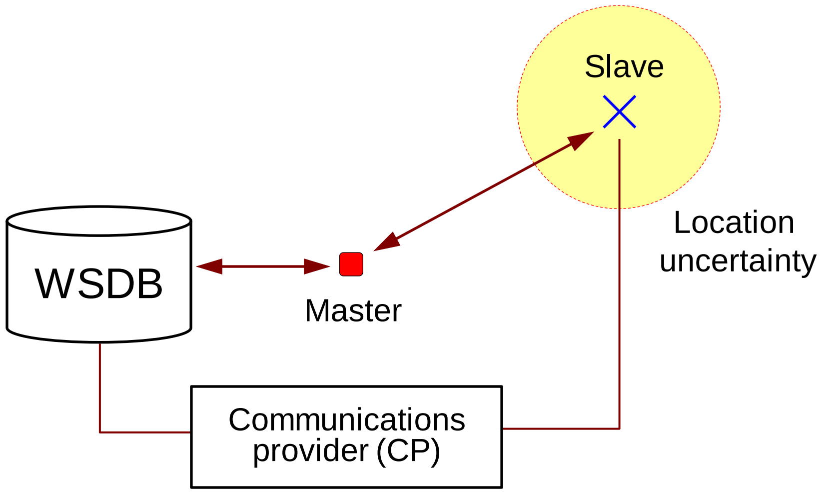
Location uncertainty: Slave

- The location of a slave WSD may be significantly different from the location of its serving master WSD(s).
- 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.
- In any case, in order to calculate the TVWS available for a slave WSD, we reuiqre some indication of the range of pixels wherein the slave WSD might be located; i.e., the slave's location and location uncertainty.
- We can then compute the maximum permitted slave WSD EIRP in the same manner as for the master WSD (see Section 4.2).
- Question: How can we know the location and location uncertainty of a slave WSD?
- A number of possibilities are described next.



Scenario 1: Slave is geolocated

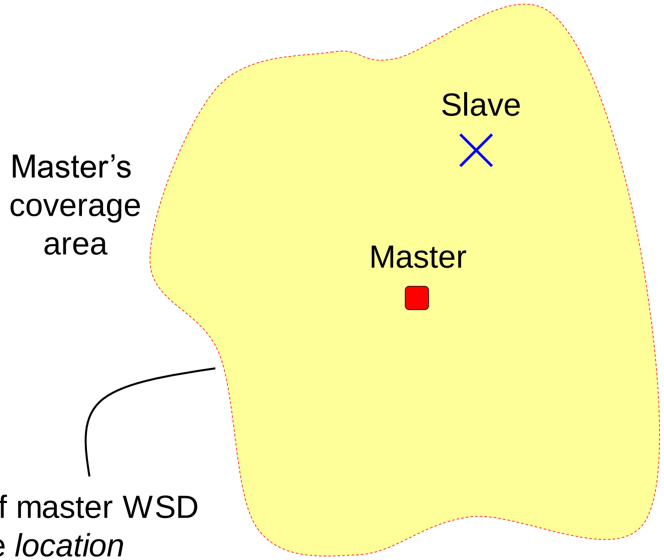
- Assume that the master WSD (or a CP) reports to a WSDB the location and location uncertainty of a served slave WSD; i.e., the slave WSD is geo-located. Note that slave geo-location is optional (see Section 3).
- Here, the maximum permitted slave EIRP is calculated precisely in the same way as it is for a master WSD. See Section (4.2).



Scenario 2: Slave is not geolocated

WSDB calculates coverage area

- The WSDB calculates the coverage area of a master WSD; i.e., the area within which the master WSD can communicate with a slave WSD.
- The WSDB uses a nominal value for the slave WSD minimum sensitivity. This will be based on the technology ID of the slave WSD, which must be reported to the relevant WSDB.
- The WSDB uses this to calculate a nominal coverage area of a master WSD, based on an algorithm specified by Ofcom. This is effectively a link-budget calculation.
- The calculated coverage area of the master WSD is then a proxy for the location uncertainty of the slave WSD.
- The maximum permitted slave EIRP is then calculated in precisely the same way as for a master WSD. See Section (4.2).



The coverage area of master WSD is effectively the *location uncertainty* of the slave WSD.

Summary and conclusions

- The calculation of the coupling gain between WSDs and DTT receivers is a key element in quantifying the impact of interference on DTT reception, and hence the location-specific TVWS availability.
- The coupling gain is a function of radio propagation, WSD antenna directionality, TV aerial gain, TV aerial directionality, and TV aerial polarisation (w.r.t. the polarisation of the WSD signal). The coupling gain is uniquely defined by the geometry between the WSD interferer and a victim TV aerial.
- In this section we addressed the following two issues:
  - We first explained how appropriate default reference and non-reference geometries can be constructed and incorporated into Ofcom's calculations of vanilla TVWS availability (co-existence calculations), taking into account the inherent uncertainty in the locations of the potential victim TV aerials.
  - We then explained how a WSDB provider can account for the uncertainty in the locations of master and slave WSDs, by associating each device with multiple pixels.
- Provisional technical parameter values with respect to the constructed geometries are outlined in Section (6).

Outline

1. Introduction
2. Database-assisted access: eco-system
3. High-level approach
4. Geometries & coupling gains
5. Calculations
6. Default parameter values
7. Conclusions

Annex (for information)

Overview

- In this section we address issues relating to the various calculations which Ofcom and WSDBs will need to perform in the calculation of vanilla and enhanced TVWS availability, respectively.
- We first discuss DTT location probability as a suitable metric for quantifying the impact of interference from WSDs to the DTT service.
- We then present an iterative algorithm for the calculation of the maximum permitted WSD in-block EIRP originating from any given pixel and in any DTT channel. These relate to the calculation of *vanilla* TVWS availability by Ofcom.
- We finally present an iterative algorithm for the calculation of the maximum permitted interferer power received at any given pixel and in any DTT channel. These are again calculated by Ofcom, and can be used by WSDBs for the calculation of *enhanced* TVWS availability.

Outline

DTT planning in the UK

- Location probability is widely used in the planning of DTT networks in order to quantify the quality of coverage, and in the UK this is calculated for every 100 m × 100 m pixel across the country. 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.

- 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.

- 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)

$$q_1 = \Pr\left\{ P_S \geq P_{S,\min} + \sum_{k=1}^{K} r_{U,k} P_{U,k} \right\} = \Pr\left\{ P_S \geq P_{S,\min} + V \right\} = \Pr\{ P_S \geq U \}$$

  where $\Pr\{A\}$ is the probability of event A, P_S is the received power of the wanted DTT signal, $P_{S,\min}$ is the DTT receiver's (noise-limited) reference sensitivity level[1], $P_{U,k}$ is the received power of the k^{th} unwanted DTT signal, and $r_{U,k}$ is the DTT-to-DTT protection ratio (co-channel or adjacent-channel) for the k^{th} DTT interferer.

- The powers P_S and $P_{U,k}$ are typically modelled as log-normal random variables. It is well-known that the sum of a moderate number of log-normal random variables is well approximated by another log-normal distribution. For this reason, V can also be modelled as a log-normal random variable.

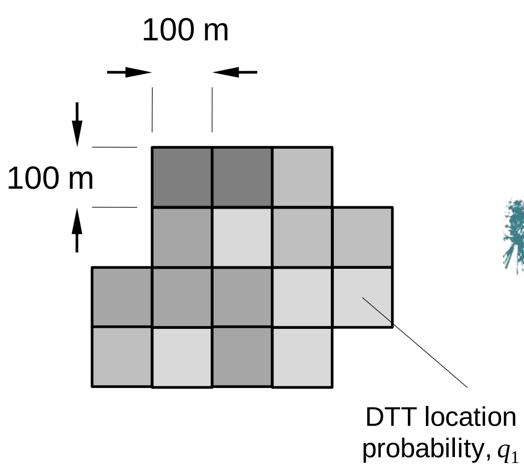
1 The reference sensitivity level of a receiver is the minimum wanted signal power for which the receiver can operate correctly in a noise-limited environment.

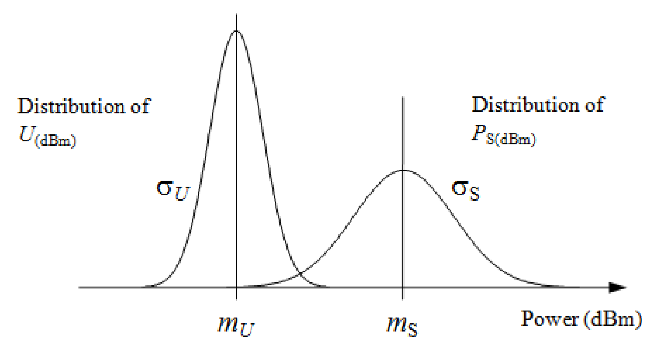
The UK planning model (UKPM)

- The planning tool developed by the UK broadcasters is referred to as the UK planning model (UKPM). This tool models both P_S and U as log-normal random variables[1], i.e., $P_{S\,(\text{dBm})} \sim \mathrm{N}(m_S, \sigma_S^2)$ and $U_{(\text{dBm})} \sim \mathrm{N}(m_U, \sigma_U^2)$, for each pixel in the UK. Then, naturally,

$$q_1 = \Pr\{P_S \geq U\} = \Pr\left\{\frac{P_S}{U} \geq 1\right\} = \Pr\left\{P_{S\,(\text{dBm})} - U_{(\text{dBm})} \geq 0\right\} = 1 - \frac{1}{2}\operatorname{erfc}\left\{\frac{1}{\sqrt{2}} \frac{m_S - m_U}{\sqrt{\sigma_S^2 + \sigma_U^2}}\right\}.$$

- 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. Location probability is a useful tool for assessing the impact of interference. This is because it can be explicitly related to the number of households served in the UK[2].





