Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

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

Cardiff, January 2011

"CEPT has subsequently developed ECC Report 185 and 186 as complementary studies to ECC Report 159. In particular, the geo-location approach is considered in more details in ECC Report 186, including the initial considerations contained in this Report (ECC Report 159)"

0 EXECUTIVE SUMMARY

This report was developed to provide technical and operational requirements for cognitive radio systems (CRS) in the 'white spaces' of the frequency band 470-790 MHz in order to ensure the protection of the incumbent radio services.

Taking as a starting point the definition of white spaces provided in CEPT Report 24 [1], this report identifies a range of possible deployment scenarios for white space devices (WSDs) and, in the absence of specific system characteristics related to WSDs, sets up some key assumptions, such as the use of OFDM technology for WSDs, in order to perform first sharing studies.

Various different methodologies have been chosen in this report to develop protection criteria for each of the incumbent services studied. Some of these protection criteria have been developed using results of measurements whilst others have been developed using parameters from ECC, ITU or ETSI deliverables. This has resulted in a number of different recommendations for the technical and operational requirements that should be applied to WSD operating in the frequency band 470-790 MHz in order to protect the various incumbents. All of the different results of the protection requirements for incumbent services/systems need to be taken into account before concluding on the technical and operational requirements for WSDs.

Whilst three cognitive techniques (sensing, geo-location database and beacon) were considered at the start of the study, most of the efforts were devoted to the assessment of the appropriateness of the sensing and geo-location techniques to provide protection to the incumbent radio services.

It should be noted that the consideration of cable services is outside the scope of this report and, therefore, was not addressed.

- **Protection of the broadcasting service**

The studies presented in this Report have addressed a method for calculating an appropriate sensing threshold method and the corresponding maximum emission limits for WSD under various configurations.

The sensing thresholds were derived for a limited number of scenarios using the methodology developed within this report and taking into account a range of potential DTT receiver configurations. Some of the values obtained (being in the range from -91 to -155 dBm depending on the DTT planning scenario) appear to be extremely challenging to implement using current technologies. Moreover, in some scenarios, even these low values for the detection threshold do not guarantee a reliable detection of the presence/absence of the broadcasting signals at a distance corresponding to the interference potential of a WSD.

This led to the conclusion that, the sensing technique investigated, if employed by a stand-alone WSD (autonomous operation), does not to be reliable enough to guarantee protection of nearby DTT receivers using the same channel. Therefore, the use of a geo-location and to avoid possible interference to DTT receivers appears to be the most feasible option. In addition it is concluded that in cases where the use of a geo-location database can provide sufficient protection to the broadcast service, sensing is not required. There may be some potential benefit in using a combination of sensing and geo-location database to provide adequate protection to DTT receivers but these benefits would need to be further considered.

In the geo-location database models studied the database would provide a WSD with information on the available frequencies and the associated maximum e.i.r.p. values that the WSD is permitted to use. In the models studied in this report it is necessary to specify or make an assumption on the minimum required adjacent channel leakage ratio (ACLR) for the WSD using the geo-location database . Administrations who intend to authorise the use of geo-location database-assisted WSD use will have to decide on the most appropriate parameters and algorithms that are the most relevant for their own specific national circumstances.

In some of these geo-location database usage models it may not be necessary for administrations to define, assume or mandate a fixed value for the maximum permitted e.i.r.p. for WSDs. However, Administrations may still decide to assume or mandate maximum permitted e.i.r.p. of WSDs considering their usage and the DTT implementations they are protecting.

- **Protection of PMSE**

Spectrum sensing is currently considered as a problematic approach for the protection of PMSE systems from WSD interference. Taking into account the range of potential PMSE deployment scenarios, the studies show that there is a great level of variability in the derived sensing thresholds. Temporal fading caused by multipath propagation is likely to be one of the main factors affecting the ability of WSDs to use sensing as a viable technique to protect PMSE systems from interference. In some cases, taking account of this type of fading may lead to a very low detection threshold, far below the WSD receiver noise floor, which would make this technique quite impractical. This points to

a need for further study of the propagation characteristics of PMSE systems operating in various configurations and specifically on ways for any WSD utilising spectrum sensing to cope with temporal fading.

Although not considered in all details, the disable beacon concept, where the detection by the WSD of the beacon implies that the channel is occupied and therefore not available may be an approach which can help to overcome some of difficulties highlighted in relation to implementing sensing. Additional information would be needed from the industry to further consider aspects related to the implementation of this technique and its impact on the efficient use of the spectrum.

Again use of a geo-location database appears to be the most feasible approach considered so far for the protection of PMSE. A number of practical questions, some of them beyond the scope of this Report still require resolution, such as how users will enter their data into the system, what information should be stored, and how often WSDs must consult the database, to name a few.

In addition, it appears that the identification by national administration of at least one (or more) safe harbor channels for PMSE use and, therefore not available for WSDs, would be helpful for the protection of PMSE in particular for casual or unplanned usage by PMSE which would not be registered in a geo-location database. These safe harbor channels could be allocated either on a national and/or geographic basis.

- **Protection of Radio Astronomy (RAS) in the 608-614 MHz**

The studies conducted 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 revealed that very large separation distances are needed. Therefore, it is recommended that the TV channels 37 to 39 should be avoided for autonomous WSDs based on a sensing only mechanism. This requirement can be relaxed provided that the device is aware of its geographical location and that the regulation of the country where it is located allows the use of this channel. For WSDs which have access to a geo-location database, exclusion zones around RAS sites should be defined in the database. In that case, consultation between neighbouring administrations may be required when WSD operation in channel 38 is proposed.

- **Protection of aeronautical radionavigation (ARNS) in the 645-790 MHz band**

Preliminary considerations have been provided on the relevance of the sensing and geo-location techniques for the protection of ARNS. However, some additional information would be required on the ARNS deployment considerations in order to perform an appropriate analysis.

- **Protection of Mobile/Fixed services in bands adjacent to the band 470-790 MHz**

Two different methodologies for deriving suitable protection for the Mobile Services in the bands adjacent to 470 – 790 MHz were proposed. Both methodologies are not fully developed and will require further studies to be carried out,

One study on the impact from WSDs on the mobile service in the band 790-862 MHz show that, in order to maximize permitted in-block power for WSDs operating close to the band edge at 790 MHz, very high adjacent channel leakage ratios (ACLR) over frequencies in the band 790-862 MHz are required. A reduction of required ACLR is possible if in return a stricter limitation of the in-block power limit is defined. Depending on the anticipated deployment scenario and business case for WSDs, different trade-offs between permitted in-band power and required ACLR will likely be regarded as optimum.

The other study addresses protection requirements for Private Mobile Radio systems operating in the adjacent band below 470MHz.

No study has been performed for the protection of public mobile systems below 470 MHz.

- **Definition of the requirements for the geo-location database approach**

The Report sets up the principles and defines the requirements for the operation of WSDs under the geo-location approach. Specific requirements are provided for WSD deployment using a master/slave architecture

It identifies the information which needs to be communicated by the WSD to the geo-location database and vice-versa.

A key element in the geo-location database approach is that the WSD will be providing information to the database which will then be used by the database to calculate and output information containing a list of allowed frequencies and their associated maximum transmit powers to the WSD. The Report also provides guidance to administrations on a general methodology for this input/output translation process that needs to be carried out between the WSD and the database as well as some examples of the algorithms that can be used in the calculations to be performed by the database. The approach of providing example algorithms is motivated by the need to enable flexibility for administrations to adapt the framework to their national circumstances (e.g. national DTV planning model, specific national quality requirements, etc.). The algorithms and underlying modeling assumptions made on a national level can nevertheless have a significant influence on the effectiveness of the protection of incumbent users and therefore have to be chosen very carefully.

Several options are presented for the management of a geo-location database including the decision for a database at a national or European level, one or various databases, public or closed database, etc

It is expected that this report could be used as a basis to develop an appropriate regulatory framework within CEPT for the operation of a geo-location database in the 470-790 MHz band. The information provided in this report should also be considered by the standardisation bodies in order to develop relevant specifications and testing procedures.

- **Assessment of the spectrum potentially available for WSD**

The amount of spectrum available for WSDs depends upon a number of factors including decisions on the level of protection given to the incumbent services and how well the WSD can cope with interference from these incumbent services and other WSDs.

The exact amount of available spectrum at any location will be dependent upon each national situation or circumstances (e.g. DTT planning configuration, PMSE use, Radio Astronomy use). The objectives of the study presented in this report are to provide a general methodology to assess the amount of spectrum potentially available and some examples of the technical parameters that will be required to protect incumbent services based on specific scenarios. This is an iterative process that requires the full determination of the technical and operational conditions for WSD.

- **Further activities**

Taking into account the innovative nature of cognitive techniques and the ongoing research and industry activities in this field, it is recognised that this Report may need to be updated in a relatively short timeframe in order to reflect the latest developments in the technology. Therefore a list of areas that may require further work has been developed.

Table of contents

LIST OF ABBREVIATIONS

ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ARNS	Aeronautical Radionavigation Service
AWGN	Additive White Gaussian Noise
BPL	Building Penetration Loss
BS	Broadcasting Service
CCDF	Complementary Cumulative Distribution Function
CPE	Customer Premise Equipment
CPC	Cognitive Pilot Channel
CRS	Cognitive Radio System
DAA	Detect And Avoid
DTT	Digital Terrestrial Television
DTV	Digital Television
DVB-T	Digital Video Broadcasting – Terrestrial
DVB-H	Digital Video Broadcasting- Handheld
ECN	Electronic Communication Network
ENG/OB	Electronic News Gathering outside broadcast
ETSI	European Telecommunications Standards Institute
ETSI TC RRS	Technical Committee Reconfigurable Radio Systems
FCC	Federal Communications Commission
FWA	Fixed Wireless Access
IEEE	Institute of Electrical and Electronics Engineers
IEM	In-Ear Monitoring
LBT	Listen Before Talk
LP	Location Probability
LTE	Long Term Evolution
MI	Multiple interference margin
PR	Protection Ratio
PMSE	Program Making and Special Event
RAS	Radio Astronomy Service
RRC-06	Regional Radiocommunication Conference, Geneva, 2006
RFSENS	Reference Sensitivity
RLS	Radiolocation service
RSBN	Radio system of short-range navigation
O_{th}	Overloading threshold
PAMR	Public Access Mobile Radio
PMR	Private Mobile Radio
PWMS	Professional Wireless Microphone system
SFN	Single Frequency Network
SM	Safety margin
TPC	Transmit Power Control
UE	User Equipment
VLBI	Very Long Base Interferometry
WSD	White Space Device

Technical and operational requirements for the possible operation of cognitive radio systems in the 'white spaces' of the frequency band 470-790 MHz

1 INTRODUCTION

As part of its digital dividend strategy in the band 470-790 MHz, the CEPT aims at high efficiency of the overall spectrum use and the most flexible spectrum usage while allowing the widest possible ranges of uses and technologies. Therefore, CEPT Report 24 [1] indicates that cognitive radio devices may be allowed to use the interleaved spectrum ('white space') subject to the restriction that they will not cause harmful interference to incumbent services to which the band is allocated. A cognitive radio will therefore have to obtain information about the available channels before being allowed to transmit on locally unused channels.

This report was developed in order to provide appropriate technical and operational requirements for cognitive radio systems (CRS) which are to be used in the 'white spaces' (and thus the designation white spaces devices, WSDs) of the frequency band 470-790 MHz to ensure the protection of the primary and secondary services to which the band is allocated.

The definition of the above requirements is based on the following compatibility studies:

1. Protection of broadcasting service (BS) in the band 470-790 MHz from interference from WSDs operating in the band 470-790 MHz;
2. Protection of Program Making and Special Event (PMSE) services in the band 470-790 MHz from interference from WSDs operating in the band 470-790 MHz;
3. Protection of Radio Astronomy Service (RAS) stations operating in the band 608-614 MHz from interference from WSDs operating in the band 470-790 MHz;
4. Protection of Aeronautical Radionavigation Service (ARNS) operating in the band 645-790 MHz from interference from WSDs operating in the band 470-790 MHz.
5. Protection of Mobile/Fixed services in bands adjacent to the band 470-790 MHz from emissions of WSDs operating in 'white spaces' in the band 470-790 MHz.

It should be noted that these studies, which are based on the spectrum usage and expected deployments in CEPT, may not be applicable to other regions of the world.

It should be further noted that within a given area, WSDs may use the same channels as cable services. This may cause interference to cable services. However, the consideration of cable services is outside the scope of this report and, therefore, was not addressed.

2 DEFINITIONS

2.1 White Space

From CEPT Report 24: *'White Space' is a label indicating a part of the spectrum, which is available for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other services with a higher priority on a national basis.*

2.2 Cognitive Radio

From ITU-R Report SM.2152 [2]:

Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.

2.3 White space device

White space devices (WSDs) are devices that can use White Space spectrum without causing harmful interference to protected services by employing required cognitive capabilities.

2.4 Incumbent radio service/system

In this report incumbent radio services/systems authorized for operation on a given frequency band with a regulatory priority include:

- Terrestrial Broadcasting Service (BS) including DVB-T in particular.
- Program Making and Special Event (PMSE) systems including radio microphones in particular.
- Radio Astronomy Service (RAS) in the 608-614 MHz band.
- Aeronautical Radio Navigation Service (ARNS) in the 645–790 MHz band.
- Mobile Service (MS) below 470 MHz and above 790 MHz.

3 WORKING ASSUMPTIONS ON THE TECHNICAL AND OPERATIONAL CHARACTERISTICS OF WHITE SPACE DEVICES FORESEEN FOR THE DEPLOYMENT IN THE BAND 470-790 MHz

This section illuminates some of the possible device categories, deployment scenarios and cognitive techniques which may be envisaged for WSD, for the purpose of studying the protection requirements of existing services. The assumptions laid out here are not intended to restrict industry flexibility to innovate in using white spaces. It is very likely that there can be other kinds of devices and deployments. Indeed the potential for innovation is an important justification for considering the opening up of white spaces.

The usage of WSD installed by a network operator might be different compared to a consumer or ad-hoc installation.

3.1 Scenarios

The following are illustrative scenarios, building on familiar uses of similar established technologies. It is possible to foresee at least three broad categories of WSDs:

- Personal/portable;
- Home/office devices;
- Private and public Access points.

3.1.1 General

Personal/portable and home/office devices would be used at low height. 1.5m is a representative height for use in protection studies; however, WSDs may appear at other heights (e.g. inside a building or on a balcony). Access points, in particular public access points are expected to be higher (e.g. 10 to 30 m).

Ad-hoc networking and self-configuring networks may be supported by personal/portable devices, allowing users the ease of installation and flexibility that wireless technology can enable. Thus, for example, consumers may want to move equipment within their home or office, introduce new devices and decide which devices should be powered on or off at any given time.

3.1.2 Personal/Portable

Personal/portable devices are envisaged to be of such a size that they can be carried by individual users, much in the manner of mobile phones or personal media players. They could also be embedded in laptop computers. Access to the Internet is likely to be a common feature, but the range of applications may be very broad. They could include content browsing (online video and audio, for example), but could also encompass machine to machine communication: such as electronic payment or tracking applications. The personal/portable devices may contain transmitters and receivers that are operating in bands outside 470-790 MHz.

Personal/portable devices are likely to go wherever their users go: within houses and offices, along the street, on a train or bus, in a car etc.

3.1.3 Home/office devices

Personal/portable devices as described in the previous paragraph are likely to be used within homes, offices and other buildings. However there may also be non-portable WSDs built in flat panel TVs, personal video recorders and other appliances, which are designed to remain primarily in one place.

The use of white spaces enables access to high quality video services as well as sharing/navigation of content stored locally within the home or office. One potential application is the distribution of television services to secondary television receivers, compensating for reduced viability of portable reception in some areas after the switchover to digital television. Another example of machine-to-machine applications could be remote metering.

3.1.4 Private and Public access points

It is also likely that there will be private access points operating in a similar manner as today's WiFi access points, but utilizing the better propagation of the lower frequencies and thus offering an extended coverage, e.g. inside buildings.

Another important category of device is the public access point or base station, essentially providing a gateway to the Internet. These may support higher power transmission than the other categories of device and might be more commonly located in rural areas, to extend geographic availability of broadband even if city centres are also possible.

Within the coverage of a base station or access point, other categories of WSD may be used. For example, personal/portable devices could use access points or base stations to reach Internet services and content. Another example would be fixed-mounted Customer Premise Equipments (CPE) used as client devices in fixed wireless access scenarios.

Base station and access points are likely to be fixed in position, typically located where connection to a backhaul network is readily available. For example, an optical fibre might be provided to a community centre within a rural area and a white space spectrum base station could be located at the same place, to distribute access across the local area. To enable cost effective coverage in less densely populated areas, such base stations might use higher power combined with high antennas. The backhaul link used by an access point or a base station could also be realized as wireless point-to-point link. Such links could also use white space frequencies.

3.2 Deployment scenarios

The following sections describe some example deployment scenarios. The sharing conditions and regulatory requirements can be considered separately for different deployment types addressing output power, detection threshold etc. These deployment scenarios are examples with respect to propagation and sharing assumptions and do not necessarily represent actual use cases. It should be noted that there are also other scenarios, which can be employed when the networks and devices are deployed.

3.2.1 Radio unit to radio unit-low height - outdoors

This may be the most likely scenario in order to utilize white spaces. In this case, both the access point, operator installed, and the personal/mobile WSD are at low height and outdoors (see Figure 1).

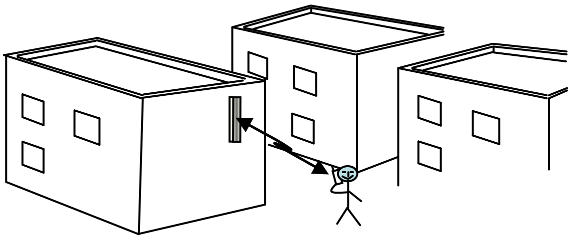

Figure 1: Radio units on low height

3.2.2 Radio unit to radio unit-low height – direct mode - outdoors

Another possibility would be the pure ad-hoc (direct) mode (see Figure 2).

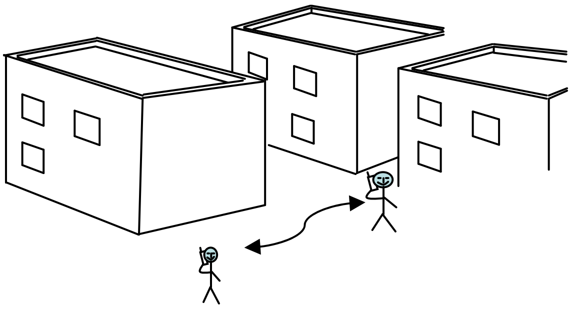

Figure 2: Radio units on low height, in an ad-hoc (direct) mode

3.2.3 Radio unit to radio unit-low height - Indoors

Radio units may also be located indoors enabling direct indoor usage. In this case portable/mobile WSD's are connected to public or private access point indoors (see Figure 3).

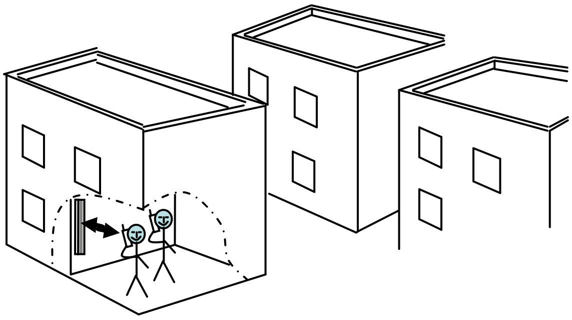

Figure 3: Radio units on low height, indoors

3.2.4 Radio unit to Radio unit – both are mounted high

This resembles the traditional Fixed Service usage, point-to-point, scenarios. But there may also be point to multipoint applications. The key assumption in this scenario is that both receiving and transmitting cognitive radio units are above the roof tops or the surrounding clutter (see Figure 4).

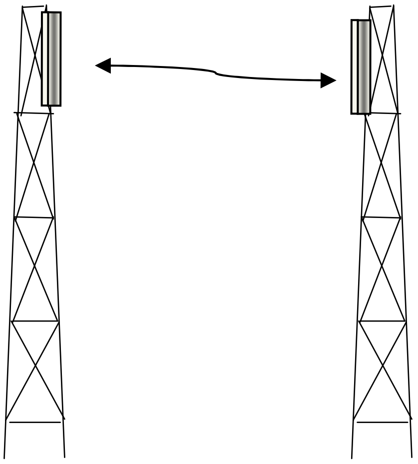

Figure 4: Radio unit to radio unit – both mounted high

3.2.5 Radio unit to Radio unit- one unit is high and the other is on low height

In this scenario, one of the cognitive radio units is low, below roof tops or the surroundings, and the other one, an access point, is high (see Figure 5). This scenario resembles a traditional network for public mobile networks.

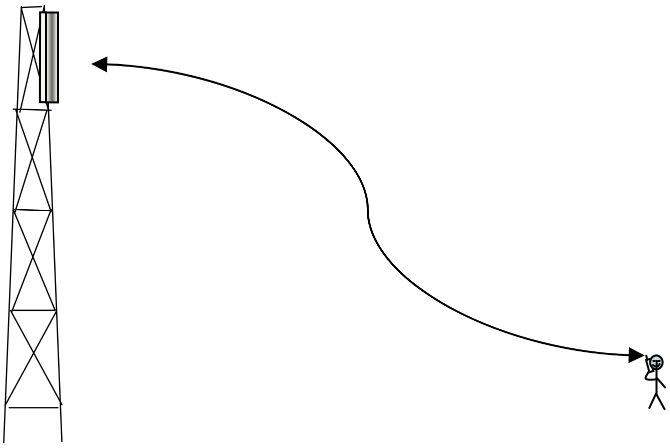

Figure 5: Radio unit to Radio unit- one unit is high and the other is on low height.

3.3 Emission characteristics

The potential risk of interference into protected services depends among others on the transmission characteristics of white space devices. This section defines a set of parameters which can be used to characterise and control the potential to cause interference.

The exact transmission technology or technologies to be used by WSDs cannot be determined at this point in time. There are currently several standardisation activities ongoing in parallel and several technologies are being considered. However, since the OFDM family of technologies seems to currently represent the most efficient and reliable transmission, it is reasonable to assume this type of technology for the purpose of the studies in this report.

Nor can more detailed assumptions be made on the duplexing arrangements because either TDD or FDD could be possible. Furthermore, the transmissions may be continuous or bursty in nature. Some technologies may also be able to combine several available channels at the same time to increase the throughput of the WSD.

The intended transmitted power levels would depend on the use case, but short range communications by WSDs are likely to use power levels between 10 mW to around 50 mW and longer range communications are likely to use powers between 1 to 10 W.

The allowed emission parameters to be defined are directly linked to the technologies used by the services to be protected from WSDs, and especially to the performance of potential victim receivers. They should be chosen in such a way that transmissions from WSDs will not cause harmful interference to protected services, neither in co-channel nor in any adjacent channel.

- **In-block power limit:** When a WSD is operating within a vacant channel, the in-block power limit determines how much power can be emitted within the bandwidth of this particular channel. When a channel adjacent to the vacant channel is occupied by a protected service then the in-band power limit may be linked to the level of the signal(s) in the adjacent channels.
- **Out of block limit:** This determines how much power can be tolerated in channels adjacent to the vacant channel. This limit also may be linked to whether and where there are protected services in adjacent channels, what their signal levels are.
- **Bandwidth:** The WSD-bandwidth within which transmission occurs determines the power density, which in turn influences the potential impact on the protected services.

3.4 Potential cognitive techniques for white space devices (spectrum sensing, geo-location with database access, beacon transmitter)

Three main techniques have been proposed to assist the white space devices in finding unoccupied channels.

3.4.1 Spectrum Sensing

With spectrum sensing, WSDs try to detect the presence of the protected incumbent services in each of the potentially available channels. Spectrum sensing essentially involves conducting a measurement within a candidate channel, to determine whether any protected service is present. When a channel is determined to be vacant, sensing might also be applied to adjacent channels to determine what constraints there might be on transmission power, if any. So for sensing only WSD some channels may have to be permanently excluded, because the occupying service is not amenable to detection by sensing, such as passive service. For example, in the band 608-614 MHz some countries have stations for radio astronomy services which cannot be protected by sensing.

An increasingly sophisticated array of techniques is being applied to spectrum sensing which can yield enhanced levels of sensitivity in return for using more detailed knowledge of the signal characteristics of the service to be protected. However, such techniques can be applied only if the signal characteristics of the protected service are known and if spectrum sensing implemented in WSDs adapts to any change in these characteristics.

A significant advantage of spectrum sensing (stand alone) would be that it does not rely on any existing local infrastructure, such as connection to a database. This could be important where access to the internet is more limited, or when WSDs are used to provide only local connectivity between multiple devices, without requiring access to e.g. the Internet. However, if sensing thresholds are to be set very low in order to protect existing services, this will result in increasing complexity as well as a reduced number of available channels. This would reduce the potential value to end users, particularly in areas of higher population density, and would hinder commercially viable deployment numbers of the WSD technology.

So far analyses of sensing performance assume that detection is carried out independently by each device, in ignorance of results found by other cognitive devices in the same location. The emergence of cooperative sensing, in which devices share their findings, may bring in the future the potential to improve sensing reliability.

The cooperative sensing devices could for example, cover an area, be on different heights, or one device could act as a master and collect the results from the others.

However, this report does not analyse the option of co-operative sensing in any detail and further studies would have to be carried out before assessing the effectiveness of cooperative sensing.

In addition to initial sensing of the band when a device is installed or powered on, we anticipate that sensing devices should periodically re-sense the channel. This will allow them to detect changes in the presence of incumbent services, in a channel previously considered vacant or in one or more of the adjacent channels.

Key parameters for spectrum sensing include:

- Sensing threshold
- Periodicity of re-sensing on channels that have been detected as vacant
- Sampling duration

Sensing methods can be in general divided to two categories: energy detection and feature detection. The energy detection method is used to detect the signal power in the channel under study. The detector can be either wide band matching the channel bandwidth or narrow band with a possibility to slide it across the channel. The advantage of an energy detector is that it is independent of the radio system to be detected and as such future proof and capable of adapting to any new system introduced into the band. A disadvantage is the required low sensitivity due to the noise floor and the possibility of false detections. In case of a very low required detection thresholds an energy detector alone might not be a feasible solution, but can perhaps be used as one element in the detection process.

In order to theoretically approach the problem of energy detection spectrum sensing in a statistical manner the work was initiated to update the SEAMCAT software such that WSD interference into radiocommunication services can be modelled. This approach allows simulating multiple WSD interferers with the presence of one victim system. Its implementation in the SEAMCAT is presented in ANNEX 9.

A feature detector would use certain known characteristics of the signal that is to be detected. This may be a specific pilot carrier signal, preamble, continual or scattered pilots in an OFDM signal, certain periodicity (GI) or sequence in the signal in the time or frequency domain. Using these features will result in a processing gain, which will enable detection below the noise floor in the usual sense. It should be noted that the feature detectors are not in general trying to demodulate the signal and thus are not able to access most of the information carried by the signal. Still they are able to detect the type of the signal e.g. DVB-T or DVB-T2, and thus decreasing the possibilities of false alarms. A drawback in the feature detector is its dependence on the specific features and that it may have difficulties to adapt to any new radio system introduced by the incumbent in the band later. To some extent this may be solved by designing some flexibility within the detector, e.g. by updating the software after the product is placed on the market. A good example of a DVB-T feature detector was shown in [3]. A general example of a feature detector based on cyclostationary principle, is shown in [4].

3.4.2 Geo-location

In this approach, WSDs would measure their location and consult a “geo-location” database to determine which frequencies they can use at their location (i.e. the location which they have indicated to the database). Parameters such as location accuracy, frequency of database enquiry and quality of the database are essential. As an example, the accuracy of the location measured by a WSD installed under the control of an operator is expected to be better compared to an ad hoc installation.

WSDs are not allowed to transmit until they have successfully determined from the database which channels, if any, are available in their location. This requires that the initial access to the database is done by some other means than using white space frequencies.

In some cases, for example if a WSD is connected to an access point, one WSD may act as a proxy for the database queries for another WSD or a set of other WSDs. The querying WSD would be called the master WSD and the WSD(s) it does the query for would be called slave WSD(s). In this case the master WSD would have to ensure in an appropriate way that the slave WSDs operate according to the constraints returned by the database. Depending on the particular implementation this may require that the master WSD has some form of control over the operation of the slave WSDs. Examples for Master-Slave Operation of geo-location database are provided in the ANNEX 11.

In the case where there are several access points available that are connected to each other by some means (e.g. a core network or a distribution system), triangulation or some other network based positioning method can be used to measure the WSD location. This measured position may be used by the WSD, or by an access point (e.g. a master WSD), to query the database for available radio channels, bandwidths and corresponding maximum transmit powers. Using the geo-location approach would require that the WSD has valid information about the available channels, either by including the time validity of the received information or by requiring sufficiently frequent re-consultation with the database.

3.4.3 Beacons

Beacons are signals which can be used to indicate that particular channels are either in use by protected services or vacant. The use of beacons can ease the performance requirements on devices that use spectrum sensing, by increasing the likelihood of detection at lower threshold values. The interference protection provided to licensed users comes at a cost in spectrum capacity as well as the cost of purchasing and operating the beacons.

There are various possible beacon setups:

- **Enable beacon**: If the beacon is detected, the considered channel can be used.

  With enabling beacons, a network of beacon transmitters covering an entire country or region in which WSD are allowed to operate would be required. WSDs would only be permitted to operate after they have received authorization from one of these beacons. Each device would need to be fitted with a beacon receiver, and fine-grain control over individual devices would not be possible without a back-end database.

- **Disable beacon**: If the beacon is detected, the considered channel is occupied and cannot be used by WSDs.

