



# ECC Report 186

Technical and operational requirements for the operation  
of white space devices under geo-location approach

approved January 2013

## 0 EXECUTIVE SUMMARY

In response to an increased interest in the possibilities potentially provided by white space devices (WSDs) by its members and the industry, the CEPT developed ECC Report 159 [1] where appropriate technical and operational requirements for such devices in the band 470-790 MHz have been formulated. However, recognizing the preliminary nature of some elements used in the first studies, the innovative nature of cognitive techniques and the ongoing research and industry activities in this field, ECC Report 159 [1] listed a number of technical and regulatory issues requiring further consideration. One of the issues, ECC Report 159 [1] looked into, was the assessment of the appropriateness of the geo-location technique to provide the required protection.

This ECC Report is intended to complement and enhance the findings previously published in ECC Report 159 [1] in relation to the geo-location technique with additional technical investigations identified by the CEPT as required to facilitate the development of regulations for WSDs in the band 470-790 MHz. In order to improve the readability of this complementary report, the relevant parts of ECC Report 159 [1] are included in this report and amended with additional information.

Geo-location is an approach, where WSD determine their location and make use of a geo-location database in order to get information on which frequencies they can use at their location.

CEPT administrations have pointed out the importance of providing guidance on some of the approaches being considered for the technical algorithms to be used when implementing a geo-location database for WSD use of the 470-790 MHz band. By providing this information it gives scope for administrations to follow a common approach towards the development, operation and maintenance of a geo-location database. This report primarily focuses on providing guidance on some of the possible approaches to the algorithms to be used in the translation process to enable the protection of the relevant incumbent services as well as looking at the suitable data elements that would need to be exchanged between a WSD and a geo-location database. The technical elements presented in this report could be used as a basis for administrations to choose a sub-set of the common approaches to the algorithms presented in the translation process. More importantly the set of data elements presented in this report could be used to give guidance to ETSI and other standards bodies on what could constitute the minimum set of data elements that a WSD would have to understand and communicate with any geo-location database in Europe.

It should be noted that there are also a number of non-technical elements in relation to the management and operational requirements that administrations would need to address separately. For example, the database provider accreditation and management, the method for entering data for services that needs to be protected and suitable processes to deal with the monitoring and/or the resolution of interference cases. The consideration of these elements is outside the scope of this report.

Within this report, the CEPT is giving advice on general principles and basic requirements for WSDs operating under the geo-location database:

### (a) Considerations on location accuracy

With regard to providing location information there are three different areas of uncertainty that the geo-location database will have to deal with:

- Uncertainty in the location of the victim receiver
- Uncertainty in the location of the master WSD
- Uncertainty in the location of the slave WSD.

These uncertainties will determine the interference area that a geo-location database will have to consider when looking at the suitable reference and non-reference geometries used by the database to carry out any interference calculations.

### (b) WSD requirements and the master/slave concept

The general principles and operational requirements to WSDs operating under the master/slave concept have been defined and are in conformity with general operating requirements to WSDs. The information flows between (i) the master WSD and the geo-location database, and (ii) the master WSD and the slave WSDs are detailed. Both geo-located and non geo-located slave WSDs are considered.

As a basic operational requirement, a master WSD may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by the NRA of that country.

The following parameters for the master WSD will need to be communicated (normally by the master WSD) to the geo-location database: its antenna geographical location, location accuracy, device class, emission class, technology identifier, device model, device category and device identifier. In addition, the master WSD may communicate to the database its antenna height, antenna angular discrimination, and antenna polarisation. The slave WSD will in certain situations provide to the master WSD a subset of the above information that the master needs to communicate to the database. This subset as a minimum should include the slave WSD device class, emission class, technology identifier, device model and device identifier.

The geo-location database will communicate to the master WSD as a minimum, operational parameters consisting of a list of available frequencies, associated maximum transmit powers for the current WSD location, limits on the maximum contiguous DTT channels and total number of DTT channels that WSD can transmit and time of validity of these parameters for the master and associated slaves. In addition, the database may communicate to the master WSD the appropriate national/regional database to consult and any information related to spectrum sensing if the latter is required.

After receiving operational parameters from the geo-location database, the master WSD will communicate to the database the selected frequency block, intended transmit power and in some cases the coverage area of the master WSD.

### **(c) Database management**

The management of the geo-location database involves consideration of a number of issues including the technical information on services/systems to be protected, the database update delay and update frequency, as well as the translation mechanism.

### **(d) Translation process in the geo-location database**

The database translates the information on incumbent services contained in the database and the information communicated from the WSD to the database into a list of allowed frequencies and associated transmit powers for WSDs. , NRAs may pre-calculate the allowed frequencies and associated transmit powers at each location for different WSD types and make this information available .

With respect to the protection of the broadcasting services, as guidance to administrations the report develops approaches, both Monte-Carlo and analytical, for calculating in-block and out-of-block emission levels. The methods to deal with interference aggregation from multiple WSDs are proposed. The key parameters to be used to calculate location specific WSD power levels are the reference interference geometries, the DTT reception modes, receiving antenna pattern, and location probability and the acceptable degradation of the location probability.

The key elements for the translation process to protect PMSE<sup>1</sup>, RAS, ARNS and the services in the bands adjacent to 470-790 MHz have been listed. For mobile service in the adjacent bands there are no translation process developed.

### **(e) Combined sensing and geo-location**

Spectrum sensing could be used to support the detection of incumbent radio services conducted using the geo-location database. However, studies have shown that currently the implementation of reliable sensing has a number of challenges, thus some of the potential benefits may not be achievable in practice. This situation may change in the future.

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<sup>1</sup> The calculations in this report deal only with professional wireless microphone systems PWMS with focus on radio microphones, in-ear monitors, and audio links.

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## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Explanation</b>
<b>ACL</b>	Adjacent Channel Leakage Ratio
<b>ACS</b>	Adjacent Channel Selectivity
<b>agl</b>	Above ground level
<b>ARNS</b>	Aeronautical Radio-Navigation Systems
<b>BPL</b>	Building Penetration Loss
<b>BS</b>	Broadcasting Service
<b>CDF</b>	Cumulative distribution function
<b>CEPT</b>	European Conference of Postal and Telecommunications Administrations
<b>CRS</b>	Cognitive Radio System
<b>DB</b>	Data base
<b>DTT</b>	Digital Terrestrial Television
<b>DTV</b>	Digital Television
<b>DVB-T</b>	Digital Video Broadcasting – Terrestrial
<b>DVB-H</b>	Digital Video Broadcasting- Handheld
<b>EBU</b>	European Broadcasting Union
<b>ECC</b>	Electronic Communications Committee
<b>e.i.r.p.</b>	equivalent isotropically radiated power
<b>ENG/OB</b>	Electronic News Gathering outside broadcast
<b>ETSI</b>	European Telecommunications Standards Institute
<b>FCC</b>	Federal Communications Commission
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>IMD</b>	Inter-Modulation Distortion
<b>IM</b>	Interference margin
<b>LIM</b>	Limiting nuisance power
<b>LP</b>	Location Probability
<b>M-to-M</b>	Machine-to-Machine communication
<b>MI</b>	Multiple interference margin
<b>NB</b>	Narrow Band
<b>NRA</b>	National Regulatory Authority
<b>O<sub>th</sub></b>	Overloading threshold
<b>OOB</b>	Out-of-Band
<b>PI</b>	Portable Indoor
<b>PR</b>	Protection Ratio
<b>PM</b>	Propagation model
<b>PMSE</b>	Program Making and Special Event
<b>PO</b>	Portable Outdoor
<b>POL</b>	Polarisation discrimination
<b>PPCI</b>	Protected Pixel-Channel Interference
<b>PWMS</b>	Professional wireless microphone systems
<b>QAM</b>	Quadrature amplitude modulation
<b>RAS</b>	Radio astronomy service
<b>RFSENS</b>	Reference Sensitivity
<b>RBW</b>	Resolution bandwidth
<b>PWMS</b>	Professional Wireless Microphone system
<b>R.V.</b>	Random variable
<b>SEAMCAT</b>	Spectrum Engineering Advanced Monte Carlo Tool
<b>SINR</b>	Signal to interference plus noise ratio
<b>TVWS</b>	TV White Spaces
<b>USB</b>	Universal Serial Bus
<b>WSD</b>	White Space Device

## 1 INTRODUCTION

Cognitive radio systems (CRS) may be deployed in the “white spaces” of the frequency band 470-790 MHz provided that no harmful interference to incumbent services<sup>2</sup> is generated by such a deployment. In other words, the incumbent services need to be protected from any potential WSD interference. This is to be ensured through geo-location databases, whereby the WSD looks up the TVWS spectrum availability at its particular location. ECC Report 159 [1] concluded that stand alone sensing was not considered to be a viable technique at present to manage interference, but a combined geo-location and sensing approach may be possible in the future.

In response to an increased interest in the possibilities potentially provided by white space devices (WSDs) by its members and the industry, the CEPT developed ECC Report 159 [1] where appropriate technical and operational requirements for such devices in the band 470-790 MHz have been formulated. However, recognizing the preliminary nature of some elements used in the first studies, the innovative nature of cognitive techniques and the on-going research and industry activities in this field, ECC Report 159 [1] listed a number of technical and regulatory issues requiring further consideration. One of the issues, ECC Report 159 [1] looked into, was the assessment of the appropriateness of the geo-location technique to provide the required protection.

This ECC Report is intended to complement ECC Report 159 [1] with additional technical investigations in relation to the geo-location technique. In order to improve the readability of this complementary report, the relevant parts of ECC Report 159 [1] are included in this report and amended with additional information.

Some CEPT administrations pointed out the importance of providing guidance on some of the approaches being considered. This would give scope for administrations to follow a common approach towards the development, operation and maintenance of a geo-location database. This report primarily focuses on providing guidance on some of the possible approaches to the algorithms to be used in the translation process to enable the protection of the relevant incumbent services as well as defining minimum data elements that would need to be exchanged between a WSD and a geo-location database. The technical elements presented in this report could be used as a basis for administrations to choose a sub-set of the common approaches to the algorithms presented in the translation process. More importantly the set of data elements presented in this report could be used to give guidance to ETSI and other standards bodies on what could constitute the minimum set of data elements that a WSD would have to understand and communicate with any geo-location database in Europe.

It should be noted that there are also a number of non-technical elements in relation to the management and operational requirements that NRAs would need to address separately. For example, the database provider accreditation and management, the method for entering data for services that need to be protected and suitable processes to deal with the monitoring and/or the resolution of interference cases. The consideration of these elements is outside the scope of this report.

## 2 PRINCIPLES AND GENERAL CONSIDERATIONS

The cognitive technique of geo-location is an approach, where WSDs determine their location and consult a geo-location database to obtain information on the frequencies they can use at their location.

With regard to providing location information there are three different areas of uncertainty that the geo-location database will have to deal with:

- 1) uncertainty in the location of the victim receiver,
- 2) uncertainty in the location of the master WSD, and
- 3) uncertainty in the location of the slave WSD.

These uncertainties will determine the interference area that a geo-location database will have to consider when looking at the suitable reference and non-reference geometries (see Annex 2) used by the database to carry out any interference calculations.

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<sup>2</sup> See § 2.4 of ECC Report 159 **Error! Reference source not found.** for definition of incumbent services/systems in the band 470-790 Hz.





### 3 REQUIREMENTS FOR WSD

The main purpose of using a geo-location database for WSD operation is to ensure that there is no harmful interference from the WSD to the protected services. This requires that some minimum amount of information is exchanged between the device and the database. The following sections give some guidance on what this minimum information should be for the different types of WSD.

#### 3.1 DEFINITIONS

A master WSD is a WSD, which obtains the operational parameters (for both master and associated slaves) directly from a geo-location database (for example, through an internet connection).

A slave WSD is a WSD that does not directly communicate with a geo-location database, and obtains operating parameters directly from its serving master WSD.

Within this report the WSDs are classified into two types:

- (a) a Type A is a WSD whose antennas are permanently mounted on a fixed outdoor installation at a specified fixed location.
- (b) a Type B WSD is a WSD whose antennas are not permanently mounted on a fixed outdoor installation at a specified fixed location. Type B WSD shall have integral antenna<sup>3</sup>.

WSD operational situation can be covered by the master/slave concept described below.

#### 3.2 GENERAL PRINCIPLES OF MASTER/SLAVE CONCEPT

Deployments of master/slave WSDs are divided into two cases shown schematically in Figure 2:

- the master does not know where, within its coverage area, the slaves are located (non geo-located slaves)

This case represents the general deployment scenarios for master/slave operation.

In this case, the coverage area of the master needs to be identified. The coverage area depends on the used technology, transmit power, antenna characteristics, frequency within the white space band (e.g. propagation at the bottom of the band may be superior to that at the top) and the terrain. The coverage area could be determined by the master WSDs itself or by the database as specified by the NRA– (this would be a choice for the NRA). It needs, however, to be noted that the coverage area of the master WSD can only be determined once the operating frequency and power of the master WSD have been provided by the database and the master WSD has chosen its intended transmission power and operating frequency.

When the slaves are non geo-located, the master needs first to send a request to the database for itself taking into account its location uncertainty. When the coverage area of the master WSD is determined (either by the database or by the master itself), the database returns generic operational parameters<sup>4</sup> (i.e. the available channels, associated transmit power, etc), which is pertinent/valid for all slave WSDs transmission within the coverage area of the master WSD.

After receiving generic operational parameters for slave WSDs from the database, the master WSD communicates these parameters to slave WSDs located within its coverage area. These slave WSDs can then associate with the master WSD using 470-790 MHz band with these parameters.

- the master knows where the slaves are located (geo-located slaves)

This case can follow from the previous case when after being instructed by the master, the slave WSDs inform the master about their geographical positions. There could be also situations when the

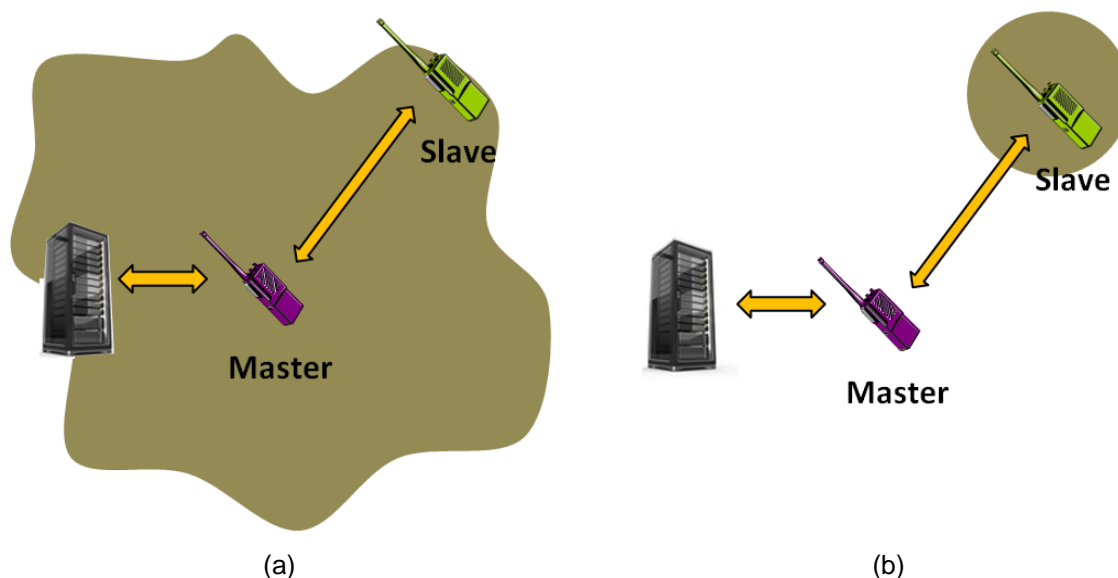
<sup>3</sup> An integral antenna is designed as a fixed part of the equipment, without the use of an external connector, and as such, cannot be disconnected from the equipment by a user with the intent to connect another antenna.

<sup>4</sup> "Generic operational parameters" refer to the values applicable to any slave WSDs operating in the coverage area of the master WSD and take account of the most susceptible pixel in the coverage area.

whole master/slave network is professionally installed (i.e. fixed networks) and, therefore, either the master or the database knows the positions of the slave WSDs.

This case is relatively straightforward. The master sends to the database separate requests for specific operational parameters<sup>5</sup> for each slave (and also for itself, if necessary). These requests take into account the location uncertainty for master WSDs and its slaves.

After receiving specific operational parameters from the database, the master cascades the appropriate database response to the appropriate slave WSD.



**Figure 2: Concept of (a) non-geo-located and (b) geo-located slaves. The shaded regions show the area within which the slave WSD has been determined to be situated. In case of non geo-located slaves this area corresponds to the coverage area of the master WSD**

One approach to determine the coverage area where non geo-located slave WSDs may be able to receive instructions from a master WSD would be for the operator of the master WSD to use a pre-agreed coverage planning tool to determine coverage contours for a number of pre-defined powers and frequencies. The operator of the master WSD might then place a database request for the master device and then, based on the allowed power levels from the database, determine the coverage area and then place further database requests for potential slave operation on all the pixels within this coverage area.

An alternative would be for the NRA to determine the coverage based on propagation models taking into account the actual terrain or if possible based on simpler models such as the Hata model. The transmit powers for the slaves inside the master coverage area would have to be determined assuming default worst case technical characteristics of the slaves. An assumption would also need to be made on the antenna gain of the slave WSD in order not to underestimate the coverage area of the master WSD. Since most of non geo-located slave WSDs are likely to be personal portable devices, a maximum antenna gain of 2.15 dBi for non-geo-located slave WSD is proposed assuming a dipole antenna. There may also be a mechanism to take into account the actual slave characteristics, especially if they are better than the default technical characteristics defined by the NRA. In general the full details of the approach can be determined by the NRAs.

Hence, no further regulation is required to facilitate the master/slave concept.

Note that the master/slave approach does not, in principle, solve the “aggregation problem” since other users unconnected with the master could also be operating on the same, or nearby white space channels. Also, if the master is unaware of the exact location of the slaves then it will not be able to determine whether they are clustered tightly around a victim receiver. Nevertheless, it is likely that master/slave operation would

<sup>5</sup> "Specific operational parameters" refer to the values applicable to a WSD at a known location. These values are typically less restrictive than the generic operational parameters.

reduce the probability of harmful aggregation occurring since the master would limit the number of slaves transmitting simultaneously as the communication occurs mainly between the master and the slaves.

An example illustrating how a master/slave approach might work in practice is given in ANNEX 7:.

### 3.3 REQUIREMENTS FOR MASTER WSD

As a basic operational requirement, a master WSD may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by the NRA of that country.

In order to be authorised to transmit within the band 470-790 MHz, a master WSD shall:

- discover an approved geo-location database<sup>6</sup>,
- communicate its device parameters to the geo-location database,
- receive permitted operational parameters from the geo-location database,
- communicate its chosen channel usage parameters to the geo-location database prior to transmission within the band 470-790 MHz,
- operate subject to the operational parameters received from the geo-location database,
- manage and communicate appropriate information to its associated slave WSDs so that the slave WSDs are able to operate subject to the operational parameters received by the master WSD from the geo-location database,
- cease transmission immediately upon
  - expiry of time validity of these information or
  - where it moves outside geographical area of validity or
  - when instructed to do so by WS database.

Communication between a master WSD and a geo-location database shall not occur within the band 470-790 MHz, unless the master WSD has already been authorised by the database to transmit within this band.

#### 3.3.1 Device parameters to be communicated from a master WSD to the geo-location database

The following information shall be communicated by the master WSD to the geo-location database:

- *master WSD antenna location*

The location is the current position of the master WSD expressed in terms of geographical coordinates (e.g. latitude and longitude) as determined by means of an internal geo-location method. Some WSD may also have the ability to determine and report its altitude which is the height of its antenna above sea level.

- *master WSD antenna location accuracy*

The location accuracy is the absolute accuracy with which the geographical position of the WSD is determined. It is expressed in terms of an uncertainty radius (derived with a certain confidence probability) around the location. This may include information on the vertical accuracy. Location accuracy could be taken into account by the database in providing information on available frequencies. This approach would also allow different device implementations and different approaches on how the location is determined. By doing this the device could get different frequency

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<sup>6</sup> A European harmonized approach for WSD to discover the listing of approved WSDB operating in different national regulatory authorities should be defined and addressed in an appropriate harmonized standard.

availability based on its technical characteristics and capable devices could benefit from better location accuracy. The location granularity of the database (pixel size) may need to be fine enough to be able to serve devices with finer location accuracy.

- *device type of the master WSD and the associated slave WSDs*

The device type is used by the database to select an appropriate interference reference geometry in the translation process.

Providing the device type (i.e. Type A or Type B) will allow information to be returned according to device capabilities and interference characteristics. The database could then take into account device type known operating parameters in returning appropriate frequencies and allowed maximum transmission power. WSDs with different technical characteristics, can exhibit different interference characteristics (e.g. antenna type, antenna height) allowing different e.i.r.p. limits.

- *device emission class of the master WSD and the associated slave WSDs*

The emission class would enable the database to identify the emission masks of the WSD, and would thus allow the database to derive appropriate device emission class specific protection ratios, which take into account ACLR of the WSD and protection ratios measured for a reference ACLR (see ECC Report 185 [16]).

- *technology identifier of the master WSD and the associated slave WSDs*

The technology identifier would describe the specific technology being used and typically refer to particular standard (e.g. LTE or IEEE 802.16xx). This would be helpful in informing the WSDB with regards to framing, modulation and emission methods, including the broad time-frequency structure, of the emission technology employed by the WSD signals, channel raster and minimum number of channels needed to operate.

- *device model of the master WSD and the associated slave WSDs*

The device model is used by the database to narrow the device identity to one model of a certain manufacturer.

This information would be important e.g. in tracing reports of interferences and to potentially exclude certain devices/models. Applications of the latter would be e.g. reported causes of interferences or information that this particular model would not be able to adjust its sensing method to the new technology of the potential victim.

The device model and device unique identifier (see below) may be relevant for solving possible interference problems encountered in the field.

- *device unique identifier of the master WSD and the associated slave WSDs*

The device unique identifier is used by the database to point to one specific device.

This would allow tracing of individual devices to enable the database to instruct a particular master WSD and/or a particular associated slave WSD to cease transmission when required.

- *device category (master or slave WSD)*

Device category would allow database to identify whether request for operating parameters from a master WSD is for itself or it's slave WSD's transmission.

Master WSD must communicate to the database device parameters provided by the slave WSD who wish to operate in the 470-790 MHz band in accordance with the operational parameters from the database.

The following information may be *optionally*<sup>7</sup> communicated by a master WSD to the geo-location database:

- *master WSD antenna height*

If antenna height is not supplied automatically by the Type A WSD then it is recommended that the NRA decides on appropriate antenna heights based on an assumption that takes account of the terrain and clutter information for the antennas location associated with a value for the antenna's height above ground level (for example, maximum building height + 3 m in urban areas and 30 m in rural areas). The assumptions to be made by the NRA on these values should be conservative (high) enough to encourage installers of fixed antennas to provide the correct details to the database if the WSD cannot supply this automatically.

- *master WSD antenna angular discrimination if it's a Type A WSD*

Where the antenna angular discrimination of a *Type A WSD* (professional installed) is known this can be taken into account by the database in order for the *Type A WSD* to benefit from better whitespace availability. This can be specified as relevant gain (in dB) at specific intervals (in degrees) in absolute azimuth and elevation. Where multiple antennas are involved, the angular discrimination must apply to the combined emissions from the antennas,

- *master WSD antenna polarisation if it's a Type A WSD*

This can be specified as either horizontal polarisation, vertical polarisation or slant ( $\pm 45$  degrees) polarisation.

- *antenna locations and antenna characteristics of the associated slave WSDs (provided such information is available)*

Antenna characteristics may include the antenna height, maximum antenna gain, the pointing direction, and antenna polarisation.

After receiving instructions from the geo-location database and prior to initiating transmissions within the UHF TV band, the master WSD shall communicate to the database the channel usage parameters:

- *Selected frequency block:* The lower and upper frequency boundaries of the intended in-block emissions of the master WSD, and those of the in-block emissions of its associated slaves.

It should be noted that a WSD may transmit over multiple, non-contiguous, whole DTT channels or fractions of DTT channels.

- *Intended transmit power:* The maximum in-block e.i.r.p. spectral densities that the master WSD, and its associated slaves, intend to radiate between each reported lower frequency boundary and its corresponding upper frequency boundary.
- *Coverage area of the master WSD* (when the slave WSDs are non geo-located and when it is the master WSD which determines its coverage area).

The information received from the WSD will enable the geo-location database to assess the usage of the frequency resource by WSDs in a given geographical area, for example, with regard to aggregate interference.

### 3.3.2 Operational parameters to be received by a master WSD from the geo-location database

The following information will be sent from the geo-location database and which the master WSD shall be capable of receiving:

- *Available frequencies*

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<sup>7</sup>In some countries the regulator may agree for professional installers to provide some of this information through an alternative national process.



This is a list of lower and upper frequency boundaries within which the master WSD and its associated slave WSDs are authorised to operate. Available frequencies are the frequencies that could be used within the device's location taking into account the uncertainty with the position of the device. Frequency information could be based on specific DTT channels or alternatively might be provided as a start and end frequency. The frequency availability will be valid across an area comprising of one or more pixels, (where a pixel would be defined as a square of pre-determined dimension, (e.g. 100m x 100m) depending on the WSD characteristics or if the WSD asks the frequency availability in an area. WSDs that move outside the current pixel or set of pixels, within which they know they are allowed to transmit, must re-consult the database to get information about their new location before they transmit again.

- *Maximum transmit power*

A maximum permitted master and its served slave WSD e.i.r.p. spectral density between each lower frequency boundary and its corresponding upper frequency boundary. Different limits could be defined to protect incumbent services from both broadband and narrowband WSD usage. For example, two sets of limits could be defined to protect DTT (defined in 8MHz) and PMSE (defined in 100 kHz).

- *The maximum number of contiguous DTT channels and maximum number of DTT channels that master WSDs (and their served slave WSDs) can transmit*

This parameter could be defined based on requirement of NRA if it wishes to limit the maximum bandwidth that the WSD is capable of transmitting for the purpose of managing aggregate interference to incumbent service to be protected.

- *Time validity for the parameters communicated by the database*

This parameter defines the time validity of the available frequencies and the associated emission limits that can be used without re-consulting the database by the WSD operating at its reported location or geographical area. If the WSD needs available frequencies after the end of the validity time, or if it moves outside the area within which was allowed to transmit, it needs to re-consult the database. The time validity depends on the time dependency and usage pattern of the protected services specific to individual NRA.

The following information may be sent from the geo-location database and which the master WSD shall be capable of receiving:

- *A sensing level for the detection of protected services/systems*

This parameter flags the need of sensing in conjunction with the geo-location, for the detection of protected services/systems, such as DTT and/or PMSE. This would allow flexibility in working with, for example, license exempt wireless microphones that operate in some countries that are not registered in the database. If sensing is needed then the database could also return details such as on what frequency to sense and of what type of signal it is necessary to sense and the sensitivity level required for sensing in that country. It should be noted, that if certain kind of sensing is required in some bands in some countries, WSD's without such capability would not be allowed to operate in those bands. In practise this would mean that the required sensing capabilities need to be implemented in all WSD's to be operated in those countries, even if such feature would not be needed in other countries.

- *'Cease operation' message*

This is the instruction for the master WSD and its associated slave WSDs to cease transmissions immediately when requested by the database. It is expected that this message will only be used in exceptional cases. However, the equipment must be capable of recognizing the message in the event of an unexpected problem.

### 3.3.3 Operational and security requirements

A master WSD must only transmit within the band 470-790 MHz in accordance with the relevant operational parameters provided by an approved geo-location database as listed in § 3.3.2, and for a time period which does not exceed the time validity of those operational parameters and in a geographic area which does not exceed the geographic validity of those parameters.

For a master WSD which wishes to simultaneously transmit over multiple DTT channels, the power sum of the individual in-block e.i.r.p. for all DTT channels that the WSD simultaneously transmits over shall not exceed the lowest of the in-block e.i.r.p. limits for any of the DTT channels to be used.

A master WSD that is associated with slave WSDs shall ensure that it communicates appropriate information to those slave WSDs, so that the slave WSDs are able to transmit within the band 470-790 MHz in accordance with the operational parameters provided by an approved geo-location database as listed in § 3.3.2, and for a time period which does not exceed the time validity of those instructions and parameters and in a geographic area which does not exceed the geographic validity of those parameters if it's a geo-located slave WSD.

A master WSD shall ensure that it has access to valid instructions and parameters from a geo-location database whenever its geographical location changes with respect to that determined at the time of its previous consultation with the database. This implies that WSD needs to have capability to apply different rules on when it would need to re-consult an approved database to revalidate its operational parameters when operating in different countries.

Communications between a master WSD and a geo-location database shall be performed using secure protocols that avoid malicious corruption or unauthorised modification of the data.

Communications between a master WSD and a slave WSD for purposes of relaying database-related instructions and parameters shall employ secure protocols that avoid malicious corruption or unauthorised modification of the data.

### 3.4 REQUIREMENTS FOR SLAVE WSDS

In order to be authorised to transmit within the 470-790 MHz band, a slave WSD shall:

- communicate device parameters to its serving master WSD,
- receive operational parameters from its serving master WSD,
- communicate channel usage parameters to its serving master WSD,
- operate subject to the operational parameters received from its serving master WSD.

Communication between a slave WSD and a master WSD shall not occur within the band 470-790 MHz, unless the WSDs have already been authorised by the database to radiate within this band.

#### 3.4.1 Device parameters to be communicated from a slave WSD to a master WSD

The following information shall be communicated by the slave WSD to its serving master WSD:

- slave WSD device type,
- slave WSD device emission class,
- slave WSD technology identifier,
- slave WSD model identifier,
- slave WSD unique device identifier,
-



The following information may be *optionally* communicated by a slave WSD to its serving master WSD:

- slave WSD antenna location (only for geo-located slaves),
- slave WSD antenna location accuracy (only for geo-located slaves),
- slave WSD antenna height,
- slave WSD antenna angular discrimination if it's a Type A WSD,
- slave WSD antenna polarisation if it's a Type A WSD,

### 3.4.2 Operational parameters to be received by a slave WSD from a master WSD

The following information will be sent from the master WSD and which the slave WSD shall be capable of receiving:

- the lower and upper frequency boundaries within which the slave WSD is authorised to operate,
- a maximum permitted slave WSD e.i.r.p. spectral density between each lower frequency boundary and its corresponding upper frequency boundary,
- a validity time for the parameters communicated by the serving master WSD,
- the maximum number of contiguous DTT channels and maximum number of DTT channels that served slave WSDs can transmit,

The following information may be sent from the master WSD and which the slave WSD shall be capable of receiving:

- a sensing level for the detection of protected services/systems
- instructions for the slave WSD to cease transmissions immediately when requested by the master WSD (so called "Cease operation").

### 3.4.3 Operational requirements

A slave WSD must only transmit within the band 470-790 MHz in accordance with the operational parameters provided by its serving master WSD as listed in § 3.4.2, for a time period which does not exceed the time validity of those operational parameters and in a geographic area which does not exceed the geographic validity of those parameters if it's a geo-located slave WSD.

For a slave WSD that wishes to transmit simultaneously over multiple DTT channels, the power sum of the individual in-block e.i.r.p.s for all DTT channels that the WSD simultaneously transmits over shall not exceed the lowest of the in-block e.i.r.p. limits for any of the DTT channels to be used.

A slave WSD shall cease its emissions immediately when

- instructed to do so by its serving master WSD, or
- when no communication is established with the master WSD after the time validity for the parameters received previously, or
- losing communications with its serving master WSD within a period to be defined by the NRA,

A slave WSD may communicate with another slave WSD provided that each is controlled via communication over the band 470-790 MHz by its serving master WSD.

### 3.5 CONSIDERATIONS ON THE WSD LOCATION HEIGHT

A WSD may be operating indoors within a tall building and so be at a greater height above ground level than would normally be expected. While such a device may still be able to determine its x-y position using normal location methods, it is unlikely to be able to determine its height (z-position) since most location methods do not provide for accurate height information. It would be unreasonable to expect non-fixed WSDs to be able to return accurate height information and hence the geo-location database must accommodate this uncertainty. However, as already noted in § 3.3.1, the height information of fixed (professional installations) WSDs is usually known at the installation and, therefore, can be reported to and taken into account by the geo-location database.

A device high above ground level will have enhanced propagation as a result of being above the clutter. This may be balanced to some degree by a building penetration loss, but there is much variability in all of these factors. The propagation loss from an elevated WSD to a victim service may be modelled using the extended Hata<sup>8</sup> model, and the predicted loss is a function of device height.

Given that it is unclear to what degree terminals at raised heights will be problematic in terms of generated interference, a NRA might decide to introduce an additional margin into the geo-location calculations to account for this uncertainty. Another possibility for the NRA could be to monitor the situation, perhaps performing occasional measurements or deploying a sensor network. If evidence emerged to suggest that increased interference was likely then the database parameters for the relevant geographical area could be modified accordingly, perhaps with a higher margin. An alternative approach is to use the clutter height as a WSD height for the purpose of the calculations to be performed by the translation engine of the geo-location database.

## 4 REQUIREMENTS FOR GEO-LOCATION DATABASE MANAGEMENT

There are several issues related to the geo-location database management:

- *Technical information on services/systems to be protected*

This information, that should be loaded into the database, could either be a set of transmitter parameters (including antenna location, height and pattern, e.i.r.p., etc.) as well as the receiver (protection ratios, sensitivity, etc.) or a grid of pixels associated with characteristics of the received signals of incumbent services to be protected or some combination of the two.

- *Database update delay*

Database update delay is the period within which the database should be updated once protected services/systems provide a notice of a change in their assignments. If the assignment updates are provided electronically over the Internet the update delay may be very short. The assignments may be provided to each database directly, or distributed from one central database depending on the requirements set by the National Authority. In the latter case the update delay defines the delay through the whole link of interconnected databases.

- *Database update frequency*

Database update frequency is the periodicity with which the database should be updated so that the information it contains remains valid. This may be especially valid in case there is a master database and a number of query databases, which the WSD's will consult, and which have to have identical data related to incumbent use.

The appropriate update frequency will depend on the rate at which the assignments of the protected services/systems change and the notice provided. In general, protected services may need a rapid update as this will provide them with flexibility to make rapid changes to their assignments; this holds especially for PMSE and for DTT used in cases of events or field trials.

The type of protected services/systems and the speed with which they change their use of the spectrum may vary from country to country.

- *Translation of the information provided to the database into the basic elements in the database*

<sup>8</sup> The extended Hata model used is the same as the reference model contained in the SEAMCAT modelling tool see <http://www.erodocdb.dk/Docs/doc98/official/pdf/REP068.PDF>.

The database would have to convert the incumbent information provided to the database into a list of allowed frequencies and associated transmit powers to WSDs. Hence, a translation must be performed between these two.

It is clearly critical that this translation is performed appropriately. If it is not then there is a risk either of interference occurring to the protected services or of the WSDs' access to the spectrum being limited unnecessarily.

The translation mechanism depends on the type of a protected service and its coverage information already available. The cases when a WSD in one country could potentially interfere with a protected service in a neighbouring country should be taken into account in the translation process.

The database will provide WSDs with a maximum power level that it can use in a given location and for a particular frequency range. In arriving at these data, the algorithms employed need to ensure that a device in that location – plus a certain area of location uncertainty – transmitting with the given power level will not cause harmful interference to a protected service.

The algorithms need to know the potential location of receivers to be protected, the level of interfering signal they can tolerate before the interference becomes harmful and the propagation loss between the WSD and the receiver. If all these are known then the WSD transmitted power can readily be determined.

An example of the high level description of the general translation process is provided in Section 5.1. The algorithms used in the database may also take into account the frequencies and powers used by other WSDs.

## 5 TRANSLATION PROCESS FOR THE PROTECTION OF DIFFERENT SERVICES

As stated in Section 4, through the translation process the geo-location database will determine a list of allowed frequencies for WSDs and associated transmit powers. Both in-block and out-of-block emissions will need to be considered by the translation process and in this report these are defined as follows:

- In-block emissions are 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.
- Out-of-block emissions are emissions corresponding to those segments of a radiated signal's frequency spectrum (outside the in-block segment) which are generally unintended radiations. These typically result from finite filtering of the transmitted signal and intermodulation of the in-block signals within the transmitter power amplifier.

### 5.1 GENERAL APPROACH FOR GEOLOCATION DATABASE MANAGEMENT

The previous sections of this report presented the requirements for the technical information exchanged between the WSD and the geo-location database. This will be used by the translation process undertaken by the Geo-location database to determine the permitted operating conditions (power, frequency or area restrictions) for WSD.

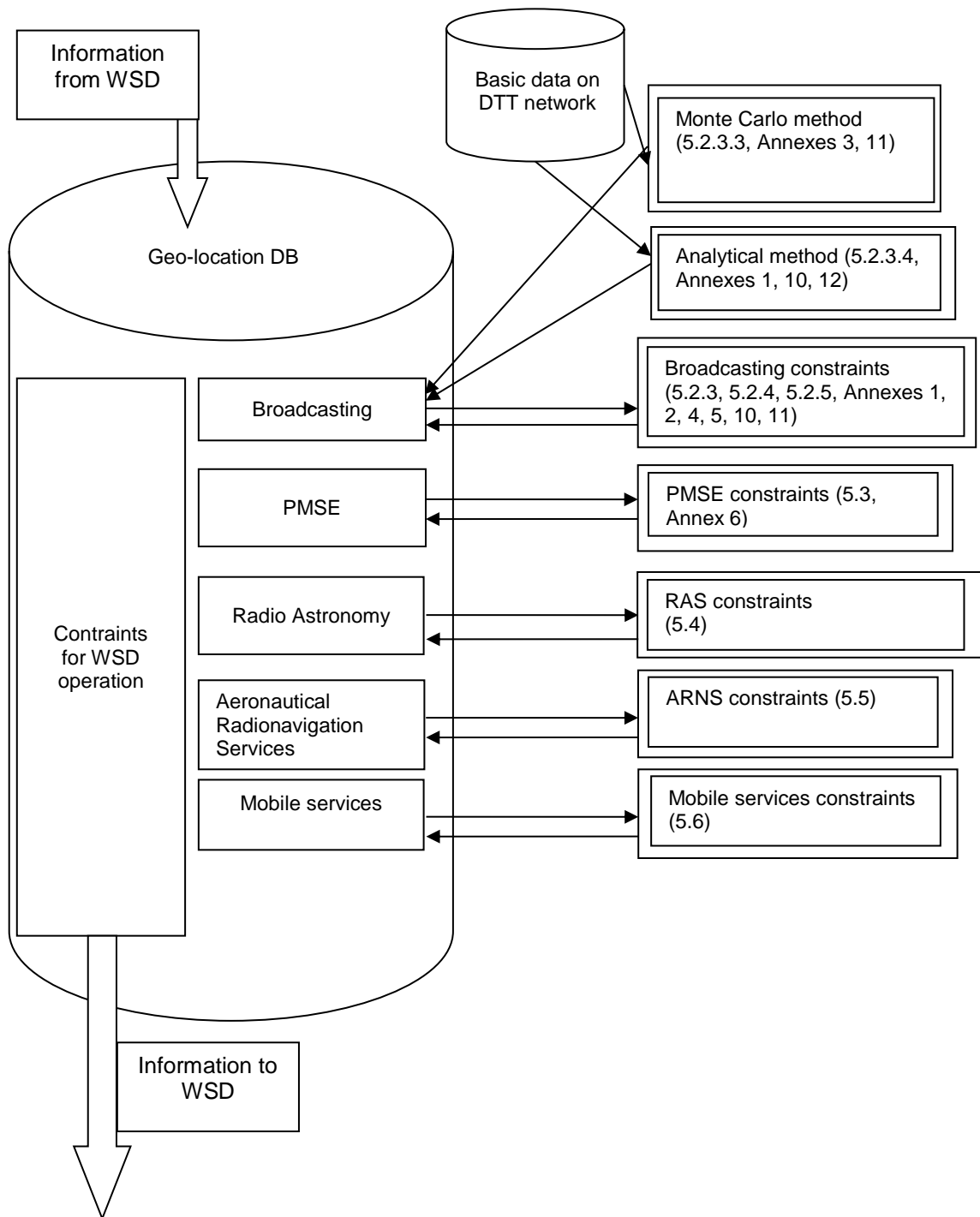
This section of the report presents the different methods proposed for the translation process that will be necessary to protect the relevant incumbent services. The set of incumbents requiring protection may vary on a national or international basis.

The database should contain information related to WSD as well to the services/systems to be protected (please refer to the section 5.1.1 below), namely:

- data from the authorised WSD: category, emission characteristics (maximum e.i.r.p., protection ratios, etc.), antenna characteristics (Tx- height and antenna directivity), WSD location and the authorised e.i.r.p.. Also, for some services it could be important to associate the power received by a certain WSD at a specific pixel (see below for more details);
- data from the victim services/systems, namely the location and protection related parameters (e.g., protection ratios, maximum field strength allowed, etc.). For each victim it is presented in sections below the minimum required data.

For each individual service/system analysed in the referred ECC Report 159 [1] and ECC Report 185 [16] it is presented in the sections below the corresponding methodology for the translation process. Then, taking into account the combination of the different restrictions, a final decision should be adopted and communicated to the WSD.

The figure below shows the different incumbent services and the corresponding sub section number where the associated translation process is described.



**Figure 3: Concept for the geo-location database translation process**

The geo-location database will complete the relevant translation process for each of the relevant incumbent services to be protected. The technical characteristics chosen by the database for configuring the WSD will depend upon each of these individual calculations. The e.i.r.p. available to WSD will be determined by the most stringent case. The corresponding sections provide detailed guidance on the algorithms and supporting information for the protection of each of the individual services.

**5.1.1 Recorded data of authorised WSDs**

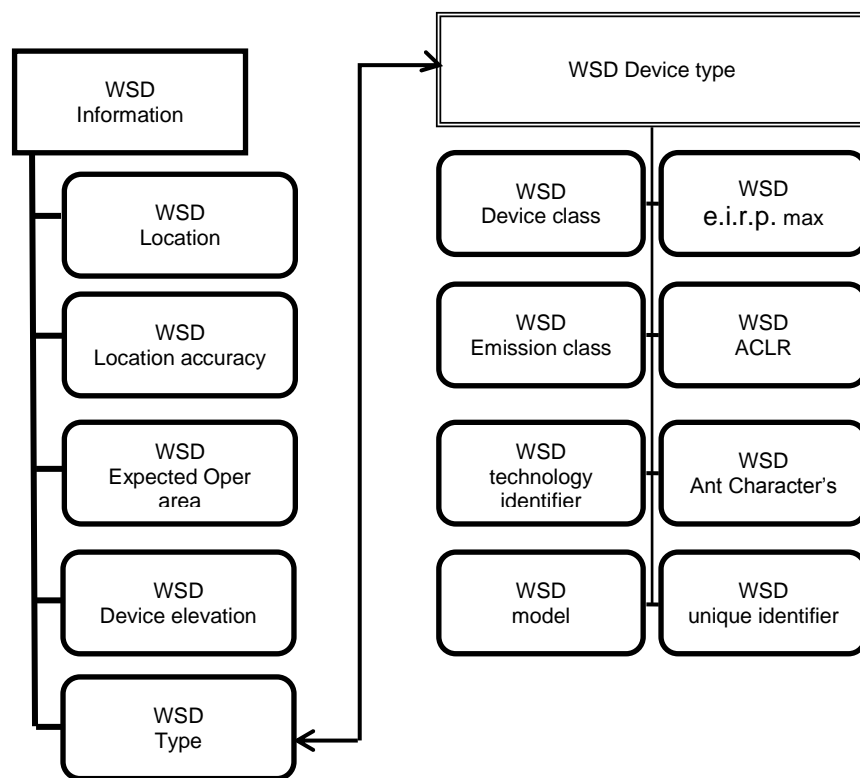
The database should store the characteristics of the WSD which have been authorised. These WSDs must confirm the frequency and the e.i.r.p. that they are using.

The database stores the following e.i.r.p. levels:

- e.i.r.p.-type-max: the maximum e.i.r.p. of the WSD type;
- e.i.r.p.-auth-max: the authorised maximum e.i.r.p.;
- e.i.r.p.-eff: the e.i.r.p. effectively used by the WSD and confirmed to the database.

For each WSD the database contains also the protection ratios that will be used for the calculation of the nuisance fields, for all the offsets corresponding to the relevant frequencies.

The following figure gives a schematic representation of the WSD characteristics that the database will need to perform particular calculations.



**Figure 4: WSD information stored in database**

## 5.2 PROTECTION OF THE BROADCASTING SERVICE IN THE BAND 470-790 MHz

Broadcasting is the primary service in the 470-790 MHz band.

The following sections in this document describe:

- How broadcast networks currently plan coverage accounting for self-interference.
- How the same methodology can be extended to calculate suitable power levels for a single WSD interferer
- How to calculate the additional interference margin necessary to compensate for aggregate interference from a number of WSD.
- Introduction of two different worked examples which are described further in the annexes for the full translation process.

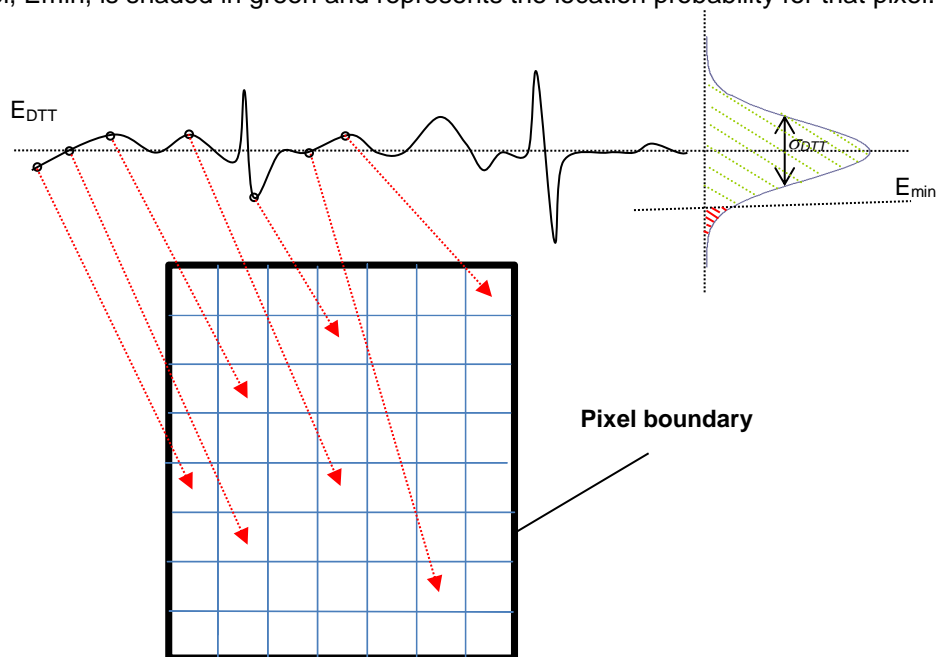
### 5.2.1 Methods for Planning the Coverage of Broadcast Networks

The total coverage area of a broadcast network is usually sub-divided into area units known as pixels. These are typically 100m by 100m in size. The quality of reception will vary with location and is characterised by the fraction of receivers that can receive the service in each pixel. This quantity is known as the location probability for that pixel.

It should be noted that the service area to be protected is typically only be a sub-set of the total coverage area of an individual transmitter. Broadcast services are usually planned with multiple overlapping transmissions from different transmitter sites and it is usual to protect only the best coverage. Furthermore, spill over coverage into international neighbours or adjacent regions of a country do not usually form part of the intended service area and may not require protection.

The location probability is determined by the ratio of the received carrier power to the power sum of the noise and unwanted interference. This quantity is known as the Carrier to Interference plus Noise ratio ( $C/(I+N)$ ). The wanted carrier power varies across the coverage area as will any interfering power from distant transmitters. For a particular location these quantities are characterised by statistical parameters, namely a median value and a corresponding standard deviation. The location probability is calculated for a pixel by considering the statistical variation of the signals within a pixel and assessing what fraction of the total pixel area has sufficient  $C/(I+N)$  to support demodulation of the digital TV signal.

Figure 5 illustrates how the signal strength, characterised by the electric field  $E_{DTT}$  might vary in a pixel together with the corresponding normal distribution. The fraction of locations that have signal level above a minimum level,  $E_{min}$ , is shaded in green and represents the location probability for that pixel.



**Figure 5: Variation of Electric field strength within a pixel**

In practice, the pixels in a broadcast network will be degraded both by noise and interference from other broadcast networks where the channel frequency is re-used<sup>9</sup>. Both the noise and the interference, with its associated statistics, must be considered to calculate the location probability for the pixel.

A further complication is the variation in interference over time. Certain atmospheric conditions can result in enhanced propagation particularly in the summer months and this tends to degrade the C/I+N and associated location probability. The effect is quite rare, cannot be easily predicted, and occurs for typically 1% of the year. It is commonly known as “*ducting*”, as the unwanted long range signals are ducted into the affected pixels by the unusual atmospheric conditions. As a consequence, the location probability for a pixel will depend both on its position in relation to the wanted transmitter and the time of the year. As the location probability for a pixel is time dependent, it is usually expressed for 50% time and 99% of the year; the 99% time figure takes account of the 1% time interference resulting from *ducting*.

The location probability is generally highest close to the centre of the broadcast cell, where the received signals are greatest and reduces as the distance to the transmitter increases. The edge of coverage is defined by the contour of pixels where the location probability has fallen to a level considered unacceptable by the NRA. In most of Europe, the edge of coverage is defined by the 95% location probability contour.

Broadcasters plan for 99% time coverage of their networks and take account for 1% time interference in order to provide a reliable service.

For example typically in Europe-R, reception at the DTT coverage edge is protected against interferers located outside of the DTT coverage area with a 95% location probability<sup>10</sup> (ensuring reception ‘almost everywhere’) and 99% time probability (‘almost all the time’).

To calculate the location probability, assumptions about the receiver and antenna quality must be made. Different reception modes (e.g. fixed, portable, mobile), will have different receiver parameters and different coverage areas.

Broadcasters plan for the various reception modes (e.g. fixed, portable, mobile.) in various environments (e.g. rural, sub-urban, urban). Network planning of broadcasting services is carried out on the basis of several assumptions, regarding reception modes and associated antenna and receiver characteristics. Interference calculations employ well defined reception and interference configurations, according to the required reception mode.

The concepts of time and location probability are fully discussed in the next sections.

## 5.2.2 Time and location probability

As discussed, the electric field strength within a DTT planning pixel is understood to have a normal distribution characterized by a median value and a standard deviation.

For modern DTT networks, the location probability is affected by both the receiver noise and the interference from other unwanted DTT stations which share the same frequency. The level of interference from the unwanted DTT stations is time dependent and can be described by a statistical model. These effects are accounted for in standard broadcast planning using time availability for the location probability.

The time varying propagation conditions (e.g. due to atmospheric conditions) result at any given site in a time-dependent fluctuation in field strength. Full details are given in section 5.2.2.1 below.

### 5.2.2.1 Time probability

In the presence of noise alone, digital television transmissions provide a very stable reception quality when the wanted signals are ‘sufficiently’ strong. The reception, accounting for noise alone, does not vary with time. Any time variability in reception quality is usually associated with long range interference from distant TV stations which occurs for short periods in a year, typically up to 3 days (1% time).

The reliability of the reception is determined by the carrier to noise ratio, [C/N]. Laboratory measurements to determine the required  $[C/N]_{ref}$  value are usually carried out using ‘constant’ wanted signal strength and constant noise level.

<sup>9</sup> Such interference depends on the network topology but typically originates from long range transmissions from distant DTT transmitters, either co-channel or adjacent channel, where the DTT frequency is re-used.

<sup>10</sup> This varies from 70% to 95% amongst Member States.



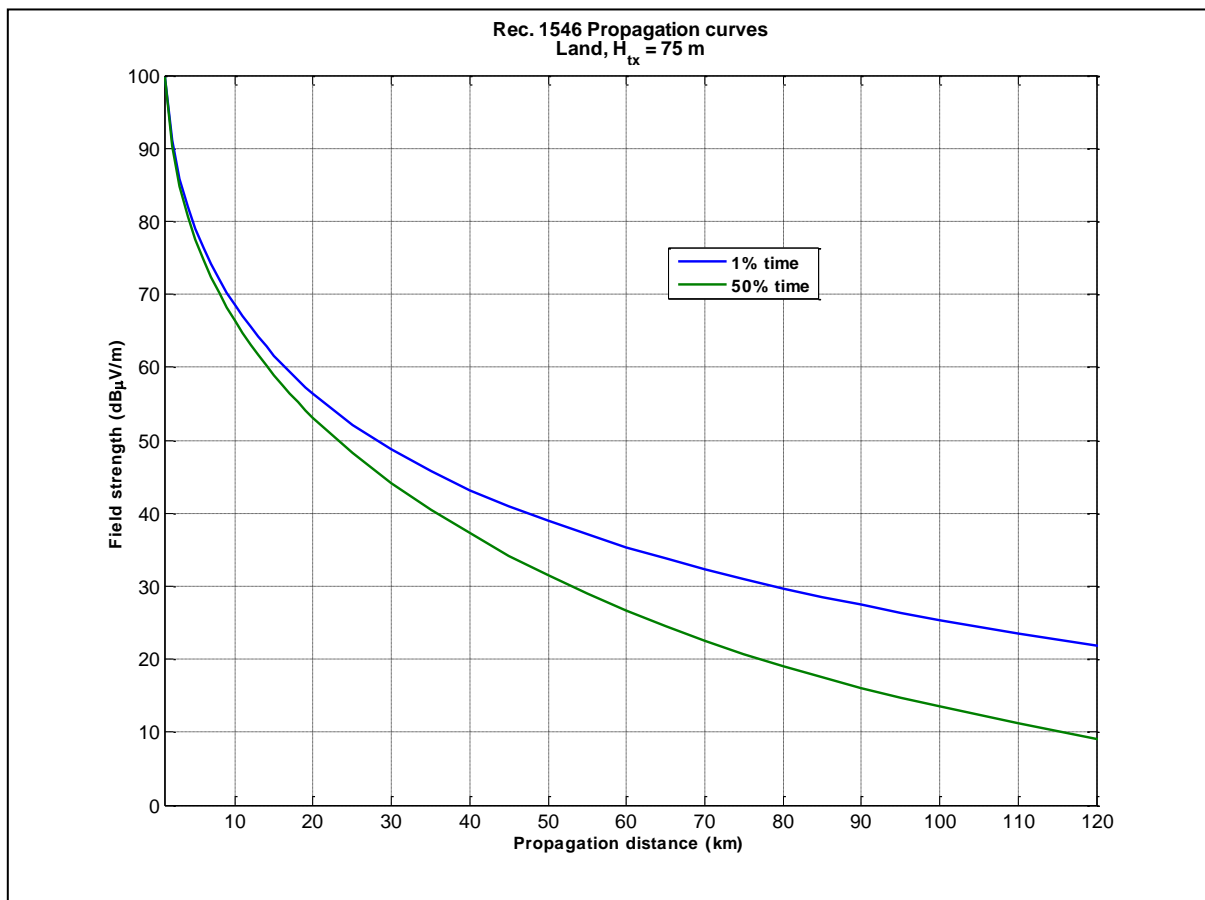
For the wanted signal, these temporally ‘constant’ conditions usually prevail within any DTT coverage area in the following sense:

- In Figure 6, a Recommendation ITU R P. 1546-4 [8] propagation curves are indicated for 1% and 50% of the time. The X% curve gives median (location) field strength values,  $E_{med}$ , which are exceeded X% of the time.
- The curve which would give median (location) field strength values which are exceeded for 99% of the time,  $E_{99\%}$ , is virtually identical to the 50% time curve and hence is not shown in the figure below. Thus choosing  $[E_{med}/N] \geq [C/N]_{ref}$  is essentially the same as choosing  $[E_{99\%}/N] \geq [C/N]_{ref}$ , in other words the  $[C/N]_{ref}$  limit is met or exceeded for 99% time, i.e. ‘always’ or ‘constant’.

For the interfering signals (which are to be protected against for 99% of the time), reference is made to the 1% time curves, i.e. those curves which detail the median (i.e. 50% location) fields exceeded for 1% of the time:

- (a) Note that the 1% time median (location) signal behaves very much differently than the 50% time median (location) signal. There is a difference between the 1% time curves and the 50% time curves, and this difference increases with propagation path distance. For small propagation distances (< 3 km), the difference is small (< 1 dB), growing larger (2 dB to 10 dB or more) as the propagation distance increases (5 km to 100 km, or more). Thus 1% time conditions tend to favour long range propagation, but have only a marginal effect at shorter distances.

It should be noted that the time variation of the propagating field does not follow an easily describable statistical distribution (e.g. a Gaussian distribution). For this reason the time statistics are reflected in the Recommendation ITU-R P.1546-4 [8] 1%-time and 50%-time propagation curves, respectively. Figure 6 below, compares the 1% and 50% time field strengths from Recommendation ITU-R P.1546 [8], considering a 1kW e.r.p. TV transmitter, at 75m height, as a function of distance.



**Figure 6: Comparison between 1% and 50% time propagation curves for a 1kW Transmitter at 600MHz operating at 75 m height**



### 5.2.2.2 Location probability

#### **Theoretical planning and protection aspects**

DTT *location probability* (LP) is defined over a unit area known as a pixel. It defines the fraction of the pixel area where the required minimum  $C/(I+N)$  is met for the desired broadcast mode and reception mode under consideration. A location probability of 100% would imply that the broadcast signal can always be received within the pixel. A location probability of 50% implies that only half of the possible locations within the pixel have sufficient  $C/(I+N)$  to receive the broadcast signal.

Location probability is widely used in the planning of DTT networks and will vary from a high value (almost 100%) at the centre of the broadcast cell, falling away to 0% outside the coverage area. A value of 95% is commonly used in Europe to define the edge of the protected coverage, where reception is considered less reliable, as 5% of locations within the pixel cannot receive the service<sup>11</sup>. If a minimum agreed reference LP (e.g. 95%) is reached everywhere on the DTT coverage edge, the coverage area is generally considered covered sites interior to the DTT coverage area typically have an even higher LP as the signal strength will be higher and the reception will be more reliable.

In order to quantify the quality of coverage throughout a DTT service area, LP is typically calculated for every  $100\text{ m} \times 100\text{ m}$  pixel across the country. The introduction of any additional interference naturally results in a reduction of the planned DTT location probability. Such a reduction in LP is therefore a highly suitable metric for specifying regulatory emission limits for WSDs operating in DTT frequencies.

In analytical terms, we can discuss LP as follows. Consider a pixel where the DTT location probability is  $q_1$  in the presence of noise and interference. Then it can be written (in the linear domain):

$$q_1 = \text{Prob}\left\{P_S \geq P_{S,\min} + \sum_{i=1}^K r_{U,i} P_{U,i}\right\} = \text{Prob}\{P_S \geq U\} \quad (1)$$

where:

- $\text{Prob}\{A\}$  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<sup>12</sup>;
- $P_{U,i}$  is the (1%-time) received power of the  $i^{\text{th}}$  unwanted signal;
- $r_{U,i}$  is the protection ratio for the  $i^{\text{th}}$  interferer.

In the planning of DTT networks,  $P_{S(\text{dBm})}$  and each individual  $P_{U,i(\text{dBm})}$  are modelled as Gaussian random variables.  $U$  represents the random variable which is the power sum of the individual interference sources and  $P_{S,\min}$ .

Note that in Equation (1), the (statistically varying) powers are summed in the linear domain and a closed form analytical solution is not possible. For this reason, the most accurate way of calculating the probability  $q_1$  is to use a Monte Carlo simulation where a large number of trials are performed with values for each variable generated according to their Gaussian distribution. Such a Monte Carlo approach is described in section 5.2.3.3. An approximate analytic approach is described in section 5.2.3.4.

### 5.2.2.3 General planning considerations of time and location probability

When planning broadcasting networks (e.g. at RRC-06) the protection criteria for international co-ordination are based on a 'constant' (50% time) median (for 50% locations) wanted signal, and a 1% time median (for 50% locations) interfering field strength.

As seen in Figure 6, for short propagation distances, less than 1 km or 2 km, the difference between the 1%-time ('rare') interference level and the 50%-time interference level is practically nil. This means that WSD interference sources inside a DTT coverage area, arriving over short distances, is nearly constant. In other words, the interference effects (e.g. DTT dropout when it occurs) are essentially continuous (i.e. 'all the time').

<sup>11</sup> Some CEPT countries define the coverage edge at 70% LP.

<sup>12</sup> 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. It corresponds to the DTT minimum median field strength.

For this reason, when dealing with short range WSD interference to DTT reception (i.e. with distances less than 1 or 2 km), where the interference is effectively constant in time, extremely stringent location probability restrictions must be imposed. In the past, when planning for analogue television, an additional 10 dB or so was added to the relevant protection ratios when the interference was continuous (i.e. for 50% time instead of 1% time).

### 5.2.3 Methodologies to calculate power levels for location-specific WSD

The methodology described in previous section describes how the coverage quality of a broadcast network can be evaluated and characterised by a quantity known as location probability (LP). For a particular unit area in the total coverage area of the transmitter, known as a pixel, the LP defines the fraction of that unit area where the DTT service can be received. The calculation of LP takes into account noise and interference from other DTT transmitters for both co-channel and adjacent channels. The relative effects of co-channel and adjacent channel interference are calculated using receiver protection ratios. The receiver protection ratios are determined by the adjacent channel selectivity characteristics of the receiver, the DTT broadcast mode and the characteristics of the interfering signals.

Since the planning method developed for broadcasting takes account of interference from other broadcasts, it can readily be extended to account for the effects of additional interference from WSD. The addition of WSD interference will inevitably degrade the LP within a pixel. The extent to which this degradation, and associated loss of coverage is acceptable is a decision for a NRA. A degradation of 0.1% would be practically imperceptible, whereas a 50% degradation would be unacceptable as, from a planning perspective, half the viewers in a pixel would be expected to lose service when the WSD operates.

The location probability for a pixel, taking into account interference from a WSD will be given by:

$$q_2 = \text{Prob} \left\{ P_S \geq P_{S,\min} + \sum_{i=1}^K r_{U,i} P_{U,i} + r(\Delta f) G P_{IB} \right\} = \text{Prob} \left\{ P_S \geq U + r(\Delta f) G P_{IB} \right\} \quad (2)$$

where

- $r(\Delta f)$  is the protection ratio for the WSD interferer at frequency offset,  $\Delta f$ , from the wanted DTT signal
- $G$  is the coupling gain between the WSD and the DTT victim receiver;
- $P_{IB}$  is the in-block power limit (e.i.r.p.) for the WSD.

Note all terms in the above equation are expressed in linear units.

The term  $G$  defines the coupling gain between the WSD and requires knowledge of the exact positions of the DTT receiver and the WSD. Since this cannot be precisely determined, assumptions need to be made about the possible location. For the case where the WSD is operating within the same, pixel<sup>13</sup> as a DTT receiver, the concept of reference geometry needs to be used. The reference geometry defines a possible coupling geometry between the WSD and a DTT receiver and ideally should take account of the closest separation possible to guarantee that interference to the DTT receiver will not occur. The reference geometry used will depend upon the type of WSD deployment (e.g. mobile, fixed, base station) and possible scenarios and the associated values for  $G$  are described in Annex 2.

The distance between the WSD and the DTT receiver,  $d_{\text{WSD\_DTT}}$ , and the antenna characteristics and associated discrimination (if any) allows  $G$  to be calculated.

Note the term  $r(\Delta f) G P_{IB}$  represents the received interference power from the WSD weighted by the protection ratio, which accounts for receiver selectivity and WSD interference characteristics. The term describes the effective received power from the WSD; WSDs operating at increased offsets  $\Delta f$  will have less impact on the LP as the protection ratios  $r(\Delta f)$  will generally be lower as a consequence of the receiver selectivity.

The reduction in location probability and subsequent loss in DTT coverage is given by:

<sup>13</sup> In practice it may be necessary to also consider the neighbouring pixels as the WSD may be located on a pixel boundary.

$$\Delta q = q_1 - q_2 = \text{Prob}\{P_S \geq U\} - \text{Prob}\{P_S \geq U + r(\Delta f)GP_{IB}\} \quad (3)$$

The received interference power from the WSD will define the degradation in LP and provides the interference budget necessary for WSD operation. The permitted e.i.r.p. ( $P_{IB}$ ) for the WSD is then determined by the coupling term G and the protection ratio. Note that different WSD types will be characterised by different protection ratios; devices which are more disruptive to DTT reception will require higher protection ratios and will be subject to lower limits for  $P_{IB}$ .

In relation to the acceptable degradation of the location probability,  $\Delta q_{lim}$ , two approaches can be followed:

(i) by defining of fixed value of  $\Delta LP$  for acceptable degradation to the location probability (example given in Annex 5 uses  $\Delta LP = 0.1\%$ ) throughout the DTT coverage area, respecting the most stringent DTT reception modes, i.e., fixed roof top, portable outdoor, portable indoor, according to the ambient DTT field strength

(ii) by defining upper limits for the acceptable degradation to the location probability throughout the DTT coverage area, respecting the most stringent DTT reception modes, i.e., fixed roof top, portable outdoor, portable indoor, according to the ambient DTT field strength.

Each NRA should consider the appropriate level for the degradation, balancing the usage of white spaces and guaranteeing the protection for the broadcasting service. Annex 5 presents the basis of both approaches as well the implications of the choice of  $\Delta LP$  level.

In addition, the WSD e.i.r.p. should be restricted to an absolute maximum level defined by the DTT overloading threshold,  $O_{th}$ , corresponding to each DTT reception mode and channel adjacency. This corresponds to satisfying the following inequality:

$$\text{Prob}\{GP_{IB} > O_{th}\} < \Delta q_{lim} \quad (4)$$

Further details are discussed in Annex 5.

The three modes of DTT reception, fixed roof top, portable outdoor and portable indoor can be protected, progressively, from the DTT coverage edge moving inwards toward the DTT transmitter. The switch to each mode is made as function of the wanted field strength level by referring to the thresholds of field strength above which a given mode of reception is possible (going from fixed roof top to portable outdoor to portable indoor). Refer to ANNEX 4: to more detailed calculations.

This methodology defines the maximum e.i.r.p. for a single WSD interfering with a DTT receiver in a pixel. In practice if multiple devices operate within a pixel, interference aggregation can occur and it may be necessary to reduce the WSD e.i.r.p. limits to avoid exceeding the acceptable degradation in LP. Approaches to deal with this problem are described in section 5.2.4.

### 5.2.3.1 WSD location considerations and requirement for reference and non-reference geometries

WSDs can cause interference to DTT reception in two different ways:

- Interference from WSDs operating inside a given DTT transmitter coverage area

Because of the extremely high interference potential of co-channel usage, the WSDs will be limited to using frequencies adjacent to that (or those) of the DTT service(s) in the area in question. Consideration of 'short distance' WSD interference provides one of the main constraints on WSD e.i.r.p. limits, in particular because of its 'continuous' effect. Several 'reference interference scenarios' have been developed (see Annex 2) to calculate the 'nearby' interference effects.

- Interference from WSDs operating outside a given DTT transmitter coverage area

Due to greater separation distances between WSD interferer and DTT receiver, potential co-channel interference will tend to be the most significant, but care must also be taken with respect to certain adjacent channel usage. Consideration of 'longer distance' WSD interference provides the other constraints on WSD e.i.r.p. limits (especially for high power WSD base stations). Monte Carlo techniques as well as approximate analytical formula can be used to determine WSD e.i.r.p. limits for each scenario. The coupling term G in equation 3 will be calculated using the actual distance from the WSD to the pixel under consideration. This

distance is sometime referred to a “non-reference geometry”, as the actual distance between the WSD and the protected DTT pixel is used to determine the coupling gain.

### 5.2.3.2 Determination of maximum WSD received power

The degradation in LP considered acceptable by a NRA will determine the maximum level of interference that can be tolerated at the DTT receiver. The e.i.r.p. that can then be radiated by the WSD will be determined by the reference and non-reference geometries. To calculate the maximum acceptable received interference, equation 3 must be solved. Numerical techniques (i.e. a Monte Carlo simulation) or an analytical approximation must be used as it is not possible to provide a simple closed form solution.

These two approaches are discussed in the following two subsections.

### 5.2.3.3 Monte Carlo simulation approach

Monte Carlo simulations can be used to determine location probability in situations where a statistically varying wanted DTT signal is present and also noise and one or more statistically varying interfering sources are present. In other words, Monte Carlo simulations can be used to evaluate equation (1) in an exact manner<sup>14</sup>.

To briefly sketch how a Monte Carlo simulation is effected, we first list the relevant parameters that would be included and indicate how they are used:

- $E_{W\_med}$ ,  $\sigma_W$ : median wanted DTT field strength and standard deviation;
- $r_{U,i}$ : the appropriate protection ratio(s) corresponding to the relevant frequency offset(s)  $\Delta f$ ;
- $E_{WSD\_med\_J}$ ,  $\sigma_{WSD\_J}$ : median WSD interfering field strength and standard deviation for J interferers;
- $POL_J$ ,  $ATT_J$ ,  $DISC_J$ : polarization discrimination(s), transmit antenna attenuation(s), receive antenna discrimination(s).

In a Monte Carlo simulation, a large number of ‘trials’ are made in which the statistical variables are used; and on the basis of the statistics of the trials, probabilities (in our case, location probabilities) can be calculated.

For each trial the following calculations are carried out:

- a random wanted DTT field strength is calculated using  
 $E_W = E_{W\_med} + \text{random (Gaussian, } \sigma_W) \text{ variation}$
- random interfering WSD field strengths, for each interferer J, are calculated using  
 $E_{WSD\_J} = E_{WSD\_med\_J} + \text{random (Gaussian, } \sigma_{WSD\_J}) \text{ variation};$
- The corresponding nuisance<sup>15</sup> fields,  $NU_{WSD\_J}$ , are calculated using the  $E_{WSD\_J}$  with the relevant protection ratios, POL, DIR, etc;
- The power sums for the  $NU_{WSD\_J}$  and the noise nuisance field  $NU_N$  are carried out for each trial, leading to a ‘total’ nuisance field  $NU_{sum}$ , which is compared to the trial value of  $E_W$ .
- The ratio of the number of trials where  $E_W \geq NU_{sum}$  to the total number of trials gives the location probability, LP, in the presence of the interfering WSDs and the noise.