[1] The modelling of U as a log-normal random variable is a common and pragmatic approach, but is nevertheless, an approximation. See Annex I for an alternative formulation which avoids such modelling (for information only).

[2] In the past, we have also used location probability in assessing the impact of interference from mobile communication networks in the 800 MHz band (digital dividend) to DTT reception.

What happens when a WSD radiates?

- Consider a WSD which operates at a carrier frequency $f_{\mathrm{WSD}} = f_{\mathrm{DTT}} + \Delta f$, where f_{DTT} is the DTT carrier frequency. For the special case of co-channel operation with DTT, $\Delta f = 0$. Also assume that the WSD radiates with an *in-block*[1] EIRP of P_{IB} over a channel bandwidth of 8 MHz. The presence of the WSD interferer inevitably reduces the DTT location probability from q_1 to q_2. Assuming a coupling gain, G, between the WSD and the DTT receiver, the WSD interferer power at the DTT receiver is given by the product GP_{IB}. Following the framework described earlier, we may write (again in the linear domain)

$$q_2 = q_1 - \Delta q = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k} P_{U,k} + r(\Delta f, m_{\mathrm{S}})\, G\, P_{\mathrm{IB}} \right\} = \Pr\left\{ P_{\mathrm{S}} \geq U + r(\Delta f, m_{\mathrm{S}})\, G\, P_{\mathrm{IB}} \right\}$$

- The coupling gain includes transmitter antenna angular discrimination, propagation gain, receiver antenna gain, as well as receiver antenna angular and polarization discriminations. As is common practice, the coupling gain is modeled as a log-normal random variable; i.e., $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$.

- The protection ratio, $r(\Delta f, m_{\mathrm{S}})$, 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. The protection ratio is a function of the spectral *leakage* of the WSD signal into the adjacent DTT channel, as well as the *adjacent channel selectivity* (ACS) of the DTT receiver. The ACS characterizes the overall behavior 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 gain control to respond to large interferer power fluctuations).

- The protection ratio broadly decreases[2] with increasing frequency separation, Δf, between the WSD and DTT signals. Following the framework adopted in recent co-existence studies involving mobile communications networks and DTT, we model protection ratio also as a function of the received median wanted DTT signal power. This dependence implicitly characterizes the non-linear behavior (including hard overload) of the DTT receiver

1 Emissions corresponding to those segments of a radiated signal's frequency spectrum which carry information intended for a receiver. The width of the in-block segment of the frequency spectrum is the nominal bandwidth of the signal.

2 Notwithstanding the N+9 effect observed in *can* tuners.

In pictures…

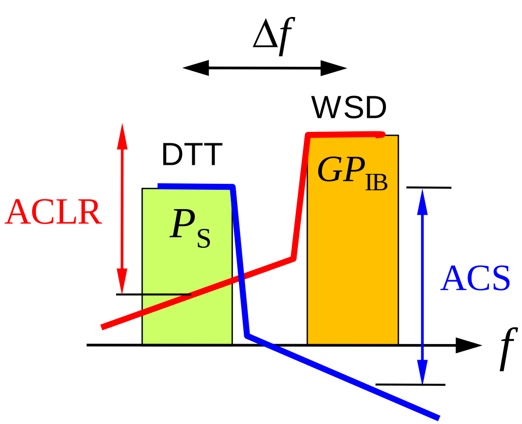
- As described in the previous slide:

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

WSD in-block (carrier) EIRP

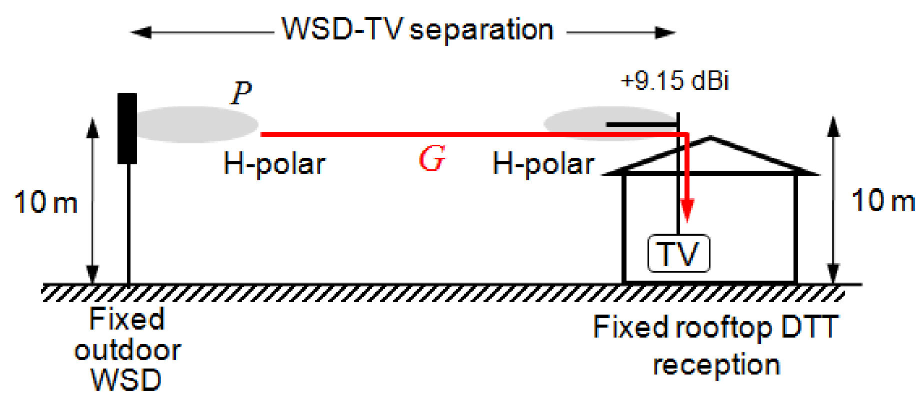
WSD-to-DTT protection ratio

WSD-to-DTT coupling gain (log-normal)



Protection ratio, r , is ratio of received wanted power over received interferer power at the point of receiver failure and depends on:
a) interferer's adjacent channel leakage ratio (ACLR), and
b) victim's adjacent channel selectivity (ACS).

Coupling gain, G , depends on the interferer-victim geometry, and the antenna characteristics.



Interferer power vs. interference power

- As described earlier, the WSD interferer power arriving at a DTT receiver is given by the product GP_{IB}. However, the interference power experienced by DTT receiver (sometimes called the received *nuisance* power) is given by the product , $Z = r(\Delta f, m_S)\, G\, P_{IB}$. This is evident from the rise in the required wanted signal power:

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

Z
Received interference (nuisance) power

X
Received interferer power

- Given that r and P_{IB} are deterministic, and $G_{(dB)} \sim N(m_G, \sigma_G^2)$, it follows that the received interference power, $Z = r(\Delta f, m_S)\, G\, P_{IB}$ is also log-normal; i.e., $Z_{(dBm)} \sim N(m_Z, \sigma_Z^2)$ where

$$m_Z = r(\Delta f, m_S)_{(dB)} + m_G + P_{IB\,(dBm)}\,,$$
$$\sigma_Z = \sigma_G\,.$$

- It also follows that the received interferer power, $X = GP_{IB}$ is also log-normal; i.e., $X_{(dBm)} \sim N(m_X, \sigma_X^2)$ where

$$m_X = m_G + P_{IB\,(dBm)}\,,$$
$$\sigma_X = \sigma_G\,.$$

Outline

Formulation

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

- Given that the UKPM models the term $U_{\mathrm{(dBm)}}$ as a Gaussian[1] random variable $\mathrm{N}(m_U\,,\,\sigma_U{}^2)$, the problem may be re-formulated as

$$q_2 = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_k r_{\mathrm{U},k} P_{\mathrm{U},k} + r(\Delta f, P_{\mathrm{S}})\; G\; P_{\mathrm{IB}} \right\} = \Pr\left\{ P_{\mathrm{S}} \geq U + r(\Delta f, P_{\mathrm{S}})\; G\; P_{\mathrm{IB}} \right\}$$

$$= \Pr\left\{ 1 \geq \frac{U}{P_{\mathrm{S}}} + \frac{G\, r(\Delta f, P_{\mathrm{S}})\, P_{\mathrm{IB}}}{P_{\mathrm{S}}} \right\} = \Pr\left\{ 1 \geq \frac{U}{P_{\mathrm{S}}} + \frac{Z}{P_{\mathrm{S}}} \right\} = \Pr\left\{ 1 \geq A + B \right\} = \Pr\left\{ 1 \geq Y \right\} = \Pr\left\{ 0 \geq Y_{\mathrm{(dB)}} \right\}.$$

- 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 the Schwartz-Yeh algorithm. Note that since P_{S}, U, and Z are independent, it follows that $A_{\mathrm{(dB)}}$ and $B_{\mathrm{(dB)}}$ are uncorrelated.

[1] The modelling of U as a log-normal random variable is a common and pragmatic approach, but is nevertheless, an approximation. See Annex I for an alternative formulation which avoids such modelling (for information only).

Calculation of WSD EIRP

- So, the objective here is to calculate the WSD in-block EIRP, P_{IB}, such that

$$\Pr\left\{0 \geq Y_{(\mathrm{dB})}\right\} = q_{\mathrm{T}},$$

where q_{T} is a target reduced location probability (i.e., $q_{\mathrm{T}} = q_1 - \Delta q_{\mathrm{T}}$). Since Y is log-normal, we have

$$q_{\mathrm{T}} = \frac{1}{2}\mathrm{erfc}\left(\frac{m_Y}{\sqrt{2}\sigma_Y}\right).$$

- This is clearly a non-linear problem.
- Also, note that the random variable Y is itself a function of P_{IB} (the unknown). For this reason, we need to use an iterative approach to calculate P_{IB}. This is described next.