- **Beacon as pilot channel**: identifies locally used TV channels, i.e. local database.

No detailed proposal was received in relation to the use of beacons as a cognitive technique for the operation of WSDs in the 470-790 MHz. However, the ‘disable beacon’ approach may have some merit for the protection of PMSE. It is therefore further discussed in Section 5.5.

4 PROTECTION OF BROADCASTING SERVICE IN THE BAND 470-790 MHz FROM EMISSIONS OF WHITE SPACE DEVICES

Broadcasting reception is considered for fixed (rural and urban), portable and hand-held conditions. The problem of interference between broadcast service and WSD is schematically depicted in Figure 6. If a WSD transmits near the antenna of a broadcasting receiver using the same frequencies, it might cause harmful interference. However, the WSD has to avoid any harmful interference by collecting information on spectrum for transmissions using the cognitive techniques described in Section 3.4. If the WSD cannot identify any broadcasting transmissions, it may be concluded that there are no nearby active receivers in that spectrum (because there would be nothing for them to receive).

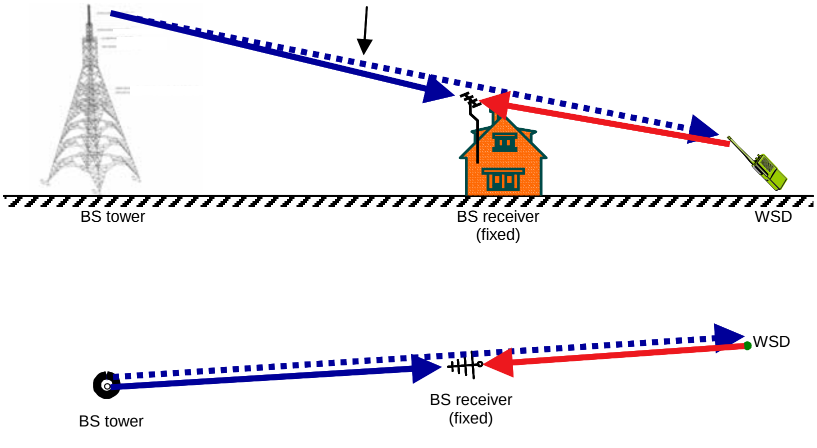

Figure 6: Interference scenario example

This chapter studies the protection requirements for the BS against potential interference from WSDs and on this basis establishes the technical and operational requirements for WSDs in the band 470-790 MHz.

4.1 BS system characteristics and protection criteria

The DVB-T parameters shown in Table 1 were used for compatibility studies.

Parameter	**Units**	**Fixed reception rural**	**Fixed reception urban**	**Fixed Reception HDTV (DVB-T2) Urban *****	**Portable indoor reception urban**	**Portable outdoor / Mobile Reception urban**	**Mobile TV (Handheld indoor)* (DVB-H) urban**	**Mobile TV (DVB-H), handheld outdoor**	**Comment**
Calculation of DTT cell size (single transmitter)									
Link BW	**MHz**	**7,60**	**7,60**	**7.77**	**7,60**	**7,60**	**7.60**	7.60	Bandwidth occupied by link
Thermal noise density	**dBm/Hz**	-173.98	-173.98	**-173.98**	-173.98	-173.98	-173.98	-173.98	kT_0
Receiver noise figure	**dB**	7	7	**7**	7	7	6	6	NF (Rec. ITU-R BT.1368)****
Noise power (inc. NF) over link BW	**dBm**	**-98.17**	**-98.17**	**-98.07**	**-98.17**	**-98.17**	**-99.17**	**-99.17**	Pn = kTB+NF plus any noise rise
Cell edge reliability	**N/A**	95%	95%	95%	95%	95%	95%	90%	CEPT Report 30 [6]
Gaussian confidence factor	**N/A**	1.645	1.645	1.645	1.645	1.645	1.645	1.280	N/A
Shadowing loss standard deviation	**dB**	5.5	5.5	5.5	5.5	5.5	5.5	5	P.1546
Wall loss standard deviation	**dB**	0	0	0	5.5	0	5.5	0	GE06
Total loss standard deviation	**dB**	5.5	5.5	5.5	7.78	5.5	7.78	5	Root of sum of STD squares
Loss margin	**dB**	**9.05**	**9.05**	**9.05**	**12.79**	**9.05**	**12.79**	**6.4**	Lmargin
Minimum SNR at cell-edge*	**dB**	21	21	21	17	19	15.5	8.5	SNRmin for DTT 64 QAM, 2/3 for fixed reception 16 QAM, 2/3 for portable reception 16 QAM 1/2 CR, MPE-FEC 3/4 for handheld indoor QPSK 1/2 CR PE-FEC 1/2

									for handheld outdoor (Rec. ITU-R BT.1368)
Target "mean" received signal level	**dBm**	**-68.12**	**-68.12**	**-68.02**	**-68.37**	**-70.12**	**-70.88**	**-84.27**	Ptarget = (Pn + SNR) + Lmargin
e.i.r.p.	**dBm**	**79.15**	**72.15**	**79.15**	**79.15**	**79.15**	**79.15**	NA(**)	P
Mean wall loss	**dB**	0	0	0	8.0	0	8.0	0	Lw
Receiver Antenna Gain (inc. feeder losses)	**dBi**	9.15	9.15	9.15	2.15	2.15	-6.85	-7	Ga (Rec. ITU-R BT.1368)
Max allowed path loss	**dB**	**156.42**	**149.42**	**156.32**	**141.67**	**151.42**	**135.18**	NA(***)	Lp = (P - Lw + Ga) - Ptarget
DTT transmitter height	**M**	200	100	200	200.	200	200	NA(***)	Ht
DVB-T Rx height	**m**	10	10	10	1.5	1.5	1.5	NA(***)	Hr
cell size	**km**	**52.9**	**31.15**	**52.8**	**12.5**	**21.9**	**8.2**	NA(***)	Rec. ITU-R P.1546
Other DTT planning parameters									
Minimum median field strength at 650 MHz	**dBμV/m**	56.21@10m	56.21@10m	56.21@10m	70.95@1.5m	61.21@1.5m	77.49@1.5m	56 @ 1.5 m	

* These values spring from GE06 [5] and take into account various reception modes. Consequently they may be higher than those measured in a Gaussian channel. Only an example SNR is provided, and SNR used in real implementations may differ from this value.

** Values referred to the following assumptions: QPSK ½, MPE-FEC activated, required C/N for MFER= 5%, outdoor. Required C/N is referred to TU06 channel model.

*** In some cases DVB-H networks are implemented though and SFN composed of high power primary sites and cellular-like secondary sites. In this case e.i.r.p. varies greatly from site to site and the concept of cell size has no significance (SFN gain)

**** Several measurement campaigns have shown that the noise figure of modern receivers is lower by at least 1 or 2 dB.

NOTE 1. Minimum median field strength in case of Single Frequency Network operation is typically lower than the value provided in the table due to the SFN gain. In particular, shadowing loss standard deviation and the resulting loss margin are lower due to statistical SFN gain. In addition, combined field strength from all transmitters needs to be taken into account. Therefore, many of the values in the table are valid for a single transmitter, only.

Table 1: DVB-T parameters used in compatibility studies

It is noted that all these parameters are based on single transmitters, only, and that single frequency networks (SFN) were not considered. The values provided in Table 1 are for reference configurations, and those which are implemented and to be protected on a national basis may differ.

The protection ratios and the overloading thresholds for interference from WSD into DVB-T were not available at the time of the studies mainly because of the absence of any specification for WSD intended for operation in the band 470-790 MHz. Therefore, the values provided in ECC Report 148 [7] for interference from LTE into DVB-T were used in the compatibility studies between DVB-T and WSD. This would be under the assumption that WSD signals will be similar to those from LTE including especially the ACLR values of the interfering LTE signal used in the measurements reported in [7]. These values are listed in ANNEX 1. If this assumption is not confirmed by the technological development of WSDs then additional analyses should be carried out with the updated protection ratios.

4.2 Sensing (including calculation of detection threshold)

4.2.1 Detection threshold

The electric field strength available for spectrum sensing at WSD antenna will not be a fixed value, but will exhibit a statistical variation affected by WSD position and also propagation variations with time. The statistics of this variation are understood to have a normal distribution characterized by a median value and a standard deviation. An illustration of how signals might vary with location is shown in Figure 7.

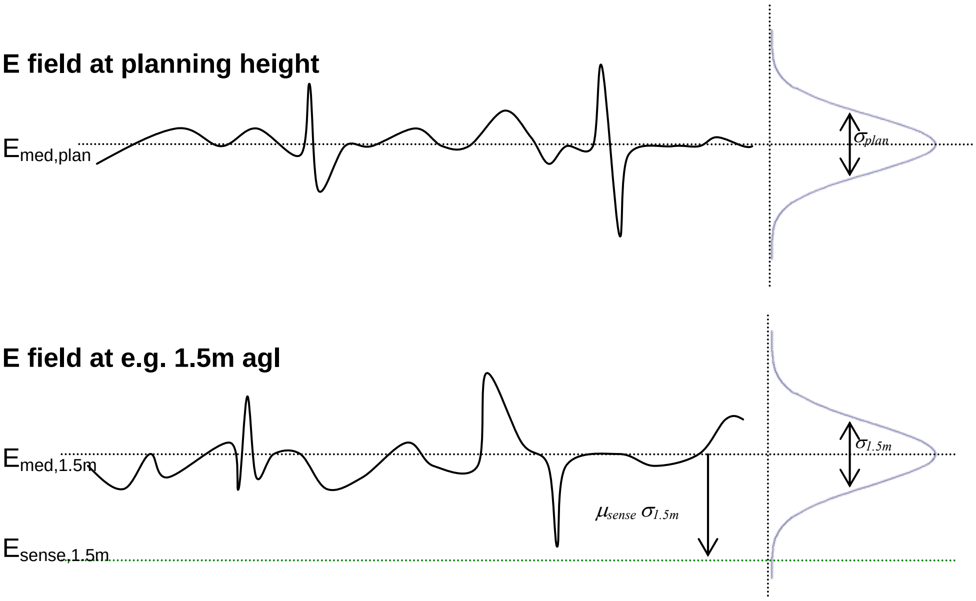

Figure 7: Variation of Electric field strength at planning height and 1.5m

At the height at which TV reception is planned, the signal variation is characterized by a median electric field strength, $E_{med,plan}$, and a standard deviation, σ_{plan} .

For sensing at WSD height (H_{WSD}) , the important parameters are the median electric field strength at that height, E_{sense} and the standard deviation of the signal variation, σ_{sense}.

In calculating a sensing threshold, we must consider the required sensing reliability. Should the sensing device fail to detect the primary service, co-channel interference will result which could affect a considerable number of DTT receivers. To prevent this, a very high reliability of detection is required, typically 99.99% in the planned area.

Obviously, this is the most important parameter when looking to detect reliably the presence of DTT signals above a certain level in order to assume whether the channel is used or not.

For calculating the detection threshold for WSD, first we need to calculate the DTT field strength at the WSD receiver antenna "E_{med}", which is obtained by subtracting the height loss from H_{DTT} to H_{WSD} ("L_{HDTT-H_WSD}") from the planned DTT field strength "$E_{med,plan}$" and so that:

$$E_{med}\ (dB\mu V/m) = E_{med,plan}\ (dB\mu V/m) - L_{HDDT\text{-}HWSD}\ (dB) \qquad (4.2\text{-}1)$$

The height loss $L_{HDDT-HWSD}$ can be calculated according to the prescription given in ITU-R Rec. P.1546.

After having calculated E_{med}, we can then define a detection threshold E_{sense} given by:

$$E_{sense}\ (dB\mu V/m) = E_{med}\ (dB\mu V/m) - \mu_{sense}\sigma_{sense} \qquad (4.2\text{-}2)$$

The power available to the WSD and that should be sensed, P_{sense} can be derived by considering the frequency, f_{sense}, the antenna gain of the device, G_{sense} and the polarization loss L_{pol}, resulting from misalignment between the antenna of the white space device and the polarization of the primary signal to be detected. Also, for a mobile WSD a margin for Body Loss "L_{body_loss}" has been considered. The result is given by:

$$P_{sense}\ (dBm) = E_{sense}\ (dB\mu V/m) - 20\log(f_{sense}\ (MHz)) - 77.2 + G_{sense}\ (dB) - L_{pol}\ (dB) - L_{body\_loss}\ (dB) \qquad (4.2\text{-}3)$$

The following considerations are valid for single transmitters, only. The resulting thresholds will be lower if the broadcasting network is based on SFN-topology (see also Section 4.1).

In the following sections detection thresholds are calculated assuming the reference configurations presented in Table 2. It should be noted that additional values for detection thresholds are presented in the Annex A.5.2 , for other scenarios and/or planning assumptions. As we can see the detection threshold changes in accordance to the protected scenario.

When defining the detection threshold, Administrations should consider making the appropriate assumptions in order to reflect the national implementation. For example, a scenario presented in the tables of Annex A.5.2 refers to the case where local broadcasters, considering their need to expand geographical coverage rather than maximizing capacity, have decided to use 16-QAM.

4.2.1.1 *Detection threshold for outdoor WSDs*

The detection threshold for the reference configurations is calculated from (equation 4.2-3). It is noted that these power levels could be lower in case that the DVB-T service in the area under consideration is based on SFN network topology.

DTT	**DTT fixed outdoor, planned for SubUrban area**		**Portable outdoor**	**Mobile TV (DVB-H) outdoor**	
Percentage location in the target detection area:	**95%**		**95%**	**90%**	
DTT receiver antenna height	**@10 m**		**@1.5 m**	**@1.5 m**	
WSD	**Mobile Outdoor @1.5m**	**Fixed Outdoor @30m**	**Mobile Outdoor @1.5m**	**Mobile Outdoor @1.5m**	
$E_{med,plan}$	56.21	56.21	61.21	56.00	dBµV/m
$L_{HDTT\text{ - }HWSD}$	17.01	-9.84	0.00	0.00	dB
E_{med}	39.20	66.05	61.21	56.00	dBµV/m
Sensing reliability	99.99%	99.99%	99.99%	99.99%	%
$\sigma_{1,5m}$	5.50	5.50	5.50	5.50	dB
μ_{sense}	3.72	3.72	3.72	3.72	dB

$\mu_{sense}\cdot\sigma_{1,5m}$	20.46	20.46	20.46	20.46	dB
f_{sense}	650.00	650.00	650.00	650.00	MHz
G_{sense} (Note 1)	0.00	0.00	0.00	0.00	dBi
L_{pol} (Note 2)	3.00	3.00	3.00	3.00	dB
L_{body_loss}	3.00	0.00	3.00	3.00	dB
E_{sense}	18.74	45.59	40.75	35.54	dBμV/m
$P_{sense\_1,5m}$	-120.71	-90.86	-98.70	-103.91	dBm

Note 1: The detection thresholds are referenced to an omnidirectional receive antenna with a gain of 0 dBi. If a receive antenna with a minimum directional gain of less than 0 dBi is used, the detection threshold shall be reduced by the amount in dB that the minimum directional gain of the antenna is less than 0 dBi.

Note 2: Margin in order to take into account depolarization of the received DTT signal. The detection thresholds are referenced to cross polar discrimination. If the receive antenna of the fixed WSD has a different polarization configuration, the detection threshold shall be modified by the amount of dB corresponding to the configuration (+13 dB if the polarization are orthogonal, -3dB if the polarization are the same).

Table 2: Detection threshold for outdoor WSD

4.2.1.2 Detection threshold for indoor WSDs

Taking account of the building penetration loss, BPL and its standard deviation σ_{BPL}, a modified expression for detection threshold can be derived.

Also, it should be noted that the variation of the DTT signal indoors is a result of three factors:

- variation of the signal outdoors due to reflections on outdoor objects;
- variation of the building penetration loss;
- variation of the signal indoor due to reflections on indoor objects.

In DTT planning for portable indoor reception in GE06, only the two first factors were considered to derive the overall standard deviation, once according to the definition of portable indoor reception in GE06[5] (section 1.3.12 in Chapter 1 to Annex 2 – Definitions), it is assumed that the optimal receiving conditions will be found by moving the antenna up to 0.5 m in any direction. The optimal position of the DTT receive antenna is frequency dependent. However, the WSD might be located in a 'null' position with respect to the ambient DTT field strength of a particular channel, and it will not be moved to search for the 'optimal' position (i.e. optimal for DTT reception), and therefore a variation of the signal indoors due to reflections on indoor objects (standard deviation σ_{indoor}) has to be considered if the BPL values and their standard deviation from GE06 [5] are to be used.

However, there are other values of BPL, obtained by measurements, which include this effect (cf. bmcoforum white paper on Mobile Broadcast Technologies Link Budgets). When using these values of BPL there is no need to consider additional σ_{indoor} in the calculations (please see the calculations in Annex A.5.2).

$$P_{sense} = (E_{med,plan} - L_{plan,H\_WSD}) - BPL - \mu_{sense}\sqrt{(\sigma^2_{H\_WSD} + \sigma^2_{BPL} + \sigma^2_{indoor})} - 20 \log f_{sense} - 77.2 + G_{sense} - L_{pol} - L_{boddy\_loss}\ (dB) \qquad (4.2\text{-}4)$$

For a typical BPL value according to GE06 (8dB) with the associated standard deviation (σ_{BPL} = 5.5dB) and an additional indoor signal variation (σ_{indoor} = 3.5dB), the sensing threshold is modified as shown in Table 3. The values indicate that the sensing requirements for indoor operation of sensing devices will be extremely stringent.

DTT deployment	**DTT fixed outdoor, at SubUrban area**	**Portable outdoor**		**Mobile TV (handheld outdoor)**	
Percentage location in the target detection area:	**95%**	**95%**	**70%**	**90%**	
DTT receiver antenna height	**@10m**	**@1.5 m**	**@1.5 m**	**@1.5 m**	
WSD deployment	**Mobile indoor @1.5m**	**Mobile indoor @1.5m**	**Mobile indoor @1.5m**	**Mobile indoor @1,.5m**	
$E_{med,plan}$	56.21	61.21	47.00	56.21	dBμV/m
$L_{HDTT - HWSD}$	17.01	0.00	0.00	0.00	dB
E_{med}	39.20	61.21	47.00	56.21	dBμV/m
$\sigma_{1,5m}$	5.50	5.50	5.50	5.50	dB
BPL	8.00	8.00	8.00	8.00	dB
σ_{BPL}	5.50	5.50	5.50	5.50	dB
σ_{indoor}	3.50	3.50	3.50	3.50	dB
Sensing reliability	99.99%	99.99%	99.99%	99.99%	%
μ_{sense}	3.72	3.72	3.72	3.72	dB
$\mu_{sense}\sqrt{(\sigma^{2}_{1.5m}+\sigma^{2}_{BPL}+\sigma^{2}_{indoor})}$	31.72	31.72	31.72	31.72	dB
f_{sense}	650.00	650.00	650.00	650.00	MHz
G_{sense}	0.00	0.00	0.00	0.00	dBi
L_{pol}	3.00	3.00	3.00	3.00	dB
L_{body_loss}	3.00	3.00	3.00	3.00	dB
E_{sense}	-0.52	21.49	7.28	16.49	dBμV/m
$P_{sense\_1.5m}$	-140.0	-118.0	-132.2	-123.0	dBm

Note 1: The detection thresholds are referenced to an omnidirectional receive antenna with a gain of 0 dBi. If a receive antenna with a minimum directional gain of less than 0 dBi is used, the detection threshold shall be reduced by the amount in dB that the minimum directional gain of the antenna is less than 0 dBi.

Note 2: Margin in order to take into account depolarization of the received DTT signal. The detection thresholds are referenced to cross polar discrimination. If the receive antenna of the fixed WSD has a different polarization configuration, the detection threshold shall be modified by the amount of dB corresponding to the configuration (+13 dB if the polarization are orthogonal, -3dB if the polarization are the same).

Table 3: Detection threshold for indoor WSD

From the tables presented in the above sections, as well as from Annex A.5.2, it can be concluded that it is not possible to derive a single value for the detection threshold since that depends from the planning assumptions of the protected broadcasting services, but the following range:

For a Fixed located WSD with 30 m antenna height the detection threshold varies between:

- -91 dBm (to detect the reception of DTT fixed @10 m, planned for 95% of locations), and
- -101 dBm (to detect the reception of DTT fixed @30 m, planned for 95% of locations).

It should be noted that scenario of detecting DTT fixed at 30 m, planned for 70% of locations leads to a detection threshold of -107 dBm but is considered as less relevant because 30 m receiving antenna height corresponds to urban environment whereas the location probability of 70% corresponds to rural areas.

For a mobile/portable WSD at 1.5 m (considering that *indoor* is the stringent scenario) the detection threshold varies between:

- -140 dBm (to detect the reception of DTT fixed @10 m, planned for 95% of locations – suburban areas), and
- -155 dBm (to detect the reception of DTT fixed @10 m, planned for 70% of locations).

It should be noted that scenario of detecting DTT fixed at 30 m, planned for 70% of locations leads to a detection threshold of -165 dBm but is considered as less relevant because 30 m receiving antenna height corresponds to urban environment whereas the location probability of 70% corresponds to rural areas.

4.2.2 *Hidden node problem*

Spectrum sensing as a cognitive technique needs to account for so called hidden node problem. This arises because the receiver of the service to be protected is better able to receive the licensed transmissions than a WSD in a low height scenario can (due to their different spatial locations). Figure 8 illustrates an example of this. For a high height scenario, i.e. WSD antennas at height of e.g. 10 or 30 meters, the hidden node problem will be reduced.

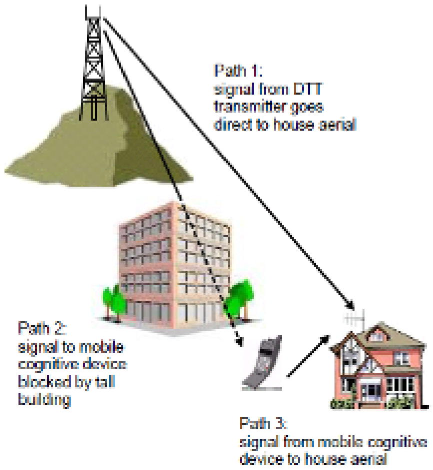

Figure 8: Hidden node problem

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

It is important that WSD use an appropriate detection threshold i.e. a sufficiently low level, in order to mitigate the impact of the hidden-node problem.

For a given reference TV receiving location, the hidden node margin is to be understood as the difference between field strength levels received at the location of the WSD and at the TV receiving antenna, taking into account the statistical distribution of signals as well as antenna directivity and polarization discrimination (if applicable).

It should be noted that the calculations presented in the Section 4.2.1 implicitly include the Hidden Node Margin. For information ANNEX 4 provides some national administration studies related to the hidden node margin.

4.3 WSD Emission limits

There are two general approaches in order to determine allowed WSD emission limits:

- Location specific maximum output power: this allows the maximum output power to be calculated for each broadcasting receiving location and for each device type/class
- Fixed maximum output power: There may be a few device types (such as portable and fixed) for which the key main characteristics are defined, and maximum fixed output power limits are allowed for them outside

the protected areas. The limits may be different for use of adjacent channels and for other channels. This approach has currently been chosen by the FCC.

The location specific maximum output power approach is addressed in the following sections. This approach is mainly relevant for the geo-location database approach. For the determination of the maximum output power based on sensing, the uncertainty of the actually measured BS power needs to be taken into account in addition, i.e. a hidden node margin. Studies have shown that such a determination of the location specific maximum output power based on sensing alone is not accurate and would not provide adequate protection of the broadcasting service. Studies have also shown that the information acquired by autonomous spectrum sensing is not sufficient for the WSD to determine its maximum allowable e.i.r.p.

4.3.1 e.i.r.p. limits in case of autonomous operation

4.3.1.1 Methodology

The maximum permitted in-block e.i.r.p. of a single WSD to ensure a specific level of protection of the co- and adjacent channel BS reception is evaluated from the minimum BS power. In a general way, it can be written in one of the following form:

$$P_{IB}^{WSD}(f_{WSD}) = P_{\min}^{BS}(f_{BS}) + \mu\sigma_{BS} - PR(f_{WSD} - f_{BS}) - q\sqrt{(\sigma_{BS}^2 + \sigma_{WSD}^2)} - MI - SM + D_{dir} + D_{pol} - G_i + L_f + L_{WSD(H_{WSD})-BS(H_{DTT})}(d_{WSD-BS}) \quad (4.3\text{-}1)$$

In the non-co channel case this can be expressed in terms of ACS and ACLR:

$$P_{IB}^{WSD}(f_{WSD}) = P_{\min}^{BS}(f_{BS}) + \mu\sigma_{BS} - PR(0) - 10\log_{10}\left(10^{\frac{-ACS^{BS}(f_{WSD}-f_{BS})}{10}} + 10^{\frac{-ACLR^{WSD}(f_{WSD}-f_{BS})}{10}}\right) - q\sqrt{(\sigma_{BS}^2 + \sigma_{WSD}^2)} - MI - SM + D_{dir} + D_{pol} - G_i + L_f + L_{WSD(H_{WSD})-BS(H_{DTT})}(d_{WSD-BS}) \quad (4.3\text{-}1')$$

where:

f_{BS}: sensed operational frequency of a BS transmitter (MHz);

f_{WSD}: target operational frequency of a WSD (MHz);

$P_{IB}^{WSD}(f_{WSD})$: maximum permitted in-block e.i.r.p. of a WSD at frequency f_{CR} (dBm);

$P_{min}^{BS}(f_{BS})$: mimimum BS power assumed at the BS receiver input at frequency f_{BS} (dBm);

$PR(f_{WSD} - f_{BS})$: appropriate BS protection ratio for a frequency offset $f_{CR} - f_{BS}$ to protect the BS reception from WSD interference (dB). In situations, when the protected signal level is close to receiver sensitivity (i.e. when the WSD operates close to the edge of the broadcasting coverage), this protection ratio should also include a margin of 3 dB to take account of receiver sensitivity degradation (see [7]);

$PR(0)$: co-channel BS protection ratio;

d_{WSD-BS}: distance between the WSD and the BS receiver (m);

$L_{CR(H_{WSD})-BS(H_{DTT})}(d_{WSD-BS})$: propagation path loss at distance d_{CR-BS} between the WSD with an antenna height at H_{WSD} and the BS receiver with an antenna height at H_{DTT} (dB);

σ_{BS}: standard deviation of the shadowing between the BS transmitter and the BS receiver (dB);

σ_{WSD} : standard deviation of the shadowing between the WSD and the BS receiver (dB);

μ: Gaussian confidence factor related to target location percentage where BS coverage is sought;

q: Gaussian confidence factor related to target location percentage where protection is sought;

$\mu\sigma_{BS}$: shadowing margin (dB) related to the variation of the wanted signal (BS);

$q\sqrt{(\sigma_{BS}^2+\sigma_{WSD}^2)}$: shadowing margin (dB) related to the variation in the difference between the interfering signal (WSD) and the wanted signal (BS);

$P_{\min}^{BS}(f_{BS})+\mu\sigma_{BS}$: mimimum median BS power assumed at the BS receiver input at frequency f_{BS} (dBm);

MI : Multiple interference margin of 3-6 dB (depending on the number of interferes) that takes account of aggregated interference from multiple (co-channel and adjacent channel) WSDs operating in a given area at the same time (3 dB corresponds to 2 interferes, 5 dB – 3 interferes, 6 dB – 4 interferes);

SM : safety margin (dB).; This margin is required to provide protection against existing interference sources including long-range DTT interference, impulsive interference and other co-primary services. A range of values can be considered (e.g. 3 to 20 dB). Some administrations are considering a safety margin of 0 dB;

D_{dir} : BS receiver antenna directivity discrimination with respect to the WSD signal (dB);

D_{pol} : BS receiver polarization discrimination with respect to the WSD signal (dB);

G_i : Isotropic antenna gain of the BS receiving installation;

L_f : Feeder loss of the BS receiving installation;

$ACS^{BS}(f_{WSD}-f_{BS})$: Adjacent Channel Selectivity of the BS receiver for a frequency offset $f_{CR}-f_{BS}$ (dB). $ACS(0)=0$ dB;

$ACLR^{WSD}(f_{WSD}-f_{BS})$: Adjacent Channel Leakage Ratio of the WSD for a frequency offset $f_{CR}-f_{BS}$ (dB). $ACLR(0)=\infty$ dB;

The maximum permitted out-of-block e.i.r.p. of a WSD is evaluated as follows:

$$P_{OOB}^{CR}=P_{IB}^{CR}(f_{CR})-ACLR^{CR}, \tag{4.3-2}$$

where:

P_{OOB}^{CR}: maximum permitted out-of-block e.i.r.p. of a WSD (dBm);

$P_{IB}^{CR}(f_{CR})$: maximum permitted in-block e.i.r.p. of a WSD at frequency f_{CR} (dBm);

$ACLR^{WSD}$: Adjacent Channel Leakage Ratio of a WSD (dB).

ACS is an intrinsic feature of a BS receiver. It can be derived from protection ratio measurements (e.g. for LTE interference into DVB-T or for UMTS interference into DVB-T, etc) provided that the ACLR of the interferer as well as of the reference source used in the protection ratio measurements are known. ANNEX 3 provides the relationship between PR, ACS and ACLR. There are two views on this issue:

(1) ACS is independent on the interference source, i.e. ACS values extracted from different protection measurements are the same;

(2) ACS does depend on the interfering source[1]. Therefore, it is important to correctly choose the reference measurements.

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[1] This view is supported by comparing ECC Reports 138 and 148, especially for user equipment interferences.