In cases where the degradation in LP is to be calculated when WSD interference is introduced, it is necessary to carry out two complete Monte Carlo simulations, one for the initial situation without WSD interference (giving  $LP_{before}$ ), and the second with the WSD interference included (giving  $LP_{after}$ ). The degradation in LP,  $\Delta_{LP}$ , is calculated as  $\Delta_{LP} = LP_{before} - LP_{after}$ .

### 5.2.3.4 Analytical approximation approach

We extend and simplify the mathematical notation in Equation (1) as:

$$q_I = \text{Prob} \left\{ P_S \geq \sum_{i=0}^K r_{U,i} P_{U,i} \right\} \quad (5)$$

<sup>14</sup> Monte Carlo simulations provide the most accurate results because the statistical variations of the signals are taken into account in a comprehensive manner. Because of the ‘complete’ incorporation of the statistics, a computer must be used for the simulations

<sup>15</sup> ‘Nuisance field’ is defined, and its use described, in Annex 3.

where

$$r_{U,0} = r_N = 10^{C/N/10}, \text{ with the minimum } [C/N] \text{ ratio,}$$

$$P_{U,0} = P_N, \text{ the noise power}$$

$q_1$  expresses the location probability that the wanted DTT power is stronger than the total (power summed) interfering power.

If an additional received interfering power,  $P_{wsd\_rec}$  with protection ratio  $r_{wsd}$ , is introduced, the location probability will be reduced to  $q_2$

$$q_2 = Prob \left\{ P_S \geq \sum_{i=0}^K r_{U,i} P_{U,i} + r_{wsd} P_{wsd\_rec} \right\} \quad (6)$$

Two new random variables,  $Z$  and  $Z'$ , can be introduced by defining

$$Z = P_S - \sum_{i=0}^K r_{U,i} P_{U,i} \quad (7)$$

and

$$Z' = \begin{cases} Z, & Z \geq 0 \\ 0, & Z < 0 \end{cases}$$

$Z'$  (dBm) can be approximated by a log-normal random variable,  $\hat{Z}_{dBm}$ , which has mean  $m_{\hat{Z}_{dBm}}$  and standard deviation  $\sigma_{\hat{Z}_{dBm}}$ .

and the maximum WSD e.i.r.p.. is

$$P_{wsd\_tx\_dBm} \leq m_{\hat{Z}_{dBm}} - m_{G\_dB} - r_{wsd\_dB} - \sqrt{2} \operatorname{erfc}^{-1} \left[ 2 \left( 1 - \frac{q_2}{q_1} \right) \right] \sqrt{\sigma_{\hat{Z}_{dBm}}^2 + \sigma_{G\_dB}^2} \quad (8)$$

A margin,  $IM_{dB}$ , to account for multiple interfering WSD sources or as a 'safety factor', could be added to this expression, if desired.

Equation 5-8 summarizes the following information:

- An existing interference situation (represented by a median interference power  $m_{\hat{Z}_{dBm}}$ , a normal distribution with standard deviation  $\sigma_{\hat{Z}_{dBm}}$ ) leads to  $q_1\%$  LP for DTT reception,
- A single additional allowed (e.g., WSD) interferer (represented by a (maximum) transmitted e.i.r.p.  $P_{wsd\_tx\_dBm}$ , with a median coupling gain,  $m_{G\_dB}$ , a log-normal distribution with standard deviation  $\sigma_{G\_dB}$ , and protection ratio  $r_{wsd\_dB}$ ) leads to  $q_2\%$  LP for DTT reception, where  $q_2 < q_1$ .
- The resulting degradation in LP is  $\Delta_{LP} = q_1 - q_2$ .
- Looking at it the other way around, if a desired  $\Delta_{LP}$  is required, choosing  $q_2 = q_1 - \Delta_{LP}$  in Equation A12-12 will provide the maximum single-entry WSD e.i.r.p.,  $P_{wsd\_tx\_dBm}$ , which leads to an LP degradation not exceeding the desired  $\Delta_{LP}$ .

The full mathematical details are provided in Annex A12.

### 5.2.3.5 Considerations of WSD out-of-block emission limit

The receiver protection ratios are defined taking into account the out-of block characteristics of the WSD interferer and so out of block limits are considered implicitly in equation 5-8 and the methodology described so far.

This is because the protection ratio is a function of both the spectral leakage of the WSD transmitter and the spectral selectivity of the DTT receiver. Specifically, the protection ratio  $r(\Delta f)_{(dB)}$  is given (in the linear domain) by:

$$r(\Delta f) = \frac{P_S^*}{P_{AC}^*} = \frac{P_S^*}{P_I^*} \cdot \frac{P_I^*}{P_I^*} = r(0) \frac{1}{ACIR(\Delta f)} = r(0) (ACLR_{CR}^{-1}(\Delta f) + ACS_{DTT}^{-1}(\Delta f)) \quad (9)$$

where:

1. \*: denotes the value at the point of receiver failure;
2.  $P_I$ : is the interference power;
3.  $P_{AC}$ : is the power of the adjacent channel interferer;
4.  $ACIR$ : is the adjacent-channel interference ratio;
5.  $ACLR_{CR}$ : is the adjacent-channel leakage ratio of the WSD transmitter;
6.  $ACS_{DTT}$ : is the adjacent-channel selectivity of the DTT receiver.

By definition, the maximum permitted WSD out-of-block emission level,  $P_{OOB}^{CR}$ , is given (in the logarithmic domain) as

$$P_{OOB}^{CR}(\Delta f) = P_{IB}^{CR} - ACLR_{CR}(\Delta f) \quad (10)$$

If the emission limits for a WSD with lower ACLR performance are required, the protection ratios used must be increased to account for the increased interference potential of the WSD with lower ACLR. Four classes of WSD ACLR are under consideration by ETSI BRAN and different emission limits will apply. The appropriate protection ratios must be measured using the actual ACLR characteristics of the WSD or estimated. Further information on this is available in the ECC Report 185 [16].

#### 5.2.4 Approaches to account for interference aggregation from multiple WSDs

This section introduces three different methodologies for deriving interference margins ( $IM$ ) to take account of multiple interferers as follows:

- Fixed/Predetermined  $IM$  value setting based on the potential maximum number of WSD interferers in each operational frequency in a given area at the same time;
- Flexible  $IM$  value setting based on the maximum number of active/actual WSD interferers, in a given area operating at the same time;
- Flexible minimized  $IM$  value setting based on the actual characteristics of each active WSD interferer in each operational frequency of WSD in a given area at the same time".

In Section 5.2.3.4 equation (8), was derived providing an approximate upper limit for a single WSD interferer. This would be insufficient to protect a DTT installation if subjected interference from two or more WSDs, each radiating at the single-device e.i.r.p. limit. An additional margin,  $IM_{dB}$ , will be required to account for multiple interfering WSD sources to provide the necessary 'safety factor'. This section presents three methods that could be used to determine the appropriate  $IM_{dB}$ .

Consider equation 5-8 again, this time with an additional 'multiple interference margin',  $IM_{dB}$ :

$$P_{wds\_tx\_dBm} \leq m_{z\_dBm} - m_{G\_dB} - r_{wds\_dB} - \sqrt{2} \operatorname{erfc}^{-1} \left[ 2 \left( 1 - \frac{q_2}{q_1} \right) \right] \sqrt{\sigma_{z\_dB}^2 + \sigma_{G\_dB}^2} - IM_{dB} \quad (11)$$

It should be noted that the relative frequency offsets between wanted DTT and interfering WSDs are reflected in the protection ratio term,  $r_{wds\_dB}$ . This means that, for example, three different WSD powers may

have the same individual interference effect, because they are perhaps working in different channels, co-channel, 1<sup>st</sup> adjacent, 2<sup>nd</sup> adjacent:

$$P_{\text{wsd0}} = -50 \text{ dBm}, P_{\text{wsd1}} = 0 \text{ dBm}, P_{\text{wsd2}} = 10 \text{ dBm}.$$

Nevertheless, the same  $IM_{dB}$  factor would apply to each of them when attempting to compensate for aggregate interference.

If a set of WSD base stations (or UEs) lies outside of a DTT coverage area, the cumulative interference of those interferers at the DTT coverage edge will force the e.i.r.p. values of the individual base stations to be reduced compared to the values they could have if they were 'acting alone'. One way to deal with this situation is to introduce a fixed 'multiple interference margin',  $IM$ , in the 'single entry' protection criteria (as done in Equation 5.1-8 above), in order to make an estimated correction to the total cumulative effect. This could be done on the basis of an assumed number of interferers, e.g.  $IM_{dB} = 10 \log_{10} N$ , if there are  $N$  assumed WSD interferers. If the assumed number,  $N$ , is larger than the actual number of WSDs simultaneously transmitting, the restriction on the e.i.r.p. of the WSD base stations would be more severe than necessary. If the assumed number,  $N$ , is smaller than the actual number of WSDs simultaneously transmitting, the interference at the DTT coverage edge would exceed the allowed limit.

**Any of the following three methods, described in the subsections below, could be used to determine the appropriate (though approximation)  $IM_{dB}$  value for multiple base stations and/or UEs in a WSD network in order to maintain the required protection of the incumbent DTT service.**

The first two methods are based on the assumption that  $N$  interfering powers add, and a power reduction factor  $10 \log_{10} N$  dB should provide an adequate compensation.

#### **METHOD 1: Fixed/Predetermined $IM$ value**

This approach is based on the potential maximum number of interferers in each operational frequency in a given area at the same time which is defined as follows:

$$IM_{dB} = 10 \log_{10} (N_{\text{potential maximum number of interferers}}) \quad (12)$$

It would be up to the geo-location database to determine in each area what the potential 'maximum number' of WSD interferers might be. The disadvantage here is that the 'maximum number' of WSDs might not be all working at the same time. This situation would impose an additional, unnecessary restriction on WSD usage.

#### **METHOD 2: Flexible $IM$ value**

This approach is based on the maximum number of active/actual interferers, in a given area operating at the same time, which is defined as follows:

$$IM_{dB} = 10 \log_{10} (N_{\text{number of active interferers}}) \quad (13)$$

It would be up to the geo-location data base to determine in each area what the actual 'maximum number' of active WSD interferers is at any given time. The disadvantage here is that some of the WSDs might be working far below the maximum allowed e.i.r.p. Thus, the required reduction may be more than actually needed, again imposing an unnecessary restriction on WSD usage, although less than the 'fixed/predetermined' approach.

#### **METHOD 3: Flexible Minimized $IM$ value**

This approach is based on the characteristics of each active interferer, registered in the geo-database, in each operational frequency of WSD in a given area at the same time.

The flexible minimized margin is 'fitted' to correspond to the number of active WSD interferers, and their relative interfering nuisance powers, so its calculation engine must check the changes to the number of active WSD interferers in each operational frequency of WSD in cases where i) a 'new' WSD starts operation, ii) an 'old' WSD stops operation and iii) a WSD changes from active state to power-off/power-saving mode.

The method is carried out in the following steps:



- The desired value of acceptable degradation to LP is selected ;
- Test pixels,  $L = 1, \dots, T$ , are chosen (e.g., along the DTT coverage edge) for the interference calculation. Within each pixel $_L$ , the allowable nuisance power level for DTT receiver in pixel  $L$  is calculated to be  $P_{allow\_nuis\_L}$ ;
- The existing LP,  $q_{1L}$ , is calculated for each pixel $_L$  taking account of all interference except WSD interference;
- For each WSD $_J$ , registered at the geo-database,  $J = 1, \dots, K$ , the single entry WSD transmitter e.i.r.p.  $P_{wsd\_tx\_LJ}^{SE}$ , is calculated for each pixel $_L$ , according to Equation (5-11), using  $q_1$ ,  $q_2 = q_1 - \Delta_{LP}$ , and the other known WSD $_J$  parameters.
- For each WSD $_J$ , a 'trial' e.i.r.p. is selected as the minimum of the  $P_{wsd\_tx\_LJ}^{SE}$  over all of the pixels,  $L=1, \dots, T$ ,

$$P_{trial\_tx\_J}^{SE} = \min_{L=1, \dots, T} \{ P_{wsd\_tx\_LJ}^{SE} \} \quad (14)$$

- In the  $L^{th}$  pixel $_L$ , the  $J^{th}$  WSD $_J$  single entry nuisance power,  $P_{nuis\_LJ}^{SE}$ , at the DTT receiver is calculated using

$$P_{nuis\_LJ}^{SE} = P_{trial\_tx\_J}^{SE} + G_{LJ} \quad (15)$$

where  $G_{LJ}$  is the coupling gain for the  $J^{th}$  WSD $_J$  with respect to the  $L^{th}$  pixel $_L$ .

- For  $q_2\%$  LP, the following inequality holds for each pixel $_L$  and WSD $_J$  nuisance power:

$$P_{allow\_nuis\_L} \geq P_{nuis\_LJ}^{SE} \quad (16)$$

- Thus, for each pixel $_L$ , we can define a maximum allowed nuisance power

$$P_{nuis\_L}^{MAX} = P_{allow\_nuis\_L} \quad (17)$$

- The power sum of the single entry nuisance powers of each WSD $_J$ ,  $J = 1, \dots, K$ , is calculated at each test pixel $_L$ , yielding the 'overall' nuisance power at each test pixel $_L$ ,  $L = 1, \dots, T$ ,

$$P_{nuis\_L}^{OVERALL} = 10 \log \left( \sum_{\oplus J=1}^K 10^{\frac{P_{nuis\_LJ}^{SE}}{10}} \right) \quad (18)$$

- A 'flexible minimized margin',  $\alpha$ , is defined as the minimum difference of:

$$P_{nuis\_L}^{MAX} - P_{nuis\_L}^{OVERALL} \quad (19)$$

for all the test pixels,

$$\alpha = \min_{L = 1, \dots, T} (P_{nuis\_L}^{MAX} - P_{nuis\_L}^{OVERALL}) \quad (20)$$

where  $\alpha$  represents a flexible term which is to minimize  $IM_{dB}$  every time a new interference situation arises (for example, whenever a 'new' WSD starts operation, or an 'old' one stops operation).

- The maximum allowed WSD $_J$  e.i.r.p.s,  $P_{tx\_J}^{maxallowed}$ ,  $J = 1, \dots, K$ , are chosen such that:



$$P_{tx\_J}^{\max \text{ allowed}} \leq P_{trial\_tx\_J}^{SE} + \alpha \quad (21)$$

Simulation results for this calculation method are presented in Annex 1.

### 5.2.5 Introduction of two different worked examples for the translation process for the protection of DTT

Two broadly equivalent worked examples have been developed to illustrate how a geo-location database could be constructed. Both examples use the concept of an acceptable degradation in LP to calculate a maximum received interference power from the WSD. One example suggests a Monte-Carlo simulation to determine this quantity, and the second one uses an analytical approximation. This analytical approximation was chosen to reduce the computing time for the calculations.

With regard to aggregate interference, the Monte Carlo approach uses a method where the database attempts to track the aggregate received power at the DTT victim receivers and reduces the WSD emission limits as the number of WSDs increase.

The analytical approach does not deal with aggregate interference with this level of complexity and a fixed IM would be required. Also, this approach recognizes that not all broadcast coverage areas, in a particular pixel will be protected. Only the service area needs to be protected. This is a consequence of overlapping coverage areas in an MFN network supporting regional variations. It should be noted that the Monte-Carlo approach does not cover this aspect.

The referred two examples are detailed in ANNEX 10: and ANNEX 11:.

## 5.3 PROTECTION OF PMSE IN THE BAND 470-790 MHz

### 5.3.1 Scope

This section provides a brief introduction to PMSE equipment and its use and outlines the administrative considerations in the protection of PMSE. It is followed by a section which discusses technical considerations taken during several measurement campaigns and studies. This section concludes with a practical discussion and a worked example showing how a PMSE installation might be protected.

### 5.3.2 Introduction to PMSE

PMSE (Programme Making and Special Events) is a term covering many different wireless production systems operating in a number of frequency bands. For this report we focus on wireless microphone systems using the band 470-790 MHz, also referred to as professional wireless microphone systems (PWMS). PWMS includes wireless microphones (typically hand-held or body-worn devices), In-Ear Monitoring (IEMs) and other audio systems including fixed point-to-point links for programme contribution feeds.

There is no single scenario which describes the diverse usage of PMSE; compatibility and sharing studies must consider various possible scenarios. The parameters required for a geo-location approach will also be dependent upon the PMSE application and usage scenario. For example, an outdoor event, using receive antennas at elevated height, will require a larger exclusion zone than an indoor application.

PMSE receiver locations may be fixed in the case of radio microphones, or mobile in the case of IEMs and airborne use for sporting events. Non-airborne PMSE use cases include indoor and outdoor applications at antenna heights ranging from 1.5m to 10m or 30m and will be significantly higher for airborne use.

From the geo-location point of view the two main scenarios for PMSE are:

- Stationary site, such as a theatre, studio or a concert hall/stadium: In this category PMSE could be used either outdoors or indoors, but typically the locations would cover a building, or a few buildings or a limited area. Typically these sites stay in the same location and PMSE is used daily or frequently.

- Temporary sites such as an exhibition, sports event, interview at a location related to TV Programme making, etc. In this case, the PMSE could also be used either indoors or outdoors, in fixed or mobile manner. The nature of this use is temporary.

In order to manage and protect the above requirements efficiently it will be necessary to address both the administrative and technical concerns of the PMSE users when setting up a geo-location database for cognitive devices.

### 5.3.3 Administrative Considerations When Providing PMSE Protection

On the administrative side, it is crucial that PMSE users who need interference protection can conveniently register<sup>16</sup> their locations in the database. The registration process must be straightforward and easy to complete so that it can be done quickly in line with the timescales and needs of the PMSE industry. The question of how frequently the database should be updated and how often WSD should re-consult it is also a factor that will be important to PMSE users. This is particular true for PMSE applications, TV-productions and Electronic News Gathering (this can change on an hourly basis). It could be beneficial if the PMSE registration includes the dates and times when the PMSE equipment will be operational and the exact location of each receiver requiring protection.

### 5.3.4 Technical Consideration When Providing PMSE Protection

From the compatibility testing identified in ECC Report 185 [16] a number of interference parameters have been identified. Whichever methodology of protection is used the following should be considered:

#### 5.3.4.1 Safe Harbour

When an NRA is employing safe-harbour channels to accommodate PMSE needs (see section 5.6 of ECC Report 159 [1] for the discussion on the safe-harbour), the geo-location database will simply exclude these channels from the list of candidate channels for WSDs with the appropriate restrictions on adjacent channel usage.

#### 5.3.4.2 Principles of Protection

Both fixed and mobile PMSE receivers will require protection. Interference from a WSD will potentially degrade the sensitivity of the PMSE receiver and a NRA will define the maximum allowable degradation. To achieve this, the received interference power from the WSD must usually be positioned below the noise floor of the PMSE receiver. Using this interferer-to-noise ratio (I/N) approach, the maximum received interference power at the PMSE receiver can then be calculated for the co-channel case given the chosen sensitivity degradation. By using an appropriate propagation model, a set of power restrictions for a WSD operating in the vicinity of the PMSE receiver can then be calculated.

Similarly, the required WSD e.i.r.p. limits for a device operating in the adjacent channels of the PMSE receiver can be calculated by considering the ACS of the PMSE receiver and the ACLR of the WSD at the chosen frequency offset. The same I/N approach would be used, but the interference power received at the PMSE receiver must be calculated using the appropriate ACS and ACLR values.

#### 5.3.4.3 Co-Channel Operation

Using the methodology described in the principles of protection above, it appears that co-channel operation of WSD within the operational area of PMSE receivers would be impractical. Consequently, a co-channel exclusion zone around the PMSE receiver is envisaged.

The exclusion zone required around a PMSE receiver will vary with the power, type and bandwidth of the WSDs. For example, simulations and measurements indicated the following:

- Seamcat simulations indicated separation values of 650m for a 100mW (+20dBm) WSD with a 5MHz bandwidth increasing to 1km for a 1MHz bandwidth WSD with a 5% probability of interference. Increasing these distances by 10% reduces the probability of interference and provides a safety margin (refer to Annex 13).

<sup>16</sup> Denmark currently uses a smart phone application to allow user to identify usable radio microphone channels at their location. This could potentially be used in the future to register the location of PMSE to be protected.

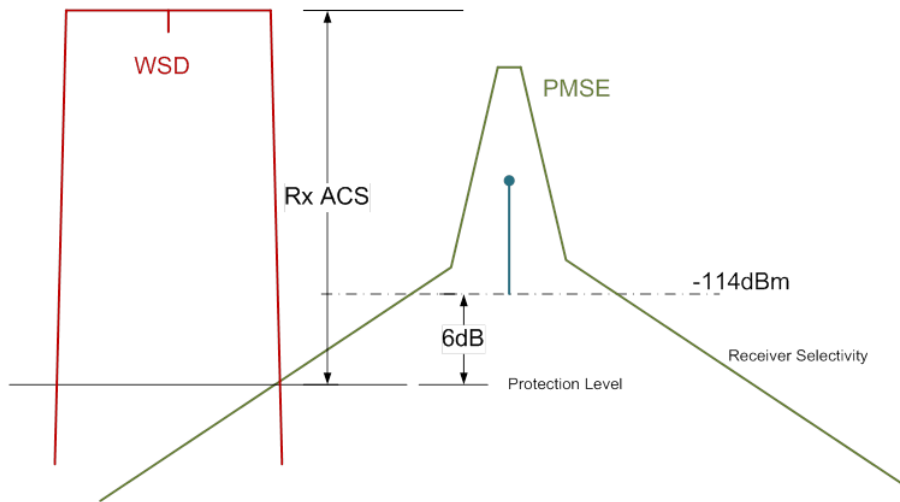
- Theatre measurements described in ECC Report 185 [16], indicated that separation distances of 400m were necessary to protect the indoor PMSE receiver from an outdoor 400mW e.i.r.p. WSD operating in a dense urban environment.

#### 5.3.4.4 PMSE Receiver Adjacent Channel Selectivity (ACS)

The selectivity characteristics of the receiver will be expressed in terms of protection ratios that define the minimum ratio of the wanted PMSE signal to unwanted WSD interference for an acceptable impairment in performance. The protection ratios depend upon the frequency offset between the PMSE and WSD signals, the ACLR characteristic of the WSD and also the saturation characteristics of the PMSE receiver. The saturation characteristics can be modelled in detail or simplified by considering an overload threshold. From these protection ratio measurements, receiver ACS values can be derived.

By referring to the measurement results, presented in Annex 10 of ECC Report 185 [16], where a number of different receivers were tested, the typical spread of receiver ACS was found to be between 45dB and 65dB for the first adjacent channel. Receiver overloading typically occurred for interferer levels between -20 dBm and 0dBm.

Consider two signals being received by a PMSE receiver, one from a white space transmitter (in red) and another from a radio microphone (in blue) in adjacent TV channels. The receiver selectivity characteristic is indicated in green.. The dashed line represents the noise floor of the receiver. The solid line below this represents the effective level of WSD interference degrading the receiver sensitivity, and is calculated by subtracting the ACS value (in dB) for the receiver from the level of received power from the WSD. The maximum permitted value is known as the “protection level” and will be determined by the chosen I/N value.



**Figure 7: Rx ACS Considerations**

For wideband whitespace signals (typically 5MHz bandwidth in a single TV channel), we also need to apply a correction factor, as not all of this signal will appear at the PMSE demodulator. The bandwidth of a typical PMSE Rx is about 200 kHz. So the proportion of the WSD power that appears in the PMSE receiver bandwidth is:

$$BW_{corr} = 10 \cdot \log_{10} \left( \frac{BW_{PMSE}}{BW_{WSD}} \right) \quad (22)$$

Then the maximum allowable power of the WSD at the PMSE Rx can be calculated:

$$WS_{P_{RX}} (dBm) = \Psi + BW_{corr} + Rx_{ACS} \quad (23)$$

where:  $\Psi$  is the PMSE protection Level in dBm (i.e. receiver noise floor + acceptable I/N value)  
 $BW_{corr}$  is the bandwidth correction factor in dB  
 $Rx_{ACS}$  is the PMSE receiver's adjacent channel selectivity (ACS) in dB

5.3.4.5 ACS considerations for multiple narrowband WSD slave signals

Now consider a different sort of slave WSD that simultaneously uses narrow band signals, when connected to a master WSD. As the bandwidth of the slave WSD signal is less than the bandwidth of the PMSE receiver, all of its power will be seen by the PMSE receiver and now we do not get the benefit of  $BW_{corr}$ . Additionally, as the frequency offset of the narrowband slave WSD reduces in relation to the PMSE signal, the ACS is much reduced.

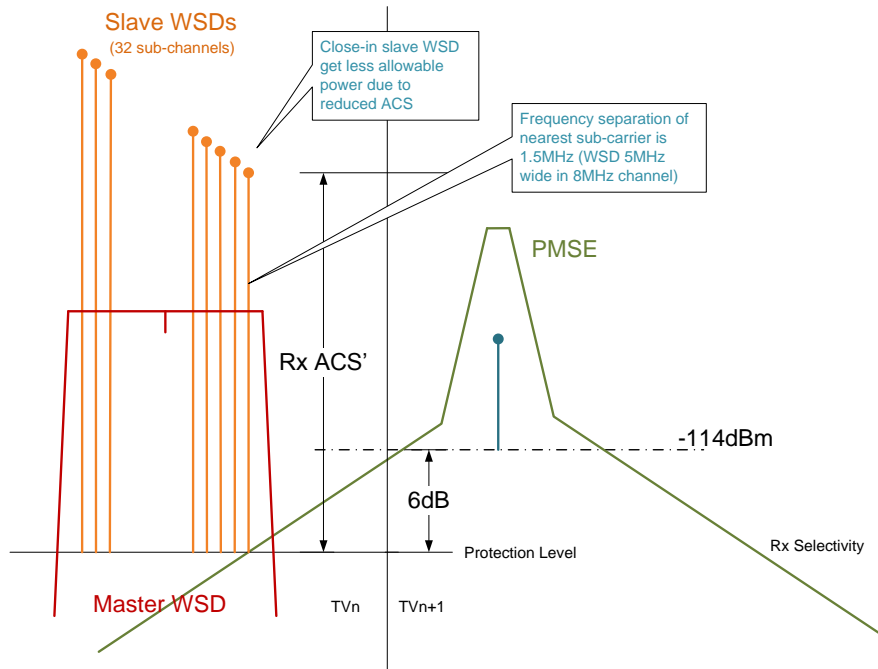


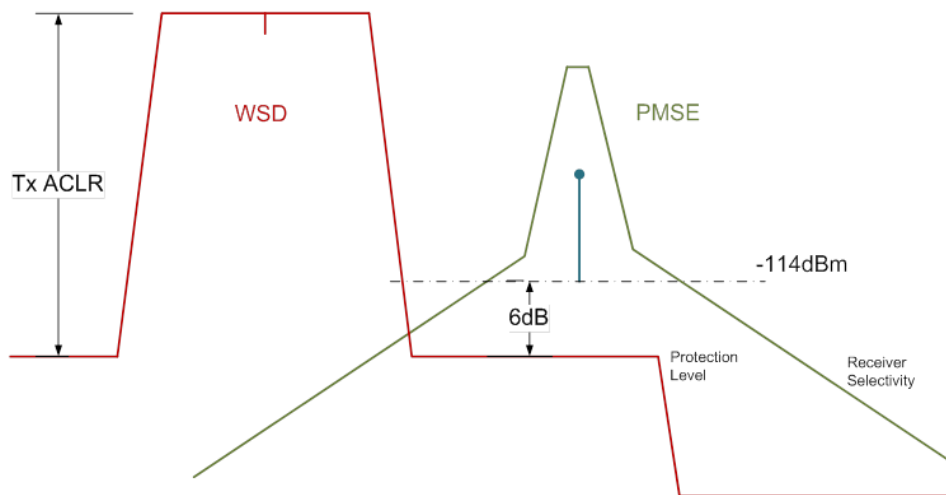
Figure 8: Graphic Showing PMSE Rx ACS with Narrowband WSDs

5.3.4.6 WSD Transmitter Adjacent Channel Leakage Ratio (ACLR)

It is envisaged that different emission classes of WSD transmitter will be defined, meeting different ACLR performance levels. For example, low cost WSD designed for battery operation may not be able to achieve high ACLR performance.

Measurements have indicated that the interferer ACLR will often be the dominant effect on PMSE performance given the typical selectivity performance and high ACS values achieved by most professional PMSE receivers.

Consider a WSD is deployed in channel N-1 with an adjacent channel leakage ratio of TxACLR as shown below.



**Figure 9:Tx ACLR Considerations**

The PMSE receiver cannot provide any attenuation of the power emitted in the WSD transmitter's adjacent channel as it appears co-channel as far as the receiver is concerned. To ensure PMSE protection, the maximum power of the WSD at the PMSE receiver can be calculated as follows:

$$WS_{P_{RX}} (dBm) = \Psi + TX_{ACLR} \quad (24)$$

where:  $\Psi$  is the PMSE protection Level in dBm (i.e. receiver noise floor + acceptable I/N value)  
 $TX_{ACLR}$  is the WSD transmitter's adjacent channel leakage ratio in dB

#### 5.3.4.7 Reverse Intermodulation

The subject of intermodulation distortion (IMD), more specifically reverse IMD, is covered fully in Annex 10 of ECC Report 185 [16].

#### 5.3.4.8 Indoor and Outdoor

If a PMSE installation is deployed indoors, then it would have the benefit of any building attenuation as a further protection margin. Additionally, when indoors, the device might be by an open door or window, hence it could be assumed that all devices are outdoors. NRA may wish to include allowances for indoor and outdoor attenuation within the database for certain known situations.

#### 5.3.4.9 Propagation Model

There are many propagation models that can be used to calculate the path-loss under different environmental conditions such as but not limited to:

- Inverse-square law (free-space)
- Ibrahim-Parsons
- Hata rural
- Hata sub-urban
- Hata urban

Each model attempts to represent actual measured data as a simple closed equation. However, the environment in which PMSE and WSDs are used varies enormously from flat rural landscapes to mountainous terrain or highly dense inner cities, which influences the calculations of the link budget. Using a clutter database an appropriate propagation model could be used.



For example, from Seamcat simulations the exclusion zone varies from 25km with a free space model to 650m with an Extended Hata Urban model for the same device parameters (please see Annex 13 for Seamcat results).

For these reasons, it is necessary to select the appropriate clutter class for the PMSE deployment to ensure the correct variant of the propagation model is used (e.g. rural, sub-urban, urban, etc). This information might be provided in a clutter database or it could be estimated using maps that indicate land-use. The appropriate propagation model can then be selected to provide the required protection for PMSE. The following example map shows land-use (source: <http://www.openstreetmap.org/>) and shows urban and sub-urban regions.



**Figure 10: Map Showing Land-Use**

### 5.3.5 Overview of Methodology

Geo-location databases appear at present to be the only practical way forward to protect the needs of PMSE users. The database will require continual updates to protect both permanent and temporary sites within appropriate timescales. Known PMSE sites with fixed and mobile receivers can be permanently registered in the database with either positional coordinates or an address. Registration of temporary sites would be a frequent occurrence that would require dynamic changes to the database in order to protect these sites. The location uncertainty of any mobile receivers, e.g. IEMs or airborne, must also be considered.

The suggested approach is a set of location dependant power limits for all relevant TV whitespace channels such that the interference at all PMSE receivers is kept below an appropriate value. A particular location, described by its pixel coordinate, will need power limits to protect all PMSE receivers within the interference range of the WSD.

This report presents one methodology to protect PMSE, but does not exclude alternatives that could be developed in the future.

### 5.3.6 Methodology for Protection of PMSE

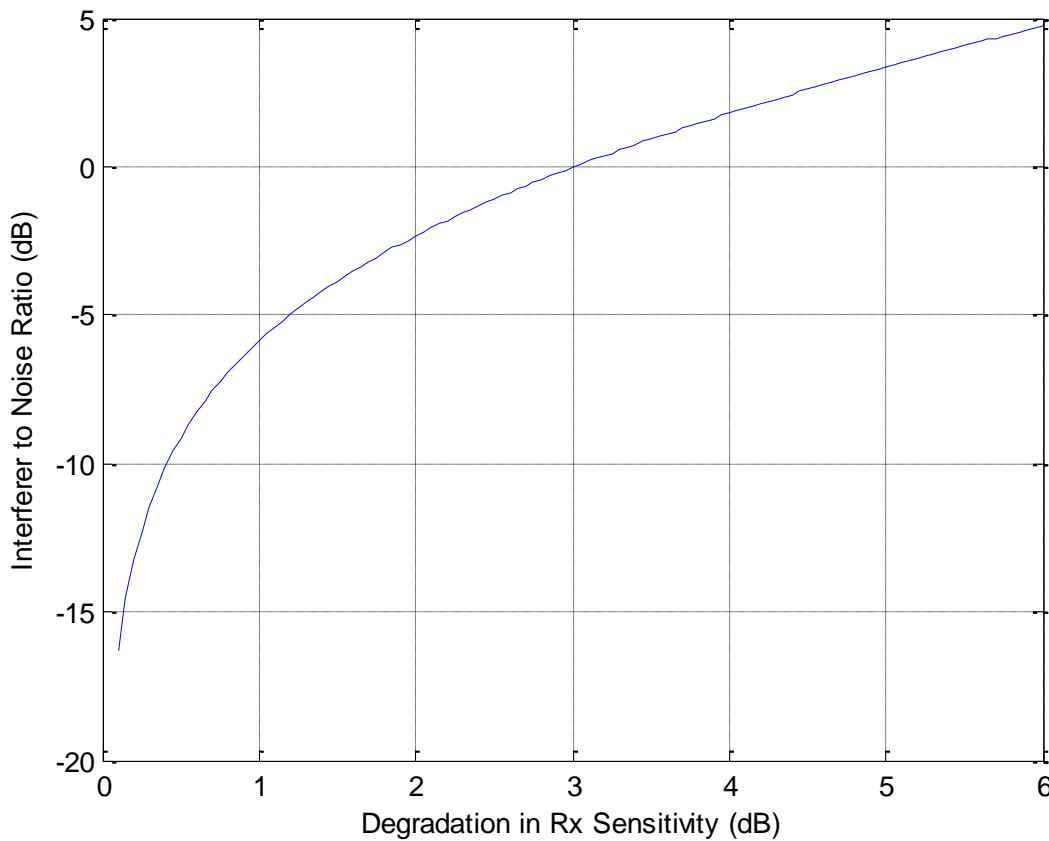
#### 5.3.6.1 Protection Level

In order to protect PMSE, appropriate e.i.r.p. restrictions must be placed on WSDs operating in the vicinity of the event. In this section we first introduced the concept of interferer-to-noise approach where the level of an interferer is allowed to degrade the receiver sensitivity by an acceptable amount which is the basis for all protection mechanisms subsequently discussed.

The proposed method is to limit the received interferer power from the WSD such that the sensitivity of the PMSE receiver is not degraded significantly. This is often referred to as an interferer-to-noise (I/N) approach and can be expressed mathematically as:

$$\delta = 10 \cdot \log_{10}(10^{(\gamma/10)} - 1) \tag{25}$$

where  $\delta$  is the power level of the WSD relative to the PMSE receiver noise floor in dB and  $\gamma$  is the degradation in PMSE Rx sensitivity in dB. The behaviour of this function is shown in the next figure.



**Figure 11: Degradation in Receiver Sensitivity as a Function of I/N**

For example, from the graph above, it can be seen that for 1dB degradation in PMSE receiver sensitivity, the WSD power should be 6dB below the receiver noise-floor.

We can express the absolute level of received interference power by:

$$\psi (dBm) = 10 \cdot \log_{10}(k \cdot T) + 30 + \nu + 10 \cdot \log_{10}(\beta \cdot (10^{(\gamma/10)} - 1)), \tag{26}$$

- where:  $k$  is Boltzmann’s constant,  $13.806 \cdot 10^{-24}$  J/K
- $T$  is temperature in Kelvin
- $\nu$  is the PMSE Rx noise figure in dB

- $\beta$  is the PMSE signal bandwidth in Hz
- $\gamma$  is the degradation of PMSE Rx sensitivity in dB
- $\psi$  is the PMSE Rx protection level in dBm

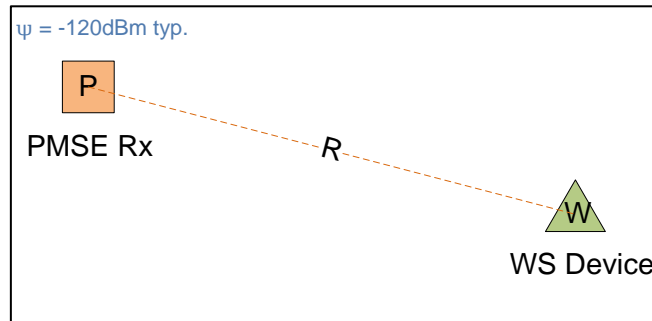
For example, for a typical PMSE system at a temperature of 290K, with a receiver noise figure of 7dB and a bandwidth of 200kHz and allowing for a 1dB degradation in receiver sensitivity, the maximum permitted received interferer power  $\psi$  would be  $-120\text{dBm}$ .

$$\psi \text{ (dBm)} = -174 + 7 + 10 \cdot \log_{10}(200 \cdot 10^3 \cdot (10^{(1/10)} - 1))$$

$$\psi \text{ (dBm)} = -120$$

### 5.3.6.2 Prevention of Co-channel Interference

Consider a WSD operating at a distance R from a protected PMSE receiver:



**Figure 12: WSDs Link Budget & Co-Channel Interferer Levels**

The interference power received by the PMSE receiver is given by  $\psi$ .

$$\psi \text{ (Watts)} = P_{IB} \cdot G(R, h_{PMSE}, h_{WSD}) \leq v \cdot K \cdot T \cdot \beta_{PMSE} \cdot \delta \quad (27)$$

where  $G(R, h_{PMSE}, h_{WSD})$  is the coupling gain between the WSD and the PMSE receiver.

Solve for  $P_{IB}$ , rearranging eq. (27)

$$P_{IB} \leq \frac{v \cdot K \cdot T \cdot \beta \cdot \delta}{G(R, h_{PMSE}, h_{WSD})} \quad (27)$$

Using eq. (28), the location dependent power limits  $P_{IB}$  for a WSD can be calculated at any chosen location.

In practice, both co-channel and adjacent interference must be considered together with the protection requirements associated with each PMSE receiver. The most restrictive limits, considering all PMSE receivers and all adjacent channel considerations will apply at a particular location.

### 5.3.6.3 Prevention of Adjacent Channel Interference

The effects of adjacent channel operation can be accounted for by considering the selectivity of the PMSE receiver and the emission characteristics of the WSD.

In general, the effective interference power received by the PMSE receiver is given by:

$$P_{IB} \leq \frac{v \cdot K \cdot T \cdot \beta \cdot \delta}{G(R, h_{PMSE}, h_{WSD})} \cdot \text{ACIR} \quad (28)$$

where ACIR, known as the adjacent channel interference ratio (expressed in linear units) is given by:



$$ACIR = \left(1/ACS + 1/ACLR\right)^{-1} \quad (29)$$

#### 5.3.6.4 Interference Margin (IM) considerations

A database describes the power restrictions on a WSD for any chosen location within a country. To construct the WSDB, the country is usually subdivided into small areas known as pixels (similar to the approach discussed in section 5.2.1) and the power restrictions for each pixel are calculated by considering the co-channel (using equation (28)) and adjacent channel restrictions (using equation (29)) imposed by all relevant PMSE receivers. In this way, the restrictions imposed by the most susceptible PMSE receiver are accounted for at any given location.

This methodology accounts for interference from a single WSD interfering with one or more protected PMSE receivers. An additional margin will be required when considering multiple WSDs. This additional margin interference margin IM, will be determined by the number of WSDs operating in the vicinity of the protected PMSE receiver and is given by:

$$IM = 10 \cdot \log_{10}(N) \quad (30)$$

where N is the number of active WSDs, accounting for WSD operation in all relevant TVWS channels.

It may be possible for the WSDB to track dynamically the number of active WSDs. Alternatively, a fixed value of IM could be chosen by the NRA.

#### 5.3.6.5 Prevention of Intermodulation Distortion

As outlined above and Appendix 10 of ECC Report 185 [16], reverse intermodulation distortion is a serious threat to PMSE productions and requires careful consideration. The level of any intermodulation products caused by the introduction of one or more WSDs into the PMSE service area must not exceed the power allocated by the WSDB for the relevant frequencies for the protection of the PMSE receivers.

To be able to quantify the magnitude of the reverse intermodulation problem, this characteristic of the WSD must be known. It has been suggested that ETSI could include inter-modulation requirements for WSD transmitters in the upcoming draft EN. This may help the database to make assumptions in order to calculate the effect of possible reverse inter-modulation products. Until a long-term solution is achieved, a practical solution could be to limit adjacent channel operation of WSD such that the anticipated reverse IMD products do not exceed the value determined by the co-channel and adjacent channel protection limits defined above. This might include factoring in an additional adjacent channel protection zone.

### 5.3.7 Example of a Practical Solution for registered PMSE in the database

#### 5.3.7.1 Introduction

PMSE in the band 470-790 MHz is in general operating under one of the following regulatory regimes (or a combination of these):

- On a licence exempt basis in interleaved spectrum
- On a licensed basis
- Under some sort of light licensing.

In countries following option 2 or 3 the information needed for the protection of PMSE is available for the translation process, e.g. the location and technical characteristics of the service to be protected is known a priori.

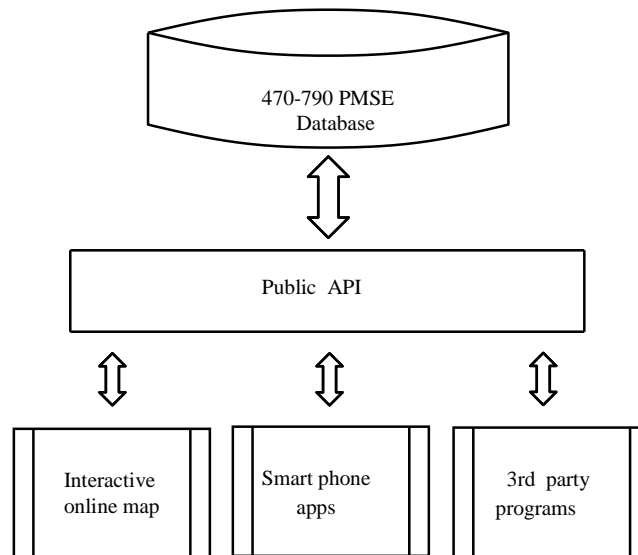
If PMSE is allowed on a licence exempt basis the location and spectrum usage of the PMSE devices is unknown to the NRA. The lack of such information is a key challenge in protecting PMSE against WSD. One example of trying to address this problem is to give users an easy overview of the spectrum available for PMSE in the band 470-790 MHz and to allow PMSE users to register their usage and thereby claim protection from WSD.

5.3.7.2 System overview

In Figure 13 it is illustrated how a database containing information on:

- spectrum available for PMSE in 470-790 MHz
- and registered use of this spectrum

and can serve PMSE users with relevant tools through a public API (Application Programming Interface).



**Figure 13: Overview of the setup of a PMSE location registration in database**

The public API allows for 3rd party programs such as channel assignment software by PMSE manufacturers to automatically get a list of available spectrum at a given location and to subsequently register the specific usage of this spectrum. Such a solution could prove especially efficient for high-level PMSE users (i.e. large scale concerts, film sets, etc.).

The interactive online map and smart phone application provide a generic, ready-to-use solution for the small and mid-level PMSE user (e.g. a local theatre or small touring band) to get a list of available spectrum and register their usage. The smart phone application can take advantage of the built-in GPS in the phone. The widespread use of smart phones makes this an inexpensive solution with a very low access barrier and light workload for the small and mid-level PMSE user.

When registering the usage of spectrum the user should indicate the timeframe for the usage. A more advanced option would be to let the user define an area of usage (e.g., by a polygon).

The data collected by the public API on PMSE usage could serve as a basis for the protection of PMSE against WSD in the translation process.

The NRA would have to consider if incentives such as fees or limits on the frequency bands that may be registered should be imposed to ensure fair registration of usage. This would aid in avoiding unnecessary sterilization of spectrum.

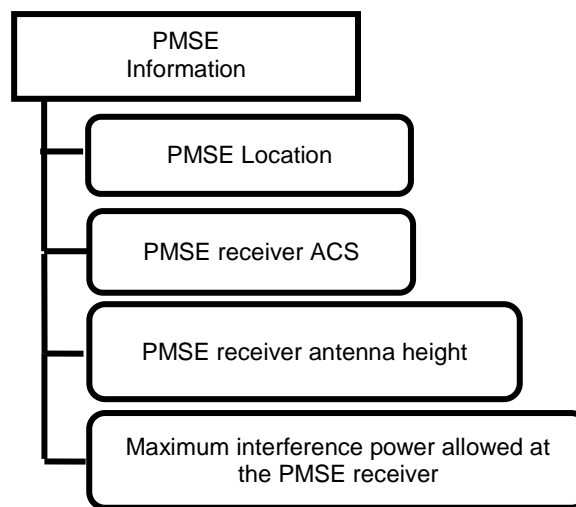
It could be considered to develop a common set of data elements to enable PMSE devices to register with API within CEPT countries.

### 5.3.8 Example of a translation process for the protection of PMSE

#### 5.3.8.1 PMSE parameters that need to be registered

For each PMSE receiver registered at the database, the used frequencies are stored. For each frequency, the following data should be stored Figure 13:

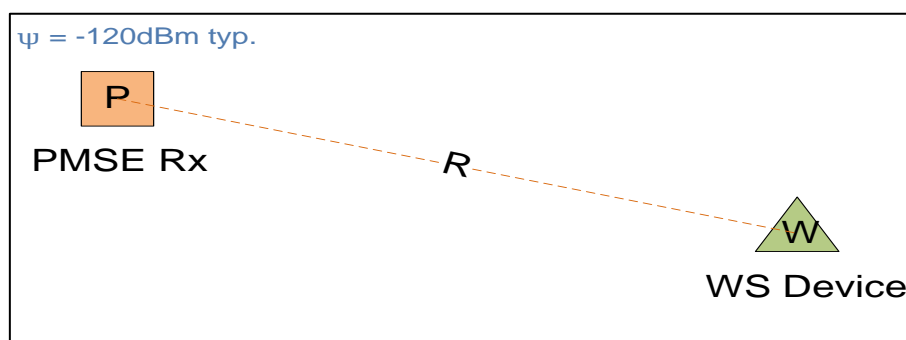
- The location of each receiver (this could include the expected area of operation of the receivers);
- Maximum interference power allowed at the receiver;
- receiver ACS;
- receiver antenna height;
- duration of PMSE use.



**Figure 14 PMSE information stored in database**

#### 5.3.8.2 Interference Management Methodology

The proposed WSDB methodology is based on an approach to interference effects shown above in section 5.3.6. Location dependent power limits are then calculated for each protected PMSE receiver, by considering the geometry in Figure 14 and using the appropriate propagation model to calculate the coupling between the WSD and the PMSE receiver. Further information on some deployment scenarios of PMSE is provided in Annex 6, which will have an impact on the reference geometry used in the translation process.



**Figure 15: Interference geometry between PMSE and WSD**

**Step 1: Determination of the maximum authorised co-channel WSD power level**

It is assumed that the location and height of the interfering WSD are known by the database. From this the distance R from a protected PMSE receiver can be calculated. The WSD power level can then be calculated:

- By making certain assumptions on the allowable degradation of the PMSE receiver sensitivity the database can use equation (5-26) to calculate a value for the allowable interfering power at the victim PMSE receiver. Then by using equation (5-28), the location dependent co-channel power limit for a WSD can be calculated.
- The database will have to repeat this calculation for a number of PMSE receivers located in the vicinity of the interfering WSD in order to determine the lowest location dependent co-channel power limit for the WSD.
- The above calculations account for interference into one or more protected PMSE receivers from a single interfering WSD. An additional interference margin (IM) may be required in order to take account of possible aggregate interference effects. This (IM) will need to be factored into the eventual co-channel power limit for the WSD. The formula to calculate this IM can be seen in Equation (5-31). Alternatively, the database can calculate IM based on the actual power levels of authorised WSD deployments.

**Step 2: Determination of the maximum authorised WSD power levels for adjacent channels taking into account ACS and ACLR values**

- If we assume that the database has known values for the victim PMSE receiver ACS and the interfering WSD ACLR then we can substitute these values into equations (5-29) and (5-30) to calculate the location dependent power limit for a WSD for known adjacent frequency offsets to the PMSE receiver.
- The database will have to repeat this calculation for a number of PMSE receivers located in the vicinity of the interfering WSD in order to determine the lowest location dependent power limit for the WSD for known adjacent frequency offsets to the PMSE receiver.

**Step 3: Determination of the maximum authorised WSD power levels for adjacent channels taking into account possible reverse inter-modulation products at the PMSE receiver**

Given the reverse intermodulation characteristic of the PMSE transmitter and WSDs and their relative locations, the magnitude of any reverse IMD can be calculated. Intermodulation between multiple WSDs and WSDs and radio microphones must be considered. Using a propagation model from the device (WSD or radio microphone) generating the IMD to the victim PMSE receiver, the level of interference can be assessed and compared to the protection level for the PMSE receiver. Appropriate adjacent channel power limits can then be determined which would typically result in an additional protection zone in the vicinity of the PMSE receiver.

**Step 4: Update the data stored for the WSD power levels**

The lowest power levels calculated for the co and adjacent channels as a result of steps 1 to 3 above should be used to update the table of results for WSD usage at that particular WSD location.

**5.4 PROTECTION OF RAS IN THE BAND 608-614 MHZ**

In the frequency range 608-614 MHz (TV Channel 38) there is a secondary allocation to the radio astronomy service (RAS) used for observations in a number of European countries<sup>17</sup>. The use of this band for RAS is also addressed in footnote 5.149 of the ITU RR<sup>18</sup>.

<sup>17</sup> **5.306 Additional allocation:** in Region 1, except in the African Broadcasting Area (see Nos. **5.10** to **5.13**), and in Region 3, the band 608-614 MHz is also allocated to the radio astronomy service on a secondary basis.

The sharing studies conducted in ECC Report 159 [1] for both the co-channel (WSD in the 608-614 MHz band) and adjacent channel cases (WSD in the TV channels 37 and 39) have shown that the separation distances between WSDs and RAS depend largely on the type of RAS observations and on the radiated power of the WSDs. For WSDs which have access to a geo-location database, when necessary exclusion zones around RAS sites can be defined at a national level in the database for TV channels 37, 38 and 39. Guidance on the size of the exclusion zones can be defined on the basis of the results of sharing studies given in ECC Report 159 [1].

Regarding the usage of TV Channel 38 it is noted that the separation distances can go beyond the national borders of some European countries and thus, where necessary will need to be subject to bilateral/multilateral agreements.

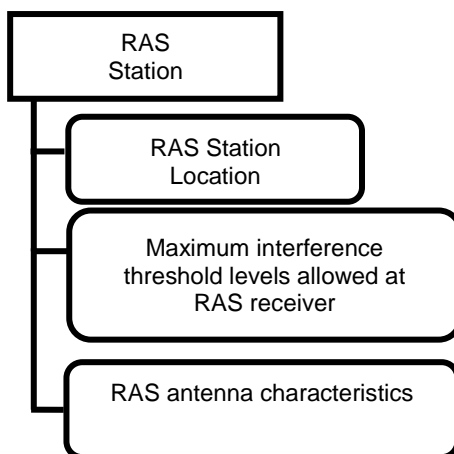
ECC Report 159 [2] also presents the levels maximum interfering field strength at the RAS station, converted from the maximum power flux densities:

- Single dish: -40.2 dB $\mu$ V/m assuming an integration time of 2000 s and -46.5 dB $\mu$ V/m assuming an integration time of 10 h;
- VLBI: +0.79 dB $\mu$ V/m assuming an integration time of 10  $\mu$ s;
- Interferometry -23.2 dB $\mu$ V/m assuming an integration time of 1 s.

#### 5.4.1 Example of a translation process for the protection of RAS

For each RAS receiver registered at the database the following data should be stored Figure 15:

- the location of the RAS station;
- the maximum interference threshold levels allowed at the RAS receiver (e.g. Recommendation ITU-R RA.769 [17] can be used);
- RAS antenna characteristics (height, pattern, etc) .



**Figure 16: RAS information stored in database**

##### 5.4.1.1 Interference Management Methodology

The proposed methodology is based on a global approach to interference effects. That means that for each new WSD that requests authorisation to operate within a pre-defined radius (coordination distance, Figure 16), the database must check the impact that an authorised WSD would have on the RAS receiver stations that have been identified for protection.

**Figure 17: Illustration of the methodology**

For each new WSD request (to operate within  $R_{max}$ ), the database must be check the impact of the authorised WSD on the RAS receiver station.

<sup>18</sup> According to 5.149, "administrations are urged to take all practicable steps to protect the radio astronomy service operating in the band 608-614 MHz from harmful interference. Emissions from space borne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29)."

Each proposed WSD located within  $R_{max}$  should be examined.  $R_{max}$  can be derived using a predefined WSD power level. So, for each authorised WSD, the maximum permitted power is calculated based on the frequency offset of the WSD from the RAS receiver, the distance from the RAS receiver and the maximum interference threshold levels allowed at the RAS receiver.

## 5.5 PROTECTION OF ARNS IN THE BAND 645-790 MHZ

In the frequency range 645 – 790 MHz there is also a primary allocation of the aeronautical radio-navigation systems (ARNS) use in some CEPT countries.

One study conducted in the ECC Report 185 has shown that the protection of ARNS from interference generated by typical WSD deployment scenarios would require separation distances to be in the range of 76-257 km for WSD transmitters with e.i.r.p. 36 dBm or in the range 280-430 km for WSD transmitters with e.i.r.p. 55 dBm depending on the area (rural, urban-suburban-rural), WSD deployment densities and propagation path type.

It is noted that required separation distances can go beyond the national borders and thus protection of ARNS could be subject to bilateral/multilateral agreements between countries intending to implement WSD and the limited number of countries operating ARNS in accordance with 5.312 of the ITU RR.

Based on the results of bilateral/multilateral agreements the necessary exclusion zones or power limitations placed on WSD geographically in all or parts of the frequency bands 645-790 MHz could be included into the geo-location database in order to protect ARNS in the neighbouring countries.

## 5.6 PROTECTION OF MOBILE SERVICES IN THE BANDS ADJACENT TO 470-790 MHZ

### 5.6.1 General

From the analysis on permissible WSD e.i.r.p. limits for protection of LTE in the adjacent bands to 470-790 MHz (provided in [16]) it is clear that some limitations towards WSDs are necessary in order to limit the interference towards LTE to acceptable levels.

In principle, such limits could be solely calculated on a case-by-case basis by the geo-location database, e.g. by using the calculation method and scenario geometries provided in [16] and by using context-specific information eventually provided by the WSD (e.g. antenna height). This would have the advantage of maximum flexibility for NRA to decide about the details of how this calculation should be done and which parameters and scenarios the calculation should be based on. Note that this approach would lead to only device-specific emission limits (as opposed to the location *and* device dependent limits for protection of TV broadcasting and PMSE) for protection of services in adjacent bands. This would have to be reconciled with the limits for protection of the incumbent services within the TV band in order to identify the most limiting interference scenario.

This approach would, for example, be appropriate for those cases where “intermediate” e.i.r.p. limits can be allowed, which means that the results are inconclusive as to whether a reasonable WSD operation under those limits is possible or not.

Nevertheless the analysis has also shown that some cornerstones seem to be rather independent from scenario and selected parameters (e.g. see Section 6.3.5 of ECC Report 185 [16]). It might thus be beneficial to regulate those elements in a generic way in order to provide certainty and optimization potential to the WSD industry and reduce the computational complexity of a geo-location database.

### 5.6.2 Protection of mobile service in the band 450-470 MHz

#### 5.6.2.1 Protection of TETRA TEDS 25 kHz

The band 450-470 MHz is predominantly expected to be used by PMR/PAMR applications, including TETRA and its evolution, which have to be protected with respect to the introduction of WSD operating in the 470-790 MHz frequency band. ECC Report 185 [16] presents the results of the conducted studies, for the protection of TETRA TEDS 25 kHz, which have taken into account Link budget assessments both for wanted signals and interferers, which allowed the evaluation of possible performance degradation. Adjacent channel interference was computed taking into account ACLR (*Adjacent Channel Leakage Ratio*), which describes out-of-band emissions of the interfering transmitter, and ACS (*Adjacent Channel Selectivity*), which describes the selectivity of the victim receiver.

The results of the studies for the protection of TETRA TEDS (25 kHz) operating at 450-470 MHz have shown that the interference caused by WSD is not significant, taken into account the assumptions in terms of emitted power and WSD density.

#### 5.6.2.2 Protection of CDMA PAMR

The protection of CDMA-PAMR operating at 450-470 MHz was also analysed in ECC Report 185 [16]. The conclusions show that a maximum power of fixed WSDs operating on TV Channel 21 should be limited; the limitation will be dependent of the accepted capacity loss, environment (urban or rural areas) and CDMA-PAMR cell radius.

#### 5.6.3 Protection of mobile service in the band 790-862 MHz

Calculations of WSD power limits for protection of the mobile services in the band 790-862 MHz need to be conducted as part of the translation process within the geo-location database. Though appropriate calculations methods and scenarios may still need to be developed, those elaborated in Section 6.3 of ECC Report 185 [16] could be used as a starting point.

The studies for the protection of mobile services operating at 790-862 MHz seem to indicate that WSDs operation on TV Channel 60 and additionally for the particular case of portable WSDs on TV Channel 59 are generally not advisable for all scenarios. Also certain limitations in terms of maximum output power for WSDs operating in TV Channel 57 to 59 may be necessary.

For channel 56 and below the required e.i.r.p. limits do no longer depend on frequency offset since it is assumed that the LTE UE selectivity does not increase further beyond the corresponding frequency offsets. The allowable WSD e.i.r.p. levels on these channels seem not to be constraining the respective use case scenarios significantly.

It should be noted that these results are based on a number of assumptions, particularly with regard to the WSD baseline levels, and the performance of the LTE duplex filters.

It is also recommended for the geo-location database to assume conservative parameters for a WSD to derive its power limits, when the database does not receive the information from the WSD necessary to categorize it for the purpose of translation calculations.

#### 5.6.4 Example of a translation process for the protection of mobile services

In principle it is possible to base the translation process on the methodologies used in the studies presented in ECC Report 185 [16], but since the three different studies use different methodologies it is at this stage not straightforward to derive a unified approach from them. Moreover the NRA could perform appropriate analysis for other services/systems not covered by any of the above mentioned studies, which might result in additional aspects that need to be considered for the design of a translation process.

In principle the technical approach for protection of services in adjacent bands has similarities with the case of protecting DTT on adjacent channels, in the sense that the reference geometry chosen to look at the interference to the incumbent services will be dependent upon the WSD usage scenario, i.e., fixed or mobile.

In any case the studies indicate that there may be a need for some limitations of WSD operation in order to provide protection to services in adjacent bands. For example countries may wish to apply an exclusion on the use of channel 60 by WSDs in order to protect LTE above 790 MHz. For countries implementing this process the related "translation process" would be trivial as there would be no actual calculations needed to be carried out by the database. Other countries may wish to calculate what powers would be suitable to provide protection to the adjacent mobile services using a similar methodology to that proposed in CEPT



Report 30 which would take account of parameters such as frequency offset, the ACS of the mobile service, the ACLR values of the WSDs plus suitable reference geometries etc.

Given the above deliberations, the NRA could decide to implement a predefined approach, e.g., by establishing constraints for the WSD powers for each of the frequency offsets adjacent to those frequencies operated by adjacent mobile services. In this case, the database will also need to take into account those constraints calculated to protect other services (e.g. the broadcasting service) or systems.

## 6 COMBINED SENSING AND GEO-LOCATION

### 6.1 METHODOLOGY

The spectrum sensing can be used to support the detection of incumbent radio services conducted using the geo-location database. Such a combined technique to compute the white space spectrum has the following advantages:

- It reduces the risk of interference compared to cases when either sensing only or geo-location only techniques are used;
- It allows detection of services/systems that are not registered in the database;
- It allows using sensing devices which do not meet the required standalone sensitivity requirements because of practical implementation reasons.

However, as discussed in section 2.4.1 and Annex 3 of the ECC Report 185 [16] the implementation of reliable and economically viable sensing has a number of challenges, thus some of the potential benefits mentioned above may not be reachable in practice.

The conclusion on the channel occupancy as derived on the basis of spectrum sensing only ( $D_{S(T)}$ ) can be presented as given in the table below.

**Table 1: Channel occupancy based on spectrum sensing only**

Flag	Conclusion
$DS(T) = 1$	The detected power is equal or higher than the detection threshold T. Hence the channel is occupied
$DS(T) = 0$	The detected power is below the detection threshold T. Hence the channel is vacant

Similarly, the conclusion on the location of a WSD relative to the protected service contour as derived on the basis of geo-location only ( $D_G$ ) can be presented as given in the table below **Error! Reference source not found..**

**Table 2: Channel occupancy based on geo-location only**

Flag	Conclusion
$DG = 1$	The WSD is within the protected service contour. Hence the channel is occupied
$DG = 0$	The WSD is outside the protected service contour. Hence the channel is vacant

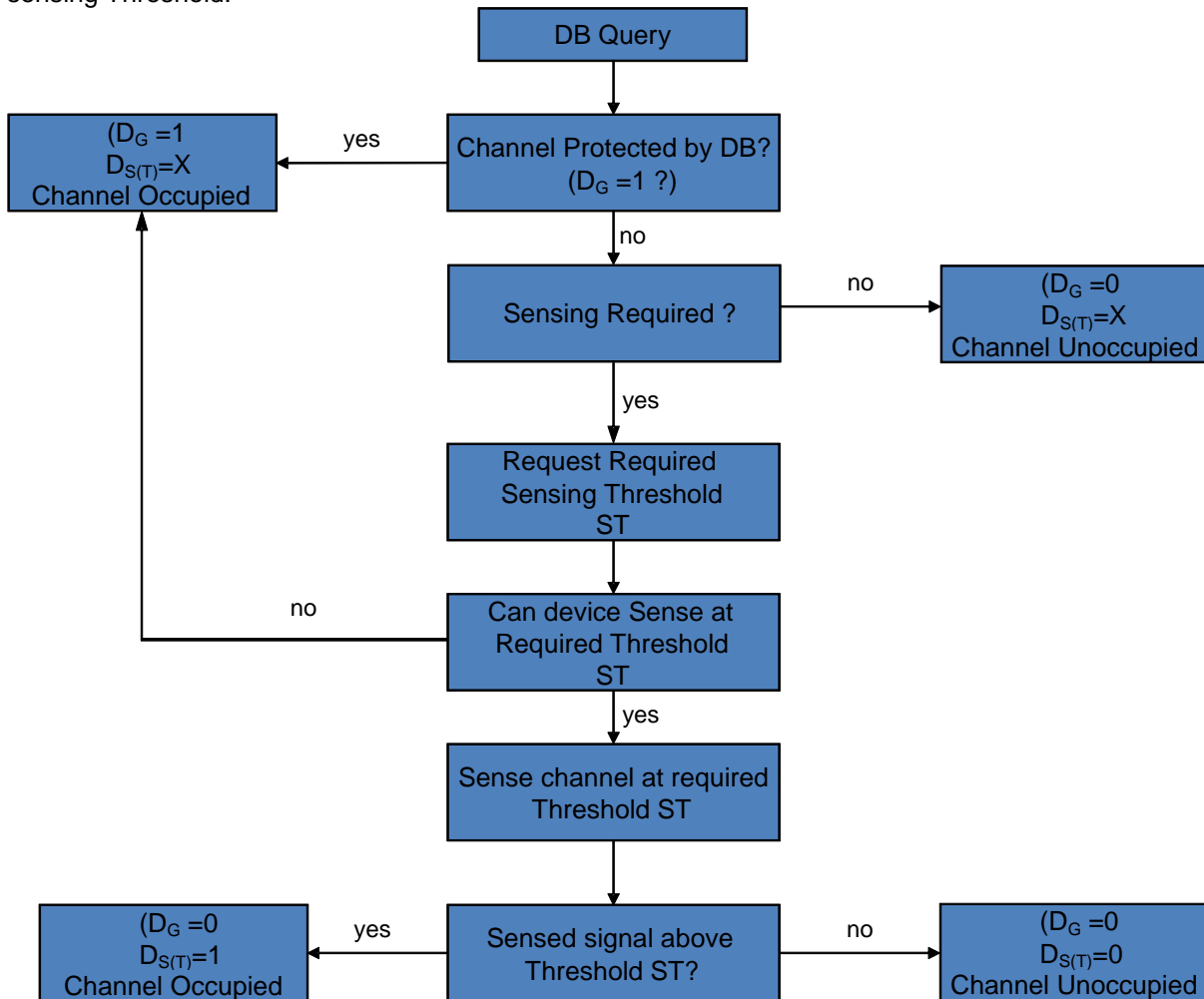
When combining geo-location information with sensing results, the conclusion on the channel occupancy can be presented as given in Table 3.

**Table 3: Channel occupancy based on combined detection**

Geo-location flag	Sensing flag	Conclusion
$DG = 1$	$DS(T) = 1$	The channel is occupied.
$DG = 1$	$DS(T) = 0$	The channel is occupied.
$DG = 0$	$DS(T) = 1$	The channel is occupied.

Geo-location flag	Sensing flag	Conclusion
DG = 0	DS(T) = 0	The channel is vacant.

Figure 18 below shows the flow chart of decision in line with Table 3 and introduces the notion of required sensing Threshold.



**Figure 18: Decision chart for the combined sensing and geo-location approach**

Because both geo-location facilities and WSD sensing are ‘imperfect’, there is the possibility, using either (or both) technique(s), of arriving at

**Table 1.** a ‘false-vacancy-detection’, i.e. the indication that the DTT channel is not being used when in fact it is occupied, or

**Table 2.** a ‘false-occupancy-detection’, i.e. the indication that the DTT channel is occupied when in fact it is not being used.

Both geo-location and WSD sensing decisions will have more likelihood of error in areas where the DTT field strength is low, and DTT reception is most likely to be degraded. Thus it is necessary to use both geo-location and WSD sensing capabilities to their fullest extent.

In order to discuss the consequences of using an imperfect sensing device in terms of false-vacancy-detection and false-occupancy-detection decisions, two entities related to sensing are defined:

- The actual sensitivity of the device: This expresses the physical capability of the sensor to recognize the wanted signals with low levels. It can be defined in terms of a signal level associated with a probability of good detection (see for example Figure 53 in Annex 3 of ECC Report 186 [16]).

- The decision threshold: This is a level which is 'default' value based on the point at which the sensor can begin to detect signals at all. Note that the detection is based only on the cyclic features of the DTT signal, and not on the actual strength of the signal: **no** decisions are based on the signal level.

The required sensitivity should ideally be equal to the lowest level that corresponds to the presence of a useable signal in the configuration being considered. For example, for a portable indoor sensing device that has to detect a DTT signal received with a roof top antenna, its sensitivity level should ideally be as low as -140 dBm (see ECC Report 159 [1], Table 3, second column).

Practical implementation of sensors with such a low sensitivity level is very challenging, if not impossible for the time being, as is shown in Section 2.4.1 and associated Annex 3 of [16]. Referring to Figure 33 in Annex 3 of [16], the actual measured sensitivity level of a practical sensor is -117dBm with 100% probability of detection and -127 dBm with 5% probability of detection (the simulated sensitivity is -122dBm with 100%probability of detection and -133 dBm with 5% probability of detection).

Using the practical example of implementation described in § 2.4.1 and Annex 4 of [16], it is demonstrated in Annex 8 that:

- Relaxing the WSD sensor sensitivity level can lead to an increased number of 'false-vacancy-detections', which would lead to an increased number of interference situations for DTT reception;
- Conversely, the probability of 'false-occupancy-detection' would decrease with relaxed WSD sensor sensitivity level, which would lead to more spectrum available for the WSDs.

If the WSD sensor sensitivity level is relaxed from -140 dBm to -100 dBm, the increase in the average probability for false-vacancy-detections for receive signals in the lower power region (in our example, in the interval [-140 dBm, -100 dBm]) is greater than the decrease in probability for false-occupancy-detections. It is most important that the 'false-vacancy-detections' be kept to a minimum, in order to keep interference to DTT reception to a minimum.

For the practical sensor considered (with sensitivity level -117 dBm) and the range of signals to be detected in the example, the 'default' decision threshold can be set at -127dBm (instead of -140dBm) as this corresponds to the point where the sensor 'wakes up', i.e., starts to detect. Nevertheless, the overall probability of 'false vacancy detection' is high, about 52%. It would be more efficient to use sensors with more stringent sensitivity level, e.g. -130 dBm (with corresponding decision threshold -140 dBm) having only an 11.9% probability of 'false vacancy detection', or even -140 dBm (with corresponding decision threshold -150 dBm) which have effectively 0% probability of 'false vacancy detection'.

Such a sensitivity level (-117 dBm) and decision threshold (-127 dBm) would not be usable in an autonomous operation as it has a 52.25% chance to give a false-vacancy-detection (see Figure 92 in Annex 8). However, if used in combination with geo-location and using the decision algorithm described above it offers an additional check, giving an overall probability of false-vacancy-detections lower than the individual probabilities of false-vacancy-detections of each method (geo-location or sensing) used autonomously.

However, a relaxation in the sensitivity level, if imposed for practical implementation reasons, would only apply for incumbent services/systems that are registered in the database. For incumbent services/systems that might operate without being registered in the database the sensitivity level for WSD standalone operation will need to be preserved. As already suggested in § 9.3.4 of ECC Report 159 [1], the geo-location database may require the WSD to sense in conjunction with the geo-location at a given frequency. In this case, the database may also provide the WSD with information on the type of services/systems to be sensed as well as with sensitivity levels required for this purpose.