Iterative algorithm for calculation of WSD EIRP

- Assume that the UKPM has calculated $P_{S\,(dBm)} \sim N(m_S, \sigma_S^2)$, $U_{(dBm)} \sim N(m_U, \sigma_U^2)$, and DTT location probability q_1 for a certain victim pixel. The objective is to calculate the maximum permitted WSD EIRP, P_{IB}, such that the interference from a WSD to the victim DTT receiver reduces the DTT location probability to a target value $q_2 = q_T = q_1 - \Delta q_T$. Let the relevant WSD-to-DTT coupling gain and protection ratio be $G_{(dB)} \sim N(m_G, \sigma_G^2)$ and $r(\Delta f, m_S)$, respectively.

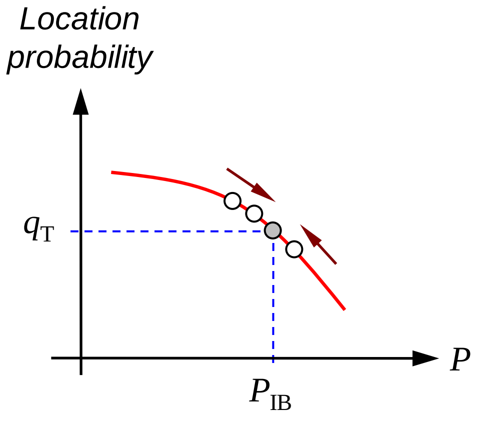
Iterative algorithm

Assume target location probability is q_T .

Initialize: Select an initial value, $\boldsymbol{P}$, for $P_{IB\,(dBm)}$;

1) Calculate $m_Z = r(\Delta f, m_S)_{(dB)} + m_G + \boldsymbol{P}$.
2) Calculate $m_A = m_U - m_S$, $\sigma_A = (\sigma_U^2 + \sigma_S^2)^{1/2}$, $m_B = m_Z - m_S$, $\sigma_B = (\sigma_Z^2 + \sigma_S^2)^{1/2}$.
3) Use the Schwartz-Yeh algorithm to derive m_Y and σ_Y (from m_A, m_B, σ_A, σ_B).
4) Calculate the reduced location probability as $q_2 = (1/2)\,\mathrm{erfc}\{(1/\sqrt{2})\, m_Y / \sigma_Y\}$.
5) If q' is suitably close to q_T, then STOP,
   otherwise appropriately increment/decrement $\boldsymbol{P}$ and go to (1);
   i.e., $\boldsymbol{P} := \boldsymbol{P} \pm \delta$.

The maximum permitted WSD EIRP, P_{IB} , is the value of $\boldsymbol{P}$ when the loop is existed at step (5).



Discussion

- For a WSD in a given pixel, all pixels in the UK are potential victim pixels. In principle, the algorithm presented earlier would need to be applied to each and every interferer-victim pixel pair (where the victim pixel has non-zero population and receives the DTT service), accounting for the WSD and DTT frequencies, and the WSD-to-TV coupling gains.
- In order to reduce the computational complexity, the algorithm need only be applied to the most susceptible victim pixels; i.e., those victim pixels which

  a) have a poor quality of DTT reception, and
  b) correspond to a high WSD-to-DTT coupling gain, and
  c) correspond to a high WSD-to-DTT protection ratio.

Outline

Formulation

- In the previous sub-section we explained how the maximum permitted WSD EIRP, P_{IB}, can be calculated for any interferer-victim pixel pair, given the relevant coupling gain, G, protection ratio, $r(\Delta f, m_{\mathrm{S}})$, DTT wanted signal power, P_{S}, DTT self-interference and noise term, U, and a target degradation, Δq_{T}, in location probability.

- As explained in earlier sections, in cases where we calculate the *vanilla* TVWS availability, we will assume specific *default* values for some of the WSD antenna characteristics. These default values include:

  - A multitude of WSD locations to account for geo-location inaccuracy;
  - Omni-directional WSD antennas;
  - WSD height of $\max(h_{\mathrm{Clutter}}, 10)$ metres;
  - Same-as-DTT polarised WSD signals; etc.

- However, in certain circumstances, we might have additional *a priori* information regarding the location, directivity, polarisation, height, or other characteristics of a WSD's antennas. Such additional information can be accounted for in the calculation of *enhanced* TVWS availability for the WSD. In this section we address mechanisms for achieving this.

The obvious solutions

- There are two obvious options for calculating enhanced TVWS availability:

  Option -1: Real-time calculations

  Ofcom could perform the calculation of the enhanced maximum permitted WSD EIRP, P_{IB}, in real-time, and in response to requests from WSDBs. These requests being, in turn, in response to WSDs which consult WSDBs and which report non-default WSD characteristics.

  The drawback of this approach is that WSDBs would need to refer these special cases to Ofcom on an on-going basis. This, and the computational complexity involved in the calculations, will slow down the response time of the WSDBs. This is especially the case where large numbers of WSDs report non-default characteristics.

  Option -2: Off-line calculations

  Ofcom could perform the calculation of the enhanced maximum permitted WSD EIRP, P_{IB}, for a limited number of combinations of (quantized) non-default WSD characteristics, and make these available to WSDBs. A WSDB would then select the "most appropriate" permitted EIRPs in response to WSDs which consult the WSDB and which report non-default WSD characteristics.

  The drawback of this approach is the excessive storage requirements, especially if the objective is to capture WSD characteristics with reasonable granularity.

- Both options have a further drawback, in that the burden of quantifying enhanced TVWS availability rests with Ofcom. This stems from the difficulties in making the output of the UKPM (i.e., the statistics of P_S and U) available to WSDB providers.

- However, there is a third option. This is presented next.

Formulation

Maximum permitted received interference (nuisance) power

- Instead of calculating the maximum permitted WSD EIRP, P_{IB}, originating from each pixel in the UK, Ofcom could calculate the maximum permitted median interference (nuisance) power, m_Z, received at each victim pixel in the UK.

- The calculation[1] of m_Z would require access to the output of the UKPM (i.e., m_{S}, σ_{S}, m_U, σ_U), and this will be available to Ofcom. The values of m_Z calculated for each victim pixel can then be forwarded to the WSDB providers. The database providers can subsequently calculate the maximum permitted WSD EIRP, P_{IB}, for the protection of any given victim pixel. Specifically (see earlier), we have

$$P_{\mathrm{IB\,(dBm)}} = m_Z - r(\Delta f, m_{\mathrm{S}})_{\mathrm{(dB)}} - m_G \,.$$

  where $r(\Delta f, m_{\mathrm{S}})$ is the WSD-to-DTT protection ratio, and m_G is the WSDT-to-DTT median coupling gain.

- A problem with the above approach is that the WSDB providers would need access to the median wanted DTT signal power, m_{S}, in order to use the appropriate protection ratio. The commercial obstacles in making m_{S} (a key output of the UKPM) available to third parties implies that WSDB providers would not be able to appropriately interpret the maximum permitted received interference powers, m_Z , as calculated by Ofcom.

- A pragmatic alternative is described next.

[1] See Annex II for the details of such calculations using an iterative algorithm.

Formulation

Maximum permitted received interferer power

- Instead of calculating the maximum permitted WSD EIRP, P_{IB}, originating from each pixel in the UK, Ofcom could calculate the maximum permitted median interferer power, m_X, received at each victim pixel in the UK.

- The calculation of m_X would require access to the output of the UKPM (i.e., m_S, σ_S, m_U, σ_U), and this will be available to Ofcom. The values of m_X calculated for each victim pixel can then be forwarded to the WSDB providers. The database providers can subsequently calculate the maximum permitted WSD EIRP, P_{IB}, for the protection of any given victim pixel. Specifically (see earlier), we have

$$P_{\mathrm{IB\,(dBm)}} = m_X - m_G \, .$$

  where m_G is the WSDT-to-DTT median coupling gain.

- Note here that the derivation of P_{IB} by a WSDB does not involve the protection ratios, and is only a function of the median coupling gain as defined by the relevant WSD-to-TV geometry and WSD antenna characteristics.

- An iterative approach for the calculation of P_{IB} is described next.

Iterative algorithm

Ofcom's calculation of maximum permitted interfer<u>er</u> power

- The iterative algorithm presented earlier for the direct calculation of WSD EIRP, P_{IB}, can be readily adapted to calculate the maximum permitted median interferer power, m_X, in any victim pixel. Let the relevant WSD-to-DTT coupling gain and protection ratio be $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$ and $r(\Delta f, m_{\mathrm{S}})$, respectively. Note that $\sigma_Z = \sigma_G$.