In order to restrict the maximum permitted in-block e.i.r.p. of a WSD to avoid overloading of a BS receiver, under which this receiver loses its ability to discriminate against interfering signals at frequencies differing from that of the wanted signal, the following formula is applied:

$$P_{IB}^{WSD}(f_{WSD}) = O_{th}^{BS}(f_{WSD} - f_{BS}) + D_{dir} + D_{pol} - G_i + L_f + L_{WSD(H_{WSD})-BS(H_{DTT})}(d_{WSD-BS}), \quad (4.3\text{-}3)$$

where:

$O_{th}^{BS}(f_{WSD} - f_{BS})$: appropriate BS overload threshold for a frequency offset $f_{CR} - f_{BS}$ (dBm);

In general terms, the maximum permitted in-block e.i.r.p. of a single WSD to ensure any given level of protection of co- and adjacent channel BS reception is set as the minimum of in-block e.i.r.p. computed on the basis of protection ratios/adjacent channel selectivity and the overloading threshold for different frequency offsets.

4.3.1.2 Assumptions

In applying Equation (4.3-1) an assumption needs to be made with regard to protection ratios on adjacent channels noting the absence of any measurements on protection ratios between WSDs and BS receivers. Based on information received so far, WSDs to be potentially deployed in the UHF band are primarily intended to provide broadband internet access. It is, therefore, reasonable to assume that the transmission technology employed will be based on OFDM, i.e. similar to LTE technologies with noise-like signal characteristics. This would allow using, to a 1st order approximation, the results of studies presented in [7].

In applying Equations (4.3-1') and (4.3-2) an assumption needs to be made with regard to the value of ACLR for WSDs. One possibility would be to assume that the burden of frequency selectivity is equally apportioned between the BS receiver and the WSD. In this case, Equation (4.3-1') will read

$$\begin{aligned} P_{IB}^{WSD}(f_{WSD}) &= P_{\min}^{BS}(f_{BS}) + \mu\sigma_{BS} - PR(0) - 3 + ACS^{BS}(f_{WSD} - f_{BS}) \\ &- q\sqrt{(\sigma_{BS}^2 + \sigma_{WSD}^2)} - MI - SM + D_{dir} + D_{pol} - G_i + L_f + L_{WSD(H_{WSD})-BS(H_{DTT})}(d_{WSD-BS}) \end{aligned} \quad (4.3\text{-}1'')$$

and Equation (4.3-2) will read

$$P_{OOB}^{CR} = P_{IB}^{CR}(f_{CR}) - ACS^{BS} \quad (4.3\text{-}2')$$

However, solid justifications would be required before proceeding further with this suggestion.

In the case when ACLR of the WSD is smaller than the ACS of the BC receiver, the permitted e.i.r.p. of the WSD will need to be reduced. In this respect it can be noted that typical ACS values of the BC receivers are about 60 dB or above.

Another possibility would be to set ACLR to an appropriate large reference ACLR value , '$ACLR_{Const}$',obtained on the basis of numerical calculations and derived ACS-values:

$$P_{OOB}^{CR} = P_{IB}^{CR}(f_{CR}) - Const \quad (4.3\text{-}2'')$$

4.3.1.3 e.i.r.p. limits

An autonomous WSD should reliably detect the absence of the BS reception both in its immediate vicinity and at a certain distance from its location in order not to interfere with co-channel BS reception, which could be available at this distance (this corresponds to the case when the WSD is located outside but relatively close to the BS coverage edge at a given frequency). The reliability of detection of the BS signal in the close vicinity of the WSD can be improved by taking into account appropriate hidden node margins, i.e. by lowering the detection threshold. However, it remains an issue as to how to determine autonomously the absence of the BS signal at any given distance from a DTT coverage area.

It follows from Equations (4.3-1) and (4.3-2') that the proposed approach requires knowledge of a number of parameters related to path propagation. This information is a priori not available to a WSD operating autonomously. In particular, in equations 4.3-1, 4.3-1′ and 4.3-1′′ the possible distances "$d_{WSD\text{-}BS}$" from WSD to DTT receivers, the terrain shape and clutter along the path and consequently the propagation loss and the relative DTT receive antenna discrimination "D_{dir}" cannot be known. Therefore, because of this intrinsic lack of relevant geographical information, it is impossible for the WSD to reliably set its own emission limit. Hence, the application of the approach for an autonomous operation of a WSD would require the usage of the most conservative transmitting/receiving parameters and propagation characteristics in order to cover entirely different situations likely to occur in reality.

There are two general operational conditions to be satisfied by a WSD:

1. the device is not allowed to be operated within the coverage area of a co-channel BS transmitter;
2. the device may operate within the coverage area of a non co- channel BS transmitter, provided that any reception of this particular BS channel – which could be adjacent to the WSD channel – is protected.

These conditions may imply different interference ranges into the BS reception (exclusion zones) to be allowed for WSDs on co- and adjacent channels. However, it needs to be pointed out that the minimum median field strength of the broadcasting service should be protected independent whether the WSD is operating within or outside the coverage area of the broadcasting service.

The distance between the WSD and the BS receiver d_{WSD-BS} defines the allowed minimum operational distance of a WSD from a DTT receiving antenna. This distance, together with the specified protection criterion (e.g. permitted degradation of DTT LP), allows its emission limits to be calculated.

Noting the difficulties an autonomous WSD may encounter in detecting DTT signals (see Section 4.3.1.3.1) as well as very low WSD emission levels which would be allowed under an autonomous operation, such operation may appear to be not plausible. Therefore, the operation of an autonomous WSD assisted by a geo-location database may need to be considered.

A collaborative sensing technique can also be mentioned, under which different WSDs exchange mutual information regarding the frequency and time of usage of the spectrum. This technique is today still an open topic of research.

4.3.1.3.1 Limitations

This section provides some examples showing some limitations that the autonomous operation of a WSD may have:

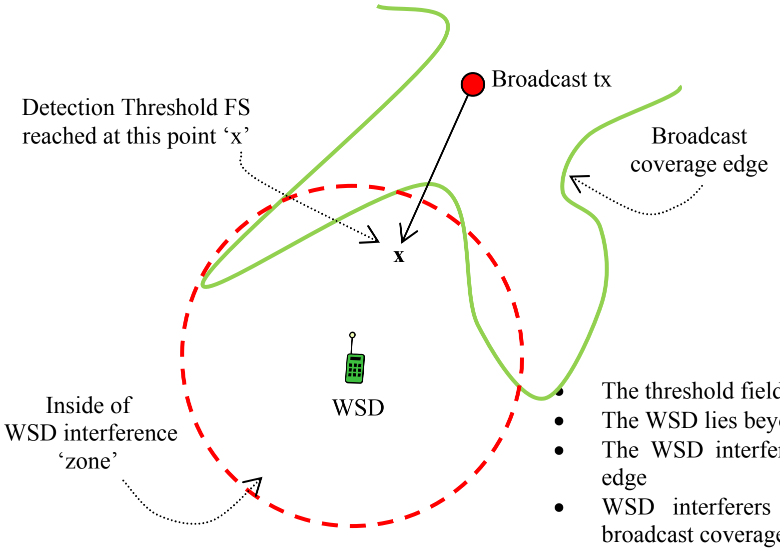
- **Co-channel considerations**

  If the e.i.r.p. of a WSD is 'large', its potential interference range may also be 'large' vis-à-vis a DTT service operating on the same channel.
  For example, if the co-channel interference range of a WSD is of the order of several kilometers, it may be necessary to restrict or prohibit the use of the co-channel by a WSD within, and also for a certain distance outside of, a DTT coverage area (see Figure 9).

- **Co-channel detection threshold difficulties**

  In the case of protecting a DTT coverage area from co-channel WSD interference originating outside of the DTT coverage area, the problem of detection becomes critical because the WSD lying outside the DTT coverage area will, in general, be a potential interference threat over large distances. Therefore

a) the WSD detection threshold for detecting a DTT signal might be significantly less than the DTT signal level required for reception (not only because of 'hidden nodes')
b) as shown in Figure 9, a complex DTT coverage contour may nullify the utility of a DTT signal detection threshold.



- The threshold field strength level is reached at the point 'x'
- The WSD lies beyond the point 'x'
- The WSD interference zone still intersects the broadcast edge
- WSD interferers at points in the intersection of the broadcast coverage area and the WSD interference zone

Figure 9: protecting convoluted DTT coverage areas/edges

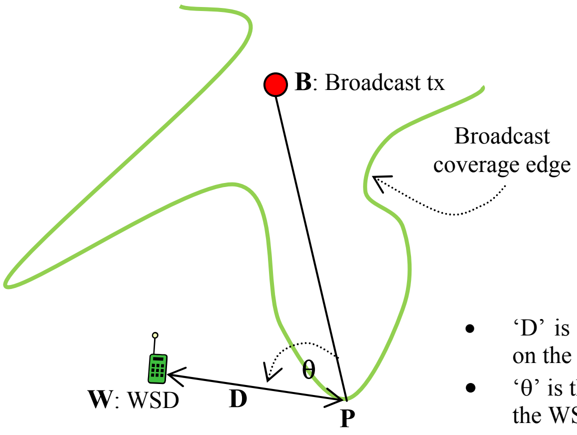
The situation described in b) may arise if the WSD is located beyond the point where the detection threshold level is measured, but its distance to the nearest points on the coverage contour is less than the WSD interference range.

The solution to protect against such an interference threat would have to involve the possibility to determine whether the WSD is

- inside the DTT coverage area, in which case the use of that frequency by the WSD would be prohibited, or
- outside the DTT coverage area, in which case intimate knowledge of the broadcast coverage edge and a means to calculate the distance from the WSD to points on the broadcast coverage edge would be required.

In the latter case, an e.i.r.p. limitation would have to be imposed on the WSD as a function of distance and relative position of the WSD, the DTT transmitter site, and points on the DTT coverage contour. The geometrical configuration is shown in Figure 10. The coordinates for the DTT transmitter site, 'B' and the coordinates of the points of the DTT coverage contour must be stored somewhere. In addition, a means to calculate the distance, D, from the WSD site to each of the points on the contour, and the relative receive antenna discrimination angle between the vectors $\vec{Pi}$ and $\vec{PW}$ must be available.

The calculation of the angle can be carried out easily with knowledge of the coordinates of the DTT transmitter site, of the WSD location, and those of the points along the DTT coverage contour.



- 'D' is the distance from the WSD site, 'W', to a point, 'P', on the DTT coverage contour
- 'θ' is the angle between the DTT transmitter site, 'B', and the WSD site, 'W', as seen from point 'P'

Figure 10: Geometry of protecting convoluted DTT coverage areas/edges

As the geographical information is not available to an autonomous WSD, it would seem that this particular, but very important, interference situation can only be resolved with the help of a geo-location database, i.e. direct 'threshold detection' methods cannot be considered reliable.

- **Adjacent channel considerations**

If the WSD e.i.r.p. is potentially very large, considerations similar to those in the preceding subsection, this time with respect to the coverage area of adjacent channels, would also have to be made when the WSD is located outside of the adjacent channel DTT coverage area.

If the WSD e.i.r.p. is small enough that it will not interfere with neighboring adjacent channel DTT coverage areas, then the only restriction to the e.i.r.p. would be based on the DTT service to be protected, the corresponding field strength to be protected, and the horizontal 'protection distance', pd, say 1 m or 2 m. In this case, the distance "$d_{WSD\text{-}BS}$" for calculating the loss in equations 4.3-1, 4.3-1′, 4.3-1′′ is:

$$d_{WSD\text{-}BS} = \{pd^2 + \Delta h^2\}^{½},$$

where Δh is the vertical distance between the WSD (at 1.5 m height above street level, say) and the DTT receive antenna (at 30 m above street level, say) The DTT receive antenna discrimination, in case of fixed BS reception, D_{dir}, is based on the angular discrimination angle:

$$\varphi = \arctan(\Delta h/pd).$$

For the preceding reasons it can be concluded that the Sensing technique investigated, employed by a stand-alone WSD (autonomous operation), does not appear to be reliable enough to guarantee a correct identification of available channels at a given location and to avoid causing interference to possible nearby co-channel coverage areas. The use of a geo-location database appears, therefore, necessary.

4.3.2 e.i.r.p. limits in case of geo-location database operation

4.3.2.1 Geo-location database

The calculation of regulatory emission limits for an autonomous WSD for operation in DTT bands has to be inevitably based on worst-case geometries between the interfering WSD and the victim DTT receiver. Consequently, adequate protection of the DTT service can result in very stringent (i.e. low) regulatory emission limits for the WSD. This may reduce the utility of the WSDs.

It is, however, generally understood that the extent of harmful interference to a DTT receiver is significantly influenced by the quality of the DTT coverage in the geographical area of interest. The implication is that, with the aid of a *geo-location database*, the regulatory emission limits for a WSD may be significantly increased in areas where the received wanted DTT signal power is high (i.e., where DTT coverage quality is good).

To this end, it is necessary for the database to specify the maximum permitted WSD emission levels over all DTT channels and in all geographic locations where the DTT service is being used. To accomplish this, the database needs access to the following information:

1) The quality of national DTT coverage to within a suitable spatial resolution (e.g. 100m x100m).
2) A suitable criterion (or metric) for quantifying and specifying a tolerable level of interference to the DTT service.
3) Specified interferer-victim reference geometries for which the regulatory emission limits would result in the specified tolerable level of interference.
4) Appropriate values of WSD-to-DTT protection ratios and overloading thresholds defined as a function of interferer-victim frequency separation (see [7] and [8]). C/I values as a function of the received wanted DTT power can also be used.
5) A methodology for calculating the appropriate WSD regulatory emission limits.

4.3.2.2 Geo-location database and location probability

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

Location probability is widely used in the planning of DTT networks in order to quantify the quality of coverage, and is typically calculated for every 100 m × 100 m pixel across the country. The presence of any interferer naturally results in a reduction of the DTT location probability. Such a reduction is therefore a highly suitable metric for specifying regulatory emission limits for WSDs operating in DTT frequencies.

4.3.2.2.1 Definition of location probability

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

$$q_1 = \Pr\left\{ P_S \geq P_{S,\min} + \sum_{i=1}^{K} r_{U,k} P_{U,k} \right\} = \Pr\{P_S \geq U\} \qquad (4.3\text{-}4)$$

where $\Pr\{A\}$ is the probability of event A, P_s is the received power of the wanted DTT signal, $P_{S,\min}$ is the DTT receiver's (noise-limited) reference sensitivity level[2], $P_{U,k}$ is the received power of the k^{th} unwanted DTT signal, and $r_{U,k}$ is DTT-to-DTT protection ratio for the k^{th} DTT interferer.

Equation (1) is a direct result of the definition of protection ratio; i.e., the minimum ratio of wanted signal power to interferer signal power (as measured at the input to the receiver) required for the correct operation of the receiver.

In the planning of DTT networks, $P_{S\,(\text{dBm})}$ and each individual $P_{U,k(\text{dBm})}$ are modelled as Gaussian random variables. Note that in Equation (4.3-4), the powers are summed in the linear domain. 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, along with numerical examples is described in ANNEX 6. In addition, an approximate analytic approach, along with numerical examples are given in ANNEX 7.

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[2] 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.

4.3.2.2.2 Calculation of WSD in-block emission limit for a specific degradation in location probability

In the previous section we showed how the DTT location probability can be calculated as a function of the median and standard deviations of the DTT signal power and DTT-to-DTT interference power within a given pixel.

Let us now consider a WSD which operates at a frequency $f_{\mathrm{CR}} = f_{\mathrm{DTT}} + \Delta f$, and radiates with an in-block e.i.r.p. of $P_{\mathrm{IB}}^{\mathrm{CR}}$. Note that for the special case of co-channel interference, $\Delta f = 0$.

The presence of the WSD interferer will inevitably reduce the DTT location probability from q_1 to $q_2 = q_1 - \Delta q$. Assuming a coupling gain, G, the received WSD interferer power is then given by the product $G \; P_{\mathrm{IB}}^{\mathrm{CR}}$. Following the framework described in Equation (4.3-3), we may write (in the linear domain)

$$q_2 = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_{i=1}^{K} r_{\mathrm{U},k} P_{\mathrm{U},k} + r(\Delta f)\, G\, P_{\mathrm{IB}}^{\mathrm{CR}} \right\} \qquad (4.3\text{-}5)$$

The coupling gain includes path loss, receiver antenna gain, as well as receiver antenna angular and polarisation discrimination. The coupling gain, $G_{(\mathrm{dB})}$ is typically modelled as a Gaussian random variable with a median value, $m_{G\,(\mathrm{dB})}$, and a standard deviation $\sigma_{G\,(\mathrm{dB})}$. In this case it should, however, be ensured that assuming a Gaussian distribution for the coupling gain is consistent with the radio propagation model used to calculated the median coupling gain. $r(\Delta f)$ is the WSD-BS protection ratio for a given frequency offset.

It should be noted that Equation (4.3-5) does not account for cumulative interference from multiple WSDs potentially presented in a given geographical location.

As explained for the case of Equation (4.3-4), the most accurate calculation of q_2 can be performed by using Monte Carlo simulations. Such a Monte Carlo approach along with numerical examples are given in ANNEX 6. In addition, an approximate analytic approach, along with numerical examples are given in ANNEX 7.

4.3.2.2.3 Calculation of WSD out-of-block emission limit for a specific degradation in location probability

Equation (A.7.2.2) explicitly describes how the maximum permitted WSD in-block e.i.r.p. can be calculated such that it results in degradation $\Delta q = q_2 - q_1$ in DTT location probability. However, Equation (A.7.2.2) also implicitly specifies the maximum permitted WSD out-of-block e.i.r.p. through the use of WSD-to-DTT protection ratios.

This is because the protection ratio is a function of both the spectral leakage of the WSD transmitter and the spectral selectivity[3] of the DTT receiver. Specifically, the protection ratio $r(\Delta f)$ is given (in the linear domain) by

$$r(\Delta f) = \frac{P_{\mathrm{S}}^{*}}{P_{\mathrm{AC}}^{*}} = \frac{P_{\mathrm{S}}^{*}}{P_{\mathrm{I}}^{*}} \frac{P_{\mathrm{I}}^{*}}{P_{\mathrm{AC}}^{*}} = r(0)\,\frac{1}{\mathrm{ACIR}\;(\Delta f)} = r(0)\left(\mathrm{ACLR}_{\mathrm{CR}}^{-1}(\Delta f) + \mathrm{ACS}_{\mathrm{DTT}}^{-1}(\Delta f)\right) \qquad (4.3\text{-}6)$$

where * denotes the value at the point of receiver failure, P_{I} is the interference power, and P_{AC} is the power of the adjacent channel interferer. ACIR is the adjacent-channel interference ratio, $\mathrm{ACLR}_{\mathrm{WSD}}$ is the adjacent-channel leakage ratio of the WSD transmitter, and $\mathrm{ACS}_{\mathrm{DTT}}$ is the adjacent-channel selectivity of the DTT receiver.

If the receiver selectivity is defined as a function of the wanted signal power, then the protection ratios can also be used to implicitly model the non-linear behaviour (*overloading*) of the DTT receiver.

The protection ratio $r(\Delta f)$ in Equation (A.7.2.2) implicitly identifies the spectral leakage of the WSD via the adjacent-channel leakage ratio $\mathrm{ACLR}_{\mathrm{WSD}}(\Delta\mathrm{f})$.

Then, by definition, the maximum permitted WSD out-of-block emission level is given (in the logarithmic domain) as

$$P_{\mathrm{OOB}}^{\mathrm{CR}}(\Delta f) = P_{\mathrm{IB}}^{\mathrm{CR}} - \mathrm{ACLR}_{\mathrm{CR}}(\Delta f)\,. \qquad (4.3\text{-}7)$$

Naturally, the extent of interference caused by a WSD is a function of both its in-block and out-of-block emission levels. This is evident from Equations (A.7.2.2), (4.3-60) and (4.3-7).

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[3] The selectivity can derived from measurements of the protection ratios of DTT receivers in the presence of adjacent channel test interferers. The selectivity of the DTT receivers is calculated by accounting for the contribution to interference caused by the spectral leakage of the test interferer.

Since the ACLR of the WSD is implicitly incorporated in the protection ratios used in Equation (A.7.2.2) to derive the maximum permitted WSD in-block levels, it is important that technical standardisation bodies specify the ACLR of WSDs for use by geo-location databases. Otherwise the geo-location database would need to be established based on an ACLR value that is only representative of the spectral leakage performance of WSDs.

For the purposes of the numerical examples in ANNEX 7, ACLR of the WSD is set to be equal to the ACLR of other broadly similar communication devices; e.g., LTE terminal stations (for mobile WSDs) and LTE base stations (for fixed WSDs).

4.3.2.3 Database calculations

In this section the type of calculations is summarized, which a geo-location database must perform in order to specify the *location-specific* WSD regulatory emission limits as defined over all DTT frequencies.

Specifically, 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. Each WSD-to-DTT frequency separation then results in maximum permitted WSD in-block and out-of-block emission levels required for a tolerable level of interference to the DTT services. We describe these calculations further in Section 4.3.2.3.1.

Subsequently, it is shown that the database must reconcile all calculated WSD in-block and out-of-block emission levels for the given pixel, in order to derive the WSD regulatory emission limits over all DTT frequencies. This is illustrated by a simple example in Section 4.3.2.3.2.

Annex A.9.4 provides a non-exhaustive list of the required harmonised set of parameters for the calculation of WSD location specific power limits.

4.3.2.3.1 Calculation of location-specific WSD in-block and out-of-block levels for a given frequency separation between WSD and victim DTT channel

The following calculations must be performed for any given pixel where the WSD operates, and for all frequency separations between the WSD's operating channel and the victim DTT channels:

1) The geo-location database must be aware of the frequencies, median $m_{\text{S (dBm)}}$ and standard deviation $\sigma_{\text{S (dB)}}$ of the received DTT signal power/field strength, the median $m_{\text{U (dBm)}}$ and standard deviation $\sigma_{\text{U (dB)}}$ 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 (4.3-4).

2) The geo-location database must then 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* (see ANNEX 6 and ANNEX 7 for examples) 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 victim 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.

3) The geo-location database must also assume a tolerable degradation[4], $\Delta q = q_1 - q_2$, in the DTT location probability of pixels where the DTT services are used.

4) The geo-location database must assume an appropriate ACLR for the WSD. This ACLR would be a function of the frequency separation Δf between the WSD and the victim DTT channel. Combined with values of DTT receiver ACS (derived from measured PR and ACLR values), the database must calculate appropriate WSD-to-DTT protection ratios $r(\Delta f)$ as described in Equation (4.3-6).

5) With the above parameters calculated, the database can readily compute the maximum permitted WSD in-block and out-of-block e.i.r.p.s given by

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[4] The tolerable degradation can be different in different pixels; e.g., may be set according to the number of households in each pixel.

$$P_{\mathrm{IB}\ (\mathrm{dBm})}^{\mathrm{CR}} \leq m_{Z\,(\mathrm{dBm})} - m_{G\,(\mathrm{dB})} - r(\Delta f)_{(\mathrm{dB})} - \mu(q_2)\sqrt{\sigma_{Z\,(\mathrm{dB})}^2 + \sigma_{G\,(\mathrm{dB})}^2} + \mathrm{IM}_{(\mathrm{dB})},$$

$$P_{\mathrm{OOB}}^{\mathrm{CR}}(\Delta f) \leq P_{\mathrm{IB}}^{\mathrm{CR}} - \mathrm{ACLR}_{\mathrm{CR}}(\Delta f),$$

and as described in Equations (A.7.2.2) and (4.3-6). Needless to say, the out-of-block e.i.r.p. calculation is not applicable to co-channel interference scenarios.

To account for the potential inaccuracies (or estimation errors) in the reported location of a WSD within a pixel, it would be prudent for the above maximum permitted in-block and out-of-block e.i.r.p.s levels for the operation of a WSD within a pixel to be specified as the minimum of those calculated for the M surrounding pixels. This is illustrated in Figure 11 for $M = 8$. This approach would also account for the cases where a WSD within a pixel is actually in the proximity of a victim in a neighbouring pixel or for the case where a master WSD (see § 9.3 for the master-slave concept) queries the database for its entire service area (in this case M would be included in the database query).

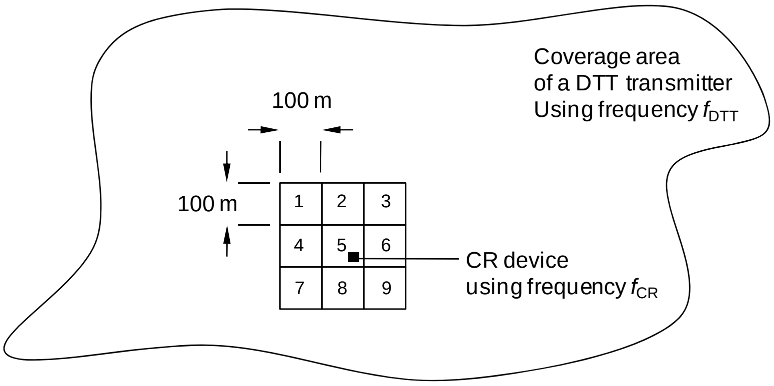


Figure 11: Calculations over surrounding pixels to account for errors in the estimation of WSD location

4.3.2.3.2 Reconciliation of the calculated WSD in-block and out-of-block levels to derive WSD regulatory emission limits over all DTT channels

It is important to note that all DTT channels can be potential victims of a WSD operating in a given pixel. However, the critical cases correspond to those DTT channels that are close in frequency to the WSD in-block emissions (i.e. up to N±9) and/or those DTT channels that are used by the DTT service in locations close to the pixel where the WSD operates. It is therefore important that all cases (or at least the critical cases) are examined by the database, and that the appropriate WSD in-block and out-of-block emission levels are calculated appropriately for each case.

Having performed these calculations (as described in Section 0), it is important that the in-block and out-of-block limits are reconciled in such a way so as to provide a consistent set of WSD regulatory emission limits over (and for the simultaneous protection of) all DTT channels. We illustrate this subtle point via a simple example.

Let us consider an artificial situation where there exist a total of only 3 DTT channels at frequencies f_1, f_2, and f_3. Let us also focus on a given pixel where the WSD operates. To simplify the description, and for illustrative purposes only, we ignore the standard deviations of all wanted and interferer signals and assume that a victim DTT receiver is protected so long as the received interferer signal power is less than the received DTT signal power minus the relevant protection ratio.

Figure 12 illustrates the assumed spatial pattern of the usage of the three DTT channels. As can be seen, the WSD operates in a given pixel within which the DTT network uses frequency f_2 (hence a reference separation of only 22 m), while frequencies f_1 and f_3 are used in other distant pixels, the closest of which (or more specifically, those most susceptible to interference) are 5 and 20 km from the pixel of interest, respectively.

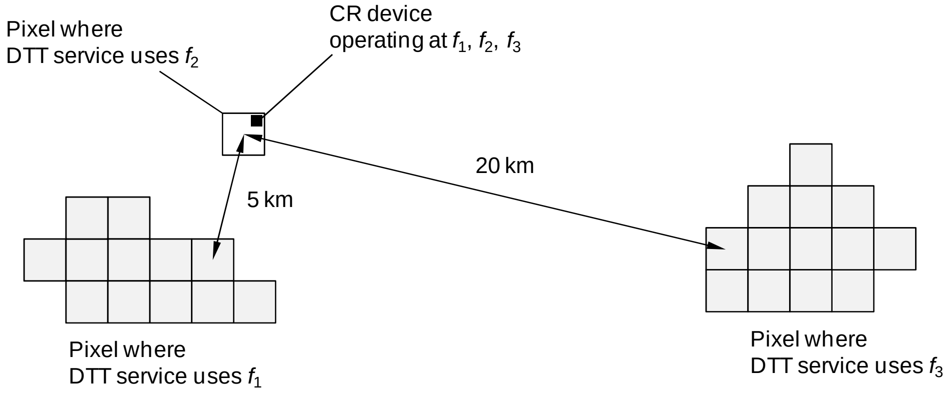


Figure 12: Usage of frequencies f_1, f_2, and f_3 by the WSD and the DTT service. The nearest pixels where f_1 and f_3 are used by the DTT service are 5 and 20 km away, respectively

As described in Section 0, for each combination of WSD operating frequency and victim DTT frequency, the database can calculate the maximum permitted in-block and out-of-block e.i.r.p.s for a WSD transmitting within the given pixel.

The database must then generate the following 3 tables for the given pixel. Table 4 describes the calculated maximum permitted e.i.r.p. levels for a WSD operating at frequency f_1 within the pixel. Table 5 and Table 6 describe the permitted e.i.r.p. levels for a WSD operating at frequencies f_2 and f_3, respectively.

Note that the numerical values in the tables are selected as examples and are only intended to illustrate the manipulations which the database must perform. For simplicity, we assume that the DTT signal power at the victim DTT receiver is -70 dBm in every pixel of interest. We also assume WSD ACLRs of 33 and 36 dB in the first and second adjacent channels. Combined with ACSs of 56 and 61 dB, and a co-channel protection ratio of 16 dB, this implies protection ratios of -17 and -20 dB in the first and second adjacent channels. Also note that, while for simplicity victim-interferer separation is used as an indicator of the potential for interference, it is actually the coupling gain (incorporating suburban Hata path gain at 650 MHz, TV receiver antenna gain of 9.15 dBi, and antenna angular/polarisation discrimination of 3 dB) which is the relevant factor. The maximum permitted WSD in-block e.i.r.p. levels are then calculated as the DTT signal power, minus the protection ratio, plus coupling gain.