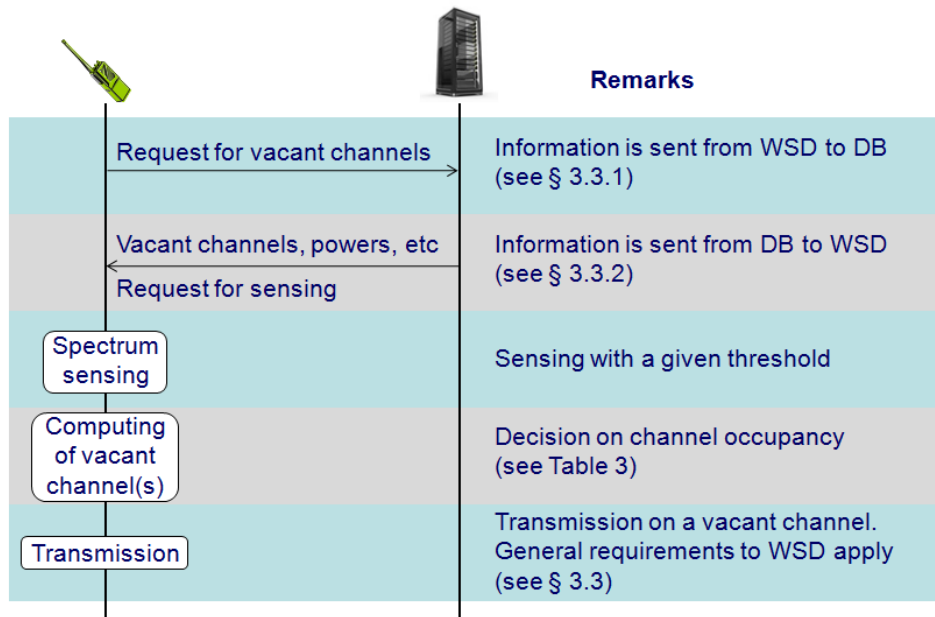
Further investigations for the possibility of relaxation of required sensitivity level as well as the amount of this relaxation and exact conditions are needed. ANNEX 9: provides a case study on the combined sensing and geo-location approach in a real scenario to identify spectral resource available for WSD.

## 6.2 ALGORITHM

The combination of sensing with geo-location can be used in the following operational architectures:

- Single WSD. The device has access to a geo-location database and is equipped with spectrum sensing capabilities.
- Master/Slave WSDs. The master WSD has access to a geo-location database and is not necessary equipped with spectrum sensing capabilities. The slave WSD is equipped with spectrum sensing capabilities and does not access the database itself.

The algorithm of information exchange with the geo-location database under the combined detection approach for both single WSDs and Master/Slave WSDs is presented in Figure 19 and Figure 20, respectively.



**Figure 19: Operational algorithm for the combined detection approach in a single WSD**

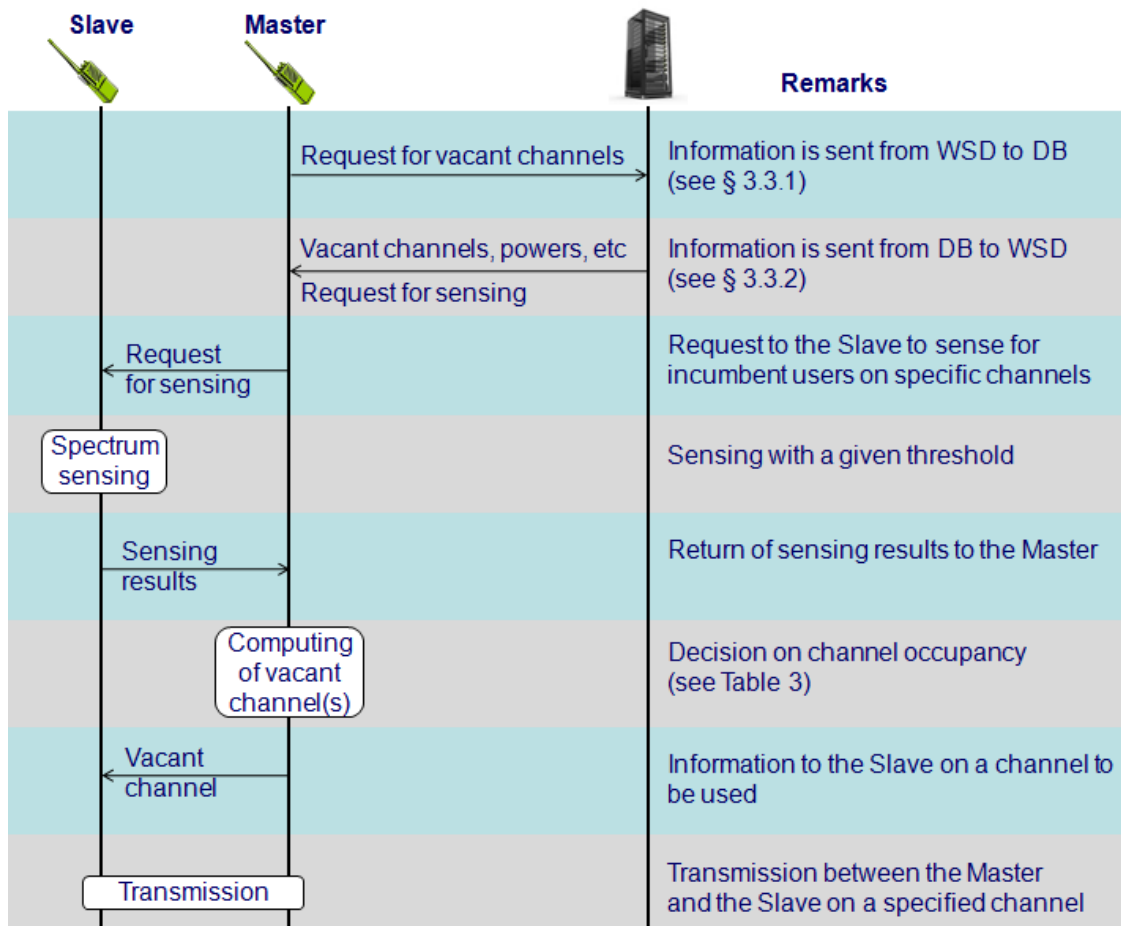


Figure 20: Operational algorithm for the combined detection approach in Master/Slave WSDs

## 7 CONCLUSIONS

Within this report, the CEPT is giving advice on general principles and basic requirements for WSDs operating under the geo-location database:

### (a) Considerations on location accuracy

With regard to providing location information there are three different areas of uncertainty that the geo-location database will have to deal with:

- Uncertainty in the location of the victim receiver
- Uncertainty in the location of the master WSD
- Uncertainty in the location of the slave WSD.

These uncertainties will determine the interference area that a geo-location data base will have to consider when looking at the suitable reference and non-reference geometries used by the database to carry out any interference calculations.

### (b) WSD requirements and the master/slave concept

The general principles and operational requirements to WSDs operating under the master/slave concept have been defined and are in conformity with general operating requirements to WSDs. The information flows between (i) the master WSD and the geo-location database, and (ii) the master WSD and the slave WSDs are detailed. Both geo-located and non geo-located slave WSDs are considered.

As a basic operational requirement, a master WSD may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by the NRA of that country.

The following parameters for the master WSD will need to be communicated (normally by the master WSD) to the geo-location database: its antenna geographical location, location accuracy, device class, emission class, technology identifier, device model, device category and device identifier. In addition, the master WSD may communicate to the database its antenna height, antenna angular discrimination, and antenna polarisation. The slave WSD will in certain situations provide to the master WSD a subset of the above information that the master needs to communicate to the database. This subset as a minimum should include the slave WSD device class, emission class, technology identifier, device model and device identifier.

The geo-location database will communicate to the master WSD as a minimum, operational parameters consisting of a list of available frequencies, associated maximum transmit powers for the current WSD location, limits on the maximum contiguous DTT channels and total number of DTT channels that WSD can transmit and time of validity of these parameters for the master and associated slaves. In addition, the database may communicate to the master WSD the appropriate national/regional database to consult and any information related to spectrum sensing if the latter is required.

After receiving operational parameters from the geo-location database, the master WSD will communicate to the database the selected frequency block, intended transmit power and in some cases the coverage area of the master WSD.

**(c) Database management**

The management of the geo-location database involves consideration of a number of issues including the technical information on services/systems to be protected, the database update delay and update frequency, as well as the translation mechanism.

**(d) Translation process in the geo-location database**

The database translates the information on incumbent services contained in the database and the information communicated from the WSD to the database into a list of allowed frequencies and associated transmit powers for WSDs. , NRAs may pre-calculate the allowed frequencies and associated transmit powers at each location for different WSD types and make this information available .

With respect to the protection of the broadcasting services, as guidance to administrations the report develops approaches, both Monte-Carlo and analytical, for calculating in-block and out-of-block emission levels. The methods to deal with interference aggregation from multiple WSDs are proposed. The key parameters to be used to calculate location specific WSD power levels are the reference interference geometries, the DTT reception modes, receiving antenna pattern, and location probability and the acceptable degradation of the location probability.

The key elements for the translation process to protect PMSE<sup>19</sup>, RAS, ARNS and the services in the bands adjacent to 470-790 MHz has been listed.

**(e) Combined sensing and geo-location**

Spectrum sensing could be used to support the detection of incumbent radio services conducted using the geo-location database. However, studies have shown that currently the implementation of reliable sensing has a number of challenges, thus some of the potential benefits may not be achievable in practice. This situation may change in the future.

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<sup>19</sup> The calculations in this report deal only with professional wireless microphone systems PWMS with focus on radio microphones, in-ear monitors, and audio links.

## ANNEX 0: SUMMARY OF THE ANNEXES OF THIS REPORT

A number of annexes support the considerations presented in the main body of the report:

- **Annex 1:** Multiple-interference

This annex presents calculations of maximum e.i.r.p. levels for WSD networks (lying outside of any given co-channel or adjacent channel DTT coverage area) based on different IM calculation methods which take into account the cumulative effects of multiple sources of interference.

- **Annex 2:** DTT Interference scenarios

This annex presents interference scenarios and the appropriate reference geometries necessary to calculate the WSD maximum power levels when protecting DTT services within the same area (pixel) or in neighbouring areas (pixels).

- **Annex 3:** Number of WSDs and nuisance power

This Annex describes the concept of individual and aggregate 'nuisance field' for various cases involving noise and one or more interfering sources. The relationship between total aggregate nuisance field, degradation of DTT reception probability, and maximum WSD e.i.r.p. level is discussed using examples of 'close' WSDs (within the same pixel as the wanted DTT receiver) as well as all WSDs ('close' and 'distant').

- **Annex 4:** DTT reception mode and WSD single entry interference considerations

This annex shows:

- The extent of the possibility of different DTT reception modes (fixed, portable outdoor and portable indoor) within DTT coverage areas (large, medium, or small sized) planned for fixed-reception.
- Various relationships between DTT wanted field strength, location probability, propagation distance, I/N. In particular, their relationship to fixed DTT reception as well as portable outdoor/indoor DTT reception modes is illuminated for a protection criterion related to a fixed permissible degradation of the DTT reception location probability;
- Parameters, formulas, etc. to be used for determining maximum WSD e.i.r.p. for reference scenarios.
- Calculated examples providing a comparison of maximum WSD e.i.r.p. limits and corresponding I/N values (as a function of protection ratio) for various values of permissible degradation of the DTT reception location probability.

- **Annex 5:** Considerations of degradation of coverage location probability for the determination of maximum WSD e.i.r.p. limits

This annex aims to assist NRAs in assessing an appropriate level for the degradation of the location probability to be used in the geo-location database calculations for the protection of the broadcasting services.

- **Annex 6:** PMSE reference geometries

This annex presents interference geometries for WSD interfering with PMSE receivers.

- **Annex 7:** Application examples of master/slave concept

This annex presents the case of Machine-to-Machine network deployment as an example of how a master/slave approach might work in practice.



- **Annex 8:** Trade-off between ‘false-vacancy-detection’ and ‘false-occupancy-detection’ as a function of increasing detection thresholds

This annex presents various (limited) measurement results and theoretical models showing the impact of setting the detection threshold level on the protection of DTT.

- **Annex 9:** Combination of geo-location database and sensing techniques in a real scenario

This annex presents an Italian case study to investigate possible benefits in terms of protection of DVB-T services, derived from a combined approach of geo-location and sensing techniques.

- **Annex 10:** Worked example for the translation process for the protection of DTT using an analytical method

This annex presents a possible implementation of the translation process. It uses an analytical method to perform a full computation of the data required to populate the geo-location database and use them to compute an upper limit for maximum e.r.p. of WSDs so as to contain their impact to DTT coverage.

- **Annex 11:** Worked example for the translation process for the protection of DTT using the Monte-Carlo method

This annex presents another possible implementation of the translation process (compared to Annex 10). It uses Monte Carlo method to perform a full computation of the data required to populate the geo-location database and use them to compute an upper limit for maximum e.r.p. of WSDs so as to contain their impact to DTT coverage.

- **Annex 12:** Derivation of the equation in the ‘analytical’ approach

This annex details the mathematical derivation of the analytical approach summarized in section 5.2.3.4 of the main report.

- **Annex 13:** Seamcat simulations used to simulate a typical PMSE scenario

This annex presents Seamcat simulations used to analyse the WSD Exclusion Zone to protect PMSE receivers.

- **Annex 14:** List of references

This annex lists the references used in the report.

## ANNEX 1: MULTIPLE-INTERFERENCE

### A1.1 INTRODUCTION

The information in this Annex is relevant for calculating maximum e.i.r.p. levels for networks of WSDs lying outside of any given co-channel or adjacent channel DTT coverage area, taking into account the cumulative effects of multiple sources of interference. Calculation methods for treating this situation are presented in section 5.2.4.

Methods for dealing with maximum WSD e.i.r.p. levels for WSDs lying inside of an adjacent channel DTT coverage area are presented in Section 5 and in Annex 5, using the parameters of the various reference interference scenarios of Annex 2.

### A1.2 SIMULATION METHODOLOGY AND ITS RESULTS

Figure 21 shows the simulation methodology. The simulation parameters based on ECC Report 159 [1] are shown in Table 4. The simulation procedure is as follows:

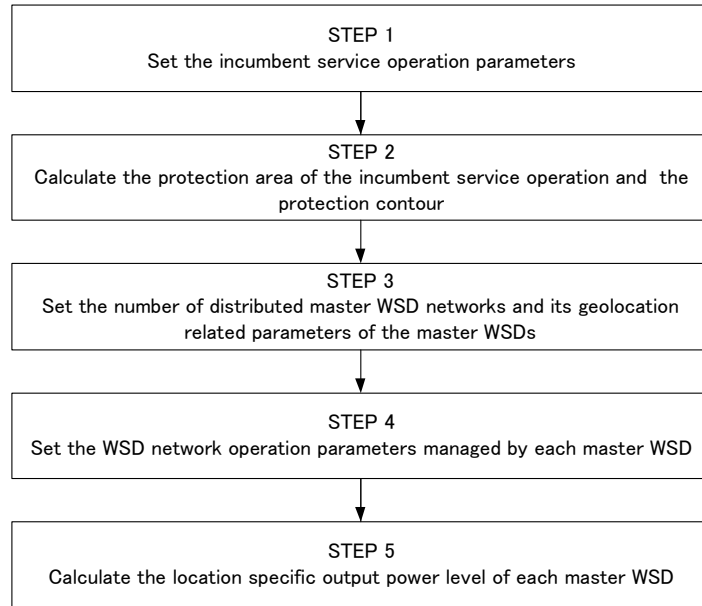
- STEP 1.** Set the incumbent service operation parameters  
The parameters in Section 4.1 of ECC Report 159 [1] are adopted.
- STEP 2.** Calculate the protection area of the incumbent service operation and the protection contour  
The protection contour is calculated based on the method in Section 4.1 of ECC Report 159 [1].
- STEP 3.** Set the number of distributed master WSDs and its geo-location related parameters of the master WSDs.

The following parameters related to the geo-location information of the master WSD are considered in this simulation:

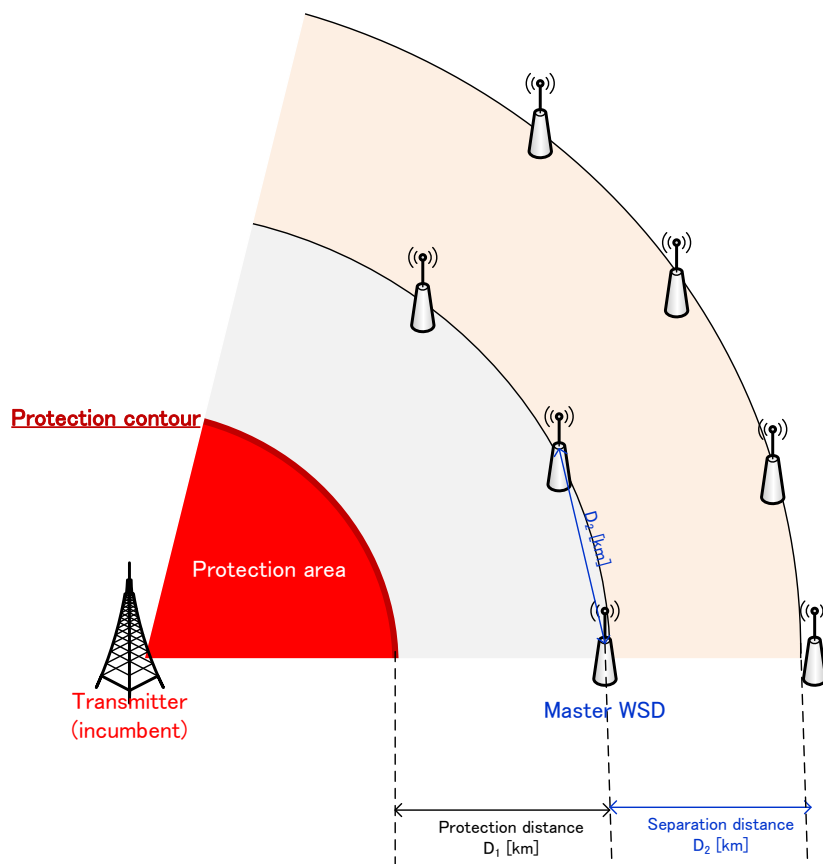
- Protection distance ( $D_1$  [km]).
- This parameter is required in considering the interference effects from the slave WSD in each WSD network managed by each master WSD.
- Separation distance ( $D_2$  [km]) of each master WSD.

Each master WSD is located to a distributed point where is separation distance ( $D_2$  [km]) away from each other as shown in Figure 21.

- STEP 4.** Set the WSD network operation parameters managed by each master WSD  
TRX configuration parameters such as antenna height and antenna gain are set to be here. The detail simulation parameters are shown in Table 4.
- STEP 5.** Calculate the location specific output power level of each master WSD  
The detail simulation parameters are shown in Table 4.



**Figure 21: Simulation methodology**



**Figure 22: Geo-location information related parameters**

Table 4: Simulation parameters

Parameter	Value
<b>Frequency-related parameters</b>	
Frequency	600 MHz
Number of channels	1, 5 or 10
Channel bandwidth	7.6 MHz
Channel separation	8 MHz
$ACL R (= ACLR^{WSD}(f_{WSD} - f_{BS})) \vee$	Scenario #1 ACLR: 33 dB for the first adjacent channel, 36 dB for the second and later adjacent channels(from 3GPP TS36.101) ACS:
$ACS (= ACS^{BS}(f_{WSD} - f_{BS}))$	33 dB (from 3GPP TS36.101)  Scenario #2 ACLR: 36 dB for all adjacent channels ACS: 61 dB
<b>Geolocation-related parameters</b>	
Protection contour from incumbent transmitter	52.9 km
Protection distance (=D1)	20, 40 km
Separation distance (=D2)	2 km
Reference point selection criteria for incumbent service protection	Regarding the calculation step in fixed/flexible method, the closest point in the protection contour of the incumbent service would be chosen as the reference point of each target master WSD. Regarding the calculation step in maximized method, the closest point in the protection contour of the incumbent service should be chosen for the reference point of each target master WSD in the first calculation step. After that, the calculation engine will try to find the most severe interference-victim reference point of each WSD to adjust the output power of WSDs while considering in-block/out-block interference effects from multiple WSDs.
Number of active master WSDs	300
Range of angle where master WSD are distributed	0 – 180 degrees
<b>Propagation-related parameters</b>	
BS broadcaster antenna height	200 m
BS receiver antenna height	10 m
Master WSD antenna height	20 m
$m_{G(dB)}$	
Slave WSD antenna height	10 m
Propagation model $L_{WSD(H_{WSD})-BS(H_{DTT})(d_{WSD-BS})$	Recommendation ITU-R P.1546[8] (Rural, Time percentage = 1%)
BS receiver antenna directivity discrimination	0 dB (with respect to DTT transmitter), -16 dB (with respect to WSD Ddir)
TV receiver antenna gain (= $G_i$ )	12.15 dBi

TV receiver feeder loss ( $= L_f$ )	3 dB
BS receiver polarization discrimination with respect to the WSD signal ( $D_{pol}$ )	0 dB
<b>Output power-related parameters</b>	
WSD location specific output power calculation methods	Fixed method (based on Eq.(2)), Flexible method (based on Eq.(3)), and Maximized method (based on Eq.(11))
Limit of WSD output power	36 dBm
TV broadcaster transmission power	79.15 dBm/channel
<b>Aggregated interference power level related parameters</b>	
Multiple interference margin: IMdB(Fixed method)	$10 \cdot \log_{10}$ (Potential maximum number of active master WSDs in each available channel which depends on the simulation parameter setting in allocating active WSDs in available channels)
Multiple interference margin:IMdB(Flexible method)	$10 \cdot \log_{10}$ (Maximum number of all the number of active master WSDs in each available channel)
<b>Incumbent service operation parameters</b>	
Minimum incumbent service (BS) power @ receiver $m_{Z(dB)}$	-77.1 dBm
Protection ratio $r(\Delta f)_{(dB)}$	23.1 dB
Location probability (LP) without interference from WSD $q_1$	95 %
LP with interference from WSD $q_2$	94.9 %
Acceptable degradation to LP $\Delta LP (= q_1 - q_2)$	0.1 %
Standard deviation of BS power @ receiver $\sigma_{Z(dB)}$	5.5 dB
Standard deviation of coupling gain between BS receiver and WSD transmitter $\sigma_{G(dB)}$	3.5 dB

### A1.2.1 Comparison of the location specific output power level of WSD

The location specific output power level of WSD is shown here. The results of 5% and 50% CDFs of the location specific WSD e.i.r.p. [dBm] when the number of master WSDs is 300 are highlighted.

**Table 5: Comparison of output power level of WSD (Number of TVWS channels = 1)**

Number of master WSDs		300					
Number of channels		1					
Protection distance [km]		20			40		
Output power calculation method		Fixed	Flexible	Flexible Minimized	Fixed	Flexible	Flexible Minimized
Output power level of WSD [dBm]	5% CDF	10.4	10.4	17.5	23.1	23.1	28.3
	50% CDF	12.3	12.3	19.3	24.0	24.0	29.1

**Table 6: Comparison of output power level of WSD (Number of TVWS channels = 5)**

Number of master WSDs		300					
Number of channels		5					
Protection distance [km]		20			40		
Output power calculation method		Fixed	Flexible	Flexible Minimized	Fixed	Flexible	Flexible Minimized
Output power level of WSD [dBm]	5% CDF	10.4	16.5	23.4(Scenario#1) 23.2(Scenario#2)	23.1	29.2	34.1
	50%	12.3	18.4	25.6 Scenario# 1) 25.4 (Scenario#2)	24.0	29.9	35.2

**Table 7: Comparison of output power level of WSD (Number of TVWS channels = 10)**

Number of master WSDs		300					
Number of channels		10					
Protection distance [km]		20			40		
Output power calculation method		Fixed	Flexible	Flexible Minimized	Fixed	Flexible	Flexible Minimized
Output power level of WSD [dBm]	5% CDF	10.4	19.0	25.4(Scenario#1) 25.4(Scenario#2)	23.1	31.6	36.0
	50%	12.3	21.0	27.7(Scenario#1) 27.7(Scenario#2)	24.0	32.4	36.0

### A1.3 COMPARISON AMONG DIFFERENT IM CALCULATION METHOD AND ITS ANALYSIS

The results in previous section show that the consideration of the number of active WSDs of each available channel in the calculation engine will bring us the highest communication opportunity of WSDs, according to the performance differences among fixed  $IM_{dB}$ , flexible  $IM_{dB}$  and flexible minimized  $IM_{dB}$  method. In this simulation, the potential maximum number of active WSDs in each available channel is fixed, so we can just see no performance difference between the fixed  $IM_{dB}$  method and flexible  $IM_{dB}$  method in a case where the number of available channel is in case of single available channel. However, in actual operation, the geolocation database does not know the potential maximum number of active WSDs in each available channel, so an excessive value should be adopted. Hence, we can see more performance differences between fixed method and flexible  $IM_{dB}$  method or flexible minimized  $IM_{dB}$  method in actual TVWS operation.

The flexible minimized  $IM_{dB}$  method can show the highest performance in three methods, because there will be some redundancy in calculating output power level of WSDs in cases where the fixed and flexible margin based calculation methods are adopted. This may be due to the fact that the fixed and flexible margin based calculation methods cannot differentiate between the path loss conditions of a target WSD from one of the other potential interferers in calculating output power level of a target WSD.

Table 8 shows the comparison of different calculation methods from viewpoints of the calculation overhead, the system overhead and the WSD network capacity<sup>20</sup>. One can see that the calculation overhead for the calculation engine and its system overhead will increase due to the consideration of the number of active master WSDs in each available channel, so some additional study on this issue will be necessary.

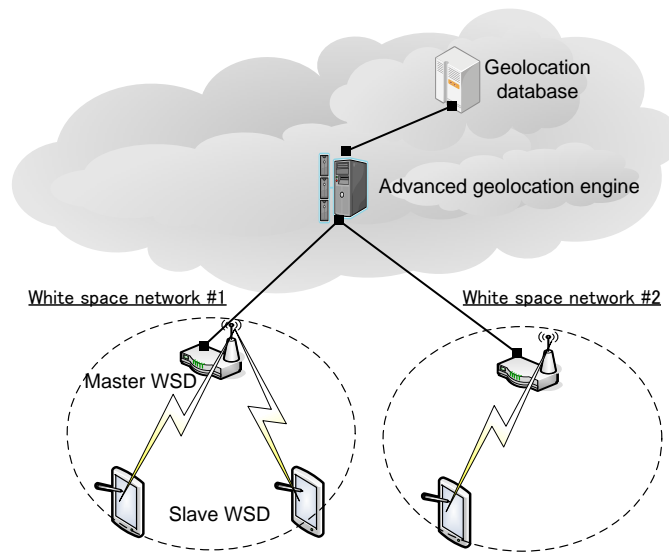
**Table 8: Comparison of different calculation methods**

	Calculation overhead	System overhead	WSD network capacity
Fixed margin based method	Low	Small	Low
Flexible margin based method	Moderate	Moderate	Moderate
Flexible minimized method	High	Large	High

There will be several possible deployment scenarios for the calculation engine of location specific output power level. For example, the calculation engine may be a part of geo-location database controlled by a NRA, or a separate engine (namely advanced geo-location engine) from the geo-location database managed by NRA as shown in Figure 23. In a case where it is a separate engine, a third party should take a responsibility to protect the incumbent service receivers from an aggregated interference problems, and the operation should be kept under surveillance by NRA. The merit will be to enable the processing load of the geo-location database managed by NRA to offload to the third party engine. Such third party engines may be also provide other services, such as coexistence services (which will be standardized in specifications such as ETSI TS102 908 Cognitive radio network coexistence for white space or IEEE P802.19.1 (TVWS network coexistence system) to the WSDs operating in the same area.

<sup>20</sup>The WSD network capacity is compared here based on the simulation results on the location specific output power level when different types of  $IM_{dB}$  calculation method are used.





**Figure 23: Network deployment scenario**

#### A1.4 CONCLUSIONS

This Annex introduces the performance comparison between the location specific WSD output power level calculation method for database approach in ECC REPORT159 and its extension methods which consider the number of active master WSDs of each available channel in WSD master-slave operation. This result shows that the consideration of the number of active master WSDs of each available channel will have large impact for location specific output power level of WSDs while satisfying the incumbent service protection.

Further study will be necessary, specifically for the feasibility of the interface between the geo-location database and WSDs allowing for the number of active master WSDs to calculate the location specific WSD output power level in a geo-location database.

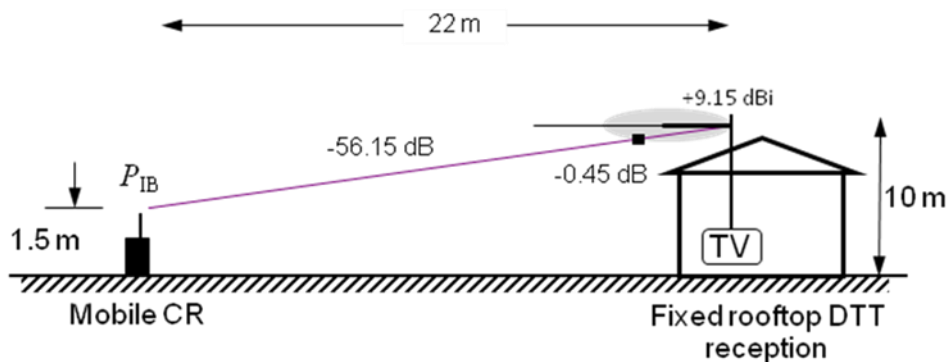
## ANNEX 2: DTT INTERFERENCE SCENARIOS

When extending the basic methodology of ECC Report 159 [1] to calculate the WSD maximum power levels the following scenarios could be considered:

### A2.1 PORTABLE OUTDOOR WSD TRANSMISSION

#### A2.1.1 Mobile WSD transmission and fixed roof-top DTT reception (Scenario 1)

The used model is shown below. A mobile WSD at 1.5 m above ground level (agl) radiates into a rooftop DTT antenna. Taking account of the vertical DTT receive antenna pattern, the maximum loss and receive antenna discrimination from the WSD to the DTT antenna is  $56.15 + 0.45 \text{ dB} - 9.15 = 47.45 \text{ dB}$ .

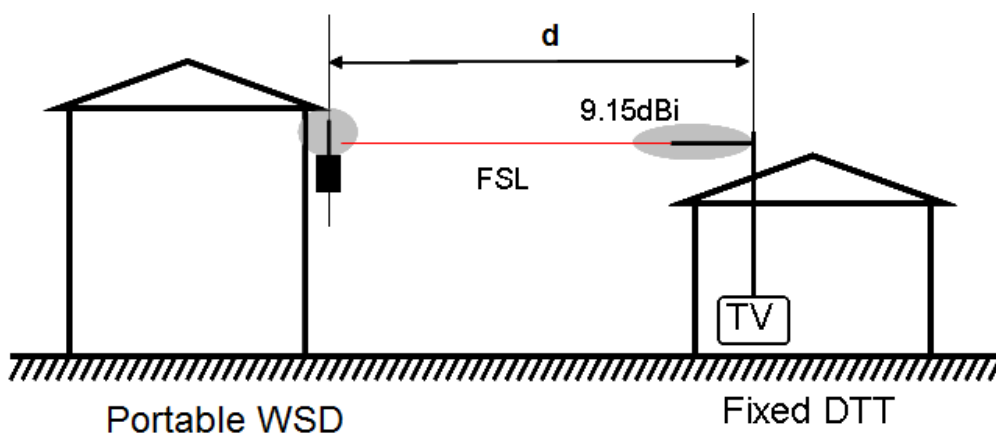


**Figure 24: Scenario 1: Reference geometry for mobile WSD at 1.5 m agl.**

The path loss shown is valid for a carrier at 650 MHz.

#### A2.1.2 Portable WSD transmission at 10 m agl and fixed roof-top DTT reception (Scenario 2)

The used model is shown below. A mobile WSD at 10 m agl (e.g. from a window in a multi-story house) radiates directly into a rooftop DTT antenna at 10 m agl. There is no receiving antenna or polarisation discrimination. The maximum loss from the WSD to the DTT antenna is 54.72 dB.



**Figure 25: Scenario 2: Reference geometry for mobile WSD at 10 m agl.**

The path loss shown is valid for a carrier at 650 MHz and is based on a distance ( $d$ ) ranging from 6 m to 20 m. In practice this separation will vary across Europe, and a different value may be appropriate where the

housing density is lower. The justification for the 6 m can be found at APPENDIX 1, which presents details of UK household separation analysis.

For the general case, the coupling loss G, between WSD and Fixed DTT, will be given by:

$$G = FSL(D) - G_{ant,DTT}$$

$$G = 20 \cdot \log(F_{MHz}) + 20 \cdot \log(D_m) - 27.5 - G_{ant,DTT}$$

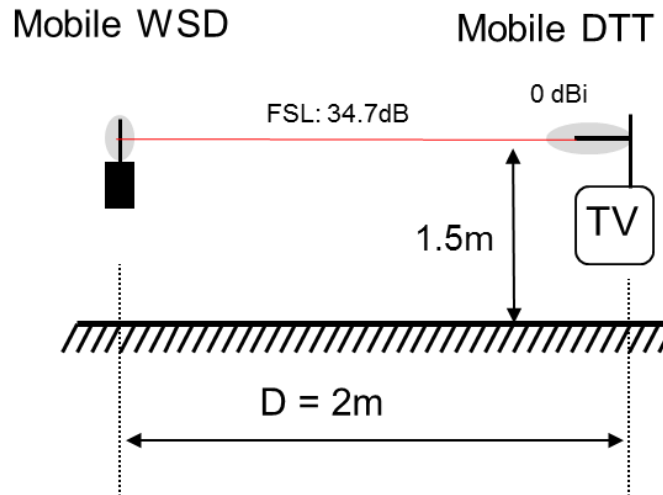
In order to take into account the varying distance across Europe, the distance D may be classified as a variable. Three selectable distance separations which determine the coupling loss, G, are included in the table below.

**Table 9: Variable distance (d) and resulting Coupling Loss (G)**

Distance (m)	FSL @ 650MHz (D) [dB]	DTT Antenna Gain ( $G_{ant,DTT}$ ) [dBi]	Coupling Gain (G) [dB]
6	44.32	9.15	35.17
10	48.76	9.15	39.61
20	54.79	9.15	45.63

**A2.1.3 Mobile WSD transmission at 1.5 m agl and mobile DTT reception at 1.5 m agl (Scenario 3a)**

The used model is shown below. A mobile WSD at 1.5 m agl radiates directly into a mobile DTT antenna at 1.5 m agl. There is no receiving antenna or polarisation discrimination. The maximum loss from the WSD to the DTT antenna is 34.7 dB.

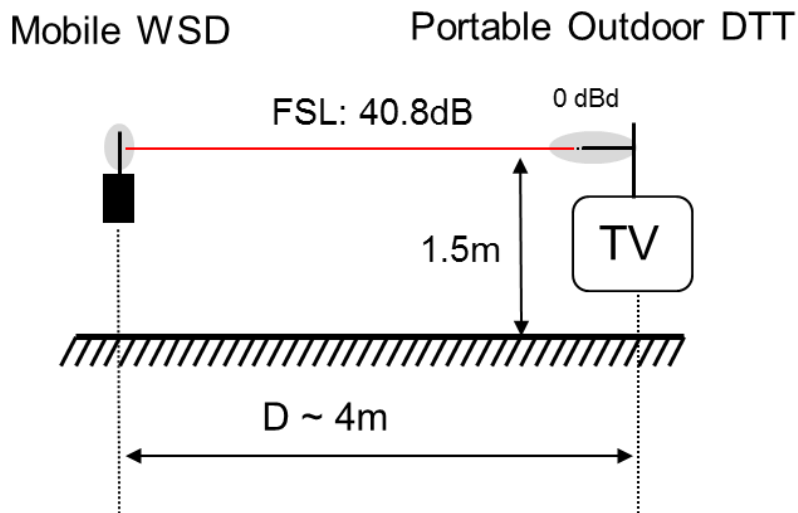


**Figure 26: Scenario 3a: Reference geometry for mobile WSD and mobile DTT at 1.5 m agl**

The path loss shown is valid for a carrier at 650 MHz.

**A2.1.4 Mobile WSD transmission at 1.5 m agl and mobile DTT reception at 1.5 m agl (Scenario 3b)**

The reference geometry for the protection of outdoor portable reception is shown in next Figure. The choice of separation between the WSD and the DTT antenna is a compromise. Short separations will imply the greatest restrictions on the WSD.

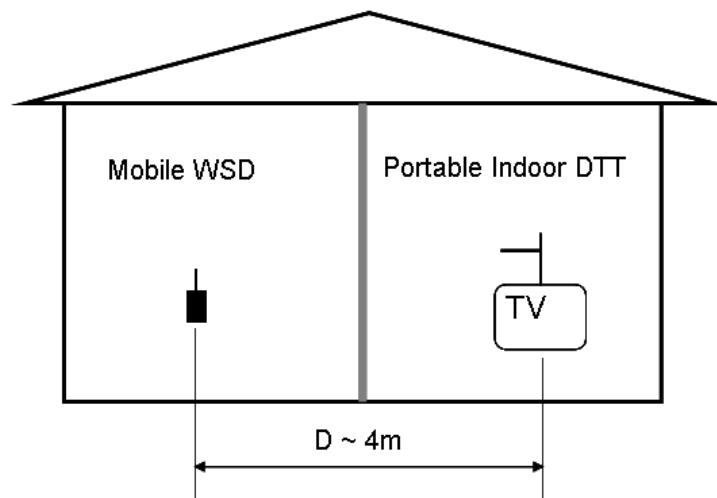


**Figure 27: Scenario 3b: Reference geometry for mobile WSD and portable outdoor DTT at 1.5 m agl**

The coupling loss  $G$  between the WSD and the victim portable receiver at short range can be modelled as free space loss. Assuming a portable DTT antenna gain of 2.15 dBi, and no polarization discrimination and a separation of 4 m, the coupling loss  $G$  at 650MHz will be  $G = 40.8 - 2.15 = 38.65$  dB. This path loss figure is valid for a WSD operating at 650 MHz.

#### A2.1.5 Geometry for Protection of Indoor Portable DTT from mobile WSD UE (Scenario 3c)

The ECC 159 geometry for protection of portable is shown in Figure below.



**Figure 28: Scenario 3c: Reference geometry for portable indoor reception**

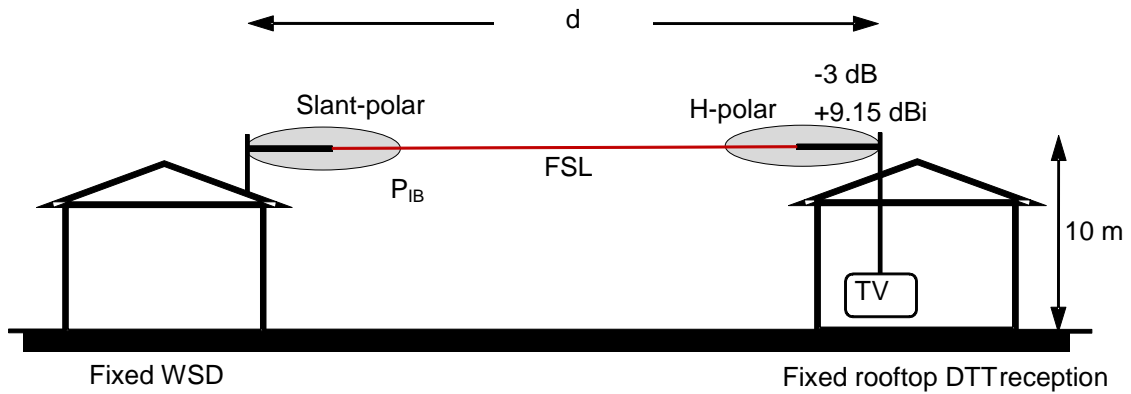
The coupling loss  $G$  between the WSD and the victim portable receiver at short range is modelled as free space loss. Assuming 8 dB wall loss, 40.8dB free space loss at 4m, 0dB polarization discrimination and 2.15dBi DTT antenna gain, the typical coupling loss  $G = 40.8 + 8 - 2.15 = 46.6$ dB at 650 MHz.

## A2.2 FIXED WSD TRANSMISSION

### A2.2.1 Fixed WSD transmission and fixed DTT reception at 10 m agl (Scenario 4a)

The used model is shown below. A fixed WSD at 10 m agl radiates directly into a fixed DTT antenna at 10 m agl. The distance between the antennas ranges from 6 m (densely inhabited area) to 20 m (less densely inhabited area). There is no receiving antenna discrimination. There would be 3 dB polarisation

discrimination. The maximum loss from the WSD to the DTT antenna, including polarisation discrimination, ranges from  $44.32 + 3 = 47.32$  dB to  $54.72 + 3 = 57.72$ dB.



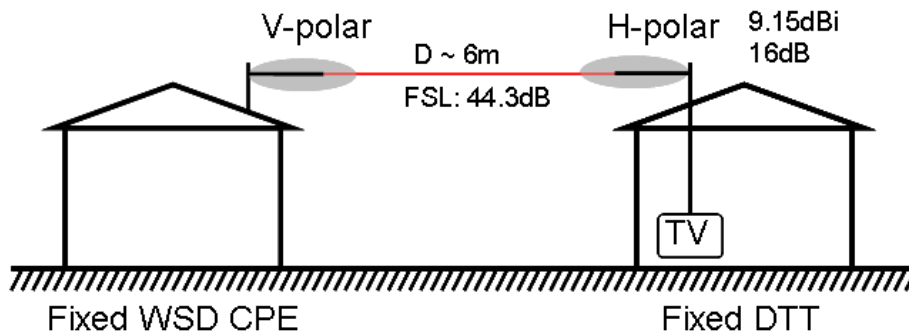
**Figure 29: Scenario 4a: Reference geometry for fixed WSD and fixed DTT reception at 10 m agl**

The path loss shown is valid for a carrier at 650 MHz.

**A2.2.2 Fixed WSD transmission and fixed DTT reception at 10 m agl (Scenario 4b)**

The used model is shown below. A fixed WSD at 10 m agl radiates directly into a fixed DTT antenna at 10 m agl. The separation  $D$ , used for coupling loss calculations will depend upon the density of housing in a particular NRA. For the UK, studies of typical housing separations (see APPENDIX 1) suggest a distance of 6m should be used for the free space loss calculation.

Assuming a fixed DTT antenna gain of 9.15dBi, 6m separation with a free space loss of 44.3dB at 650MHz, and 16dB cross polar discrimination, the coupling gain  $G$  will be 51.2dB. For CPE installations where the CPE is operating on the same polarization as the fixed DTT receiver, the coupling  $G$  reduces to 35.2dB.



**Figure 30: Reference geometry for fixed outdoor reception and fixed WSD CPE**

Note that the 6 m separation between WSD antenna and DTT receive antenna may also occur in less densely inhabited areas if the two antennas are situated on the same roof.

For the general case, the coupling loss  $G$  will be given by:

$$G = FSL(D) + D_{pol} - G_{ant,DTT}$$

$$G = 20 \cdot \log(F_{MHz}) + 20 \cdot \log(D_m) - 27.5 + D_{pol} - G_{ant,DTT}$$

For cross-polarisation between the WSD and the DTT antenna, and in order to take into account the varying distance across Europe, the distance D may be classified as a variable. Three selectable distance separations which determine the coupling loss, G, are included in the table below.

**Table 10: Variable distance (D) and resulting Coupling Loss (G) for Cross-Polarisation**

Distance (m)	FSL @ 650MHz (D) [dB]	$D_{pol}$ [dB]	DTT Antenna Gain ( $G_{ant,DTT}$ ) [dBi]	Coupling Gain (G) [dB]
6	44.32	16	9.15	51.17
10	48.76	16	9.15	55.61
20	54.79	16	9.15	61.62

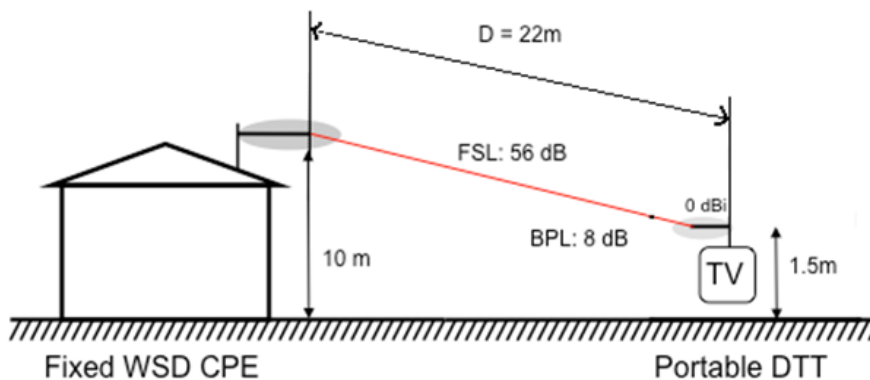
For non-co-polarisation between the WSD and the DTT antenna, and in order to take into account the varying distance across Europe, the distance D may be classified as a variable. Three selectable distance separations which determine the coupling loss, G, are included in the table below.

**Table 11: Variable distance (D) and resulting Coupling Loss (G) for Co-Polarisation**

Distance (m)	FSL @ 650MHz (D) [dB]	$D_{pol}$ [dB]	DTT Antenna Gain ( $G_{ant,DTT}$ ) [dBi]	Coupling Gain (G) [dB]
6	44.32	0	9.15	35.17
10	48.76	0	9.15	39.61
20	54.79	0	9.15	45.63

**A2.2.3 Fixed WSD transmission at 10 m agl and mobile DTT reception at 1.5 m agl (Scenario 5)**

The used model is shown below. A fixed WSD at 10 m agl radiates directly into a mobile DTT antenna at 1.5 m agl. There is no receiving antenna or polarisation discrimination. We assume a 0.5 dB transmit antenna attenuation in the downward direction. The maximum loss from the WSD to the DTT antenna, including transmit antenna attenuation, is  $56 + 0.5 = 56.5$  dB at 650 MHz.



**Figure 31: Scenario 5: Reference geometry for fixed WSD at 10 m and mobile DTT at 1.5 m agl.**

The path loss shown is valid for a carrier at 650 MHz.

**A2.2.4 FIXED WSD AT 10 m agl INTERFERING WITH PORTABLE INDOOR DTTB AT 1.5 magl (Scenario 6)**

The geometry used to calculate the interference from a fixed WSD transmit antenna at 10 m to a portable indoor DTT receiver at 1.5 m height is shown below.

The relevant parameters are the following:

Reference frequency: 650 MHz

Horizontal separation between the WSD and the DTTB: 20 m

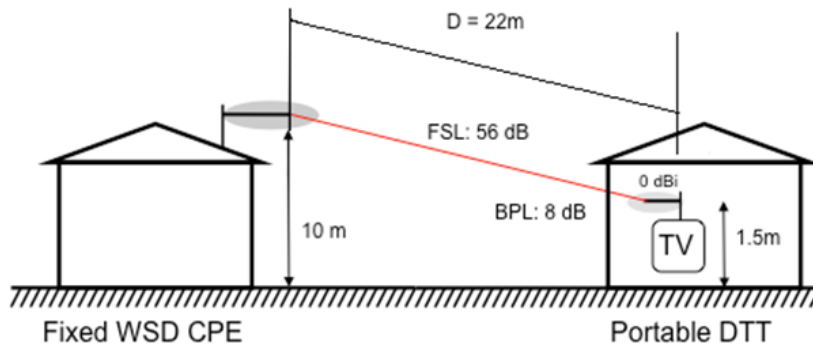
Path loss: 56 dB

WSD transmit antenna discrimination: 0.5 dB

Polarization discrimination: 0 dB

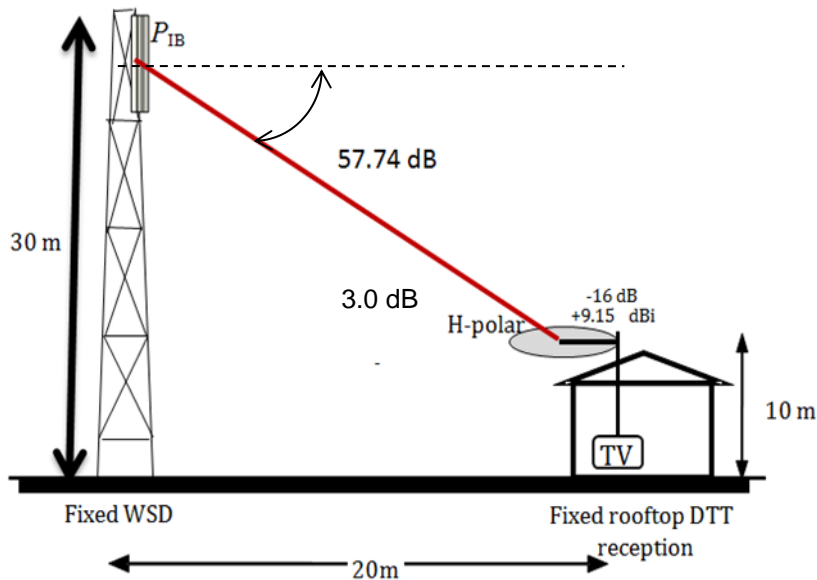
Wall loss: 8 dB, standard deviation 5.5 dB

We assume a 0.5 dB transmit antenna attenuation in the downward direction. The maximum loss from the WSD to the DTT antenna, including transmit antenna attenuation, is  $56 + 0.5 + 8 = 64.8$  dB at 650 MHz.



**Figure 32: Scenario 6: Reference geometry for fixed WSD at 10 m and mobile indoor DTT at 1.5 m agl.**

**A2.2.5 Fixed WSD transmission at 30 m agl and fixed DTT reception at 10 m agl (Scenario 7)**



**Figure 33: Scenario 7: Reference geometry for fixed WSD at 30 m and fixed DTT at 10 m agl.**

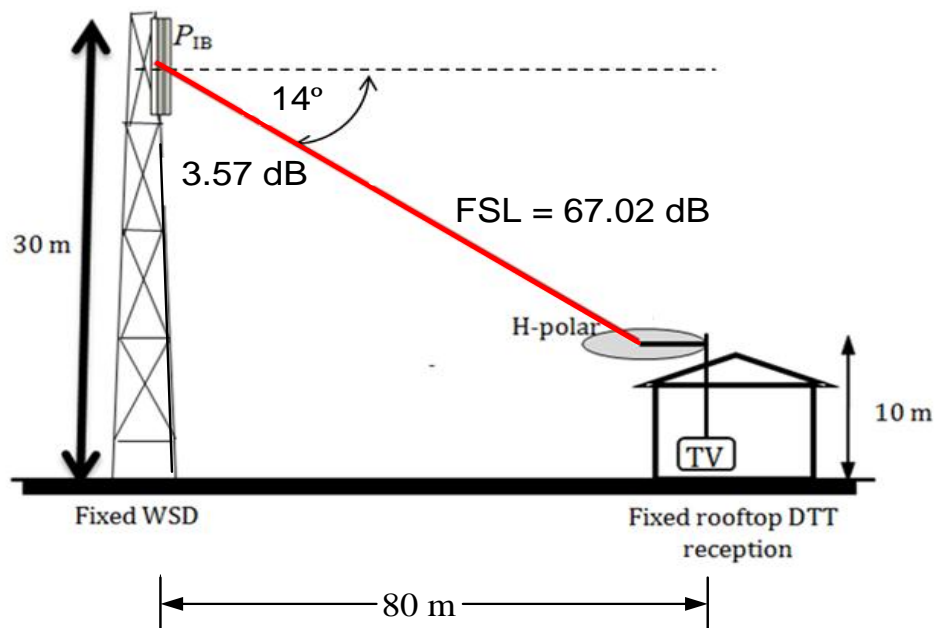


If 30 m BS transmit antennas are foreseen, this type of usage should be restricted to rural areas. In urban environments, fixed DTTB receive antenna installations might also be foreseen at 30 m. In this case the WSD e.i.r.p. restrictions would be the same as that calculated for Scenario #4.

Other assumptions for this scenario were proposed, referring to the results presented in APPENDIX 1, where both horizontal and vertical polarization of the WSD antenna is considered.

A fixed WSD at 30m agl, horizontally polarized, radiates into a fixed horizontally polarized DTT antenna at 10 m agl. Taking into account the vertical radiation pattern of the WSD antenna the path loss is  $67 + 3.6 - 9.15 = 61.44\text{dB}$ . The vertical radiation pattern of the DTT antenna has been considered but gives no extra discrimination for less than 20 degrees.

A fixed WSD at 30m agl, vertically polarized, radiates into a fixed horizontally polarized DTT antenna at 10 m agl. Taking into account the vertical radiation pattern of the WSD antenna the path loss is  $(67 + 3.6 - 9.15) + 16 = 77.45\text{dB}$ .

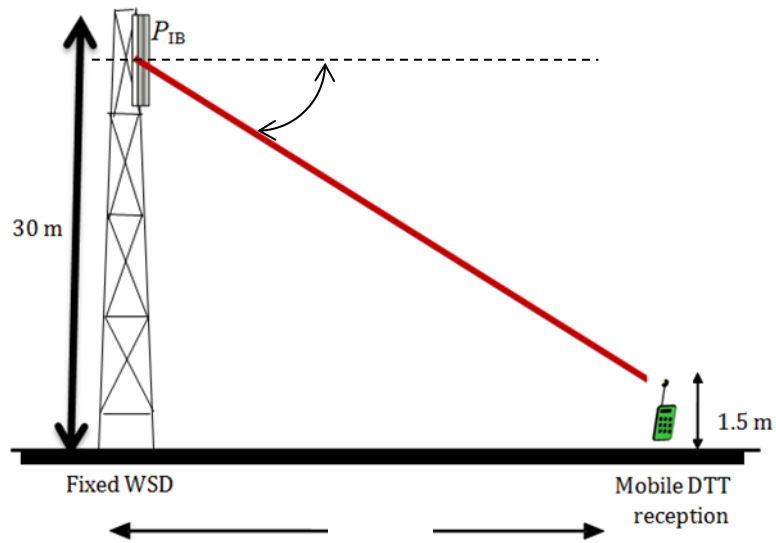


$$\text{Loss (WSD Horizontally Polarised)} = 67.02 + 3.57 - 9.15 = 61.44\text{dB}$$

$$\text{Loss (WSD Vertically Polarised)} = (67.02 + 3.57 - 9.15) + 16 = 77.44\text{dB}$$

**Figure 34: Reference Geometry for 30m WSD BS and Fixed DTT receiver**

A2.2.6 Fixed WSD transmission at 30 m agl and mobile DTT reception at 1,5 m agl (Scenario 8a)



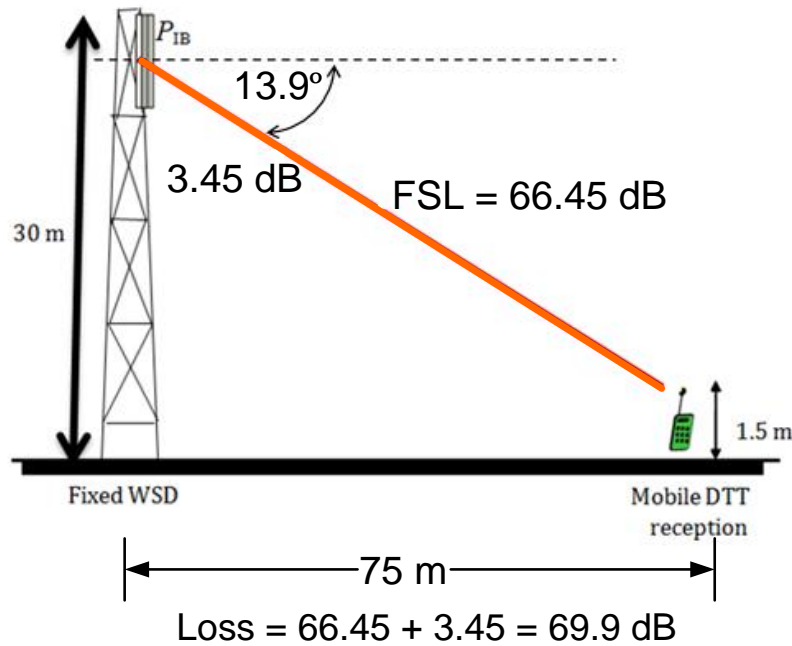
**Figure 35: Scenario 8 a): Reference geometry for fixed WSD at 30 m and fixed DTT at 10 m agl.**

If 30 m BS transmit antennas are foreseen, this type of usage should be restricted to rural areas. In urban environments, when Portable Outdoor DTTB reception is to be protected, because of the portability of the mobile DTTB apparatus, such equipment can also be located at higher than 1.5 m (e.g. at 10 m or 20 m at the window of a high rise).

### A2.2.7 Fixed WSD transmission at 30 m agl and mobile DTT reception at 1,5 m agl (Scenario 8b)

Other assumptions for this scenario were proposed by one NRA, referring to the antenna pattern presented in APPENDIX 2.

A fixed WSD at 30m agl, radiates into a mobile DTT antenna at 1.5 m agl. Assume co-polarisation of the WSD and DTT antennas. Taking into account the vertical radiation pattern of the WSD antenna the path loss is  $66.45 + 3.45 = 69.9\text{dB}$ . The vertical radiation pattern of the DTT antenna has been considered but gives no extra discrimination for less than 20 degrees.



**Figure 36: Reference Geometry for 30m WSD BS and Fixed DTT receiver**

If 30 m BS transmit antennas are foreseen, this type of usage should be restricted to rural areas. In urban environments, when Portable Outdoor DTT reception is to be protected, because of the portability of the mobile DTT apparatus, such equipment can also be located at higher than 1.5 m (e.g. at 10 m or 20 m at the window of a high rise).

## APPENDIX 1 OF ANNEX A2

### INTRODUCTION

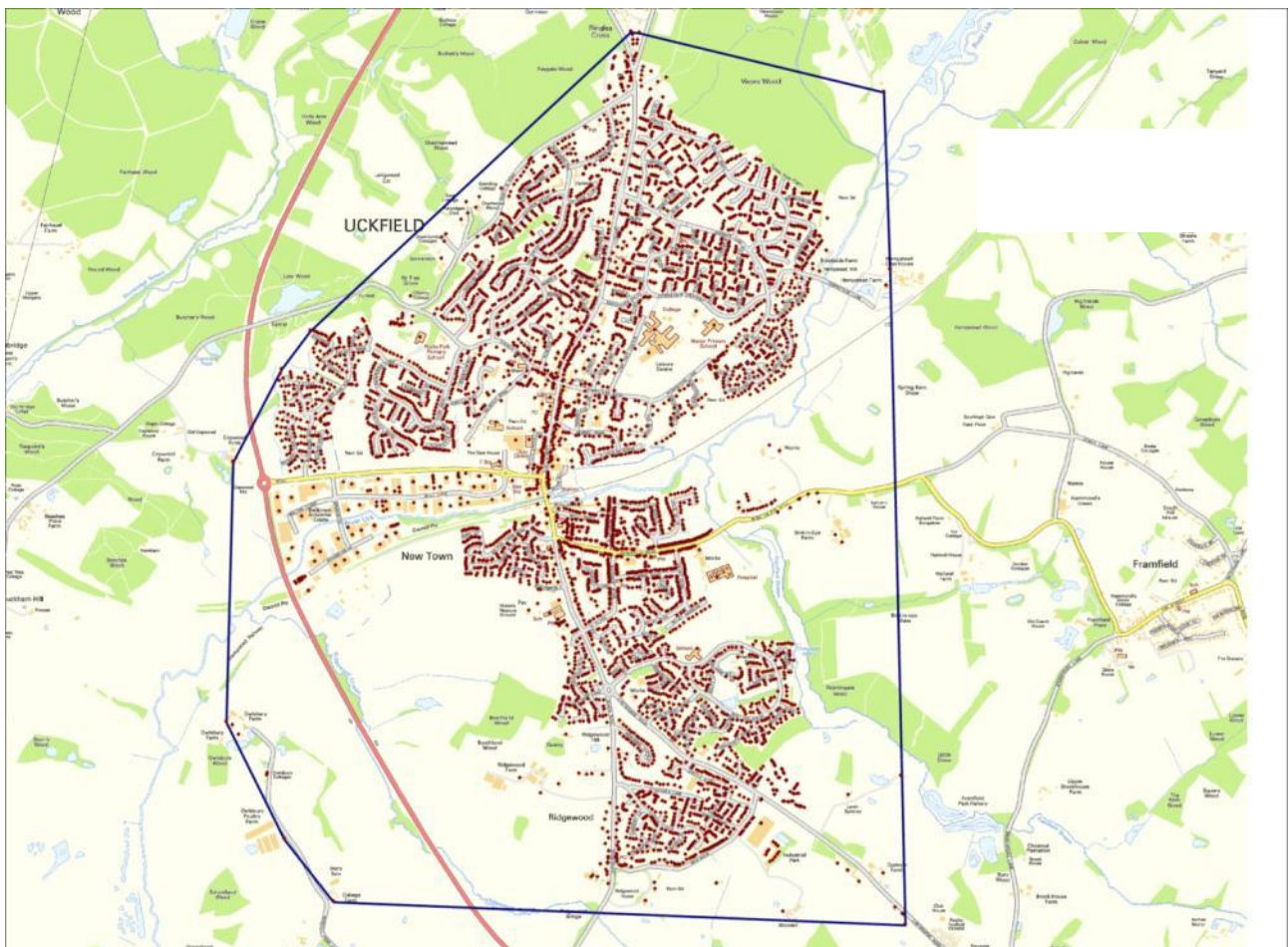
High quality address location data for the UK and Northern Ireland is available from the Ordnance Survey and Ordnance Survey Northern Ireland as commercially licensed products. Equivalent data is also available from other sources for the Isle of Man and Channel Islands, but these jurisdictions are excluded from this analysis.

The address data is at a positional resolution of 10cm, in many cases determined by GPS positioning. The physical point in the address selected for the location is determined by the OS product purchased, and varies from a point somewhere within the dwelling for the basic product through to the precise location of the postal delivery point, usually the letter box, in the premium product.

It is possible to process the positional data to determine the distance between address locations which is a first approximation to the separation between dwellings. The data available to Digital UK is at the lowest order of accuracy, i.e. the address position represents a point somewhere within the dwelling, but not necessarily the Delivery Point.

The “MapInfo” GIS software package includes a tool to calculate separation distances and this can be used to find the “nearest neighbour” to selected addresses. The tool is computationally intensive and the computational resource available to Digital UK means that analysis must be restricted to relative small geographical areas.

“MapInfo” was initially used to assess the address separations in Uckfield, a typical small rural town in East Sussex. The assessment area and the delivery points are shown in Figure 37.



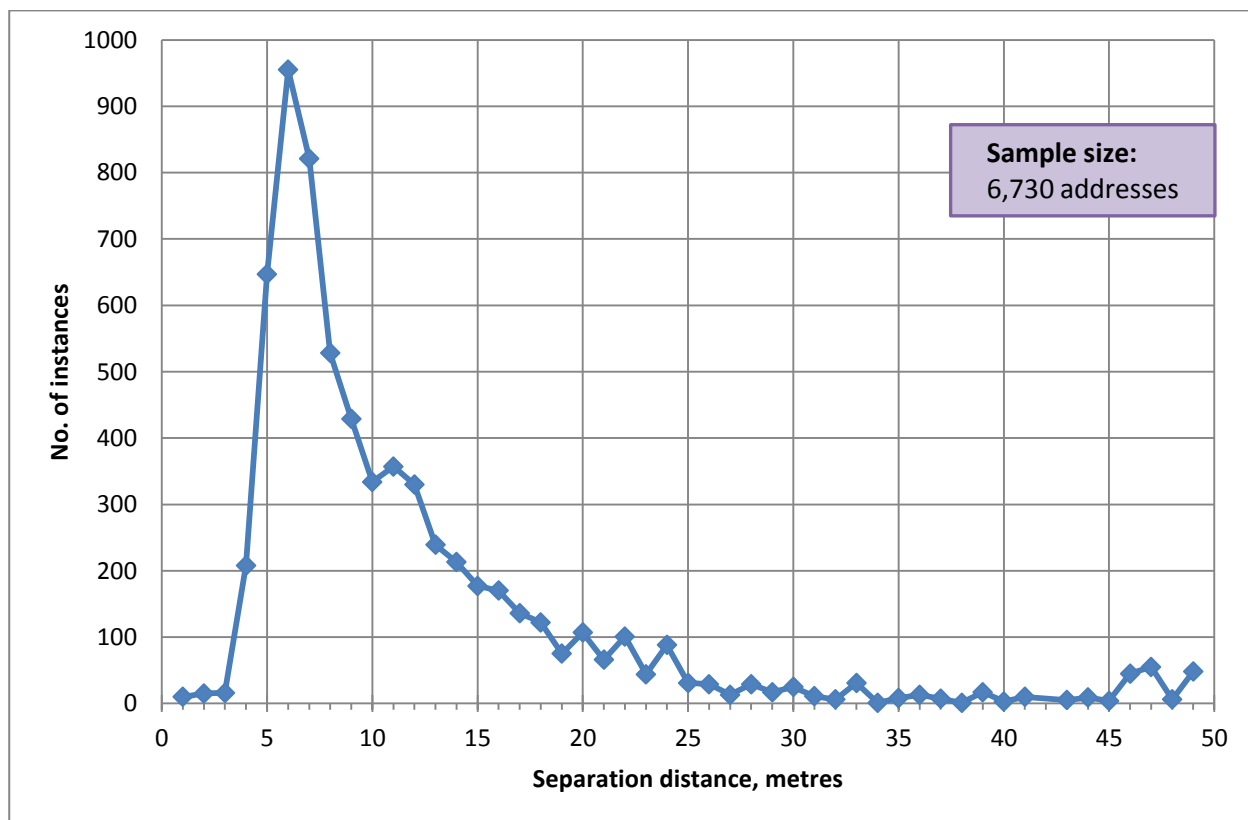
**Figure 37: Assessment area and the delivery points**

This area contains 6,730 separation distances of 1metre or more. Separations of less than 1 metre are treated as co-located addresses and therefore have been ignored. Similarly, addresses in multi-occupancy dwellings have been ignored, the building being treated as having a single address, rather than multiple addresses. This will tend to skew the results towards an over-estimate, rather than an under-estimate of the separation distances for the affected premises.

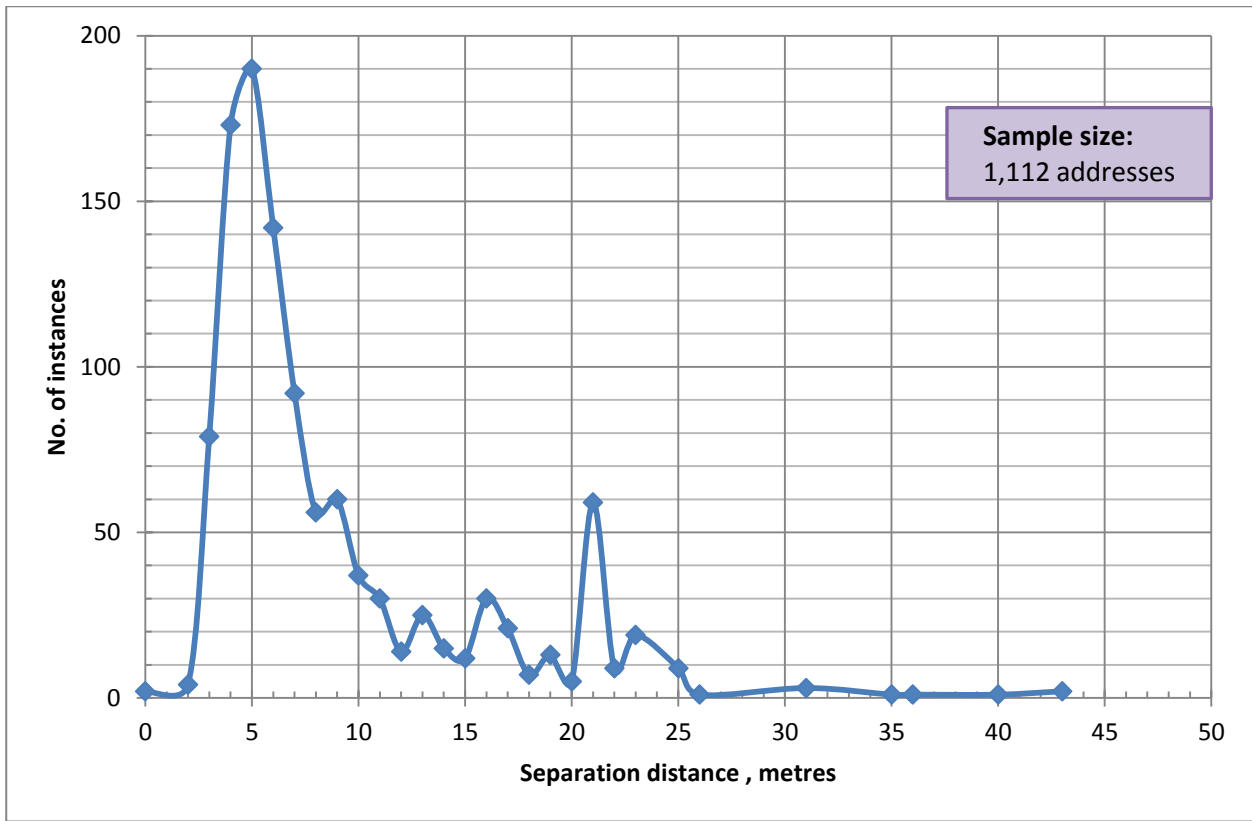
Figure 38 shows the frequency of occurrence of the distances, to the nearest metre. Note that the curve has a long tail and has been truncated at 50m for clarity. The maximum separation distance in this area is 373m.

A closer view of the Newtown area, which is in the central part of the town to the south of the railway station, is given in Figure 41.

Newtown comprises a mix of housing types and ages, typical of the town. The map also shows the OS address points, the 100m tiles with address count, and the nearest-neighbour derivation. The corresponding separation distance histogram is given in Figure 39.