Iterative algorithm

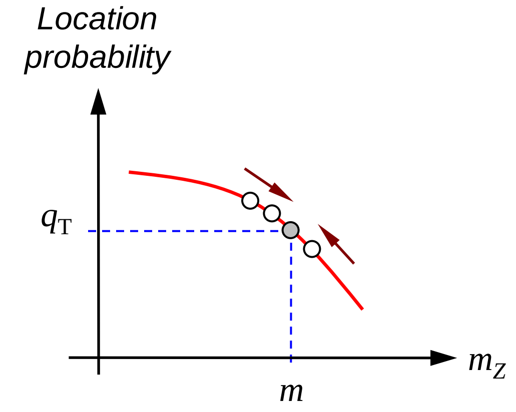
Assume that the target location probability is q_{T}.
Initialization: Select an initial value, $\boldsymbol{m}$, for m_Z.

1) Calculate $m_A = m_U - m_{\mathrm{S}}$, $\sigma_A = (\sigma_U^2 + \sigma_{\mathrm{S}}^2)^{1/2}$, $m_B = \boldsymbol{m} - m_{\mathrm{S}}$, $\sigma_B = (\sigma_Z^2 + \sigma_{\mathrm{S}}^2)^{1/2}$.
2) Use the Schwartz-Yeh algorithm to derive m_Y and σ_Y (from m_A, m_B, σ_A, σ_B).
3) Calculate the reduced location probability as $q_2 = (1/2)\,\mathrm{erfc}\{(1/\sqrt{2})\, m_Y / \sigma_Y\}$.
4) If q' is suitably close to q_{T}, then <u>STOP</u>,
   otherwise appropriately increment/decrement $\boldsymbol{m}$ and go to (1);
   i.e., $\boldsymbol{m} := \boldsymbol{m} \pm \delta$.

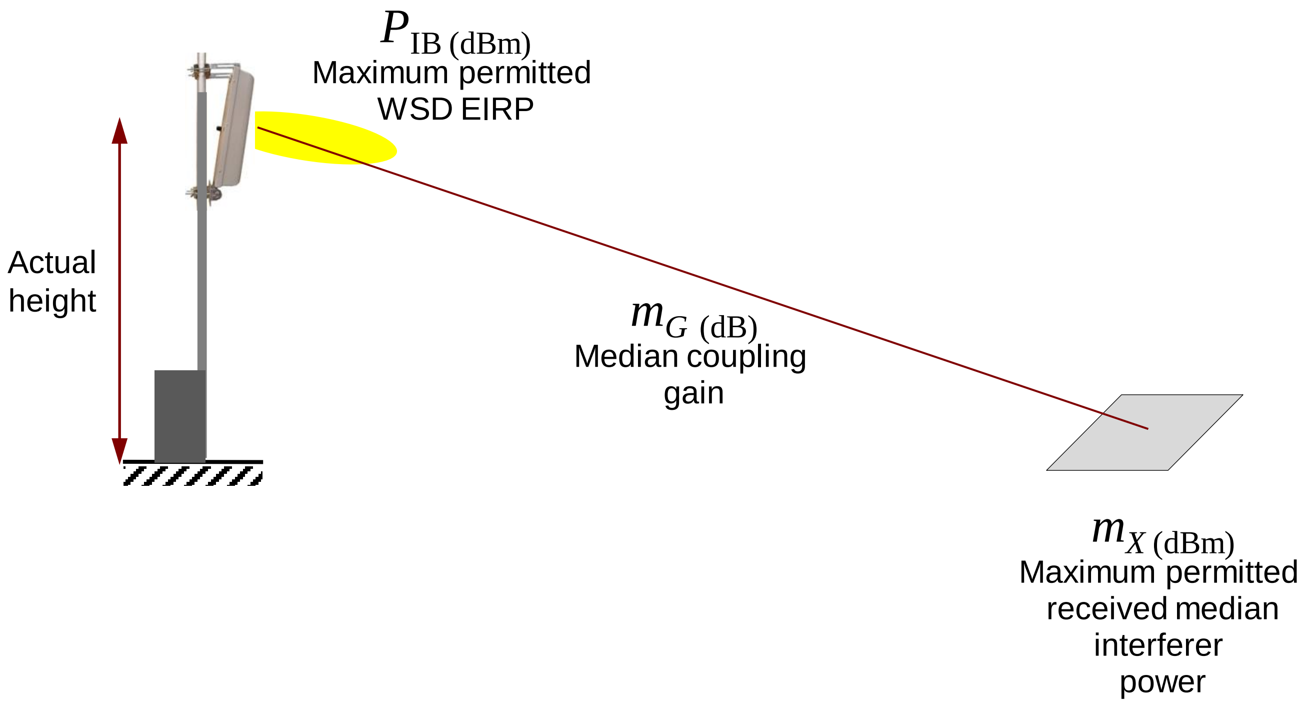
The maximum permitted median received interfer<u>ence</u> power, m_Z,
is the value of $\boldsymbol{m}$ when the loop is existed at step (4).

The maximum permitted median received interfer<u>er</u> power, m_X,
can then be calculated (by Ofcom) as $m_X = m_Z - r(\Delta f, m_{\mathrm{S}})_{(\mathrm{dB})}$.

The maximum permitted WSD EIRP, $P_{\mathrm{IB}\ (\mathrm{dBm})}$,
can then be calculated (by a WSDB provider) as $P_{\mathrm{IB}\ (\mathrm{dBm})} = m_X - m_G$.

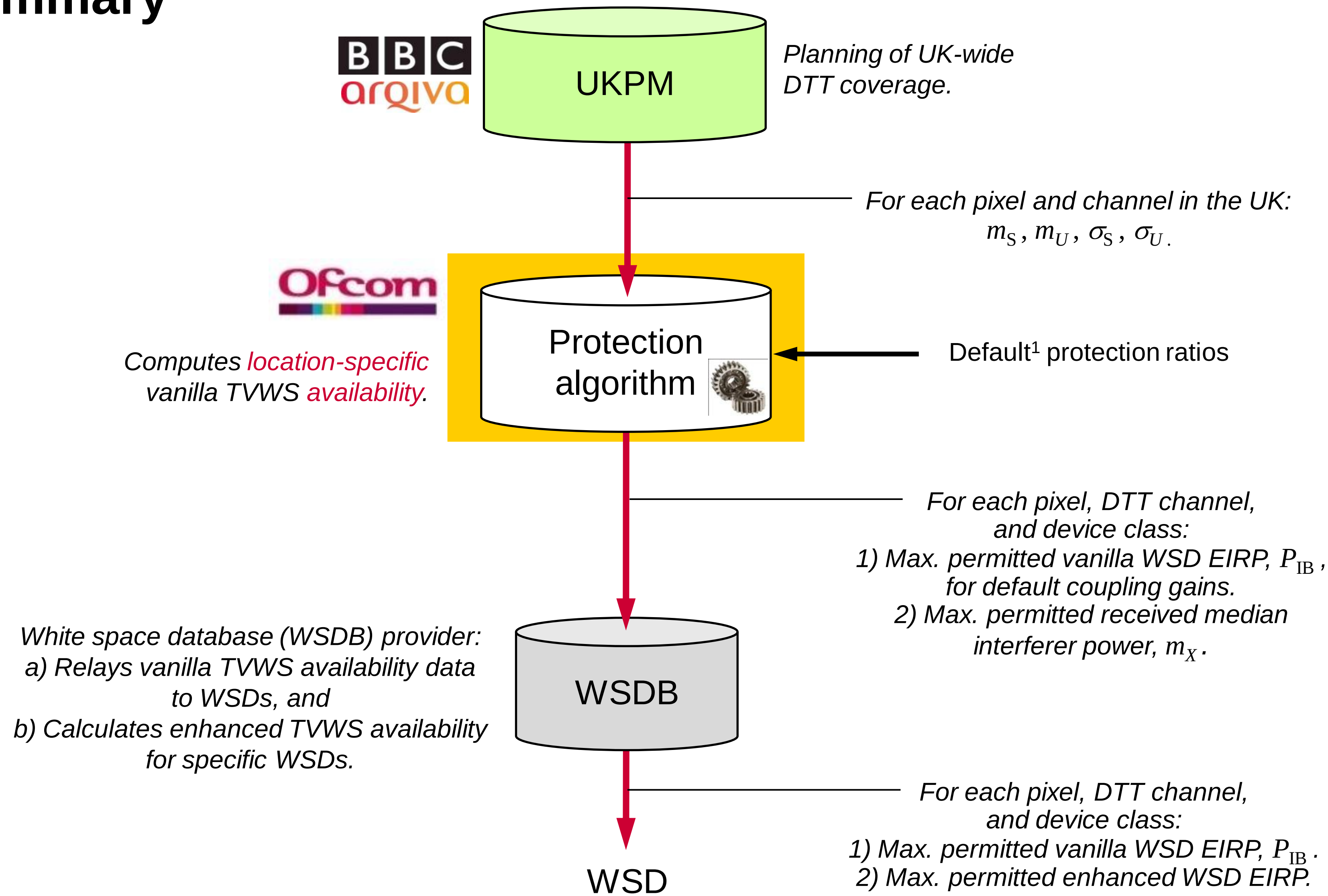


In pictures…



$P_{\text{IB (dBm)}}$
Maximum permitted WSD EIRP
Actual height
m_G (dB)
Median coupling gain
m_X (dBm)
Maximum permitted received median interferer power

Summary



[1] Eventually to be complemented with technology-specific protection ratios.