WSD operating frequency $f_{WSD} = f_1$				
Victim DTT channel frequency f_{DTT}	**WSD-to-TV separation (coupling gain)**	**Protection ratio (dB)**	**WSD in-block e.i.r.p. over $f_{WSD} = f_1$ (dBm)**	**WSD out-of-block e.i.r.p. over f_{DTT} (dBm)**
f_1	5 km (-142 dB)	+16	56	N/A
f_2	22 m (-50 dB)	-17	**-3**	-36
f_3	20 km (-165 dB)	-20	115	79

Table 4: In-block and out-of-block emission limits calculated for a WSD operating in frequency f_1

WSD operating frequency $f_{WSD} = f_2$				
Victim DTT channel frequency f_{DTT}	**WSD-to-TV separation (coupling gain)**	**Protection ratio (dB)**	**WSD in-block e.i.r.p. over $f_{WSD} = f_2$ (dBm)**	**WSD out-of-block e.i.r.p. over f_{DTT} (dBm)**
f_1	5 km (-142 dB)	-17	89	56
f_2	22 m (-50 dB)	+16	**-36**	N/A
f_3	20 km (-165 dB)	-17	112	79

Table 5: In-block and out-of-block emission limits calculated for a WSD operating in frequency f_2

WSD operating frequency $f_{WSD} = f_3$				
Victim DTT channel frequency f_{DTT}	**WSD-to-TV separation (coupling gain)**	**Protection ratio (dB)**	**WSD in-block e.i.r.p. over $f_{WSD} = f_3$ (dBm)**	**WSD out-of-block e.i.r.p. over f_{DTT} (dBm)**
f_1	5 km (-142 dB)	-20	92	56
f_2	22 m (-50 dB)	-17	**-3**	-36
f_3	20 km (-165 dB)	+16	79	N/A

Table 6: In-block and out-of-block emission limits calculated for a WSD operating in frequency f_3

Table 4 indicates that, if a WSD wishes to operate at frequency f_1 in the pixel of interest, then the protection of DTT channel f_2 is the bottleneck case. This is because f_2 is being used by the DTT service in the same pixel as the WSD. For this reason the WSD is only allowed to radiate at most -3 dBm in f_1. Table 4 also implies that the maximum permitted WSD out-of-block emission level is -36 and -39 dBm over frequencies f2 and f3 (33 dB and 36 dB lower than the in-block level of -3 dBm).

In a next step the database needs to compile the maximum permitted WSD in-block emission levels depicted in Table 4, Table 5, and Table 6 into a consistent set of regulatory emission limits over frequencies f_1, f_2, and f_3.

Table 7 illustrates the required compilation. The regulatory emission limits applicable to the WSD over each DTT frequency channel is the minimum of the calculated maximum permitted in-block emission levels derived in each of Table 4, Table 5 and Table 6.

Frequency of emission, f	Regulatory emission limit (dBm)
f_1	-3
f_2	-36
f_3	-3

Table 7: Regulatory limits

In the real world where we need to establish the permitted WSD emission limits over all UHF DTT channels 21 through to 60, the geo-location database needs to generate 40 such tables for each pixel wherein the WSD might be located. It is also worth noting that each table should examine the victim pixels that are most susceptible to interference for each DTT channel. Of course such calculations are not required to be performed in real time, and despite the high volume of computations, they are not prohibitively complex.

4.4 Conclusions related to the protection of Broadcast Service

Chapter 4 has addressed the sensing threshold calculation method and WSD emission limits for various configurations. The detection thresholds were derived for a limited number of scenarios using the methodology developed within this report. Some of the values so obtained (being in the range from -91 to -155 dBm depending on the DTT planning scenario) appear to be too low to be implemented using current technologies. Moreover, in some scenarios, even these low values for the detection threshold do no guarantee a reliable detection of the presence/absence of the broadcasting signals at the distance corresponding to the interference potential of a WSD.

The feasibility of reliable autonomous operation of WSDs using sensing should be further addressed taking into account the possibilities offered by collaborative sensing techniques and experience that may be gained from sensing field tests. In addition, the future work on sensing should address operational requirements of WSDs and the impact of WSD architecture on the detection threshold.

In section 4.3.2.3 the types of calculations have been presented which a geo-location database might perform in order to calculate *location-specific* maximum permitted e.i.r.p. levels for WSDs in different geographic areas. It has also been shown how these values may be adjusted to derive consistent regulatory emission limits for WSDs for the simultaneous protection of multiple DTT channels. Furthermore, it has been indicated how DTT planning models may be used for these purposes.

It should be noted that any harmful interference caused to DTT reception is a function of both the in-block and out-of-block emissions of the WSD. The calculation of the maximum permitted in-block e.i.r.p. limit requires an assumption with regards to the spectral leakage of the WSD.

It is recommended that the geo-location database should provide to a WSD both the list of available frequencies and associated maximum permitted e.i.r.p. values. It would be necessary to specify or assume a minimum required adjacent channel leakage ratio (ACLR) for the WSDs for use by geo-location databases. Administrations who intend to authorise the use of database-assisted WSDs can decide on the most appropriate parameters/algorithms for their specific circumstances.

It may not be necessary to carry out the calculations based on a pre-defined fixed value for the maximum permitted e.i.r.p. of WSDs when they operate with the assistance of a geo-location database. However, Administrations may still decide to define maximum permitted e.i.r.p. of WSDs considering their DTT implementations. In some situations there may be a need to limit the e.i.r.p. of WSDs in order to avoid cross-border issues related to potential interference into the broadcasting service.

It is anticipated that standardisation organisations, such as ETSI, are likely to specify maximum output power for WSDs on the basis of technology limitations or taking into account certain usage models.

5 PROTECTION OF PROGRAM MAKING AND SPECIAL EVENT (PMSE) SYSTEMS IN THE BAND 470-790 MHZ FROM EMISSIONS OF COGNITIVE RADIO DEVICES OPERATING IN 'WHITE SPACES'

5.1 PMSE system characteristics and protection criteria

5.1.1 Background on PMSE

5.1.1.1 PMSE system in UHF-TV bands

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 devices using the band 470-862 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.

Note: The study is based on currently available FM systems. Future PMSE systems will use different modulation techniques such as digital modulation, which would require additional consideration.

5.1.1.2 Link reliability

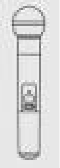
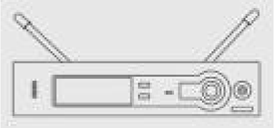
Radio links used for PMSE typically use analogue FM technology and must deliver reliable, high quality audio with 100 % duty cycle. Any interference to the radio link will typically result in severe audio impairments which are not considered acceptable, in particular for professional events.

5.1.2 PMSE deployment scenario

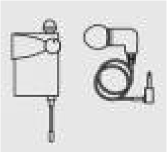
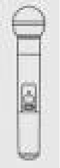
There is no single scenario which describes the diverse usage of PMSE. Compatibility and sharing studies must consider various possible scenarios. The parameters required for a geo-location approach will also be dependent upon the PMSE application and usage scenario. For example, an outdoor event, using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

Typical use cases for PMSE include indoor and outdoor applications at antenna heights ranging from 1.5m to 10, or even 30m in some cases. Receive and transmit antennas may be fixed or mobile

5.1.2.1 *Wireless Microphone - fixed*

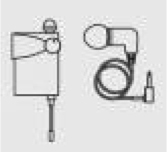
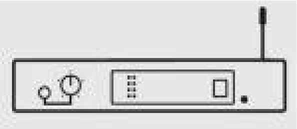
mobile Tx  <<< distance typ. 20-100 m >>> fixed Rx 
Typical application: TV presenter, artist on stage.

5.1.2.2 *Wireless microphone - mobile*

mobile Rx  <<< distance typ. 20-100 m >>> mobile Tx 

Typical application: Electronic News Gathering, touring guides.

5.1.2.3 *InEar Monitoring*

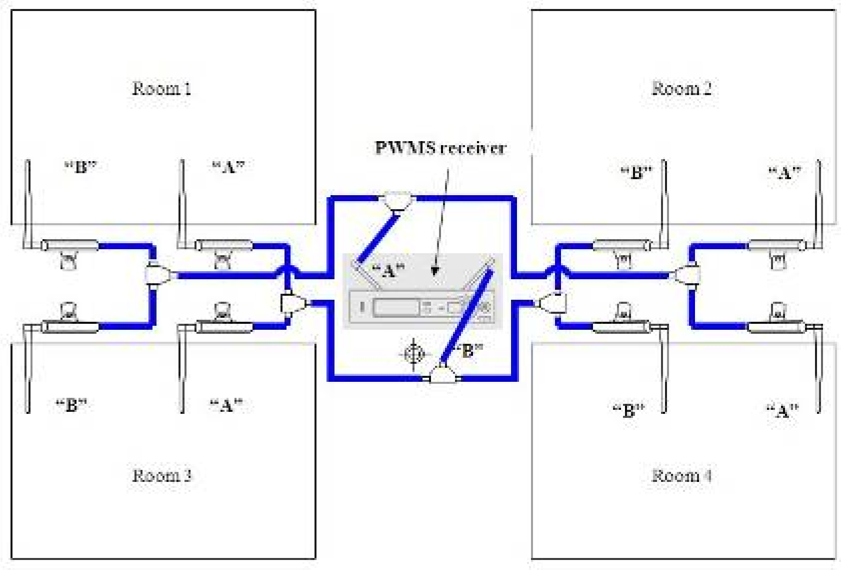
mobile Rx  <<< distance typ. 20-100 m >>> fixed Tx 

Typical application: audio back channel to a presenter or an artist on stage.

5.1.2.4 *Distributed antenna systems*

These are used together with a diversity receiver to expand the receiving coverage area

Typical applications: Studios, Theatre stages, music events, wide-area events (e.g. sports events)



Examples:
Multiple rooms:

- Concert halls
- Conference centres

- Broadcast studios

Large area events:

- Processions and street parades (e.g. a mobile transmitter moving along a 2 km long street)
- Broadcast production and presentation (e.g. a mobile transmitter roaming over a 4 km² area)
- Point to point links (typically outdoor)
    - many 100 m between PWMS receiver and the receiving antennas
    - PWMS Tx distance to receiving antennas typical 100 m.

5.1.3 PMSE Technical parameters

PMSE Receiver sensitivity and C/I requirement

A typical analogue FM PMSE receiver has a sensitivity of -110 dBm. The RF squelch threshold, at which level the audio is muted, is typically set to -95 dBm.

The minimum required signal level for high quality audio is typically -95 dBm with a C/I requirement of 20 dB for current analogue FM equipment (50-200 kHz bandwidth). Digital systems (up to 600 kHz RF bandwidth) may operate at lower signal strength depending on the chosen modulation scheme. In some practical situations, PMSE systems may operate with values above -95 dBm. However, for the purpose of this study the received PMSE signal level is set to this minimum value in order to address the reliability objective of the PMSE link.

The interference permitted from WSD should be below -115 dBm at the PWMS receiver, taking as a basis analogue FM PMSE system.

Blocking parameter
Blocking parameters are defined in ETSI TR 102 546 [10]. These values may be revised due to foreseen changes in the PMSE specification and will be published in ETSI TR 103 058 [11].

PMSE receiver protection mask:

The following Figure 13 is available in draft TR 103 058 [11] and provides the maximum interference level for a 200 kHz channel PMSE receiver.

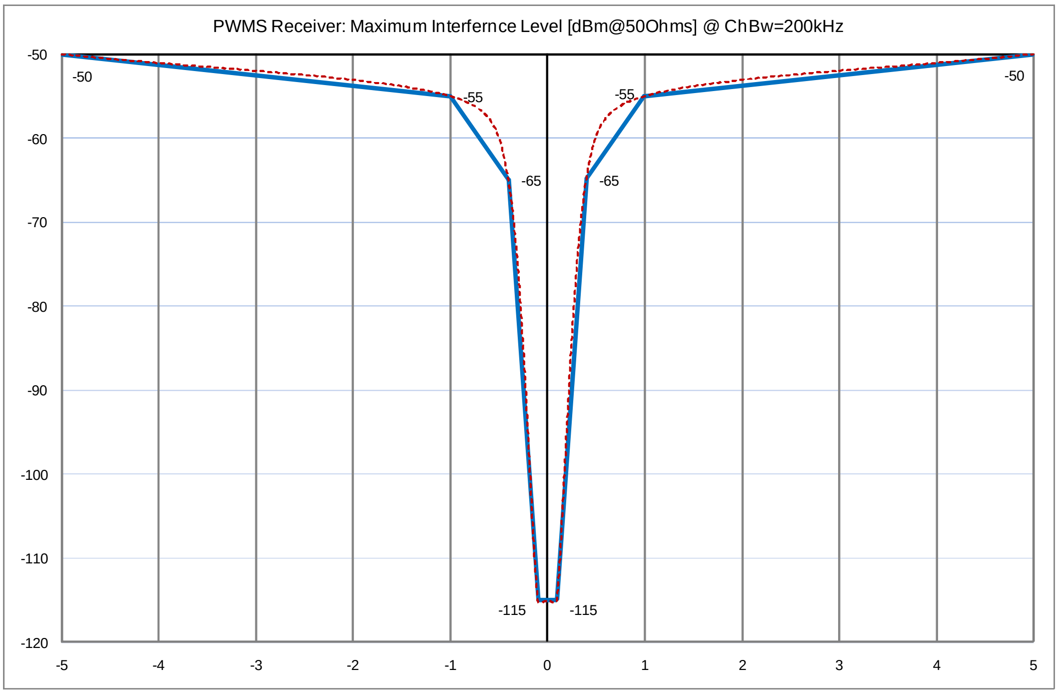


Figure 13: PMSE maximum interference level

Offset Frequency [MHz]	-5	-1	0,4	0,1	0	0,1	0,4	-1	-5
Maximum Interference Level [dBm@50Ohms]	-50	-55	-65	-115	-115	-115	-65	-55	-50

Table 8: PMSE maximum interference level

PMSE transmitter output power:

PMSE transmitter output power varies typically between 0dBm and 17dBm for hand held applications.

Audio point to point links operate at increased powers, typically up to 47dBm (50W).

RF bandwidth:

The usual RF bandwidth for analogue FM systems is 200 kHz , while ETSI EN 300 422 [12] allows up to 600 kHz to support newer digital modulation systems.

PMSE Antenna:

Antennas may be internal or external to the transmitter using omni-directional or directional patterns.

Antenna heights are typically 1.5 m for mobile transmitters and 5 -30 m for fixed transmitters.

Receive antennas are often rigged at elevated height (5-30m) to improve coverage and reduce the effects of frequency-selective and temporal fading.

The following antennas types are used:

For transmitting and receiving:

a) Omnidirectional: 2.15 dBi
b) Directional:
    a. circular polarization:
        i. 14 dBi; 57° beamwidth; Front-to-back ratio: 30 dB
        ii. 10 dBi; 80° beamwidth;
    b. directional: 9 dBi; 90 ° beamwidth; Front-to-back-ratio 14 dB

For receiving only:
The same antennas are used as above, however an RF pre-amplifier may be used to compensate for the antenna cable loss between the PMSE Rx antenna and the receiver.

Fading Margin:

Up to 25 dB (measured value) is commonly used for link budgets. A Rayleigh fading distribution of up to 35 dB may occur.

Body Absorption:

Values of 6dB for hand-held radio-microphones and of 24 dB for body worn are suggested. It should be noted that, for body worn, according to ERC Report 42 [13], body absorption can be up to 22dB added with 15dB antenna shielding.

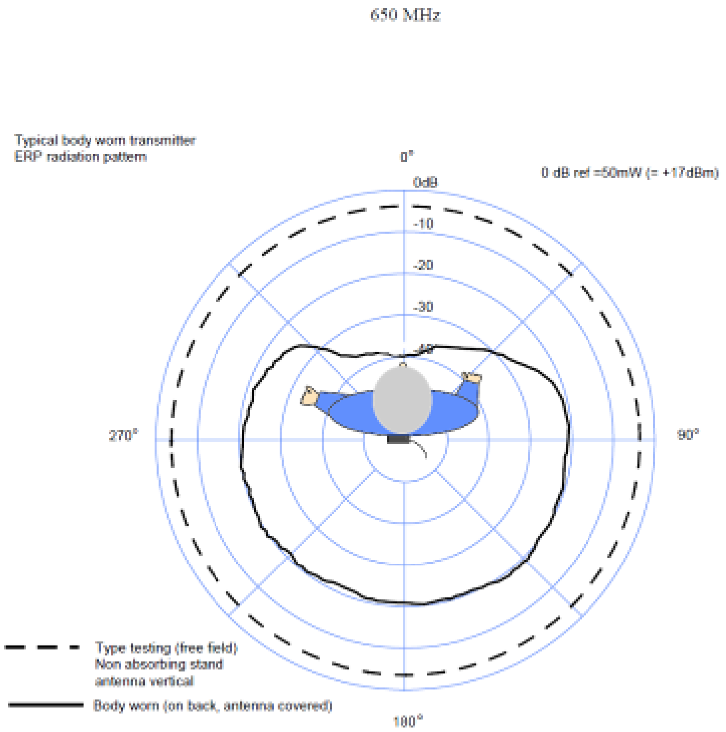


Figure 14: Radiation pattern body worn transmitter (Tx RF ERP = 14 dBm)

Distance PMSE Transmitter to Receiver antennas:

A separation of 20 to 100 m is typical for radio microphones.

Up to 10km is possible for outdoor point-to-point applications.

Wall attenuation:

Several references show that the building penetration loss varies significantly with different wall materials. Therefore calculations, which include building penetration loss, should be performed for minimum and maximum wall attenuation, ranging from 5.5 dB to 20 dB. These values typically cover 99 % of all possibilities.

- WSD Sensing level calculations: 5.5 to 20 dB (= maximum wall loss; covers 99 % of different possibilities)
- WSD RF maximum power calculation: 5.5 to 20 dB (minimum wall loss, also used on DVB-T parameters)

Further studies are required to properly understand the statistical nature of these variations.

5.2 WSD Emission limits

The emission limits for a WSD will depend on the following parameters:

- PMSE receiver protection ratio
- Path loss between WSD and the victim PMSE receiver antenna
- Antenna isolation resulting from directivity or polarisation discrimination

There is some similarity between this approach and the method developed for protecting DTT receivers.

The maximum permissible in-block power for the WSD will be given by:

$$\mathcal{P}_{IB}^{WSD}(f_{WSD}) = \mathcal{P}_{\min}^{PMSE}(f_{PMSE}) - PR(f_{WSD} - f_{PMSE}) - IM + \mathcal{D}_{dir} + \mathcal{D}_{pol} - \mathcal{G}_i + \mathcal{L}_f$$
$$+ \mathcal{L}_{WSD(\mathcal{H}_{WSD})-PMSE(\mathcal{H}_{PMSE})}(d_{WSD-PMSE}) + BPL_{WSD-PMSE}$$

where:

f_{PMSE} : operational frequency of the PMSE transmitter (MHz);

f_{WSD} : The target operational frequency of the WSD (MHz).

$P_{IB}^{WSD}(f_{WSD})$: The maximum permitted <u>in-block</u> e.i.r.p. of a WSD device at frequency f_{WSD} (dBm).

$P_{min}^{PMSE}(f_{PMSE})$: The minimum PMSE power at the receiver input at frequency f_{PMSE} (dBm);

$PR(f_{WSD} - f_{PMSE})$: The appropriate PMSE receiver protection ratio for the frequency offset $f_{WSD} - f_{PMSE}$ to protect PMSE reception from WSD interference (dB).

$d_{WSD-PMSE}$: The distance between the WSD and the PMSE receiver (m).

$L_{WSD(H_{WSD})-PMSE(H_{PMSE})}(d_{WSD-PMSE})$:
The path loss for the distance $d_{WSD-PMSE}$ between the WSD with antenna height H_{WSD} and the PMSE receiving antenna at height H_{PMSE} (dB).

IM: An interference margin, to allow for other impairments to reception at the PMSE receiver. This margin may need to account for a reception statistics, impulsive noise, or other sources of interference.

D_{dir}: PMSE receiver antenna directivity discrimination with respect to the WSD signal (dB);

D_{pol}: PMSE receiver polarization discrimination with respect to the WSD signal (dB);

G_i: Antenna gain of the PMSE receiving installation, referred to an isotropic antenna.

L_f: Feeder loss of the PMSE receiving installation.

$BPL_{WSD-PMSE}$: Building penetration loss (if any) between the WSD and the PMSE receiving antenna.

The propagation model used to calculate the $L_{WSD(H_{WSD})-PMSE(H_{PMSE})}(d_{WSD-PMSE})$ will depend on the use case scenario. For example, for a PMSE receive antenna at elevated height (10m – 30m) a line of sight model will be appropriate. For PMSE antennas at low height (1.5 – 5m), a low-height to low height propagation model is needed. Further studies are required to identify appropriate models for these scenarios.

The protection ratios $PR(f_{WSD} - f_{PMSE})$ required for this model are a function of the particular PMSE system (analogue or digital) and the characteristics of the WSD. For noise-like or CW interferers, the PMSE receiver characteristics shown in Figure 13 may be appropriate. However, further studies are required to characterize the performance e of typical PMSE receivers in the presence of interference from candidate WSD technologies (e.g. LTE,…).

Case of WSD having access to a geo-location database:

For WSD that have access to the geo-location database, one potential approach is to define a PMSE protection zone rather than to define WSD maximum e.i.r.p. This zone is drawn around the PMSE receiving antennas and will be dependent upon the expected WSD output power. PMSE Rx antenna distribution system can cover a larger area than the typical PMSE operation range of 20 – 100 m.

One important factor for defining the PMSE protection zone is the location accuracy combined with the database accuracy. For example, if the accuracy is low the more headroom needs to be added in distance between the interferer WSD and the victim (PWMS receiver).

The maximum RF output definition as well as the headroom in distance depends also on the mobility of the interferer and the victim in combination of the database ask-before-talk update the WSD has to perform.

5.3 Sensing (including calculation of detection threshold)

A WSD can only detect the PMSE transmitter, while the PMSE receiver, which is generally at a different location is the victim and needs protection from the interference. This is a particularly important consideration for outdoor point to point use and PMSE applications where receive antennas are rigged at elevated height to receive PMSE transmitters at low height. Two approaches to calculating the requirements for sensing are discussed in the following sections.

5.3.1 Calculation of detection threshold using an experimental approach with hidden node margin

The detection / sensing threshold is given by:

$$P_{\mathrm{Det\ (dBm)}} = P_{\mathrm{min\ (dBm)}} - G_{\mathrm{A\ (dB)}} - L_{\mathrm{HN\ (dB)}}$$

where:

P min (dBm) = minimum sensitivity
G A = receiving antenna gain = 0 dB
LHN (dB) = Hidden node margin

Note, the hidden-node margin geometry for a wireless microphone is quite different from that for DTT. The value obtained was gained by several measurements in typical PMSE scenarios which included a fixed installations in a theatre and an installation in a TV production studio.

A 3D ray-tracing model was developed for each of the scenarios using architect drawings and the model was validated against the measured data. The model allowed the PMSE level to be computed over an increased number of test points to give a statistically valid estimate of the hidden node margin.

Concerning the PMSE receiver sensitivity, the theoretical standard value is -95 dBm. This was supported by measurements of the sensitivity of a range of wireless microphones (200 kHz bandwidth) which concluded that the average sensitivity was -91.5 dBm at the input of the wireless microphone receiver.

However, when making measurements in a range of venues, it was noted that the receivers were typically operated at signal levels above -67 dBm in order to ensure a high quality link (e.g. in a theatre), which explains why a PMSE receiver mean operating level of -67 dBm is considered under this approach.

Based on these measurements and the subsequent modelling, the following detection thresholds are proposed in Table 9.

Parameter	**Units**	**PWMS**
PMSE Rx mean operating level	dBm	-67.00
Rx antenna gain	dB	2.15
Min. signal at Rx ant.	dBm	-69.15
Hidden-node margin	dB	59*
WSD detection threshold	dBm	-128.15
* Results of statistical estimation		

Table 9: Detection threshold for the protection of PMSE based on an experimental approach with hidden node margin

5.3.2 *Calculation of detection threshold using a theoretical approach based on geometry*

5.3.2.1 *Methodology*

This approach is based on the geometry depicted in Figure 15:

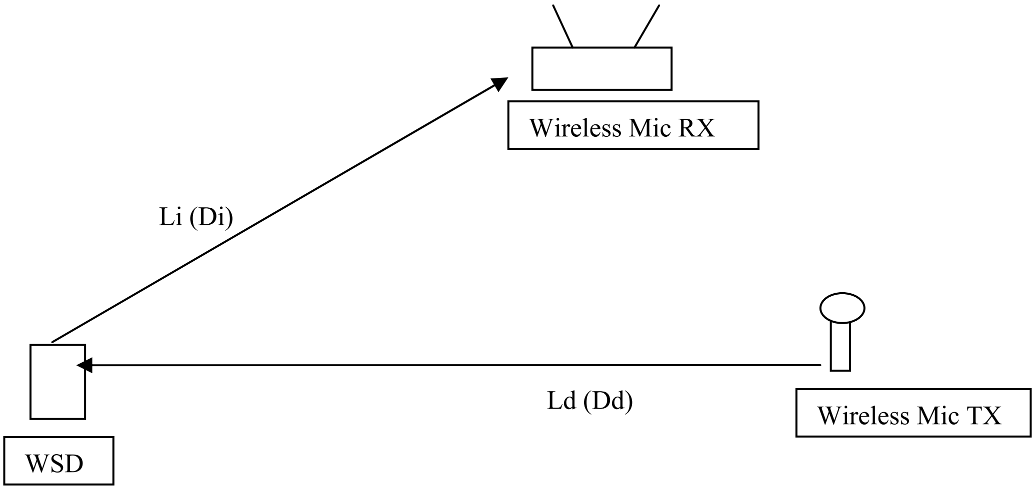


Figure 15: General geometry for the calculation of the detection threshold for the protection of PMSE

For the determination of the detection threshold in order to protect PMSE reception, two links are mainly of interest:

- Interfering link (WSD→ PMSE Rx): associated path loss Li. This sets up the level of interference Pint generated by the WSD transmitter at the PMSE receiver.

$$\text{Pint} = \text{Pwsd} + \text{Grx pmse} - \text{Lb wsd} - 10*\log(\text{Bwsd}/\text{Bpmse}) - \text{Li} \qquad (5.3.1)$$

- Detection link (PMSE Tx → WSD): associated path loss Ld. This sets up the level of the signal Pdet transmitted by the PMSE transmitter detected at the WSD receiver.

$$\text{Pdet} = \text{Ppmse} + \text{Grx wsd} - \text{Lb pmse} - \text{Ld} \qquad (5.3.2)$$

where:

Pwsd and Ppmse are the WSD and PMSE e.i.r.p respectively(dBm),

Grx pmse and Grx wsd are the antenna gains of the PMSE and WSD receivers respectively (dBi),

Lb wsd and Lb PMSE are the body loss for the WSD and the PMSE respectively dB,

Bwsd and Bpmse are the bandwidths of the WSD and PMSE respectively, i.e. 8 MHz for the WSD and 200 kHz for the PMSE.

Concerning the wanted link (PMSE Tx → PMSE Rx), it is supposed, in order to cover the most critical cases, that the level of wanted signal from the PMSE transmitter obtained at the PMSE receiver is set up at the receiver sensitivity value of -95 dBm.

In order to avoid that the WSD transmitter creates interference into the PMSE receiver, the detection threshold DTh(dBm) should be set at a level, which would ensure that, when the power of the interfering link Pint reaches the maximum allowable interference level Pintmax (dBm), the power of the detection link Pdet should reach the sensing threshold DTh.

This means, that, when the interfering path loss Li is such that Pint= Pintmax (dBm), the sensing threshold DTh value should verify that, taking into account the detection path loss Ld, Pdet= DTh (dBm).

Considering equations (5.3.1) and (5.3.2), this implies that, when

$$\text{Pint} = \text{Pwsd} + \text{Grx pmse} - \text{Lb wsd} - 10*\log(\text{Bwsd}/\text{Bpmse}) - \text{Li} = \text{Pintmax} \qquad (5.3.1)'$$

we should have simultaneously,

$$Pdet = Ppmse + Grx\ wsd - Lb\ pmse - Ld = DTh \quad (5.3.2)'$$

Therefore, when comparing equations (5.3.1)' and (5.3.2)'

$DTh = Pdet - (Pint - Pintmax)$

$= Pintmax + (Ppmse-Pwsd+ 10*\log(Bwsd/Bpmse)) + Grx\ wsd - Grx\ pmse - (Lb\ pmse-Lb\ wsd) - (Ld-Li)$ (5.3.3)

From equation (5.3.3), the detection threshold can be expressed as a function of the difference ΔL in path loss between the two links (Ld-Li) and therefore its determination would require an assessment of ΔL.

Taking into account the various PMSE deployment types and the numerous possible configurations, it is not possible to estimate a single value for ΔL. Therefore, in the following sub-sections various examples are proposed for which the detection threshold is calculated.