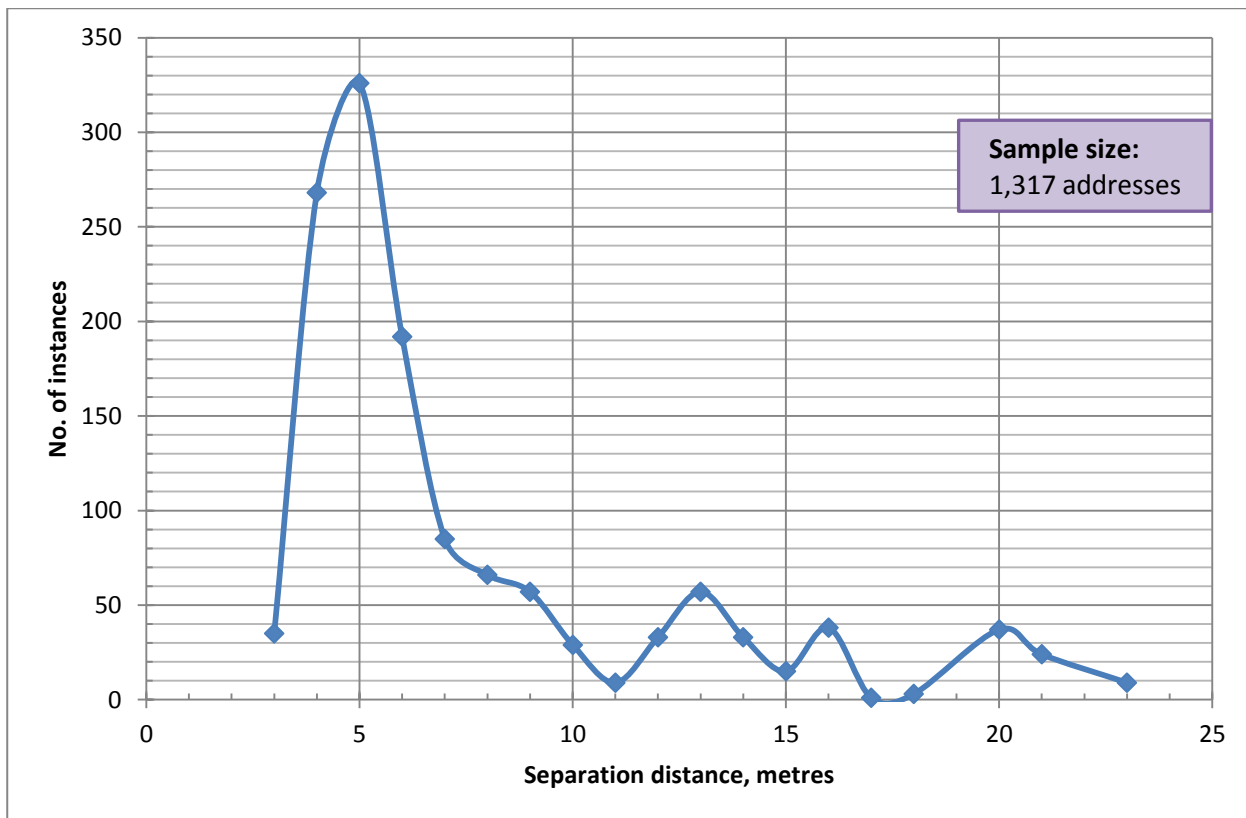


**Figure 38: Address separation distances in Uckfield**



**Figure 39: Address separation distances in New Town, Uckfield**

By way of comparison, a MapInfo assessment has also been made of a small sample area in Islington, London. The area selected is shown in Figure 42: As for Newtown, the map also shows the OS address points, the 100m tiles with address count, and the nearest-neighbour derivation. The corresponding separation distance histogram is given in Figure 40.



**Figure 40: Address separation distances in Islington**

**CONCLUSION**

This limited analysis demonstrates that the typical Ordnance Survey address separation distance in both areas is around 5m. In many cases this will be an underestimate because the Ordnance Survey position is located somewhere within the dwelling, whereas in many cases the address in the sample areas are terraced or semi-detached which means that parts of the adjacent dwellings are much closer to each other than 5m.





Figure 41: Address locations and nearest neighbours in Newtown, Uckfield





Figure 42: Address locations and nearest neighbours in Islington, N1

## WIDER ANALYSIS

Although the areas for the initial analysis were selected at random, it is not a given that they are representative of the wider UK situation. While interesting, it is not necessary to identify and map the nearest neighbours to each address; rather, the separation distance alone provides sufficient information to make the necessary assessment.

To permit larger areas to be analysed within the available computing power, a “Nearest Neighbour” routine was developed in MySQL. While still computationally intensive, this can calculate the separation distances for larger datasets than is possible using MapInfo. Even so, the realistic upper limit is around 450,000 addresses, which still takes in excess of 12 hours to compute.

The computational limitations make it necessary to sub-sample the 26.1million UK addresses to allow calculation to be possible. One way would be to select blocks of addresses based on the National Grid, but this would be hit-and-miss as to the number of addresses contained within each block. An alternative, more convenient, method is to use UK post areas – identified by the initial letter or two letters of the address postcode – because post areas generally contain fewer than 450,000 addresses and generally (but not always) have boundaries in more sparsely populated areas.

It is acknowledged that any analysis area with artificial, rather than natural, boundaries (i.e. where the boundary is not uninhabited water!) will introduce a degree of error because the nearest neighbour to a perimeter address may be outside the boundary selected, but the proportion of the total number of distances so affected will be small, and the error will tend to over-estimate, rather than under-estimate, the minimum separation distance so the overall results will not be skewed to be lower than reality.

The post areas selected for the analysis provide a range of geographies. The areas are shown in Figure 43 and the details are set out in the table below.

**Table 12: Post Areas analysed**

Post Area	Description	Addresses	Geography
BH	Bournemouth	266,765	Urban, sub-urban and rural
CF	Cardiff	453,344	Urban, sub-urban and rural
CV	Coventry	368,537	Urban, sub-urban and rural
DG	Dumfries & Galloway	77,231	Small towns and rural
HS	Western Isles	15,475	Sparsely populated, remote rural
IG	Ilford	127,509	Urban and sub-urban
KT	Kingston-upon-Thames	230,976	Urban and sub-urban
LS	Leeds	364,705	Urban and sub-urban
NW	North West London	212,186	Urban and sub-urban
PO	Portsmouth and Isle of Wight	383,881	Urban, sub-urban and rural
RH	Redhill	234,140	Urban, sub-urban and rural
SO	Southampton	297,604	Urban, sub-urban and rural
SR	Sunderland	117,584	Urban and sub-urban
SY	Shrewsbury and mid-Wales	158,566	Urban, sub-urban, rural and remote
TD	Galashiels	60,127	Small towns and rural
ZE	Shetland	11,565	Sparsely populated, remote rural
	Total	3,380,195	

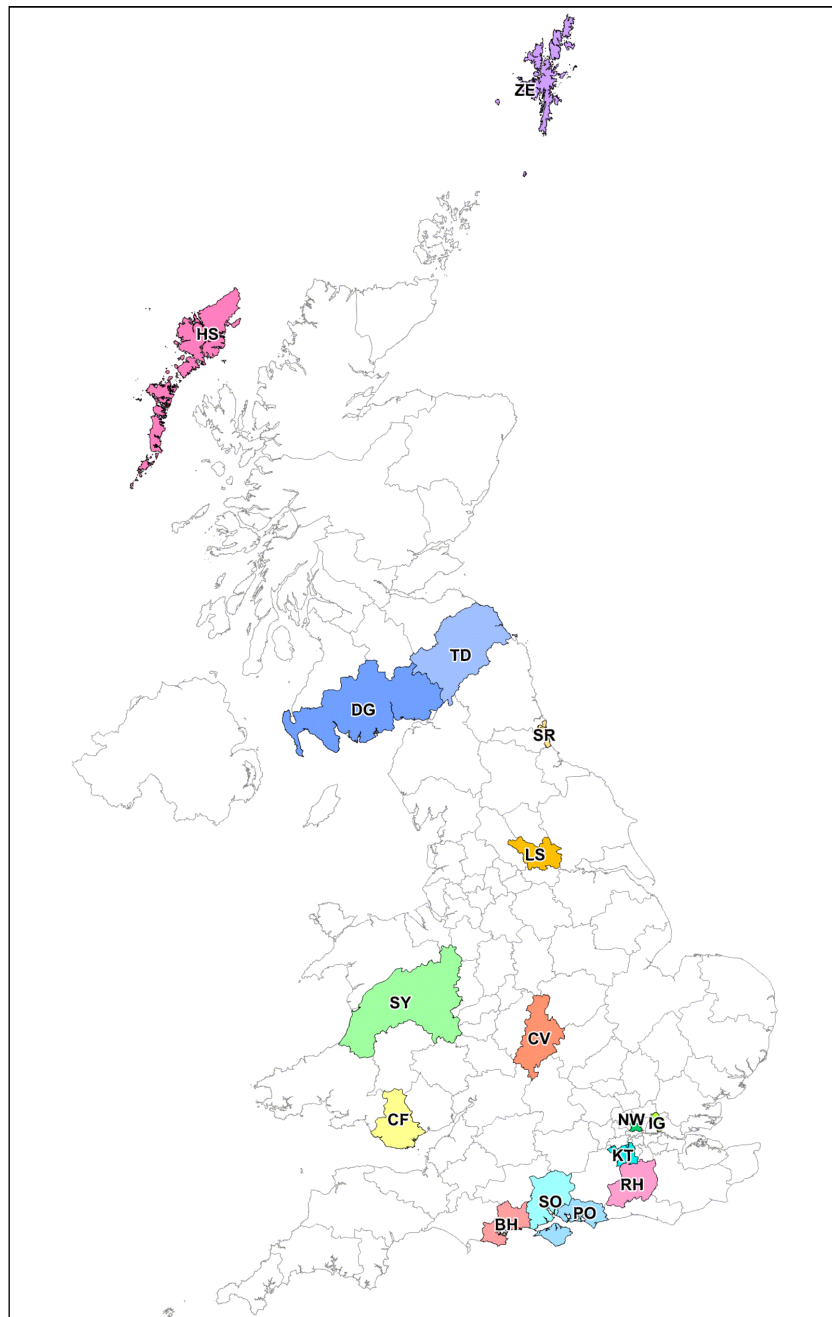
The normalised frequency of separation distance found in these areas are shown in Figure 44 and the CDF in Figure 45.



## CONCLUSION

The wider analysis of 3,380,195 address locations demonstrates that, except for the remote rural areas represented by the HS and ZE post areas, the typical Ordnance Survey address separation distance is around 6 m. As for the initial analysis, this will tend to be an overestimate because the Ordnance Survey position is located somewhere within the dwelling, whereas in many cases the address in the sample areas are terraced or semi-detached which means that parts of the adjacent dwellings are much closer to each other than 6 m.

The analysis also shows that, except in the sparsely populated remote rural areas, at least 50% of addresses have the nearest neighbour within 10m.



**Figure 43: Post Areas selected for analysis**

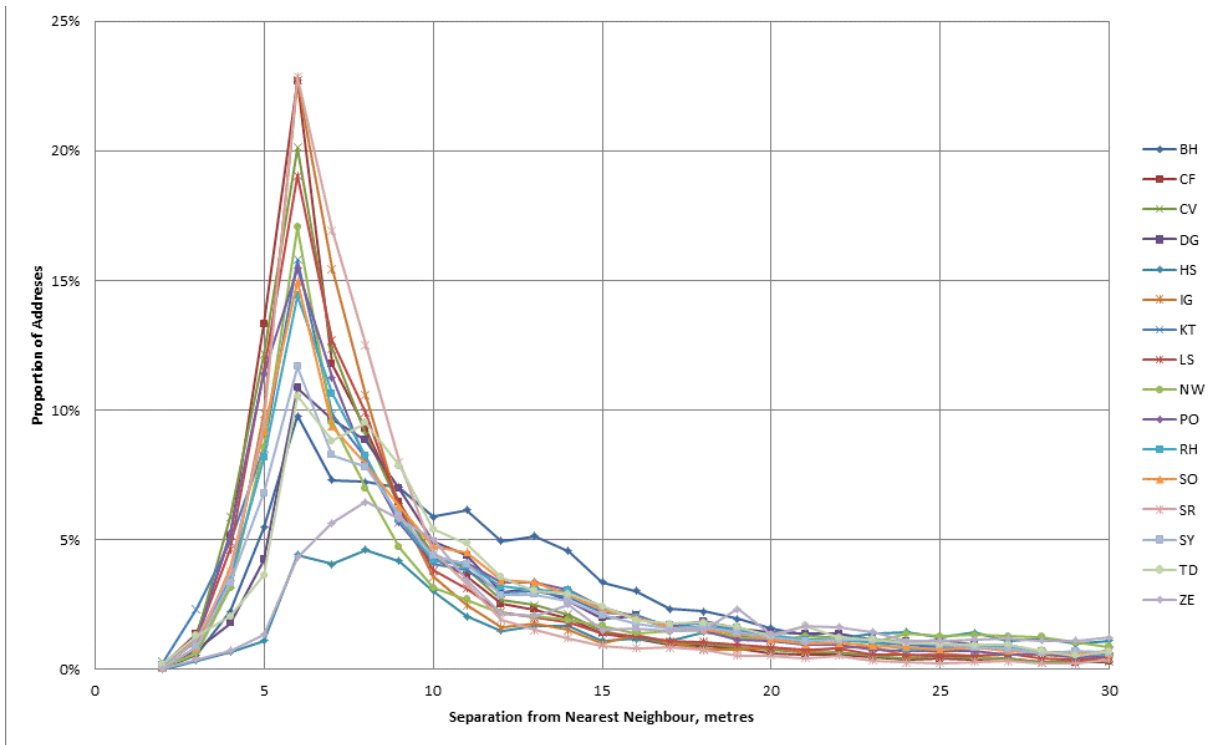


Figure 44: Frequency of UK address separation distance by post area

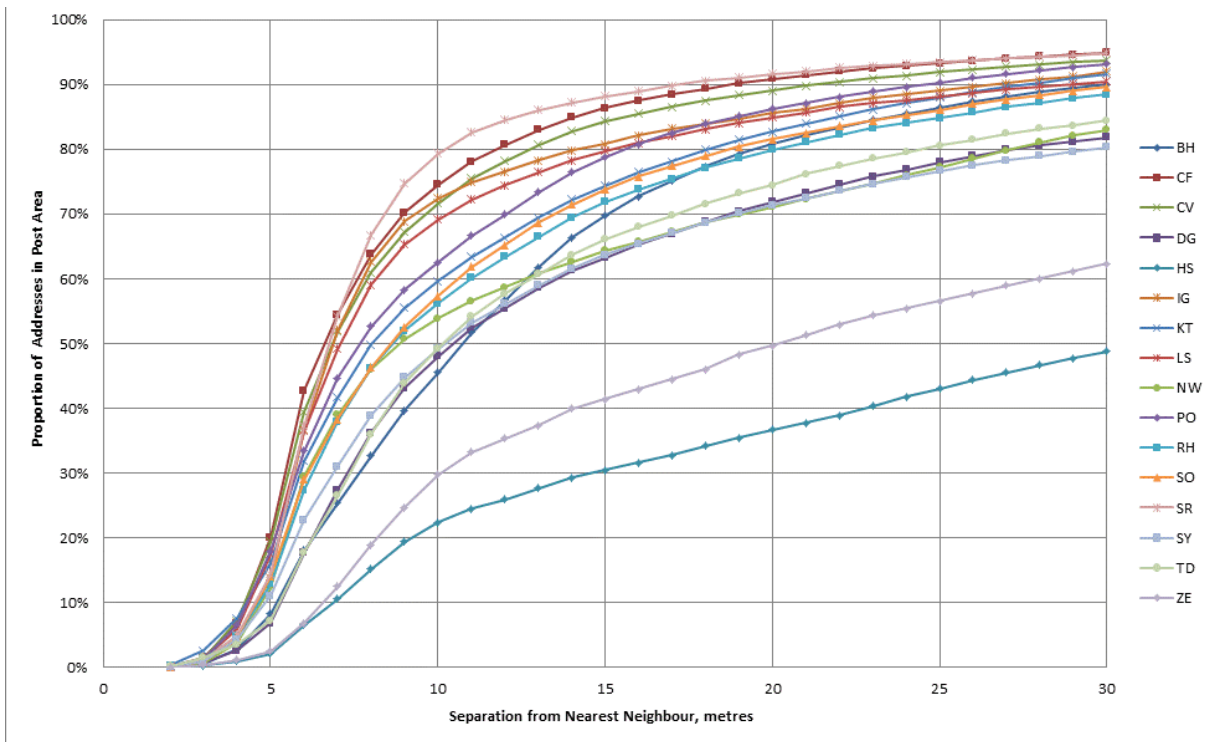
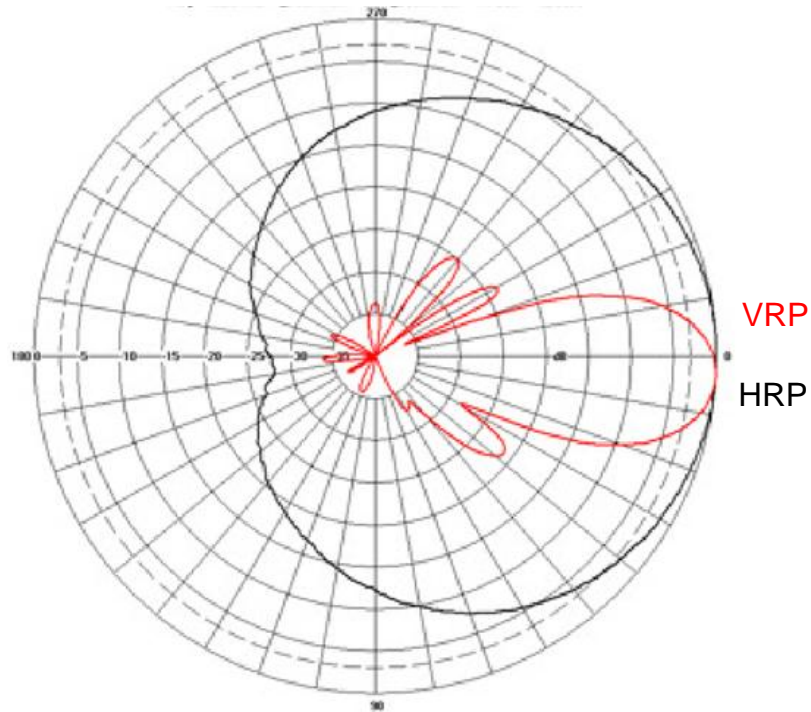


Figure 45: CDF of UK address separation distance by post area

**APPENDIX 2 OF ANNEX A2: VERTICAL RADIATION PATTERN OF THE WSD ANTENNA FOR FIXED WSD TRANSMISSION AT 30 M**

To calculate the coupling loss, G, between the fixed WSD antenna mounted at a height of 30m with 0° beam tilt and a DTT receiver (sections A2.2.4 and A2.2.5), the attached vertical radiation pattern was used.



**Figure 46: Vertical Radiation Pattern of the WSD Antenna for Fixed WSD transmission at 30 m**

## ANNEX 3: NUMBER OF WSD'S AND NUISANCE POWER

### A3.1 NUISANCE FIELDS AND POWER SUMMATION

The 'nuisance field' is a convenient concept when calculating interference effects. 'Instantaneous' nuisance fields are used in Monte Carlo simulations, and 'median' nuisance fields are used in analytical calculations, involving interference determination.

#### A3.1.1 NOISE ONLY

For acceptable DTT reception at a given point, in the presence of noise only, the wanted DTT field strength  $E_w$  must exceed the noise equivalent field strength,  $N$ , by a minimum amount,  $[C/N]$ , the required DTT carrier-to-noise ratio:

$$E_w \geq N + [C/N].$$

The expression,  $N + [C/N]$ , is called the nuisance field,  $NU_N$ , for the noise<sup>21</sup>:

$$NU_N = N + [C/N].$$

Thus, the condition/requirement for acceptable DTT reception in the presence of noise only can be written simply as

$$E_w \geq NU_N.$$

#### A3.1.2 ONE INTERFERER

If, at a given point, the wanted DTT field strength is  $E_w$  and a (single) interfering field strength is  $E_{i1}$ , then the DTT reception is 'acceptable' (in the absence of noise) if

$$E_w \geq E_{i1} + PR(\Delta f) - POL - DIR,$$

where  $PR(\Delta f)$  is the required protection ratio for a given frequency offset,  $\Delta f$ ;  $POL$  is the polarization discrimination, if any;  $DIR$  is the receive antenna discrimination (vis-à-vis the interfering signal), if any.

'Nuisance field' is defined as  $NU_{i1}$ , corresponding to the interfering field  $E_{i1}$  to be

$$NU_{i1} = E_{i1} + PR(\Delta f) - POL - DIR.$$

Thus, the condition/requirement for acceptable DTT reception in the presence of one interferer (ignoring the noise) can be written simply as

$$E_w \geq NU_{i1}$$

#### A3.1.3 NOISE AND ONE INTERFERER

Taking into account the noise and a single interferer, the requirement for an acceptable reception is

$$E_w > NU_{i1} \oplus NU_N,$$

where  $\oplus$  represents the power sum<sup>22</sup> of the nuisance fields, and  $NU_{i1} \oplus NU_N$  is the 'total summed nuisance field',  $NU_T$ ,

$$NU_T = NU_{i1} \oplus NU_N.$$

Thus, the condition/requirement for acceptable DTT reception in the presence of one interferer and the noise can be written simply as

$$E_w \geq NU_T.$$

<sup>21</sup> Sometimes the nuisance field for the noise is called the 'minimum field',  $E_{min}$ .

<sup>22</sup> The power sum of two fields, A and B, is calculated as  $A \oplus B = 10 \log_{10} (10^{A/10} + 10^{B/10})$ .



### A3.1.4 NOISE AND MULTIPLE INTERFERERS

If there are K interfering signals,  $E_{i1}$ ,  $E_{i2}$ , ...,  $E_{iK}$ , then the total summed nuisance field (including noise) is

$$NU_T = NU_{i1} \oplus NU_{i2} \oplus \dots \oplus NU_{iK} \oplus NU_N.$$

And for an acceptable DTT reception,

$$E_w \geq NU_T.$$

### A3.1.5 UTILISATION OF NUISANCE FIELDS

Nuisance fields can be used in Monte Carlo simulations (as 'instantaneous' values) for determining location probabilities and also in analytical expressions (as 'median' values) to determine maximum WSD e.i.r.p. limits.

In **Monte Carlo simulations**, the statistical variations of the various fields are incorporated directly into the calculations, and the results faithfully reflect those statistics.

In **analytical calculations**, the statistical behaviour of the fields is only approximated. When multiple interfering WSD sources may be present, it is sometimes proposed to include an appropriate 'margin' to produce results which better reflect the more accurate Monte Carlo results.

If such a multiple interference margin should be included 'IM', the single-interferer nuisance field for a WSD interferer would be modified to incorporate the IM term.

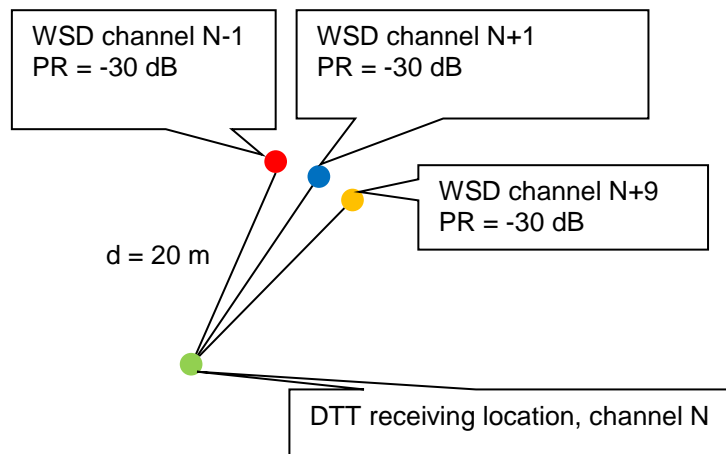
$$NU_{WSD} = E_{WSD} + PR(\Delta f) - POL - DIR + IM.$$

The appropriate magnitude of IM would depend on the number of interfering WSDs to be expected.

### A3.2 THE USUAL POWER SUMMATION WOULD AGAIN BE USED TO DETERMINE THE TOTAL SUMMED NUISANCE FIELD. NUMBER OF WSDS AND NUISANCE POWER

In order to assess whether broadcasting service protection is granted from the WSD operation the protection criteria of the broadcasting service together with the planning principles have to be applied, for example as laid down in GE06.

At a given location more than one WSD can operate and these devices can use different channels available in this location. Some channels have the same interference impact on the wanted channel received in the corresponding location (example: channels N+1, N-1, N+9 have similar Protection Ratios (PR) with regard to channel N, therefore if they are used simultaneously in the same location their interference on channel N will add up correspondingly). Figure 47 sketches the situation.



**Figure 47: Example of geographical configuration and channel combination**

Based on this simple but realistic configuration, a margin of 5 dB (corresponding to the difference between one single WSD and 3 WSDs with equal impact) is proposed.

In order to further investigate this effect of cumulative interference from multiple WSDs, this section contains a detailed study showing that WSD adjacent channel usage, with a fixed antenna at 10 m height, within a DTT coverage area can lead to cumulative interference effects with respect to DTT fixed reception. The probability and the magnitude of the cumulative effect are shown to be functions of the density of WSDs used in a given area.

In order to properly take into account the impact of cumulative interference caused by several WSDs in the UHF band the following principles have to be considered:

Cumulative interference can result from

- (i) different WSDs using the same channel in different geographical locations or
- (ii) different WSDs using different channels in the same geographical locations.

Two options exist:

- a) Option 1: Single WSD treatment: The maximum permissible output powers on the channels potentially available for a single WSD have to be derived by applying a margin for each WSD (e.g. 5 dB for the adjacent channels configurations).
- b) Option 2: Multiple WSDs treatment: The maximum permissible output powers on the channels potentially available for all relevant WSDs have to be derived in a calculation that takes into account the cumulative interference in a single step. The allocation of powers and the channels onto the WSDs, i.e. the underlying algorithm, rests with the data base management system. This Option 2 could imply continuous adjustment of the already allocated powers each time a new WSD comes into operation.

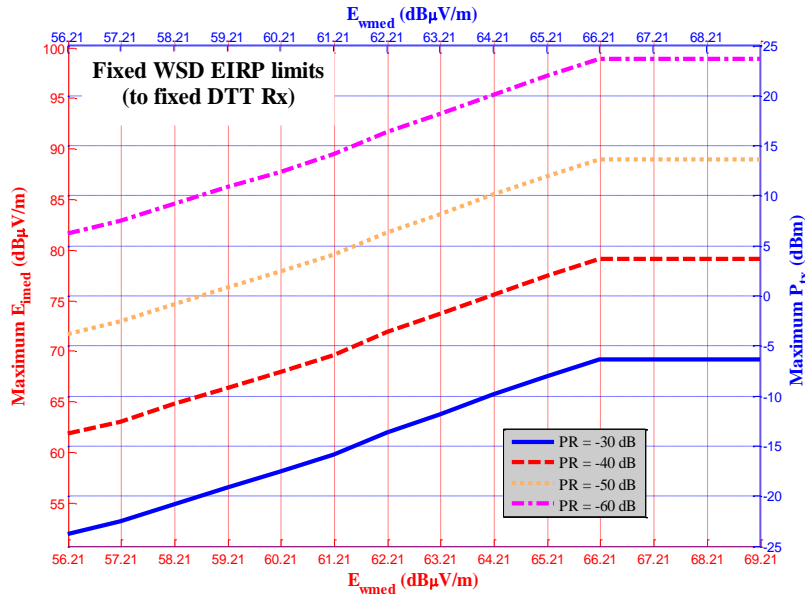
An alternative solution, yet to be proven implementable in practice, would consist in maintaining minimum separation distances between fixed WSD transmitters (using the same or different channels), in order to protect DTT reception.

For simplicity, as an approximation, it has been considered only the interfering median nuisance powers from the WSDs (i.e. noise is not taken into account) and their power sum. Because of the short distances involved, SEAMCAT Hata propagation model has been used.

It has been considered explicitly only the case of non-co-sited adjacent channel WSD base stations. Otherwise the multiple interference margin would have to be increased by at least  $10 \log_{10} N$ , where  $N$  is the number of co-sited WSD transmissions.

### A3.3 NUISANCE POWER AND ITS APPLICATION

In Figure below is a graphical representation of the maximum fixed WSD e.i.r.p. limits to protect fixed DTT reception, using a location probability degradation of  $\Delta LP=0.1\%$  criterion.



**Figure 48: Maximum fixed WSD e.i.r.p. limits for fixed WSDs ( $\Delta LP = 0.1\%$ )**

It is seen that, at coverage edge ( $E_{med} = 56.21$  dBμV/m):

- $P_{tx\_lim} = -23.5$  dBm (channel  $N\pm 1, N + 9$ , PR = -30 dB),
- $P_{tx\_lim} = -13.5$  dBm (channel  $N\pm 2$ , PR = -40 dB),
- $P_{tx\_lim} = -3.5$  dBm (channels  $N\pm 3$  and beyond, PR = -50 dB).

At 20 m distance from the fixed interfering WSD transmit antenna, the limiting median power present at the DTTB fixed receive antenna is  $P_{rx\_lim} = P_{tx\_lim} - L_{FS}(0.02) - POL$ , where  $L_{FS}(0.02) = 54.73$  dB is the free space loss at 20 m, and  $POL = 3$  dB slant polarisation discrimination.

Thus, explicitly, at the DTT coverage edge (56.21 dBμV/m) the limiting median received interfering powers are

- $P_{rx\_lim} = -23.5$  dBm  $- 57.73$  dB =  $-81.23$  dBm (channel  $N\pm 1, N + 9$ , PR = -30 dB),
- $P_{rx\_lim} = -13.5$  dBm  $- 57.73$  dB =  $-71.23$  dBm (channel  $N\pm 2$ , PR = -40 dB),
- $P_{rx\_lim} = -3.5$  dBm  $- 57.73$  dB =  $-61.23$  dBm (channels  $N\pm 3$  and beyond, PR = -50 dB).

Notice that, in each case  $P_{rx\_lim} + PR = -111.23$  dBm. The quantity " $P_{rx\_lim} + PR$ " is called the 'limiting median nuisance power',  $P_{nuis\_lim}$ , and it has a single value for all adjacent channel configurations. Thus, the limiting median nuisance power must not be exceeded at the DTT receive antenna in order to protect DTT reception to the required extent. This approach allows us to treat all relevant adjacent channels simultaneously, on an equal footing.

More generally, the quantity  $P_{nuis} = "P_{rx} + PR - [POL, DIR]"$  is called the median 'nuisance power'.

If there are 2 or more interfering WSDs ( $WSD_1, WSD_2,$  etc) each will produce a median nuisance power ( $P_{nuis\_1}, P_{nuis\_2},$  etc). The power sum of these nuisance powers will give rise to a total median nuisance power  $P_{nuis\_tot} (= P_{nuis\_1} + P_{nuis\_2} + \dots)$ , using power summation. In particular, in order to protect DTT fixed reception, the total (summed) median nuisance power must not exceed the limiting median nuisance power:  $P_{nuis\_tot} \leq P_{nuis\_lim}$ .

### A3.4 PROPAGATION LOSS: DETERMINATION AND USAGE

SEAMCAT Hata propagation model has been used to determine the loss,  $LOSS(d)$ , at a distance  $d$  between the WSD transmit antenna and the DTT fixed receive antenna, and thus the median receive power,  $P_{rx\_med}$ , at the DTT receive antenna (including the slant polarisation discrimination, if applicable):

$$P_{tx} - LOSS(d) - POL = P_{rx\_med}$$

Knowing the median receive power,  $P_{rx\_med}$ , and the relevant adjacent channel protection ratio,  $PR_i$ , the corresponding median nuisance power can be determined  $P_{nuis\_med\_i} = P_{rx\_med} + PR_i$ .

In order for DTT fixed reception to be protected from the WSD transmission, the median wanted power,  $P_{w\_med}$ , at the DTT receive antenna must satisfy  $P_{w\_med} \geq P_{nuis\_med\_i}$  for each relevant adjacent channel  $N_{\pm i}$ . In particular, at a 20 m separation distance (and more)  $P_{nuis\_lim} \geq P_{nuis\_med\_i}$ .

In the presence of two (or more) adjacent channel interferences,  $N_{+i}$  and  $N_{+j}$  (and  $N_{+k}, \dots$ ) say, the individual median nuisance powers ( $P_{nuis\_i}$ ,  $P_{nuis\_j}$ ,  $P_{nuis\_k}$ , ...) must not only not exceed the limiting median nuisance power,  $P_{nuis\_lim}$ , but also the total median nuisance power  $P_{nuis\_tot} = P_{nuis\_i} + P_{nuis\_j} + P_{nuis\_k} + \dots$ , must not exceed  $P_{nuis\_lim}$ .

### A3.5 WSD CUMULATIVE INTERFERENCE

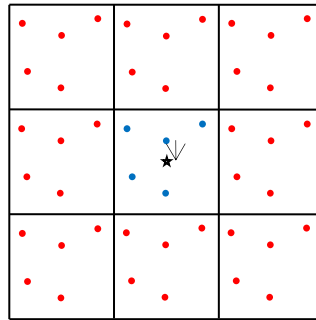
In this section, it is considered the possibility of multiple interference due to WSD transmitters, assuming a WSD transmitter density,  $\delta$ , of 1 to 10 WSD base stations per pixel (and also  $\delta = 17$  to give a potential upper limit).

It is considered a constellation consisting of 9 pixels (100 m x 100 m) as shown in Figure 47. For simplicity of explanation, in Figure 47 it was considered  $\delta = 5$  WSD base stations per pixel (the same pictorial representation could be made for any number of WSDs by increasing or decreasing the number of points to  $\delta$ ).

A DTT receive site is located at the centre of the central pixel (indicated by the star). A WSD is placed at 20 m in front of the star to represent a single WSD interferer. It were choose ( $\delta - 1 = 4$ ) other WSD sites within the central pixel in a random manor. WSD sites are chosen only if they are separated by 20 m or more from the DTT receive site. To get 'representative' results, let's consider 1 000 000 random distributions of the possible  $\delta - 1$  WSD sites.

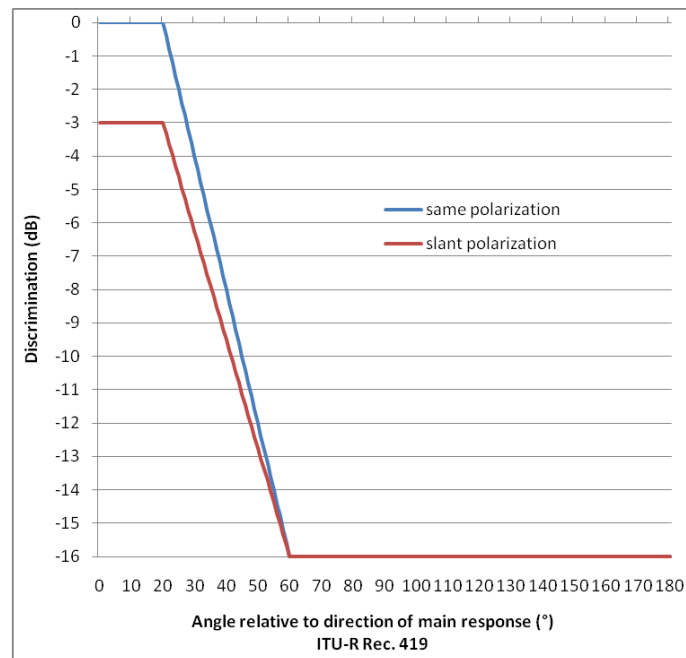
For a given Monte Carlo trial, a random distribution of  $\delta - 1$  WSD transmitters is selected within the central pixel (see the small blue 'circles'); the same relative distribution of the  $\delta$  WSDs is positioned within each of the other 8 pixels (see the small red 'circles'). This gives an approximate WSD 'network structure' with which to do calculations. Interference calculations (power summing the individual contributions) are carried out for each  $\delta$  WSD distribution to determine the cumulative interference effect of the WSDs. The 8 pixels (and their WSDs) surrounding the central pixel are included to ensure that the full effects of cumulative WSD interference are reflected.

The e.i.r.p.s of the WSDs are chosen so that the limiting median nuisance power,  $P_{nuis\_lim}$ , at 20 m distance is  $P_{nuis\_lim} = -106.73$  dBm (from section 3.1 above). Recall that  $P_{nuis\_lim} = P_{rx\_perm} + PR_i - [POL, DIR]$ .  $P_{rx\_perm}$  is the limiting permissible power occurring 20 m away from the WSD at a potential DTTB receive antenna,  $PR_i$  is the relevant adjacent channel protection ratio.



**Figure 49: 9 pixels with  $\delta = 5$  WSD transmitters per pixel**

The DTT receive antennas are all assumed to point to the top of the diagram in above, the assumed direction of the 'faraway' DTT transmitter. The Recommendation ITU-R BT.419 [2] antenna pattern is used to determine the discrimination of the DTT receive antenna relative to the interfering WSDs, including a 3 dB slant-polarisation discrimination (see above).



**Figure 50: ITU-R BT.419 [2] antenna pattern**

1 000 000 Monte Carlo trials were carried out for each WSD density (i.e. 1 000 000 different random distributions of  $\delta = 1$  to 10, and  $\delta = 17$  WSDs, respectively, within the central pixel, with 'clones' placed in the surrounding 8 pixels). The distribution of the cumulative interfering nuisance powers occurring at the DTTB receiver site is shown in Figure 51, Figure 52 and Figure 53, in increasing 'close-ups'.

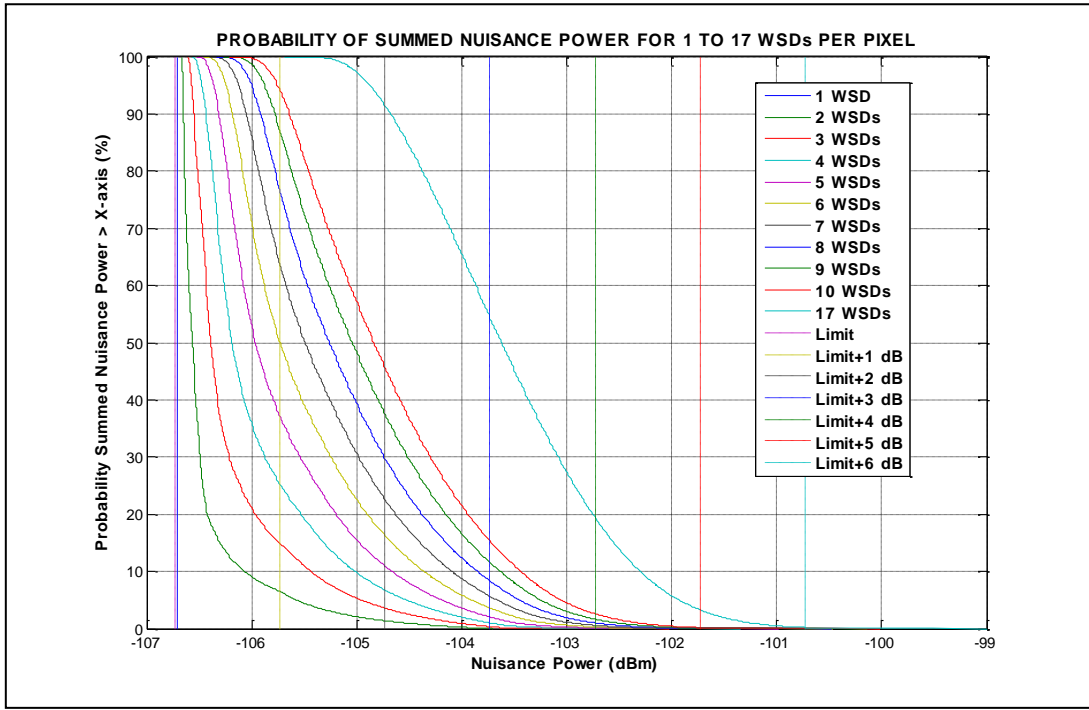


Figure 51: Distribution of the cumulative interfering nuisance powers

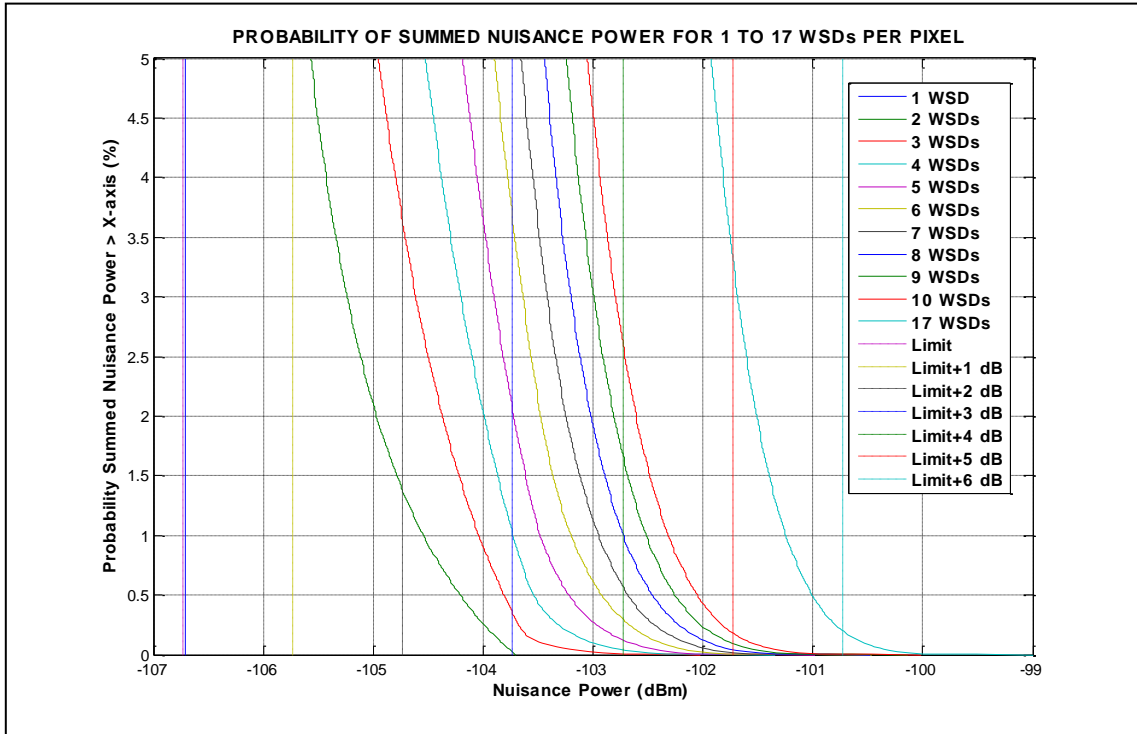
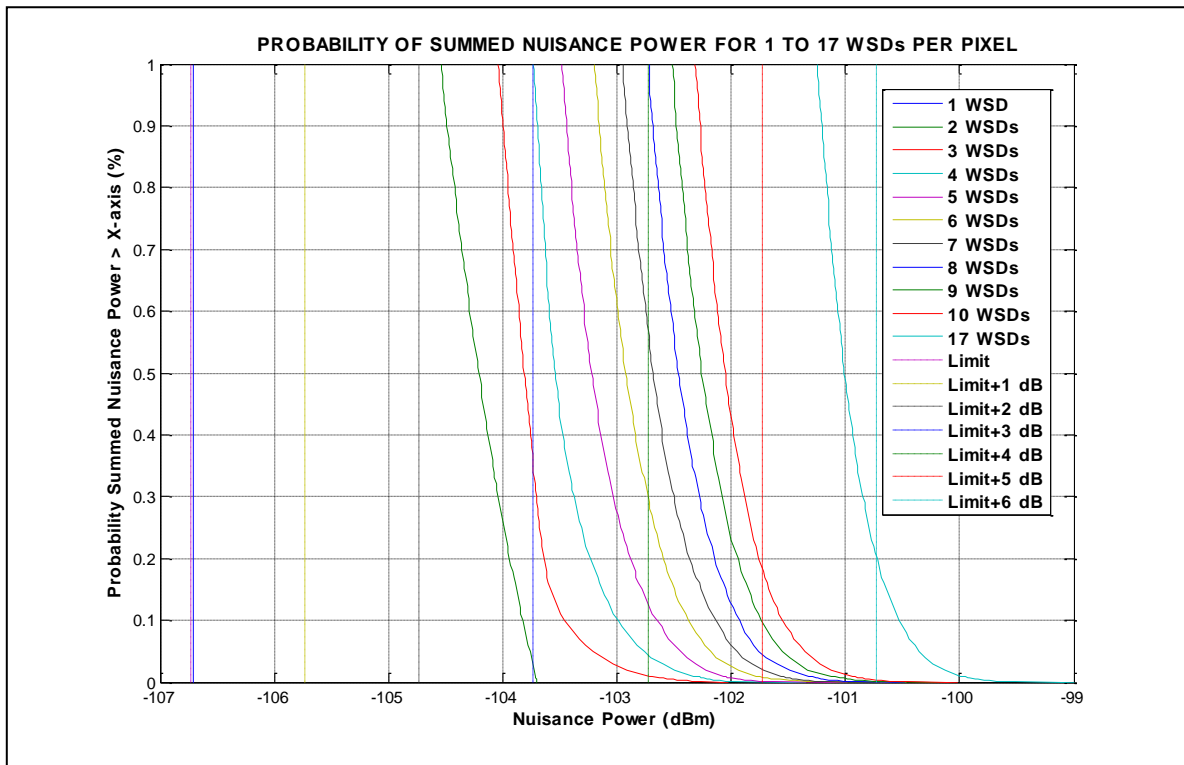


Figure 52: Close-up of Figure 51



**Figure 53: Close-up of Figure 51**

In Table 13 below are listed the ‘extremes’ of the distributions, according to the number of WSDs per pixel. It is seen that, as the WSD density increases:

- both the minimum and the maximum cumulative nuisance power increase,
- the percentage of incidents where the limiting nuisance power limit is exceeded increases,
- the allowable nuisance power limit is exceeded 0.02 dB to 7.73 dB depending on the density of the interfering WSD networks.

**Table 13: Margin to ensure protection of DTT, considering different WSD densities**

WSD Density $\delta$ (# of WSDs/pixel)	Cumulative Nuisance Interference Power		% exceeding limit + X dB X =					Margin (dB) to ensure the single entry limit is observed
	Minimum (dBm)	Maximum (dBm)	1	2	3	4	5	
1	-106.71	-106.71	0.00%	0.00%	0.00%	0.00%	0.00%	0.02 dB
2	-106.66	-103.70	6.49%	1.35%	0.02%	0.00%	0.00%	3.03 dB
3	-106.61	-102.02	14.86%	3.59%	0.33%	0.01%	0.00%	4.71 dB
4	-106.57	-101.34	25.10%	6.74%	0.99%	0.04%	0.00%	5.39 dB
5	-106.52	-100.95	38.86%	10.92%	2.02%	0.12%	0.00%	5.78 dB
6	-106.46	-100.76	49.82%	16.24%	3.60%	0.29%	0.01%	5.97 dB
7	-106.40	-100.60	63.42%	22.44%	5.65%	0.56%	0.02%	6.13 dB
8	-106.34	-100.48	76.24%	29.62%	8.30%	1.00%	0.04%	6.25 dB
9	-106.27	-100.14	86.77%	37.32%	11.53%	1.65%	0.09%	6.59 dB
10	-106.22	-100.02	93.95%	45.38%	15.28%	2.59%	0.18%	6.71 dB
17	-105.69	-99.00	91.38%	54.20%	19.33%	3.29%	0.20%	7.73 dB



In the scenario with  $\delta = 1$  WSD/pixel, the median nuisance power 'limit', -106.73 dBm, at the fixed DTTB receive antenna (at 10 m height) is exceeded by 0.02 dB by the cumulative interference compared to the single entry fixed WSD base station (at 10 m height).

It is seen from the Figures 51 to 53 and Table 13 that 'limit' will be exceeded in the case of multiple WSD interferers by larger and larger percentages, as the density of WSDs/pixel increases. It is seen that the increase in the maximum cumulative nuisance power can be as much as 6 dB or more if the density is as large as  $\delta = 7$  WSDs/pixel.

The final column in Table 13 indicate by how much the individual e.i.r.p. limits would have to be reduced in order that the single base station cumulative interference effect is not exceeded. It is seen that with a WSD density of  $\delta = 3$ /pixel or larger, a margin between 4 dB and 6 dB would be appropriate.

All in all, it is seen that cumulative interference effects due to 'equivalent' WSD base stations is indeed 'probable', with cumulative effects amounting to up to about 6 dB. In order for cumulative effects to be ignored, a 'rule' would have to be established that would allow only one adjacent channel (i.e. 1 adjacent channel between N - 8 to N + 9) WSD network to be operated within a given channel-N DTTB coverage area, and only one of the network's base stations within each pixel.

### A3.6 WSD e.i.r.p. LIMITS BASED ON TOTAL NUISANCE FIELD: NUIS<sub>TOT</sub>

In addition to the possibility of having adjacent channel interference arising from the short-distance reference scenarios, there may also be situations where there will be long distance co-channel interference.

Figures 54-56 show that the WSD interference distance can range up to 200 km for 30 m WSD antenna heights and high e.i.r.p.s (e.g. 60 dBm). The figures have been obtained using the JTG 5-6 propagation model, and are based on protecting 56.21 dB $\mu$ V/m at 10 m at a DTT coverage edge; this means that an interfering field cannot exceed 5.69 dB $\mu$ V/m to avoid a degradation  $\Delta_{LP} > 0.1\%$ . Note that neither 3 dB polarisation discrimination nor 16 dB receive antenna discrimination have been taken into account. This is because it is not generally known in which direction the DTT antennas will be pointing with respect to the WSD interferer.

With these large separation distances, it is possible that a relatively large number of co-channel WSDs will be contributing to the total interference. Theoretical studies based on dense uniform networks of interferers operating at large distances have shown that the cumulative interference effects can be much as 20 dB increase in compared to the 'single-entry' interference effect. This means that aggregated interference effects must be calculated.

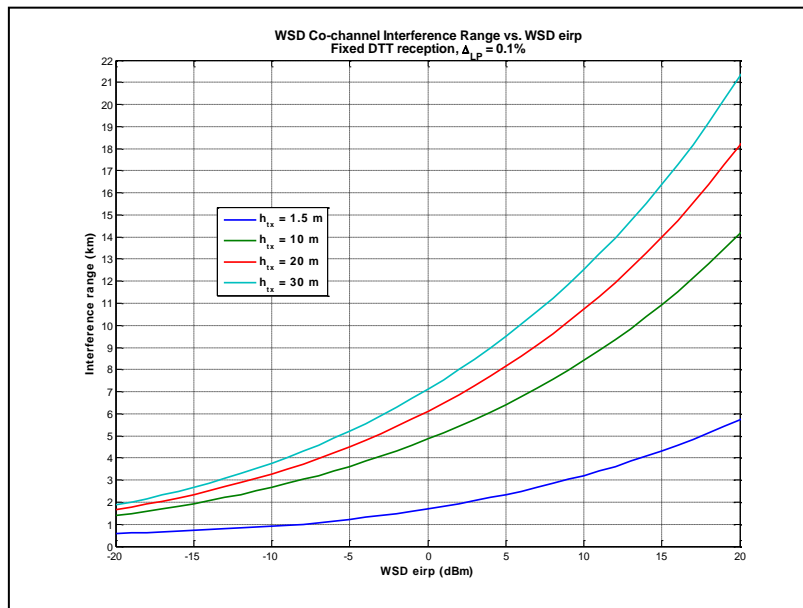


Figure 54: WSD co-channel interference range vs WSD e.i.r.p.

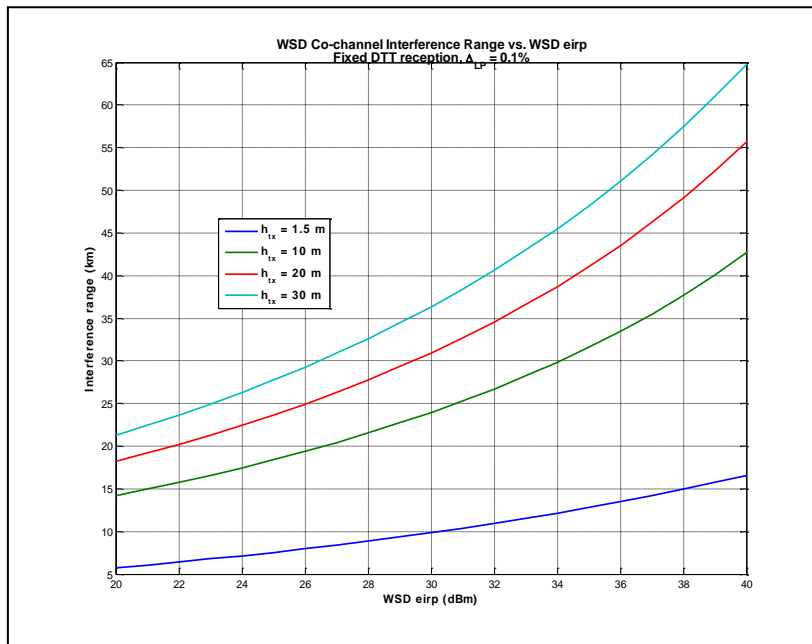


Figure 55: WSD co-channel interference range vs WSD e.i.r.p.

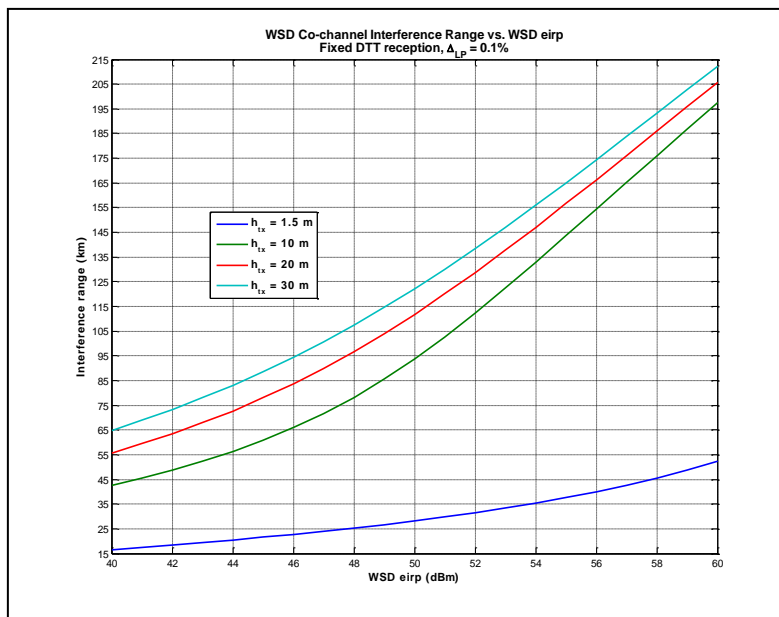


Figure 56: WSD co-channel interference range vs WSD e.i.r.p.

It is shown that, when using analytical methods to calculate e.i.r.p. limits for large numbers of WSDs in a WSD network (either base stations or UEs) located outside a DTT coverage area, the task can be reduced to limiting the total (power-summed) median nuisance field,  $NUIS_{TOT}$ , arising at the DTT coverage edge. Note that the calculation to determine the total interference when nearby adjacent channel WSDs are also operating (for example, with the reference geometries) is more difficult and is under study.

In order to calculate the total nuisance field, it was considered the situations with 1, 10, 100, and 1000 WSDs. These situations will be divided into 2 sub-cases, one where all the powers are equal, and the other where the powers are not equal and are chosen randomly or non-randomly

The parameters are the following:

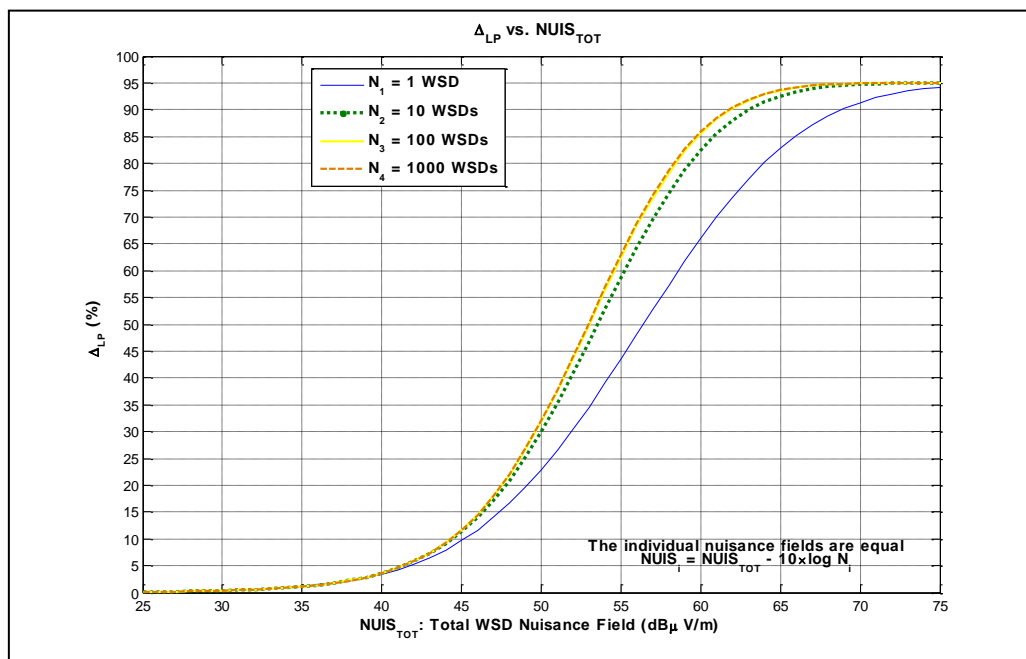
- $F_w = 56.21 \text{ dB}\mu\text{V/m}$
- $\sigma_w = \sigma_i = 5.5 \text{ dB}$
- NUIS<sub>TOT</sub> is the total median nuisance field (power sum of the individual median nuisance fields)
- Number of WSDs for cases 1 to 4:  $N_1 = 1, N_2 = 10, N_3 = 100, N_4 = 1000$ .
- Equal individual median nuisance field for each WSDs for cases  $i = 1, 2, 3, 4$ :  $\text{NUIS}_i = \text{NUIS}_{\text{TOT}} - 10 \log N_i$ .

In Figure 57 the degradation in location probability,  $\Delta_{LP}$ , is plotted as a function aggregate median nuisance field, NUIS<sub>TOT</sub>. NUIS<sub>TOT</sub> ranges from 25 dB $\mu$ V/m to 75 dB $\mu$ V/m. The first simulations involved 100 000 trials (in steps of 1 dB $\mu$ V/m).

It is seen that:

- the curves are ‘higher’ as the number of WSDs increases,
- the curves converge for sets of WSDs containing more than about 100 WSDs
- all the curves converge for total nuisance fields less than about 35 dB $\mu$ V/m, i.e. for  $\Delta_{LP}$  values less than about 1% or 2%.

Because the protection criterion for protecting DTTB reception is  $\Delta_{LP} \leq 0.1\%$ , this convergence indicates that a simplification in WSD e.i.r.p./nuisance field management might be possible.



**Figure 57:  $\Delta_{LP}$  vs. NUIS<sub>TOT</sub> (equal partition of total nuisance field)**

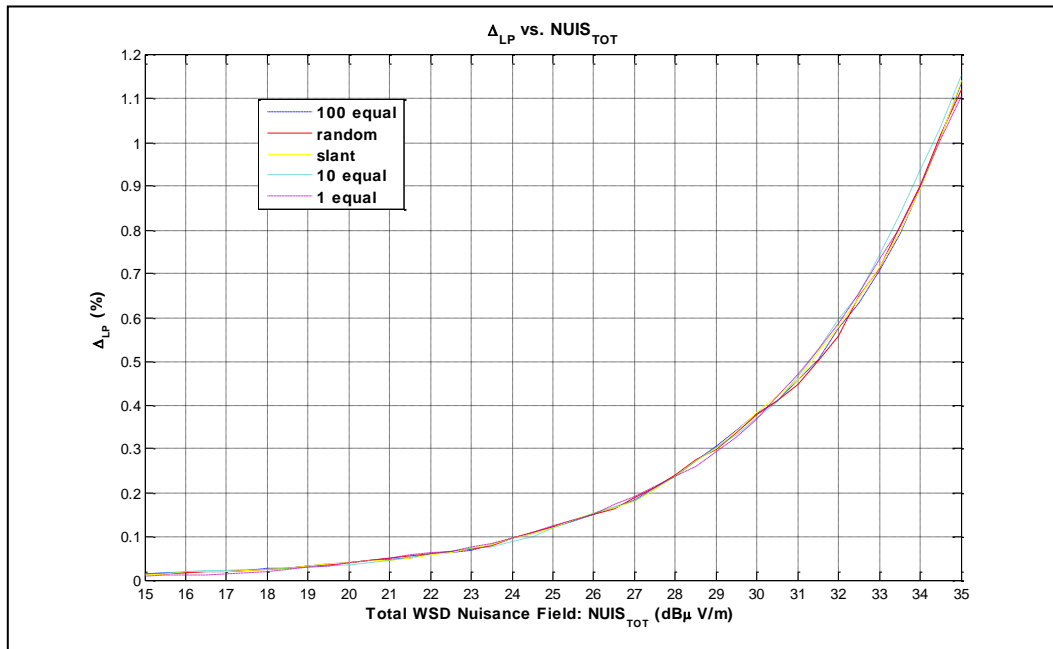
### A3.7 FURTHER CONSIDERATIONS

Since the curves seem to converge into a single curve at small values of  $\Delta_{LP}$ , we consider this situation more closely. We look at the case of 100 WSDs and at a narrower aggregate nuisance field region: 15 dB $\mu$ V/m to 35 dB $\mu$ V/m. This is the region encompassing  $\Delta_{LP} = 0.1\%$ . We consider a situation with 100 WSDs and 5 variations:

- $V_1$  ('equal') consists of all WSDs having the same individual median nuisance field, NUIS<sub>i</sub> (whose power sum is NUIS<sub>TOT</sub>)
- $V_2$  ('random') consists of a uniform random distribution of individual median nuisance fields (whose power sum is NUIS<sub>TOT</sub>),
- $V_3$  ('slant') consists of a 'stepped' (i.e. evenly spaced in the linear domain) distribution of individual median nuisance fields (whose power sum is NUIS<sub>TOT</sub>);
- $V_4$  ('10 equal') consists of 10 WSDs with equal median nuisance fields (whose power sum is NUIS<sub>TOT</sub>), and 90 WSDs with no nuisance field (i.e. 0 mV/m in the linear domain)

- $V_5$  ('1 equal') consists of 1 WSD with median nuisance field =  $\text{NUIS}_{\text{TOT}}$ , and 99 WSDs with no nuisance field (i.e. 0 mV/m in the linear domain).

In Figure 58 the degradation in location probability,  $\Delta_{\text{LP}}$ , is plotted as a function of  $\text{NUIS}_{\text{TOT}}$ .  $\text{NUIS}_{\text{TOT}}$  ranges from 15 dB $\mu$ V/m to 35 dB $\mu$ V/m, for each of the 5 variations. The simulations again involved 100 000 trials (in steps of 0.5 dB $\mu$ V/m).



**Figure 58:  $\Delta_{\text{LP}}$  vs.  $\text{NUIS}_{\text{TOT}}$  (100 WSDs, various partitions of total nuisance field)**

Again it is seen that the curves are nearly identical in this region. It is felt that the small variations in the curves are due to the fineness of the statistical distribution in this very low  $\Delta_{\text{LP}}$  region.

Notice that, for any given  $\text{NUIS}_{\text{TOT}}$ , the  $\Delta_{\text{LP}}$  is the 'same' for whatever combination of 100 WSD nuisance fields which add up to  $\text{NUIS}_{\text{TOT}}$ .

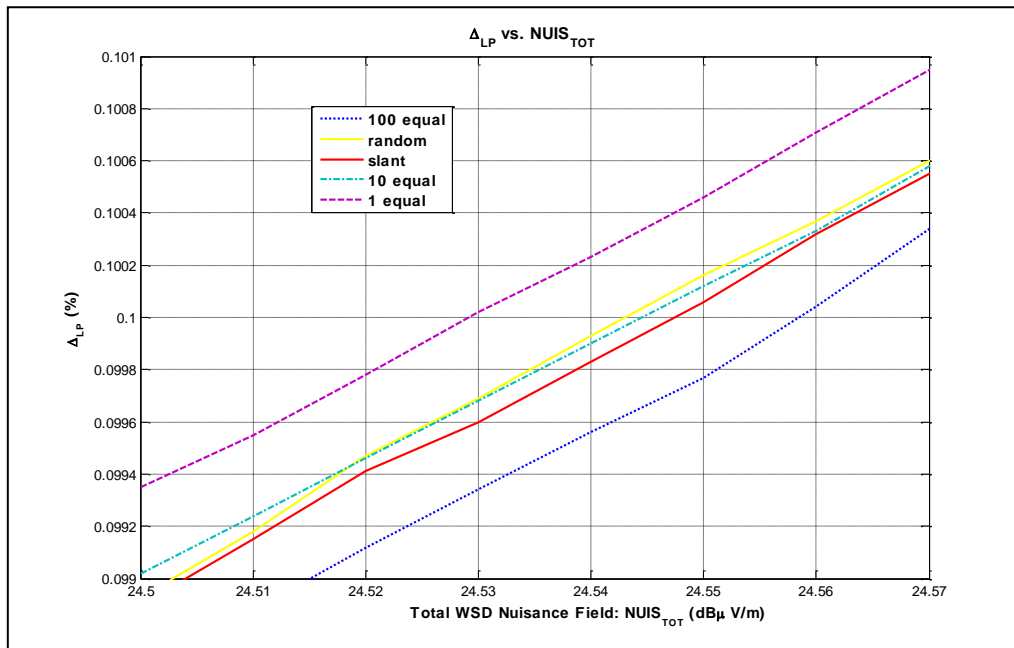
A still closer view around  $\Delta_{\text{LP}} = 0.1\%$  is given in Figure 59. To obtain more precision, 30 000 000 trials were used at 0.01 dB spacing.

It is seen that for  $\Delta_{\text{LP}} = 0.1\% \pm 0.0004\%$ ,  $\text{NUIS}_{\text{TOT}} = 24.545 \text{ dB}\mu\text{V/m} \pm 0.015 \text{ dB}$  for all the curves.

Other things to note at the low end of  $\text{NUIS}_{\text{TOT}}$  are the following:

- -  $\Delta_{\text{LP}}$  is higher for a smaller number of equal WSD contributors to the interference (see the dotted and dashed lines in Figure 58 for '1 equal', '10 equal', and '100 equal' WSDs); this is in contrast to Figure 57 where the 'order' is reversed,
- - in the case of 100 WSDs, it is seen that a 'slant distribution' (solid red line) and a 'random distribution' (solid yellow line) of 100 individual interference contributions gives higher values of  $\Delta_{\text{LP}}$  than 100 equal contributions (lowest dotted line), seeming to be close to the distribution for 10 WSDs (middle dot-and-dashed line) having equal interference contributions.
- - for the case of 1 WSD interferer only,  $\text{NUIS}_{\text{TOT}} \cong 24.53 \text{ dB}\mu\text{V/m}$ , for 100 equal WSD interferers,  $\text{NUIS}_{\text{TOT}} \cong 24.56 \text{ dB}\mu\text{V/m}$ ; the difference between these two values is 0.03 dB. We propose  $\text{NUIS}_{\text{TOT}} = 24.545 \text{ dB}\mu\text{V/m}$  as the single limit value which will protect against all WSD situations to  $0.1\% \pm 0.0004\%$ .

Thus, a single value of  $\text{NUIS}_{\text{TOT}}$  emerges to protect DTTB from all WSD configurations. This includes the possibility to take into account distant adjacent channel interference.



**Figure 59:  $\Delta LP$  vs.  $NUIS_{TOT}$  (various partitions of total nuisance field)**

### A3.8 CONCLUSIONS

It is proposed that a total aggregate nuisance field limit  $NUIS_{TOT} = 24.545 \text{ dB}\mu\text{V/m}$  be used as the limiting value when considering all contributing co-channel (or adjacent channel) sources of WSD interference which are operating **outside** of the co-channel DTT coverage area. As mentioned above, the case where the reference scenarios are also contributing interference, the calculation is more difficult (and requires further study).

For any given WSD and any given DTTB reception site (usually located at the DTTB coverage edge) the individual nuisance field,  $NUIS_i$ , is calculated as

$$NUIS_i = FS_i(d, H_{t_i}, 10 \text{ m, e.i.r.p.}_i) + PR - POL - DIR \tag{31}$$

where  $FS_i(d, H_{t_i}, 10\text{m, e.i.r.p.}_i)$  is

- the field strength at the distance  $d$  (between the WSD and the DTTB receive site), at the DTTB receive height 10 m, resulting from a WSD with e.i.r.p.<sub>i</sub>, and antenna height  $H_{t_i}$ ,
- and  $PR$  is the protection ratio,  $POL$  is the polarization discrimination (if any) and  $DIR$  is the DTTB receive antenna discrimination.

The aggregate median nuisance field  $NUIS_{TOT}$  is the power sum of all contributing individual median nuisance fields.

The magnitude of a total permissible aggregate nuisance field depends on the following parameters:

- Initial DTT location probability
- Permissible degradation of location probability

For small values of location probability degradation (0.1% to 1%) the number of contributing individual nuisance fields contributing to the total aggregate nuisance field is irrelevant. Therefore Monte Carlo simulations can be carried out using a single WSD interferer in addition to the DTT interferers to determine the permissible total aggregate nuisance field. The procedure to do so is the same as described above (sections A3.6 and A3.7) for an initial 95% location probability a 0.1% permissible degradation.

Once the permissible total aggregate nuisance field is determined for the given conditions (initial location probability and its permissible degradation), it is only necessary to calculate the totality of WSD nuisance fields and power sum them to determine whether the permissible total nuisance field is exceeded. That is to

say, no additional Monte Carlo simulations (or analytical) calculations are required. This will accelerate the calculation process considerably.

It is this approach that is detailed in ANNEX 12:.

**ANNEX 4: DTT RECEPTION MODE AND WSD SINGLE ENTRY INTERFERENCE CONSIDERATIONS**

In this annex it is shown:

- various relationships between DTT wanted field strength, location probability, propagation distance, I/N;
- in particular, their relationship to fixed DTT reception as well as portable outdoor/indoor DTT reception modes is illuminated for a protection criterion related to a fixed permissible degradation,  $\Delta_{LP}$ , of the DTT reception location probability;
- A comparison of maximum WSD e.i.r.p. limits and corresponding I/N values (as a function of protection ratio) for various values of  $\Delta_{LP}$ .

DTT coverage areas are often planned for a specific reception scenario, however other reception modes may also be available within the same area, or within sub-areas as shown in the Table below.