Outline

Parameter values

- In this section we present the various default parameter values which will be used in the calculation of location-specific TVWS availability. The values cited here are provisional.

Parameter	Default value
Same-pixel and 1st tier pixel coupling gain $G_{(\mathrm{dB})} \sim \mathrm{N}(m_G, \sigma_G^2)$	For same-pixel pixel scenarios, m_G = –49.1 dB at 474 MHz, σ_G = 8 dB at all frequencies. For m_G at f (MHz), add $20 \log_{10}(474/f)$. The above median and standard deviation are based[1] on household separation data provided by DUK[2] subject to the assumption of free-space path loss. Simulations[3] indicate that the above median and standard deviation represent the same restrictions as would a default reference geometry (see Section 4.1) with a WSD-TV separation of 14 metres, and free-space path loss. For the 1st tier pixel scenarios, $G_{(\mathrm{dB})}$ is modelled in the same was as for the same-pixel scenario, except $m_G = -49.1 + g_{\mathrm{A,TV}}(\theta)_{(\mathrm{dB})}$ at 474 MHz, where $g_{\mathrm{A,TV}}(\theta)$ is the relevant TV aerial angular (azimuth,θ) discrimination (see Section 4.1).

1 Kostas Tsioumparakis, "Ideas on the statistics of coupling gains between white space devices and TV receivers," BBC technical note, 16 April 2012.

2 Mark Evans, "TV white space: UK address separation distances," Digital UK technical note, 23 March 2012.

3 R.Karimi, "Same pixel or 1st tier pixel coupling gains: A review of the approach proposed by K. Tsioumparakis," discussion document, contribution to the Ofcom TVWS Technical Working Group, 3 June 2012.

Parameter values

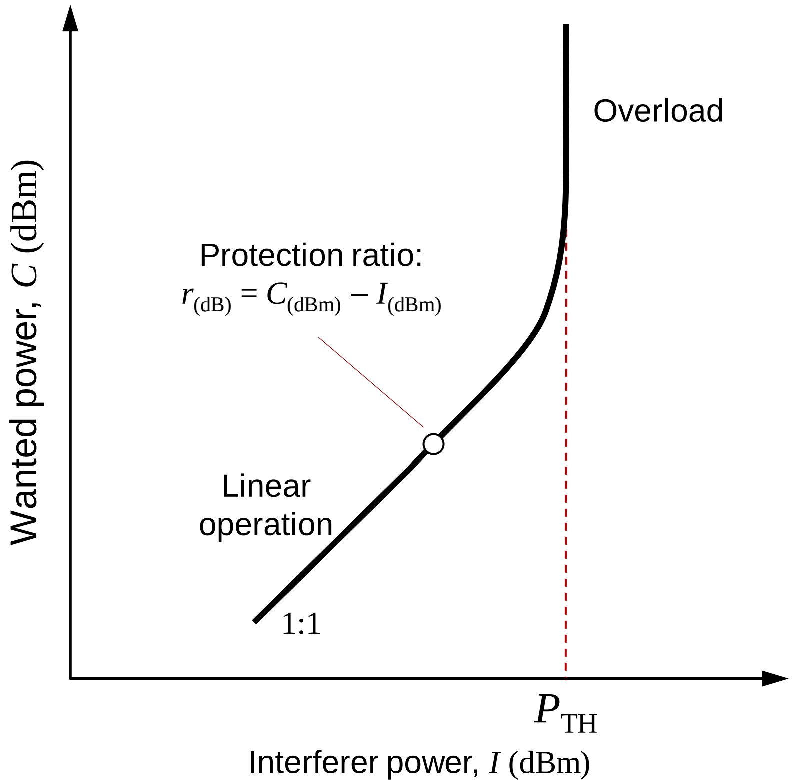
Parameter	Default value
m^{th} tier pixel ($m \geq 2$) coupling gain $G_{(\text{dB})} \sim \text{N}(m_G, \sigma_G^2)$	For m^{th} tier pixels ($m \geq 2$), $m_G = g_{\text{A,WSD}}(\alpha)_{(\text{dB})} + m_{\text{Prop}}(d_{\min}, h_{\text{TV}}, h_{\text{WSD}})_{(\text{dB})} + G_{\text{A,TV (dB)}} + g_{\text{A,TV}}(\beta)_{(\text{dB})} + g_{\text{Polar,TV}}(\beta)_{(\text{dB})}$ where $g_{\text{A,WSD}}(\alpha)$ is the WSD antenna angular discrimination, m_{Prop} is the median propagation gain based on the extended urban/suburban Hata model (see SEAMCAT manual), $G_{\text{A,TV (dB)}}$ = 9.15 dBi is the TV aerial gain, $g_{\text{A,TV}}(\beta)$ is the TV aerial angular discrimination, and $g_{\text{Polar,TV}}(\beta)$ is the TV aerial polarisation discrimination. Note that α and β are the relevant cone angles with respect to the boresights of the WSD antenna and TV aerial respectively (see Section 4). In the calculation of m_{Prop}, it is assumed that the TV aerial is at a height of h_{TV} = 10 m, and that the WSD antenna is at a default height of $h_{\text{WSD}} = \max\{h_{\text{Clutter}}, 10\}$ m, where h_{Clutter} is the clutter height in the relevant pixel. Terrain height will be added to h_{TV} and h_{WSD}. The term $d_{\min}$, is the minimum horizontal separation between the WSD interferer and TV aerial victim (see Section 4.1). Finally, $\sigma_G = (5.5^2 + 5.5^2)^{1/2}$ = 7.8 dB, and accounts for shadowing loss at both the transmitter and receiver. Note that terrain shadowing is not included in the calculation of path gain (at least not in the context of vanilla TVWS availability).

Parameter values

Parameter	Default value
DTT protection criterion	Maximum degradation in location probability of Δq = 0.01.
Definition of DTT service	A pixel is considered to receive the DTT service if it is protected by a DPSA layer, and the PSB location probability is greater than 70%.
Co-channel protection ratio	$r(0)$ = 17 dB.
Adjacent channel protection ratios	Cautious default values, $r(\Delta f, m_S)$, based on measurements using WiMAX signals (see following slides).
Free space path gain	$G_{FS\ (dB)} = +147.56 - 20 \log_{10} f_{(Hz)} - 20 \log_{10} d_{(m)}$ where f is frequency in Hz, and d is separation in metres.
TV aerial directional pattern	ITU Rec. 419-3.

WSD-to-DTT protection ratios

- Protection ratio is defined as the ratio of received wanted power, C, to received interferer power, I, at the point of receiver failure. For a specific interferer-victim carrier separation, Δf , the protection ratios may appear as shown below.
- In our terminology, $C = P_S$, and $I = GP_{IB}$.
- Note that the protection ratios are a function of the wanted signal power, P_S .
- This means that protection ratios can be used to implicitly model non-linear receiver behaviours.
- In what follows, we present cautious *default* (technology-neutral) protection ratios which will be used by Ofcom for the purpose of calculating TVWS availability for each WSD class. Eventually, these will be complemented by technology-specific protection ratios.
- Note that we use the subscript "$_M$" to denote measured values. For tractability, we also use the median value m_S as a proxy for P_S in identifying the appropriate protection ratio.



Measured protection ratios

Based on BBC's protection ratio measurements (ignoring the worst 3 (out of 14) tested DTT receivers)

WiMAX WSD signals $r_M(\Delta f, m_S)$ (dB)		m_S (dBm) (a.k.a C)						
		≤ -70	-60	-50	-40	-30	-20	-12[1]
Channel offset (8 MHz)	$\Delta f = \pm 1$	-23	-21	-18	-12	-10	-10	-10
	$\Delta f = \pm 2$	-32	-28	-24	-19	-13	-10	-7.6
	$\Delta f = \pm 3$	-33	-30	-23	-17	-13	-10	-7.6
	$3 < \|\Delta f\| < 9$	Linearly interpolate (in dB) between ±3 and ±9						
	$\Delta f = \pm 9$[2]	-37	-34	-30	-24	-20	-15	-11
	$9 < \|\Delta f\|$	Same as ±9						

[1] Values derived by Ofcom by linearly extrapolating the "C vs. I" curves at m_S = -30 and -20 dBm to -12 dBm (used in LTE studies).

[2] Strictly speaking these results apply to the +9 channel offset only.

- We propose to use the protection ratios, $r_M(\Delta f, m_S)$, measured for WiMAX WSD signals, as a basis for the cautious default (technology-neutral) protection ratios. The adjacent channel interference ratios, ACIR_M , in the measurements can be derived given that

$$\mathrm{ACIR}_M(\Delta f, m_S) = \frac{r_M(0)}{r_M(\Delta f, m_S)}.$$

- For purposes of computing the ACIR_M , a co-channel protection ratio of $r_M(0)$ = 17 dB is assumed. This is consistent with measured co-channel protection ratios. The derived ACIR values are presented next.