5.3.2.2 Detection threshold calculations for various scenarios

Scenario 1:

The WSD is located far enough from the PMSE receiver and transmitter so that the PMSE Rx and Tx are seen as a single point from the WSD (see Figure 16). For example, the WSD is operating outside at a certain distance from a building where the PMSE Rx and Tx are located. In that case, it is assumed that Ld=Li,

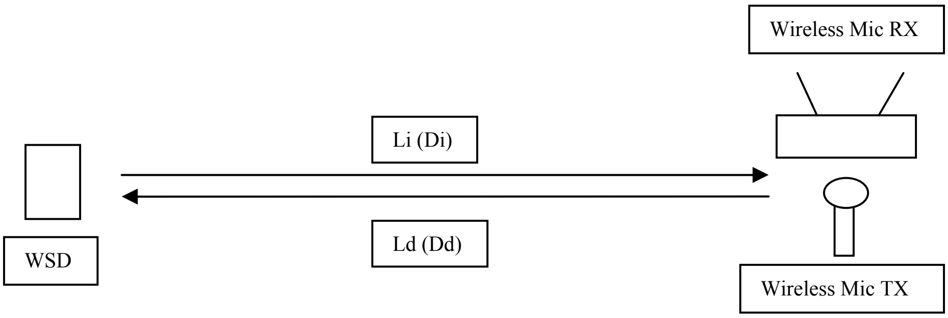


Figure 16: Scenario 1

The following parameters are assumed with this scenario:

Pintmax=-115 dBm
Ppmse=10 dBm
Pwsd=20 dBm
10*log(Bwsd/Bpmse)=16 dB
Grx wsd=Grx pmse
Lb pmse= 15 dB
Lb wsd = 5 dB

Since, under this scenario, ΔL = Ld-Li = 0 dB, the detection threshold can easily be derived from the equation (5.3.3). This leads to:
DTh (dBm)
= Pintmax + Ppmse-Pwsd+ 10*log(Bwsd/Bpmse) + (Grx wsd – Grx pmse) – (Lb pmse-Lb wsd) –(Ld-Li)
=-115 + 10 – 20 + 16 + 0 – 0 - 10 = -119 dBm

Scenario 2: Hand-held wireless microphones

10 mW handheld wireless microphone and 50 mW handheld WSD with equal 100m path lengths between the WSD and PMSE RX (Di) and between the WSD and PMSE TX (Dd) (see Figure 17)

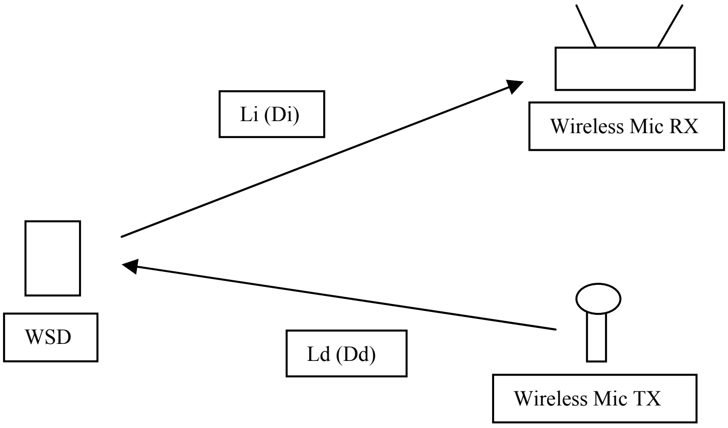


Figure 17: scenario 2 (Di=Dd)

Interference power calculation:

P wsd = 50 mW ERP = +20 dBm
Lb wsd = 6 dB (hand held device)
Li = 70 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz; no Rayleigh temporal fading loss assumed for the interfering path
Grx pmse = 2 dBi (half wave dipole antenna)
Lc pmse = 0 dB (antenna mounted directly on back of receiver at input connector)
Bwsd = 8 MHz
Bpmse = 200 kHz
Pint limit = -115 dBm for a PMSE sensitivity of -95 dBm with a 20 dB D/U ratio = Pintmax

Pint = +20 dBm – 6 dB – 70 dB + 2 dB – 0 dB – 16 dB = -70 dBm, which exceeds the defined maximum interference power level Pintmax of -115 dBm by 45 dB.

Detection power calculation:

P pmse = 10 mW ERP = +10 dBm
Lb pmse = 6 dB (hand held wireless microphone)
Ld = 70 to 105 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz + temporal Rayleigh fading loss of 0 to 35 dB (assuming a deep fade)
Grx wsd = -4 dB (small internal antenna with losses, including switching losses)
Lb wsd = 6 dB (same value as used for the interfering link)

Pdet = +10 dBm -6 dB – 70 to 105 dB – 4 dB – 6 dB = -76 to -111 dBm.

Detection threshold derivation

With a detection power of -76 to -111 dBm the WSD is exceeding the PMSE Rx protection limit by 45 dB. Therefore detection threshold is -76 to -111 dBm – 45 dB = -121 to -156 dBm.

Scenario 3: Body pack wireless microphones

50 mW body pack wireless microphone and 50 mW handheld WSD with equal 100m path lengths between the WSD and PMSE RX (Di) and between the WSD and PMSE TX (Dd) (see Figure 18).

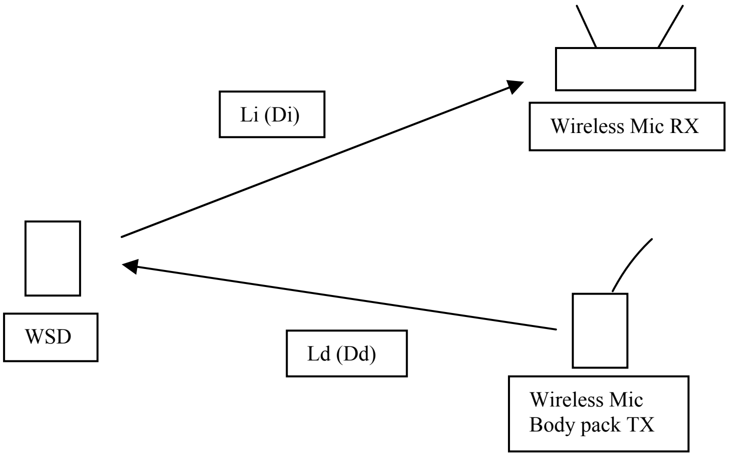


Figure 18: Scenario 3 (Di=Dd)

Interference power calculation:

P wsd = 50 mW ERP = +20 dBm
Lb wsd = 6 dB (hand held device)
Li = 70 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz, no Rayleigh temporal fading loss assumed for the interfering path
Grx pmse = 2 dBi (half wave dipole antenna)
Bwsd = 8 MHz
Bpmse = 200 kHz
Pint limit = -115 dBm for a PMSE sensitivity of -95 dBm with a 20 dB D/U ratio = Pintmax

As before, Pint = +20 dBm – 6 dB – 70 dB + 2 dB – 0 dB – 16 dB = -70 dBm, which exceeds the defined maximum interference power level Pintmax of -115 dBm by 45 dB.

Detection power calculation:

P pmse = 50 mW ERP = +17 dBm
Lb pmse = 24 dB (body pack wireless microphone)
Ld = 70 to 105 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz + temporal Rayleigh fading loss of 35 dB (assuming a deep fade
Grx wsd = -4 dB (small internal antenna with losses, including switching losses)
Lb wsd = 6 dB (same value as used for the interfering link)

Pdet = +17 dBm – 24 dB – 70 to 105 dB – 4 dB – 6 dB = -87 to -122 dBm

Detection threshold derivation

With a detection power of -87 to -122 dBm the WSD is exceeding the PMSE Rx protection limit by 45 dB. Therefore detection threshold is -87 to -122 dBm – 45 dB = -132 to -167 dBm

Scenario 4: in-ear monitor:

50 mW in-ear monitor transmitter and 50 mW handheld WSD with equal 100m path lengths between the WSD and PMSE RX (Di) and between the WSD and PMSE TX (Dd) (see Figure 19)

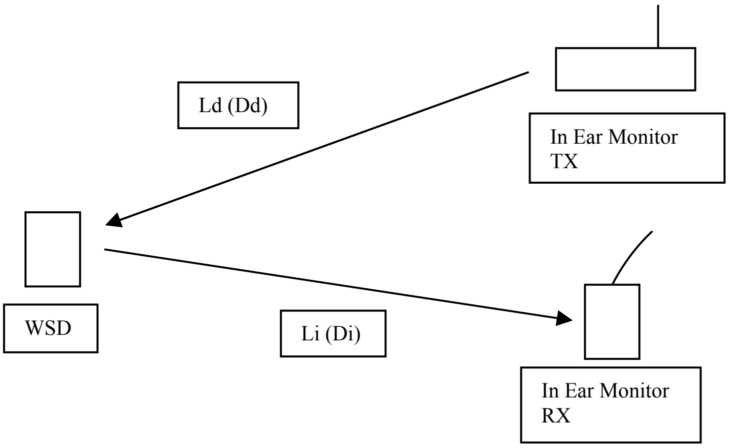


Figure 19: Scenario 4 (Di=Dd)

Interference power calculation:

P wsd = 50 mW ERP = +20 dBm
Lb wsd = 6 dB (hand held device)
Li = 70 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz , no Rayleigh temporal fading loss assumed for the interfering path
Grx pmse = -2 dB (wire antenna)
Lb pmse = 24 dB (body worn receiver)
Bwsd = 8 MHz
Bpmse = 200 kHz
Pint limit = -115 dBm for a PMSE sensitivity of -95 dBm with a 20 dB D/U ratio = Pintmax.

Pint = +20 dBm – 6 dB – 70 dB – 24 - 2 dB - 16 dB = -98 dBm, which exceeds the defined maximum interference power level Pintmax of -115 dBm by 17 dB.

Detection power calculation:

P pmse = 50 mW ERP = +17 dBm
Lc pmse = 0 dB (antenna mounted directly at transmitter output)
Ld = 70 to105 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz + temporal Rayleigh fading loss of 0 to 35 dB (assuming a deep fade)
Grx wsd = -4 dB (small internal antenna with losses, including switching losses)
Lb wsd = 6 dB (same value as used for the interfering link).

Pdet = +17 dBm – 0 dB – 70 to 105 dB – 4 dB – 6 dB = -63 to -98 dBm.

Detection threshold derivation

With a detection power of -63 to -98 dBm the WSD is exceeding the PMSE Rx protection limit by 17 dB. Therefore detection threshold is -63 to -98 dBm – 17 dB = -80 to -115 dBm.

Scenario 5:

10 mW handheld wireless microphone and 100 mW handheld WSD with 100m path length between the WSD and elevated (10m) PMSE RX (Di) and 200m low path length between the WSD and PMSE TX (Dd) (see Figure 20).

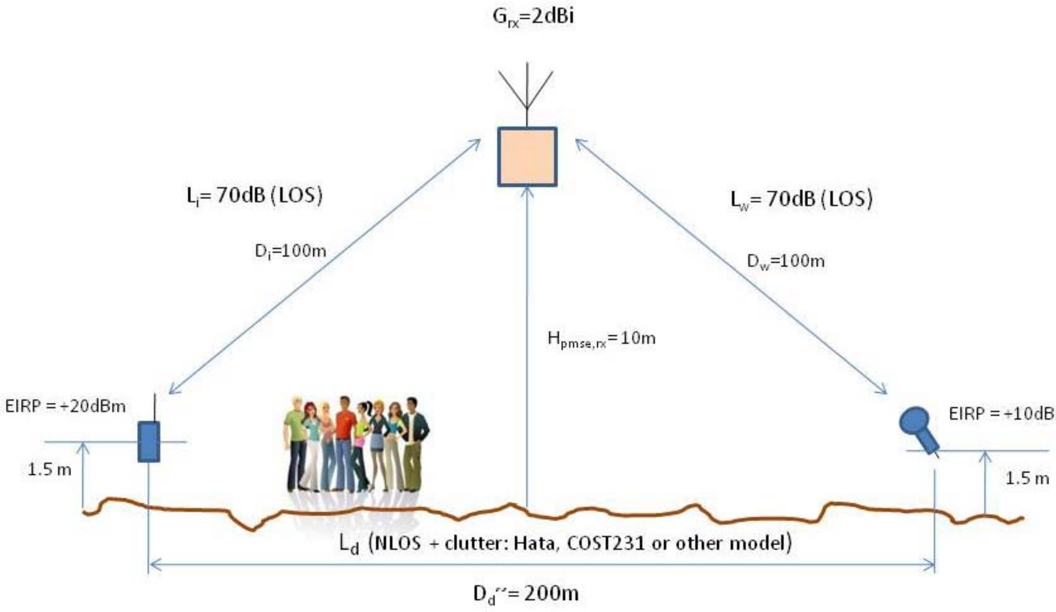


Figure 20: PMSE Scenario - Studio

Interference power calculation:

P wsd = 100 mW ERP = +20 dBm
Lb wsd = 6 dB (hand held device)
Li = 70 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz; no Rayleigh temporal fading loss assumed for the interfering path
Grx pmse = 2 dBi (dipole antenna)
Bwsd = 8 MHz
Bpmse = 200 kHz
Pint limit = -115 dBm for a PMSE sensitivity of -95 dBm with a 20 dB D/U ratio = Pintmax

Pint = +20 dBm – 6 dB – 70 dB + 2 dB - 16 dB = -70 dBm, which exceeds the defined maximum interference power level Pintmax of -115 dBm by 45 dB if the WSD transmits.

Detection power calculation:

P pmse = 50 mW ERP = +17 dBm
Lb pmse = 6 dB (handheld wireless microphone)
Ld = 76 to 111 dB; Free space path loss contribution of 76 dB for 200m path at 750 MHz + temporal Rayleigh fading loss of 0-35 dB (obstructed low height path)
Grx wsd = -4 dBi (small internal antenna with losses, including switching losses)
Lb wsd = 6 dB (handheld device)
Pdet = +17 dBm – 6 dB – 76 dB – [0… 35] – 6 dB – 4 dB = -75 to -110 dBm depending upon temporal fading losses.

Detection threshold derivation

With a detection power of -75 to -110 dBm the WSD is exceeding the PMSE Rx protection limit by 45 dB. Therefore detection threshold is -75 to -110 dBm – 45 dB = -120 to -155 dBm.

Scenario 6:

10 mW handheld wireless microphone and 100 mW handheld WSD with 36m path length between the WSD and elevated (20m) PMSE RX (Di) and 1300m low path length between the WSD and PMSE TX (Dd) (see Figure 21).

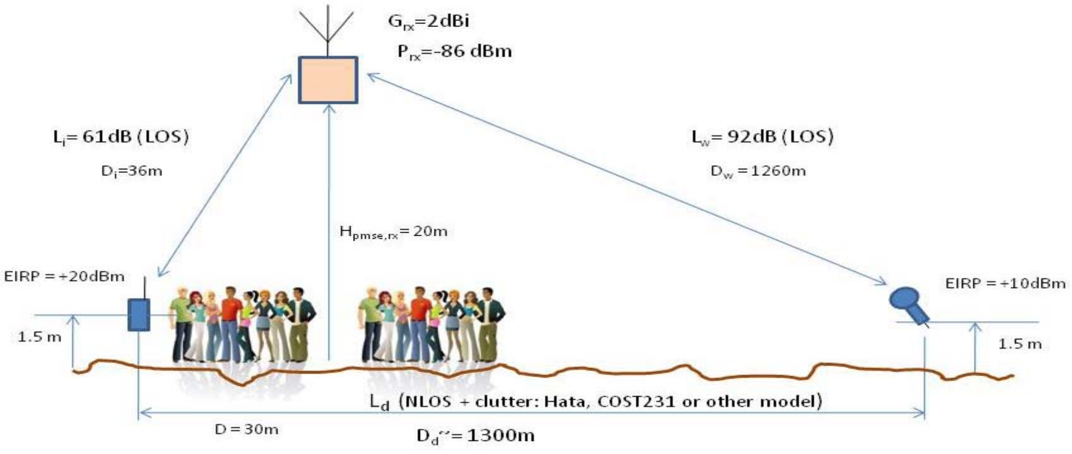


Figure 21: PMSE Scenario – Sports Event

Interference power calculation:

P wsd = 100 mW ERP = +20 dBm
Lb wsd = 6 dB (hand held device)
Li = 61 dB; Free space path loss contribution of 70 dB for 100m path at 750 MHz; no Rayleigh temporal fading loss assumed for the interfering path
Grx pmse = 2 dBi (dipole antenna)
Lb pmse = 6 dB (handheld wireless microphone)
Bwsd = 8 MHz
Bpmse = 200 kHz
Pint limit = -115 dBm for a PMSE sensitivity of -95 dBm with a 20 dB D/U ratio = Pintmax

Pint = +20 dBm – 6 dB – 61 dB + 2 dB - 16 dB = -61 dBm, which exceeds the defined maximum interference power level Pintmax of -115 dBm by 54 dB if the WSD transmits.

Detection power calculation:

P pmse = 50 mW ERP = +17 dBm
Lb pmse = 6 dB (handheld wireless microphone)
Ld = 76-111 dB; Free space path loss contribution of 92 dB for 1300m path at 750 MHz + temporal Rayleigh fading loss of 0-35 dB (obstructed low height path)
Grx wsd = -4 dBi (small internal antenna with losses, including switching losses)
Lb wsd = 6 dB (handheld device)
Pdet = +17 dBm – 6 dB – 92 dB – [0… 35] – 6 dB – 4 dB = -91 to -126 dBm depending upon temporal fading losses.

Detection threshold derivation

With a detection power of -91 to -126 dBm the WSD is exceeding the PMSE Rx protection limit by 45 dB. Therefore detection threshold is -75 to -110 dBm – 45 dB = -120 to -155 dBm.

5.3.3 Summary

	Scenario 1	Scenario2	Scenario3	Scenario4	Scenario5
Maximum interference level at the PMSE receiver(dBm)	-115	-115	-115	-115	-115
PMSE e.i.r.p. (dBm)	10	10	10	10 to 17	17
WSD e.i.rp. (dBm)	20	20	20	20	20
PMSE receiver antenna gain (dBi)	0	2	2	-2	2
WSD receiver antenna gain (dBi)	0	-4	-4	-4	-4
PMSE body loss	15	6	24	0	6
WSD body loss	5	6	6	6	6
Bandwidth correction factor (dB)	16	16	16	16	16
Difference ΔL in propagation losses (dB)	0				
Interference path propagation loss Li		70	70	70	70
Detection path propagation loss Ld		70 to 105	70 to 105	70 to 105	76 to 111
Resulting detection threshold (dBm)	**-119**	**-121 to -156**	**132 to -167**	**-80 to -115**	**-120 to -155**

Table 10: Summary of resulting detection thresholds

From the calculations presented above, it can be seen that there is a great level of variability in the derived detection threshold depending upon the considered scenarios. The main driving factor for these calculations is the difference of propagation loss between the interfering link (from the WSD transmitter to the PMSE receiver) and the detection link (from the PMSE transmitter to the WSD receiver). In particular, consideration of temporal Rayleigh fading (up to 35dB) leads in general to very low detection threshold, far below the WSD receiver noise floor, which would make this technical quite impractical.

Thus, there is a need to further study the propagation characteristics of PMSE systems operating in various configurations and the potential ways for spectrum sensing to cope with temporal fading.

It is expected that implementation of sensing based on sufficiently long windowed signal (few ms) may help since it will averaged out the deep instantaneous fades. This requires detailed analysis.

Operational requirements for sensing

- PWMS transmitter can be mobile as well as the PWMS receiver. Therefore a mobile WSD would need to sense on a regular basis to detect a change in the environment. A sufficiently short interval time between two scans would need to be considered. An interval time of 2 seconds is recommended, based on the value adopted in the IEEE 802.22 draft standard. A wireless microphone user would normally expect the microphone to be usable within about 2 seconds after it is switched on. If not, the user would be likely to conclude that it was not working properly.
- Sensing duration: There are two durations that need to be specified. The first is the sensing duration before a WSD decides that a channel is available. This is usually a large number, for example 30 seconds in the FCC rules. This ensures that temporal fades do not cause an erroneous decision. The second sensing duration that needs to be specified is the in-service sensing duration which is typically much smaller, for example 5 ms every 160 ms as specified in the IEEE 802.22 standard.
- Each WSD is requested to perform sensing detection in a sensing-only environment to protect PMSE. The purpose of this is to mitigate the hidden node problem caused by Rayleigh fading.
- The capability of the sensing process to detect a PMSE signal in a channel adjacent to one used by high power DTT transmissions needs to be addressed. This requirement is driven by the fact that PMSE systems mainly operate in channels that are adjacent to occupied DTT channels. If spectrum sensing failed to work under

these circumstances or if the sensing threshold was degraded, it would be an ineffective solution for protecting PMSE from interference.

- It should be noted that sensing the PMSE signal is very different from sensing of DTT signals and in general the same sensing device is not usable for both directly. DTT sensing is based on wideband receiver and will likely be using some feature detection principle. PMSE signal can basically be just FM modulated analogue signal, which is detected with narrow band energy detection or detection a pilot beacon signal.

5.4 Geo-location database

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.

The stationary sites could relatively easily be registered in a database, but there may be changes in the use of microphones within the site that may need to be registered. A simple approach to protect the site would be to define a protection zone around the sites. The exact location of the stationary sites can also be defined relatively easily, coordinates could be used, or an address.

Registration of the temporary sites would be a frequent task, thus an easy registration procedure should be employed.

Additional information on the geo-location process can be found in Section 9.3.

5.5 Beacon transmitter

Although no detailed study was performed, it is envisaged that the use of beacon transmitter may be helpful for the protection of PMSE.

In particular, the approach of ‘disable beacon’ (see Section 3.4.3), discussed within IEEE 802.22 can have some merit. It consists in enhancing detection of wireless microphones through the operation of low powered beacons to provide a “bubble of protection” in locations where PMSE equipment is in use. It can be implemented through the use of a single disabling beacon that would aggregate the occupied channel information for all PMSE systems operating at that location. This would somewhat be similar to the Cognitive Pilot Channel (CPC) approach being considered by ETSI TC RRS. If the CPC were standardized, it might be worthwhile to consider further the single disabling beacon approach.

The beacon needs to transmit with enough RF output power to protect the required area / zone. Depending on the RF output power level, two disadvantages of the disable beacon concept need to be considered: the beacon will consume frequency resources and will add an additional interference source, which reduces the overall spectrum efficiency. This problem might be solved if e.g. combining the beacon approach with sensing, when the beacon is transmitted as part of the normal protocol.

The use of other beacon approaches (multiple disabling beacons, enabling beacon) looks more problematic.

5.6 Planned usage for PMSE including reserved channels for PMSE

It may be possible to reserve some channels which are not used by DTT only for the PMSE use. Such an approach is known as safe-harbour channels.

Safe-harbour channels are channels set aside for PMSE use, which would not be available for use by WSD.

There are a number of ways of operating a safe harbour:

- One or more fixed channels can be made available across a nation or region - opportunities to do this are scarce, by the nature of TV planning in the interleaved spectrum
- One or more channels, whose position changes according to DTT use in each coverage area

- A dynamically varied number of channels - which can be adapted according to place and time, so that for example in rural areas there might not be a need for safe harbour channels or they might be enabled only for certain events (e.g. golf championships)

Safe-harbour can be used in conjunction with either geolocation or sensing. When used with geolocation, it can support cases where access is needed more rapidly than database protection might be able to provide. However, since this is a dedicated use of spectrum, it should be used carefully. Safe harbour channels would probably be left fallow in many places. In rural areas, for example, such channels would almost always be left vacant. Even in the places where they are used, this would typically not be continuous (i.e. 24 hours per day).

From Section 5.1.2 above we can see there are many different PMSE deployment scenarios, most of these usage scenarios will be for events that are either limited in geographical location or in the time period they will be deployed. Due to this limited use of the spectrum it would not be efficient use of spectrum for regulators to dedicate a good proportion of the available spectrum (i.e. safe harbor channels) to PMSE users on a national basis.

There are however a number of venues that have almost constant usage (i.e. television studios and theatres), at these venues the spectrum usage may already be planned and can be protected by implementing appropriate geographical exclusion zones around the venues on the channels that are required for the day to day needs of these PMSE users. The protection requirements for other major broadcasting events that are restricted both in their duration and geography could also be planned in advance by the geo-location database. If regulators can plan and manage interference into these types of PMSE users through use of the geo-location database then this would constitute the majority of the spectrum occupied by PMSE at any given time.

In addition it would be prudent for regulators to make at least one (or more) safe harbor channel available to cater for casual or unplanned usage by PMSE users on a national usage. The number of channels regulators should make available on a national basis would be dependent upon the amount of planned uses of PMSE can be factored into the protection requirements of the geo-location database. The less information available to regulators on the venues that have planned or constant usage then the greater the number of nationally available safe harbor channels will be needed in order to provide protection through the database. This will also be the case if ENG/OB events cannot be factored into the protection requirements of the database through the timing of the information update cycle between WSD and the geo-location database.

When looking to implement a new plan to reserve some of channels either nationally or geographically for PMSE users, the tuning ranges of the microphones need to be taken into account, so that (if possible) the channels being protected are within the tuning range of the PMSE users existing equipment.

5.7 Conclusions related to the protection of PMSE

The geo-location database appears to be the most satisfactory approach considered so far. A number of practical questions still require resolution, such as how users will enter their data into the system, what information should be stored, and how often WSDs must consult the database, to name a few. There do not appear to be any overriding technical problems with the database concept.

Spectrum sensing remains a problematic approach for protecting PMSE systems from interference, which needs more development. Temporal fading caused by multipath propagation is likely to be one of the main factors affecting the ability of WSDs to protect PMSE systems from interference through the use of spectrum sensing techniques. The path loss between a WSD and a PMSE transmitter or receiver can be very different even if the path lengths are similar, because PMSE transmitters and receivers operate in physically different locations and circumstances. The PMSE receiver is vulnerable to interference, but the WSD can only sense the PMSE transmitter.

As a result, we have identified the need to further study the propagation characteristics of PMSE systems operating in various configurations. Spectrum sensing techniques that are able to cope with temporal fading losses are needed.

The use of the different beacon concepts are not discussed in all detail yet. The disable beacon concept is an approach which can help to overcome sensing issues very easily. On a backside it requires frequency resources and would decrease spectrum efficiency. We need to identify required power level of the beacon and how much this affects the spectrum efficiency. Moreover the implementation of this concept, as every protected application will need a beacon installed.

In addition, it appears that the identification by national administration of at least one (or more) safe harbor channel, not used by DTT and which would be reserved for PMSE use would be helpful for the protection of PMSE, in particular for casual or unplanned usage by PMSE which would not be registered.

6 PROTECTION OF RADIO ASTRONOMY SERVICE IN THE BAND 608-614 MHz FROM EMISSIONS OF COGNITIVE RADIO DEVICES OPERATING IN 'WHITE SPACES'

Potential deployment of WS devices in the band 470-790 MHz is conditioned by the necessity to protect incumbent radio services/systems in this band.

In the frequency range 608-614 MHz (TV Channel 38) there is a secondary allocation to the RAS used for observations in a number of European countries[5]. The use of this band for RAS is also addressed in footnote 5.149 of the ITU RR[6].

Therefore, a careful interference analysis between RAS and WSDs is required in order to address the potentiality of deployment of WSDs in the frequency range 608-614 MHz.

This chapter presents the compatibility assessment between RAS and WSDs.

6.1 RAS system characteristics and protection criteria

The protection criterion depends on the observation mode, which must be defined for each RAS site.

The recommended protection criteria to be used for radio astronomical measurements are given in Rec. ITU-R RA.769-2. For this study the following levels for Single dish and Very Long Baseline Interferometry (VLBI) RAS sites from Rec. ITU-R RA. 769-2 are used:

Observation mode	**Protection levels**
• Single dish:	-253 dB(W/m^{2}Hz) assuming an integration time of 2000 s;
	-259.3 dB(W/m^{2}Hz) assuming an integration time of 10 h;
• VLBI:	-212 dB(W/m^{2}Hz) assuming an integration time of 10 µs.

For interferometry observation, the protection criterion is derived using the method given in Recommendation ITU-R RA.769-2, the parameters given in this recommendation and assuming an integration time of 1 second. This gives:

Observation mode	**Protection levels**
• Interferometry	-236 dB(W/m^{2}Hz) assuming an integration time of 1 s.

The maximum allowed (interfering) power flux density depends on the bandwidth of an interfering signal.

---

[5] **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.

[6] 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)."

6.2 Calculation assumptions

Table 11 lists the parameters used in calculations.

Parameter	**Units**	**Value**	**Remarks**
Bandwidth of WSD	MHz	5	The transmission technology employed by WSD is assumed to be similar to the one used by LTE technologies with noise-like signal characteristics
ERP of WSD	W	≤ 1	
Antenna height of WSD	m	10	
Antenna height of RAS site	m	10	
Antenna discrimination	dB	0	The RAS antenna could be tilted nearly horizontally for certain observations

Table 11: Calculation parameters

6.2.1 Co-channel interference

Taking into account the assumption for the WSD bandwidth (5 MHz), the levels of maximum power flux density at the RAS site are:

- Single dish: -186 dB(W/m^2) assuming an integration time of 2000 s;
  -192.3 dB(W/m^2) assuming an integration time of 10 h;
- VLBI: -145 dB(W/m^2) assuming an integration time of 10 µs.
- Interferometry -169 dB(W/m^2) assuming an integration time of 1 s.

These maximum power flux densities can be converted to the following values of maximum interfering field strength at the RAS site.

- Single dish: -40.2 dBµV/m assuming an integration time of 2000 s;
  -46.5 dBµV/m assuming an integration time of 10 h;
- VLBI: +0.79 dBµV/m assuming an integration time of 10 µs.
- Interferometry -23.2 dBµV/m assuming an integration time of 1 s.

6.2.2 Adjacent channel interference

In order to assess interference to RAS from a WSD operating on channels adjacent to the RAS band (608-614 MHz) some assumptions have been made with regard to Adjacent Channel Leakage Ratio ($_{ACLR}\quad ^{WSD}$) of the WSD. In particular, ACLR was assumed to be equal to 50 dB/5MHz, in accordance with the UMTS signal characteristics for the base station (see Table 2 of ECC Report 138)[7].

It needs to be noted that the usage of ACLR allows assessment of interference from channels immediately adjacent to the RAS band (i.e. TV Channel 39 and TV Channel 37) only. The effect of interference from WSDs operating on channels beyond (above or below) the first adjacent channel would require further assumptions to be made. In particular, the slope of out-of-band emission mask would need to be supposed[8].

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[7] It needs, however, to be noted that ACLR of a UMTS signal was observed to vary significantly (from 35 to ∞ dB/5MHz) due to Transmit Power Control in case of UMTS User Equipment (see ECC Report 138).

[8] Another approach would be to define the out-of-band emission mask such that the RAS receiver experiences no interference from WSDs operating in adjacent channels.

If $P^{WSD}_{adj.int.}(Ch.38 \pm 1)$ is referred to as the WSD power on a channel adjacent to TV Channel 38, then RAS in-channel effective interference power $P^{RAS}_{eff.int.}(Ch.38)$ is defined as

$$P^{RAS}_{eff.int.}(Ch.38) = P^{WSD}_{adj.int.}(Ch.38 \pm 1) - ACLR^{WSD}, \tag{6.1}$$

where $ACLR^{WSD}$ is the Adjacent Channel Leakage Ratio of the WSD.