**Table 14: DTT reception possibilities**

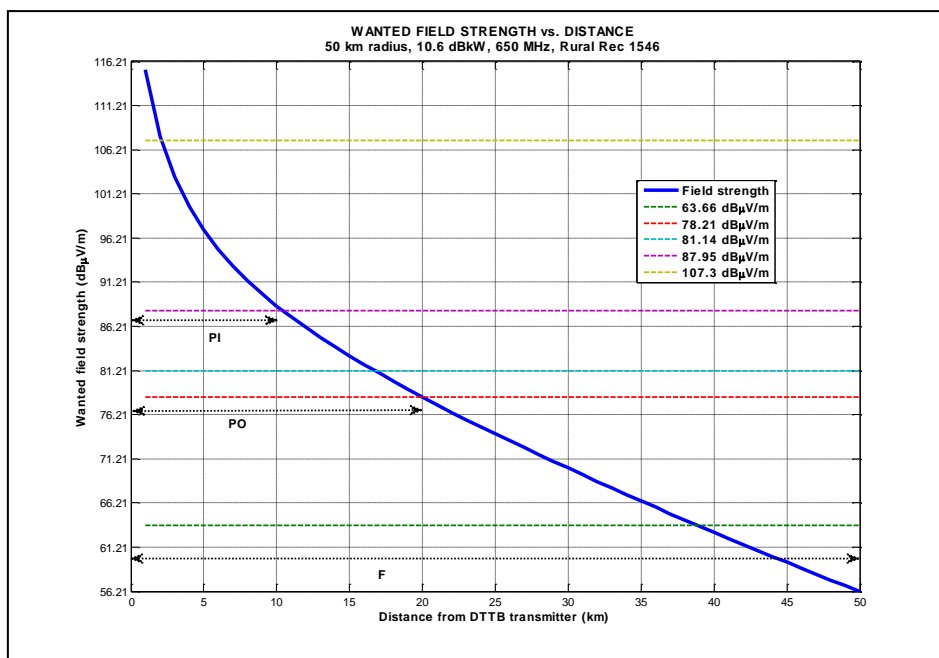
Within planned reception area	Within sub areas of planned reception area
Fixed	Portable outdoor, portable indoor
Portable outdoor	Portable indoor

Such additional reception possibilities must not be interfered with by non-licensed WSD services. This aspect of protection for DTT reception and the required protection criteria are treated in the next sections.

**A4.1 DTT RECEPTION MODE CONSIDERATIONS**

**A4.1.1 Wide area rural environment (planned for fixed DTT reception)**

Figure 62 displays the median wanted field strength levels (solid blue curve) as a function of distance from the DTT transmitter. In this case, the coverage area has a 50 km radius serving a rural district. The transmit antenna is 300 m, radiating with an e.i.r.p. = 10.6 dBkW, providing a 56.21 dB $\mu$ V/m field strength at 50 km distance (and 10 m reception height). The entire 50 km radius coverage area serves fixed (F) DTT antenna installations. In addition, portable outdoor (PO) reception at 1.5 m is possible within a 20 km radius of the DTT transmitter and portable indoor (PI) reception at 1.5 m is possible within a 10 km radius of the DTT transmitter.

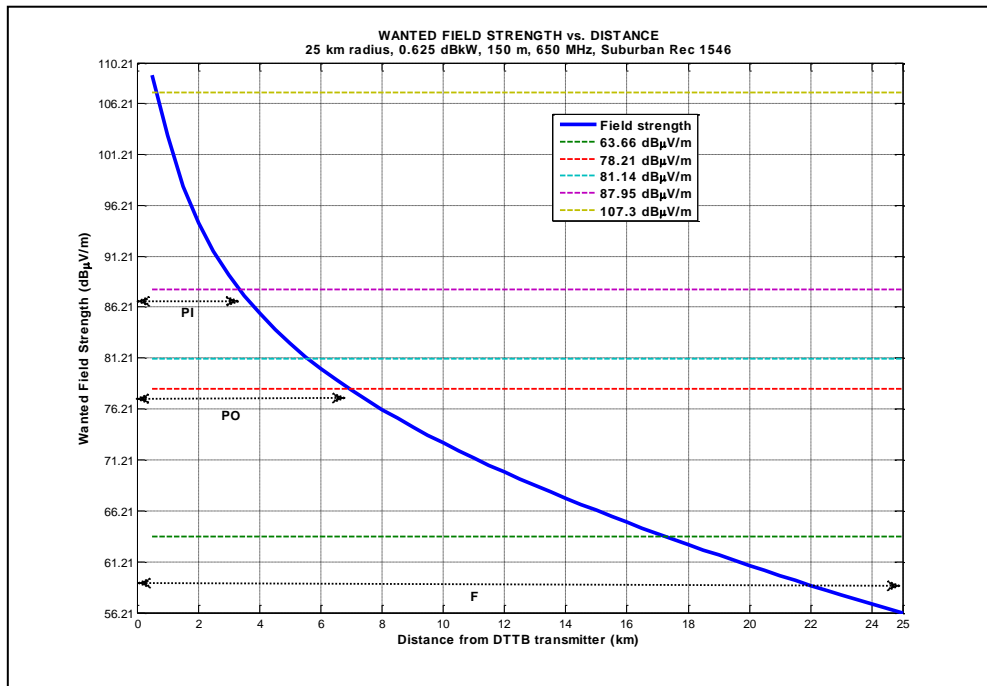


**Figure 60: Wide area rural environment (50 km radius, F, PO, PI reception)**

**A4.1.2 Large area suburban environment (planned for fixed DTT reception)**

Figure 61 displays the median wanted field strength levels (solid blue curve) as a function of distance from the DTT transmitter. In this case, the coverage area has a 25 km radius serving a suburban district. The transmit antenna is 150 m, radiating with an e.r.p. = 0.625 dBkW, providing a 56.21 dBµV/m field strength at 25 km distance (and 10 m reception height).

The entire 25 km serves fixed (F) DTT antenna installations; portable outdoor (PO) reception at 1.5 m is possible within a 7 km radius of the DTT transmitter; portable indoor (PI) reception at 1.5 m, inside, is possible within a 3.3 km radius of the DTT transmitter.



**Figure 61: Large area suburban environment (25 km radius, F, PO, PI reception)**

**A4.1.3 Medium area suburban environment (planned for fixed DTT reception)**

Figure 62 displays the median wanted field strength levels (solid blue curve) as a function of distance from the DTT transmitter. In this case, the coverage area has a 10 km radius serving a suburban district. The transmit antenna is 150 m, radiating with an e.r.p. = -16.05 dBkW, providing a 56.21 dBµV/m field strength at 10 km distance (and 10 m reception height).

The entire 10 km serves fixed (F) DTT antenna installations; portable outdoor (PO) reception at 1.5 m is possible within a 1.9 km radius of the DTT transmitter; portable indoor (PI) reception at 1.5 m, inside, is possible within a radius of 0.8 km from the DTT transmitter.



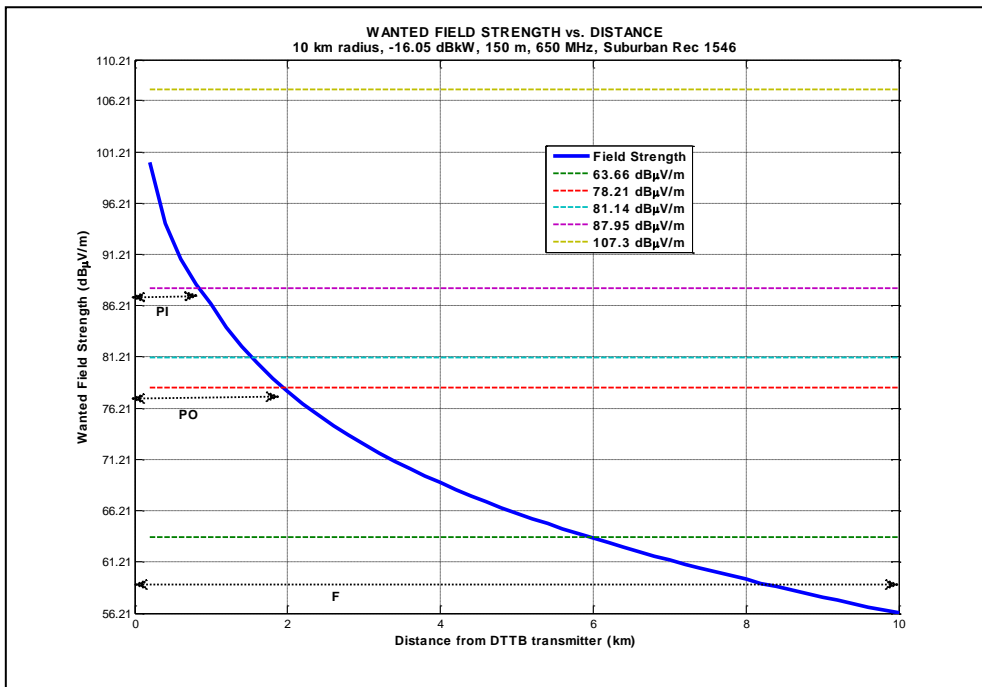


Figure 62: Medium area suburban environment (10 km radius, F, PO, PI reception)

**A4.1.4 small area urban environment (planned for PO DTT reception)**

Figure 63 displays the median wanted field strength levels (solid blue curve) as a function of distance from the DTT transmitter. In this case, the coverage area has a 5 km radius serving an urban district with PO reception. The transmit antenna is 75 m, radiating with an e.r.p. = 0.68 dBkW, providing a 78.21 dBµV/m field strength at 5 km distance (and 10 m reception height; i.e. 61.21 dBµV/m at 1.5 m reception height).

The entire 5 km serves portable outdoor (PO) reception at 1.5 m; portable indoor (PI) reception at 1.5 m, inside, is possible within a 2.5 km radius. Needless to say that fixed reception at 10 m is possible everywhere.

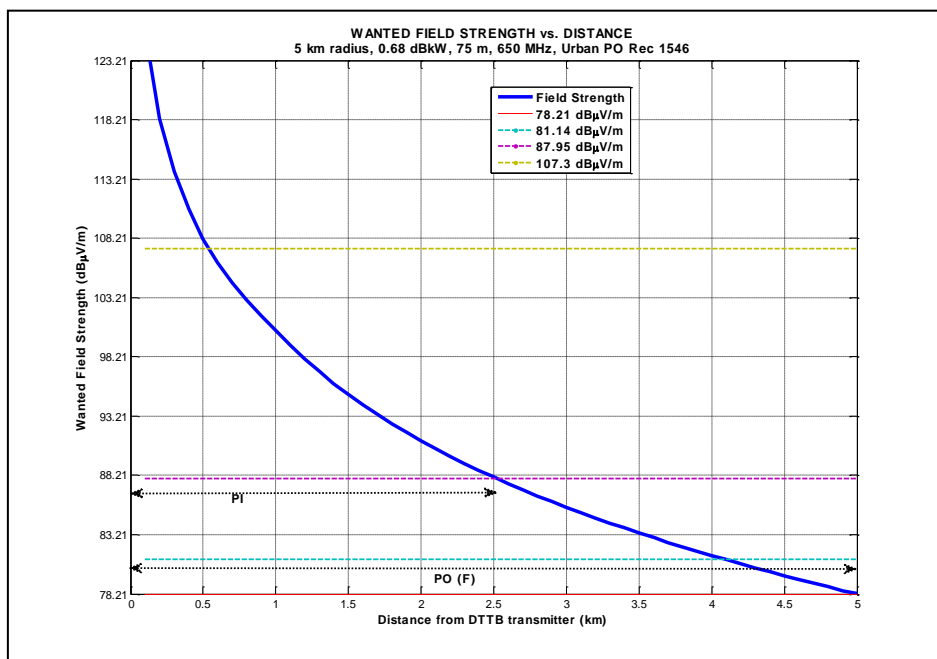


Figure 63: Small area urban environment (5 km radius, F, PO, PI reception)

#### A4.1.5 Conclusions

It is seen in Figures 59 to 63 that significant sub-areas of any DTT coverage area is suitable for portable outdoor (PO) and portable indoor (PI) DTT reception.

Any limits to be set on WSD e.i.r.p. values must provide protection not only for fixed DTT reception, but also protect PO and PI reception in those areas where this reception is possible.

For this reason, maximum WSD e.i.r.p. limits must be calculated very carefully, taking into account each and every reception mode possible in the area, using the most restrictive limits in order to protect every relevant DTT reception mode.

#### A4.2 RELATIONSHIPS BETWEEN DTT WANTED FIELD STRENGTH, LOCATION PROBABILITY, PROPAGATION DISTANCE, I/N

This section discusses the relationship between the DTT wanted field strength and various parameters:

- Wanted field strength vs. the corresponding propagation distance,
- Wanted field strength vs. the reception location probability, LP,
- Wanted field strength vs. the resulting I/N to maintain  $\Delta_{LP} = 0.1\%$ .

This exposition will give an idea of the behaviour of these parameters within a DTT coverage area and not just at the DTT coverage edge.

##### A4.2.1 Fixed DTT reception areas

Within a DTT coverage area, the wanted field strength generally increases the closer the DTT receiver is to the DTT transmitter. At the same time, the location probability (LP) for acceptable DTT reception also increases.

Figure 61 displays the dependency of LP on wanted DTT field strength. Figure 62 displays two other related relationships, viz.

- the relationship between distance and wanted DTT field strength, and
- the relationship between I/N on wanted DTT field strength which result when maintaining  $\Delta_{LP} = 0.1\%$ .

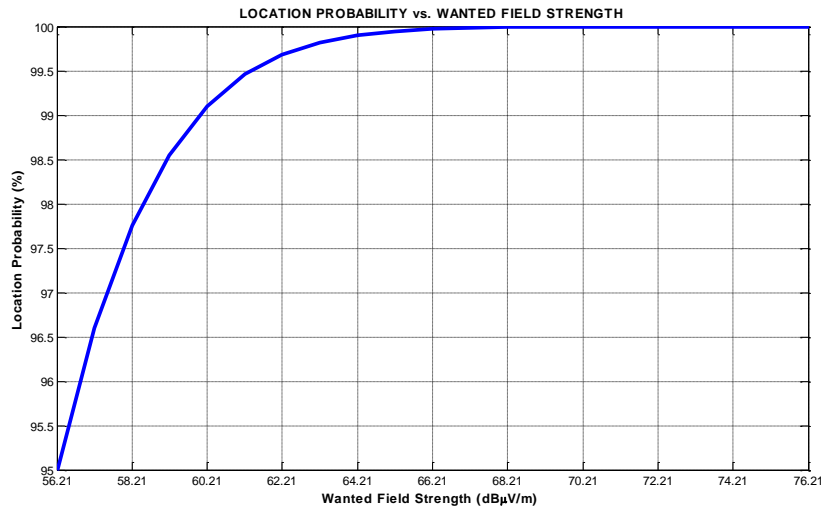
In Figure 62, the horizontal axis represents the wanted field strength, ranging from 56.21 dB $\mu$ V/m to 116.21 dB $\mu$ V/m. The vertical axis represents either a propagation path distance (measured in km) or a value of I/N (measured in dB), as relevant.

##### LP vs. median wanted field strength

Figure 64 shows the relationship between the wanted field strength and the corresponding LP, in the presence of noise only. It is representative for an entire fixed reception DTT coverage area.

It is seen from the Figure 61 that, for example,

- the wanted field strength = 56.21 dB $\mu$ V/m corresponds to a 95% LP (in the presence of noise only)
- the wanted field strength = 66.21 dB $\mu$ V/m (i.e. a 10 dB increase) the LP raises to 99.97%, and
- the wanted field strength = 74.21 dB $\mu$ V/m (i.e. with a further 8 dB increase), the LP rises to  $\approx 100\%$ .



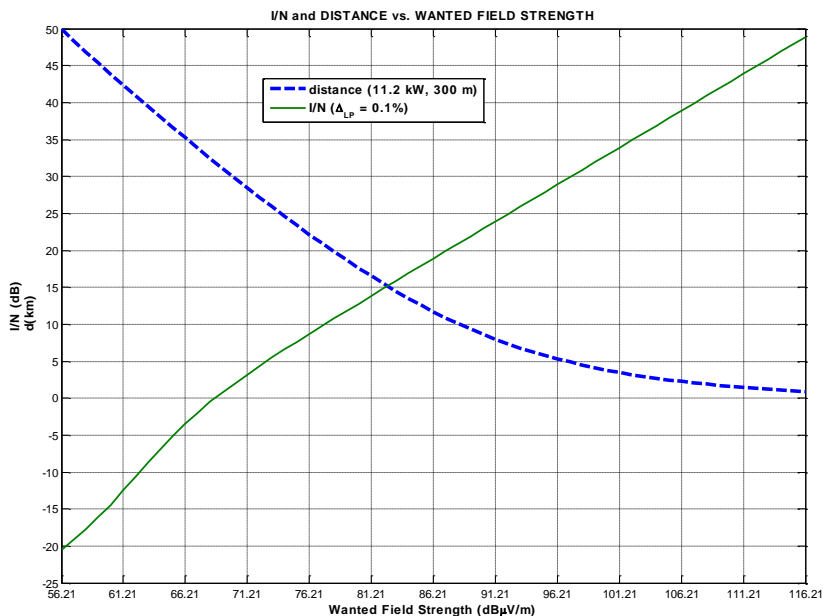
**Figure 64: Fixed DTT reception: LP vs. Wanted Field Strength (WFS)**

**Coverage distance vs. wanted field strength**

In this example, for a land propagation path, the frequency is 600 MHz, the wanted transmitter e.r.p. is 10.5 dBkW = 11.2 kW, and the transmit antenna height is 300 m; Recommendation ITU-R 1546 [8] is the propagation model used.

The dashed blue curve in Figure 65 shows the distance from a DTT transmitter as a function of the wanted field strength. The upper 2/3<sup>rd</sup>s (0 km to 50 km) of the vertical axis in this case represents the propagation distance, ranging from 0 km to 50 km.

It is seen that, as the wanted field strength increases, the distance to the wanted transmitter decreases.<sup>23</sup> In particular, in this example, the propagation distance 50 km corresponds to wanted field strength = 56.21 dBµV/m, and the propagation distance<sup>24</sup> 0.9 km corresponds to wanted field strength = 116.21 dBµV/m.



**Figure 65: Fixed DTT reception: I/N and Propagation Distance vs. Wanted Field Strength**

<sup>23</sup> Note: this is a slightly unusual way of representing this relationship. Usually the field strength is plotted as a function of distance. The present representation is convenient for the purposes of this contribution.

<sup>24</sup> Note: we have extrapolated Recommendation ITU R P.1546 below 1 km to 0.9 km in order to ‘finish’ the curve.

### **I/N vs. WANTED FIELD STRENGTH**

In order to calculate  $[I/N]_{med}$  vs. median wanted field strength, the following model was used:

- within a given pixel having a given median wanted field strength, the LP (in the presence of noise only) was calculated using Monte Carlo simulation.
- a second Monte Carlo simulation to determine LP was carried out after introducing a median interfering field,  $I$ , with 3.5 dB standard deviation. Noise and interference were power summed in the simulations.
- $[I/N]_{med}$  values were calculated from median interfering and wanted field strength values leading to  $\Delta_{LP} = 0.1\%$ . One million (1 000 000) trials were used in each simulation.

The solid curve in Figure 62 shows the relationship between  $[I/N]_{med}$  and wanted field strength for  $\Delta_{LP} = 0.1\%$ . The vertical axis in this case represents the values of  $[I/N]_{med}$  ranging from -25 dB to 50 dB. The wanted field strength can increase by as much as 50 dB or more as the wanted transmitter is approached. Correspondingly,  $[I/N]_{med}$  can increase up to 50 dB or more, if not limited.

This represents an  $[I/N]_{med}$  which is 70 dB (or 60 dB) higher than  $[I/N]_{med} = -20$  dB (or -10 dB) often used as a protection criterion.

From the Figure 65, it is seen that, within a 50 km radius DTT coverage area, 35 km is the distance at which a wanted field strength = 66.21 dB $\mu$ V/m (for LP  $\approx$  100%), 10 dB higher than at the coverage edge.

Thus,  $(35/50)^2 \approx 70\%$  of the coverage area has  $\approx$  100% LP. This means that, in the central coverage area (i.e. less than, equal 35 km distant from the DTT transmitter)  $[I/N]_{med}$  ranges from  $[I/N]_{med} = -3.5$  dB at 35 km from the transmitter to  $[I/N]_{med} = 48.9$  dB at 1 km from the transmitter for  $\Delta_{LP} = 0.1$

Note in Figure 65 that excessive values of  $I/N$  are reached within DTT coverage areas if adjacent channel WSDs are not subject to e.i.r.p. limits. Setting a fixed value of permissible  $\Delta_{LP}$  leads to increased values of  $I/N$ , potentially up to  $I/N = 30$  dB, or more.

Such large  $I/N$  values imply correspondingly large interference powers which, unless restricted, can lead to DTT receiver overloading (the consequences of this are discussed in more detail in section A5.5.4).

#### **A4.2.2 PO and PI DTT reception areas**

The behaviour of LP,  $I/N$  and propagation distance vs. wanted field strength is similar for portable outdoor and portable indoor DTT reception areas is similar to that for fixed DTT reception, as shown in the following four figures 63 to 66. Note that the wanted field strength values are calculated at 1.5 m DTT receive antenna height (outdoors).

The relationships between wanted field strength, LP,  $I/N$  and propagation distance are analogous to those discussed in section A4.2 above and will not be discussed further here.

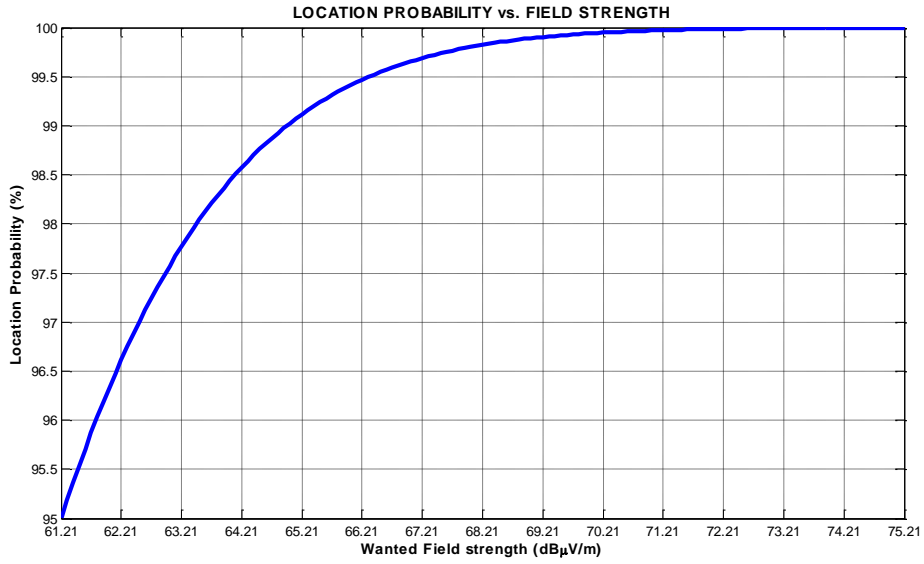


Figure 66: Portable Outdoor reception: LP vs. Wanted field strength

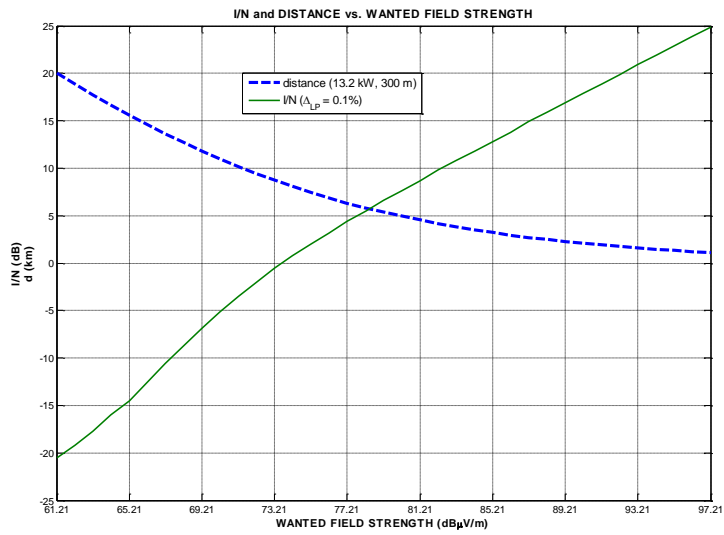


Figure 67: Portable Outdoor reception: I/N and Distance vs. Wanted field strength

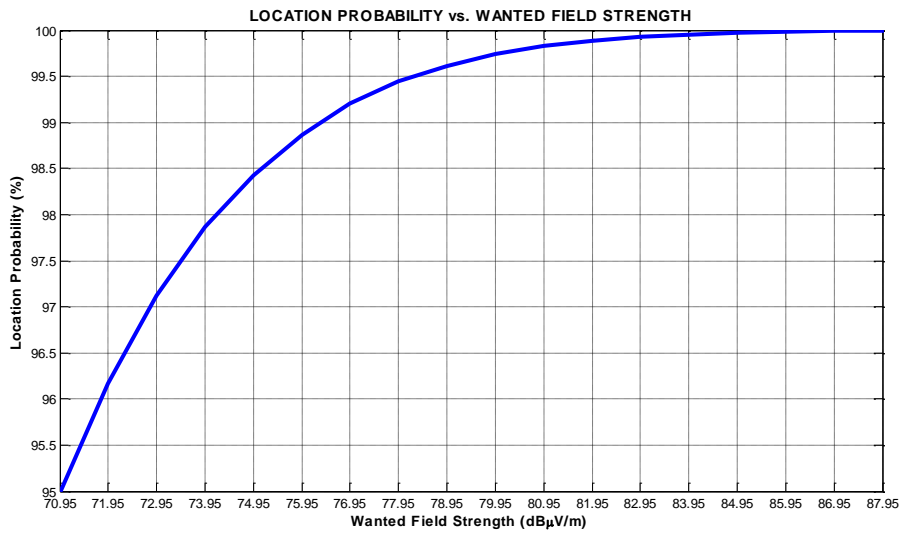


Figure 68: Portable Indoor reception: LP vs. Wanted field strength

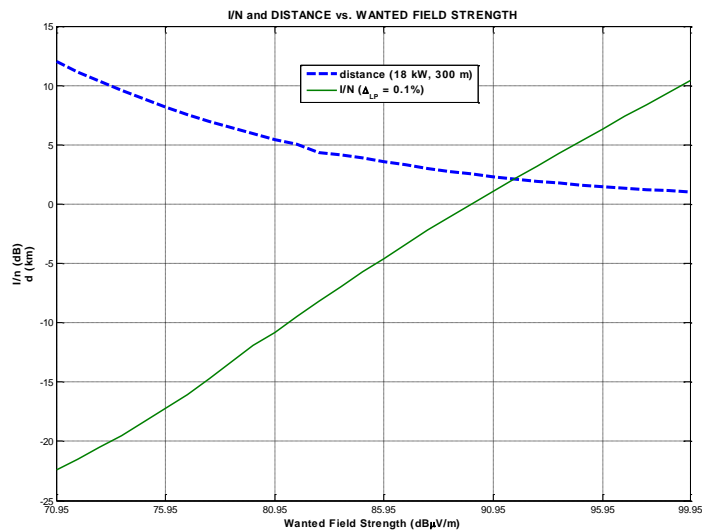


Figure 69: Portable Indoor reception: I/N and Distance vs. Wanted field strength

### A4.3 STUDY PARAMETERS, FORMULAS AND e.i.r.p. CONSTRAINTS FOR SHORT DISTANCE, SINGLE ENTRY INTERFERENCE CONTRIBUTIONS

#### A4.3.1 General

- At the DTT antenna input, the median field strength and median (and instantaneous) received power are related by:

$$P_{r\_dBm} = E_{dB\mu V/m} - 20 \log f_{MHz} - 77.2 ; f = 650 \text{ MHz}$$

$$P_t = P_r + \text{LOSS}(r) + \text{POL} + \text{DISC}_r + \text{ATT}_t$$

LOSS is the propagation loss, POL the polarization discrimination, if any, DISC<sub>r</sub> the receive antenna discrimination, and ATT<sub>t</sub> the transmit antenna attenuation.

Treating at the receive antenna input, we don't need to take into account G<sub>a</sub> (except when dealing with DTT receiver overload).

- Free space loss:  $LOSS(r_{km}) = 32.5 + 20 \log f_{MHz} + 20 \log r_{km}$
- Median wanted field strength:  $E_{w\_med}$  ; standard deviation:  $\sigma_w$
- Required C/N ratio: [C/N]
- N effective noise at antenna input:  $N = E_{w\_med} - [C/N] - \mu\sigma_w$
- Probability factor:  $\mu = 1.645$  for 95% LP,  $\mu = 2.323$  for 99% LP,  $\mu = 3.090$  for 99.9% LP
- $E_{i\_med}$  median interfering field at antenna input,  $\sigma_{w_{sd}} = 3.5$  dB
- For non-interference at a DTT reception site:  $E_i + PR < E_w$
- Height loss (10 m – 1.5 m): 17 dB
- Wall penetration loss: 8 dB,  $\sigma_{wall} = 5.5$  dB
- DTT receiver overload (dBm):  $O_{th}$
- DTT receive antenna gain:  $G_a$
- $P_t < O_{th} - \mu_{x\%}\sigma_{w_{sd}} + [POL, DISC_{TV}] + DISC_{WSD} - G_a + LOSS(d)$  (+ wall loss if any)

#### A4.3.2 WSD e.i.r.p. to I/N CONVERSIONS

In this section, for information, the determination of maximum WSD e.i.r.p. limits assuming I/N restrictions instead of degradation to location probability  $\Delta_{LP} = 0.1\%$  are imposed on WSD operation, to protect a given location probability,  $X\%$ <sup>25</sup>.

##### A4.3.2.1 WSD e.i.r.p. LIMITED BY PROTECTION RATIO CONSTRAINTS

Let N represent the DTT noise power (thermal plus receiver noise),  $P_t$  the WSD e.i.r.p., and  $N_n$  the nuisance noise power:

$$N_n = N + [C/N]$$

and  $I_{med}$  the median WSD power in the DTT receiver

$$I_{med} = P_t - LOSS(r) - ATT_t - POL - DISC_r + G_a$$

Let  $I_n$  represent the median interference nuisance power

$$I_n = I_{med} + PR.$$

Then<sup>26</sup>,

$$\begin{aligned} [I_n/N_n]_{med} &= I_{med} + PR - (N + [C/N]) = [I_{med}/N] + PR - [C/N] \\ &= P_t - LOSS(r) - ATT_t - POL - DISC_r + G_a + PR - [C/N] \end{aligned}$$

##### A4.3.2.2 WSD e.i.r.p. limited by protection ratio and [I/N] constraints

The ambient 'effective noise' field strength,  $N_{eff}$ , and corresponding powers are calculated from the minimum median field strength,  $E_{w\_dB\mu V/m}$  (assuming 95% location probability).

$$N_{eff} = E_{w\_dB\mu V/m} - [C/N] - \mu_{95\%}\sigma_w$$

The 'effective noise' power,  $P_{eff}$ , is

$$P_{eff} = N_{eff} - 20 \log f_{MHz} - 77.2$$

The median nuisance noise power,  $P_n$ , is

$$P_n = P_{eff} + [C/N]$$

For a given median field strength (wanted or interfering),  $E_{med}$ , the median ambient power,  $P_r$ , at the DTT receive antenna input is

<sup>25</sup> Presumably  $X\%$  would be a percentage higher than 95% (which usually is the minimum percentage considered acceptable).

<sup>26</sup> If wall loss is to be considered, then

$$[I_n/N_n]_{med} = [I_{med}/N] + PR - [C/N] = P_t - LOSS(r) - W_{loss} - ATT_t - POL - DISC_r + G_a + PR - [C/N.]$$

$$P_{r\_dBm} = E_{med} - 20 \log f_{MHz} - 77.2$$

Taking account of the relevant protection ratio, PR, the median interfering nuisance power,  $I_{nuis}$ , at the DTT receive antenna input, due to an ambient interfering field,  $P_r$ , is

$$I_{nuis} = P_r + PR$$

$[I_{nuis}/P_n]_{med}$  is the median interfering nuisance field/power 'divided' by the nuisance noise field/power. Here we work with powers (dBm);

$$\begin{aligned} [I_{nuis}/P_n]_{med} &= P_r + PR - P_{eff} - [C/N] = \\ &= P_t - LOSS(r) - ATT_t + PR - P_{eff} - [C/N] \end{aligned}$$

If the median limiting  $[I/N]$  is set as  $[I/N]_{lim}$ , then we need as the protection criteria, for protecting DTT reception for X% location probability,<sup>27</sup>

$$P_t < [I/N]_{lim} + LOSS(r) + ATT_t - PR + P_{eff} - \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2}$$

#### EXAMPLES:

We calculate examples for 3 reception modes.

##### Fixed reception:

- $E_w = 56.21$  dB $\mu$ V/m,  $\mu = 1.645$  (95%),  $\sigma = 5.5$  dB,  $C/N = 21$  dB
- Effective  $N_f = 26.16$  dB $\mu$ V/m  $\equiv P_{eff} = -107.30$  dBm
- Noise nuisance power:  $N_f + C/N = N_f + 21$
- $LOSS = 54.77$  dB, [POL, DISC] = 3 dB, DIR = 0, wall loss = 0 dB
- $P_r = P_t - 54.77 - 3 - 0 - 0 = P_t - 57.77$
- $P_t < [I/N]_{lim} + 57.77 - PR + 21 + (-107.3) + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2} = [I/N]_{lim} - PR - 28.5 + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2}$

##### Portable Outdoor reception:

- $E_w = 61.21$  dB $\mu$ V/m,  $\mu = 1.645$  (95%),  $\sigma = 5.5$  dB,  $C/N = 19$  dB
- Effective  $N_o = 33.16$  dB $\mu$ V/m  $\equiv P_{eff} = -100.3$  dBm
- Noise nuisance power:  $N_o + C/N = N_o + 19$
- $LOSS = 55.5$  dB, [POL, DISC] = 0 dB, DIR = 10, wall loss = 0 dB
- $P_r = P_t - 55.5 - 10 - 0 - 0 = P_t - 65.5$
- $P_t < [I/N]_{lim} + 65.5 - PR + 19 + (-100.3) + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2} = [I/N]_{lim} - PR - 15.8 + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2}$

##### Portable Indoor reception:

- $E_w = 62.95$  dB $\mu$ V/m inside at 1.5 m,  $\mu = 1.645$  (95%),  $\sigma = 7.78$  dB,  $C/N = 17$  dB
- Effective  $N_i = 33.16$  dB $\mu$ V/m  $\equiv P_{eff} = -100.3$  dBm
- Noise nuisance power:  $N_i + C/N = N_i + 17$
- $LOSS = 55.5$  dB, [POL, DISC] = 10 dB, DIR = 0, (inside at 1.5 m, so) wall loss = 8 dB
- $P_r = P_t - 55.5 - 10 - 0 - 8 = P_t - 73.5$
- $P_t < [I/N]_{lim} + 73.5 - PR + 17 + (-100.3) + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2} = [I/N]_{lim} - PR - 9.8 + \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2)^{1/2}$

#### A4.3.2.3 WSD e.i.r.p. limited by overload and $[I/N]$ constraints

In the case of overloading,  $[I/N]_{med}$  is simply  $O_{tr}/N$ , where N is the actual noise power in the receiver. In the preceding subsection, it has been the 'effective noise',  $N_{eff}$ , which has been used. The effective noise at the DTT antenna input and the actual noise in the DTT receiver are related by  $N_{eff} + G_a = N$ .

So at DTT overload, to protect at X% locations,

<sup>27</sup> If wall loss is to be considered  $P_t < [I/N]_{lim} + LOSS(r) + W_{loss} + ATT_t - PR + P_n - \mu_{x\%} (\sigma_w^2 + \sigma_{wsd}^2 + \sigma_{wl}^2)^{1/2}$



$$[I/N]_{med} = O_{thr}/N - \mu_{x\%}\sigma_{wsd} = \{P_t - LOSS(r) - POL - DISC_r - ATT_t + G_a\}/N$$

$$[I/N]_{med} = P_t - LOSS(r) - POL - DISC_r - ATT_t + G_a - N.$$

If  $[I/N]_{med}$  limits are set,  $[I/N]_{lim}$ , this would imply that limits on  $P_t$  would also result, including DTT protection for X% location probability<sup>28</sup>,

$$P_t < [I/N]_{lim} + LOSS(r) + POL + DISC_r + ATT_t - G_a + N - \mu_{x\%}\sigma_{wsd}$$

---

<sup>28</sup>If wall loss is to be considered  $P_t < [I/N]_{lim} + LOSS(r) + W_{loss} + POL + DISC_r + ATT_t - G_a + N - \mu_{x\%}(\sigma_{wsd}^2 + \sigma_{wl}^2)^{1/2}$

## ANNEX 5: CONSIDERATIONS OF DEGRADATION OF COVERAGE LOCATION PROBABILITY FOR THE DETERMINATION OF MAXIMUM WSD e.i.r.p. LIMITS

### A5.1 INTRODUCTION

This annex is aimed to assist administrations in assessing an appropriate level for the degradation of the location probability to be used in the geo-location database calculations for the protection of the broadcasting services. In particular, considerations supported by calculation examples are provided (i) regarding the approach when the probability degradation is set to a fixed value and (ii) regarding the approach when the probability degradation varies across the coverage area of the broadcasting service.

As stated in the section 5.2.3 of the report, two options could be used when applying the methodology developed in the ECC Report 159 [1].

This Annex provides the following information in various sections:

- Section A5.2 briefly summarizes the parameters of the 8 reference WSD to DTT protection scenarios (see Annex 2) that are used in other sections.
- Section A5.3 considers the WSD e.i.r.p. limits based on a fixed value for the acceptable degradation of the coverage probability,  $\Delta LP = 0.1\%$ , providing
  - a theoretical derivation of an analytical equation for calculating WSD e.i.r.p. limits based on DTT receiver overload thresholds as well as providing justification using Monte Carlo simulation
  - a derivation of absolute WSD e.i.r.p. limits based on DTT receiver overload (for both fixed and UE WSDs)
  - a derivation of relative WSD e.i.r.p. limits based on a protection ratio,  $PR = 0$  dB, which by translation provides WSD e.i.r.p. limits for all protection ratio values (for both fixed and UE WSDs)
  - a derivation of WSD e.i.r.p. limits based on combined protection ratio and overload threshold (for both fixed and UE WSDs)
  - consideration of WSD e.i.r.p. limits based on I/N limits
- Section A5.4 describes the determination of limiting WSD e.i.r.p. values near areas with differing DTT reception modes
- Section 5.5 considers the possibility of adopting variable acceptable degradation of the coverage probability, providing
  - a theoretical derivation of interference upper limits at the DTT receiver according to the capability of the receiver in dealing with interference, i.e. by respecting protection ratios and receiver overloading thresholds;
  - a derivation of WSD e.i.r.p. limits based on the interference limits at the DTT receiver (for both fixed and UE WSDs)
  - derivation of  $\Delta LP$  upper limits based on the derived interference limits at the DTT receiver (original and resulting LPs assessed through Monte Carlo simulations)
  - discussion on the impact of  $\Delta LP$  levels higher than 0.1% on the DTT service
- Section A5.6 details possible ramifications when choosing the degradation of the location probability

It should be noted that the protection considerations in this Annex only apply to WSD interference interior to a DTT coverage area, and as such, WSD co-channel usage will not be allowed.

The treatment of co-channel (and adjacent channel) WSD interference arising from sources outside the DTT coverage area is treated in Annex 6

## A5.2 WSD INTERFERENCE SCENARIOS

Various reference scenarios are considered to determine the appropriate WSD e.i.r.p. limits in most foreseen adjacent channel protection situations (see Annex 2) where the interfering WSDs are within a few dozen meters of the DTT antennas. In co-channel interference situations, the interfering WSDs and the DTT antennas may be separated by many dozens of km. Reference scenarios have not been developed for this situation. Instead, for example, the WSD interference potential is calculated between the WSD (with its given characteristics) and the DTT reception mode (e.g. fixed at the DTT coverage edge).

In the Table below, the relevant parameters are summarised (using the abbreviations of the preceding section). The values of  $E_{med}$  for DTT are given at the receive antenna heights indicated. For example, for DTT, F (10) means that the DTT receive antenna height is 10 m; F (1.5) means that the DTT receive antenna height is 1.5 m.

In order to determine the corresponding  $E_{med}$  at 1.5 m, or 10 m, respectively, it is necessary to take into account the field strength height loss between 10 m and 1.5 m:

$$\text{Field strength Height loss (10 m – 1.5 m)} = 17 \text{ dB}$$

$$E_{med} \text{ (at 10 m)} = E_{med} \text{ (at 1.5 m)} + 17 \text{ dB}$$

These parameter values can be used in the equations in sections A5.5 and A5.6 below to evaluate the relevant e.i.r.p. limits, [I/N] values, etc, according to the relevant interference scenarios.

**Table 15: Scenario parameters for protection ratio and non-overload conditions**

Scenario	$E_{med}$ (dB $\mu$ V/m)	$P_{med}$ (dBm)	LOSS(d) (dB)	DISC/POL (dB)	DISC <sub>wsd</sub> (dB)	PR (dB)	Scenario Description		
							WSD	DTTB	d (m)
#1	56.21	-77.25	56.15	0.45	0	21	PO(1.5m)	F(10 m)	22
#2	56.21	-77.25	54.72	0	0	21	PO(10m)	F(10 m)	20
#3	61.21	-72.25	34.72	0	0	19	PO(1.5m)	PO(1.5m)	2
#4	56.21	-77.25	54.72	3	0	21	F(10m)	F(10m)	20
#5	61.21	-72.25	55.45	0	10	19	F(10m)	PO(1.5m)	20
#6	62.95*	-70.51	55.45**	0	10	17	F(10m)	PI(1.5m)	20
#7	56.21	-77.25	62.87	3	13.55	21	F(30m)	F(10m)	47
#8	61.21	-72.25	60.59	0	18.01	19	F(30m)	PO(1.5m)	27

$E_{med}$   $\equiv$  wanted median field strength;  $P_{med}$   $\equiv$  wanted median power; LOSS(d)  $\equiv$  propagation loss

DISC/POL  $\equiv$  receive antenna /polarization discrimination; DISC<sub>wsd</sub>  $\equiv$  transmit antenna attenuation

PR  $\equiv$  protection ratio; d  $\equiv$  separation distance between WSD transmit antenna and DTT receive antenna

\*62.95 dB $\mu$ V/m inside at 1.5 m corresponds to 70.95 dB $\mu$ V/m outside at 1.5 m and to 87.95 dB $\mu$ V/m outside at 10 m

\*\* there is an additional 8 dB wall penetration loss to take into account, with a 5.5 dB standard deviation

## A5.3 COMPARISON $\Delta_{LP}$ VALUES

Although  $\Delta_{LP} = 0.1\%$  is a satisfactory (i.e. sufficiently relaxed) protection criterion in a secondary service 'non-interference' scenario, Figure 70 displays similar results (left vertical axis  $[I/N]_{med}$  vs. wanted field strength), this time for several values of  $\Delta_{LP} = 0.1\%$ , 0.2%, 0.5%, 1%, 2%, 5% relative to protecting a fixed DTT service. Similar graphs could also be drawn for portable outdoor and portable indoor DTT reception.

In addition, corresponding WSD e.i.r.p. limits (restrictions) are indicated (right vertical axis) assuming a PR = -40 dB adjacent channel protection ratio. The -40 dB value is used for computation of the graph, based on a typical value for a noise-like WSD interferer operating in the second adjacent channel to the wanted DTT signal. A co-channel protection ratio of 20 dB is assumed, corresponding to the DVB-T 64-QAM 2/3 mode. The values of e.i.r.p. are also a function of the DTT receiver performance characterised by the required [C/N] (protection ratio) for the WSD interference.

It is seen that  $[I/N]_{med}$  is increased from about -21 dB to about -4 dB at the coverage edge (wanted field strength = 56.21 dB $\mu$ V/m) and by about 9 dB at points interior to the coverage area, e.g. from about 28 dB to about 37 dB where the wanted field strength = 96.21 dB $\mu$ V/m, from about 48 dB to about 57 dB where the wanted field strength = 116.21 dB $\mu$ V/m, etc.

Note that if the protection ratio were  $\lambda$  dB greater than (less than) -40 dB, then the corresponding WSD e.i.r.p.s would be  $\lambda$  dB less than (greater than) the corresponding e.i.r.p. values depicted in Figure 70.

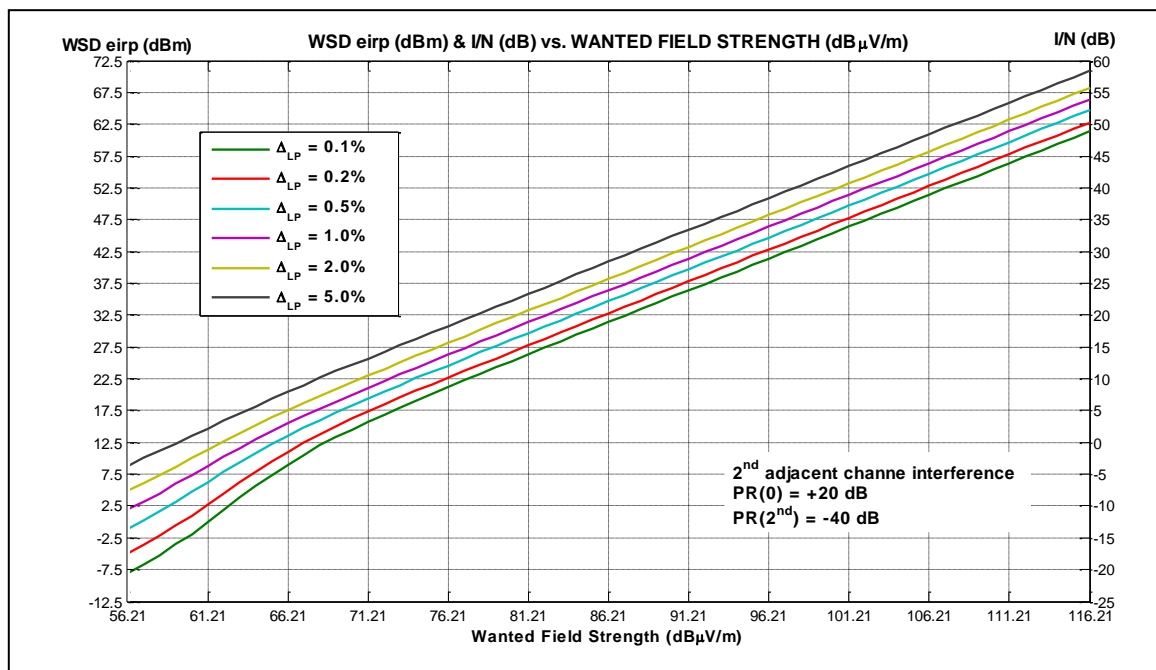
Obviously it is possible to apply  $\Delta_{LP} = 1\%$ ,  $2\%$ ,  $5\%$  (or even  $50\%$  and more) as a ‘protection criterion’ for WSD interfering with DTT reception.

However a corresponding loss in LP of  $1\%$ ,  $2\%$ ,  $5\%$ , etc is considered by broadcasters not to reflect the ‘non-interference’ stipulation for the use of secondary services, as this clearly represents a significant loss in coverage.

In addition, the concomitant acceptance of  $[I/N]_{med}$  values significantly  $> 0$  dB (e.g.  $10$  dB,  $20$  dB,  $30$  dB, ...) would seem to pose a dangerous precedent for other primary services, which may also one day be called upon to ‘share’ with non-licensed secondary services.

For this reason, the  $\Delta_{LP} = 0.1\%$  curve in Figure 70 is considered in detail. It is seen that as the DTT wanted field increases (e.g. approaching the DTT transmitter) the permitted WSD e.i.r.p. also increases. The DTT wanted field would nevertheless be protected for fixed DTT reception (i.e. with a  $0.1\%$  degradation in LP).

However, eventually the interfering field would be strong enough to cause DTT receiver overloading, irrespective of the strength of the wanted DTT field, and therefore a cut-off WSD e.i.r.p. would be necessary.



**Figure 70: Maximum WSD e.i.r.p., I/N vs. fixed reception DTT wanted field strength (parameter  $\Delta_{LP}$ )**

Often, to protect a primary service against another service a fixed value of  $I/N$  is foreseen (e.g.  $I/N = -20$  dB, or  $-10$  dB or  $-6$  dB). Here, to offer more flexibility for implementing WSDs (a non-licensed secondary service), it is proposed to use the degradation to the LP,  $\Delta_{LP}$ , caused by WSDs as the protection criterion. In particular, because secondary services are allowed to use spectrum on a ‘non-interfering’ basis, the value  $\Delta_{LP} = 0.1\%$  seems appropriate.

## A5.4 USE OF A FIXED VALUE FOR THE ACCEPTABLE DEGRADATION OF THE COVERAGE PROBABILITY

### A5.4.1 INTRODUCTION

The proposed approach in this section offers a flexible solution, by proposing a fixed value for the  $\Delta_{LP}$ , but considering nevertheless the real potential of portable outdoor and indoor DTT reception and its protection requirements.

By defining *a priori* a fixed value for the  $\Delta_{LP}$ , the interference will be limited, consistent with protection to be provided by a non-licensed service (WSD) for a primary service (DTT). The constant, fixed  $\Delta_{LP} = 0.1\%$  approach is shown to be flexible with respect to extended WSD usage nearer the DTT transmitter, in addition to preserving the DTT viewer's flexibility in choosing his or her mode of viewing, fixed or portable, outdoor or indoor.

Based on these considerations, the proposed methodology and parameters are as follows:

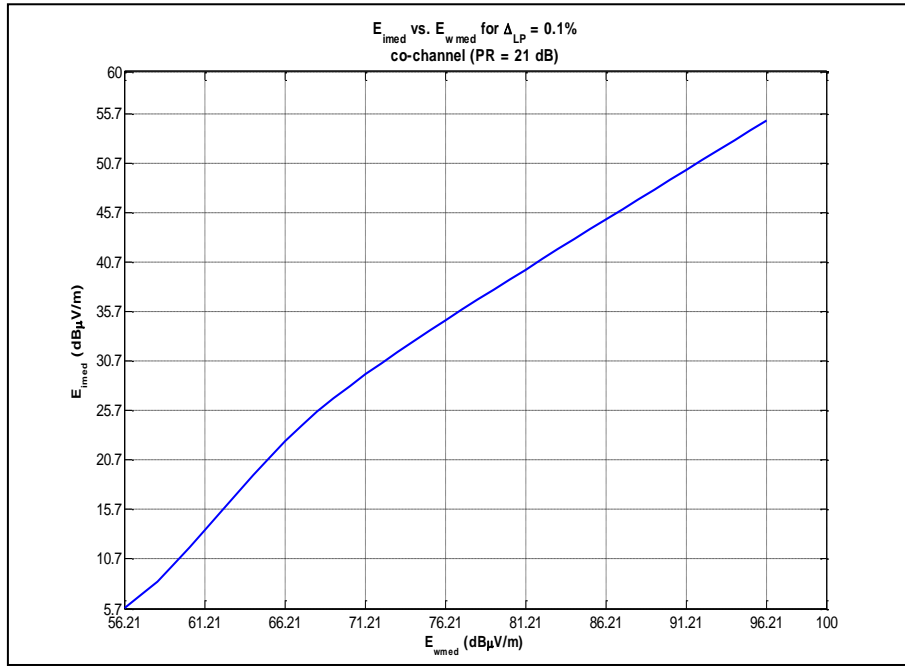
- The calculation is made according to the methodology described in the ECC Report 159 [1], and reference scenarios presented in Annex A2;
- Limiting the location probability degradation to 0.1% everywhere in the coverage area of the DTT transmitter.
- Protecting the three modes of reception progressively from the edge of the coverage inwards. The switch to each mode is made as function of the wanted field strength level by referring to the thresholds of field strength above which a given mode of reception is possible (going from fixed roof top to portable outdoor and to portable indoor);
- Limiting the e.i.r.p. to a maximum level defined by the overloading threshold corresponding to each interference scenario and channel adjacency;
- Taking account of multiple interference from UE WSD by assuming that 3 equivalent UE WSDs are contributing to the interference to DTT coverage when adjacent channels are used (Annex A5 of the Report 159 [1] presents the basis of this assumption);
- Taking account of multiple interference from fixed WSD, if N Fixed WSD transmissions are made from a common WSD antenna, then the e.i.r.p. limits indicated above must be reduced by a factor  $10 \log N$ .

#### *A5.4.1.1 $\Delta_{LP} = 0.1\%$ and the increase of permissible median wsd interfering field strength as a function of median wanted DTT field strength*

It has being proposed a  $\Delta_{LP} = 0.1\%$  criterion to limit the interference potential of WSDs to DTT reception. This criterion is used with the location specific e.i.r.p. calculation taking into account the wanted signal level and allows the WSD e.i.r.p. to increase almost without limit as the WSD location is situated closer and closer to the DTTB transmitter.

Figure 71 shows how the allowed interfering field of a WSD can increase as we pass from the DTT coverage edge (where the wanted field strength at 10 m receive antenna height for fixed reception is 56.21 dB $\mu$ V/m) towards the DTTB transmitter (where the field strength may reach 100 dB $\mu$ V/m or more), still limiting the degradation to location probability to 0.1% (ignoring the overload threshold, however).

Large increases in the interfering field will be due to high values of WSD transmit e.i.r.p.s which may lead to overloading effects in nearby DTT receive installations. To avoid this type of situation, WSD e.i.r.p. limits must be set.



**Figure 71: Eimed vs. Ewmed to achieve ΔLP = 0.1% in the co-channel (PR = 21 dB)**

**A5.4.2 THEORETICAL ANALYSIS FOR DTT RECEIVER OVERLOADING PROTECTION**

We wish to calculate the suitable WSD e.i.r.p. limits on the basis of respecting the overload threshold for any given channel adjacency. In this section we use analytical calculations to get a feel for the magnitude to the problem.

We use a simple model in which a fixed WSD transmit antenna, situated at 10 m height, interferes with a fixed DTTB receiver with fixed antenna at 10 m height. The separation between the WSD and the DTTB is 20 m.

- The wanted signal strength is only taken into account as a reference – we are only interested in the DTT overload threshold and its relationship to Pt\_wsd, the transmit e.i.r.p. of the WSD transmitter.
- Noise can be ignored compared to the field strength levels where DTT overloading occurs.
- The frequency considered is f = 650 MHz
- The interfering signal is assumed to have standard deviation σ<sub>wsd</sub> = 3.5 dB.

Referring to Figure 72 at the DTT receive antenna level, the field strength (median or stochastic<sup>29</sup>) and received power (median or stochastic) are related by:

$$P_{r\_dBm} = E_{dB\mu V/m} - 20 \log f_{MHz} - 77.2 \tag{32}$$

The (median and stochastic) power entering the receiver, after having passed through the antenna system, will be:

$$P_{rec} = P_{r\_dBm} - POL + G_a, \tag{33}$$

where POL = 3 dB antenna polarisation discrimination, and Ga is the receive antenna gain (including feeder losses). Ga = 9.15 dBi for fixed DTTB reception, and Ga = 2.15 dBi for portable DTTB reception.

The WSD transmit e.i.r.p., Pt, is related to the median Pr\_dBm by

$$P_t - LOSS(d) = P_{r\_dBm} \tag{34}$$

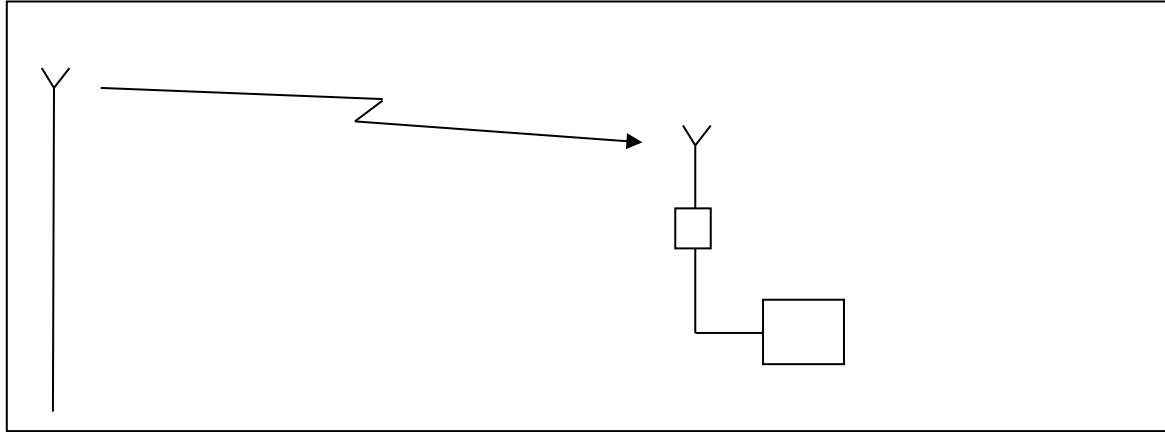
where 'LOSS(d)' is the median propagation loss over the distance d<sub>km</sub>.

<sup>29</sup> Note: the 'stochastic' values referred to represent the statistical fluctuations of the log-normal variable involved.

To protect against overloading the following must be satisfied:

- $P_{rec} < O_{th}$  for the stochastic power entering the receiver, and
- $P_{rec} < O_{th} - \mu_x \cdot \sigma_{wsd}$  for the median power entering the receiver to protect at x% location probability<sup>30</sup>.

$\mu_x$  is the probability factor for x% of the locations; e.g. for 95%,  $\mu_x = 1.6448$ , for 99.9%,  $\mu_x = 3.0902$ .



**Figure 72: Explanatory diagram of the terminology used in the calculation**

As mentioned, we ignore the effects of noise, and we make a simplifying assumption so that an analytical calculation can be carried out easily.

The assumption is explained in the following:

- Protection of DTTB to the extent that only a  $\Delta LP = 0.1\%$  degradation to the location probability is permitted. The protection from overload is taken by using:

$$P_{rec} < O_{th} - \mu_x \sigma_{wsd}, \quad (35)$$

- We would like to determine the value of “x” which will give a good approximation to a  $\Delta LP = 0.1\%$  degradation.
- We combine equations (32), (34) and (35) as follows:

$$\begin{aligned} P_t &= P_{r\_dBm} + \text{LOSS}(d) = \\ P_t &= P_{rec} + \text{POL} - G_a + \text{LOSS}(d) = \\ P_t &< O_{th} - \mu_x \sigma_{wsd} + \text{POL} - G_a + \text{LOSS}(d) \end{aligned} \quad (36)$$

If there is DTT receive antenna discrimination, DISCTV, then the term ‘POL’ should be replaced by ‘[POL,DISCTV]’ which can be taken as  $\max(\text{POL}, \text{DISCTV})$  if Recommendation ITU-R BT.419 [2] is used for the receive antenna characteristic.

If there is WSD transmit antenna attenuation, DISCWSD, then an additional term ‘DISCWSD’ should be introduced into equation (36).

Then we can rewrite equation (36) as:

$$P_t < O_{th} - \mu_x \sigma_{wsd} + \text{POL} + \text{DISC}_{TV} + \text{DISC}_{WSD} - G_a + \text{LOSS}(d) \quad (36)$$

Knowing the overload threshold value for any given situation, we can evaluate the maximum permitted WSD e.i.r.p. from equation (36).

For the fixed DTTB reception case we have<sup>31</sup>

<sup>30</sup> Note that  $\sigma_w$  does not appear in this expression, because there is no dependence on the wanted power when considering DTTB receiver overloading.

$$P_t < O_{th} - \mu_x * 3.5 + 3 + 0 - 9.15 + 54.72 = O_{th} - 3.5\mu_x + 48.57 \text{ dBm} \quad (37)$$

We can take an example from the overload threshold information provided in ECC Report 159 [1] the  $O_{th}$  values can be as low as -19 dBm for 10th percentile DTTB receivers (-26 dBm for silicon USB receivers).

As an example we chose  $O_{th} = -20$  dBm. Then equation (37) tells us that

$$P_{t_{max}} = O_{th} - 3.5\mu_x + 48.57 \text{ dBm} = 28.57 - 3.5\mu_x \text{ dBm}$$

is the maximum fixed WSD power limit to avoid DTT overload. It should be noted that no cumulative WSD interference effects have been taken into account. For example, if we had 3 co-sited WSDs transmitting from a single site, then the aggregate interference would exceed the  $O_{TH}$ , unless of course, the power of each transmission were reduced by  $10 \log 3 = 4.77$  dB. In this case,  $P_{t_{max}} = 28.57 - 3.5\mu_x$  dBm would be reduced to  $P_{t_{max}} = 23.8 - 3.5\mu_x$  dBm.

In order to determine the value of “x” to be used in this analytic calculation of the WSD e.i.r.p. restrictions due to DTTB overload, we calculate exact results in the following section, using Monte Carlo simulation.

### A5.4.3 MONTE CARLO SIMULATION TO CALCULATE THE PERCENTAGE OF LOCATIONS

The results in the previous section was based on ‘approximate’ analytic formulas. In this section we carry out the interference calculation using Monte Carlo simulations, with no approximations, in order to determine what value the parameter “x” should be given.

The Monte Carlo simulations are carried out on the following basis, with respect to protection ratio (giving protection information for the small to large WSD e.i.r.p.s) and also with respect to  $O_{th}$  (giving information for the largest WSD e.i.r.p.s). For simplicity, we carry out the calculation using powers (and not field strengths).

At the DTTB coverage edge the median wanted field strength at the DTTB fixed receive antenna (at 10 m height) for 95% location probability is  $E = 56.21$  dB $\mu$ V/m. We convert this to median receive power (at the receive antenna) using:  $P_w = E - 20 \log f - 77.2 = -77.245$  dBm.

The calculations are carried out for wanted DTTB receive powers (at the receive antenna) starting at the median value -77.245 dBm and increasing by 1 dB, step by step. This represents the increase in wanted field strength as the receiver approaches the DTTB transmitter.

The Monte Carlo trial for compatibility consists of the usual steps with one additional condition: the interfering power inside the receiver (i.e. including the receive antenna gain and polarization loss) must be less than the DTT receiver overload threshold.

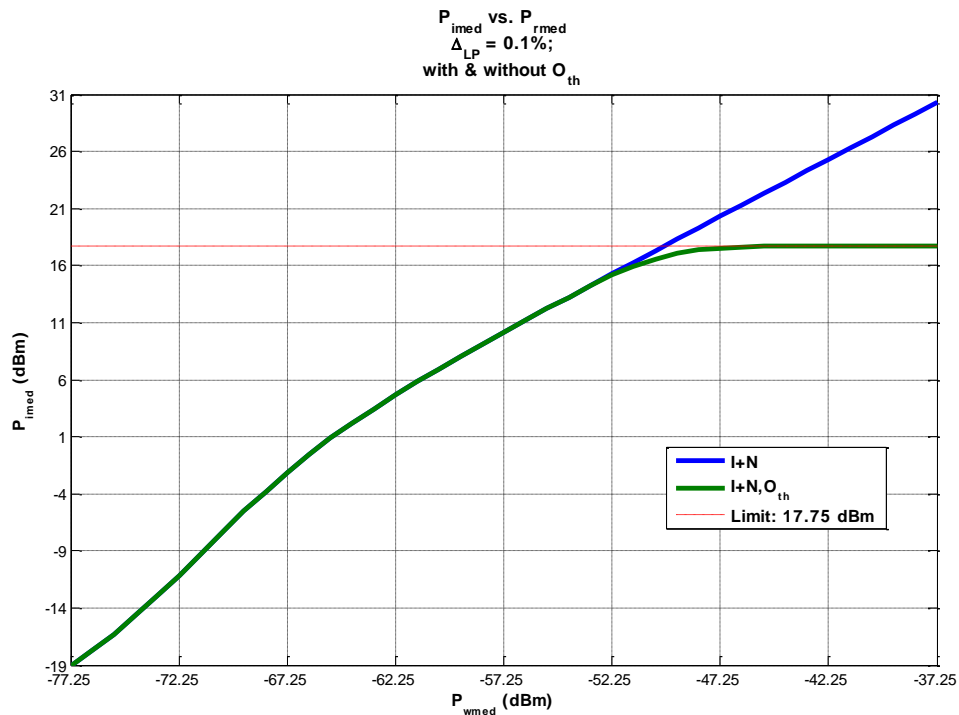
#### A5.4.3.1 Fixed WSD (10 m) to Fixed DTTB (10 m) (1st adjacent channel interference)

The results of Monte-carlo simulations are shown in Figure 73. It is seen that, as the wanted power at the DTTB receive antenna increases, the WSD allowed transmit power also increases (while maintaining  $\Delta_{LP} = 0.1\%$ ).

The curve which includes  $O_{th}$  in the protection criteria, however, increases roughly linearly, but eventually approaches 17.75 dBm asymptotically, and rises no further.

<sup>31</sup> We use free space loss for 20 m separation distance:  $LOSS(.02) = 32.45 + 20 \log f + 20 \log .02 = 54.72$  dB.





**Figure 73: WSD E.I.R.P. RESTRICTIONS: Fixed WSD (10 m) to Fixed DTTB (10 m) 1<sup>st</sup> Adjacent channel (PR = -30 dB), O<sub>th</sub> = -20 dBm**

**Analytic approximation**

We can substitute the previous result into equation (36)' to determine the corresponding value of "x".

Inserting all the relevant parameters<sup>32</sup>, we find  $P_{t,max} = 28.57 - 3.5\mu_x \text{ dBm} = 17.75 \text{ dBm}$ , which means that  $3.5\mu_x = 10.82$ , or  $\mu_x = 3.091$ . This value of  $\mu_x$  corresponds to  $x = 99.9\%$ . This means that if we are trying to protect LP at the level  $\Delta_{LP} = 0.1\%$ , we can use  $x = 99.9\%$  in equation (36)', with no approximation.

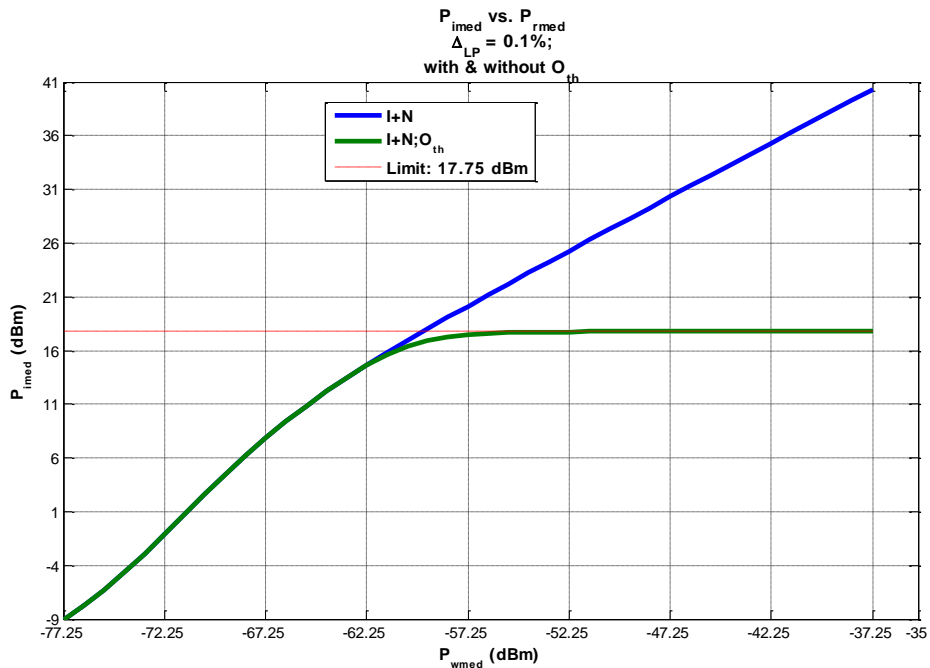
**A5.4.3.2 Fixed WSD (10 m) to Fixed DTTB (10 m) (2nd adjacent channel interference)**

The same Monte Carlo simulation has been carried out again, this time for the 2nd adjacent channel (PR = -40 dB). Other than the protection ratio, no other parameter has been changed. The results are shown in Figure 74. It is seen that the maximum WSD e.i.r.p. is again 17.75 dBm in this case, even though the protection ratio has decreased from -30 dB to -40 dB. This shows, as could be expected, that the overload interference effect is independent of the protection ratio (at least as long as the protection ratio is negative).

**Analytic approximation**

As shown in the previous subsection, the same result could have been obtained analytically using equation (36)' and  $x = 99.9\%$ .

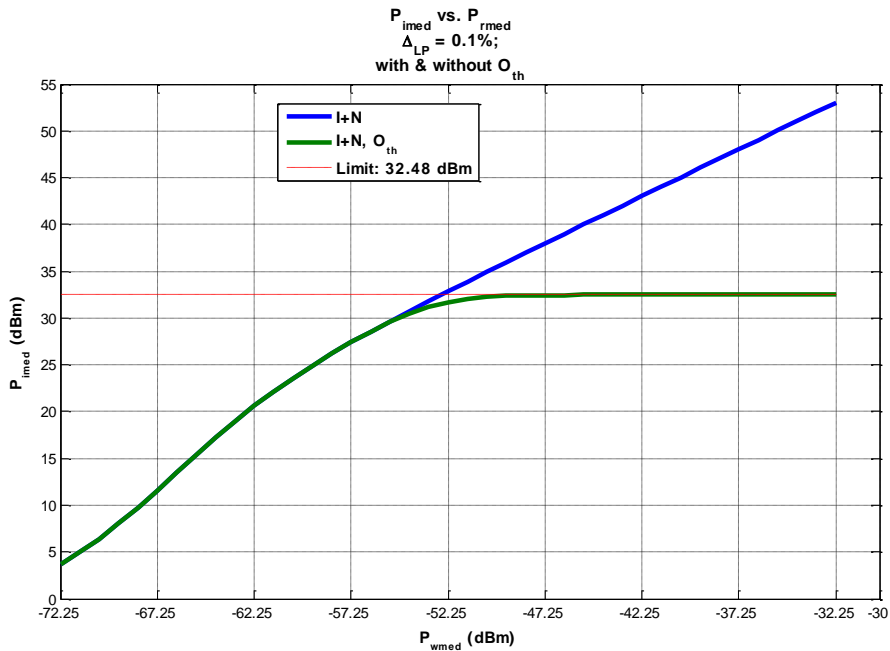
<sup>32</sup> O<sub>th</sub> = -20 dBm, G<sub>a</sub> = 9.15 dB, LOSS (.02) = 54.7 dB, POL = 3 dB, DISC<sub>TV</sub> = DISC<sub>WSD</sub> = 0 dB.



**Figure 74: WSD E.I.R.P. RESTRICTIONS: Fixed WSD (10 m) to Fixed DTTB (10 m) 2<sup>nd</sup> Adjacent channel (PR = -40 dB),  $O_{th} = -20$  dBm**

*A5.4.3.3 Fixed WSD (10 m) to PO DTTB (1.5 m) (2nd adjacent channel interference)*

We examine one more case using Monte Carlo simulation: Fixed WSD (10 m) to DTTB PO (1.5 m). We use 2<sup>nd</sup> adjacent channel interference, even though, as we have seen before, the result is independent of the value of the (negative) protection ratio. The results are shown in Figure 75. It is seen that the maximum WSD e.i.r.p. is 32.48 dBm.