Measured ACIR and ACS

Based on BBC's protection ratio measurements (ignoring the worst 3 (out of 14) tested DTT receivers)

WiMAX WSD signals $\mathrm{ACIR_M}(\Delta f, m_\mathrm{S})$ (dB)		m_S (dBm) (a.k.a C)						
		$\leq$ -70	-60	-50	-40	-30	-20	-12[1]
Channel offset (8 MHz)	$\Delta f = \pm 1$	40	38	35	29	27	27	27
	$\Delta f = \pm 2$	49	45	41	36	30	27	24.6
	$\Delta f = \pm 3$	50	47	40	34	30	27	24.6
	$3 < \lvert\Delta f\rvert < 9$	Linearly interpolate (in dB) between ±3 and ±9						
	$\Delta f = \pm 9$[2]	54	51	47	41	37	32	28
	$9 < \lvert\Delta f\rvert$	Same as ±9						

[1] Values derived by Ofcom by linearly extrapolating the "C vs. I" curves at m_S = -30 and -20 dBm to -12 dBm (used in LTE studies).
[2] Strictly speaking these results apply to the +9 channel offset only.

- The adjacent channel leakage ratio, $\mathrm{ACLR_M}$, of the WSD signal used in the measurements was very large (> 60 dB in the first adjacent channel). For this reason, the above ACIR values are a good proxy for the ACS values; i.e.,

$$\mathrm{ACS_M}(\Delta f, m_\mathrm{S}) = \left\{\mathrm{ACIR_M^{-1}}(\Delta f, m_\mathrm{S}) - \mathrm{ACLR_M^{-1}}(\Delta f)\right\}^{-1} \cong \mathrm{ACIR_M}(\Delta f, m_\mathrm{S})$$

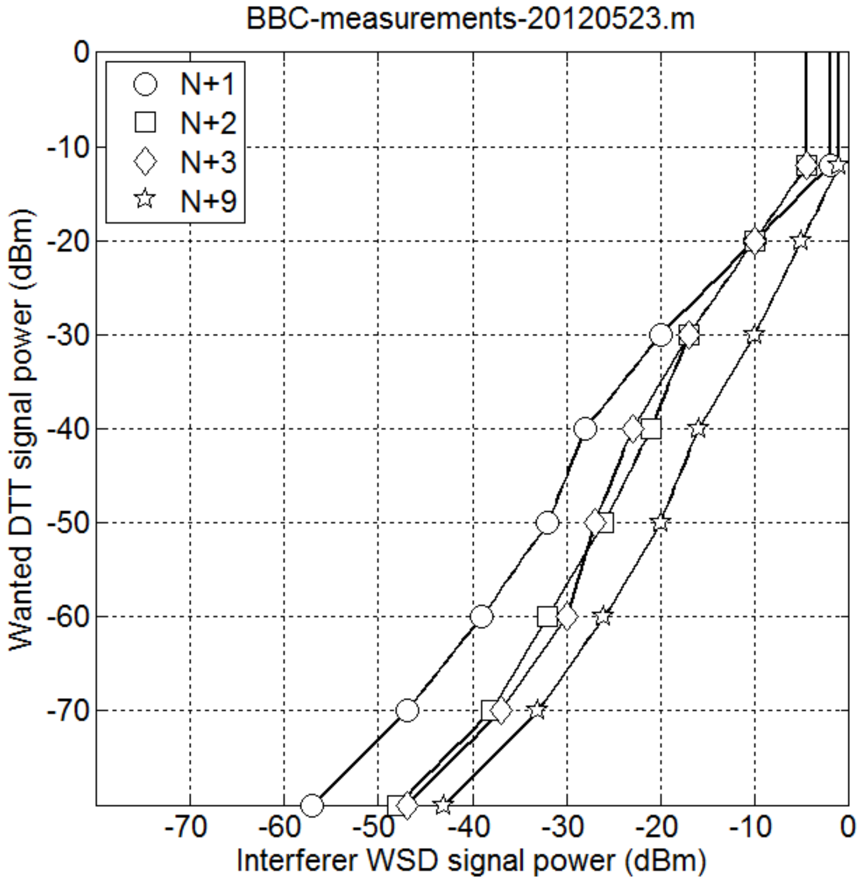
- The default protection ratios, $r_\mathrm{M}(\Delta f, m_\mathrm{S})$, for the different device classes can then be computed as

$$r(\Delta f, m_\mathrm{S}) = \frac{r_\mathrm{M}(0)}{\mathrm{ACIR}(\Delta f, m_\mathrm{S})} = r_\mathrm{M}(0)\left\{\mathrm{ACLR}^{-1}(\Delta f) + \mathrm{ACS_M^{-1}}(\Delta f, m_\mathrm{S})\right\} .$$

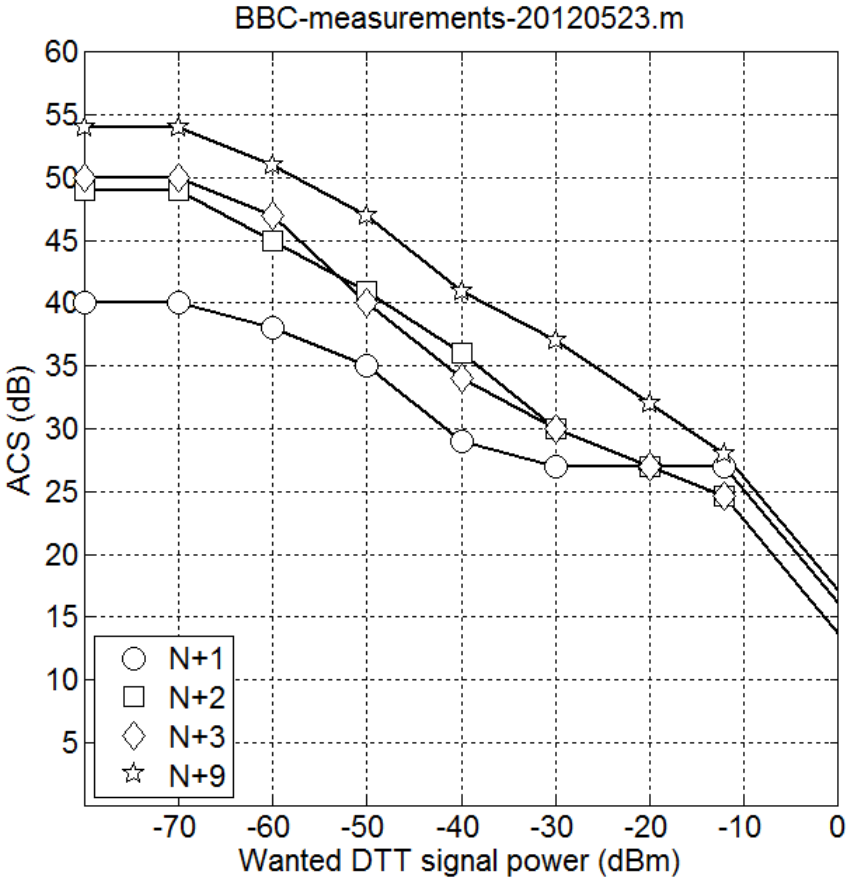
where the values of $\mathrm{ACLR}(\Delta f)$ are based on the spectrum emission masks of different device classes (see next).

Illustrations

Based on BBC's protection ratio measurements (ignoring the worst 3 (out of 14) tested DTT receivers)



Measured values of C vs. I.



Variation of ACS_M *vs.* m_S .

ACLR and device classes

- The ACLR values used for the purpose of calculating protection ratios for each device class are as follows:

Where out-of-block emissions fall within the n^{th} adjacent DTT channel		ACLR (dB)			
		Class 1	Class 2	Class 3	Class 4
$n = \pm 1$	$\Delta f = \pm 8$ MHz	55	55	45	35
$n = \pm 2$	$\Delta f = \pm 16$ MHz	60	55	55	45
$n \geq \pm 3$	$\Delta f \geq \pm 24$ MHz	65	55	65	55

Outline

1. Introduction
2. Database-assisted access: eco-system
3. High-level approach
4. Geometries & coupling gains
5. Calculations
6. Default parameter values
7. Conclusions

Annex (for information)

Conclusions

- We have presented our approach for the protection of DTT, and the type of calculations which Ofcom and WSDBs will need to perform to quantify location-specific vanilla and enhanced TVWS availability, respectively.
- We have shown how uncertainties in victim TV aerial location can be circumvented in the calculations through the use of *reference geometries*, in scenarios where the WSD and TV are in the same-pixel or in adjacent-pixels. We have also described the use of *non-reference* geometries for scenarios which involve greater WSD-TV separations.
- We have shown how uncertainties in WSD location can be circumvented in the calculations by assuming that the WSD is located in a number of pixels, calculating the TVWS availability in each pixel, and then selecting the most stringent (lowest) level. We have illustrated this for both master and slave WSDs.
- We have described how the maximum permitted WSD EIRP originating from any given pixel and in any DTT channel can be calculated via an iterative algorithm, so as to satisfy a target degradation in DTT location probability. This represents vanilla TVWS availability. We have also shown how the algorithm can be adapted to calculate the maximum permitted WSD interferer power received in any given pixel and in any DTT channel. This can be used by WSDBs to quantify enhanced TVWS availability.
- We have presented default parameter values relating to various geometries and protection ratios. These are intended for the calculation of vanilla TVWS availability by Ofcom.