6.2.3 Separation distances

Using the parameters of Table 11 minimum separation distances to be respected between the WSDs and RAS sites can be derived using the propagation curves presented in Recommendation ITU-R P.1546 [15]. These distances have been estimated under the assumption that the value of the harmful interference threshold is exceeded for not more than 1% of the time due to variable propagation conditions.

The calculated separation distances in TV Channel 38 are plotted in Figure 22 as a function of the output power (e.i.r.p.) of WSDs.

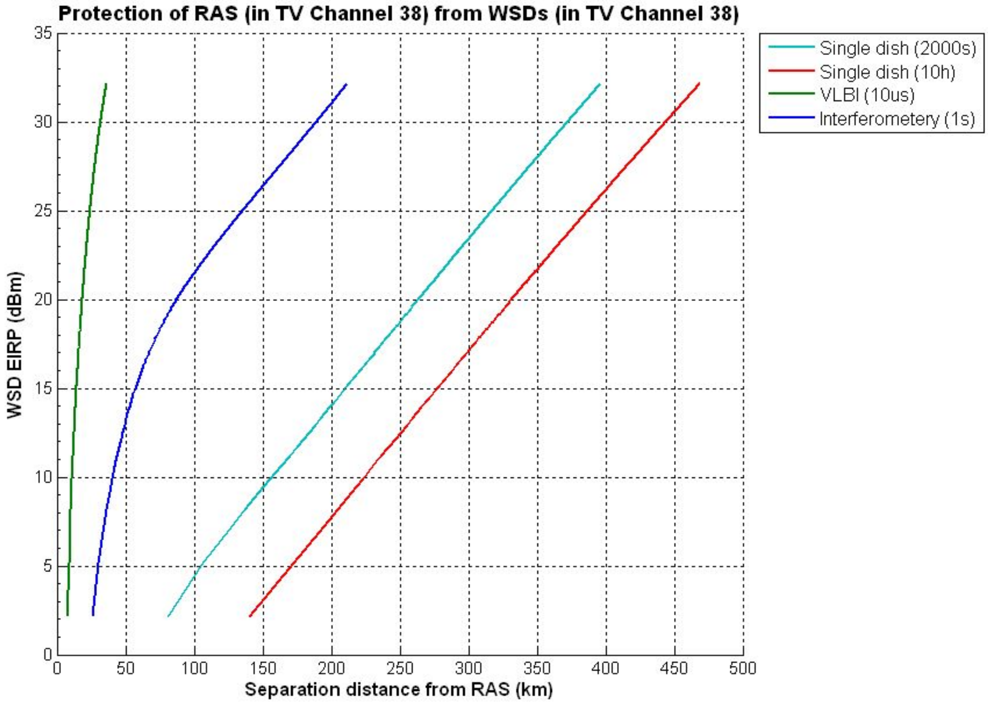

Figure 22: Separation distances for RAS interfered with by WSD

The calculated separation distances for WSDs operating on first adjacent channels (TV Channels 37 and 39) to the RAS band are calculated by reducing the WSD power according to Equation (6.1). These separation distances are plotted in Figure 23 as a function of the output power (e.i.r.p.) of WSDs.

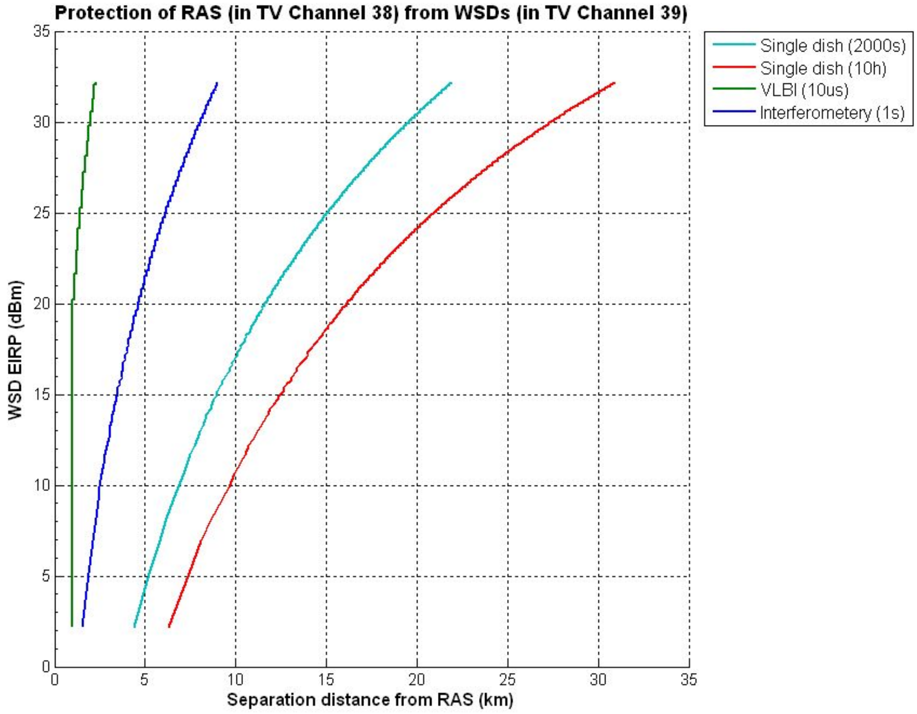

Figure 23: Separation distances for RAS interfered with by WSDs in adjacent channels

6.3 Conclusion

It has been shown that the separation distances depend largely on the type of RAS observations and on the radiated power of the WSDs.

Regarding the usage of TV Channel 38 the following is recommended:

- for autonomous WSDs: TV Channel 38 should be entirely excluded from the operational frequencies of WSDs in order to protect adequately the RAS, which is a passive service. This requirement can be relaxed provided the device is aware of its geographical location and the regulation of the country it is located allows the use of this channel;
- for WSDs controlled by a geo-location database: Noting that the separation distances can go beyond the national borders of some European countries and thus can not be regulated by an administration concerned, the use of TV Channel 38 will be subject to one of the two following options:
    - Should the database management be performed centralized on a European level, the exclusion zones can be defined for each RAS site on the basis of the results presented[9].
    - Should the database management be performed on a national level, the use of TV channel 38 is subject to bilateral/multilateral agreements.

Regarding the usage of TV Channel 37 and 39 the following is recommended:

- for autonomous WSDs: TV Channels 37 and 39 should be entirely excluded from the operational frequencies of WSDs in order to protect adequately the RAS, which is a passive service. This requirement can be relaxed provided the device is aware of its geographical location and the regulation of the country it is located allows the use of this channel;
- for WSDs controlled by a geo-location database: Exclusion zones can be defined for each RAS site on the basis of the results presented[10].

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[9] For example, for a RAS site employing 'Single dish' observation mode, the exclusion radius should be of around 350 km for WSD power levels (ERP) reaching (but not exceeding) 1 W.

[10] For example, for a RAS site employing 'Single dish' observation mode, the exclusion radius should be of around 31 km for WSD power levels (ERP) reaching (but not exceeding) 1 W.

7 PROTECTION OF AERONAUTICAL RADIONAVIGATION (ARNS) IN THE BAND 645-790 MHz FROM EMISSIONS OF COGNITIVE RADIO DEVICES OPERATING IN 'WHITE SPACES'

7.1 ARNS system characteristics and protection criteria

In accordance with No.5.312 RR the frequency band 645-862 MHz is allocated to aeronautical radionavigation service (ARNS) in several countries on a primary basis. Several types of the radionavigation systems are used in this service including:

- radio system of short-range navigation (RSBN);
- air traffic control secondary radars, including terrestrial radar and airborne transmitter;
- airfield and route primary radars for ATC

The indicated systems are used to support navigation and air traffic control.

The European Common Allocation includes the note EU13.

EU13 CEPT Administrations are urged to take all practical steps to clear the band 645-960 MHz of the assignments to the aeronautical radionavigation service.

The main characteristics of different types of the aeronautical radionavigation stations operating in the frequency band 645-862 MHz are presented in Table 12.

Characteristics / **Type of station**	**RSBN**	**RLS 2 (Type 1)**		**RLS 2 (Type 2)**		**RLS 1 (Type 1)**	**RLS 1 (Type 2)**
Application	“Air-to-Ground”	Secondary radars – Type 1 (air traffic control)		Secondary radars – Type 2		Primary radars – Type 1	Primary radars – Type 2
Transmitter characteristics							
Station name	Aircraft transmitter	Ground radar transmitter	Aircraft transponder transmitter	Ground radar transmitter	Aircraft transponder transmitter	Ground radar transmitter	Ground radar transmitter
Maximum effective radiated pulse power (e.r.p.), dBW	32	48	35	69,5	34,5	82	82
Pulse power, dBW	29	31	32	40	31	52,5	52,5
Mean power, dBW	-9	1	14	10,5	10,5	19,5	19,5
Pulse repetition cycle, ms	33	1,3	0,6	1,8	1,8	1,8	1,8
Pulse length, µs	3	1,3	8,7	2	16	0,9-2	0,9-2
Necessary emission bandwidth, MHz	3/0,7	4	4	3	3	3	3
Antenna height, m	10 000	10	10 000	10	10 000	10	10
Maximum antenna gain (dBi)	3,5	17	3	29,5	3,5	29,5	29,5
Antenna pattern	ND	3 dB beamwidth: vert. pl. = 28° hor. pl. = 4°	ND	3 dB beamwidth: vert. pl. = 45° hor. pl. = 3-5°	ND	3 dB beamwidth: vert. pl. = 45° hor. pl. = 4°	3 dB beamwidth: vert. pl. = 45° hor. pl. = 4°
Direction of the antenna main beam	Lower hemisphere	Azimuth: 0-360° Scan rate: 6 min^{-1}	Lower hemisphere	Azimuth: 0-360° Scan rate: 10 min^{-1}	Lower hemisphere	Azimuth: 0-360° Scan rate: 6/10 min^{-1}	Azimuth: 0-360° Scan rate: 6/10 min^{-1}

Type of station **Characteristics**	**RSBN**	**RLS 2 (Type 1)** (air traffic control)		**RLS 2 (Type 2)**		**RLS 1 (Type 1)**	**RLS 1 (Type 2)**
Receiver characteristics							
Station name	Ground radar receiver	Aircraft responder of ground radar	Ground radar receiver	Aircraft responder of ground radar	Ground radar receiver	Ground radar receiver	Ground radar receiver
Antenna height, m	10	0–10 000	10	0–10 000	10	10	10
Polarization	Linear, horizontal	Linear, vertical	Linear, vertical	Linear, horizontal	Linear, horizontal	Linear, horizontal	Linear, horizontal
Maximum antenna gain (dBi)	22	3	17	3	28,4	29,5	29.5
Antenna pattern	3 dB beamwidth: vert. pl. = 50° hor. pl. = 360°	ND	3 dB beamwidth: vert. pl. = 28° hor. pl. = 4°	ND	3 dB beamwidth: vert. pl. = 45° hor. pl. = 3-5°	3 dB beamwidth: vert. pl. = 45° hor. pl. = 3-5°	3 dB beamwidth: vert. pl. = 45° hor. pl. = 3-5°
Direction of antenna main beam	Azimuth: 0-360°	Lower hemisphere	Azimuth: 0-360° Scan rate: 6 min^{-1}	Lower hemisphere	Azimuth: 0-360° Scan rate: 10 min^{-1}	Azimuth: 0-360° Scan rate: 6/10 min^{-1}	Azimuth: 0-360° Scan rate: 6/10 min^{-1}
Permissible aggregate co-channel interference field strength provided for the necessary emission bandwidth (from all services), ***E***, dB(μV/m)	42	52	29	73	24	13	13

Table 12: Technical characteristics of ARNS systems operating in the 645-862 MHz frequency band

7.2 Initial consideration on the protection of ARNS in the band 645-862 MHz from WSDs in the band 470-790 MHz

On the basis of the ARNS characteristics provided in section 7.1, it would be possible to initiate preliminary studies on the protection of this service from interference generated from WSD. However, some additional information would be required on the ARNS deployment conditions to allow the development of appropriate coexistence scenarios. This includes data on the service area of the considered ARNS systems and, if possible, elements on the frequencies used for each system, i.e. whether all of the described systems actually operate in the 645-790 MHz portion of the band.

From a theoretical point of view, the following means can be envisaged to consider protection of ARNS:

- For RLS1 systems (ground based primary radars), it is expected that sensing technique similar to the Dynamic Frequency Selection implemented in 5 GHz WAS/RLAN may be applicable in WSD. Detailed study would be required to define an appropriate detection threshold and the relevant operational requirements.
- For RSBN ground radar receiver, the applicability of sensing technique is more challenging since WSD with sensing feature would have to detect the RSBN signal transmitted from transmitters on-board aircraft potentially located at 10 000 m altitude. However, it is feasible to determine protection areas around the receivers to be protected in which WSD would not be allowed.
- For RLS2 systems (secondary radar), similar approach than for RSBN may be developed for the protection of ground receiver. For the protection or airborne receiver, further consideration would be necessary that would required additional information on the RLS2 deployment scenarios. In particular, the applicability of sensing may benefit from the fact that this system is a 2-way radionavigation system.
- The possible use of the geo-location approach to protect ARNS would depend on a number of factors, which would include the possibility to register the ARNS use in a database, with sufficient parameters to allow the database to provide in an appropriate way the information to the WSD on the availability of channels potentially used by ARNS systems.

8 PROTECTION OF MOBILE/FIXED SERVICES IN BANDS ADJACENT TO THE BAND 470-790 MHz FROM EMISSIONS OF COGNITIVE RADIO DEVICES OPERATING IN ‘WHITE SPACES’ IN THE BAND 470-790 MHz

In addition to the services/systems within the band 470-790 MHz, the WSD should also protect the incumbent services in the adjacent bands for all envisaged WSD deployment scenarios.

Furthermore, due to the non-interfering non-protected status of WSDs, which also applies to adjacent band interference scenarios, different criteria with regard to the acceptable amount of interference has to be applied.

The band 790-862 MHz is expected to be widely used by mobile communication networks in Europe very soon. The band 450-470 MHz is already today used by mobile systems including IMT in some European countries.

Sections 8.1 and 8.2 propose two different methodologies for deriving suitable protection for the Mobile Services in the bands adjacent to 470 – 790 MHz. Both methodologies are not fully developed and will require further studies to be carried out.

8.1 Protection of Mobile Services/IMT systems using the band 790-862 MHz

8.1.1 Assumptions and Scenarios

The band 790-862 MHz is predominantly expected to be used by IMT systems based on the 3GPP LTE standard according to the FDD band plan, i.e. the frequency range 791-821 MHz used for downlink transmission. Therefore, LTE terminal stations are to be considered as interference victims when evaluating the coexistence with WSDs operating below 790 MHz. The risk of interference to ECN base stations operating in the frequency range 832-862 MHz is assumed to be negligible and is therefore not considered here.

Four different deployment scenarios for WSDs are considered.

The first scenario models a WSD deployed as wide area macro base station similar to the typical deployment known from wide area cellular ECNs. A WSD antenna height of 30 m is considered, and the distance between victim and interferer is assumed to be 20 m in the horizontal plane. 3 degrees mechanical antenna downtilt is assumed. The antenna height for the victim is assumed to be 1.5 m, which means that the elevation angle at which the vertical antenna diagram of the WSD antenna has to be read is 52 degrees. According to ITU-R Recommendation F.1336 the suppression (i.e. the difference between the antenna gain in the maximum gain direction and the antenna gain at the considered elevation angle) at this angle for a 120 degree sector antenna with 17 dBi max. gain (k-value = 0.7, peak model used) is 14.86 dB.

In the second scenario the WSD represents a micro base station with a 180 degree antenna mounted at a height of 10 m, while all other parameters are the same as in the wide area macro base station scenario described in the previous paragraph. In this case the elevation angle for reading the vertical antenna diagram of the WSD is 20 degrees, which according to ITU-R F.1336 [16] corresponds to 4.53 dB suppression.

The third scenario models a WSD that serves as a Customer Premise Equipment (CPE) in a Fixed Wireless Access (FWA) deployment, i.e. a device mounted at 10 m (rooftop) height. The azimuth angle of the antenna is assumed to be 180 degrees, and a distance of 10 m in the horizontal plane is considered as a reasonable worst case scenario. No downtilt on the WSD antenna is assumed in this scenario. This leads to an elevation angle of 40 degrees, which according to ITU-R F.1336 [16] corresponds to a suppression of 7.32 dB.

The fourth scenario represents the usage of WSDs as residential access point or portable device. These two cases are characterized by a potentially very short distance to the victim and both antennas at equal height of 1.5 m, which means that there is no additional suppression from the vertical antenna pattern of the WSD antenna. A distance of 2 m is considered for the calculations.

8.1.2 Derivation of ECS TS selectivity from 3GPP LTE UE receiver requirements

As a representative example deployment of an ECN system, a 10 MHz FDD LTE system is considered.

LTE UE RF selectivity is determined from the ACS, in-band and out-of-band blocking requirements defined in 3GPP TS 36.101. The requirements in TS 36.101 are defined for an interfering 5 MHz LTE system, which is considered to be a reasonably realistic proxy for a potential WSD interferer as well.

For a frequency offset of 7.5 MHz, i.e. assuming directly adjacent channels the ACS is 33 dB. Due to the 1 MHz guard band defined at 790-791 MHz this is in principle a case that cannot occur, but since on the first couple of MHz outside the wanted channel the selectivity of a LTE UE has only a very low dependence on frequency offset, this figure is considered sufficiently accurate to represent a WSD operating right at the band edge, i.e. in this particular case in the frequency range 785-790 MHz.

For frequency offsets of more than 7.5 MHz, UE RF selectivity is not defined explicitly in 36.101 and has to be derived from the defined in-band and out-of-band blocking test cases. These test cases are defined as follows. Reference performance (i.e. 95% of the theoretical maximum system throughput for BPSK 1/3 MCS) has to be achieved in the absence of any interference at wanted signal level equal to reference receiver sensitivity (i.e. at SNR = 0 dB, see 3GPP TR 36.803 v1 Sec. 7.5). RFSENS equals -94 dBm for the band 790-862 MHz. The RF selectivity has to be high enough to achieve the same reference performance for the case of wanted signal level set at 6 dB above reference sensitivity (i.e. -88 dBm), and an interfering signal set to a level that is dependent on the frequency offset, see the corresponding columns in Table 13 below. From these figures the required RF selectivity can be determined by calculating the permitted amount of interference power in order to achieve SINR = 0 dB (with noise remaining equal to RFSENS), and by subtracting this value from the interfering signal power defined in the test case, i.e.

$$ACS = P_I - 10 \cdot \log\left(10^{(P_W/10)} - 10^{(RFSENS/10)}\right),$$

where:

ACS : Required selectivity for the corresponding frequency offset
P_I : Interfering signal power
P_W : Wanted signal power
RFSENS: Reference Sensitivity according to 3GPP specifications.

Wanted signal level, interfering signal level and corresponding frequency offset for the test cases defined in 3GPP TS 36.101 and the resulting selectivity values are shown in Table 13.

Requirement type	**Frequency offset**	**Wanted Signal**	**Interfering Signal**	**Required UE selectivity to achieve SINR = 0 dB**
Units	**MHz**	**dBm**	**dBm**	**dB**
ACS	7.5	n/a	n/a	33.00
in-band	10	-88	-56	33.26
in-band	15	-88	-44	45.26
Out-of-band	60	-88	-44	45.26
Out-of-band	85	-88	-15	74.26

Table 13: ACS values for a 10 MHz LTE UE derived from 3GPP ACS and blocking requirements

8.1.3 Methodology for calculation of permitted WSD in-block power for given baseline limit

Starting point for the calculation is an interference criterion of 0.8 dB sensitivity degradation of the LTE TS receiver. For an assumed LTE UE receiver noise floor of -95.5 dBm (thermal noise of 9 MHz bandwidth plus 9 dB noise figure), this leads to an I/N of -6.94 dB, which corresponds to an allowed interference power of $P_{I,max}$ = -102.37 dBm, measured at the victim receiver's antenna port.

The total interference power P_I that reaches a victim receiver can be considered to consist of two parts: $P_{I,leakage}$, the received interference power due to interferer leakage into the victim's wanted channel, and $P_{I,selectivity}$, the received interference power the victim "collects" from within the interferer's wanted channel due to the (finite) selectivity of the (non-ideal) victim receiver. For power values measured in dBm, the following equation holds:

$$P_I = 10\log\left(10^{\left(P_{I,leakage}/10\right)} + 10^{\left(P_{I,selectivity}/10\right)}\right) \qquad (8.1)$$

Assuming that maximum interferer e.i.r.p. into the victim's receive band are subject to a regulatory requirement (e.g. a Block Edge Mask baseline level) $P_{baseline}$ and that only the interference that falls directly into the victim's wanted channel is relevant, the regulatory worst case for leakage into the victim's wanted channel would be

$$P_{I,leakage} = P_{baseline} - L(d) - G_{ant}\,, \qquad (8.2)$$

where

L(d) : Free space coupling loss according to assumed length of propagation path, considering antenna heights and distance in horizontal plane as stated in section 2,
G_{ant} : Isolation from WSD vertical antenna pattern that is valid for the respective scenario configuration as described in section 8.1.2.

Along the same lines, $P_{I,selectivity}$ can be expressed as

$$P_{I,selectivity} = P_{WSD} - L(d) - G_{ant} - ACS(\Delta f), \qquad (8.3)$$

where

P_{WSD} : In-band transmit power (e.i.r.p.) in dBm of the WSD
ACS(Δf) : ACS value of the victim receiver as a function of frequency offset, see Table 13

Substituting these two expressions into equation (8.1) above leads to the following formula to calculate the allowed in-block e.i.r.p. of the white space device:

$$P_{WSD} = 10\log\left(10^{\left(P_{I,\max}+L(d)+G_{ant}\right)/10} - 10^{\left(P_{baseline}\right)/10}\right) + ACS(\Delta f), \qquad (8.4)$$

Calculation of the maximum permitted WSD e.i.r.p. using this equation requires making an assumption on the regulatory baseline limit $P_{baseline}$ that limits WSD out-of-band emissions above 790 MHz. It is obvious that a low $P_{baseline}$ leads to a high P_{WSD} and vice versa. It somewhat less obvious that the selection of $P_{baseline}$ also implicitly determines the ratio between in-band and out-of-band emissions of the WSD, i.e. the ACLR of the WSD. Selecting a very high $P_{baseline}$ (of course $P_{baseline}$ must always be less or equal $P_{I,max}$) leaves only a very small fraction of $P_{I,max}$ to be “spent” for P_{WSD}, which may lead to the result that $P_{baseline}$ and P_{WSD} have relatively similar values, i.e. the ACLR for the considered frequency offset becomes very small.

Overall it is obviously desirable to maximize the permitted in-band power for the WSDs, which would motivate very high ACLR values for the WSD transmitters. However, the limits of feasibility of high ACLR values will in practice strongly depend on economic considerations specific to the deployment scenario and purpose of WSDs. Maximum ACLR values seen in base stations and handheld user terminal differ by several tens of dBs. Therefore, no fixed assumption on $P_{baseline}$ is taken in the calculations below. Instead results for a range of different $P_{baseline}$ values are given, corresponding to a reasonably realistic range of ACLR values for the given WSD operational scenario.

8.1.4 Resulting WSD in-block emission limits for different baseline levels

ANNEX 12 provides the resulting maximum in-block e.i.r.p. for white space devices operating at different frequency offsets. The results are shown for different assumed baseline levels over frequencies above 790 MHz, for the four WSD deployment scenarios described in section 8.1.1. It should be noted that the values for the resulting maximum in-block e.i.r.p. for white space devices operating at different frequency offsets shown in ANNEX 12 do not take into account the impact that the duplex filtering used by mobile handsets would have on the results for the different frequency offsets. The effect of this duplex filtering for some of the frequency offsets could result in a significant increase in the resulting maximum in-block e.i.r.p. for white space devices presented in the tables. The effects of this are further explained in section 8.1.5.

Since in the calculation approach taken here the baseline level is set by assumption and the in-block power is the outcome of the calculation, the calculation implicitly also delivers a required ACLR value (i.e. the difference between assumed baseline level and resulting permitted in-block power). Since with lower baseline level and increasing permitted in-block power the ACLR gets larger, trading lower baseline levels for higher permitted in-block power will be limited by the feasibility of the corresponding ACLR value. The maximum feasible ACLR value will of course be subject to business considerations and thus be different for the different scenarios considered, and for different equipment manufacturers.

The choice of the assumed baseline level values motivates as follows. The highest baseline level we assume in each scenario, respectively, is set so that the resulting WSD ACLR corresponds approximately to the LTE UE’s ACS as derived in Section 8.1.2 above. This corresponds to a situation where the contributions of $P_{I,leakage}$ and $P_{I,selectivity}$ are approximately equal. From this starting point the permitted WSD e.i.r.p. limit is calculated for lower baseline levels, leading to higher permitted WSD e.i.r.p. and consequentially to higher required WSD ACLR. Obviously this way the WSD e.i.r.p. limit can be increased by a maximum value of approximately 3 dB, which corresponds to a situation where the contribution by $P_{I,leakage}$ to the total received interference power becomes negligible and the interference is solely caused by the non-ideal selectivity of the victim receiver.

8.1.5 Conclusions

Operation of WSDs within a number of UHF channels from the edges of the band 790-862 MHz requires attention to potential interference towards services operating in adjacent bands. Appropriate regulation has to be established in order to limit such interference to acceptable levels.

There are some issues requiring further investigations that were identified in the course of this study.

In the calculations presented in this chapter it was assumed that WSDs are the only source of interference towards ECN systems. In practice there will be interference from DTT and PMSE in addition. It thus might be appropriate to introduce an apportionment into the interference budget calculation for these effects, which would lead to more challenging requirements towards WSDs close to the band edges.

The 3GPP requirements do not include breakpoints for selectivity for a rather wide frequency range between 15 and 60 MHz offset. Since it would be beneficial to define requirements towards WSD on a higher granularity of frequency offsets, some further investigation on how a realistic interpolation between the frequency offsets considered in this contribution could be done would be beneficial.

It should be noted that the values for the resulting maximum in-block e.i.r.p. for WSDs operating at different frequency offsets shown in tables of ANNEX 12 do not take into account the impact that the additional isolation that the duplex filtering provided by mobile handsets would have on the results for the different frequency offsets. The effect of this duplex filtering for some of the frequency offsets could result in a significant increase in the resulting maximum in-block e.i.r.p. for white space devices presented in the tables.

In practice, this additional isolation from the LTE UE duplex filter will improve the situation for WSDs (e.g. in terms of higher in-band power and/or reduced ACLR requirement). However since the duplexer suppression within the first few MHz is typically very low it is unlikely that the filtering will make a significant difference at low frequency offsets but at larger frequency offsets the filtering is likely to make a significant impact. In addition there are no requirements that define the suppression of the duplexer for this frequency range in the standards (e.g. 3GPP), therefore it might be difficult to find information on the duplex filtering for devices produced by different manufacturers.

From the results shown in ANNEX 12 it is visible that the permitted in-block power for WSDs strongly depends on the defined baseline level within the wanted channel of the victim (i.e. above 790 MHz).

In order to maximize permitted in-block power for WSDs operating close to the band edge at 790 MHz, very high adjacent channel leakage ratios (ACLR) over frequencies in the band 790-862 MHz are required. A reduction of required ACLR is possible if in return a stricter limitation of the in-block power limit is defined. This is however limited by, among other factors, technical and economical feasibility of realizing such high ACLR values. Depending on the anticipated deployment scenario and business case for WSDs, different trade-offs between permitted in-band power and required ACLR will likely be regarded as optimum. This chapter therefore intentionally refrains from making proposals on what levels baseline levels and in-block powers should be chosen.

8.2 Protection of Mobile Services/IMT services using the band 450-470 MHz

It is expected that an approach similar to the one developed in section 0 can be used to assess the protection of mobile services using the band 450-470 MHz. Further studies would be required to gather the appropriate characteristics related to the mobile service in this band and to perform the corresponding adjacent band compatibility studies.

A preliminary compatibility study to identify possible critical situations between Private Mobile Radio (PMR) / Public Access Mobile Radio (PAMR) systems operating in the 450-470MHz and WSD systems operating in the band 470 – 790 MHz can be performed according to a simplified methodology based on the Minimum Coupling Loss (MCL) approach similar to the one provided in [18].

The considered scenario is referred to a WSD transmitter operating in UHF Channel 21 (with 8 MHz bandwidth), which causes potentially harmful interference towards a 20-25 kHz PMR/PAMR Base Station (BS). For the 20-25 kHz PMR/PAMR BS, the victim receiver parameters listed in Table 18 have been assumed. This implies that the power at the victim should not exceed:

$$-110 \text{ dBm} - 9 + 97 = -22 \text{ dBm} = -52 \text{ dBW}$$

Sensitivity	-110 dBm
Protection ratio (12 MHz offset)	-97 dB
Antenna gain	9 dBi

Table 14: 20-25 kHz PMR/PAMR BS victim receiver characteristics

The victim receiver power can be used in order to derive separation distances between the WSD and the PMR receiver using an appropriate propagation model. For example, Table 19 provides the calculated separation distances when using the free space propagation model given in Recommendation ITU-R P.525.