**Figure 75: WSD E.I.R.P. RESTRICTIONS: Fixed WSD (10 m) to PO DTTB (1.5 m) 2<sup>nd</sup> Adjacent channel (PR = -40 dB),  $O_{th} = -20$  dBm**

**Analytic approximation**

We now compare this result ( $P_{t\_max} = 32.48$  dBm) with the results of equation (36) of Section A5.3.2:

$$P_t < O_{th} - \mu_x \sigma_{wSD} + POL + DISC_{TV} + DISC_{WSD} - G_a + LOSS(d), \quad (36)$$

using the appropriate parameters<sup>33</sup>.

Based on our determination of the value of the parameter “x” for  $\Delta_{LP} = 0.1\%$ , we can evaluate equation (36) as follows:  $P_{t\_max} = -20 - 3.09 \cdot 3.5 + 0 + 10 - 2.15 + 55.45 = 32.485$  dBm. This is precisely the result delivered by the previous Monte Carlo simulation.

**A5.4.3.4 CONCLUSION**

We conclude that the arguments given above for the applicability of Equation (36), and its accuracy, are valid. In particular,  $x = 99.9\%$  for  $\Delta_{LP} = 0.1\%$ . This allows a simplification in calculations determining permitted maximum e.i.r.p.s for WSDs. In other words, when determining absolute maximum WSD e.i.r.p.s related to DTT receiver overload, Monte Carlo simulation is not required – the analytical inequality in equation (36) suffices.

**A5.4.4 WSD e.i.r.p. LIMITS DUE TO DTT RECEIVER OVERLOAD**

Protection against DTT overloading provides an absolute upper limit to the WSD transmit power. This upper limit can be calculated simply, with no approximation (as demonstrated in sections A5.5.2, A5.5.3 above), using the following analytical expression:

$$P_t < O_{th} - \mu_{x\%} \sigma_{wSD} + POL + DISC_{TV} + DISC_{WSD} - G_a + LOSS(d) \quad (36)$$

where

- $O_{th}$  is the relevant overload threshold, dBm
- POL is the polarization discrimination, dB,
- $G_a$  is the DTT receive antenna gain, dB,
- $DISC_{TV}$  is the DTT receive antenna discrimination, dB,
- $DISC_{WSD}$  is the WSD transmit antenna attenuation, dB,
- $LOSS(d) = 32.45 + 20 \log f_{MHz} + 20 \log d_{km}$  is the free space propagation loss over the distance  $d$  between the WSD transmit antenna and the DTT receive antenna, dB;
- $\sigma_{wSD}$  is the propagation loss standard deviation,
- $\mu_x \cdot \sigma_{wSD}$  is the statistical factor ensuring protection for  $X\%$  location probability.

For example, the protection of fixed DTT reception against fixed WSD transmission, we can use equation (36) to determine<sup>34</sup> a range of limiting WSD e.i.r.p. values as a function of  $O_{th}$ . This is shown in Table 16.

Note that these limits would be valid irrespective of ambient DTT wanted field strength level.

A range of limiting WSD e.i.r.p. values is given as a function of  $O_{th}$ . Note that these limits would be valid irrespective of ambient DTT field strength level.

<sup>33</sup>  $O_{th} = -20$  dBm,  $G_a = 2.15$  dB,  $LOSS(.0217) = 55.45$  dB,  $POL = 0$  dB,  $DISC_{TV} = 0$  dB,  $DISC_{WSD} = 10$  dB.

<sup>34</sup>  $G_a = 9.15$  dB,  $POL = 3$  dB,  $LOSS(.02) = 54.7$  dB,  $\mu_{99.9\%} = 3.09$ ,  $\sigma_{WSD} = 3.5$  dB

**Table 16: FIXED WSD  $P_t$  limits with respect to  $O_{th}$  levels**

Oth	$\Delta LP = 0.1\%$ ( $\mu L = 3.090$ )
0 dBm	38 dBm
-5 dBm	33 dBm
-10 dBm	28 dBm
-15 dBm	23 dBm
-20 dBm	18 dBm
-25 dBm	13 dBm
-30 dBm	8 dBm
-35 dBm	3 dBm
-40 dBm	-2 dBm
-45 dBm	-7 dBm
-50 dBm	-12 dBm

In the next two subsections we show the range of WSD e.i.r.p. limits as a function of frequency offset. For a given frequency offset, in order to protect all 10<sup>th</sup> percentile DTT receivers, the lowest WSD  $P_t$  limit for all 10<sup>th</sup> percentile receiver types must be observed. In addition, in the case of a WSD with multiple DTT channel adjacencies, the minimum of the individual  $P_t$  limits must be observed.

The theoretical basis for these results was provided in the section A5.3.2 and the demonstration of their precision was provided in the section A5.3.3, using Monte Carlo simulations.

**A5.4.4.1 Fixed WSD limits**

Table 17 is taken from ECC Report 159 [1] for values of the overload threshold as a function of the interfering channel adjacency. These values of the overload threshold lead to fixed WSD e.i.r.p. limits as shown in Table 16. The dependency of the WSD  $P_t$  limits on the channel adjacency (horizontal axis) is to be noted.

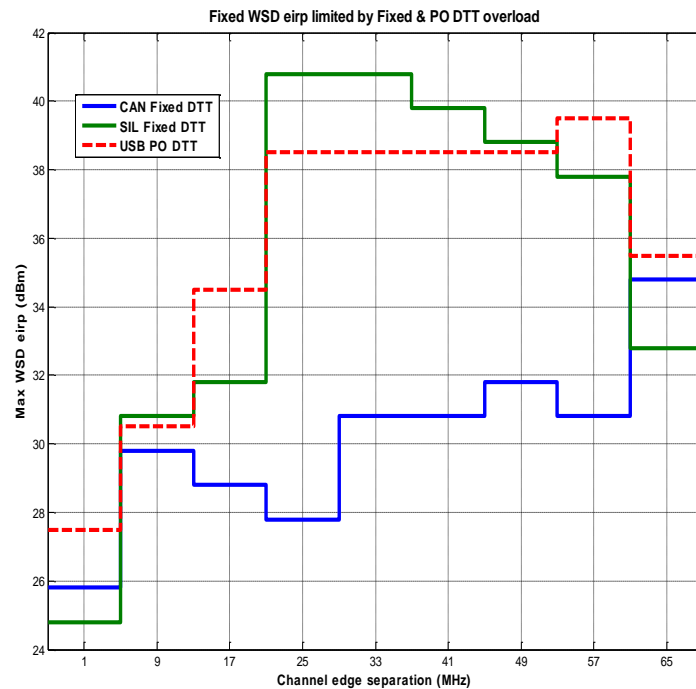
**Table 17: DVB-T  $O_{th}$  values in the presence of a time-constant LTE BS interfering signal in a Gaussian channel environment at the 10<sup>th</sup> percentile: can-tuners and silicon-tuners**

DVB-T $O_{th}$ for 64-QAM 2/3 DVB-T signal (LTE BS, Constant Average Power) Gaussian channel			
Channel edge separation (MHz)	Oth (dBm)		
	10th percentile		
	Can STB/iDTV	Silicon STB/iDTV	Silicon USB
1	-12	-13	-25
9	-8	-7	-22
17	-9	-6	-18
25	-10	3	-14
33	-7	3	-14
41	-7	2	-14
49	-6	1	-14
57	-7	0	-13
65	-3	-5	-17

In the 2<sup>nd</sup> adjacent channel,  $O_{th} = -8$  dB for fixed DTT reception (CAN and Silicon), and  $O_{th} = -22$  dB for mobile (PO and PI) USB DTT reception. These values of overload threshold correspond to maximum WSD e.i.r.p. levels 29.8 dBm (F), 30.5 dBm (PO), and 29.2 dBm (PI).

There are three horizontal dashed lines corresponding to e.i.r.p. = 29.8 dBm, 30.5 dBm, and 29.2 dBm indicated in Figure 76.

Note that although Figure 76 relates to an overload threshold,  $O_{th} = -8$  dB (-7 dBm is also possible) (fixed DTT) and  $O_{th} = -22$  dBm (portable DTT), it can be also used for other values of  $O_{th}$ .



**Figure 76: Fixed WSD e.i.r.p. limited by Fixed (CAN and silicon tuners) and PO (USB) DTT receiver overload according to the frequency offset**

It is seen from Figure 76 that fixed WSD e.i.r.p.s might be restricted to range from  $\approx 25$  dBm (1<sup>st</sup> adjacent channel) to  $\approx 29$  dBm (2<sup>nd</sup> adjacent channel) to  $\approx 28$  dBm (4<sup>th</sup> adjacent channel) to  $\approx 34$  dBm (9<sup>th</sup> adjacent channel).

As a specific example, in the 2<sup>nd</sup> adjacent channel,  $O_{th} = -8$  dB for fixed DTT reception (CAN and Silicon), and  $O_{th} = -22$  dB for mobile (PO and PI) USB DTT reception. These values of overload threshold correspond to maximum WSD e.i.r.p. levels 29.8 dBm (F), 30.5 dBm (PO), and 29.2 dBm (PI). These values are used as WSD e.i.r.p. cut-off limits in Figure 77.

**A5.4.4.2 UE WSD limits**

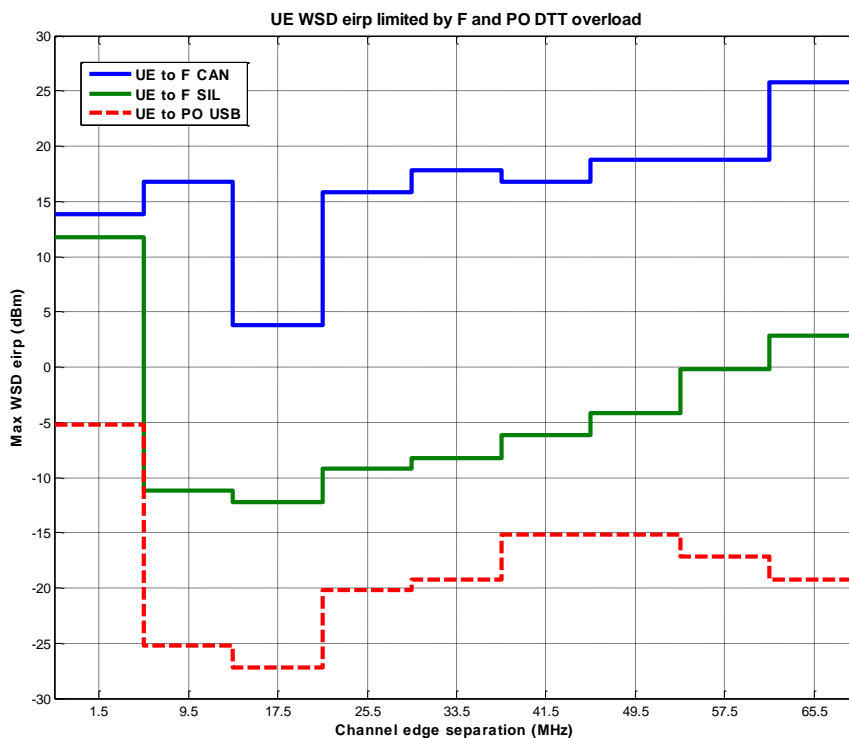
Table 18: DVB-T  $O_{th}$  values in the presence of a LTE UE interfering signal without TPC in a Gaussian channel environment at the 10<sup>th</sup> percentile: can-tuners and silicon-tuners below is taken from ECC Report 159 [1] for values of the overload threshold corresponding to UE WSD as a function of the interfering channel adjacency.

These values of the overload threshold lead to fixed WSD e.i.r.p. limits as shown in Figure 77. The dependency of the WSD  $P_t$  limits on the channel adjacency (horizontal axis) is to be noted.

It is important to further note that the values in Table 18 are valid only for UE with TPC off. With TPC on, the values may be as much as 10 dB lower.

**Table 18: DVB-T  $O_{th}$  values in the presence of a LTE UE interfering signal without TPC in a Gaussian channel environment at the 10<sup>th</sup> percentile: can-tuners and silicon-tuners**

DVB-T PR for 64-QAM 2/3 DVB-T signal (LTE UE TPC off)			
Channel edge separation (MHz)	Oth (dBm)		
	10th percentile		
	Can STB/iDTV	Silicon STB/iDTV	Silicon USB
1.5	-21 ... -19	-23 ... -17	-27
9.5	-18 ... -4	-46 ... -5	-47
17.5	<b>-31 ... -26</b>	<b>-47 ... -2</b>	<b>-49</b>
25.5	-19 ... -11	-44 ... -6	-42
33.5	-17 ... -7	-43 ... -5	-41
41.5	-18 ... -7	-41 ... -7	-37
49.5	-16 ... -3	-39 ... -5	-37
57.5	-16 ... -3	-35 ... -7	-39
65.5	-9 ... -3	-32 ... -10	-40



**Figure 77: UE WSD e.i.r.p. limited by Fixed (CAN and silicon tuners) & PO (silicon tuner) DTT receiver overload according to the frequency offset**

It is seen from Figure 77 that UE WSD e.i.r.p.s might be restricted to range from  $\approx -25$  dBm (1<sup>st</sup> adjacent channel) to  $\approx -27$  dBm (2<sup>nd</sup> adjacent channel) to  $\approx -15$  dBm (5<sup>th</sup> and 6<sup>th</sup> adjacent channel) to  $\approx -20$  dBm (9<sup>th</sup> adjacent channel).

As a specific example, in the 2<sup>nd</sup> adjacent channel,  $O_{th} = -31$  dB for fixed DTT reception (CAN),  $O_{th} = -47$  dB for fixed DTT reception (SIL), and  $O_{th} = -49$  dB for PO and PI mobile (USB) DTT reception. These values of

overload threshold correspond to maximum WSD e.i.r.p. levels 3.8 dBm (F-CAN), -12.2 dBm (F-SIL), -27.2 dBm (PO-USB), and -28.8 dBm (PI-USB). These values are used as WSD e.i.r.p. cut-off limits in Figure 78 below.

Once again, it is important to note that the values in Figure 77 are valid only for UE with TPC off. With TPC on, the limiting WSD e.i.r.p. values may be as much as 10 dB lower.

#### A5.4.5 WSD e.i.r.p. LIMITS DUE TO DTT PROTECTION RATIO

This section deals with WSD e.i.r.p. limits calculated on the basis of protection ratios. Once again we set the protection criterion to be an allowed 0.1% degradation to the location probability,  $\Delta_{LP}$ . The reference location probability (LP) is that referred to noise only.

The ‘protection ratio case’ differs from the ‘overloading case’ because, as the wanted signal increases, the interfering signal can also be increased while maintaining the required protection ratio. In addition, the magnitude of the maximum WSD e.i.r.p. also varies directly with the magnitude of the protection ratio. Because of this direct (linear) dependence, we consider ‘relative’ WSD e.i.r.p. limits. This means that the results will be ‘scaled’ to a protection ratio, PR = 0 dB. Then, with a simple ‘translation’, the relevant maximum WSD e.i.r.p. for the actual protection ratio can be obtained by a simple addition.

##### A5.4.5.1 Fixed WSD interference

Figure 78 provides a global indication of, X, the relative maximum fixed WSD e.i.r.p.. The curves were calculated to provide a  $\Delta_{LP} = 0.1\%$  degradation to the location probability as the protection criterion.

The curves have been calculated for three reference cases refer to fixed WSD at 10 m agl interfering with

- fixed DTT reception at 10 m, with a 20 m lateral separation
- portable outdoor DTT reception at 1.5 m, with 20 m lateral separation
- portable indoor DTT reception at 1.5 m, with 20 m lateral separation

Note that the three curves have different ‘starting points’:

- The ‘fixed DTT’ curve starts at 56.21 dB $\mu$ V/m at 10 m agl, which is the point at which fixed DTT reception with 95% location probability is assured,
- The ‘PO DTT’ curve starts at 78.21 dB $\mu$ V/m at 10 m agl, corresponding to 61.21 dB $\mu$ V/m at 1.5 m agl, which is the point at which PO DTT reception with 95% location probability is assured,
- The ‘PI DTT’ curve starts at 87.95 dB $\mu$ V/m at 10 m agl, corresponding to 70.95 dB $\mu$ V/m at 1.5 m agl, which is the point at which PI DTT reception with 95% location probability is assured.

These curves have been calculated using Monte Carlo simulations. A reference protection ratio of PR = 0 dB was chosen so that the curves can be easily adjusted to correspond to any value of protection ratio.

Thus, the curves can be used in the following manner. The reference WSD e.i.r.p. “X” value,

$$\text{e.i.r.p.}_{\text{PR}=0} = X,$$

can be read for any given median wanted field strength. Then the actual WSD e.i.r.p. for a protection PR = Y dB,  $\text{e.i.r.p.}_{\text{PR}=Y}$ , can be calculated as

$$\text{e.i.r.p.}_{\text{PR}=Y} = \text{e.i.r.p.}_{\text{PR}=0} - Y.$$

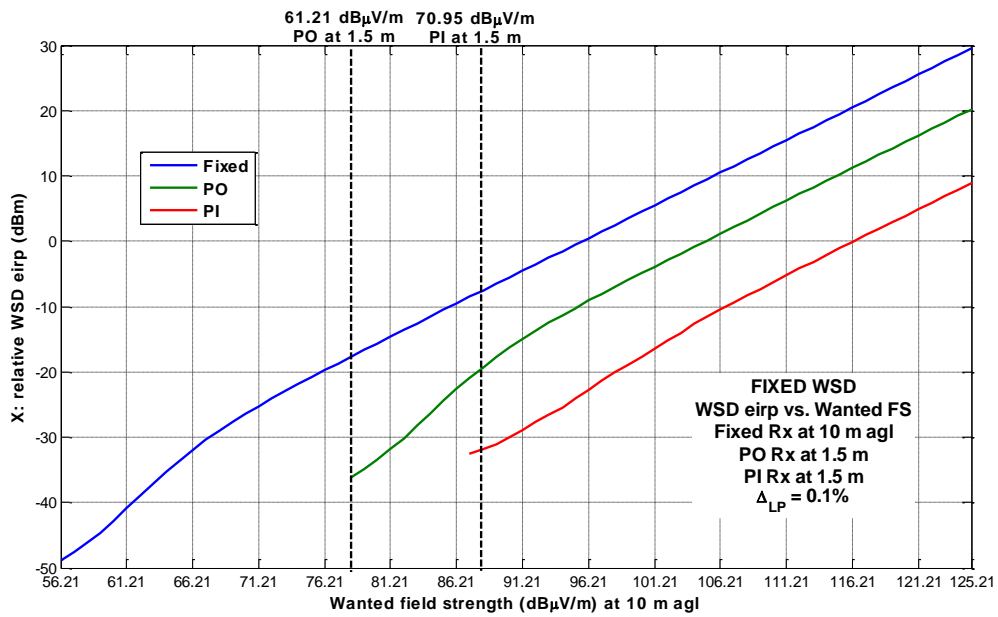
As a first example, consider the wanted field strength, 66.21 dB $\mu$ V/m, at 10 m agl. For fixed DTT reception, we see from Figure 78 that X = -32 dBm, so  $\text{e.i.r.p.}_{\text{PR}=0} = -32$  dBm. If we are actually dealing with 2<sup>nd</sup> adjacent channel WSD interference, with a protection ratio, PR = Y = -40 dB, then the maximum WSD e.i.r.p. is

$$\text{e.i.r.p.}_{\text{PR}=-40} = \text{e.i.r.p.}_{\text{PR}=0} - Y = -32 - (-40) = 8 \text{ dB}.$$

As a second example, consider the wanted field strength, 106.21 dB $\mu$ V/m, at 10 m agl. For portable indoor DTT reception, this corresponds to 89.21 dB $\mu$ V/m at 10 m (outside), we see from Figure 78 that X = -10.5 dBm, so  $\text{e.i.r.p.}_{\text{PR}=0} = -10.5$  dBm. If we are actually dealing with 1<sup>st</sup> adjacent channel WSD interference, with a protection ratio, PR = Y = -30 dB, then the maximum WSD e.i.r.p. is

$$\text{e.i.r.p.}_{\text{PR}=-30} = \text{e.i.r.p.}_{\text{PR}=0} - Y = -10.5 - (-30) = 19.5 \text{ dB}.$$





**Figure 78: Maximum fixed WSD e.i.r.p. (relative to PR = 0 dB) vs. wanted field strength at 10 m agl**

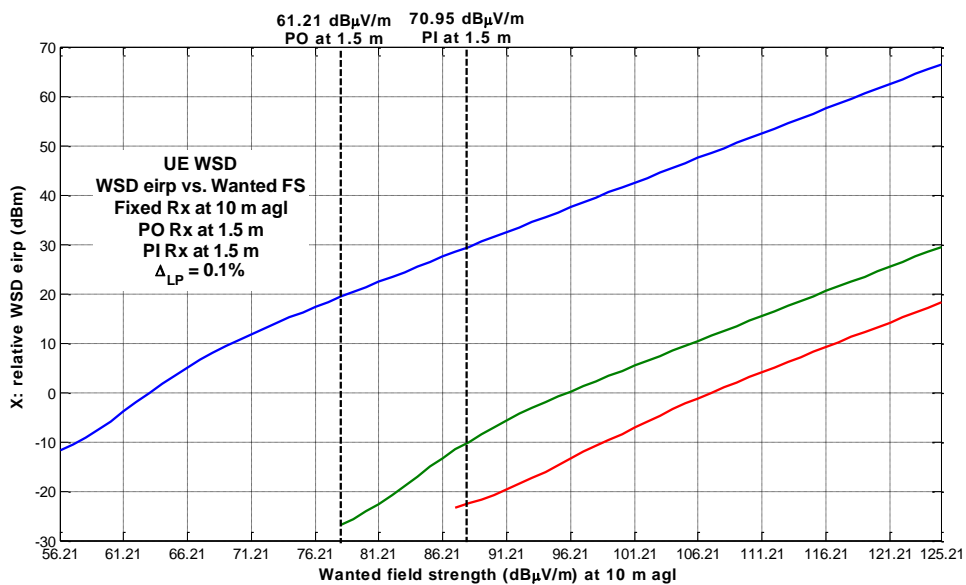
**A5.4.5.2 UE WSD interference**

Figure 79 provides a global indication of, X, the relative maximum UE WSD e.i.r.p. The curves were calculated to provide a  $\Delta_{LP} = 0.1\%$  degradation to the location probability as the protection criterion.

The curves have been calculated for three reference cases refer to UE WSD at 1.5 m agl interfering with

- fixed DTT reception at 10 m, with a 20 m lateral separation
- portable outdoor DTT reception at 1.5 m, with 2 m lateral separation
- portable indoor DTT reception at 1.5 m, with 2 m lateral separation.

The curves in Figure 79 are to be interpreted as were those in Figure 78, except they refer to UE WSD interferers instead of fixed WSD interferers.



**Figure 79: maximum UE WSD e.i.r.p. (relative to PR = 0 dB) vs. wanted field strength at 10 m agl**

**A5.4.6 OVERALL RESULTS: COMBINED PR AND  $O_{th}$  WSD E.I.R.P. LIMITS FOR WSD INTERFERENCE**

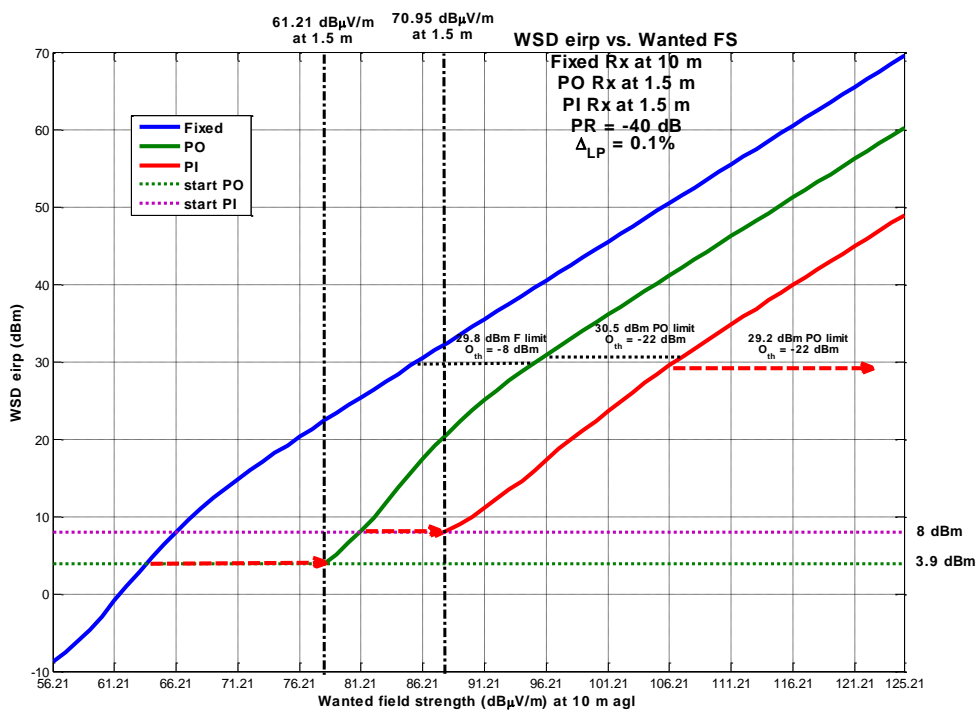
*A5.4.6.1 Combined PR and  $O_{th}$  WSD E.I.R.P. limits for Fixed WSD interference*

The parameters for the fixed WSD e.i.r.p. study are given in the section A5.2. The reference geometries are giving in Annex 2.

It has been shown in section A5.3.4 that absolute e.i.r.p. limits on WSD transmitters are imposed by DTT overload threshold values. Therefore the curves in Figure 78 and Figure 79 will have to be ‘capped’ when these absolute E.I.R.P. limits are reached

Figure 80 shows the results for the case of 2<sup>nd</sup> adjacent channel WSD interference with the protection ratio, PR = -40 dB. The protection criterion is the 0.1% degradation of the location probability:  $\Delta_{LP} = 0.1\%$ .

Note that for a different protection ratio, say PR = -50 dB, the three solid curves would be translated upward by  $(-40 - (-50)) = 10$  dB. Nevertheless, the absolute maximum WSD E.I.R.P. would still be capped at around 29 dBm, due to the (protection ratio independent) overload threshold.



**Figure 80: Maximum Fixed WSD E.I.R.P. limits for 2nd adjacent channel WSD interference**

The horizontal axis of Figure 80 corresponds to the wanted field strength level at a 10 m DTT receive antenna height. It runs from 56.21 dBµV/m (the median field strength at the DTT coverage edge for fixed reception) to 125.21 dBµV/m (which corresponds to the field strength levels very near to the DTT transmitter).

The vertical axis of Figure 80 corresponds to the maximum fixed (at 10 m antenna height) WSD e.i.r.p.. in order that the  $\Delta_{LP} = 0.1\%$  limit is not exceeded (at 10 m for fixed, and at 1.5 m for portable outdoor/indoor).

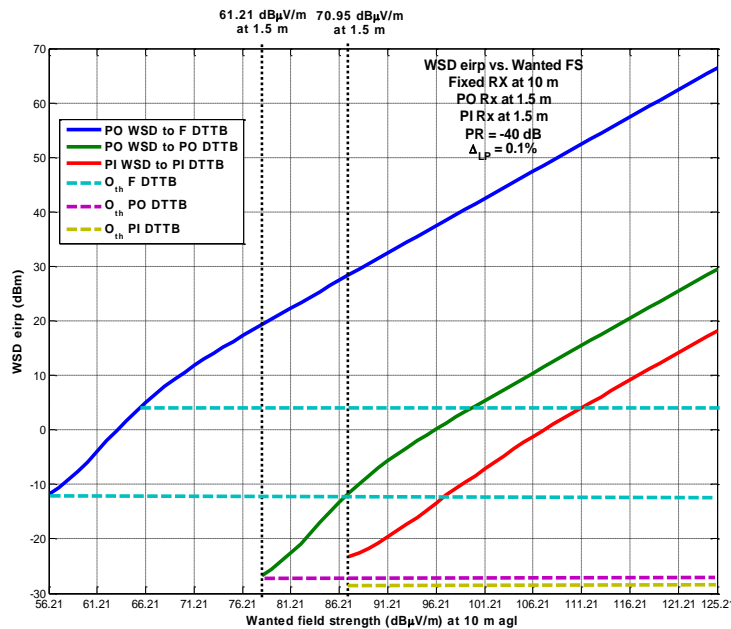
*A5.4.6.2 Combined PR and  $O_{th}$  WSD E.I.R.P. limits for UE WSD interference*

The parameters for the UE WSD e.i.r.p. study are given in the section A5.3. The reference geometries are given in Annex 2.

It has been shown in section A5.3.4 that absolute e.i.r.p. limits on WSD transmitters are imposed by DTT overload threshold values. Therefore the curves in Figure 78 and Figure 79 will have to be ‘capped’ when these absolute e.i.r.p. limits are reached.

Figure 81 shows the results for the case of 2<sup>nd</sup> adjacent channel WSD UE interference with the protection ratio, PR = -40 dB. The protection criterion is the 0.1% degradation of the location probability:  $\Delta_{LP} = 0.1\%$ .

It is seen that the maximum UE e.i.r.p. is severely restricted due to the overload threshold (horizontal dashed lines: -12.2 dBm for fixed silicon receivers and -28.5 dBm for USB receivers; see Figure 80: Maximum Fixed WSD E.I.R.P. limits for 2nd adjacent channel WSD interference, second adjacent channel). As mentioned before, these restrictions may become 10 dB more severe if the DTT overload threshold values for UE TPC 'on' are used.



**Figure 81: e.i.r.p. limits for UE WSD for  $\Delta_{LP} = 0.1\%$  (PR = -40 dB)**

**A5.4.7 CONCLUSIONS ON THE USE OF A FIXED  $\Delta_{LP} = 0.1\%$  DTT PROTECTION CRITERION**

A very stringent approach to protecting DTT against WSD interference would be to set a fixed limit of I/N, as is required for other primary services (e.g. I/N = -20 dB, or I/N = -10 dB, or I/N = -6 dB).

The wanted field strength increases as the DTT transmitter is approached. This could allow a relaxation of a fixed I/N limit. One way to relax the fixed I/N limit and still to maintain the required protection for DTT reception is to allow a fixed degradation to the location probability,  $\Delta_{LP}$ , in any given area.

A moderate value,  $\Delta_{LP} = 0.1\%$ , is felt to be suitable. This means that the interfering field strength can also be increased while maintaining the protection criterion  $\Delta_{LP} = 0.1\%$ .

Maintaining  $\Delta_{LP} = 0.1\%$  throughout the entire DTT coverage area, however, will lead to values of I/N in excess of 40 dB or more, and DTT receiver overload, if adjacent channel WSDs are not subject to e.i.r.p. limits. Larger permitted values of  $\Delta_{LP} > 0.1\%$  would only exacerbate this excess.

A fixed protection criterion of  $\Delta_{LP} = 0.1\%$  corresponds to a flexible limit to I/N, allowing I/N values to increase up to  $I/N \approx +10$  dB, a flexibility which gives more opportunity for WSD operation.

It should be noted that the higher LP reception margins available for the DTT receivers located closer to the DTT transmitter are to a large extent consumed by the fact that the receiver installations have lower performances in these areas. Furthermore, DTT viewers make use of this margin to receive programs with portable outdoor and portable indoor receivers. It is not sensible to consider that this reception margin can be consumed to allow higher interfering levels, to the detriment of the DTT viewer.

The constant, fixed  $\Delta_{LP} = 0.1\%$  approach is flexible with respect to extended WSD usage nearer the DTT transmitter, in addition to preserving the DTT viewer's flexibility in choosing his or her mode of viewing, fixed or portable, outdoor or indoor.

## A5.5 USE A VARIABLE ACCEPTABLE DEGRADATION OF THE COVERAGE PROBABILITY

The use of TV white spaces is conditioned to the protection of the primary DTT broadcasting service against WSD interference. This protection is represented by the respect of tolerable levels of DTT location probability degradation ( $\Delta LP$ ), i.e. tolerable degradations of the DTT coverage quality. Low values of  $\Delta LP$  are essentially tolerable, but they may be too restrictive to the operation of white space systems in vacant channels. On the other hand, the increase of  $\Delta LP$  may lead to good conditions for white space systems operation, but at the cost of causing harmful interference to the DTT broadcasting system.

An optimum degradation level is not expected to be found, since the decision about the  $\Delta LP$  to be adopted is influenced by several aspects, like the target DTT coverage quality, the specific characteristics of different regions (urban, suburban, rural areas), etc. In spite of this, upper limits to  $\Delta LP$  can be derived by considering the technical limitations of the DTT receivers in dealing with interference. The methodology presented in this annex provides  $\Delta LP$  upper limits and can be used to guide Administrations in their decisions about the location probability degradation levels to be adopted in different situations and scenarios. Since in some countries the protection of portable outdoor and portable indoor DTT reception is required in addition to the protection of fixed outdoor DTT reception, the three reception modes are considered.

The signal modelling and the calculation of location probability are in accordance with ECC Report 159 [1], where DTT wanted and WSD interfering signals are considered log-normal random variables with specific standard deviation, and the location probability is obtained by Monte Carlo simulations. All scenarios presented in Annex 2 of complementary report A2 are considered in the determination of WSD e.i.r.p. limits according to the type of WSD and the DTT reception mode to be protected. Aggregate or cumulative interference due to simultaneous operation of multiple WSDs is not considered. Then, the e.i.r.p. limits provided in this section should be reduced by appropriate multiple interference margins (Annex 1 of complementary report A2).

### A5.5.1 RELEVANT PARAMETERS FOR THE PROTECTION OF THE DTT RECEIVER AGAINST INTERFERENCE

WSD interference degrades two distinct aspects of DTT broadcasting service:

- The coverage quality of DTT service;
- The ability of the DTT receiver in discriminating the desired signal from interference signals.

From the perspective of the DTT receiver, two parameters are important to appropriate operation in the presence of interference:

- Protection ratio: the minimum value of the signal-to-interference ratio at the DTT receiver required to obtain a specified reception quality under specified conditions;
- Overloading threshold: the interference level above which the receiver begins to lose the ability to discriminate against interfering signals at frequencies differing from that of the wanted signal.

Conditions for the protection of the DTT receiver against interference taking into account the two aforementioned parameters provide interference limits for appropriate operation of the DTT receiver. The appropriate operation in this case means the respect of the protection ratio and the overloading threshold. Given these interference limits, it is possible to calculate the corresponding maximum permissible levels of  $\Delta LP$ , and thus to assess the feasible levels of  $\Delta LP$ , i.e. the levels of  $\Delta LP$  for which the DTT receiver is able to handle interference.

The conditions based on the protection ratio and on the overloading threshold for the protection of the DTT receiver against interference are usual in ECC compatibility studies, as in ECC Report 138 [7] (see Annex C) and ECC Report 148 [6]. They take into account statistical location variations in the wanted and interfering signals, and provide interference limits for the protection of the DTT receiver for a percentage of locations. For simplicity, interference of other DTT transmitters is ignored.

### A5.5.2 SATISFACTION OF PROTECTION RATIO

The usual protection condition of the DTT receiver against interference is related to the protection ratio. It is given by

$$E_{wmed} \geq E_{imed} + PR(\Delta f) + \mu_{x\%} \sqrt{(\sigma_w^2 + \sigma_i^2)}$$

where:

- $E_{wmed}$ : wanted DTT median field strength at the DTT receiver;
- $\sigma_w$ : wanted DTT field standard deviation;
- $E_{imed}$ : WSD interference median field strength at the DTT receiver;
- $\sigma_i$ : WSD interference standard deviation;
- $PR(\Delta f)$ : protection ratio for a  $\Delta f$  frequency offset (co-channel or adjacent channels);
- $\mu_{X\%} \sqrt{(\sigma_w^2 + \sigma_i^2)}$ : location correction factor for X% of locations within the small covered area (pixel).

Location correction factor takes into account the statistical location variations of both the wanted and the interfering signals. Therefore, the limiting interference median field strength  $E_{imed\_max\_PR}$  for the satisfaction of the appropriate (co-channel or adjacent channels) protection ratio  $PR(\Delta f)$  for X% of locations within the pixel is expressed as

$$E_{imed\_max\_PR} = E_{wmed} - PR(\Delta f) - \mu_{X\%} \sqrt{(\sigma_w^2 + \sigma_i^2)}$$

for a given wanted median field strength  $E_{wmed}$  and wanted and interfering standard deviations  $\sigma_w$  and  $\sigma_i$ .

### A5.5.3 Respect of the Overloading threshold

The protection of DTT receiver against overloading consists in satisfying:

$$IFE \leq O_{th} - \mu_{X\%} \times \sigma_i$$

where:

- $I_{FE}$ : interference power at the front-end of the DTT receiver;
- $O_{th}$ : overloading threshold;
- $\mu_{X\%} \times \sigma_i$ : location correction factor for X% of locations within the small covered area (pixel).

Location correction factor in this case takes into account the statistical location variations of the interfering signal only, since DTT receiver overload does not depend on the wanted DTT signal power. The interference power at the front-end of the DTT receiver relates to the interference power at the DTT receiver input  $I$  as follows:

$$IFE = I - POL + G_a$$

where  $POL$  and  $G_a$  represent antenna polarization discrimination and antenna gain (including feeder losses). The relation between interference  $I$  and interference median field strength  $E_{imed}$  is given by

$$I = E_{imed} - 20 \cdot \log_{10}(f_{MHz}) - 77.2$$

for the frequency of operation  $f_{MHz}$  given in MHz. Therefore, the limiting interference median field strength at the DTT receiver,  $E_{imed\_max\_Oth}$ , for the protection of the DTT receiver against overload for X% of locations within the pixel is given by

$$E_{imed\_max\_Oth} = O_{th} - \mu_{X\%} \times \sigma_i + POL - G_a + 20 \cdot \log_{10}(f_{MHz}) + 77.2$$

It is noticeable that the receiver overload does not depend on the protection ratio.

### A5.5.4 Limits for location probability degradation and wsd e.i.r.p.

The protection of the DTT receiver against interference for X% of locations inside the pixel is guaranteed by the most stringent interference upper limit for the satisfaction of the PR and the respect of the  $O_{th}$  for X% of locations. Then, the limiting interference field strength at the DTT receiver,  $E_{imed\_max}$ , is given by

$$E_{imed\_max} = \min(E_{imed\_max\_PR}, E_{imed\_max\_Oth})$$

where  $E_{imed\_max\_PR}$  and  $E_{imed\_max\_Oth}$  are calculated as previously described.

The methodology proposed in the ECC Report 159 [1] is thus used to obtain by Monte Carlo simulations both the original LP (without WSD interference) and the resulting LP with the limiting WSD interference  $E_{imed\_max}$ .

The corresponding  $\Delta LP$ , i.e. the difference between the original and the resulting LP, is considered the  $\Delta LP$  upper limit for the protection of the DTT receiver for X% of locations inside the pixel.

The WSD e.i.r.p. upper limit is finally calculated from  $E_{imed\_max}$  (or from its corresponding interference power  $I_{max} = E_{imed\_max} - 20 \log_{10}(f_{MHz}) - 77.2$ ) according to the specific WSD transmitter / DTT receiver scenario (reference geometry, as in Annex 2 of complementary report A2). This leads to the following general relationship:

$$e.i.r.p._{max} = I_{max} + LOSS + A_{att} + A_{disc}$$

where  $e.i.r.p._{max}$  is the WSD e.i.r.p. upper limit for the protection of the DTT receiver at the reference geometry for X% of locations inside the pixel,  $I_{max}$  is the interference limit at the DTT receiver,  $LOSS$  is the propagation loss between the WSD and the DTT in the reference geometry,  $A_{att}$  is the WSD antenna attenuation, and  $A_{disc}$  is the DTT antenna discrimination.

### A5.5.5 Scenarios and relevant parameters

It is important to define upper limits for the location probability degradation and the WSD e.i.r.p. according to the type of WSD and the DTT reception mode to be protected. There are three possible DTT reception modes: fixed outdoor, portable outdoor and portable indoor DTT reception. The considered WSD types are the ones present in Scenarios 1 to 8, in Annex 2 of complementary report A2: portable WSD (Scenarios 1, 2, and 3), fixed WSD at 10 m agl. (Scenarios 4, 5, and 6), and fixed WSD at 30 m agl. (Scenarios 7 and 8). Simulation parameters presented in Annex A5.8 of complementary report A2 for each scenario are adopted. Then, for each WSD type, limits for the location probability degradation and the WSD e.i.r.p. are presented for each DTT reception mode.

Table 19 presents relevant parameters for the three DTT reception modes: the wanted DTT median field strength at the DTT receiver in the coverage edge (LP = 95%),  $E_{wmed\_ref}$ , and reasonable values of protection ratio for co-channel, first, and second adjacent channels. Fixed outdoor DTT reception becomes possible with 56.21 dB $\mu$ V/m wanted median field strength at 10 m agl. For portable outdoor DTT reception, it is needed a wanted median field strength at 1.5 m agl. of at least 61.21 dB $\mu$ V/m, which corresponds to  $E_{wmed} = 78.21$  dB $\mu$ V/m at 10 m agl., with 17 dB height loss. For portable indoor DTT reception, 62.95 dB $\mu$ V/m median field strength is needed at the DTT receiver (1.5 m agl.). In this case, the corresponding median field strength at 10 m agl. is 87.95 dB $\mu$ V/m, where in addition to 17 dB height loss, 8 dB wall loss is considered.

**Table 19: Wanted DTT median field strength at the coverage edge (LP = 95%) and protection ratio**

DTT reception mode	$E_{wmed\_ref}$ [dB $\mu$ V/m]	Co-channel protection ratio PR(0) [dB]	1st adj. channel protection ratio PR( $\Delta f_1$ ) [dB]	2nd adj. channel protection ratio PR( $\Delta f_2$ ) [dB]
Fixed outdoor	56.21	21	-30	-40
Portable outdoor	61.21 (78.21 at 10 m agl.)	19	-30	-40
Portable indoor	62.95 (87.95 at 10 m agl.)	17	-30	-40

The measurements of LTE interference into DVB-T receivers reported in ECC Report 148 [6] and considered in ECC Report 159 [1] are used to define the overloading thresholds according to the types of (LTE-like) WSD transmitter and DTT receiver, as shown in Table 20: Overloading threshold. Values obtained for the silicon USB antenna type are adopted as overloading thresholds for portable DTT receivers. For fixed DTT receivers, can and silicon set-top box and/or integrated TV antenna types are considered. Measurements of overloading threshold for portable WSD – fixed DTT receiver indicate a wide range of possible values, from which -20 dBm is adopted for both first and second adjacent channels.



**Table 20: Overloading threshold**

	Fixed DTT		Portable DTT	
	1st adjacent channel overloading threshold	2nd adjacent channel overloading threshold	1st adjacent channel overloading threshold	2nd adjacent channel overloading threshold
	$O_{th}(\Delta f_1)$ [dBm]	$O_{th}(\Delta f_2)$ [dBm]	$O_{th}(\Delta f_1)$ [dBm]	$O_{th}(\Delta f_2)$ [dBm]
<b>Fixed WSD</b>	-13	-8	-26	-22
<b>Portable WSD</b>	-20	-20	-27	-47

Protection ratio and overloading threshold have strong influence on the upper limits of permissible WSD interference at the DTT receiver, and consequently on the limits of location probability degradation and WSD e.i.r.p. The methodology presented in this annex is applicable to any other values for these parameters, which can arise with the development of the actual WSDs.

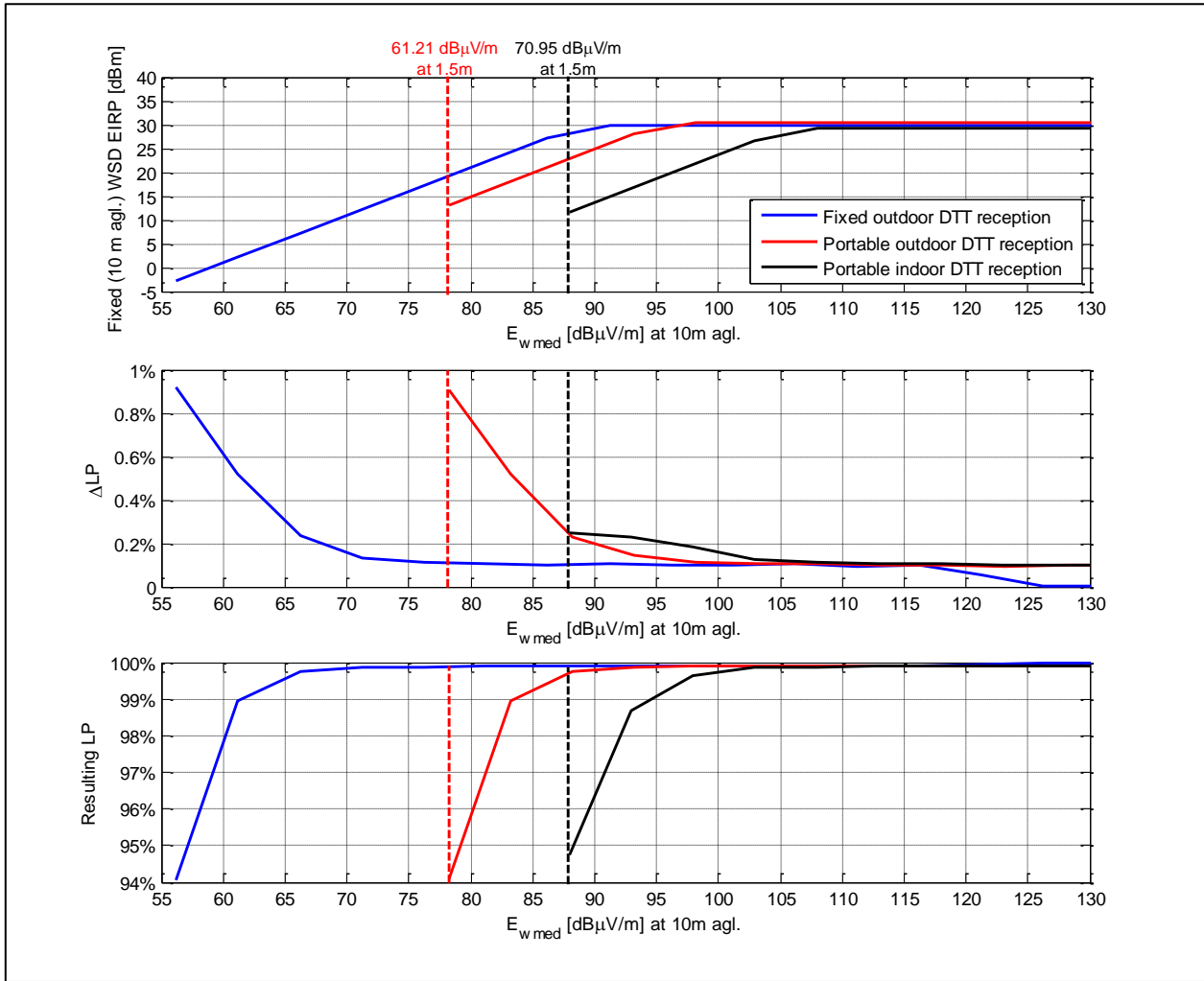
#### A5.5.6 Main results

The upper limits of  $\Delta LP$  and WSD e.i.r.p., and the resulting LP are presented below for the parameters given in Table 19 and Table 20. The reference geometries are given in Annex 2.

The first set of results is shown in Figure 82 for fixed outdoor WSD at 10 m agl., where the protection of a DTT receiver at the reference geometry is guaranteed for  $X = 99.9\%$  of locations inside a pixel (quasi perfect DTT receiver operation with respect to interference). For fixed outdoor DTT reception (blue curves), the WSD e.i.r.p. upper limits for the second adjacent channel vary from about -2.6 dBm at the coverage edge to 29.75 dBm at locations where  $E_{wmed} \geq 91.21$  dB $\mu$ V/m (wanted median field strength at least 40 dB higher than at the coverage edge), when the maximum permissible interference is limited by the overloading threshold. The limiting scenario in this case is Scenario 4 in Annex 2. The corresponding  $\Delta LP$  upper limit decays from 0.91% at the coverage edge to about 0.1% in the region where  $E_{wmed} \geq 91.21$  dB $\mu$ V/m ( $\Delta LP$  is almost negligible for  $E_{wmed} \geq 126.21$  dB $\mu$ V/m). The curve of DTT LP which results from the WSD interference indicates that already in locations where the wanted median field strength is only 5 dB above the one at the coverage edge, the resulting LP is around 99%.

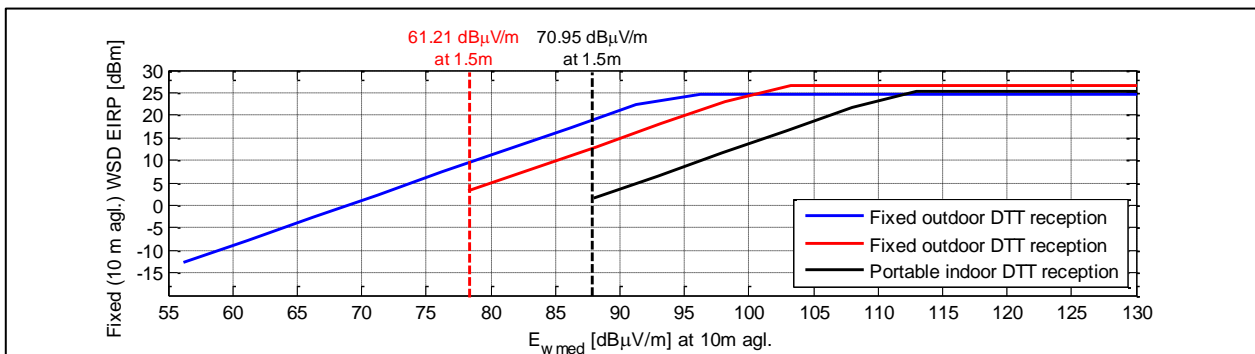
If the protection of portable outdoor and portable indoor DTT reception modes is considered, red and black curves in Figure 82 indicate the upper limits of  $\Delta LP$  and WSD e.i.r.p., and the resulting LP. For portable outdoor DTT reception (red curves), the behavior of  $\Delta LP$  upper limits and resulting LP is essentially the same as for fixed outdoor DTT reception, with similar values but for different coverage areas. The limiting scenario is Scenario 5 in Annex 2. As expected, the protection of this DTT reception mode imposes more restrictive upper limits for the e.i.r.p. of fixed outdoor WSD at 10 m agl. The protection of portable indoor DTT reception (Scenario 6 in Annex 2) for locations where  $E_{wmed}$  at 10 m agl. is at least 87.95 dB $\mu$ V/m also imposes new restrictions in this region: the WSD e.i.r.p. upper limit is about 11.5 dBm at the coverage edge and increases until 29.2 dBm for  $E_{wmed} \geq 108$  dB $\mu$ V/m (wanted median field strength 20 dB higher than at the coverage edge). The corresponding  $\Delta LP$  upper limits for portable indoor DTT reception are lower than for the other reception modes, going from 0.25% at the coverage edge to 0.1% with the increase of  $E_{wmed}$ .





**Figure 82: Fixed outdoor WSD transmission at 10 m agl. – Upper limits for WSD e.i.r.p. at the 2<sup>nd</sup> adjacent channel and the  $\Delta LP$ , and the resulting LP for the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside the pixel.**

The e.i.r.p. upper limits for fixed WSD at 10 m agl. in the first adjacent channel are shown in Figure 83. Similar overall behavior, but more restrictive e.i.r.p. values are observed.

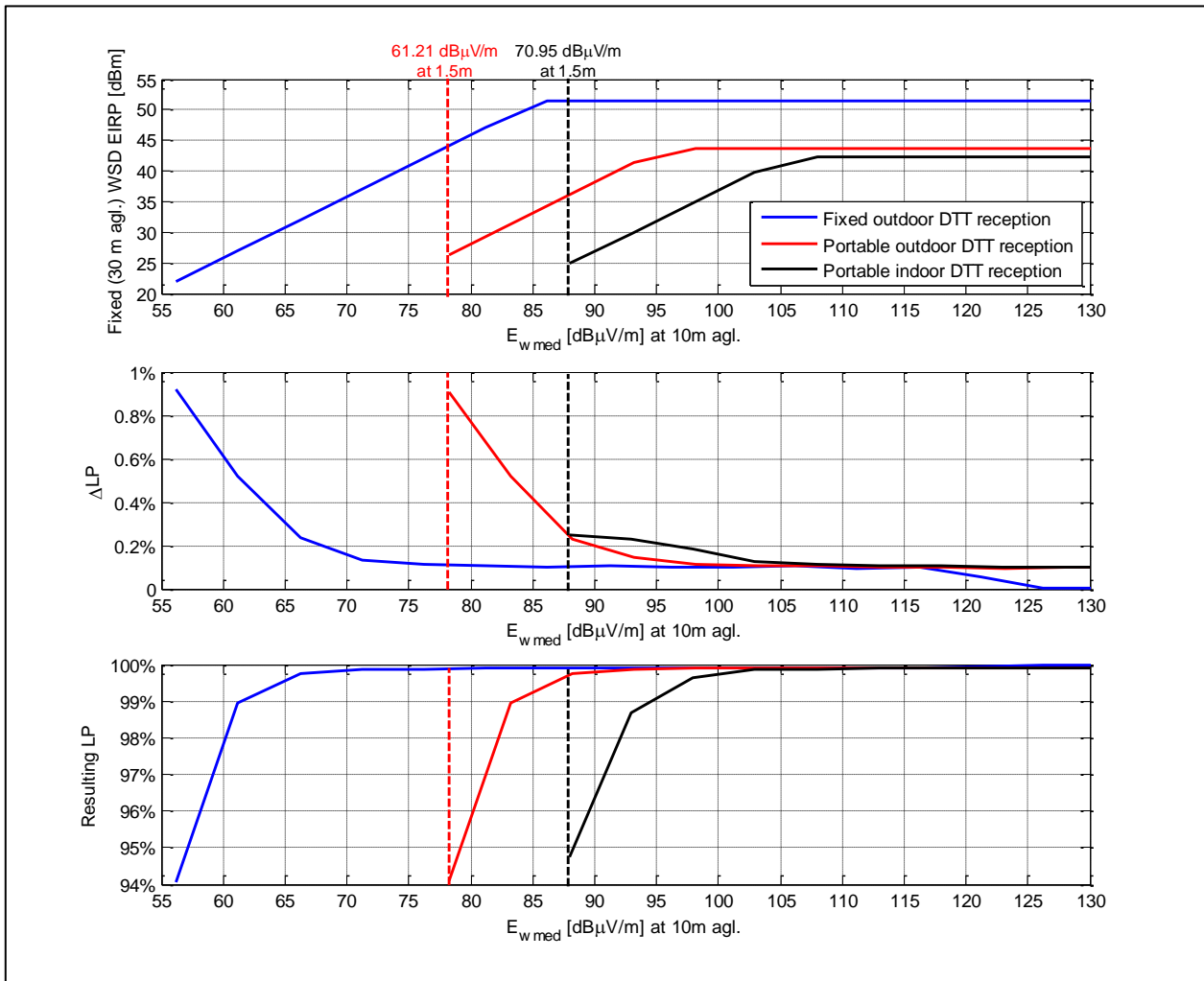


**Figure 83: Fixed outdoor WSD transmission at 10 m agl. – Upper limits for WSD e.i.r.p. at the 1<sup>st</sup> adjacent channel for the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside the pixel.**

The set of results for fixed outdoor WSD at 30 m agl. is shown in Figure 84. Once more it is considered the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside a pixel (quasi perfect DTT receiver operation with respect to interference). The  $\Delta LP$  upper limits and the resulting LP are

very similar to the ones obtained for fixed outdoor WSD at 10 m agl., but the WSD e.i.r.p. upper limits are higher because of the elevated coupling loss between WSD transmitter and DTT receiver. For the protection of fixed outdoor DTT reception (Scenario 7 in Annex 2), the WSD e.i.r.p. upper limits in the second adjacent channel increase from 22 dBm at the coverage edge ( $E_{wmed} = 56.21 \text{ dB}\mu\text{V/m}$ ) to 51.45 dBm for locations where  $E_{wmed} \geq 86.21 \text{ dB}\mu\text{V/m}$ . More restricted upper limits are obtained if portable DTT reception is taken into account. In the case of portable outdoor DTT reception (Scenario 8 in Annex 2), at locations where  $E_{wmed} = 78.21 \text{ dB}\mu\text{V/m}$  at 10 m agl., WSD e.i.r.p. is limited to 26.3 dBm, and increases with  $E_{wmed}$  until  $E_{wmed} = 98.21 \text{ dB}\mu\text{V/m}$ , when it is limited by the overloading threshold to 43.7 dBm. Similar behavior is observed if the protection of portable indoor DTT reception is considered, with WSD e.i.r.p. limited to 24.81 dBm at the coverage edge ( $E_{wmed} = 87.95 \text{ dB}\mu\text{V/m}$  at 10 m agl.), and 42.4 dBm for  $E_{wmed} \geq 108 \text{ dB}\mu\text{V/m}$ .

From the results presented above, e.i.r.p. “masks” can be derived for fixed outdoor WSD. Figure 82, Figure 83 and Figure 84 show the e.i.r.p. masks for the second adjacent channel for WSDs at 10 m and 30 m agl., respectively. If only fixed outdoor DTT reception is to be protected, the e.i.r.p. “masks” are given by the blue curves only. Depending on the values of relevant parameters (protection ratios, overloading thresholds, level of protection for the DTT receiver) the e.i.r.p. upper limits can change.



**Figure 84: Fixed outdoor WSD transmission at 30 m agl. – Upper limits for WSD e.i.r.p. at the 2<sup>nd</sup> adjacent channel and the  $\Delta LP$ , and the resulting LP for the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside the pixel.**

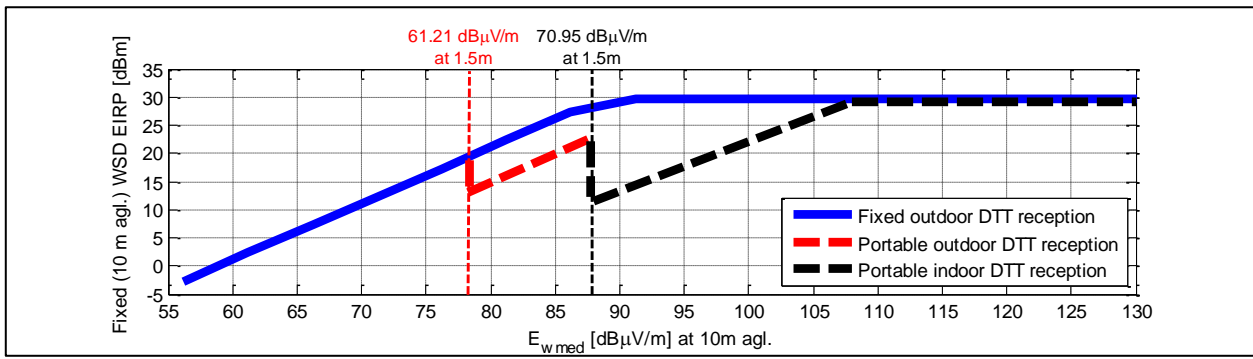


Figure 85: e.i.r.p. “mask” for fixed outdoor WSD transmission at 10 m agl. (2<sup>nd</sup> adjacent channel).

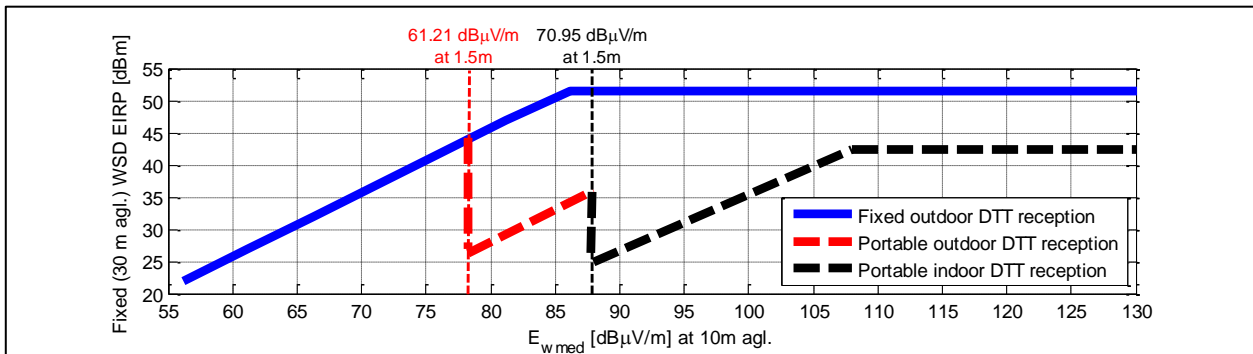


Figure 86: e.i.r.p. “mask” for fixed outdoor WSD transmission at 30 m agl. (2<sup>nd</sup> adjacent channel).

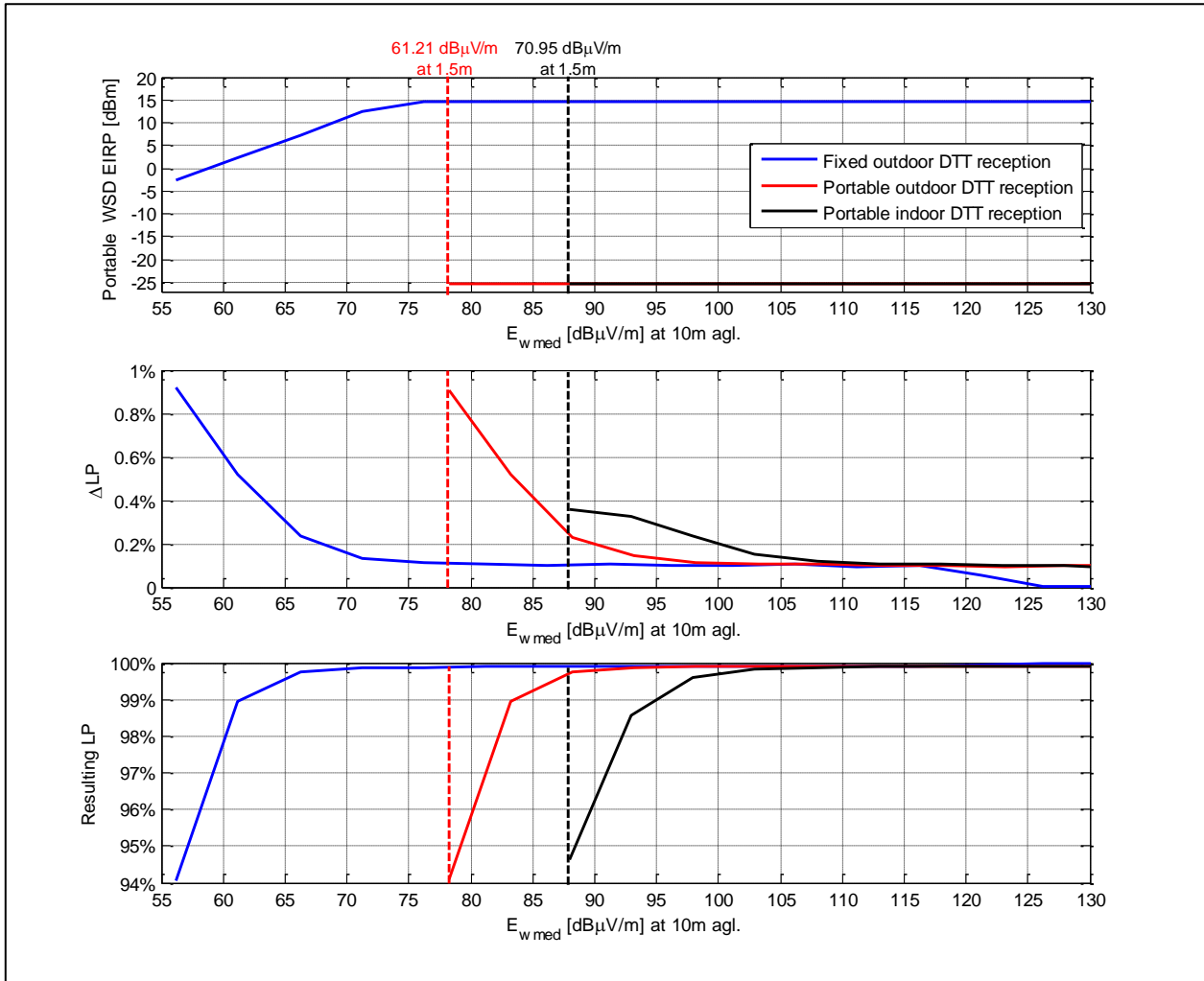
Now the results for portable WSD are shown in Figure 87, where the upper limits of  $\Delta LP$  and WSD e.i.r.p. (second adjacent channel), and the resulting LP are calculated for the protection of the DTT receiver for  $X = 99.9\%$  of locations inside the pixel. The considered overloading thresholds are given in Table 2.

To protect the fixed outdoor DTT reception (Scenario 2 in Annex 2, blue curves in Figure 87), the portable WSD e.i.r.p. is limited to  $-2.6$  dBm at the coverage edge ( $E_{wmed} = 56.21$  dB $\mu$ V/m) and increases linearly with  $E_{wmed}$  until  $E_{wmed} = 76.21$  dB $\mu$ V/m, from where the WSD e.i.r.p. is limited by the overloading threshold to  $14.75$  dBm. The corresponding  $\Delta LP$  upper limits vary from about  $0.91\%$  to  $0.1\%$  when entering the DTT coverage area, and achieve negligible values for  $E_{wmed} \geq 126.21$  dB $\mu$ V/m. As in the case of fixed outdoor WSD, the LP which results with portable WSD interference is above  $99\%$  for locations where  $E_{wmed}$  is  $5$  dB above  $E_{wmed}$  at the coverage edge.

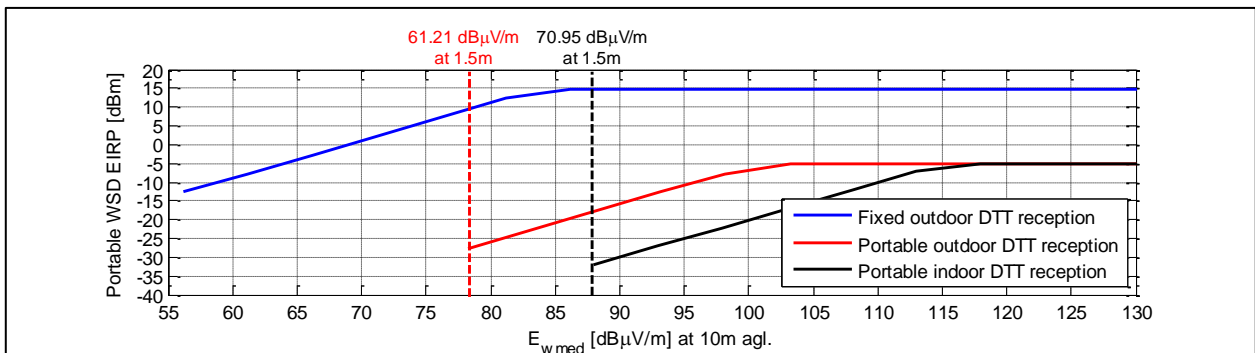
Because of the very low overloading threshold of portable DTT receiver with respect to portable WSD interference,  $-47$  dBm, the protection of portable DTT reception restricts the portable WSD e.i.r.p. to a very low value,  $-25.2$  dBm, for any location inside portable DTT coverage area. The relaxation of the protection criterion from  $X = 99.9\%$  of locations to  $X = 99\%$  or  $X = 90\%$  of locations where the DTT receiver at the reference geometry ( $2$  m distant from the WSD) is protected leads to still low and constant WSD e.i.r.p. limits like  $-22.5$  dBm and  $-18.9$  dBm, respectively.

To illustrate the strong influence of overloading threshold values on the WSD e.i.r.p. upper limits, Figure 88 shows the e.i.r.p. upper limits for the operation of portable WSD in the first adjacent channel, whose overloading threshold is  $-27$  dBm (from ECC Report 148 [6]). It is thus observed that the behaviour of WSD e.i.r.p. upper limits in this case is similar to the fixed WSD case. Therefore, according to the restrictions imposed by the overloading threshold, an e.i.r.p. “mask” for portable WSD transmission would follow:

- 1) the shape of WSD e.i.r.p. curves in Figure 87, with a constant e.i.r.p. value in the region of portable DTT coverage; or
- 2) the shape shown in Figure 88.



**Figure 87: Portable WSD transmission – Upper limits for WSD e.i.r.p. at the 2<sup>nd</sup> adjacent channel and the  $\Delta$ LP, and the resulting LP for the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside the pixel.**



**Figure 88: Portable WSD transmission – Upper limits for WSD e.i.r.p. at the 1<sup>st</sup> adjacent channel for the protection of a DTT receiver at the reference geometry for X = 99.9% of locations inside the pixel.**

## **A5.6 CONSIDERATIONS WHEN CHOOSING THE DEGRADATION OF THE LOCATION PROBABILITY**

The two approaches presented in this Annex provide location specific maximum e.i.r.p. limits for different types of WSDs and DTT reception modes. This content serves as guidance for Administrations, since it discusses first the adoption of a fixed level of degradation of the DTT coverage quality as protection criterion, and then the adoption of variable levels of degradation of the DTT coverage quality according to the capabilities of the DTT receivers in handling interference.

When considering a particular value for the degradation in location probability, it should be remembered that, this degradation will result in a reduction in coverage and a loss in the number of viewers who can receive the broadcast service - the larger the degradation, the larger the loss.

For each broadcasting service a required minimum location probability is defined that has to be reached in each pixel at the edge of the coverage. Typical values for these required minimum location probabilities at the edge are 99% (mobile reception), 95% (portable reception) or 95% (fixed reception). Location probability for pixels inside the coverage area is generally higher than those at the edge, and this represents a proportionally larger number of households that have acceptable DTT reception within those pixels.

The number of households losing DTT reception in a pixel can be estimated by multiplying the degradation in probability by the number of households per pixel. The total impact to the broadcast service can then be assessed by considering the summation of this quantity for all populated pixels in the DTT network.