Outline

1. Introduction
2. Database-assisted access: eco-system
3. High-level approach
4. Geometries & coupling gains
5. Calculations
6. Default parameter values
7. Conclusions

Annex (for information)

I - Alternative formulation

Calculation of q_1

- As noted in Sections (5.1) and (5.2), the UKPM models the parameter U as a log-normal random variable. This is an approximation based on the premise that the sum of a log-normal random variable and a deterministic variable (namely $P_{\mathrm{S,min}}$) is also a log-normal random variable. This assumption is not strictly correct. In the next two slides we reformulate the calculations of q_1 and q_2 in such a way so as to avoid the summation of a deterministic variable and a stochastic random variable. Specifically, we can write

$$q_1 = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_k r_{\mathrm{U},k} P_{\mathrm{U},k} \right\} = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + V \right\}$$

$$= \Pr\left\{ 1 \geq \frac{P_{\mathrm{S,min}}}{P_{\mathrm{S}}} + \frac{V}{P_{\mathrm{S}}} \right\} = \Pr\left\{ 1 \geq A + B \right\} = \Pr\left\{ 1 \geq W \right\} = \Pr\left\{ 0 \geq W_{(\mathrm{dB})} \right\}$$

where $A_{(\mathrm{dB})}$ and $B_{(\mathrm{dB})}$ are Gaussian random variables (on account of the fact that A and B are ratios involving log-normal random variables and a deterministic variable). Note that the terms $A_{(\mathrm{dB})}$ and $B_{(\mathrm{dB})}$ are correlated. This is an added complication in comparison with the commonly used approach of Section (5.1), where the log-normal variables were uncorrelated. The relevant correlation coefficient can be readily calculated as follows:

$$\rho_{A,B} = \frac{\mathrm{cov}(A_{(\mathrm{dB})}, B_{(\mathrm{dB})})}{\sqrt{\mathrm{var}(A_{(\mathrm{dB})})\,\mathrm{var}(B_{(\mathrm{dB})})}} = \frac{\sigma_{\mathrm{S}}}{\sqrt{\sigma_{\mathrm{S}}^2 + \sigma_V^2}}.$$

where $V \sim \mathrm{N}(m_V, \sigma_V^2)$. The term $W_{(\mathrm{dB})}$ can then be modeled as a Gaussian random variable, with its median and standard deviation m_W and σ_W derived via the Schwartz-Yeh algorithm for the sum of the two log-normal random variables A and B with correlation, $\rho_{A,B}$. Then

$$q_1 = \frac{1}{2}\mathrm{erfc}\left\{ \frac{1}{\sqrt{2}} \frac{m_W}{\sigma_W} \right\}.$$

I - Alternative formulation

Calculation of q_2

- Following the same methodology, we have

$$q_2 = \Pr\left\{ P_S \ge P_{S,\min} + V + r(\Delta f, m_S)\, G\, P_{IB} \right\} = \Pr\left\{ 1 \ge \frac{P_{S,\min}}{P_S} + \frac{V + r(\Delta f, m_S)\, G\, P_{IB}}{P_S} \right\}$$

$$= \Pr\left\{ 1 \ge A + \frac{V+Z}{P_S} \right\} = \Pr\left\{ 1 \ge A + \frac{D}{P_S} \right\} = \Pr\left\{ 1 \ge A + E \right\} = \Pr\left\{ 1 \ge Y \right\} = \Pr\left\{ 0 \ge Y_{(dB)} \right\}.$$

- The term Z is a Gaussian random variable with median and standard deviation

$$m_Z = r(\Delta f, m_S)_{(dB)} + m_G + P_{IB\,(dBm)}, \qquad \sigma_Z = \sigma_G.$$

- Since V and Z are uncorrelated log-normal random variables, $D_{(dBm)}$ can be modeled as a Gaussian random variable, whose median, m_D, and standard deviation, σ_D, can be calculated via the Schwartz-Yeh algorithm. Furthermore, since D and P_S are both log-normal random variables, it follows that $E_{(dBm)}$ is also Gaussian, with median and standard deviation

$$m_E = m_D - m_S, \qquad \sigma_E = \sqrt{\sigma_D^2 + \sigma_S^2}.$$

- Finally, since A and E are log-normal random variables, $Y_{(dBm)}$ can be modeled as a Gaussian random variable, whose median, m_Y, and standard deviation, σ_Y, can be calculated via the Schwartz-Yeh algorithm. Note that $A_{(dBm)}$ and $E_{(dBm)}$ are correlated, with correlation coefficient

$$\rho_{A,E} = \frac{\operatorname{cov}(A_{(dB)}, E_{(dB)})}{\sqrt{\operatorname{var}(A_{(dB)})\operatorname{var}(E_{(dB)})}} = \frac{\sigma_S}{\sqrt{\sigma_S^2 + \sigma_D^2}},$$

and this must be accounted for within the Schwartz-Yeh algorithm. Having calculated m_Y and σ_Y, it follows that

$$q_2 = \frac{1}{2}\operatorname{erfc}\left\{ \frac{m_Y}{\sqrt{2}\,\sigma_Y} \right\}. \qquad \blacksquare$$

II - Iterative algorithm

Ofcom's calculation of maximum permitted interfer<u>ence</u> (nuisance) power

- The iterative algorithm presented earlier for the direct calculation of WSD EIRP, P_{IB}, can be readily adapted to calculate the maximum permitted median interfer<u>ence</u> (nuisance) power, m_Z, in any victim pixel. Let the relevant WSD-to-DTT coupling gain and protection ratio be $G_{(dB)} \sim N(m_G, \sigma_G^2)$ and $r(\Delta f, m_S)$, respectively. Note that $\sigma_Z = \sigma_G$.

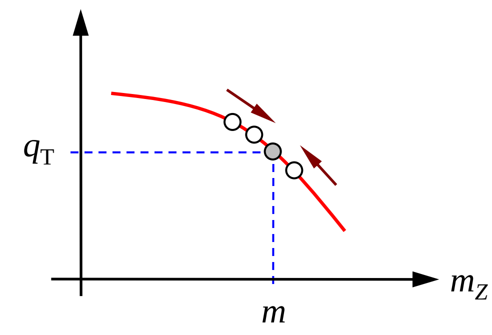
Iterative algorithm

Assume that the target location probability is q_T.
Initialization: Select an initial value, $\boldsymbol{m}$, for m_Z.

1) Calculate $m_A = m_U - m_S$, $\sigma_A = (\sigma_U^2+\sigma_S^2)^{1/2}$, $m_B = \boldsymbol{m} - m_S$, $\sigma_B = (\sigma_Z^2+\sigma_S^2)^{1/2}$.
2) Use the Schwartz-Yeh algorithm to derive m_Y and σ_Y (from m_A, m_B, σ_A, σ_B).
3) Calculate the reduced location probability as $q_2 = (1/2)\,\mathrm{erfc}\{(1/\sqrt{2})\, m_Y/\sigma_Y\}$.
4) If q' is suitably close to q_T, then <u>STOP</u>,
   otherwise appropriately increment/decrement $\boldsymbol{m}$ and go to (1);
   i.e., $\boldsymbol{m} := \boldsymbol{m} \pm \delta$.

The maximum permitted median received interfer<u>ence</u> power, m_Z,
is the value of $\boldsymbol{m}$ when the loop is existed at step (4).

The maximum permitted WSD EIRP, $P_{IB\,(dBm)}$,
can then be calculated as $P_{IB(dBm)} = m_Z - r(\Delta f, m_S) - m_G$.



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III - Minimum required DTT signal power

- The following parameter values are assumed in all scenarios:

  - Boltzmann's constant, k =1.38065 × 10^{-23} (J/K),
  - Temperature, T = 290 K,
  - DTT noise bandwidth, B = 7.5 MHz,
  - DTT receiver noise figure, NF = 7 dB.

- The minimum required wanted signal power, $P_{S,\min}$, at a DTT receiver is then calculated as

$$\begin{aligned} P_{S,\min\,(\mathrm{dBm})} &= \{10\log_{10}(kTB) + 30\} + \mathrm{NF}_{(\mathrm{dB})} + \mathrm{SNR}_{\min\,(\mathrm{dB})} \\ &= -105.22 + 7 + \mathrm{SNR}_{\min\,(\mathrm{dB})} \\ &= -98.22 + \mathrm{SNR}_{\min\,(\mathrm{dB})}\,. \end{aligned}$$

- Example

  For $\mathrm{SNR}_{\min\ (\mathrm{dB})}$ = 22.8 dB (JPP Variant I), we have $P_{S,\min}$ = -105.22 + 7 + 22.8 = -75.42 dBm.
  For $\mathrm{SNR}_{\min\ (\mathrm{dB})}$ = 25.0 dB (2.2 dB margin[1]), we have $P_{S,\min}$ = -105.22 + 7 + 25.0 = -73.22 dBm.

[1] This margin accounts for Rayleigh fading in indoor DTT reception.