Maximum e.i.r.p., dBW	Separation Distance, km
-20	0.0022
-18	0.0028
-16	0.003
-14	0.004
-12	0.005
-10	0.007
-8	0.009
-6	0.011
-4	0.014
-2	0.017
0	0.022
2	0.028
4	0.035
6	0.044
8	0.055
10	0.069
12	0.087
14	0.110
16	0.138
18	0.174
20	0.219
22	0.275
24	0.347
26	0.437
28	0.550
30	0.692

Table 15: Separation distance corresponding to an interfering field strength level (E) equal to 108 dBμV/m, as a function of WSD transmitted power

9 OPERATIONAL AND TECHNICAL REQUIREMENTS FOR WHITE SPACE DEVICES IN THE BAND 470-790 MHz

9.1 Emission limits

The different protection requirements for services/systems within the band 470-790 MHz as well as protection of services and system adjacent to the band have lead to different emission limits as described in earlier sections.

The two main approaches with WSD emission limits are:

- **Location specific output power**: the allowed output power can be determined for each location, frequency and device type/class within the database. Such an approach requires the use of geo-location. An upper limit of the output power for each device type/class could be defined, with the understanding that devices could operate at any power between zero and their associated upper limits;
- **Fixed output power**: There may be a few device types (such as portable and fixed) for which the key main characteristics are predefined, and certain fixed output power limits are allowed for them to be used outside the protected areas. The limits may be different for use of adjacent channels and for other channels. This approach has currently been chosen by the FCC. In this case the specific device types and associated e.i.r.p. should be defined.

The two approaches should allow all the scenarios described in Section 3 to operate.

The location specific output power approach may increase the complexity of a WSD and the system due to the considerable amount of calculations to be performed by the database and somewhat increased amount of information to be passed between the WSD and a geo-location database. Furthermore, some of the data, such as a precise terrain model needed in the calculation may not be easily available. This type of calculations is however already performed today by administration to assign licenses for specific devices and to coordinate transmitters with neighbouring countries so it is the amount of calculation that may increase, not the complexity.

On the other hand the location specific output power approach may allow higher WSD output power than in the fixed output power approach in places where it is possible from the protection point of view. This may be useful for some use cases and deployments, e.g. in the rural areas. Additionally, WSD's may be allowed to operate with lower output power in some locations where it would not be allowed with the fixed output power approach. This would lead to more efficient use of the spectrum.

The fixed output power approach would be simpler from the device and database point of view but could in some locations be more restrictive for the devices due to rigid power limits. Having predefined device types with fixed power limits and technical characteristics may also restrict the emergence of new innovative devices.

In conclusion, location specific output power seems to be better from spectrum usage view.

9.2 Sensing

9.2.1 Challenges related to sensing

It has been shown that, currently the achievable practical sensitivity of the sensing devices for DTT is in the order of -20 dBm. This can be achieved at the sensing receiver input at ideal conditions taking into account specific DTT transmission characteristics. Personal/portable WSDs are probably very similar in implementation as current mobile devices. Designing sensing detectors into WSD has some practical challenges. One is that the required tuning range would have to be very wide if the WSD is designed to operate over the full UHF-band. The attached antenna would have to support the same frequency range. This will result in a low antenna efficiency, perhaps in the order of -10 dBi. Furthermore, it can be expected that such an antenna would have certain directivity, instead of being ideally omni directional.

The personal/portable WSD will probably include several radio Rx/Tx systems as well as high processing power, memories and displays etc. components. The high speed clocks and busses in the device electronics are generating noise like wide band interference typically at the frequencies of interest for WSD. As the sensing receiver antenna is built in to the device, the sensing receiver will pick up this noise. State-of-the-art implementation of devices can decrease the noise level, but it is obvious that building an effective shielding for the whole TV WS frequency band will be very challenging and it is very probable that self generated noise is another factor in decreasing the sensing sensitivity in such device.

Another very similar, but external factor is the man made noise. This is very common in the current home and office environment and is known to affect DVB-T and DVB-H indoor reception. It may also have an effect on the sensing as this should happen on a very low level. Man made noise affects all types of WSD. Another challenge is that the detector may have to operate in the presence of very strong broadcasting signals from the near-by transmitters, while still trying to detect a more distant transmitter at very low level. This sets high linearity requirements to the RF-part of the sensing receiver. If we assume state of the art DVB-H receiver, having IIP3 = - 5 dBm and IIP2 = 50 dBm. The interference caused by adjacent channel transmissions at -30 dBm, will have IM3 product at power level of -80 dBm and IM2 product at power level of -110 dBm. Both will cause false detections at the spectrum sensor. IM3 product exists only when one or more interferers are located at certain frequencies relative to each other. IM2 product exists when there is an interferer anywhere at the UHF band with high enough power with feature similar than TV primary signal. Also channel conditions in the field may reduce the sensitivity as typically the theoretical figures are given for Gaussian channels.

Sensing a PMSE signal is very different from sensing DTT signals and, hence, different algorithms are needed for sensing.

Overall it can be estimated that practical sensing device implementations in personal/portable WSD may have a reduced sensitivity in the order of tens of dB.

9.2.2 Conclusions for WSDs that use sensing only

This Report has shown that sensing only will not provide adequate protection to the broadcasting service, taking into account current technologies. This means that there is a need to employ geo-location with access to database. In cases where other approaches such as geo-location in connection with access to database can provide sufficient protection to the broadcast service, sensing should not be a requirement. The potential benefit of using sensing in addition to the geo-location database – e.g. to protect DVB-T reception outside the coverage area (defined on the basis of theoretical models and used by the geo-location database) – needs to be further considered.

When sensing is implemented, testing procedures would need to be developed by standardisation bodies to assess the reliability and the efficiency of the sensing process / device.

To protect emerging DTT and PMSE systems, any sensing algorithm would require continuous developments, which may raise legacy issues.

9.3 Geo-location

9.3.1 Principles and general considerations

Principles

The cognitive technique of geo-location is an approach, where cognitive devices 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 which they have indicated to the database. They are prohibited from transmitting in the 470-790 MHz band until they have successfully determined from the database in which frequencies, if any, and with which power levels, they are allowed to transmit in the indicated location.

The approach is based on a certain accuracy of the position determination by the WSD and the guarantee that this accuracy will be maintained while the WSD is in operation. This is also true for any WSD to be operated indoor, and reliable solutions are needed for position determination in such a case. Any malfunctions of this position determination may have a severe impact on those services which have to be protected by the WSD.

The geo-location database is a management system that, on the basis of information on available frequencies associated with locations in the database and location information received from WSD, assists these devices in selecting their operational frequencies.

This approach would need to take into account the changes in the protected use and the timing of the changes, to ensure that the database has valid content and that the WSD's have valid information about the available channels.

In the case of WSD deployment following the master-slave approach, the geo-location database technique offers the possibility of having a proxy, the master, for making database queries. In this case the master is responsible for assigning available white space frequencies obtained from the database, i.e., communication resources, to the corresponding slave WSDs in a way that ensures protection of incumbent users.

Considerations on location

All the geographical area covered by a geo-location database is represented as "pixels" which are areas of predetermined dimensions (see for example Figure 24). Each pixel is associated with a list of available frequencies and other relevant data that are provided to cognitive devices querying the database. The exact dimensions of a pixel may depend on the planning decisions made in populating the database.

The size of the pixel is a trade-off. Too large a pixel would result in a larger sterilisation than necessary, too small a pixel would result in large number of calculations for the database and a larger data transfer to the device than needed. The size can be selected by each national administration.

It should be noted that the area associated with the "location" as determined by a WSD may cover one or more pixels, depending on the location accuracy of the device. This is in order to take into account the fact that there is an uncertainty about the actual device location, which is at a very high probability somewhere within the uncertainty area associated with the reported device location. Thus the channel availability information delivered to a WSD is to be derived from the information on one or more pixels.

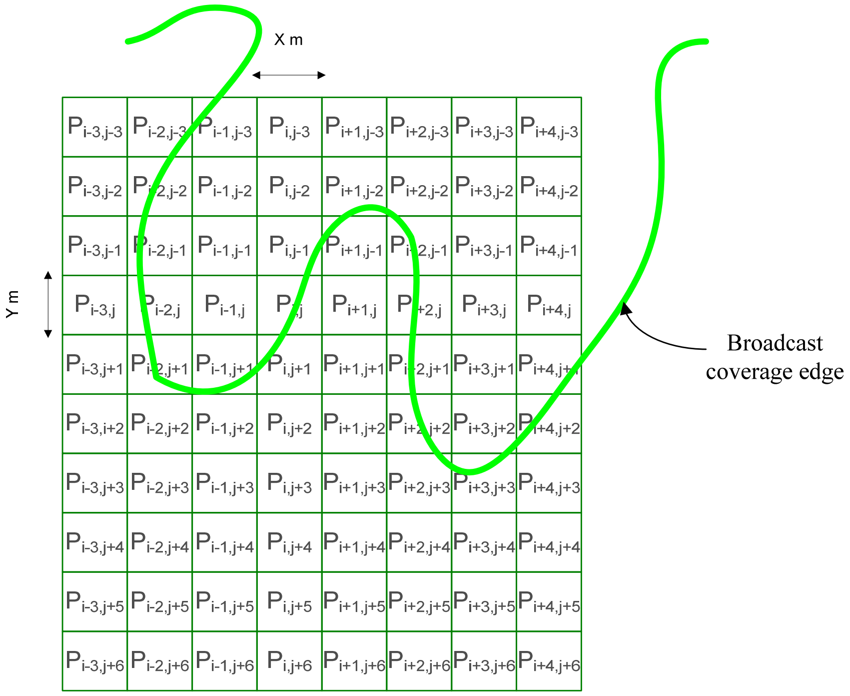

Figure 24: Illustrative example of geo-location database pixel granularity

9.3.2 Requirements on WSD in relation to geo-location

The main purpose of using a geo-location database for WSD 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. However, there may be additional benefits for the operation of the cognitive devices and for the protected services if certain additional information is passed between the devices and the database.

General requirements for WSD

When the geo-location is used as a cognitive technique, the WSD shall be capable of

- Communicating its geographical location (including height information) to the database. It shall also be capable to communicate its location accuracy, and device type or device class (including device identifier).
- Receiving from the database, at a minimum, information on frequencies that could be used by the WSD in its location. Instead of addressing only one location, the device may request frequency information for an area or some locations where it will move in the future. In addition, it is expected that the WSD would receive information on the allowed maximum transmit power of the device, the validity period of the received frequency information after which a database query should be repeated and any information related to sensing if sensing is required (e.g., sensing may be required in connection with the protection of microphones in some countries).

These items will be discussed in more detail in the next section.

The WSD shall only transmit in the 470-790 MHz band once it has successfully communicated with the database and received the instructions regarding the frequencies available in its location and the allowed power levels.

The WSD shall stop transmitting on a channel within the 470-790 MHz band immediately if

- it can not reconsult the database by the end of the validity period of the received frequency information,
- it fails to monitor its location with the required accuracy,
- it moves outside the determined area, for which the frequency information received from the database is valid.

In any such case, a new query of the database is required prior to any new transmission.

It should be noted that the need for the WSD to exchange information with the database before being allowed to use any frequency in the 470-790 MHz would imply the need to have a communication channel between both. This communication channel might be realized wirelessly, e.g. using frequencies outside the band 470-790 MHz, or via some wired connection in case of non-portable WSDs. However, the issue of implementation of such a communication channel is outside the scope of this report.

Additional requirements in the case of WSD master/slave configuration

The requirements described above apply for WSD deployments where each WSD can operate independently of a master device and is therefore required to individually query the database for information on allowed channels and corresponding allowed maximum transmit power. However, in the case of a master/slave WSD configuration, it can be envisaged that the master would be responsible for the query of the database and that associated slaves would be controlled by the master and would receive information on their operational parameters (channels, powers, etc) directly from the master without querying the database themselves.

In order to do so while protecting the incumbent primary users, a WSD master shall be able to fulfil the above requirements, and in addition also be capable of

- Communicating with the associated slave WSDs.
- Deriving the location, with associated accuracy, of a slave WSD.
- Act as a proxy for geo-location database queries towards the slave WSDs.
- Control the operation of the slave WSDs in terms of which channels, bandwidths and what maximum transmit power they are allowed to use.

A master WSD shall stop transmitting and stop allowing the associated slave WSDs to transmit on a channel within the 470-790 MHz band immediately if it fails to repeat the database query within the frequency validity period.

A slave WSD shall be capable of

- Communicating with an associated master (e.g. Receipt, Acknowledge,…).
- Receiving, at a minimum, instructions on frequency allocation and the allowed maximum transmit power for each allocated frequency from the master.

A slave WSD shall optionally also be able to

- Communicate to the master WSD, information on its location, its location accuracy, device type (including device identifier), etc.

A slave WSD unit shall not transmit within the 470-790 MHz band unless instructed to do so by the WSD master.

9.3.3 Technical information to be communicated to the geo-location database

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

- *Location (minimum requirement):* The location is the current position of the WSD expressed in terms of geographical coordinates as determined by means of a geo-location method. It should be noted that the size of the “location” depends on the location accuracy of the device as shown in Figure 25.

- *Location accuracy (minimum requirement)*: 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 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 availability based on its technical characteristics and capable devices could benefit from their high location accuracy. The location granularity of the database (pixel size) may need to be fine enough to be able to serve even the devices with the finest location accuracy.

- *Device type (minimum requirement):* Providing information about the type of device, such as the device class will allow information to be returned according to device capabilities and interference characteristics. The database could then take into account its known transmission parameters in returning appropriate frequencies and allowed maximum transmission power. Different classes of devices, with different technical characteristics, can exhibit different interference characteristics (e.g. antenna type, antenna height, type of technology and modulation) allowing different e.i.r.p. limits. For example, devices classes which would have good out-of-band emission characteristics might be able to transmit with higher power levels on some frequencies and/or locations. Defining device classes and their characteristics is a topic for standardization.

- *Device ID/model (device model – minimum requirement, device ID – optional requirement):* 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. On the other hand, a device ID may allow tracing of individual devices and monitoring user behaviour, causing potential privacy problems.

- *Expected area of operation (optional)*: *The device could* opt for downloading the information for an area. For example, if the device was aware of its speed of movement it might opt for a small radius in the case it was moving slowly or a larger radius when moving quickly. The area could also be defined as a polygon instead of a circle with a given radius. In the optimum case a moving device would not ask for frequency information in a large circle around it, but for an area towards the direction of the movement. This information is strongly related to the time interval the information by the database is valid. Being able to query the database for an area might also be relevant in some cases of master-slave operation.

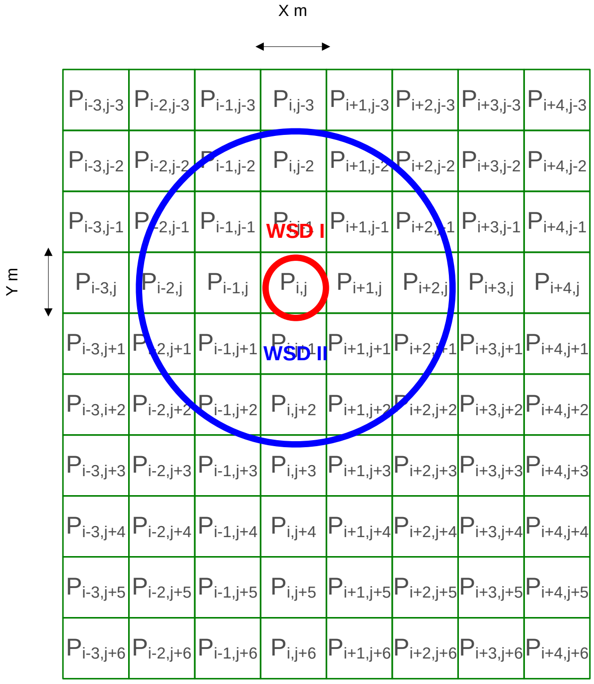

Figure 25: Relation of database pixels to cognitive device locationing accuracy. "Location" of the WSD is always an area and may comprise of one or more database pixels

In the case of a master/slave WSD configuration, the above information will be obtained by the WSD master by requesting it from its associated slaves or deriving it by other reliable means (e.g., by network positioning methods for the position and accuracy and lookups of internally stored device type lists associated with the currently associated slaves). The information relevant to a query is provided to the database when the query is performed.

9.3.4 *Technical information to be communicated to the WSD*

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

- *Available frequencies (minimum requirement)*

  Available frequencies are the frequencies that could be used within the device's location. Frequency information might be based on a particular bandwidth 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). WSD that move outside the current pixel or set of pixels (including a certain safety radius taking into account location uncertainty), 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 (minimum requirement)*

  The maximum transmit power should be provided for each location, device class and channel assignment.

- *The appropriate national/regional database to consult (optional requirement).*

During roaming the device may have to move outside the area supported by the database it is currently consulting, e.g. to another country. In this case, the database may return information about which database to consult for available frequencies.

- *Time of validity of the information provided(minimum requirement)*

  This parameter defines the time how long the available frequencies and the associated emission limits can be used without re-consultation by the WSD in its location or in the area the WSD addressed in its query. If the WSD needs available frequencies after the end of the validity time, or if it moves, it needs to re-consult the database.

  The time of validity depends on the time dependency and usage pattern of the protected services and the nationally selected policy. Thus the values can be selected by the National Administrations.

- *If sensing is required (optional requirement)*

  This information flags the need of sensing in conjunction with the geo-location at a given frequency. This would allow flexibility in working with, for example, license exempt wireless microphones that operate in some countries without being registered in the database. If sensing is needed then the database could also return details of what type of device it is necessary to sense (e.g. “wireless microphone”) and the sensitivity level required in that country (e.g. “-110dBm”).

9.3.5 Management of geo-location database

9.3.5.1 Possible options for the management of database

It is possible to have one or more databases and they could be provided by the regulator or third parties authorized by the regulator. If there are multiple databases they all need to provide the same minimum information about the available frequencies to the WSDs.

- Single open database: One option is to have a single database for the entire country or for the whole of Europe. All WSDs consult this database using a pre-defined and standardised message format. The database would be open to all users. In practice a European database may not be practical due to differences in national approaches.

- Multiple open databases: A second option is to have multiple databases. In this case, WSDs could select their preferred database but there would be no difference between them in the information related to the allowed frequencies. One benefit could be an improved availability as a result of the redundancy of databases. In addition, if some of the databases are operated by third parties, they could offer also other information and value-added services to the WSDs, in addition to the mandatory interference protection related information.

- Proprietary closed databases: A third option is to have “closed” databases corresponding to different types of devices. For example, a manufacturer of WSDs might also establish a database for those devices it had made. Multiple manufacturers might work together to share a single closed database or one manufacturer might “open up” its protocols and database for others to use if they wish.

- ‘Clearinghouse’ model:

The ‘clearing house’ model partitions the process of providing information on available channels to WSDs, in order to facilitate the development of multiple database service providers.

The key element is the clearing house, which aggregates and hosts the raw data needed to perform database calculations. Since there would be only one of these per country or region, it would need to be carefully regulated to ensure equitable access conditions as well as integrity of data handling and distribution.

Data held by the clearing house could comprise:

- Essential data on television transmitters – location, power etc.
- The location and extent of areas where PMSE is in use, with dates and times as needed

The database service providers would use the raw data together with other required regulatory inputs (algorithms, parameters and exceptions) in the process of calculating the contents of their own databases. The database would then be available for end-user devices (WSDs), via either could operate either open or closed (proprietary) interfaces for WSDs.

Figure 26 illustrates one possible partitioning of the database service. It identifies two interfaces:

A – between the clearing house and database service providers

B – between the database service provider and end-user devices (WSDs)

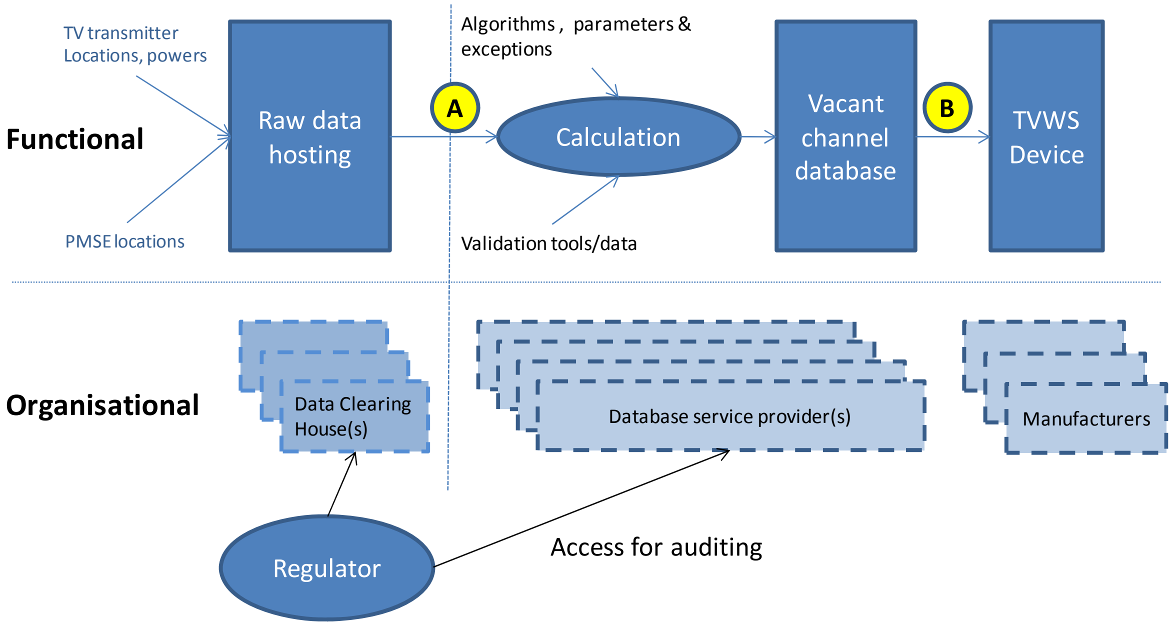

Figure 26: The clearinghouse model partitions the provision of channel information

Regarding the control and responsibility of the database, it has to be noted that in some cases there will be severe concerns in disclosing data about the incumbent services to third parties. The database approach must be conceived and implemented in such a way to leave open, for countries wishing to do so, the possibility to have the information on protected services included in one single database operated and controlled by the national Authority.

9.3.5.2 Key issues for the management of the geo-location database

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 location, height, transmit power, etc.) or an area within which receiver locations might be situated or some combination of the two.

- *Database update delay*

  Database update delay is the latency with 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 latency met over 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 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. WSD users, however, would prefer updates to be as infrequent as possible to avoid the overheads associated with database access.

The type of protected services/systems and the speed with which they change their use of the spectrum may vary from country to country. In this case, the update frequency would need to be communicated to the WSD (likely along with the list of available frequencies) so that devices understood the update periodicity in use in their location. Devices would only be allowed to transmit on an available frequency for the duration of this periodicity. After that they would need to re-consult the database to find out if the frequency is still available and/or if there is any change in the associated transmit power level.

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

  The database would have to convert the 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 neighboring country should be taken into account in the translation process.

  The database will provide a 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.

  Interference to a licensed use will occur at the receiver of the services to be protected. Hence, the algorithms need to understand the possible location of receivers, 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 perfectly then the WSD transmit power can readily be determined.

- *Example of a translation process for the protection of DTT*

  Examples of a translation process for the protection of DTT are given in ANNEX 10 as follows:

  - An example algorithm that can be implemented for the protection of DTT according to the methodology described in Section 4.3.2.3 is provided in the Annex A.10.1.
  - An example of a translation process for the protection of DTT for the case of a master/slave configuration with low complexity is given in Annex A.10.2
  - An example of a translation process for the protection of DTT for the case of master/slave configuration that allows control of the aggregated interference at critical positions is given in Annex A.10.3

- *Considerations on the implementation of the geo-location process for the protection of PMSE*

  For PMSE, there are two categories of concerns; logistical and technical. On the logistical side, it is crucial that PMSE users who need interference protection can conveniently register their locations in the database. The registration process must be straightforward and easy to complete so that it can be done quickly. This will be especially important for users whose plans must change suddenly or which operate systems which have a nationwide (general) license.

  There are several technical challenges that are of interest to PMSE users. One is the way how the location of the PMSE equipment is to be registered. If the equipment works in a certain location, a street address is usually known, but not necessarily the coordinates. Another issue is the determination of an operational area if the PMSE equipment is not in a certain "fixed" location. A third issue is that the PMSE equipment location may change in a short time.

  The question of how frequently the database should be updated, and how often WSD should query it is of great interest to PMSE users. This is in particular true for PMSE applications TV-productions and Electronic News Gathering.

  The protection zone approach could be used in connection with any registered PMSE. This zone is drawn around the PMSE receiving antennas.

9.4 Combined sensing and geo-location

It is possible to use sensing in parallel with access to database. If this combined approach were to be adopted then the following process may apply;

- Identification of WSD location (information to be provided by the device to the centralised database).
- Identification of the usable frequencies and e.i.r.p. (information to be provided by the database to the device).
- Cross-check of availability of usable frequencies (spectrum sensing carried out by the device).
- Enable transmission (the device is transmitting). Transmission should be allowed only upon confirmation by the geo-location database and by sensing.

The combined sensing and geo-location approach, where applicable, may have the advantage of reducing the risk of interference compared to sensing or geo-location, only. However, this issue needs to be studied in more detail. Combining the two approaches may provide a better protection of incumbent use systems vis-à-vis WSD emissions.

9.5 Beacon

No detailed proposal was received in relation to the use of beacons as a cognitive technique for the operation of WSD in the 470-790 MHz. However, the ‘disable beacon’ approach may have some merit for the protection of PMSE (see Section 5.5).

9.6 Additional considerations

Considerations on regulatory regime to be applied

There are several parameters that differ between WSDs installed by professional operators and WSD adhoc installations. These differences indicate that the type of regulatory n regime would have an impact on the risk of WSD-interference to incumbent users in the frequency band 470-790 MHz.

10 ESTIMATED AMOUNT OF ‘WHITE SPACE’ SPECTRUM IN THE BAND 470-790 MHz POTENTIALLY AVAILABLE FOR COGNITIVE RADIO DEVICES

10.1 Methods, criteria and assumptions to assess the spectrum availability (depending on emission limits)

The estimation of the amount of white space spectrum depends on a number of factors, such as the White Space Device radio technology, the topology of the area, the DTT adjacent channel restrictions, and many others. Since many of these factors are still undefined certain assumptions have been made.

Estimates of the amount of spectrum potentially available for WSDs will depend on the chosen spectrum opportunity detection method, i.e. geolocation or sensing. The estimated amount of spectrum is expected to reduce if sensing alone is used. It will also depend on the different type of areas (urban, rural, bordering areas which can be the geographical boundary area between countries and/or different DTT allotments)

It should be noted that the estimate must consider not only the protection requirements for DTT, but should also take account of other services, including PMSE (Section 5), radioastronomy service (Section 6), ARNS (Section 7) and mobile service in the adjacent bands (Section 8). Consideration of DTT alone will be a starting point, but this will clearly overestimate the amount of spectrum available.

Also to be noted is that the available spectrum/location for WSD is a snap-shot at any given point of time. .

This section of the report concentrates on defining a method to calculate the available spectrum/locations for WSD. In this regard:

- The assessment should be made as a function of population and/or location.
- The amount of spectrum available is a function of the allowable power, the terminal type (fixed or mobile, antenna height and diagram), and other transmission characteristics of the WSD.

Since a WSD can potentially support a diverse range of applications and the correct presentation of the data is important to understand the optimum usage.

The simplest analysis considers network coverage data on a pixel by pixel basis (see an example on Figure 27). UHF channels used by protected serves a particular pixel will be unavailable to WSDs and channels or a number of contiguous channels (2 or 3 for example) which are unused by a protected services are potentially available. The detection thresholds defined in the Section 4.2 and in ANNEX 5 should be used to define that DTT is unused in a location. This type of analysis may be particularly appropriate for identifying channels for rural broadband applications to support limited numbers of users. The impact of the interference between WSDs and from protected services into a WSD is not considered in the figure.

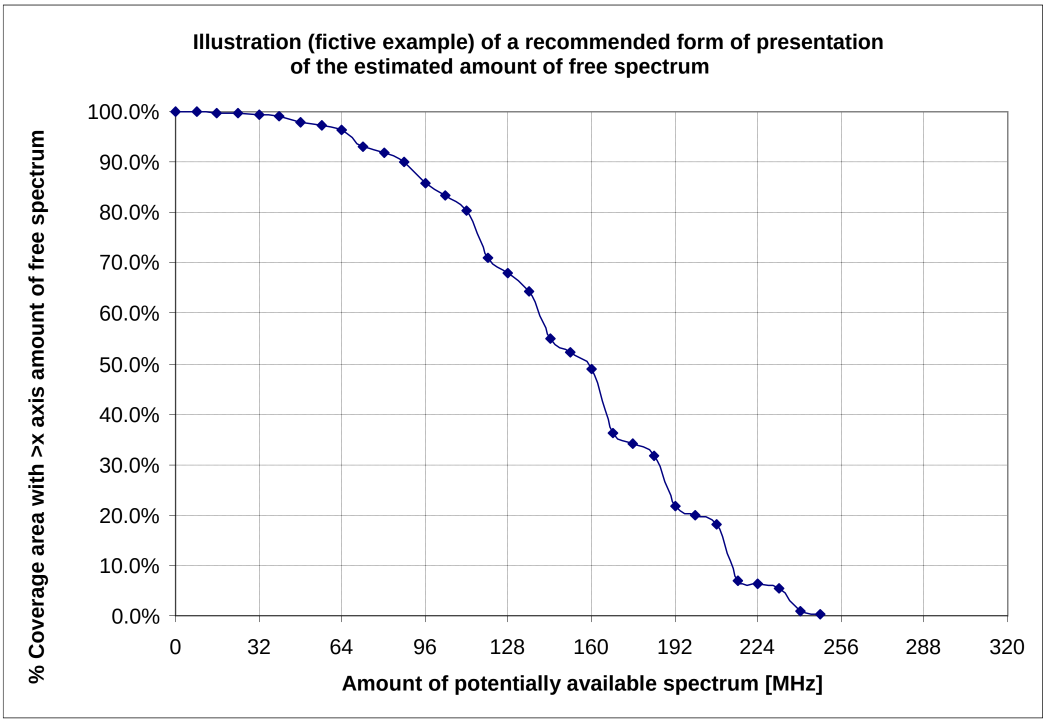

Figure 27: Example of white space availability expressed as % of coverage pixels with a given amount of spectrum

For mass-market applications, e.g. supplementing WiFi spectrum for broadband connectivity, it is useful to weight the data to account for the population in a given pixel see an example on Figure 28). The availability can then be expressed in terms of the number of UHF channels available to a given % of population.