## ANNEX 6: PMSE REFERENCE GEOMETRIES

### A6.1 OVERVIEW

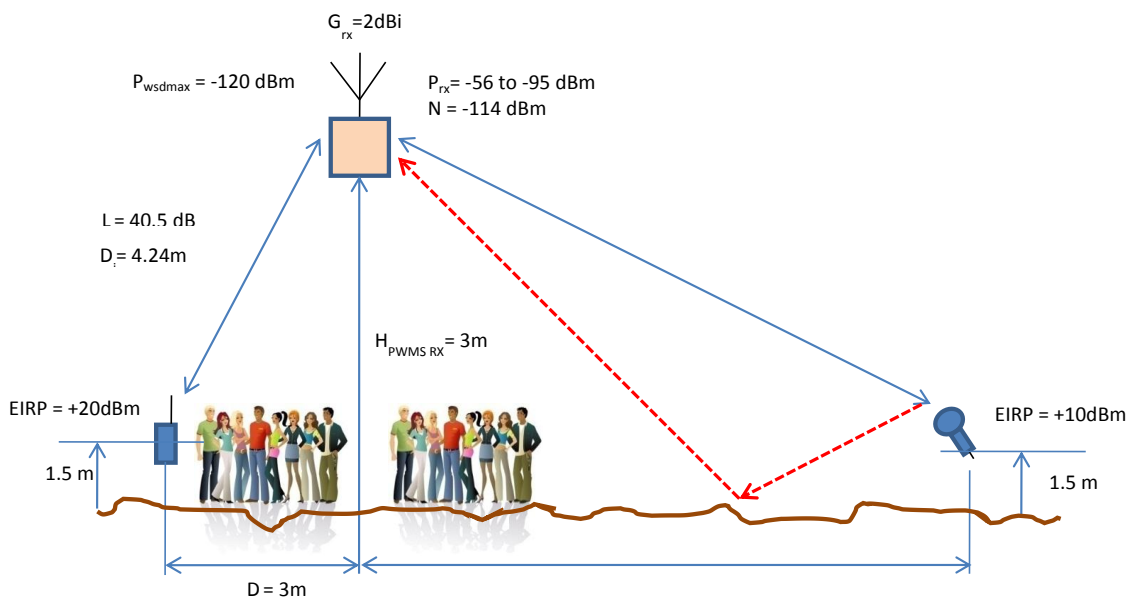
PMSE are used in many different situations, which could bring exposure to varying degrees of interference risk from WSD. Some of these situations include:

- Auditoriums and multi-purpose buildings
- Auto racing
- Broadcast production facilities
- Pubs and clubs
- Dedicated music venues and clubs
- Golf courses
- Government buildings
- Hotels and meeting spaces
- Houses of Worship—small and large
- Large music venues—indoor and outdoor
- Outdoor events including car races, foot races, and street fairs
- Political events
- Sporting events and arenas
- Theatres
- Theme parks.

Stakeholders may be unaware of the extent of PMSE use for many of these situations.

### A6.2 SCENARIO I - OUTDOOR EVENTS

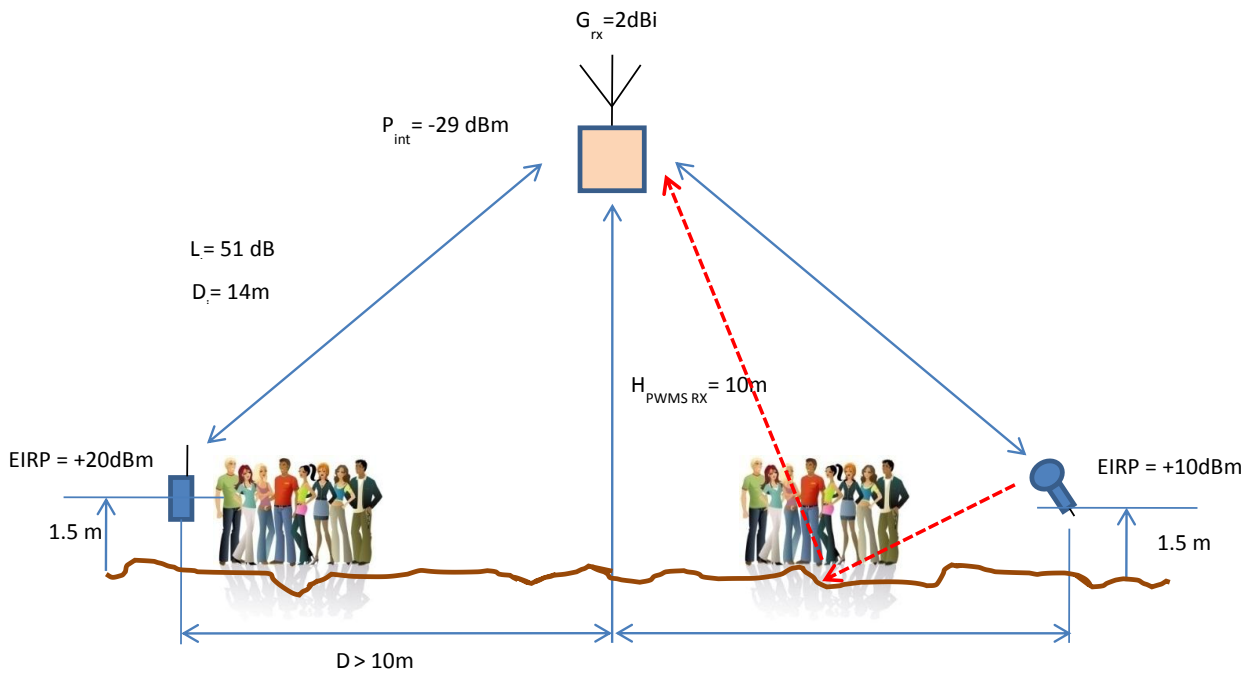
The first scenario concerns the operation of a PMSE system consisting of one or more audio channels at an outdoor event such as a breaking news event, golf tournament, road race, sporting event, street fair, or theme park. It could be anticipated that spectators would gather near the location of the PMSE receiving equipment, and that it might not be possible to ensure very much separation between them. In this case, the only way to separate the PMSE receiving antenna(s) from White Space devices might be to elevate the antennas on a temporary mast. Please refer to Figure 89.



**Figure 89: Outdoor PMSE operation at a street fair, foot race, or similar event**

### A6.3 SCENARIO II - INDOOR HALLS

The next scenario concerns the operation of a PMSE system consisting of multiple audio channels at an indoor venue such as a concert hall or theatre. In this case it should be possible to ensure some physical separation between the audience and the PMSE receiving antennas; e.g., 10m, minimum. The antennas might be fixed to rigging alongside or in back of the stage, or mounted on the proscenium arch. If directional receiving antennas are used, they should be aimed toward the stage area and away from the house. In some installations it has been the practice to locate the PMSE receivers and their associated antennas at the back of the hall in an equipment or projection room. This may be undesirable in the future, as it results in a long distance to the PMSE transmitters with potentially interfering White Space devices in the path. In this situation, directional receiving antennas would not offer any interference rejection. Please refer to Figure 90.



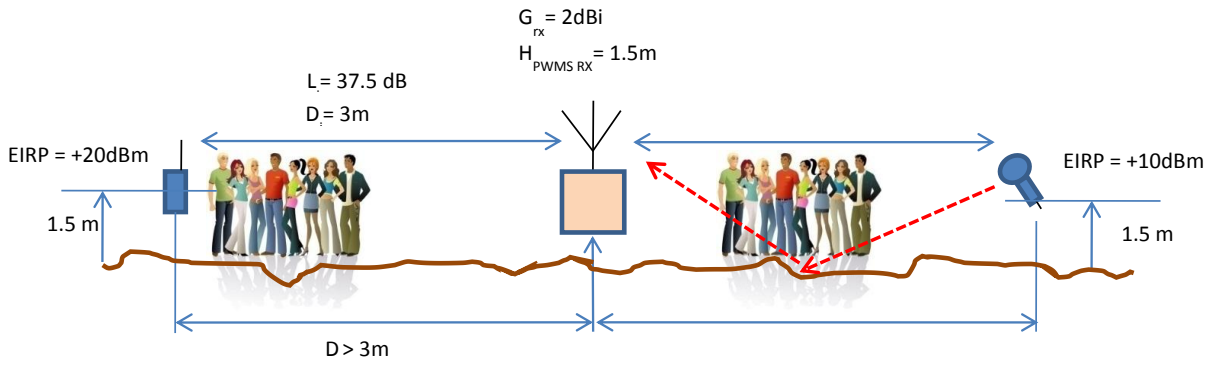
**Figure 90: Indoor PMSE operation in a concert hall or theatre**

#### A6.3.1 Scenario III - Indoor Meeting Halls

This scenario covers a variety of different indoor meeting venues, including conference centres, government buildings, hotels, and the like. In these situations, PMSE systems may be part of the installed sound reinforcement equipment, or may be “ad hoc” systems that are set up on a temporary basis for a conference or meeting and taken down afterward. It is these latter setups that are more problematic, because the PMSE equipment is less likely to be set up such that they would be better protected them from interference.

For these situations, it is difficult to guarantee more than a small minimum separation between the PMSE antenna and the attendees. Often, the PMSE equipment is set up in the back of the meeting room and microphones are operated at distances up to 50m away. Typically, the transmission path would include potentially interfering White Space devices carried by members of the public. Thus, a directional PMSE receiving antenna would not offer any advantage. Please refer to **Error! Reference source not found.**





**Figure 91: Indoor PMSE operation in a meeting room or conference center**

## **ANNEX 7: APPLICATION EXAMPLES OF MASTER/SLAVE CONCEPT**

### **A7.1 M2M NETWORK DEPLOYMENT**

The following example is provided to illustrate how a master/slave approach might work in practice. It is based on the deployment of a nationwide machine-to-machine network where there are many thousands of base stations across a country and potentially tens of thousands of machine terminals in each base station. This is the model being considered, for example, within the Weightless standard.

Each base station in such a network becomes a master device. Coverage maps for each base station at its preferred power level, antenna height, etc, are pre-generated using commercial coverage planning tools. Such base stations might have a preferred transmit power level of around 30dBm e.i.r.p. where regulation allows. Within the core network is a frequency assignment entity that is responsible for obtaining from the geo-location database a list of allowed frequencies at each base station and assigning them so that inter-base station interference is avoided as far as possible. This entity sends to the geo-location database an enquiry for each base station. Such an enquiry consists of one interrogation for the base station and multiple (often many thousand) interrogations for each pixel within the coverage area. These pixel interrogations would be for terminals that would be at a lower height and typically have a much lower transmit power than the base station (e.g. 16dBm e.i.r.p.)

The results for all base stations across the network are aggregated and a frequency plan assembled that uses the best available channels and minimizes interference. This process is repeated whenever a channel validity time expires.

Improvements could be envisaged where the geo-location database is informed of the selection of frequencies and monitors changes to licensed usage that will impact upon these. The network is then informed when such changes occur and hence only starts a re-planning process when necessary. However, this functionality would be outside of that mandated by the NRA and may be a value-added service provided by the database operator.

## **ANNEX 8: TRADE-OFF BETWEEN 'FALSE-VACANCY-DETECTION' AND 'FALSE-OCCUPANCY-DETECTION' AS A FUNCTION OF INCREASING DETECTION THRESHOLDS**

### **A8.1 GENERAL**

The purpose of WSD sensing and of the geo-location database is to ensure that incumbent services, including DTT transmissions, are not interfered with by WSD usage. To this end it may be necessary to be somewhat 'overprotective' because of the inherent limitations of the WSD sensor and of the database information and calculation abilities.

Database determinations of the presence or absence of DTT signals in a given area can be based on 'internal' calculations or on additional 'real time' information obtained from external sources, for example based on the 'actual' (measured) field strength values prevailing within the given area.

If complete 'real time' knowledge of precise 'actual' DTT field strength values were available everywhere, then database calculations for the wanted DTT field strength values would not be necessary. Neither would WSDs need to be equipped with a sensing capability.

However, a complete knowledge of the actual DTT coverage situation will probably not be available, so that reliance on database calculations as well as on WSD sensory capabilities must be taken on board to ensure sufficient protection for DTT reception.

Because both database facilities and WSD sensing are 'imperfect', there is the possibility, using either (or both) technique(s), of arriving at

- i. a 'false-vacancy-detection', i.e. the indication that the DTT channel is not being used when in fact it is occupied, or
- ii. a 'false-occupancy-detection', i.e. the indication that the DTT channel is occupied when in fact it is not being used.

We are more concerned with preventing 'false-vacancy-detections' than with preventing 'false-occupancy-detections' because the purpose of database and WSD sensors is to avoid interference to DTT reception, and 'false-vacancy-detections' will lead to DTT interference, whereas 'false-occupancy-detections' will not lead to DTT interference. Of course, 'false-occupancy-detections' should be avoided to the extent possible, but not at the cost of increasing the likelihood of 'false-vacancy-detections'.

### **A8.2 WSD SENSING**

WSD sensing is oriented towards the 'actual' values of the ambient field strength. That is, a DTT field strength is measured/detected (or not) but not calculated. The field strength value which the WSD measures/detects is that which is present at the WSD site and it is usually not that which is actually present at nearby DTT reception sites.

For example, a WSD may measure/detect a DTT field at street level (say 1.5 m) where the field may be very weak, whereas the DTT field of interest is much stronger, being received at rooftop height (say 10 m) 20 or 30 m away. Because of this 'disconnect', the WSD field strength sensor must be very sensitive, that is it must be able to detect field strengths at levels much lower than would be usable by a DTT receiver.

Also, because of this disconnect, the WSD sensing is not really reliable with respect to predicting what the actual DTT signal strength is that may be receivable nearby. In other words, a WSD might not detect an ambient DTT signal, indicating (incorrectly) that either there is no DTT signal present or else that the field at the nearby DTT reception site would be too low for satisfactory reception.

The WSD would register a 'false-vacancy-detection', although the database with complete knowledge would register a 'true occupancy'. To reduce this possibility of 'false-vacancy-detections' the WSD sensing threshold level must be very low. Of course, the lowering of the sensing threshold may increase the likelihood of 'false-occupancy-detections'.

### A8.3 DATABASE CALCULATIONS

Database calculations/determinations of the presence (or not) of a wanted DTT signal have yet to be defined. Such calculations/determinations could consist of some of the following ingredients.

Input:

- DTT transmitter characteristics (site, transmit antenna site and antenna pattern, e.r.p....);
- DTT Rx characteristics (site/area,  $E_{wmed\_ref}$ , ...).
- DTT coverage contours can be calculated using this information, or else;
- DTT coverage contours can be specified/defined by external sources.
- In addition, the WSD location would need to be known.

One potential drawback of calculating or defining the DTT coverage contour is that often it is possible to have a satisfactory DTT reception 'beyond' the calculated coverage contour. In other words, the 'true' coverage 'edge' may be 'outside' the calculated/defined coverage contour. Either this is taken into account when the 'reference' coverage contour is calculated/defined or else areas of actual DTT reception may be 'overlooked' by the database; this type of occurrence would constitute a possibility of concluding a 'false-vacancy-detection' for the presence of a DTT signal being reported by the database. Of course, the opposite effect may also arise sometimes, where a 'false-occupancy-detection' would be indicated.

### A8.4 DATABASE ERRORS

Database calculated field strength values may sometimes be erroneous. For example, calculated wanted field strength values may be 'too low' (e.g. near the DTT coverage edge) compared to the actual values which, though low, may still be sufficiently high to be receivable, and thus the database would register a 'false-vacancy-detection'.

It may also happen that the database calculated field strength values are 'too high' compared to the actual values which may not be high enough to provide satisfactory reception quality, and thus the database would register a 'false-occupancy-detection'.

Both these cases ('false-vacancy-detection' and 'false-occupancy-detection') would be most likely to occur where the DTT reception is near the coverage 'edge', i.e. where the wanted DTT signal strength is 'marginal'. For example, in an area where the wanted field strength (measured or calculated) is very high, an error in the calculations of some dB, either way, will not change the conclusion that a DTT signal is present, i.e. it will usually not lead to a 'false-vacancy-detection' decision.

### A8.5 WSD ERRORS

On the other hand, even when the database calculates the wanted field strength values incorrectly, and indicates a 'false-vacancy-detection', the WSD might detect an 'actual' field strength level at or above the threshold which, taking into account the difference in respective receiving heights (WSD at 1.5 m vs. DTT at 10 m) and other possible positional and topological/structural effects, would indicate that a receivable DTT signal could be available nearby.

To ensure that the WSD sensor is sufficiently reliable, a 99.99% reliability factor should be built into the sensor in terms of a low sensitivity threshold.

The 99.99% reliability factor ensures that even those channels providing nearby DTT receivers with a 'weak' field strength, around  $E_{min}$  (i.e. near the coverage 'edge'), are marked as being 'occupied' with a very high probability. Because of the low value of the threshold, areas which are well within the DTT coverage area will be less prone to false WSD evaluations ('false-occupancy-detection' and 'false-vacancy-detection'). That is, once again, the possibility of a WSD providing a 'false-vacancy-detection' or a 'false-occupancy-detection' evaluation would most likely occur where the DTT reception is near the coverage 'edge'.

**A8.6 WSD DETECTION ERRORS WHEN DTT SIGNAL IS PRESENT**

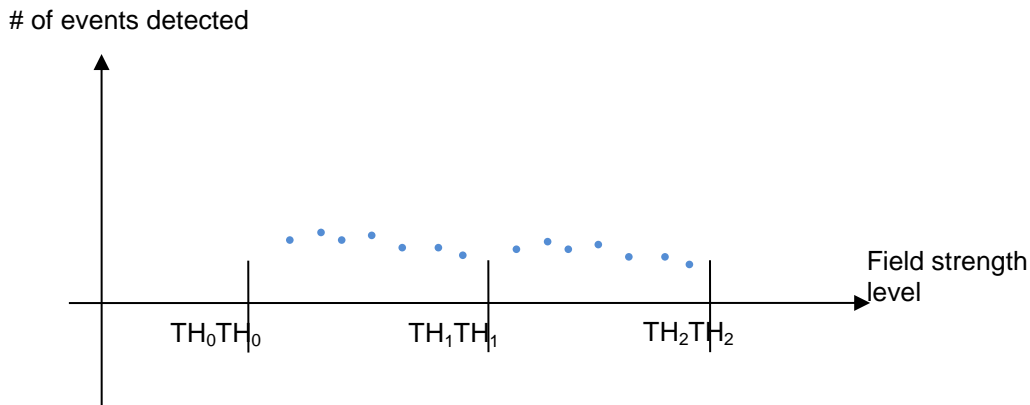
**A8.6.1 WSD sensitivity threshold  $TH_0$ .**

Assuming that a DTT signal is present at various levels of field strength, Figure 92 (1a) indicates the number of detections that are made by a sensor having a threshold level  $TH_0$ . Below  $TH_0$ , signals may be present, but they are not detected because the threshold  $TH_0$  is not low enough: i.e. there may be some 'false-vacancy-detections'.

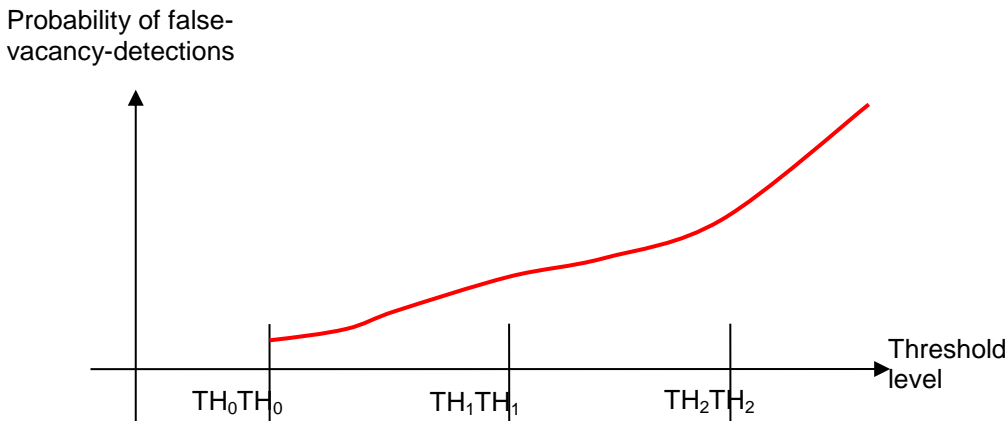
*The events between  $TH_0$  and  $TH_1$  will not be detected if the threshold is raised from  $TH_0$  to  $TH_1$ . And thus they constitute 'false-vacancy-detections'.*

The events between  $TH_1$  and  $TH_2$  as well as those between  $TH_0$  and  $TH_1$  will not be detected if the threshold is raised from  $TH_1$  to  $TH_2$ . That is, additional 'false-vacancy-detections' will be registered.

Figure 92 (1b) shows how the probability of 'false-vacancy-detections' will increase as the threshold is increased



(1a) As the threshold is increased, ambient DTT fields at low levels may, erroneously, miss being detected



(1b) Increased probability of 'false-vacancy-detections' as the threshold increases

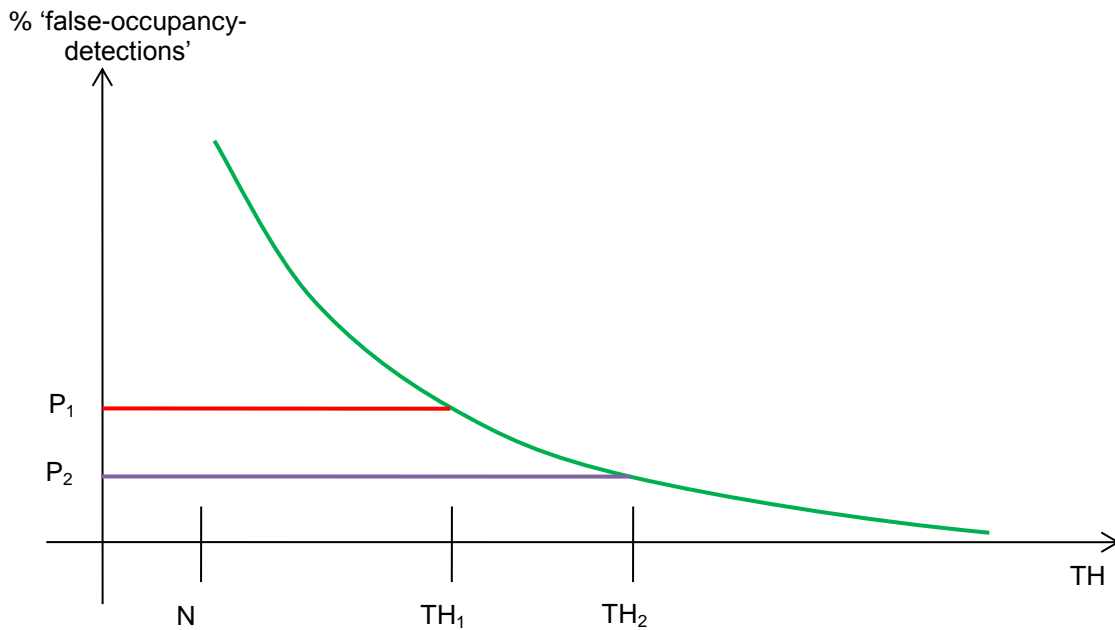
**Figure 92: (1a) As the threshold is increased, ambient DTT fields at low levels may, erroneously, miss being detected. (1b) Increased probability of 'false-vacancy-detections' as the threshold increases**

Conversely, the probability of 'false-occupancy-detections' would decrease with increasing WSD sensing threshold (e.g. if the threshold were very, very high, there would be no 'occupancy' at all, 'true' or 'false').

### A8.7 WSD DETECTION WHEN DTT SIGNAL IS NOT PRESENT

If no DTT signal is present (or it is too weak to be usable), there is nevertheless a probability that a signal is erroneously indicated by the WSD as being present – a ‘false-occupancy-detection’: green curve in the Figure below. The lower the WSD threshold level, the more probable that a ‘false-occupancy-detection’ will be indicated (the green curve increases with lowering sensing threshold). If the WSD threshold level is high the probability of ‘false-occupancy-detections’ becomes smaller: In the Figure below  $TH_2 > TH_1$ , and  $P_2 < P_1$ .

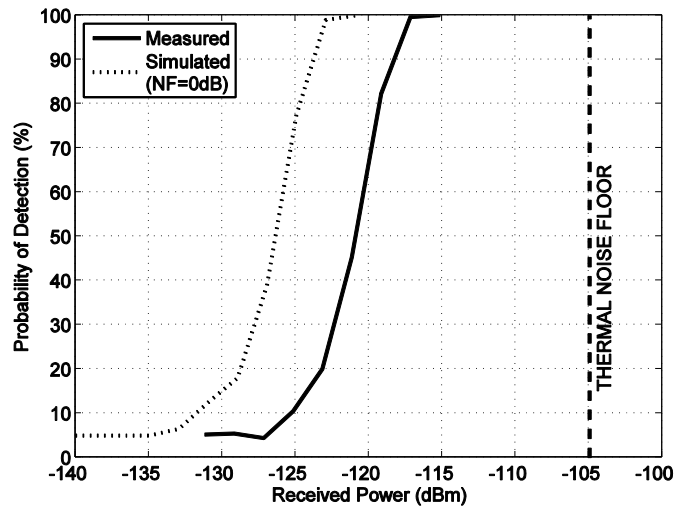
But as seen from the figure below the ‘false-vacancy-detections’ will increase with increasing WSD threshold level, and it is most important that the ‘false-vacancy-detections’ be kept to a minimum, in order to keep interference to DTT reception to a minimum.



**Figure 93: % ‘false-occupancy-detections’ when a DTT field is not present as a function of WSD sensor threshold**

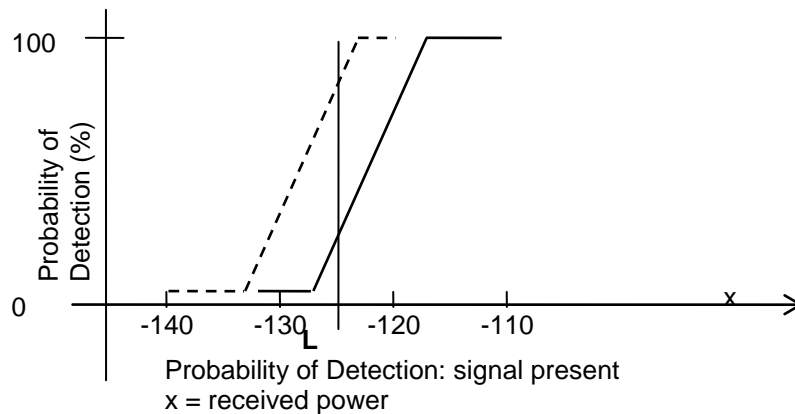
### A8.8 DEMONSTRATION WITH A PRACTICAL CASE

We will base our discussion in part on the Figure 56 of Annex 3 (“*Example spectrum sensor implementation and field test results*”) of [16]) in particular on the ‘measured’ and ‘simulated’ results, reproduced in Figure 94.



**Figure 94: Measured DVB-T probability of detection compared to simulated performance. Simulation utilizes ideal receiver (NF=0dB)**

For the sensor being simulated/measured, it is apparent that the probability of detecting an ambient signal increases as the ambient signal becomes stronger. This implies, of course, that there is a probability of not detecting a signal which is present at a frequency in the measurement range. For the sake of simplicity, we propose the corresponding linear models in Figure 95 to approximate Figure 94. The two approximations are parallel with a 6 dB shift. The corresponding equations for the probability of (correct) detection (“PROB”) are given as Equation 1M (‘measured’) below.



*measured*

$$\begin{aligned}
 \text{PROB} &= .05 \quad \text{if} \quad -134 < x < -127 \text{ dBm} \\
 \text{PROB} &= 1 \quad \text{if} \quad x > -117 \text{ dBm} \\
 \text{PROB} &= .095x + 12.115 \quad \text{if} \quad -127 \leq x \leq -117
 \end{aligned}$$

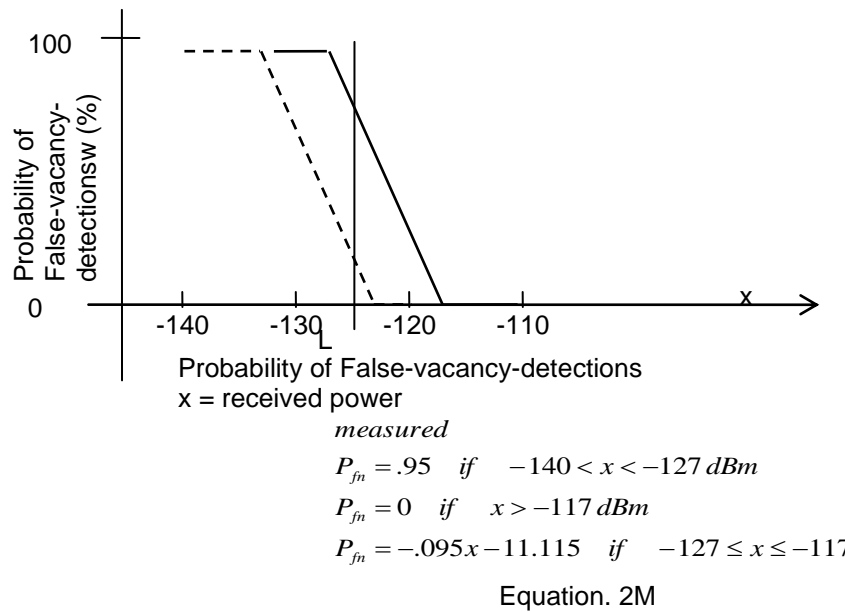
Equation. 1M

**Figure 95: Linear approximation to Figure 94**

**A8.9 FALSE-VACANCY-DETECTIONS**

Those equations can be modified to equations for the probability,  $P_{fn} = 1 - \text{PROB}$ , of incorrect ‘non-detection’, i.e. a false-vacancy-detection. These are depicted in Figure 96 with the corresponding equations equation. 2M. (We use the notation “ $P_{fn}$ ” for the probability of a ‘false-vacancy-detection’, and “ $P_{fp}$ ” for the probability of a ‘false-occupancy-detection’.)





**Figure 96: Linear approximation to Probability of False-vacancy-detections**

### A8.10 WSD SENSITIVITY MODEL

It should be noted that the real sensitivity of the implemented detector is always a fixed value, in this example -117 dBm. The decision threshold in the implemented detector is by default fixed at -127 dBm, which is the level where the detector starts to ‘wake up’.

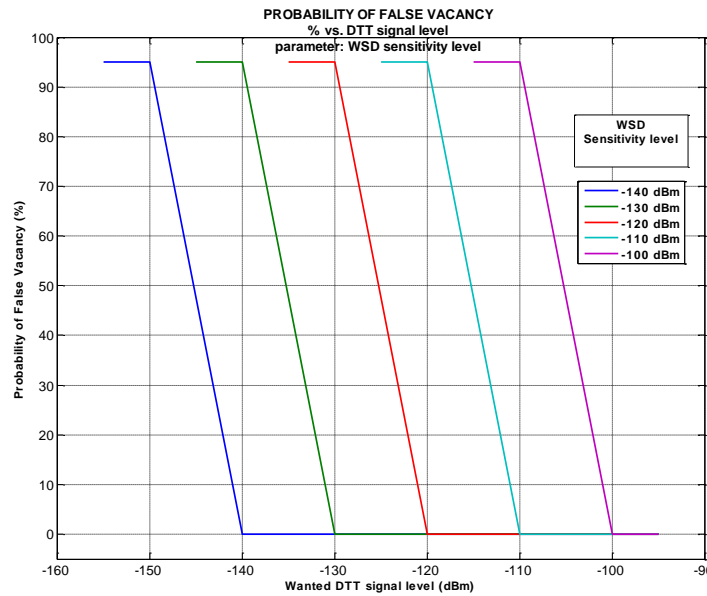
Therefore, our model will be based on indents 1 and 2 of the Introduction, explicitly:

- The correct distinction between ‘sensitivity’ and ‘detection threshold’ is made,
- Different sensitivities can be obtained by a horizontal translation, the curves remain parallel,
- The chosen sensitivity and the corresponding decision threshold differ by 10 dB; e.g. in Figure 92,
  - simulated sensitivity is -123 dBm, and decision threshold is -133 dBm
  - measured sensitivity is -117 dBm, and decision threshold is -127 dBm.

On this basis, we generalize the Figure 96 to encompass 5 WSD sensors with the following

- sensitivities:                   -140 dBm, -130 dBm, -120 dBm, -110 dBm, -100 dBm,
- decision thresholds:       -150 dBm, -140 dBm, -130 dBm, -120 dBm, -110 dBm.

The results are shown in Figure 97.



**Figure 97: Probability of false vacancy detection versus DTT signal level**

The equations describing the ‘curves’ are the following ( $P_{DTT}$  is the wanted DTT signal power,  $PROB_{FV}$  is the probability of ‘false vacancy’):

**Table 21: Model parameters**

WSD sensitivity	$PROB_{FV} = 95\%$	$0\% < PROB_{FV} < 95\%$	$PROB_{FV} = 0\%$
-140 dBm	$P_{DTT} \leq -150$ dBm	$PROB_{FV} = -9.5 P_{DTT} - 1330$ dBm	$-140\text{dBm} \leq P_{DTT}$
-130 dBm	$P_{DTT} \leq -140$ dBm	$PROB_{FV} = -9.5 P_{DTT} - 1235$ dBm	$-130\text{dBm} \leq P_{DTT}$
-120 dBm	$P_{DTT} \leq -130$ dBm	$PROB_{FV} = -9.5 P_{DTT} - 1140$ dBm	$-120\text{dBm} \leq P_{DTT}$
-110 dBm	$P_{DTT} \leq -120$ dBm	$PROB_{FV} = -9.5 P_{DTT} - 1045$ dBm	$-110\text{dBm} \leq P_{DTT}$
-100 dBm	$P_{DTT} \leq -110$ dBm	$PROB_{FV} = -9.5 P_{DTT} - 950$ dBm	$-100\text{dBm} \leq P_{DTT}$

**A8.11 PROBABILITY OF ‘FALSE VACANCY’ AS A FUNCTION OF WSD SENSITIVITY**

In Figure 97 we see how the probability of detection of an existing DTT signal varies with the DTT signal strength.

In the present section, the overall ‘efficiency’ of WSD detecting some existing signal is examined. It will be seen that this ‘efficiency’ decreases as the WSD sensitivity is reduced.

We use the parameters of the model given in the preceding section.

We derive the behaviour of the probability of ‘false vacancy’ as a function of WSD sensitivity as follows:

- We assume there is a uniform, random distribution of DTT signals with powers,  $P_{DTT}$ , between -140 dBm and -100 dBm. The strength of any given signal is not known. The probability of detecting them is to be calculated.
- The overall probability for detecting all of those signals using the WSDs with the sensitivity given for each sensitivity level given in the model is calculated.
- Those individual overall probabilities can be calculated by integrating the probability functions assumed in the model; the relevant probability functions are those shown in Figure 95, and which are described mathematically in Table 21. We are assuming that the probability of ‘false vacancy’,  $PROB_{FV}$ , never exceeds 95%. If  $PROB_{FV}$  were assumed to reach 100% for the lower values of  $P_{DTT}$ , then the results

given below would be even more pessimistic (i.e. the overall probability of 'false vacancy' detection would increase).

- Since the region -140 dBm to -100 dBm is of interest, all integrations are performed over this region. The results for these 5 sensitivity levels are given in Table 22.

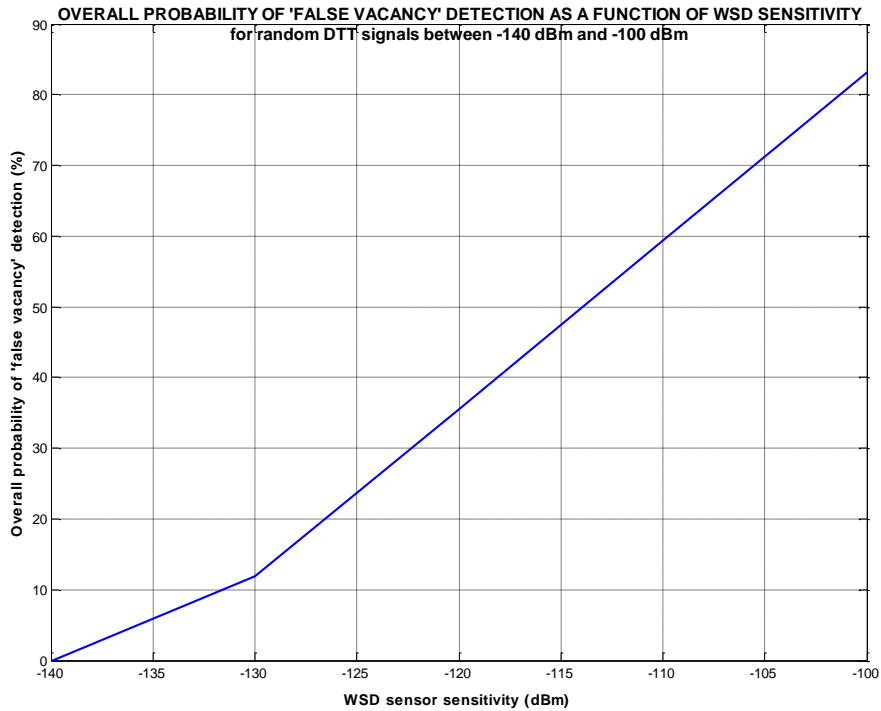
**Table 22: Probability of 'false vacancy' as a function of Wsd sensitivity**

WSD sensitivity	PROBFV_OVERALL
-140 dBm	0.00%
-130 dBm	11.875%
-120 dBm	35.625%
-110 dBm	59.375%
-100 dBm	83.125%

The results for any WSD sensitivity between -140 dBm and -100 dBm can be given, as follows:

- For sensitivity SEN,  $-140 \text{ dBm} \leq \text{SEN} \leq -130 \text{ dBm}$ :  $\text{PROB}_{\text{FV\_OVERALL}} = 19(140 + \text{SEN})/16$
- For sensitivity SEN,  $-130 \text{ dBm} \leq \text{SEN} \leq -100 \text{ dBm}$ :  $\text{PROB}_{\text{FV\_OVERALL}} = 2.375\text{SEN} + 320.6233$

The results for all WSD sensitivity values between -140 dBm and -100 dBm are plotted in Figure 98



**Figure 98: Overall probability of 'false vacancy detection' as function of WSD sensitivity**

### A8.12 PROBABILITY OF 'FALSE VACANCY' AS A FUNCTION OF WSD SENSITIVITY

It should be noted that the detection of a DTT signal is purely based on the cyclic features of the DTT signal.

This means that in order to make a 'false occupancy detection', that is to make a detection of a signal which isn't present, a well-defined "cyclic feature of the DVB-T signal" would have to somehow be registered by the WSD sensor. This detection of a 'cyclic feature' of a non-existent signal should not be very probable: it would seem that a 50% probability for such a 'detection' would be rather high.

Although it has been claimed that the probability of 'false occupancy detection' decreases as the WSD sensitivity is increased, unfortunately, no measurement information has as been provided as to the actual behaviour of the probability of 'false occupancy' as a function of WSD sensitivity.

Nevertheless, in order to provide some theoretical feeling for what might be happening, the following is assumed:

- A set of 5 WSD sensors: WSD<sub>1</sub>, WSD<sub>2</sub>, WSD<sub>3</sub>, WSD<sub>4</sub>, WSD<sub>5</sub> ranging in sensitivity from -140 dBm, -130 dBm, -120 dBm, -110 dBm, to -100 dBm, respectively – that is, from very sensitive to progressively less sensitive sensors.
- Because of the lack of information, we don't know what the actual probability of 'false occupancy detection' would be, so we take a range of possibilities: 50%, 40%, 30%, 20%, 10% for the most sensitive sensor, WSD<sub>1</sub>. Presumably this range would cover the realistic range of possible 'false occupancy detection' probabilities.
- WSD<sub>1</sub>, with sensitivity -140 dBm is assumed to have the 'worst' set of probabilities for the 'false occupancy detection' ranging from 50%, 40%, 30%, 20%, 10%.
- WSD<sub>5</sub>, with sensitivity -100 dBm is assumed to have the 'best' set of probabilities for the 'false occupancy detection' ranging from 5%, 4%, 3%, 2%, 1%.
- WSD<sub>2</sub>, WSD<sub>3</sub>, WSD<sub>4</sub> are assumed to have an increasingly improved set of probabilities for 'false occupancy detection', which are defined as linear interpolations between WSD<sub>1</sub> and WSD<sub>5</sub>.

Using these assumptions, we arrive at the following Figure 99 which is representative of how the 'improvement' in the 'false occupancy detection' might look in practice, depending on the starting probability and the degree of improvement with increasing WSD sensing capability.

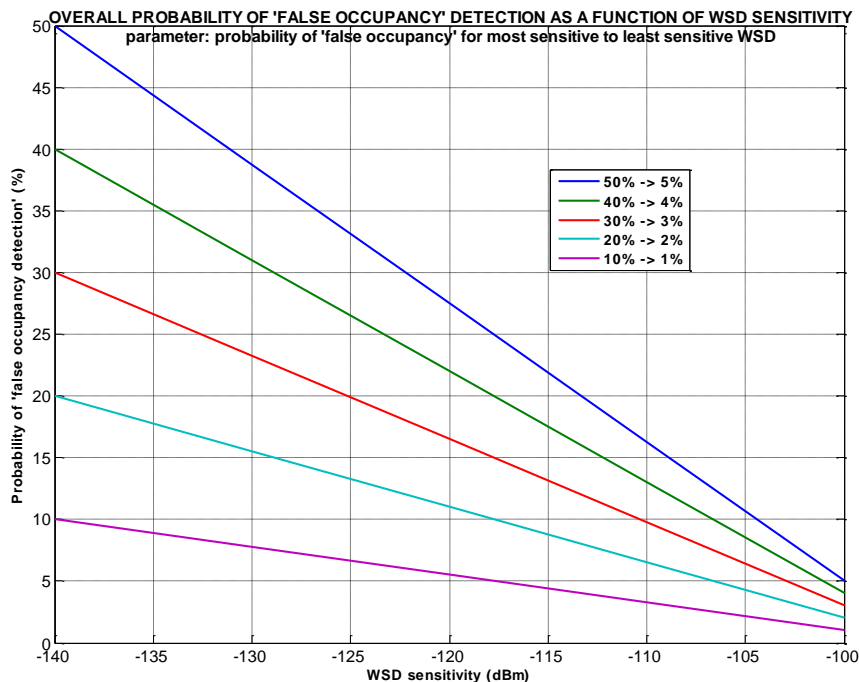
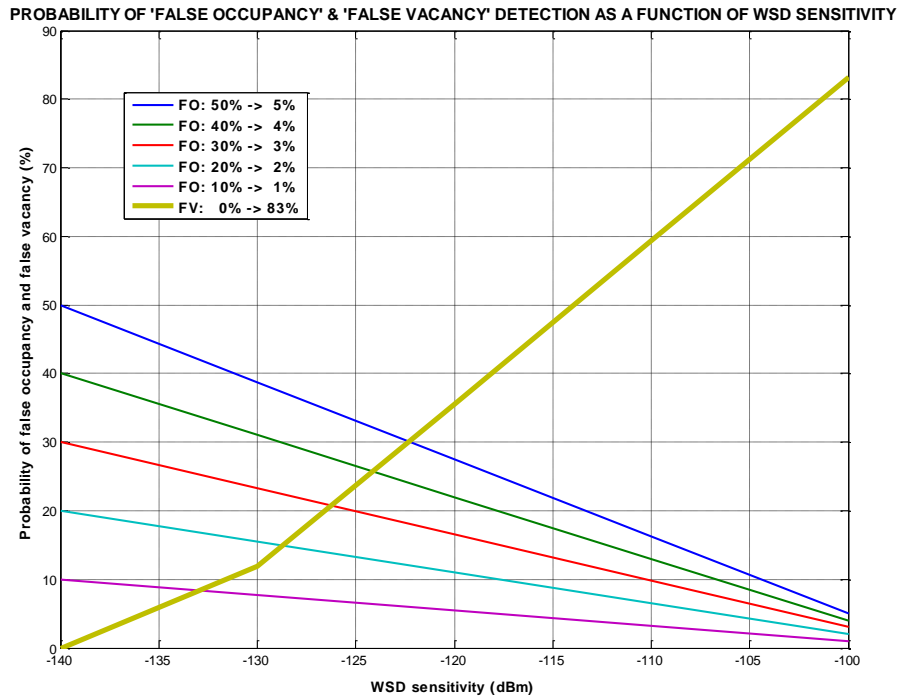


Figure 99: Overall Probability of 'False occupancy' detection as a function of WSD sensitivity

**A8.13 CONCLUSIONS**

Figure 98 and Figure 99 are combined in Figure 100 give a better overview of the complete situation.



**Figure 100: Probability of ‘false occupancy’ and ‘false-vacancy’ as a function of WSD sensitivity**

It is seen that the overall probability of ‘false vacancy detection rises significantly faster than the probability of ‘false occupation detection’ decreases, irrespective of the ‘starting’ probability of ‘false occupation’.

database calculations/determinations of ambient DTT signals may produce ‘false’ decisions, either ‘false-occupancy-detections’ or ‘false-vacancy-detections’. ‘False-vacancy-detections’ are more serious than ‘false-occupancy-detections’ because they can lead to interference to DTT reception.

WSD sensors may also produce ‘false’ decisions.

Increasing the WSD sensing threshold can lead to an increased number of ‘false-vacancy-detections’, which would lead to an increased number of interference situations for DTT reception. Conversely, the probability of ‘false-occupancy-detections’ would decrease with increasing WSD sensing threshold.

Using the practical implementation described in Annex 1, the increase in the average probability for false-vacancy-detections for receive signals in the lower power region (in our example, in the interval [-140 dBm,-100 dBm dBm]) is greater than the decrease in probability for false-occupancy-detections.

It is most important that the ‘false-vacancy-detections be kept to a minimum, in order to keep interference to DTT reception to a minimum. Therefore the WSD sensor threshold level should be kept as minimum as possible.

Portable outdoor WSD sensing levels should be very stringent. Because their location is ‘variable’ they must be able to detect ambient DTT signals under the most severe receiving conditions.

## ANNEX 9: PRELIMINARY RESULTS ON COMBINATION OF GEO-LOCATION DATABASE AND SENSING TECHNIQUES IN A REAL SCENARIO

### A9.1 INTRODUCTION

The methodology described in Section 6.1 has been applied to a real scenario in Italy, in order to assess the possible benefits of sensing techniques when used in combination with the geo-location database and verify the possibility to relax sensing detection thresholds with respect to the sensing alone approach, while granting proper protection to incumbent services. Both simulations and measurements are used to assess DVB-T channel occupancy, respectively based on the geo-location database approach and on sensing techniques. The channel occupancy by PMSE systems has not been taken into account.

The information needed for the geo-location database is derived simulating the coverage area of real DVB-T transmitters, using a proprietary software tool, whereas measurements of the actual received signal levels have been performed by means of a spectrum analyser.

### A9.2 APPLICATION OF THE METHODOLOGY IN A REAL SCENARIO

#### A9.2.1 Geo-location database

The considered scenario is the Italian province of Bologna. In that area, field strength levels for DVB-T channels from 21 to 60 are calculated over square pixels (400 m x 400 m). The path loss between each DVB-T transmitter and virtual receivers located in the centre of the pixels is computed considering a free space term to which the diffraction path loss component is added. For diffraction loss due to natural obstacles along the propagation path, the Recommendation ITU-R P.526 [4] model has been referred and the Deygout method has been adopted with a maximum of 3 obstacles, selected with the stretched string method. For calculations, the actual height of the antennas above the level has been considered and the terrain model has been taken from the public SRTM database<sup>35</sup>

For each pixel and for each channel from 21 to 60, the simulation tool evaluates the maximum field strength level  $E_{rx}$  (dB $\mu$ V/m) considering all possible DVB-T transmitters located both in the investigated area and in the neighbourhood:

$$E_{rx} \text{ (dB}\mu\text{V/m)} = \text{Max}(E_{tx} \text{ (dB}\mu\text{V/m)} - A_{tot} \text{ (dB)})$$

where  $E_{rx}$  (dB $\mu$ V/m) is a function of each considered DVB-T transmitter effective radiated power e.r.p.<sub>Tx</sub> (dBW) and  $A_{tot}$  is the path loss.

The simulation results are then compared with the proper thresholds based on the Reference Planning Configurations (RPCs) specified in ECC Report 159 [1] for the protection of the DVB-T service. In Table 23 the minimum field strength levels of the GEO-06 RPC1 (fixed reception) at 650 MHz are shown for different location probability values.

**Table 23: DVB-T Reference Planning Configurations (Fixed Reception)**

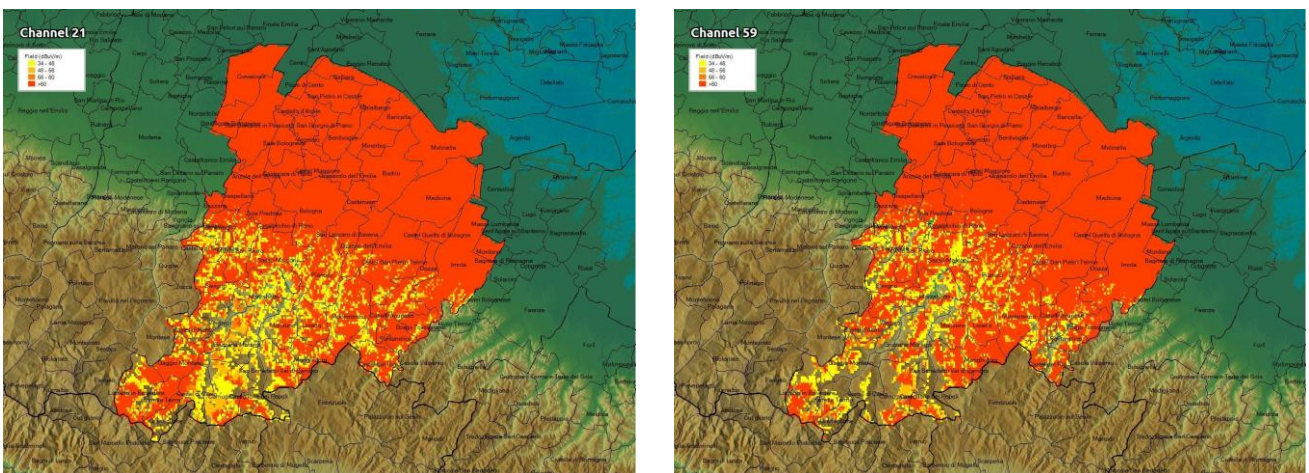
Frequency 650 MHz	
Location Probability	$F_{k,min}$ dB $\mu$ V/m at 10 m
99%	60
95 %	56
50%	48
1%	34

In particular, given a threshold  $T_{rx}$  set at one of the  $F_{k,min}$  values in Table 1:

<sup>35</sup> <http://www2.jpl.nasa.gov/srtm/>

$E_{rx} \text{ (dB}\mu\text{V/m)} \geq T_{rx}$	$D_G = 1$	The pixel is within the protected service contour. Hence the channel is occupied
$E_{rx} \text{ (dB}\mu\text{V/m)} < T_{rx}$	$D_G = 0$	The pixel is outside the protected service contour. Hence the channel is vacant

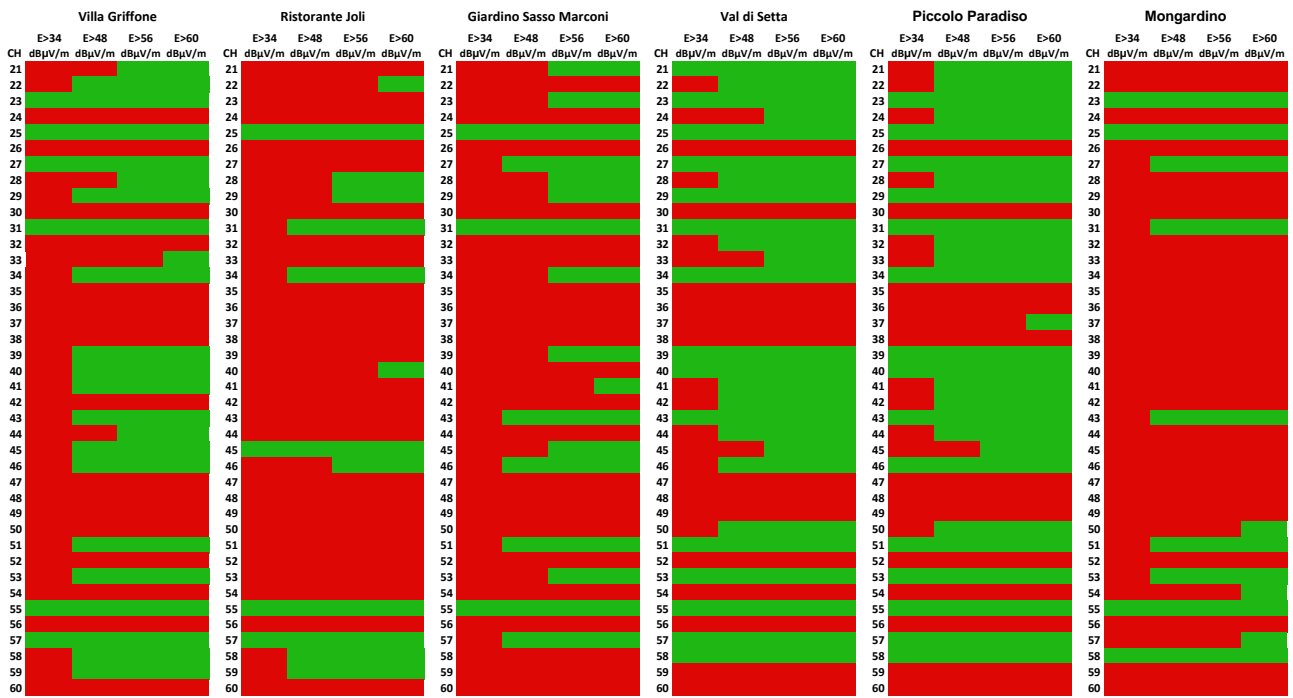
In Figure 101 simulated field strength levels (dB $\mu$ V/m) are shown for channel 21 and 59. It can be noticed that for the considered channels most of the pixels of the province of Bologna are occupied, as only some hilly and mountainous areas quite far from Bologna are not reached by the DVB-T signal. Similar results have been computed with the employed simulation tool for all the DVB-T channels in the 470-790 MHz band (channels 21-60). Based on this analysis the geo-location database can be populated: for each pixel and for each channel the proper value of the  $D_G$  parameter (1 or 0) is stored.



**Figure 101: Example of received DVB-T signal strength in the province of Bologna for channels 21 and 59**

In Figure 102 the geo-location database results obtained for channels 21-60 are reported for the six locations (Villa Griffone, Ristorante Joli, Giardino Sasso Marconi, Val di Setta, Piccolo Paradiso, Mongardino), where also measurements are available. The selected locations are those shown in the following Figure 103.





**Figure 102: Geo-location database: comparison in each location (1: Villa Griffone, 2: Ristorante Joli, 3: Giardino Sasso Marconi, 4: Val di Setta, 5: Piccolo Paradiso, 6: Mongardino) for different field strength thresholds (34 dBµV/m, 48 dBµV/m, 56 dBµV/m, 60 dBµV/m).**

Four different thresholds of 34 dBµV/m, 48 dBµV/m, 56 dBµV/m, 60 dBµV/m have been addressed in order to identify if the channel is occupied (red) or not (green). Channel occupancy is shown in 0 for the different locations and selected thresholds. From Table 24 it can be observed that the percentage of white space potentially available varies with the selected threshold, even though most of the DVB-T channels result to be occupied in the considered locations.

**Table 24: WS potentially available from the geo-location DB**

Threshold (dBµV/m)	%
<=34	20.08
<=48	38.89
<=56	46.15
<=60	50.43

### A9.2.2 Measurements for spectrum sensing

Further information on channel occupancy can be achieved by means of sensing techniques. To this aim several measurements have been realised in a number of locations of the considered area (province of Bologna).

In this work, a Narda SRM 3000 portable spectrum analyser has been adopted for spectrum sensing. The instrument has been equipped either with a tri-axial isotropic antenna, which can operate in the frequency range 75 MHz – 3 GHz, or with a log periodic dipole array antenna, which can operate in the frequency range 200 MHz – 2.75 GHz. The two different antennas were chosen in order to have different sensitivity thresholds for the measurement set up: sensitivity threshold is as high as -80 dBm with the isotropic antenna and falls to -105 dBm with the logperiodic antenna.

In line with ECC Report 159 [1], the detection thresholds have been expressed in dBm. It is also always possible to refer to field strength, once the antenna factor is known: the antenna factor is equal to 50 [1/dBm] for the omnidirectional antenna and approximately 17.7 [1/dBm] for the log periodic antenna in the frequency range of interest.

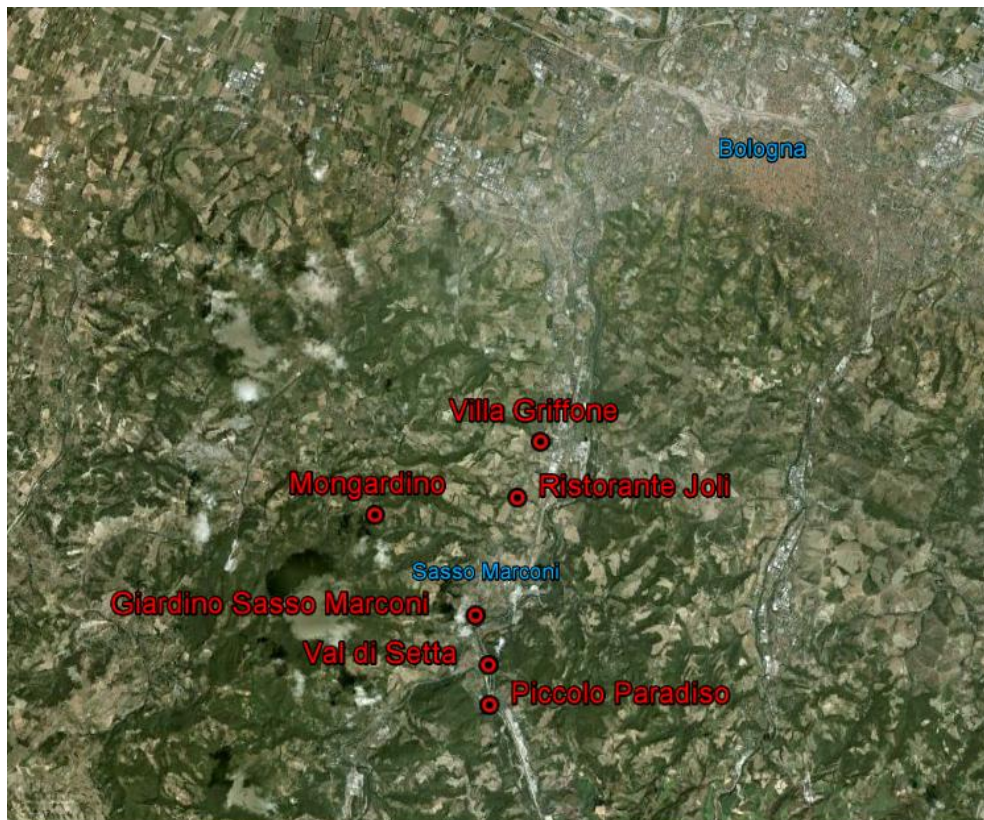
It has to be noted that, according to the ECC Report 159 [1], the detection threshold should be set to -120.71 dBm, in case sensing-alone is applied in the considered scenario. However, the measurement equipment available for this study does not permit to lower the sensitivity threshold below -105 dBm; therefore sensing-alone is not a viable approach with this set up.

Measurements have been performed using the “channel power” mode, in order to evaluate the total amount of power received in the DVB-T channel bandwidth of 8 MHz. A resolution bandwidth (RBW) of 30 kHz has been adopted and for each selected frequency range (e.g.  $F_{min} = 590 \text{ MHz} - F_{max} = 598 \text{ MHz}$ ) the Integration Bandwidth (IBW) function has been used.

Measurements have been performed in the six different locations listed in Table 25 and shown in Figure 104.

**Table 25: Measurement locations**

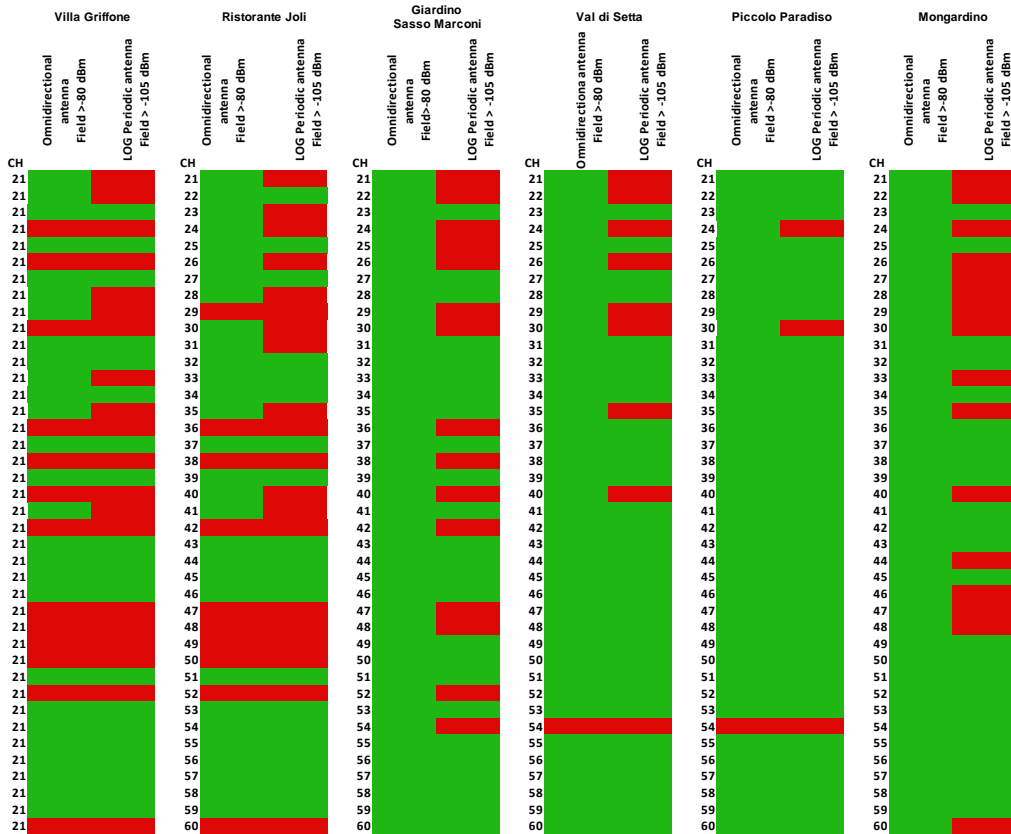
Measurement point	X-UTM (ED50)	Y-UTM (ED50)	Height (m) above ground level
Villa Griffone	680492	4922261	1.5
Ristorante Joli	679948	4920824	1.5
Sasso Marconi	679010	4917863	1.5
Val di Setta	679329	4917863	1.5
Piccolo Paradiso	679384	4915586	1.5
Mongardino	676364	4920300	1.5



**Figure 103: Measurement locations: Villa Griffone, Ristorante Joli, Giardino Sasso Marconi, Val di Setta, Piccolo Paradiso, Mongardino.**

In Figure 104 measurement results obtained for channels 21-60 are reported in the six different observed locations, for the two different probes: omnidirectional and log-periodic antenna. According to measurements, unoccupied channels (e.g. 34) correspond to field strength level below the set up sensitivity floor (-80 dBm for omnidirectional antenna and -105 dBm for log-periodic antenna). As expected, the number of vacant channel decreases as the value of the sensitivity threshold decreases.

In Figure 104 channel occupancy is shown for each location, as a function of the two different floor levels: red colour corresponds to occupied channel, whereas green colour stands for unoccupied channel. From 0 it can be noticed that there are locations (e.g. location 5: Piccolo Paradiso) where the effect of the different threshold is negligible, while in other cases the number of unoccupied channels varies with the sensitivity floor value.



**Figure 104: Measured data: comparison in each location (1: Villa Griffone, 2: Ristorante Joli, 3: Giardino Sasso Marconi, 4: Val di Setta, 5: Piccolo Paradiso, 6: Mongardino) for the two different instrument floor level (1: -80 dBm, 2: -105 dBm)**

### A9.2.3 Combined approach

In order to assess the effect of the combined approach, we considered both results from the simulations (i.e. geo-location approach) and measurements (i.e. spectrum sensing approach).

In Table 26 the percentage of channels where both geo-location database and sensing identify unoccupied channels (double green) is reported. With a detection threshold of -80 dBm any additional protection for the incumbent service is gained with respect to the geo-location alone approach (compare with Table 24, whereas adopting a detection threshold of -105 dBm the total amount of white space potentially available decreases).

Table 26: Double Green Percentage

Different field strength levels for DVB-T reference planning configurations (fixed reception) (dBµV/m)	Different instrument threshold (dBm)	
	-80	-105
<=34	20.08	18.38
<=48	38.89	34.19
<=56	46.15	38.89
<=60	50.43	41.88

As expected, the smaller percentage of *double green* channels is related to higher protection of the DVB-T service and to more stringent values for the sensing thresholds.

### A9.3 MAIN RESULTS

In this contribution we have considered a real scenario as a case study to investigate possible benefits in terms of protection of DVB-T services, derived from a combined approach of geo-location and sensing techniques.

DVB-T coverage simulations have been performed in a real area of the Italian province of Bologna in order to identify occupied and vacant DVB-T channels, according to different levels of protection. Subsequently channel occupancy in several specific locations has been investigated through measurements using a portable Narda SRM 3000 spectrum analyser, equipped with different probes, in order to investigate the effect of the detection threshold. Both simulations and measurements confirm that the WSD 470-790 MHz band is densely occupied in the considered Italian scenario.

The analysis confirms that a combined geo-location and sensing approach may give higher protection to incumbent services, provided that a proper detection threshold is applied. In this specific case study, the sensing threshold has been relaxed with respect to the case of sensing alone (-120.71 dBm for the scenario of interest). With a sensing threshold as high as -105 dBm the combined approach gives higher protection to the incumbent broadcasting service, whereas no further protection is gained with the sensing threshold set to -80 dBm.

## ANNEX 10: WORKED EXAMPLE FOR THE TRANSLATION PROCESS FOR THE PROTECTION OF DTT USING AN ANALYTICAL METHOD

### A10.1 INTRODUCTION

Ofcom have published a consultation paper [10], where they outline the idea of using a geo-location database for regulating e.r.p. of White Space Devices (WSDs) which will reuse the broadcasting spectrum. The idea is that before transmitting, a WSD will interrogate a database, called the geo-location database, providing its location and its characteristics, and it will receive a list of channels it may use, as well as a limit on its maximum permissible e.r.p. for each of these channels.

In Appendices A4 and A5 of Ofcom's consultation paper, some ideas on the generation of this geo-location database are presented. A more thorough analysis is presented in [12], accompanied with a wide range of examples. JPP has also worked on this subject, and has proposed its own views on the issue. In this document we take into account both Ofcom's and JPP's proposals and focus on their implementation.

We present a methodology to perform a full computation of the data required to populate the geo-location database and use them in order to get some statistical data. We expand the procedures outlined in [12] and illustrate how they can be used in conjunction with the coverage data provided by UKPM. An effort was made to align our implementation with the latest discussions that take place in the TVWS Technical Working Group, therefore we have adjusted some assumptions made in [12]:

- The WSD-DTT coupling geometries proposed in [12] have been replaced by the reference and non-reference geometries discussed in [16], and the propagation model was adjusted accordingly.
- We introduced the idea of DPSA layers, in order to decide which channels should be protected at each pixel
- We only protect populated pixels, although our implementation is efficient enough to consider all land pixels of the UK.

In this work we also introduce a semi-analytical approach to compute the statistics of the maximum protected WSD Field strength that can be tolerated at each pixel, without the use of computationally expensive numerical techniques (see [12] Section II.B). This allows the computation of the entire geo-location database data, with a good accuracy, in a reasonable amount of time (a few hours).

Finally we divided the methodology presented in [12] in two parts; this separation allows the caching and reuse of much of the data that are computationally expensive to derive.

The data we derived aim to protect outdoor DTT coverage, assuming a fixed directional antenna at roof top height (10m nominal). We do not take into account, for the moment, coverage protection for Portable Reception or PMSE. Issues like the presentation of the geo-location data to WSDs are also beyond the scope of this work.

### A10.2 METHODOLOGY

Our implementation suggestion is focused on a two phase approach. In the first phase we compute what we call the Protected Pixel-Channel Interference (PPCI) value, which is the maximum protected field strength of the interference that can be tolerated in any pixel-channel combination. A value higher than this will degrade TV reception in that pixel and that channel.

Once the PPCI for every pixel-channel is computed, then for every pixel in the country, we compute the maximum e.r.p. that will not result in excessive PPCI to ANY of the adjacent pixels and channels. Adjacent channel interference is taken into account at this stage. It is this maximum e.r.p. that will be presented to the WSD.

We decided to split the process for two main reasons:

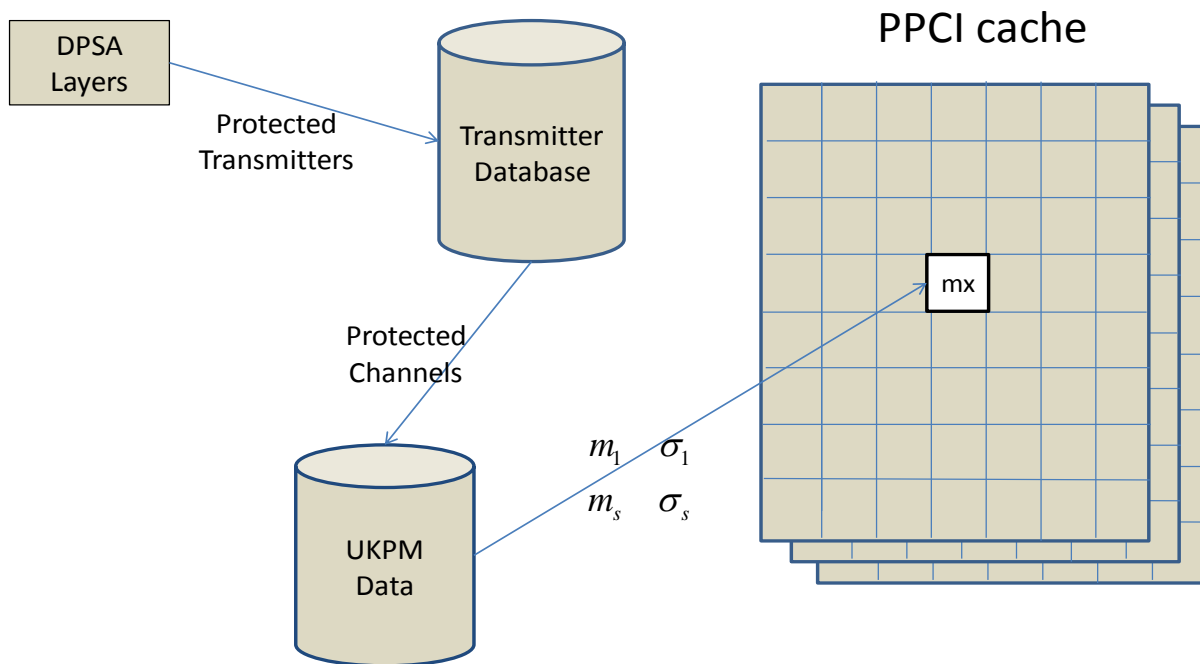
- The computation of PPCI is largely independent from the WSD type. Since it is the protected field strength that is computed and cached, it is independent on the maximum e.r.p. of the WSD or the WSD-DTT protection ratios. It is also unrelated to many of the model's parameters, the propagation model to be used, or the assumptions on the link budget.