III - Minimum required DTT field strength at 10 m

- In order to compare the results for various indoor/outdoor geometries, all field strength values will be quoted at a reference height of 10 m outdoors. For simplicity, In the following examples we use a DTT frequency of f = 500 MHz.

- For the fixed roof-top DTT reception

$$\begin{aligned} E_{\mathrm{S,min\,10\,m\,(dB\mu V/m)}} &= P_{\mathrm{S,min\,(dBm)}} + 20\log_{10} f_{\mathrm{(MHz)}} + 75.06 - G_{\mathrm{A,TV\,(dBd)}} \\ &= P_{\mathrm{S,min\,(dBm)}} + 20\log_{10} f_{\mathrm{(MHz)}} + 77.21 - G_{\mathrm{A,TV\,(dBi)}} \\ &= P_{\mathrm{S,min\,(dBm)}} + 131.19 - G_{\mathrm{A,TV\,(dBi)}}, \end{aligned}$$

where the TV aerial gain is $G_{\mathrm{A,TV}}$ = 7 dBd $\equiv$ 9.15 dBi.
For channel 39 and above, $E_{\mathrm{S,min\ 10\ m}}$ is increased by 1 dB.

- Example: Fixed roof-top reception

For $P_{\mathrm{S,min}}$ = -75.42 dBm (JPP Variant I), we have $E_{\mathrm{S,min\ 10\ m}}$ = 46.62 dBμv/m @ 500 MHz.
(Note: JPP cites 46.8).

III - Minimum required DTT field strength at 10 m

- For indoor DTT reception at different heights, we have

$$
\begin{aligned}
E_{\mathrm{S,min\,10\,m\,(dB\mu V/m)}} &= P_{S,\mathrm{min\,(dBm)}} + 20\log_{10} f_{\mathrm{MHz}} + 77.21 - G_{\mathrm{A,TV\,(dBi)}} + G_{\mathrm{H\,(dB)}} - G_{\mathrm{W\,(dB)}} \\
&= P_{S,\mathrm{min\,(dBm)}} + 131.19 - G_{\mathrm{A,TV\,(dBi)}} + G_{\mathrm{H\,(dB)}} - G_{\mathrm{W\,(dB)}},
\end{aligned}
$$

where G_{H} is height gain (e.g., +8 dB), and G_{W} is wall gain (e.g., -8 dB).
For channel 39 and above, $E_{\mathrm{S,min\ 10\ m}}$ is increased by 1 dB.

- Example: Indoor reception at 4 m

For indoor DTT reception we have $P_{\mathrm{S,min}}$ = -73.22 dBm, $G_{\mathrm{A,TV}}$ = 2.15 dBi (set-top TV aerial),
G_{H} = 7.88 dB, and G_{W} = -8 dB. Then, $E_{\mathrm{S,min\ 10\ m}}$ = 71.70 dBμv/m @ 500 MHz.

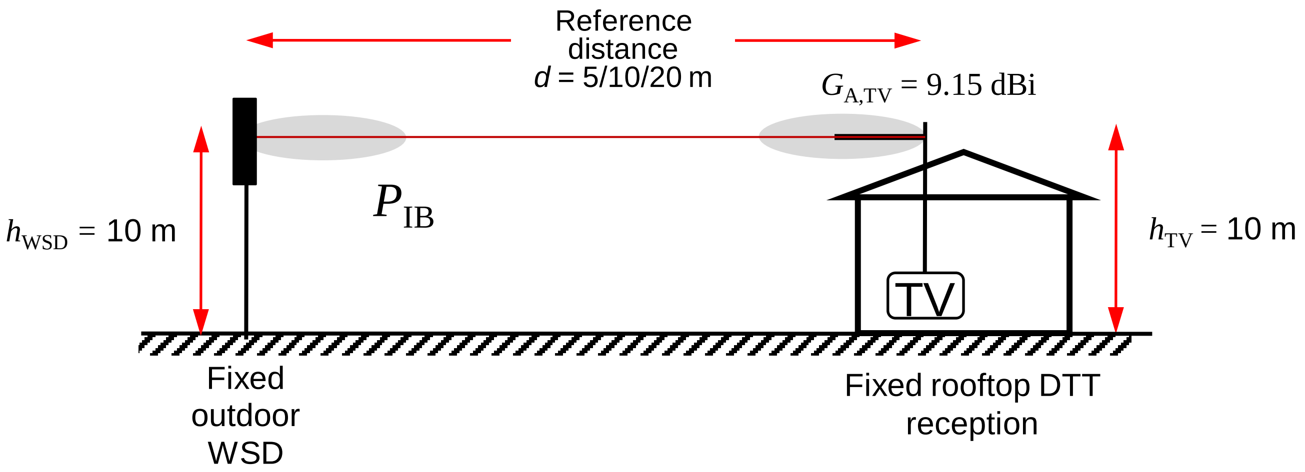
- Example: Indoor reception at 1.5 m

For indoor DTT reception we have $P_{\mathrm{S,min}}$ = -73.22 dBm, $G_{\mathrm{A,TV}}$ = 2.15 dBi (set-top TV aerial),
G_{H} = 16.3 dB, and G_{W} = -8 dB. Then, $E_{\mathrm{S,min\ 10\ m}}$ = 80.12 dBμv/m @ 500 MHz.

III - Fixed roof-top DTT reception

▪ TV aerial height:	h_{TV}	= 10 m	(rooftop reception)
▪ WSD height:	h_{WSD}	= 10 m	(base station WSD)
▪ Horizontal separation:	d	= 5/10/20 m	(to be considered)
▪ TV aerial gain:	$G_{A,TV}$	= 9.15 dBi	(includes feeder loss)
▪ Height loss:	G_{H}	= 0 dB	
▪ Wall loss:	G_{W}	= 0 dB	(outdoors)
▪ Minimum SNR:	SNR_{min}	= 22.8 dB	(JPP Variant I)
▪ Minimum receiver power:	$P_{S,min}$	= -75.42 dBm	
▪ Minimum field strength:	$E_{S,min\ (10\ m)}$	= 46.62 dBμV/m	@ 500 MHz

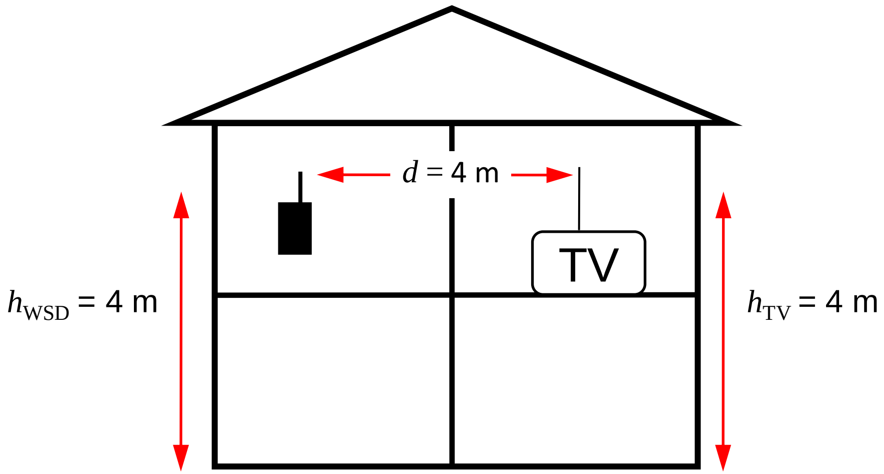
- Degradation in location probability: Δq = 0.01.



III - Indoor reception (upstairs)

[1] Margin for Rayleigh fading.

TV aerial height:	h_{TV}	= 4 m	(indoor upstairs)
WSD height:	h_{WSD}	= 4 m	(WSD UE at same height as TV)
Horizontal separation:	d	= 4 m	(to be considered)
TV aerial gain:	$G_{A,TV}$	= 2.15 dBi	(dipole)
Height loss:	G_H	= -7.88 dB	(ITU-R P.1546-4)
Wall loss:	G_W	= -8 dB	(TV/WSD in different rooms)
Minimum SNR:	SNR_{min}	= 25.0 dB	(JPP Variant I, 22.8 + 2.2[1] dB)
Minimum receiver power:	$P_{S,min}$	= -73.22 dBm	
Minimum field strength:	$E_{S,min\ (10\ m)}$	= 71.70 dBμV/m	@ 500 MHz



III - Indoor reception (downstairs)

[1] Margin for Rayleigh fading.

TV aerial height:	h_{TV}	= 1.5 m	(downstairs)
WSD height :	h_{WSD}	= 1.5 m	(UE at same height as TV)
Horizontal separation:	d	= 4 m	(to be considered)
TV aerial gain:	$G_{A,TV}$	= 2.15 dBi	(dipole)
Height loss:	G_H	= -16.3 dB	(ITU-R P.1546-4)
Wall loss:	G_W	= -8 dB	(TV/WSD in different rooms)
Minimum SNR:	SNR_{min}	= 25.0 dB	(JPP Variant I, 22.8 + 2.2[1] dB)
Minimum receiver power:	$P_{S,min}$	= -73.22 dBm	
Minimum field strength:	$E_{S,min\ (10\ m)}$	= 80 .12 dBμV/m	@ 500 MHz