- The computation of the PPCI takes significant time to compute. We developed a semi analytical method to derive it which is much faster than the Monte Carlo approach suggested in [11], but it is still relatively slow.

The two stage approach allows us to pre-calculate the PPCI values once and cache them, and then explore a number of strategies for computing the maximum e.r.p. at a reasonable amount of time.

### A10.3 COMPUTATION OF THE PPCI CACHE

The PPCI cache can be seen as a collection of 2 dimensional layers, each layer representing a single channel. Each pixel of a layer corresponds to a 100 by 100m pixel of the UK and contains the maximum protected field strength that can be tolerated at that pixel. The protected field strength is defined as the *actual field strength, adjusted by the appropriate WSD-DTT protection ratio*. In this work we decided to protect all the UK pixels, not only the populated ones.



**Figure 105: Derivation of the PPCI**

The first step in the process is to decide which transmitter to protect at each pixel. In this work we follow the JPP proposal which suggests the use of the DPSA layers. A description of the DPSA concept is presented in [13].

JPP has generated a number of DPSA layers. Each layer defines, for each pixel in the UK, a single transmitter which must be protected. All channels of this transmitter are protected. For example, the 3PSB layer may state that Transmitter A will be protected while the PSBCOM layer may indicate transmitter B. Since we do not know which transmitter viewers at this pixel may opt for, we should protect all the channels of every transmitter that is listed in any of the DPSA layers, in this case all channels of transmitters A and B.

For each of the protected channels, we look up the UKPM results for the corresponding transmitter-channel, and retrieve four values:

- the mean and standard deviation of the C/(I+N) named  $m_1$  and  $\sigma_1$ .
- the mean and standard deviation of the wanted field strength called  $m_s$  and  $\sigma_s$ .

These values allow us to derive the PPCI value as described in the following section.



### A10.4 COMPUTATION OF THE PPCI AT A PIXEL IN A CHANNEL

The computation of the PPCI is largely based on the analysis presented in [12]. Since UKPM coverage output is expressed in dBuV/m, we initially rewrite Equation (37) to (40) of [12] in terms of field strength rather than received power.

Following the notation in [12], in the absence of interference from systems other than DTT, the location probability  $q_1$  at a channel is given by:

$$q_1 = Prob \left\{ P_s^{(lin)} \geq P_{s,min}^{(lin)} + \sum_{i=1}^K r_{U,i}^{(lin)} P_{U,i}^{(lin)} \right\} \quad (37)$$

where:

- $P_s$  is the received power of the wanted signal
- $P_{s,min}$  is the minimum received power and
- $P_{U,i}$  and  $r_{U,i}$  are the received power of each interfering signal and the corresponding protection ratio.

The quantities in equation (1) are expressed in linear units, however it is more convenient to express them in dB. Then equation (37) becomes:

$$q_1 = Prob \left\{ 10^{10} \geq 10^{\frac{P_s}{10}} + \sum_{i=1}^K 10^{\frac{r_{U,i} + P_{U,i}}{10}} \right\} \quad (38)$$

equation (39) can be rewritten in terms of Field Strength as:

$$q_1 = Prob \left\{ 10^{10} \geq 10^{\frac{E_{s,min}}{10}} + \sum_{i=1}^K 10^{\frac{r_{U,i} + E_{U,i} + G_a(\theta_i)}{10}} \right\} \quad (39)$$

where:

- $E_s$  is the wanted Field Strength at the receiver's aerial.
- $E_{s,min}$  is the minimum required field strength to get an acceptable reception.
- $r_{U,i} + E_{U,i}$  is the protected field strength of each DTT interferer.
- $\theta_i$  is the angle at which the receiver's aerial 'sees' the corresponding interferer and  $G_a^{(lin)}(\theta_i)$  is the corresponding azimuth gain reduction  $(G_a^{(lin)}(\theta_i) \leq 1)$ .

If we set:

$$U = 10 \log \left\{ 10^{\frac{E_{s,min}}{10}} + \sum_{i=1}^K 10^{\frac{r_{U,i} + E_{U,i} + G_a(\theta_i)}{10}} \right\} \quad (40)$$

then equation (39) becomes:



$$q_1 = Prob\{E_s - U \geq 0\} \quad (41)$$

When expressed in dB,  $E_s$  can be modelled as a Gaussian random variable, with mean  $m_s$  and standard deviation  $\sigma_s$ . The same applies for the field strength of each interfering signal  $E_{U,i}$ . Then, according to [15],  $U$  can also be approximated by a Gaussian, with mean value  $m_u$  and standard deviation  $\sigma_u$ . Then  $E_s - U$ , which is the protected C/(I+N) of the system, will also be a Gaussian, with mean value  $m_1$  and standard deviation  $\sigma_1$ :

$$m_1 = m_s - m_u \quad \sigma_1 = \sqrt{\sigma_s^2 + \sigma_u^2} \quad (42)$$

$m_1$  and  $\sigma_1$  can be extracted from the Coverage Assessment tools and are known at each covered pixel and channel of the country.

The presence of a WSD interferer will reduce the location probability to a value  $q_2$ . Following the notation in [12]:

$$q_2 = Prob\left\{P_s^{(lin)} \geq P_{s,min}^{(lin)} + \sum_{i=1}^K r_{U,i}^{(lin)} P_{U,i}^{(lin)} + r^{(lin)}(\Delta_f) G^{(lin)} P^{WSD(lin)}\right\} \quad (43)$$

where:

- $r(\Delta_f)$  : is the WSD to DTT protection ratio.
- $P^{WSD}$  : is the in-band transmit power of WSD and
- $G$  : is the WSD – DTT receiver coupling gain.

Expressing the values of equation 43 in dB gives:

$$q_2 = Prob\left\{10^{\frac{P_s}{10}} \geq 10^{\frac{P_{s,min}}{10}} + \sum_{i=1}^K 10^{\frac{r_{U,i} + P_{U,i}}{10}} + 10^{\frac{r(\Delta_f) + G + P^{WSD}}{10}}\right\} \quad (44)$$

If a WSD with e.i.p.  $P^{WSD}$  and coupling gain  $G$  induces a field strength  $E^{WSD}$  at the receiver location, then equation (44) can be written in terms of field strength as:

$$q_2 = Prob\left\{10^{\frac{E_s}{10}} \geq 10^{\frac{U}{10}} + 10^{\frac{E^{WSD} + r(\Delta_f)}{10}}\right\} \quad (45)$$

We assume the worst case scenario where the receiver aerial points to the WSD, and the two antennas are co-polar, therefore there is no reduction in the aerial's forward gain. If we set:

$$X = r(\Delta_f) + E^{WSD} \quad (46)$$

then  $X$  is the protected field strength of the interference generated by the WSD and equation 45 can be rewritten as

$$q_2 = Prob\{E_s \geq U \oplus X\} \quad (47)$$

with operand  $\oplus$  representing addition of  $U$  and  $X$  when expressed in linear units.  $X$  can be modelled as a Gaussian random variable with mean  $m_x$  and standard deviation  $\sigma_x$ . In this work we assume that:

$$\sigma_x = 3.5dB$$

$m_x$  is expressed in dBuV/m and is the mean value of the protected WSD field strength. If we decide that the maximum deterioration in location probability is  $\Delta q$  then  $m_x$  should be such that:

$$q_1 - q_2 = \Delta_q$$

In other words  $m_x$  is the mean value of the protected field strength of the WSD interference that will result in a location probability reduction by  $\Delta_q$ . As long as the mean field strength of the interference from a WSD is kept below  $m_x$  then the location probability reduction will be less than  $\Delta_q$ . Therefore  $m_x$  is the maximum permissible mean value for the WSD protected field strength, consequently, it is the value that should be cached in the PPCI.

As suggested in [12],  $m_x$  can be derived via Monte Carlo analysis; however we have developed a semi analytical technique, presented in the Appendix of this Annex, that allows it to be computed in a reasonable amount of time.

The above procedure is only valid when we deal with MFNs. We have devised a number of approximations so that it can be applied to SFNs, but more work is required in this direction.

### A10.5 COMPUTATION OF THE MAXIMUM PERMISSIBLE e.r.p.

Once the PPCI for every pixel and channel has been computed, the computation of the maximum permissible e.r.p. of a WSD, for every pixel in the UK, and every DTT channel, can take place. In order to find the maximum permissible power of a WSD at pixel, we define a circular area of interest around it, as shown in Figure 106.

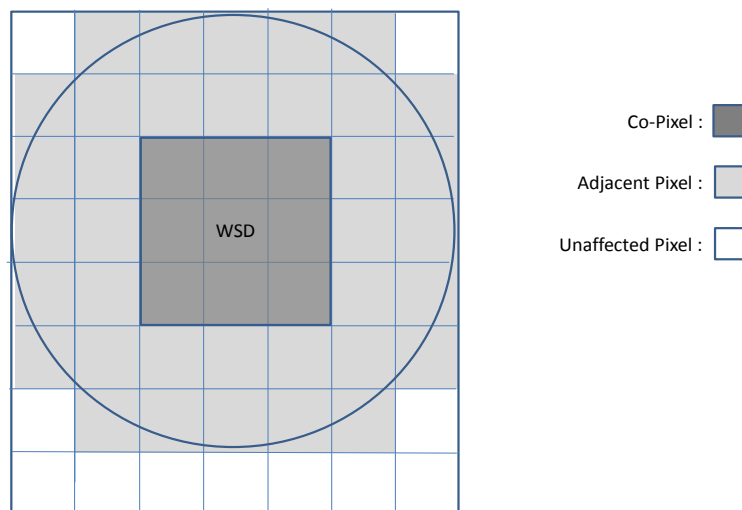


Figure 106: Definition of co and adjacent pixels

The radius of this area is a function of the class of the WSD. Following the extended Hata Urban propagation model, as suggested in [11][11] para A4.26, for WSD powers between 1-5W, a radius between 30 km and 50 km should be sufficient. If we want to consider more powerful devices, the radius should increase accordingly. The pixels outside the circle are assumed to be unaffected from the WSD.

When we consider adjacent channel interference, the radius will be significantly smaller. Given that the difference in the protection ratios can be more than 50 dB, following the extended Hata model, the radius should be 10-15 times smaller.

If the DTT receiver and the WSD are in the same pixel, we have no information on their separation, so the co-pixel computation needs to be based on a reference geometry. The same however applies for the 8 first-tier adjacent pixels, as the DTT receiver and WSD location uncertainty may result in minimal separation.

In order to find the maximum permissible e.r.p. of the WSD, we search within the ‘volume’ of interest (co & adjacent pixels, co & adjacent channels) to find the pixel-channel combination that imposes the strictest restriction. We have to look at each such combination individually, compute the e.r.p. that it permits, and select the combination that permits the lowest power. This is the e.r.p. that can be allowed for the WSD.

### A10.6 COMPUTATION OF THE PERMISSIBLE e.r.p. OF A PIXEL-CHANNEL COMBINATION

Following the discussion above, we can identify 4 different scenarios:

**Table 27: WSD to DTT receiver coupling possibilities**

	Co-channel	Adjacent channel
Co-Pixel	Scenario A: Complete Ban	Scenario B : Use of reference Geometry
Adjacent Pixel	Scenario C: Apply a propagation Model & use co-channel protection Ratios	Scenario D: Apply a propagation Model & use adjacent-channel protection Ratios

#### A10.6.1 Scenario A: co-pixel co-channel

In this case the potential of a WSD to interfere with a DTT receiver is so great, that its transmit power should be too small for any practical use. Instead of stating a power which will be in the nW range, we opted for a complete ban.

#### A10.6.2 Scenario B: co-Pixel adjacent channel

The difference between the co-channel and adjacent channel protection ratios can be large enough to allow the WSD to transmit at a useable power. In this report we only consider the ‘mobile - WSD’ reference geometry as shown in Figure 106 of [16].

If  $P^{WSD}$  is the e.r.p. of the WSD, then the resulting Field Strength at a distance  $d$  from a  $\lambda/2$  dipole is given by [14] p.39 :

$$E^{WSD} = P^{WSD} + 16.9 - 20 \log d \tag{48}$$

or:

$$E_{(dBuV/m)}^{WSD} = P_{dBm}^{WSD} + 106.9 - 20 \log d_{(m)} \tag{49}$$

In the remaining of this work we will assume that powers are expressed in dBm, field strengths are expressed in dBuV/m and distances in m. Then:

$$P^{WSD} = E^{WSD} - 106.9 + 20 \log d \tag{50}$$

Since  $m_x$  is the mean value of  $X$ , from Eqns (10) and (14) we get:

$$P^{WSD} = m_x - 106.9 + 20 \log d - r(\Delta_f) \quad (51)$$

$P^{WSD}$  is the e.r.p. of a White Space Device that results in a location probability degradation of  $\Delta_q$ .

equation (51) refers to the case where the DTT receiver aerial points directly to the WSD. If the WSDs are randomly located and randomly polarised, there will be some aerial directivity discrimination  $G_a(\theta)$ :

$$P^{WSD} = m_x - 106.9 + 20 \log d - G_a(\theta) - r(\Delta_f) \quad (52)$$

$G_a$  (dB) depends the azimuth radiation pattern of the DTT receiver aerial. ITU specify a reference pattern, which is used in the UKPM coverage calculations. In practice however, we can never be sure of the viewers' aerials characteristics. Some viewers may use good quality and correctly installed models, that achieve the ITU gain and directivity, but in the same pixel, other viewers may opt for cheaper models, with unpredictable side lobes. The latter case is more common in areas with good coverage, where viewers may opt to reduce the cost of their installation. In order to cater for both scenarios, in this report we assume that there is no angular discrimination protection for WSD interference, i.e.  $G_a(\theta) = 0$ . Introducing such discrimination requires a review of the commonly used aerial models and a derivation of a 'typical installation' reference pattern; both tasks are beyond the scope of this work. Since both WSD and DTT aerial are assumed to be at 10m above ground, no vertical radiation pattern reduction is considered. Finally, the geometries presented in [16] suggest no cross polar discrimination. Under these assumptions, with  $d=20m$ , equation (52) becomes:

$$P^{WSD} = m_x - r(\Delta_f) - 80.88$$

If the interference generated by the WSD is noise-like, we can use the protection margins suggested in [11] paragraph A4.17.

### A10.6.3 Scenario C: Adjacent-Pixel and co-channel

In order to compute the WSD e.r.p. that will result at a specific field strength in a neighbouring pixel, we need to perform a link budget analysis between the two pixels. The propagation model that we assumed in this work is the extended Hata Urban model as suggested in [11] paragraph A4.26. The path loss  $P_l$  is a function of the WSD – DTT receiver separation  $d$  and is given by:

$$P_l(d) = -69.5 + 26.16 \log f - 13.82 \log h_{wsd} - C_H + (44.9 - 6.55 \log h_{wsd}) \log d \quad (53)$$

In the above formula, the distance  $d$  is expressed in metres. Following [16], table 2:

$$h_{wsd} = \max(h_{clutter}, 10m) \quad (54)$$

We set  $C_H = 16$  dB which is a good weighted average between large and small cities.

If the e.r.p. of a WSD is  $P^{WSD}$  then the received power from a TV aerial at a distance  $d$  is

$$P_r = P^{WSD} - P_l(d) + G_r + 2.15 \quad (55)$$

The term 2.15 is added because in this work we express  $G_r$  in dBd.

If the field strength of a WSD transmission at a location is  $E$ , then the received power will be given by<sup>36</sup>:

$$P_r = E^{WSD} - 20 \log f + G_r - 75.05 \quad (56)$$

where  $f$  is the frequency in MHz. The combination of the above equations gives:

$$P^{WSD} - P_l(d) + G_r + 2.15 = E - 20 \log f + G_r - 75.05 \quad (57)$$

or:

$$E^{WSD} = P^{WSD} - P_l(d) + 20 \log f + 77.2 \quad (58)$$

Since this scenario refers to the co-channel case,  $\Delta_f = 0$  therefore from Equations (45) and (58) we get:

$$m_x = P^{WSD} - P_l(d) + 20 \log f + 77.2 + r(0) \quad (59)$$

Solving for  $P^{WSD}$  gives:

$$P^{WSD} = m_x + P_l(d) - 20 \log f - 77.2 - r(0) \quad (60)$$

Distance  $d$  is distance between the centres of the pixel where WSD transmits and that of the victim DTT receiver. According to the geometry in Figure 106, the minimum distance between 'adjacent' pixels is 200m. In practice however the WSD –DTT receiver separation can be smaller, since they can be at the edges of their pixels. It is obvious however that the actual distance can never be less than 100 m. Similarly, the distance uncertainty is always less than  $100\sqrt{2}$  m. Therefore in order to cope with the worst case scenario, we propose to use a modified value  $d'$  in equation (61), defined as:

$$d' = \max(100, d - 100\sqrt{2}) \quad (61)$$

This approach has the advantage that, since  $d' \geq 100$ , it does not violate the Tx-Rx separation restriction of the extended Hata model.

#### A10.6.4 Scenario D: Adjacent Pixel, Adjacent Channel

This scenario is the extension of Scenario C with equation (62) written as:

$$P^{WSD} = m_x + P_l(d') - 20 \log f - 77.2 - r(\Delta_f) \quad (62)$$

Putting together all the possibilities presented in Table 27, the maximum e.r.p. of a WSD device can be computed as:

$$P^{WSD} = \begin{cases} -\infty & : \text{co-pixel co-channel} \\ m_x - r(\Delta_f) - 80.88 & : \text{co-pixel, adjacent channel} \\ m_x + P_l(d') - r(\Delta_f) - 77.2 - 20 \log f & : \text{adjacent pixel} \end{cases} \quad (63)$$

<sup>36</sup> See [http://www.semtech.com/images/promo/Semtech\\_ACS\\_Rad\\_Pwr\\_Field\\_Strength.pdf](http://www.semtech.com/images/promo/Semtech_ACS_Rad_Pwr_Field_Strength.pdf)

## A10.7 IMPLEMENTATION

In order to get an estimate of the spectrum that is available for WSDs, we developed a set of utilities that implement the described procedures. We made the following assumptions:

- The standard deviation of the WSD signal is 3.5dB. This is not based on measurements; it is an estimate that takes into account the relatively short WSD-receiver separation, the random polarisation of WSD signals, and the diversity of the viewer's aerial installations.
- We chose a fixed  $\Delta_q = 1\%$ . There is still a debate on the issue, but this is a good starting point, and the algorithms can be adapted to cater for a varying  $\Delta_q$ .
- Out-of-band emissions of the WSD were ignored. They can be taken into account however by modifying the protection ratios as described in [11] para A5.19, but this is currently beyond the scope of this work.
- No receiver overloading was taken into account.
- We did not provide any extra margin for multiple WSDs, errors in the UKPM, errors in the Hata model, location uncertainty etc. Such a margin can be introduced in the calculations at a later stage.

We used the C 20.2 plan for the transmitter network, and used the final state of the network (end of Continental Clearance). The analysis was based on coverage results that take tropospheric interference into account, so the values for  $m_1$ , and  $\sigma_1$  are those predicted for 1% time interference.

Regarding the DPSA layers we used:

- The PSB layer
- The PSBCOM layer
- The Nations layer
- The dAPSA layer and
- The Marginal layer.

We decided to protect services at Marginal level. This means that for each pixel, we protect every transmitter that provides at least 70% location probability, at 50% time. The coverage data used in this analysis are based on 1% time interference therefore, for some pixel – channel combinations, location probability may drop below the 70% acceptable threshold. We decided to continue protecting such pixel-channels, down to 50% location probability. We made that decision in order to protect viewers at locations with marginal coverage. Tropospheric interference will only affect these viewers a few days a year, but if we allow WSD interference, its effects can be continuous.

The current DPSA layers protect only the UK services. At some locations in Northern Ireland, WSDs may cause interference across the border, to the services of the Irish Republic. Furthermore, viewers in the UK may wish to receive these services, so services from the Irish Republic may also have to be protected at UK pixels. One way of doing this, is by introducing an extra DPSA layer, but more work is required on this issue. We also ignored the planned N.I. multiplexes.

We restricted the maximum e.r.p. of WSDs to 1W, which is a reasonable limit for unlicensed consumer devices. The procedure described in this work can be easily adapted to cater for higher power devices. With this limit in mind, and  $h_{wsd} = 50m$ , equation (60) implies that the radius of the area of interest (see Figure 106) for the co-channel case should be about 30km.

## A10.8 CONCLUSIONS - FUTURE WORK

We presented a method of computing an upper limit for maximum e.r.p. of white space devices in the UK, so as to contain their impact to DTT coverage. We focused on low power consumer devices, although the methodology can be easily adapted to cater for higher power, fixed, outdoor units. The proposed method is flexible and it can form the basis of computing the data that will populate the geo-location database.

The methodology is still under development and Ofcom have asked the BBC to make the database available to the TVWS industry. Some DPSSA layers were not used, the number of the protected multiplexes in N.I. needs rethinking and there are no restrictions to protect PMSEs or portable coverage. We also need to decide on issues like the extra protection margins to compensate for errors in the prediction algorithms, or the presence of multiple WSDs in a pixel.

Our next plan is to address the above issues, and provide a more comprehensive set of availability maps and diagrams that will help decision making.



**APPENDIX TO ANNEX A10**  $\mathbf{m}_x$   
**DERIVATION OF THE MAXIMUM PROTECTED FIELD STRENGTH**

equation (47) can be written as:

$$q_2 = \text{Prob}\{E_s - (U \oplus X) \geq 0\} \quad (64)$$

- $E_s$ , when expressed in dB is a Gaussian random variable (R.V.) that represents the field strength of the wanted signal, and has a mean value  $m_s$  and standard deviation  $\sigma_s$ .
- $U$  is also Gaussian when expressed in dB, and represents the combined protected field strength of the DTT interferers. It has mean  $m_u$  and standard deviation  $\sigma_u$ .
- Finally, when  $X$  is expressed in dB, it is Gaussian as well, and represents the protected field strength of the WSD device, with mean  $m_x$  and standard deviation  $\sigma_x$ .  $m_x$  is the value we want to compute, and  $\sigma_x$  is set to a fixed value, in this work we set it at 3.5dB.
- Operant  $\oplus$  refers to linear addition.

The combined protected field strength of the DTT and WSD interference,  $U \oplus X$ , is then a Gaussian [15], with mean value  $m_{u+x}$  and standard deviation  $\sigma_{u+x}$ . Therefore, the  $C/(I+N)$  in the presence of the WSD, written as  $E_s - (U \oplus X)$ , is also a Gaussian R.V with mean  $m_2$  and standard deviation  $\sigma_2$ . Then:

$$m_2 = m_s - m_{u+x} \quad \sigma_2 = \sqrt{\sigma_s^2 + \sigma_{u+x}^2} \quad (65)$$

equation (65) then becomes:

$$q_2 = 0.5 \left( 1 + \text{erf} \frac{m_2}{\sqrt{\sigma_2}} \right) \quad (66)$$

If we knew  $\sigma_2$ , then:

$$m_2 = \text{erf}^{-1}(2q_2 - 1) \sqrt{2} \sigma_2 \quad (67)$$

And since  $q_2 = q_1 - \Delta q$ :

$$m_2 = \text{erf}^{-1}(2q_1 - 2\Delta q - 1) \sqrt{2} \sigma_2 \quad (68)$$

$q_1$  is the location probability in the absence of WSD interference and is computed from:

$$q_1 = 0.5 \left( 1 + \text{erf} \frac{m_1}{\sqrt{\sigma_1}} \right) \quad (69)$$

$m_1$  and  $\sigma_1$  are taken from the UKPM results.

If we can estimate  $m_2$ , then it will be possible to compute  $m_x$ . The procedure is non-trivial; the first problem is that, although we know  $q_1$  we do not know  $\sigma_2$ . The paper of Schwartz and Yeh [15] shows a method to compute  $\sigma_2$ , but it requires  $m_x$  - the exact value we want to estimate. One way to address this issue is through iterations. Initially we set  $\sigma_2 = \sigma_1$  ( $\sigma_1$  is the standard deviation of C/I+N in the absence of WSD). We use this initial value of  $\sigma_2$  to compute  $m_2$  (through equation 67), then we use  $m_2$  to compute  $m_x$ , and finally we use  $m_x$  for a more accurate estimate of  $\sigma_2$ . Our implementation has shown that the values stabilise in less than 5 iterations.

Let's have a look at the details:

If we set  $\sigma_2 = \sigma_1$  then  $m_2$  can be derived from equation 68. We name  $\Delta_m$  the degradation of the C/(I+N) that is caused by the WSD and it can be computed through :

$$\Delta_m = m_1 - m_2 \quad (70)$$

$m_1$  is the C/(I+N) value in the absence of WSD, and is a value that we get from the UKPM results (see Figure 105). From Equations 65 and 70 we have:

$$m_s - m_{u+x} = m_2 = m_1 - \Delta_m \quad (71)$$

Using equation **Error! Reference source not found.** the above equation can be written as:

$$m_s - m_{u+x} = m_s - m_u - \Delta_m \quad (72)$$

or:

$$m_{u+x} = m_u + \Delta_m \quad (73)$$

If we set  $A = X - U$ , then  $A$  is also Gaussian (since it is expressed in dB) with mean value  $m_a$  and standard deviation  $\sigma_a$ :

$$m_a = m_x - m_u \quad \sigma_a = \sqrt{\sigma_u^2 + \sigma_x^2} \quad \sigma_u^2 = \sigma_1^2 - \sigma_s^2 \quad (74)$$

Then, following equation 29 of [14]:

$$m_{u+x} = m_u + G_1(\sigma_a, m_a) \quad 37 \quad (75)$$

and combining it with equation (38) gives:

$$G_1(\sigma_a, m_a) = \Delta_m \quad (76)$$

---

<sup>37</sup> In the S&Y paper [14]  $m_a$  and  $\sigma_a$  are expressed in Neper-Bell, while in this article we work with dB. An appropriate scaling has to be applied.  $m_a$  and  $\sigma_a$  of this article correspond to  $m_w$  and  $\sigma_w$  of [14].

Since  $\Delta_m$  is known through equation (70), and  $\sigma_a$  from equation 74, we can use the above equation to compute  $m_a$  and then  $m_x$ . To do that however we need to derive the inverse of  $G$  (for a given  $\sigma_a$ ), which we believe is impractical. We chose instead to compute  $G^{-1}(\sigma_a, *)$  numerically, and fill a lookup table for every practical value of  $\Delta_m$  and  $\sigma_a$ . Once  $m_a$  is estimated,  $m_x$  can be derived from:

$$m_x = m_u - m_a = m_s - m_1 - m_a \quad (77)$$

$m_s$  is the mean value of the wanted field strength, and is one of the values that we get from the UKPM. Once a first estimate of  $m_x$  is computed (it is an estimate because we assumed  $\sigma_1 = \sigma_2$ , we can go back and compute  $\sigma_2$ :

Following equation (30) of [15]:

$$\sigma_{u+x}^2 = \sigma_u^2 - G_1^2(\sigma_a, m_a) + G_2(\sigma_a, m_a) - 2 \left( \frac{\sigma_u}{\sigma_a} \right)^2 G_3(\sigma_a, m_a) \quad (78)$$

And since  $\sigma_2^2 = \sigma_s^2 + \sigma_{u+x}^2$ :

$$\sigma_2 = \sqrt{\sigma_s^2 + \sigma_u^2 - G_1^2(\sigma_a, m_a) + G_2(\sigma_a, m_a) - 2 \left( \frac{\sigma_u}{\sigma_a} \right)^2 G_3(\sigma_a, m_a)} \quad (79)$$

If we repeat the process a few times, the value of  $m_a$  will stabilise and from that we can obtain  $m_x$  which is the protected field strength we seek.

$\sigma_s$  is the standard deviation of the wanted signal (expressed in dB). In MFN networks, the wanted signal comes from one transmitter, so  $\sigma_s = 5.5$  dB. In SFNs though the value can be different, as a result we have to read  $\sigma_s$  from the UKPM results rather than setting it to a fixed value.

## ANNEX 11: WORKED EXAMPLE FOR THE TRANSLATION PROCESS FOR THE PROTECTION OF DTT USING THE MONTE-CARLO METHOD

For a given geographic pixel, the database must examine all relevant co-channel and adjacent-channel interference scenarios with respect to the victim DTT channels.

For each WSD-to-DTT frequency offset maximum permitted WSD e.i.r.p. emission levels required for a tolerable level of interference to the DTT services.

The following calculations are to be performed for any given pixel where the WSD operates, and for all frequency separations between the WSD's candidate channel and the DTT channels:

- In order to reduce the computational time, the geo-location database could contain a set of information, namely the frequencies, median  $mS(dBm)$  and standard deviation  $\sigma S(dB)$  of the received DTT signal power/field strength, the median  $mU(dBm)$  and standard deviation  $\sigma U(dB)$  of the DTT interferer powers/field strengths, as well as the resulting DTT location probability  $q_1$  in every geographic pixel. The above parameters can be provided by the national DTT network planning model. In the absence of such a model, the above parameters can be calculated explicitly based on the technical characteristics and locations of the DTT transmitters, as described in Equation (1);
- The geo-location database translation engine will need to calculate the median and standard deviation of the coupling loss between the WSD interferer and victim DTT receiver. This requires the use of appropriate propagation models and interferer-victim geometries. The selection of such interferer victim geometries could be assisted by information provided by WSD in a database query (e.g. antenna pointing direction, type of antenna used, etc). For victim DTT channels that are used by the DTT service in the same pixel as the WSD, the coupling gain must be based on a reference coexistence geometry that are deemed suitable in the context of protecting the DTT platform. Such reference geometry is necessary because the precise spatial separation between the WSD and a victim DTT receiver within the given pixel cannot be known by the database. For DTT channels that are not used by the DTT service in the same pixel as the WSD, the coupling gain can be based on the actual spatial separation between the pixel where the WSD operates and the pixel where the DTT channel is used by the DTT service.
- The geo-location database will need to assume a certain number of parameters:
  - a) tolerable degradation  $\Delta q = q_1 - q_2$  in the DTT location probability of pixels where the DTT services are used.
  - b) the appropriate protection ratios for the WSD.
- The database can readily compute the maximum permitted WSD e.i.r.p.s by the Monte Carlo methodology or the analytical approximations described in sections above.

In general, with either the Monte Carlo or the analytical approaches, for each pixel covered by a DTT service, the location probability in the presence of DTT interference only will be calculated once<sup>38</sup> and be stored in the geo-location database.

In order to calculate the DTT location probability in the presence of DTT interference and WSD interference it would be necessary to take account of all WSD interference sources. The number of WSD interfering sources will be large and many of the WSDs will be changing locations, at least periodically. This will involve a large number of calculations (either Monte Carlo or analytical) for each pixel and each relevant frequency.

In Annex 3, sections A3.6 to A3.8, it is shown, using Monte Carlo simulation, that for a small degradation in location probability (0.1% to 1%, say) an overall aggregate nuisance field (OANF) can be calculated. That is, knowing the OANF, only the individual nuisance fields need to be calculated, power-summed and compared to the OANF. If the OANF is exceeded, the degradation in location probability will be too large.

This means that, instead of doing using Monte Carlo simulation or analytical calculations repeatedly, the maximum permissible WSD e.i.r.p. can be obtained by determining the relevant nuisance fields, and power summing.

<sup>38</sup> Of course, if additional DTT interferers are introduced at some point in time, or if some of the existing DTT interferers are modified or deleted, then a new calculation for the location probability in the presence of DTT interference only must be calculated and stored.

The section below shows the steps that would be involved and the storage requirements for this shorter, less calculation intensive, procedure

**A11.1 PROCEDURE TO DETERMINE MAXIMUM PERMISSIBLE WSD E.I.R.P. USING OANF**

**A11.1.1 Database Data Storage**

The following tables give a schematic representation of the data that the data base may contain in order to facilitate the required calculations.

*A11.1.1.1 Data for Calculation*

For each pixel, the DTT frequencies received with a sufficient level (corresponding to the planned reception mode: fixed, portable outdoor or portable indoor) in the pixel are stored.

For each frequency, the following data is stored:

- the median wanted field strength received in the pixel;
- the location percentage in the pixel, taking into account noise and interference from the DTT network;
- the total nuisance field allowed in the pixel on the basis of an acceptable degradation in the location percentage of that pixel (see section below and Annex 3 for explanation on the calculation of the total nuisance field).

**Table 28: Data stored for each frequency**

DTT Pixels				
Pixel	DTT frequencies	Wanted FS level	Loc %	Total Nuis. allowed
1	F1	Ewm1	LP1	NT1
	F2	Ewm2	LP2	NT2
	F3	Ewm3	LP3	NT3
	...	...	...	...
	Fi	Ewmi	LPi	NTi
2	F1	Ewm1	LP1	NT1
	F2	Ewm2	LP2	NT2
	F3	Ewm3	LP3	NT3
	...	...	...	...
	Fi	Ewmi	LPi	NTi
J	F1	Ewm1	LP1	NT1
	F2	Ewm2	LP2	NT2
	F3	Ewm3	LP3	NT3
	...	...	...	...
	Fi	Ewmi	LPi	NTi

*A11.1.1.2 Recorded data of authorized WSDs*

The Database (database) should store the characteristics of the WSD which have been authorized. These WSDs must confirm the frequency and the e.i.r.p. that they are using.

The Type and the Tx-Height of the WSD are used to select the reference geometry for the local interference (related to the same pixel and in the surrounding 8 pixels, see explanation below).

The database stores the following e.i.r.p. levels:

- e.i.r.p.-type-max: the maximum e.i.r.p. of the WSD type;
- e.i.r.p.-auth-max: the authorized maximum e.i.r.p.;
- e.i.r.p.-eff: the e.i.r.p. effectively used by the WSD and confirmed to the database.

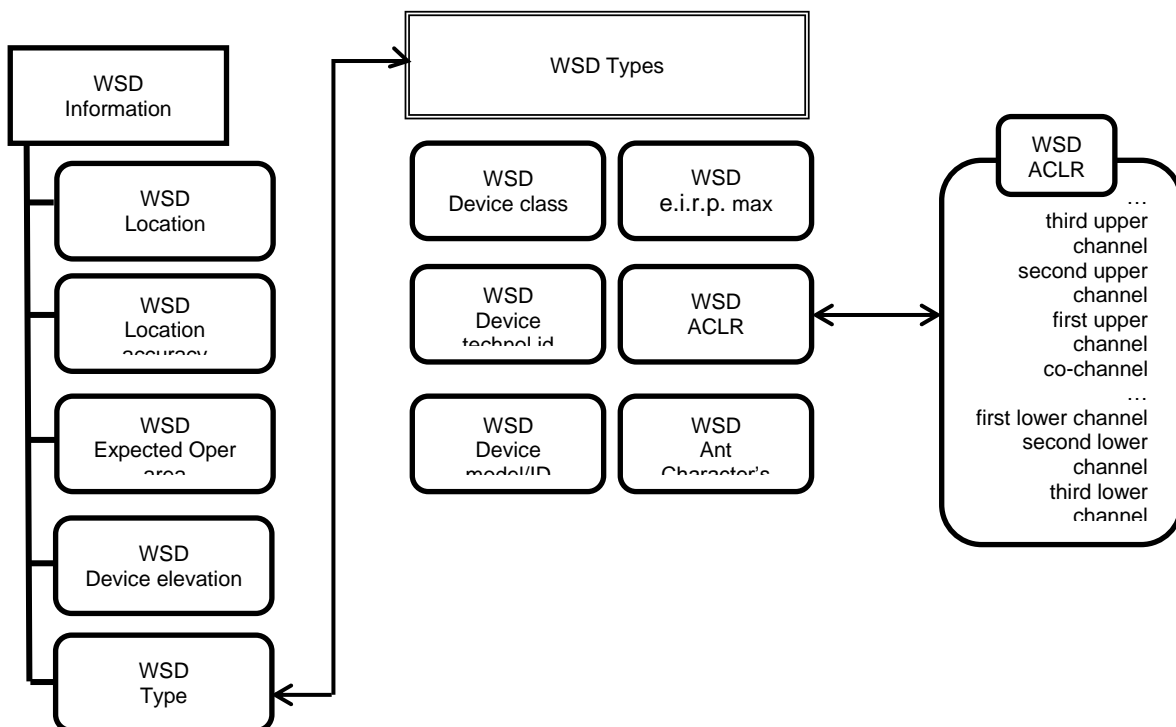
The information on the antenna transmit pattern and the polarisation are used in the calculation of the nuisance filed strength of the WSD, when relevant.

For each WSD the database contains also the protection ratios that should be used for the calculation of the nuisance fields, for all the offsets corresponding to the relevant frequencies (i.e. from co-channel to N±9).

The following Table and Figure 107 gives a schematic representation of the WSD characteristics that the database will need to perform particular calculations.

**Table 29: WSD characteristics stored in the database**

	WSD1	WSD2	WSD3	...	WSDk
Category	Portable _master	Fixed_10m _master	Fixed_30 _master		Portable _slave
Frequency or channel					
Tx-Height (Device elevation)	Clutter height	10 m	30 m		1.5 m
e.i.r.p.-max (dBm)	0	20	30		-10
e.i.r.p.-eff (dBm)	0	18	25		-13
Protection Ratios (dB)					
WSD type					
Location and its accuracy					



**Figure 107: WSD information stored in database**

*A11.1.1.3 Storage of authorized WSD*

For each WSD registered in the database (i.e. authorised at a given frequency and with a given e.i.r.p.), its nuisance field relevant for a given frequency in a given pixel is stored with a link to the concerned frequency and the concerned pixel. The criteria to decide when the nuisance field is relevant is explained in Section below - Step 4.

**Table 30: Authorized WSD**

Nuis. FS					
Pixel	WSD1	WSD2	WSD3	...	WSDk
1	N1F1_1	N1F1_2		...	N1F1_k
	N1F2_1		N1F2_3	...	N1F2_k
		N1F3_2	N1F3_3	...	N1F3_k
				...	
	N1Fi_1			...	N1Fi_k
2		N2F1_2	N2F1_3		
		N2F2_2			
		N2F3_2			
			N2Fi_3		
J		NJF1_2			NJF1_k
		NJF2_2			
		NJF3_2			NJF3_k
					NJFi_k

*A11.1.1.4 Interference Management Methodology*

The proposed database methodology is based on a global approach to interference effects. This means that all ‘significant’ WSD interferers are taken into account in each pixel affected. In order to do this, each pixel must be considered individually.

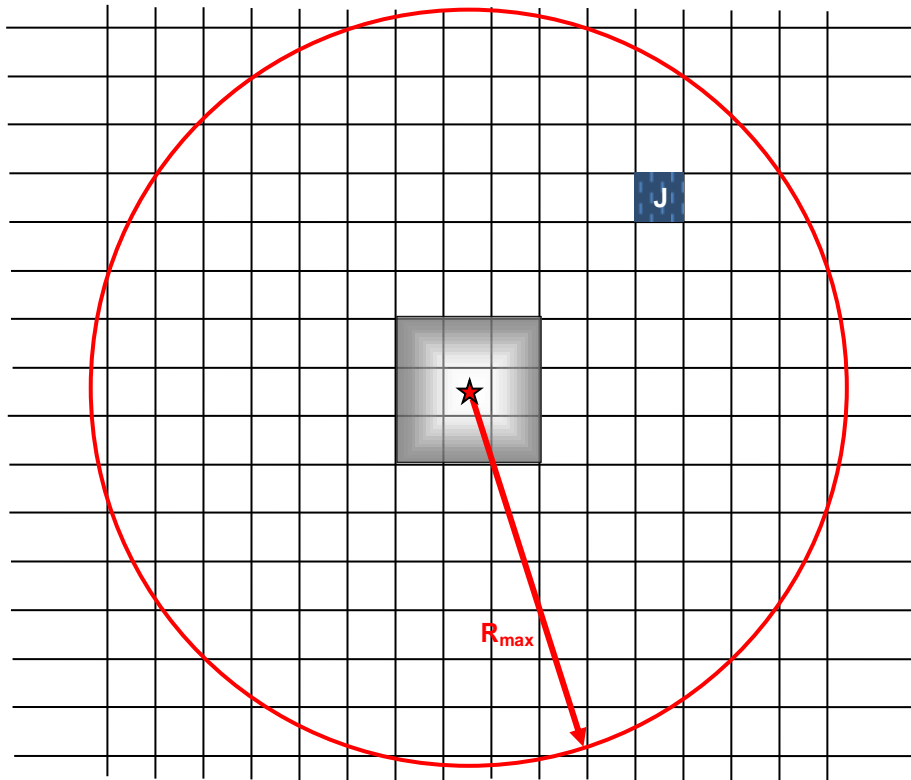
A WSD with a given transmit antenna height, htx is to be introduced within a given pixel (designated as pixel P0) – WSD0.

The database is to authorize a maximum e.i.r.p. to the WSD0, e.i.r.p.-auth-max, according to the WSD’s type, which satisfies all DTT protection criteria.

There is a set, S0, of n available frequencies for the pixel P0:  $S_0 = \{f_1, f_2, \dots, f_n\}$ .

The following steps are to be carried out for each frequency, in the set S0, or until a frequency and e.i.r.p. have been assigned to WSD0.





- The WSD<sub>0</sub> is located in the pixel, P<sub>0</sub>, with the red star.
- The 8 surrounding pixels are shaded grey.
- The 9 shaded pixels constitute the 'local' interference zone
- The radius R<sub>max</sub> is determined by the maximum distance within which a 'relevant' interference might be caused.
- The pixels within the circle other than the 9 in the 'local' zone are in the 'extended' interference zone

**Figure 108: Illustration of the local and extended interference zones**

**Step 1: Determination of pixels to be examined**

It is assumed that a maximum WSD e.i.r.p.auth-max and htx\_max have been established and known by the database. A maximum 'relevant' interference distance, Rmax, is calculated as follows:

- Using the agreed propagation model the distance, Rmax, is calculated such that the interference reference field strength,  $E_{ref\_int} = E_{ref} - PR$  is reached (here the reference field strength  $E_{ref\_int}$  is  $56.21 \text{ dB}\mu\text{V/m} - PR$ , which protects DTT coverage in the presence of noise, with a 95% location probability (LP),

$$E(\text{e.i.r.p.-auth-max} + 20; \text{htx}_{\text{max}}; R_{\text{max}}) = E_{ref} - PR = 56.21 \text{ dB}\mu\text{V/m} - PR.$$

The value e.i.r.p.-auth-max + 20 is used as the e.i.r.p. level in the field strength prediction when determining Rmax in order to ensure that interference effects from other WSD, than those which create a interference signal level equal to  $(E_{ref} - PR)$ , are fully accounted for. These WSD's individually create an interference 20 dB bellow  $E_{ref\_int}$  ( $E_{ref} - PR$ ), however they still contribute adversely when considering the aggregate/cumulative interference. It should be noted that htx\_max is referring to the maximum height of the WSD registered in the database.

- All pixels within a distance Rmax of the WSD0 to be introduced are to be 'examined'.
- A pixel grid is shown in Figure 108. The red star represents the WSD0, located in the pixel P0. The 8 surrounding pixels are designated as pixels P1 to P8.

## Step 2: Examination of individual pixels

- Each pixel within the red circle (Rmax) is examined. As an example we look at pixel J, also indicated in the Figure 107.
- The WSD0 is assumed to have  $e.i.r.p.start = e.i.r.p.cat\_max$ , as appropriate.
- According to the database, pixel J is served by a set of  $m$  frequencies  $S_J = \{F_1, F_2, \dots, F_m\}$ . Some of these frequencies are either adjacent to, or co-channel to  $f_1$  (i.e.  $F_i = f_1, f_1 \pm 1, f_1 \pm 2, \dots, f_1 \pm 9$ ). Those  $F_i$  which satisfy this condition are labelled 'relevant' frequencies.
- If there are no 'relevant' frequencies, the pixel is not affected, and the process begins again with a new pixel.
- Each 'relevant' frequency is considered in turn.

### Step 2.1 Suppose F1 is the first 'relevant' frequency

- The database has stored all relevant nuisance fields for  $F_1$  in pixel J:  $N_{JF1\_1}, N_{JF1\_2}, N_{JF1\_3}, \dots, N_{JF1\_k}$ .
- It has also stored the maximum allowed cumulative nuisance field,  $NTF_1$ , for  $F_1$  in pixel J (see Table X);

$NTF_1$  is the nuisance field which must not be exceeded by the cumulative effects of all of the interfering WSDs (see Annex 3 which describes the concept of total nuisance field).

- The new nuisance field,  $NF_1$ , produced by WSD0 in pixel J is calculated for 'relevant' frequency  $F_1$ .
- The power sum of the new nuisance field  $NF_1$  and the existing nuisance fields,  $N_{JF1\_1}, N_{JF1\_2}, N_{JF1\_3}, \dots, N_{JF1\_k}$ , is carried out ,

$$N_{TOT} = N_{F1} \oplus \left\{ \bigoplus_{i=1}^k N_{JF1\_i} \right\}, \text{ and a comparison with } NTF_1 \text{ is made.}$$

- If  $N_{TOT} \leq NTF_1$ ,  $e.i.r.p.WSD_0$  can be maintained equal to  $e.i.r.p.start$ . Otherwise,  $e.i.r.p.WSD_0$  will have to be reduced, and a new value of  $NF_1$  and  $N_{TOT}$  calculated until  $N_{TOT} \leq NTF_1$ .
- The result of this step is  $e.i.r.p.WSD_0$  which may be smaller than to begin with (i.e.  $e.i.r.p.WSD_0 \leq e.i.r.p.start$ )
- **Step 2.2** Step 2.1 is repeated for each 'relevant' frequency using the WSD0  $e.i.r.p.$  resulting at the end of Step 2.1; the consideration of each new 'relevant' frequency may reduce the allowed maximum WSD0  $e.i.r.p.$ .

## Step 3 Priority of WSDs

The steps above describe the procedure for the first-come first-served approach.

That is an existing DTT and WSD 'structure' exists and a newcomer wishes entry. A search is made to find available channels and suitable/adequate  $e.i.r.p.$  values. The newcomer must be fitted into the existing situation – if this is not possible, because of the DTT protection criteria, the new comer must wait until some better time.

A different approach might use some type of 'equitable' treatment to fit the newcomer in by reducing the  $e.i.r.p.s$  of the existing WSDs, e.g. so that:

- The relevant  $e.i.r.p.s$  are reduced by the same amount, or

- the total allowed nuisance field is shared equally amongst the newcomer and the existing WSDs which contribute to the high nuisance level.
- These possibilities are described in the following steps.

### Step 3.1 Equal reduction of e.i.r.p.s

- Once again each available frequency is treated in its own turn.
- The above Step 2.1 is carried out for every pixel within the red circle, but the e.i.r.p. is not reduced pixel by pixel. Instead, for each interfered-with frequency, the pixels are 'rated' from '*worst*' to '*best*'. The '*worst*' pixel, P<sub>worst</sub>, is the one where we have the largest  $\Delta_{diff}$  given by:

$$\Delta_{diff} = NTOT - NTF_i > 0$$

- The e.i.r.p. of each of the WSDs contributing interference to the relevant frequency could be reduced by the same amount,  $\Delta_{diff}$ , which would reduce NTOT to the required limit (NTFi).
- Once the '*worst*' pixel is 'fixed', the nuisance field contribution to the other pixels must be taken into account.

Each e.i.r.p. which has been reduced means a reduction to the nuisance fields in many other pixels. These reductions must be taken into account in re-evaluating the NTOT for each pixel.

- This continues until there are no more pixels with  $\Delta_{diff} = NTOT - NTF_i > 0$ , for any 'relevant' pixel frequency.
- The same procedure can be carried out for each available frequency for WSD0. Some selection process can be selected to determine which of the available frequencies will be used by WSD0 and at which maximum e.i.r.p. level.

### Step 3.2 Equalization of the nuisance fields

- As in Step 3.1, we must order the pixels from '*worst*' to '*best*'. And we treat the '*worst*' first.
- For a given WSD0 frequency, and a specific interfered-with frequency in the specific pixel, suppose there are N contributing WSD interference sources. If the relevant maximum cumulative nuisance field is NTF<sub>i</sub> and

$$\Delta_{diff} = NTOT - NTF_i > 0$$

- Then NTF<sub>i</sub> is to be partitioned 'equally' in the following sense. The limiting 'allowed equitable' nuisance field for each WSD interferer in the specific pixel would be  $N_{lim} = NTF_i - 10 \log N$ .
- All of the nuisance fields contributing to the interference which exceed  $N_{lim}$  would be reduced to  $N_{lim}$  (with the corresponding reduction in the relevant WSD e.i.r.p.). Those WSDs whose nuisance field does not exceed the  $N_{lim}$  value would not have their e.i.r.p. values touched.
- Once the '*worst*' pixel is 'fixed', the 'perturbations' to the other pixels must be taken into account. Each e.i.r.p. which has been reduced means a reduction to the nuisance fields in many other pixels. These reductions must be taken into account in re-evaluating the NTOT for each pixel. Some of the NTOT values will be reduced, perhaps some not. In any case a re-evaluation of the '*worst*' pixel can be made, and the same procedure as just described carried out.

This continues until there are no more pixels with  $\Delta_{diff} = NTOT - NTF_i > 0$ , for any 'relevant' pixel frequency.

The same procedure can be carried out for each available frequency for WSD0. Some selection process can be selected to determine which of the available frequencies will be used by WSD0 and at which maximum e.i.r.p. level.

#### **Step 4 Update of the database**

Once a frequency,  $F_x$ , and an e.i.r.p. $_X$  have been determined by the process above, and the WSD0 is to be implemented, the database must be updated accordingly.

This means that the nuisance field produced by WSD0 in each pixel within the red circle must be calculated, for every relevant frequency (i.e. for every co- and adjacent channel to  $F_x$ ). The level of the nuisance field is stored if it exceeds a threshold calculated using the Total nuisance field of the affected frequency in the affected pixel. For example for frequency  $F_1$  in pixel  $J$ , the threshold is calculated as follows:

Threshold =  $NTF_1 - X$  dB ,  $X$  is to be determined, values of 20 or 30 dB for  $X$  could be used.

In particular, the information for the pixel  $P_0$  must be updated. The WSD0 is situated in  $P_0$  so there is a new nuisance field for  $F_x$  and all the adjacent channels for  $P_0$  itself.

If one of the more complex procedures has been followed, there will also be readjustments of the e.i.r.p.s of some (or perhaps all) of the existing WSDs which had to be 'adjusted' to fit the newcomer in; then the database will have to be updated with respect to each of those changes (e.i.r.p. reduction).

In some sense, this is not a 'huge' undertaking'.  $X$  dB reduction in e.i.r.p. will be reflected in an  $X$  dB reduction in the relevant nuisance fields listed in the database.

#### *A11.1.1.5 Calculation of the interfering fields*

In order to implement the methodology described above it is necessary to calculate the interfering fields generated by the WSDs. This interference is calculated either

- a) within the pixel,  $P_0$ , in which WSD0 is situated and also within its immediate 8 neighbouring pixels (i.e. within the 'local' interference zone), or
- b) between the WSD0 and the pixels in the 'extended' zone which are more distant.
- c) The designations are made clear in the Figure 107.

The following 2 subsections describe how these calculations are carried out.

#### **'Local' interference zone**

The WSD0 is located in pixel  $P_0$ . The relevant nuisance field for  $P_0$  is calculated according to the corresponding reference scenario with the associated parameters, e.g. fixed WSD at 10 m height interfering with fixed DTT reception at 10 m, etc.

The free space propagation model is used over these short distances.

However, to reflect the possibility that the wanted field,  $E_{w\_med}$ , might be changing over the extent of the pixel and its direct neighbours, the relevant nuisance fields for the surrounding contiguous pixels,  $P_1$  to  $P_8$ , are calculated as if the WSD0 were located in those pixels.

Note that the median wanted field,  $E_{w\_med}$ , may change from pixel to pixel, amongst the pixels  $P_0$  to  $P_8$ . It might occur that fixed reception is to be protected in one pixel (because of the value of  $E_{w\_med}$ ) and portable outdoor reception in its immediate neighbour (because of a sufficiently higher value of  $E_{w\_med}$ ).

#### **'Extended' interference zone**

For the pixels in the 'extended' zone, the procedure to calculate the interfering field is as follows.

The propagation path of the interfering signal is calculated between a specific calculation point in the pixel P0 and a specific calculation test point in each pixel in the 'extended' zone.

The calculation location of WSD0 within P0 is taken to be its actual physical site, if it is a fixed installation. Otherwise, for a UE WSD the calculation location of WSD0 is taken to be the center of pixel P0.

The calculation test point of the 'extended' pixel is taken to be the center of that 'extended' pixel.

The height of the WSD0 is that corresponding to its use (e.g. 10 m, 30 m etc for fixed, 1.5 m for UE).

The height of the test point of the 'extended' pixel is that corresponding to the relevant DTT reception mode (e.g. 10 m for fixed, 1.5 m for PO, etc).

The agreed propagation is then used to calculate the resulting field over the calculated path.

**ANNEX 12: DERIVATION OF THE EQUATIONS IN THE 'ANALYTICAL' APPROACH**

To simplify the mathematical notation in Equation (1) (here, denoted Equation 80),

$$q_1 = \text{Prob}\left\{P_S \geq P_{S,min} + \sum_{i=1}^K r_{U,i} P_{U,i}\right\} = \text{Prob}\{P_S \geq U\} \quad (80)$$

we introduce a few new terms.

$$q_1 = \text{Prob}\left\{P_S \geq P_{S,min} + \sum_{i=1}^K r_{U,i} P_{U,i}\right\} \quad (81)$$

$P_{S,min}$  is the minimum wanted signal power with which the receiver can operate correctly in a noise-limited environment. It can be expressed as the sum of the noise power,  $P_N$ , and the minimum  $[C/N]$  ratio. In linear terms, we can write  $P_{S,min} = r_N P_N$ , where  $r_N = 10^{[C/N]_{10}}$ . To unify the terminology we write  $P_{U,0} = P_N$  and  $r_{U,0} = r_N$ . Then Equation 80 can be re-expressed as follows:

$$q_1 = \text{Prob}\left\{P_S \geq \sum_{i=0}^K r_{U,i} P_{U,i}\right\} \quad (82)$$

$q_1$  expresses the location probability that the wanted DTT power is stronger than the total (power summed) interfering power.

If an additional received interfering power,  $P_{wsd\_rec}$  with protection ratio  $r_{wsd}$ , is introduced, the location probability will be reduced to  $q_2$

$$q_2 = \text{Prob}\left\{P_S \geq \sum_{i=0}^K r_{U,i} P_{U,i} + r_{wsd} P_{wsd\_rec}\right\} \quad (83)$$

$P_{wsd\_rec}$  can be expressed, linearly, in terms of the WSD transmit e.i.r.p.,  $P_{wsd\_tx}$ , as

$$P_{wsd\_rec} = G_{wsd} \times P_{wsd\_tx} \quad (84)$$

where the coupling gain,  $G_{wsd}$ , includes the path loss, receiver antenna gain, as well as receiver antenna discrimination and polarization discrimination<sup>39</sup>. The coupling gain,  $G_{wsd}$ , expressed in dB, is a log-normal random variable with a median value,  $m_{G\_dB}$  (dB), and a standard deviation  $\sigma_{G\_dB}$  (dB). The WSD transmitter e.i.r.p.,  $P_{wsd\_tx}$ , is a constant, i.e. it is not variable.

Then Equation 83 can be expressed as:

$$q_2 = \text{Prob}\left\{P_S \geq \sum_{i=0}^K r_{U,i} P_{U,i} + r_{wsd} G_{wsd} P_{wsd\_tx}\right\} \quad (85)$$

A new random variable,  $Z$ , can be introduced by defining

$$Z = P_S - \sum_{i=0}^K r_{U,i} P_{U,i} \quad (86)$$

$Z$ , expressed in dB, has a median value,  $m_{Z\_dBm}$ , and a standard deviation,  $\sigma_{Z\_dB}$ ;  $m_{Z\_dBm}$  and  $\sigma_{Z\_dB}$  can be estimated using numerical techniques such as the Schwartz-Yeh algorithm<sup>40</sup>, the method of moments<sup>41</sup>, or Monte Carlo simulations.

<sup>39</sup>  $G_{wsd} = -\text{LOSS}_{\text{path}} - \text{POL} - \text{DISC}_{\text{rx}} + G_a$ , where POL is the polarization discrimination,  $\text{DISC}_{\text{rx}}$  is the receive antenna discrimination,  $G_a$  the receive antenna gain, including losses.

<sup>40</sup> S. Schwartz and Y. S. Yeh, "On the distribution function and moments of power sums with log-normal components", Bell Syst. Tech. J., vol. 61, pp. 1441–1462, Sept. 1982

Using these new random variables, Equation 85 can be reformulated as

$$q_2 = \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}}\right\} \quad (87)$$

In dB units, this becomes

$$q_2 = \text{Prob}\left\{P_{\text{wsd\_tx\_dBm}} \leq Z_{\text{dBm}} - r_{\text{wsd\_dB}} - G_{\text{wsd\_dB}}\right\} \quad (88)$$

Lei Shi, et al<sup>42</sup>, have shown what an approximation of Equation 88 is:

$$q_2 = \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}}\right\} = \text{Prob}\{Z < 0\} \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}} \mid Z < 0\right\} + \text{Prob}\{Z \geq 0\} \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}} \mid Z \geq 0\right\} \quad (89)$$

But the conditional probability is given by:

$$\text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}} \mid Z < 0\right\} = \text{Prob}\{P_{\text{wsd\_tx}} \leq 0\} = 0,$$

and

$$\text{Prob}\{Z \geq 0\} = q_1.$$

So, from Equation 89 it follows that:

$$q_2 = \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}}\right\} = 0 + q_1 \text{Prob}\left\{P_{\text{wsd\_tx}} \leq \frac{Z}{r_{\text{wsd}} G_{\text{wsd}}} \mid Z \geq 0\right\} \quad (90)$$

A further new variable,  $Z'$ , is defined as

$$Z' = \begin{cases} Z, & Z \geq 0 \\ 0, & Z < 0 \end{cases}$$

$Z'$  (dBm) can be approximated by a log-normal random variable,  $\hat{Z}_{\text{dBm}}$ , which has mean  $m_{\hat{Z}_{\text{dBm}}}$  and standard deviation  $\sigma_{\hat{Z}_{\text{dBm}}}$ . These parameters can also be estimated by the method of moments.

Then equation (90) can be re-written as

$$q_2 = q_1 \text{Prob}\left\{P_{\text{wsd\_tx\_dBm}} \leq \hat{Z}_{\text{dBm}} - r_{\text{wsd\_dB}} - G_{\text{wsd\_dB}}\right\} \quad (91)$$

and the maximum WSD e.i.r.p. is

$$P_{\text{wsd\_tx\_dBm}} \leq m_{\hat{Z}_{\text{dBm}}} - m_{G_{\text{dB}}} - r_{\text{wsd\_dB}} - \sqrt{2} \text{erfc}^{-1}\left[2\left(1 - \frac{q_2}{q_1}\right)\right] \sqrt{\sigma_{\hat{Z}_{\text{dB}}}^2 + \sigma_{G_{\text{dB}}}^2} \quad (92)$$

<sup>41</sup> K. W. Sung, M. Tercero, and J. Zander, "Aggregate interference in secondary access with interference protection," *Communications Letters, IEEE*, vol. 15, no. 6, pp. 629–631, June 2011.

<sup>42</sup> ECC Report 159 provides an incorrect approximation to  $P_{\text{wsd\_tx\_dBm}}$  based on equation A.7.2-2. It should be noted that this wrong approximation can lead to a WSD e.i.r.p. which is about 10 dB too large, which would have a significant detrimental impact on DTT coverage/reception.

A margin,  $IM_{dB}$ , to account for multiple interfering WSD sources or as a 'safety factor', could be added to this expression, if desired.

Equation 92 summarizes the following information:

- An existing interference situation (represented by a median interference power  $m_{\hat{z}_{dB}}$ , a normal distribution with standard deviation  $\sigma_{\hat{z}_{dB}}$ ) leads to  $q_1\%$  LP for DTT reception,
- A single additional allowed (e.g., WSD) interferer (represented by a (maximum) transmitted e.i.r.p.,  $P_{w\text{sd\_tx\_dBm}}$ , with a median coupling gain,  $m_{G_{dB}}$ , a log-normal distribution with standard deviation  $\sigma_{G_{dB}}$ , and protection ratio  $r_{w\text{sd\_dB}}$ ) leads to  $q_2\%$  LP for DTT reception, where  $q_2 < q_1$ .
- The resulting degradation in LP is  $\Delta_{LP} = q_1 - q_2$ .
- Looking at it the other way around, if a desired  $\Delta_{LP}$  is required, choosing  $q_2 = q_1 - \Delta_{LP}$  in equation 12 will provide the maximum single-entry WSD e.i.r.p.,  $P_{w\text{sd\_tx\_dBm}}$ , which leads to an LP degradation not exceeding the desired  $\Delta_{LP}$ .



**ANNEX 13: SEAMCAT SIMULATIONS USED TO SIMULATE A TYPICAL PMSE SCENARIO**

**A13.1 PREVENTION OF CO-CHANNEL INTERFERENCE**

Co-channel interference studies have been performed using SEAMCAT to determine the minimum separation required between a White Space Device (WSD) and a PMSE receiver. For these studies, two cases were considered in which the WSD emission was assumed to be flat across a 1 MHz and also a 5 MHz bandwidth. As little is yet known about the actual operating characteristics of WSDs, no attempt has been made to analyse or simulate transient behaviour.

As shown in the attached report, a co-channel exclusion zone of ~650m for the 5 MHz WSD emission bandwidth case or ~1km for the 1 MHz WSD emission bandwidth case would protect PMSE to the 5% level. It is recommended to increase these distances by a small amount, e.g. 10% to provide a “bubble of protection” including a small safety margin.

There are two additional matters that require further study. One is the required protection distance between PMSE receivers and White Space Devices operating on adjacent channels. Information on the adjacent channel leakage characteristics of WSDs is needed before these studies can be performed. This information could be derived from a draft standard when it is available.

The second matter concerns intermodulation distortion (IMD) interference from White Space Devices operating in adjacent channels. Intermodulation distortion results when the signals from two or more transmitters mix and produce sum and difference products. For example, if one WSD is operating in TV channel “N+1” and another one is operating in channel “N+2”, interference may result to channel “N” even if neither WSD operating by itself would cause interference. This is a matter of concern to PMSE because it is very common for radiofrequency devices to generate IMD when they are operating in close proximity due to mixing that occurs in the nonlinear output stages of each transmitter. It would be expected that multiple WSDs could be operated close to one another, as for example hand held WSDs carried by several theatre patrons who are sitting together. As for the adjacent channel studies, specifications for the amount of IMD emissions that WSDs are allowed to produce are needed before a SEAMCAT simulation can be done.

**A13.2 SEAMCAT CO-CHANNEL SIMULATION**

SEAMCAT tool was used to analyse the WSD Exclusion Zone. Below is the short summary of parameters used.

**Table 31: Input SEAMCAT parameters**

PMSE receiver (Victim receiver)	Operating frequency	700 MHz
	Sensitivity	-95.0 dBm
	Reception bandwidth	200.0 kHz
	Antenna height	5 m
	Noise Floor (N)	-115.0 dBm
	Desired received signal strength	Gaussian Distribution: -85 dBm with std. dev. =10 dB
	PMSE antenna pattern is shown in Figure 109	
WSD (Interfering transmitter)	operating frequency	700.0 MHz
	Power supplied	20.0 dBm
	Reference bandwidth	5 MHz
	Antenna gain	0.0 dBi
	Antenna height	1.5 m
Positioning of interfering and victim links	Path Azimuth	Gaussian Distribution(0.0, 50.0)
	Path Distance Factor	UniformDistribution(650.0, 1000.0)

	Number of active transmitters	1
Propagation model between PMSE and WSD is Extended Hata	Variations std. dev.	5 dB
	Transmitter environment	5 dB
	Receiver environment	5 dB
PMSE protection ratio (see methodology in Annex 6 to ECC Report 185)	C/(I+N)	20 dB
	C	-85 dBm with std. dev. =10 dB

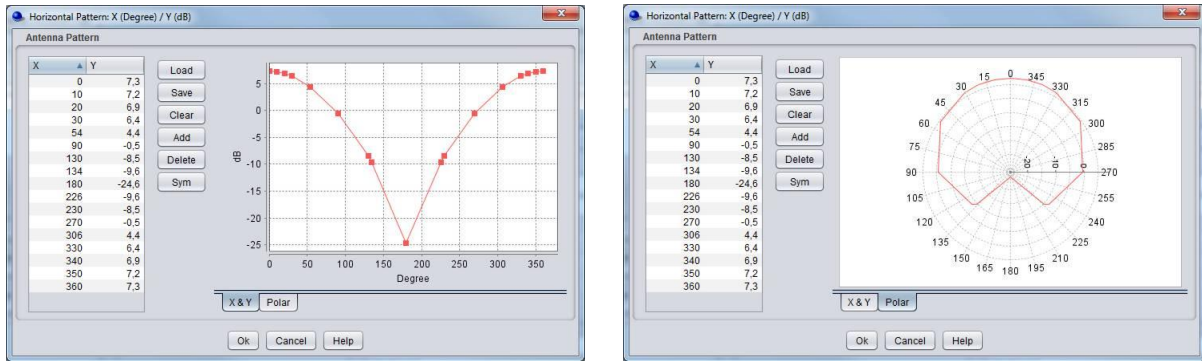


Figure 109: PMSE antenna

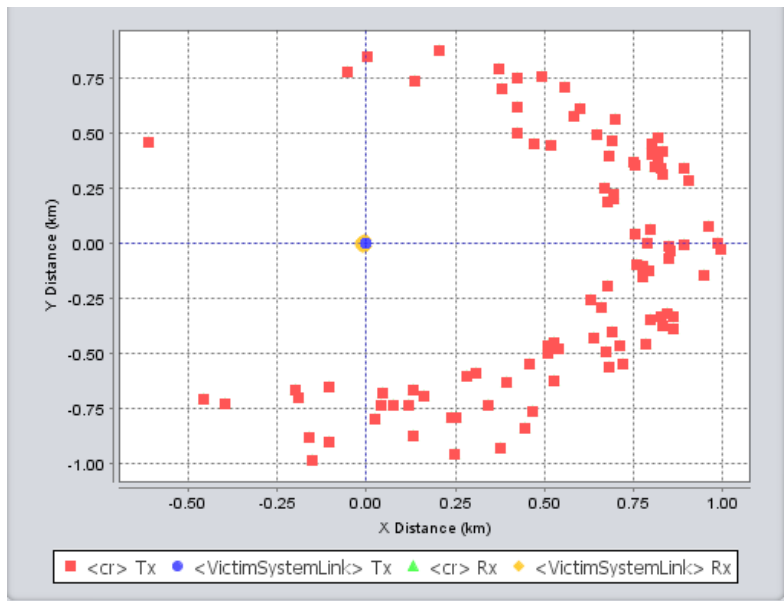


Figure 110: SEAMCAT simulation outline

**A13.3 CONCLUSIONS**

The Exclusion Zone of one WSD device with the parameters listed in the Table below, co-channel to the PMSE channel, need to be ~ 650 m for receiving an interference probability value better than 5 %.

The Exclusion Zone of the WSD device will increase with changing the spectral density, i.e. changing the WSD RF bandwidth of 5 MHz to a RF bandwidth of 1 MHz requires a distance of ~ 1000 m for achieving the same probability value.

**Table 32: Exclusion Zone for one WSD device**

WSD	Exclusion Zone Ext. Hata Rural Area	Exclusion Zone Ext. Hata Urban Area	Exclusion Zone Free Space loss
20 dBm with 5 MHz bandwidth	~ 4,500 m	~ 650 m	25 km
	Interference probability < 5 %	Interference probability < 5 %	Interference probability < 5 %
20 dBm with 1 MHz bandwidth	~ 7,000 m	~ 1,000 m	~ 100 km
	Interference probability < 5 %	Interference probability < 5 %	Interference probability < 5 %

## ANNEX 14: LIST OF REFERENCES

- [1] ECC Report 159 Technical and operational requirements for the possible operation of cognitive radio systems in the 'white spaces' of the frequency band 470-790 MHz
- [2] Recommendation ITU-R BT.419 Directivity and polarization discrimination of antennas in the reception of television broadcasting
- [3] Recommendation ITU-R F.1336-2 Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz
- [4] Recommendation ITU-R P.526-11: Propagation by diffraction
- [5] Narda ([www.narda-sts.de](http://www.narda-sts.de))
- [6] ECC Report 148 Measurements on the performance of DVB-T receivers in the presence of interference from the mobile service (especially from LTE)
- [7] ECC Report 138 Measurements on the performance of DVB-T receivers in the presence of interference from the mobile service (especially from UMTS)
- [8] Recommendation ITU-R P.1546-4
- [9] (See doc. SE43(11)11) Considerations of errors in predicting wanted DTT signal, EBU
- [10] Ofcom, Implementing Geo-Location  
<http://stakeholders.ofcom.org.uk/binaries/consultations/geolocation/summary/geolocation.pdf>
- [11] H.R.Karimi, Geo-location databases for white space devices in the UHF TV bands: Specification of maximum permitted emission levels. 2001 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) pp.443-453
- [12] JPP, Definition of the Digital Preferred Service Area Post DSO, Doc No JPP 667, v 1.04 28 June 2011
- [13] M.P.M. Hall et al Propagation of Radiowaves ISBN 0-85296-819-1
- [14] S.C.Schwartz , Y.S.Yeh On the distribution Function and Moments of Power Sums With Log-Normal Components. Bell System Technical Journal, Vol 61, No7, September 1982.
- [15] H.R.Karimi, S.Y.Tan, Interferer-victim geometries for use by white space databases in the context of DTT protection TVWS Discussion Document 29-11-2011, Updated 16-12-2011
- [16] ECC Report 185: Complementary Report to ECC Report 159 on further definition of technical and operational requirements for the operation of white space devices in the band 470-790 MHz;
- [17] Recommendation ITU-R RA.769 Protection criteria used for radio astronomical measurements.