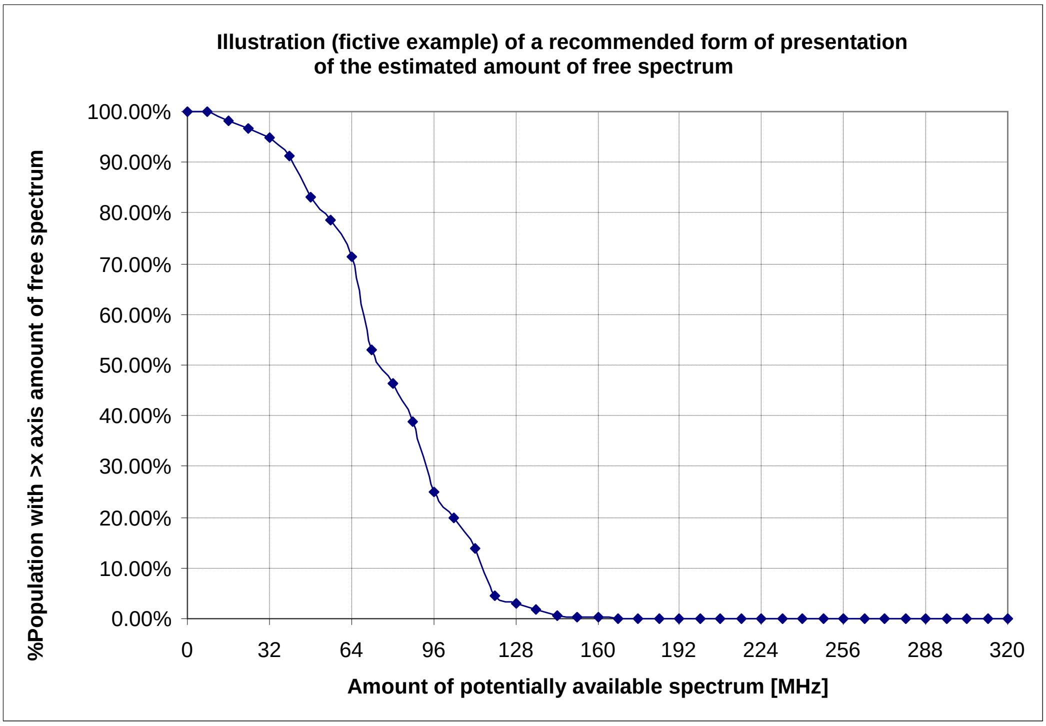

Figure 28: Example of white space availability expressed as % of population with a given amount of spectrum

An additional factor, is the e.i.r.p. that can be permitted in a given white space channel, whilst still protecting the service to which the band is assigned on a primary or secondary basis as well as adjacent band services. As WSD e.i.r.p. is increased, the number of available channels at a particular location can be expected to fall. For example, white space channels in the first adjacent channel to another service to be protected may quickly become unavailable for higher power WSDs due to finite ACS performance of the receivers of the service to be protected (see Figure 29).

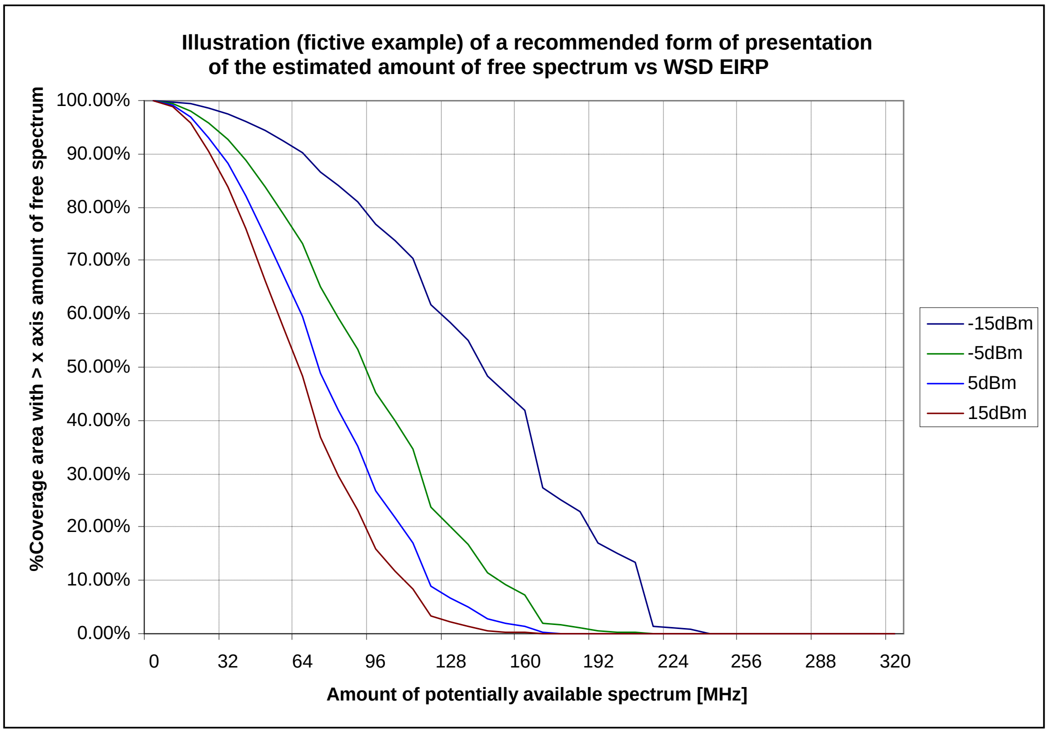

Figure 29: Example of white space availability as a function of device power

A similar reduction in availability will occur as device height is varied, as white space channels just outside a coverage area can no longer be considered as available.

Finally, it is also useful to illustrate this data on a map showing how the white space availability varies with location. This is helpful to identify regions with restricted availability. The overlay will depend on the WSD class (power, mobility and antenna parameters).

10.1.1 Sensing

This approach is based on listening for the signals from primary and other incumbent services to be protected in the band before transmitting. The reliability of the spectrum sensing technique is defined by the detection threshold set in the WSD which is defined in Section 9.

The estimation process may in case of DTT be performed as follows:

1. Determine the DTT received power on a given channel and in a given location, for example a pixel or a specific point (like the centre of a town) based on the DTT configuration relevant to each country.

   This information may be already available or has to be computed using database information containing ERP values and positions of each DTT transmitter (national database, GE06 Plan, ST61 Plan or MIFR) and a propagation model, the Recommendation ITU-R 1546 for example.

2. For all the channels 21 to 60 in the location, compare the DTT received power with a specific detection threshold = $P_{threshold}$

   The $P_{threshold}$ depends on the DTT planning characteristics (fixed or portable reception, antenna height), the protection area (above planning area or not), the sensing reliability chosen, and antenna characteristics, such as height above ground level (agl), polarisation, gain as well as antenna diagram, according to the Section 4 describing the working assumptions on the technical and operational characteristics of cognitive radio systems foreseen for the deployment in the band 470-790 MHz and Section 4 describing the protection of broadcasting service (BS) from cognitive WSD.

3. If the received power is under the detection threshold, the channel is considered as vacant;

   Optional point: if the adjacent channel in the same pixel is assumed to be in use, then the channel is assumed to be unavailable for WSD

It is underlined that the results provided by this approach do not show the spectrum that is effectively available as white space for two reasons. First of all, because we should also consider the interference that the WSD generates on the adjacent channel of the incumbent users. Secondly, because geo-location or cooperative sensing techniques might allow the WSD to use a higher detection threshold, resulting in more available spectrum for opportunistic access.

10.1.2 Geo-location database

This approach is based on geo-location technique using a database in order to determine which the conditions for the WSD (frequency, e.i.r.p. etc…)

The estimation process may in case of DTT be performed as follows:

1. Determine the wanted and unwanted DTT received power on a given channel and in a given location, for example a pixel or a specific point (like the centre of a town) based on the DTT configuration relevant to each country.

   This information may be already available or has to be computed using database information containing ERP values and positions of each DTT transmitter (national database, GE06 Plan, ST61 Plan or MIFR) and a propagation model, the Recommendation ITU-R 1546 for example.

2. Determine the location probability of each considered locations, without WSD, by applying a Monte Carlo methodology or an analytic formula

3. For all the channels 21 to 60 in each location, estimate the maximum WSD e.i.r.p. on co and adjacent channels, depending on the acceptable decrease of the location probability (like 1%, 0.1% decrease)

4. For all the channels 21 to 60 in each location, take the minimum of WSD e.i.r.p. for each frequency (for example WSD e.i.r.p.(21) = min(e.i.r.p. co-channel(21), e.i.r.p. N-1(22), e.i.r.p. N-2(23)…)
5. For all the locations, take the minimum e.i.r.p. computed in the surrounding locations, to take into account the location inaccuracy of the WSD.

10.1.3 Combination of different techniques (e.g. sensing + geo-location database)

The combination of different techniques like sensing and geo location database techniques may allow a cross check of the information obtained by sensing techniques with a database and vice versa.

In the first case the distance from the DTT station and form the broadcasting coverage may be determined with certain accuracy and thus reduce hidden node margin. However, this would mean that any broadcasting reception which is outside this broadcasting coverage would not be protected. In reality, reception outside official or predicted broadcasting coverage is used very often, e.g. because of other and more interesting programs (even of a different culture or language, like in common border areas), a certain local problem (e.g. a wind mill or any other tall building) or for historical reasons (orientation of a fixed antenna).

In the second case, sensing technique will complete the information of the users of the spectrum with the unlicensed users and thus protect the PMSE.

10.1.4 Impact of interference from incumbent users of the band

Using the methodologies exposed in the previous sections, the studies would estimate the amount of spectrum potentially available for different configurations of white space devices. However, this didn't take into account the fact that the WSDs may not operate properly as they may be interfered by incumbent services.

As a consequence, the results may be overestimated.

Consequently, a second step of the studies consists in an estimation of the capacity of the white space devices to operate in an environment used by incumbent services.

The following parameters may be used for WSD reception characteristics:

- WSD antenna height with associated antenna gain: 1,5, 10 and 30m with respectively 0, 12 and 12 dBi
- Noise factor: 5 dB for WSD at 10/30 m, 7 dB for WSD at 1.5m
- Interference criteria: I/N = 0 dB
- ACS: 40 dB

10.2 Results of studies

Some results of the application of the methods listed above can be found in ANNEX 2 for different types of WSD such as mobile WSD at 1.5m and fixed WSD at 30m.

- The amount of available spectrum is directly linked to the national deployment strategy for DTT. Thus a country deploying a large number of multiplexes for DTT would have less spectrum available for WSD. The estimated amount of spectrum depends on the different type of areas (urban, rural, bordering areas which can be the geographical boundary area between countries and/or different DTT allotments).
- The amount is also dependent of the use of the PMSE and how they are managed in the country. For example if one or several channels are chosen as a safe harbour for PMSE, these channels should not be used by WSD and thus a decrease of the available spectrum would occur.
- Radioastronomy stations have also an impact as they need a large "no talk" area in the vicinity.
- The deployment of ARNS in some countries would also have an impact
- The deployment of the mobile service in the adjacent bands should also be considered
- In order to have a full picture on the spectrum available for WSD, complementary studies would be required on a national level to assess whether WSD can properly operate in an environment used by incumbent applications.

11 LIST OF AREAS REQUIRING FURTHER STUDIES

Taking into account the preliminary nature of some elements contained in this Report, the innovative nature of cognitive techniques and the ongoing research and industry activities in this field, it is recognised that some of the areas addressed in this Report may need to be updated in a relatively short timeframe in order, for example, to reflect the latest developments in the technology. Therefore, this chapter contains a list of areas that may require further work. It is expected that some of them may lead to a revision of this Report or the development of a complementary Report(s) whilst others, e.g. the regulatory items and the areas related to WSD specifications are intended to trigger actions of a regulatory or standardisation nature that would be addressed in other deliverables.

The list of essential issues needing further studies in order to define the appropriate technical and regulatory framework for the deployment of WSDs in the band 470-790 MHz contains:

A. Areas related to WSD characteristics

A.1 Well-established technical characteristics of WSDs (including their classification) are necessary in order to confirm the analysis and conclusions made in the report. This would require information on the technology for WSDs from manufacturers and standardization bodies (e.g. IEEE and ETSI). In particular, it should be verified that the assumption made in relation to the WSD technology (OFDM) is appropriate in order to use the protection ratios for DTT subject to LTE interference, based on the ECC Report 148 [7]. There may also be a need to extend the knowledge on protection ratios to DTT receivers not covered in [7].

A.2 Feasibility of a reliable autonomous operation of WSDs using sensing should be further addressed taking into account the possibilities offered by collaborative sensing techniques and experience that may be gained from sensing field test.

A.3 Further study is needed to investigate the possible specification of the minimum required adjacent channel leakage ratio for the WSDs for use by geo-location databases.

B. Technical considerations on the protection of the broadcasting service

B.1 Identification of a common set of the parameters defined in the methodology described in § 4.3.2 and recalled in Annex 10 (§ A.10.4) to calculate location specific WSD power levels is required.

B.2 The possibility to set up fixed maximum permitted e.i.r.p. limits for WSDs taking into account indications from the industry on the foreseen operational ranges of WSDs and their possible classification.

B.3 Additionally, if future technological developments show that the autonomous operation of WSD is reliable, then a method to determine the maximum WSD e.i.r.p. limits (under the constraint of having to avoid harmful interference to primary receivers) based on sensing results may be studied.

C. Technical considerations on the protection of PMSE

C.1 The protection ratio and overloading levels for PMSE technology should be confirmed by a measurement campaign considering the interference from LTE (or other candidate WSD technology) into existing analogue and digital PMSE receivers.

C.2 Further work is required on the PMSE application scenarios that should be considered for sensing studies. The model developed so far, based on a single sensing threshold with flat fading, is too simplistic. Appropriate channel models describing the fading characteristics on the detection path should be developed to understand characteristics of the signal available for sensing.

C.3 Data on digital PMSE systems is required to understand the sensing requirements (by WSDs) of more recent PMSE equipment.

C.4 Viability of the beacons as well as usability of sensing in addition to the geo-location database to achieve protection of PMSE services should be further considered.

D. Regulatory consideration on the protection of PMSE

D.1 The approaches to protect PMSE services from WSD interference need to be identified in accordance with the regulatory regimes employed by different administrations. Specifically, there is a need for further investigation related to the development of a "package solution" that covers a number of tools from which individual countries can choose, such as registration of PMSE in the database and safe-harbour solution.

E. Protection of aeronautical radionavigation (ARNS) in the 645-790 MHz band

E.1 Clarification on ARNS deployment scenarios would be required in order to conduct appropriate studies.

F. Protection of services in the bands adjacent to 470-790 MHz

F.1 There is a need for further studies on the impact from WSD on services in the bands adjacent to the 470-790 MHz band, e.g. on mobile service below 470 MHz and above 790 MHz (see also section 8.1.6).

G. Specification and implementation of the requirements for the geo-location database approach

On the basis of the requirements identified for the geo-location approach in the Report, the following areas would need to be further addressed taking into account expected developments in the industry and in standardisation bodies:

G.1 The regulatory requirement for the communication protocol/interface between the geo-location database and WSDs should be thoroughly specified covering different situation that might be encountered in practice.

G.2 The master/slave concept needs to be developed further, e.g. with respect to information to be provided by the geo-location database and to any interference aggregation within the entire area of expected operation of the master WSD.

G.3 Alternative methods to specify the local-specific output power level of WSDs may need to be developed that would address the potential aggregate interference from various WSD transmitters taking into account the number of active WSDs and satisfying the requirements of both incumbent service protection and obtaining maximized output power of WSDs.

G.4 The approach combining the geo-location database and spectrum sensing needs to be further elaborated.

G.5 Consideration should be made on the possible allowance for devices reporting that they would use less than the maximum allowed power in the channel in question.

G.6 Further work might be needed on accurate position determination if a WSD is to be operated indoor or at a certain height above ground, e.g. on a certain floor inside a building.

G.7 Consideration should be given by standardisation bodies to the application of the geo-location translation methodology developed in this Report in order to derive maximum e.i.r.p. values for WSDs for protection of broadcast networks across Europe. This will provide useful guidance for the development of proposals for WSD technology.

H. Assessment of the consequential spectrum potentially available for WSD

H.1 Amount and utility (e.g. possible capacity and data rates) of white space and their dependency on the relevant parameters have to be examined more thoroughly (e.g. cross-border effects) and sensitivity analysis with regard to protection requirements needs to be conducted. The examination should include consideration of interference stemming from incumbent services into WSDs.

12 CONCLUSION

This report was developed to provide technical and operational requirements for cognitive radio systems (CRS) in the 'white spaces' of the frequency band 470-790 MHz in order to ensure the protection of the incumbent radio services.

Taking as a starting point the definition of white spaces provided in CEPT Report 24 [1], this report identifies a range of possible deployment scenarios for white space devices (WSDs) and, in the absence of specific system characteristics related to WSDs, sets up some key assumptions, such as the use of OFDM technology for WSDs, in order to perform first sharing studies.

Various different methodologies have been chosen in this report to develop protection criteria for each of the incumbent services studied. Some of these protection criteria have been developed using results of measurements whilst others have been developed using parameters from ECC, ITU or ETSI deliverables. This has resulted in a number of different recommendations for the technical and operational requirements that should be applied to WSD operating in the frequency band 470-790 MHz in order to protect the various incumbents. All of the different results of the protection requirements for incumbent services/systems need to be taken into account before concluding on the technical and operational requirements for WSDs.

Whilst three cognitive techniques (sensing, geo-location database and beacon) were considered at the start of the study, most of the efforts were devoted to the assessment of the appropriateness of the sensing and geo-location techniques to provide protection to the incumbent radio services.

It should be noted that the consideration of cable services is outside the scope of this report and, therefore, was not addressed.

- **Protection of the broadcasting service**

The studies presented in this Report have addressed a method for calculating an appropriate sensing threshold method and the corresponding maximum emission limits for WSD under various configurations.

The sensing thresholds were derived for a limited number of scenarios using the methodology developed within this report and taking into account a range of potential DTT receiver configurations. Some of the values obtained (being in the range from -91 to -155 dBm depending on the DTT planning scenario) appear to be extremely challenging to implement using current technologies. Moreover, in some scenarios, even these low values for the detection threshold do not guarantee a reliable detection of the presence/absence of the broadcasting signals at a distance corresponding to the interference potential of a WSD.

This led to the conclusion that, the sensing technique investigated, if employed by a stand-alone WSD (autonomous operation), does not appear to be reliable enough to guarantee protection of nearby DTT receivers using the same channel. Therefore, the use of a geo-location database to avoid possible interference to DTT receivers appears to be the most feasible option,. In addition we have concluded that in cases where the use of a geo-location database can provide sufficient protection to the broadcast service, sensing is not required. There may be some potential benefit in using a combination of sensing and geo-location database to provide adequate protection to DTT receivers but these benefits would need to be further considered.

In the geo-location database models studied the database would provide a WSD with information on the available frequencies and the associated maximum e.i.r.p. values that the WSD is permitted to use. In the models studied in this report it is necessary to specify or make an assumption on the minimum required adjacent channel leakage ratio (ACLR) for the WSD using the geo-location database . Administrations who intend to authorise the use of geo-location database-assisted WSD use will have to decide on the most appropriate parameters and algorithms that are the most relevant for their own specific national circumstances.

In some of these geo-location database usage models it may not be necessary for administrations to define, assume or mandate a fixed value for the maximum permitted e.i.r.p. for WSDs. However, Administrations may still decide to assume or mandate maximum permitted e.i.r.p. of WSDs considering their usage and the DTT implementations they are protecting.

- **Protection of PMSE**

Spectrum sensing is currently considered as a problematic approach for the protection of PMSE systems from WSD interference. Taking into account the range of potential PMSE deployment scenarios, the studies show that there is a great level of variability in the derived sensing thresholds. Temporal fading caused by multipath propagation is likely to be one of the main factors affecting the ability of WSDs to use sensing as a viable technique to protect PMSE systems from interference. In some cases, taking account of this type of fading may lead to a very low detection threshold, far below the WSD receiver noise floor, which would make this technique quite impractical. This point to a need for further study of the propagation characteristics of PMSE systems operating in various configurations and specifically on ways for any WSD utilising spectrum sensing to cope with temporal fading.

Although not considered in all details, the disable beacon concept, where the detection by the WSD of the beacon implies that the channel is occupied and therefore not available may be an approach which can help to overcome some of difficulties highlighted in relation to implementing sensing. Additional information would be needed from the industry to further consider aspects related to the implementation of this technique and its impact on the efficient use of the spectrum.

Again use of a geo-location database appears to be the most feasible approach considered so far for the protection of PMSE. A number of practical questions, some of them beyond the scope of this Report still require resolution, such as how users will enter their data into the system, what information should be stored, and how often WSDs must consult the database, to name a few.

In addition, it appears that the identification by national administration of at least one (or more) safe harbor channels for PMSE use and, therefore not available for WSDs, would be helpful for the protection of PMSE in particular for casual or unplanned usage by PMSE which would not be registered in a geo-location database. These safe harbor channels could be allocated either on a national and/or geographic basis.

- **Protection of Radio Astronomy (RAS) in the 608-614 MHz**

The studies conducted 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 revealed that very large separation distances are needed. Therefore, it is recommended that the TV channels 37 to 39 should be avoided for autonomous WSDs based on a sensing only mechanism. This requirement can be relaxed provided that the device is aware of its geographical location and that the regulation of the country where it is located allows the use of this channel. For WSDs which have access to a geo-location database, exclusion zones around RAS sites should be defined in the database. In that case, consultation between neighbouring administrations may be required when WSD operation in channel 38 is proposed.

- **Protection of aeronautical radionavigation (ARNS) in the 645-790 MHz band**

Preliminary considerations have been provided on the relevance of the sensing and geo-location techniques for the protection of ARNS. However, some additional information would be required on the ARNS deployment considerations in order to perform an appropriate analysis.

- **Protection of Mobile/Fixed services in bands adjacent to the band 470-790 MHz**

Two different methodologies for deriving suitable protection for the Mobile Services in the bands adjacent to 470 – 790 MHz were proposed. Both methodologies are not fully developed and will require further studies to be carried out.

One study on the impact from WSDs on the mobile service in the band 790-862 MHz show that, in order to maximize permitted in-block power for WSDs operating close to the band edge at 790 MHz, very high adjacent channel leakage ratios (ACLR) over frequencies in the band 790-862 MHz are required. A reduction of required ACLR is possible if in return a stricter limitation of the in-block power limit is defined. Depending on the anticipated deployment scenario and business case for WSDs, different trade-offs between permitted in-band power and required ACLR will likely be regarded as optimum.

The other study addresses protection requirements for Private Mobile Radio systems operating in the adjacent band below 470MHz.

No study has been performed for the protection of public mobile systems below 470 MHz.

- **Definition of the requirements for the geo-location database approach**

The Report sets up the principles and defines the requirements for the operation of WSDs under the geo-location approach. Specific requirements are provided for WSD deployment using a master/slave architecture

It identifies the information which needs to be communicated by the WSD to the geo-location database and vice-versa.

A key element in the geo-location database approach is that the WSD will be providing information to the database which will then be used by the database to calculate and output information containing a list of allowed frequencies and their associated maximum transmit powers to the WSD. The Report also provides guidance to administrations on a general methodology for this input/output translation process that needs to carried out between the WSD and the database as well as some examples of the algorithms that can be used in the calculations to be performed by the database. The approach of providing example algorithms is motivated by the need to enable flexibility for administrations to adapt the framework to their national circumstances (e.g. national DTV planning model, specific national quality requirements, etc.). The algorithms and underlying modeling assumptions made on a national level can nevertheless have a significant influence on the effectiveness of the protection of incumbent users and therefore have to be chosen very carefully.

Several options are presented for the management of a geo-location database including the decision for a database at a national or European level, one or various databases, public or closed database, etc

It is expected that this report could be used as a basis to develop an appropriate regulatory framework within CEPT for the operation of a geo-location database in the 470-790 MHz band. The information provided in this report should also be considered by the standardisation bodies in order to develop relevant specifications and testing procedures.

- **Assessment of the spectrum potentially available for WSD**

The amount of spectrum available for WSDs depends upon a number of factors including decisions on the level of protection given to the incumbent services and how well the WSD can cope with interference from these incumbent services and other WSDs.

The exact amount of available spectrum at any location will be dependent upon each national situation or circumstances (e.g. DTT planning configuration, PMSE use, Radio Astronomy use). The objectives of the study presented in this report are to provide a general methodology to assess the amount of spectrum potentially available and some examples of the technical parameters that will be required to protect incumbent services based on specific scenarios. This is an iterative process that requires the full determination of the technical and operational conditions for WSD.

- **Further activities**

Taking into account the innovative nature of cognitive techniques and the ongoing research and industry activities in this field, it is recognised that this Report may need to be updated in a relatively short timeframe in order to reflect the latest developments in the technology. Therefore a list of areas that may require further work has been developed.

ANNEX 1 : PROTECTION RATIO AND OVERLOADING THRESHOLD MEASUREMENTS OF LTE INTERFERENCE INTO DVB-T RECEIVERS (EXTRACTS FROM ECC REPORT 148 [7])

The protection ratios presented in this Annex have been normalised to 64-QAM 2/3 DVB-T 8 MHz bandwidth system variants in static (Gaussian channel) and time-varying (Rayleigh channel) reception conditions using the values in the GE-06 Final Acts [5]. In order to obtain protection ratios for different system variants and for different reception conditions the correction factors given in Table 16 (copy of Table A.4.4-15 of the GE-06 Final Acts) should be used. Noting that these correction factors are relative to 64-QAM 2/3 DVB-T, they need to be adjusted (normalized to a corresponding system variant) before being added to other protection ratios, e.g. for DVB-T 16-QAM 2/3 and 64-QAM 3/4.

DVB-T system variant	**Gaussian channel**	**Fixed reception**	**Portable outdoor reception**	**Portable indoor reception**	**Mobile reception**
QPSK 1/2	−13.5	−12.5	−10.3	−10.3	−7.3
QPSK 2/3	−11.6	−10.5	−8.2	−8.2	−5.2
QPSK 3/4	−10.5	−9.3	−6.9	−6.9	−3.9
QPSK 5/6	−9.4	−8.1	−5.6	−5.6	−2.6
QPSK 7/8	−8.5	−7.1	−4.5	−4.5	−1.5
16-QAM 1/2	−7.8	−6.8	−3.6	−3.6	−0.6
16-QAM 2/3	−5.4	−4.3	−2.0	−2.0	1.0
16-QAM 3/4	−3.9	−2.7	−0.3	−0.3	2.7
16-QAM 5/6	−2.8	−1.5	1.0	1.0	4.0
16-QAM 7/8	−2.3	−0.9	1.7	1.7	4.7
64-QAM 1/2	−2.2	−1.2	1.0	1.0	4.0
64-QAM 2/3	0.0	1.1	3.4	3.4	6.4
64-QAM 3/4	1.6	2.8	5.2	5.2	8.2
64-QAM 5/6	3.0	4.3	6.8	6.8	9.8
64-QAM 7/8	3.9	5.3	7.9	7.9	10.9
Note: Measurements of IMT BS interference into DVB-T reception for Gaussian and time-variant Rayleigh channels indicate that the correction factors in this table for mobile reception are more appropriate also for portable reception than those given in this table for portable reception. It is therefore recommended to use the correction factors for mobile reception for both portable and mobile reception.					

Table 16: Correction factors for protection ratios (dB) for different system variants relative to 64-QAM 2/3 DVB T signal and for different reception conditions interfered with by other primary services

The overloading thresholds are assumed to be independent from the reception conditions, also understanding that no mast heads-end amplifiers and active antennas are used.

Using statistical analysis (assuming a Gaussian cumulative distribution) the 10th, 50th, and 90th percentile of all measured protection ratios and the 10th, 50th, and 90th percentile of all measured overloading thresholds for LTE interference into DVB-T were calculated. The information on the number of receivers used in this statistical analysis is provided in Annex D of ECC Report 148 [7].

Due to recognized performance differences of different receiver types and technologies, the protection ratios and overloading thresholds presented in the tables are provided for three categories:

- Can-type tuners implemented in set-top boxes and/or integrated TV;
- Silicon-type tuners implemented in set-top boxed and/or integrated TV;
- Silicon-type tuners implemented in USB stick devices.

There are a few mitigation techniques, which might be applied in order to protect DVB-T reception from LTE interference, and some are listed in Annex 4 of CEPT Report 30 [6]. Some of these mitigation techniques were studied with respect to their suitability and efficiency in domestic environment (see Annex E of ECC Report 148 [7] for details).

It needs to be noted that PR measurements presented in this report were conducted for both 5 MHz and 10 MHz LTE signal bandwidth. The impact of the LTE signal bandwidth on the measured protection ratios was found to be of the same order of magnitude as the margin of error introduced by the statistical analysis employed to harmonise the results obtained in different measurement campaigns (see Annex F of ECC Report 148 [7] for some examples).

In view of the two different LTE signal bandwidths (5 MHz and 10 MHz) considered in the measurements, the frequency separation between the channel edges of the wanted and interfering signals is used instead of the frequency offset measured between the central frequencies of wanted and interfering signals. Figure 30 illustrates some examples of the relationship between the channel edge separation and the frequency offset.

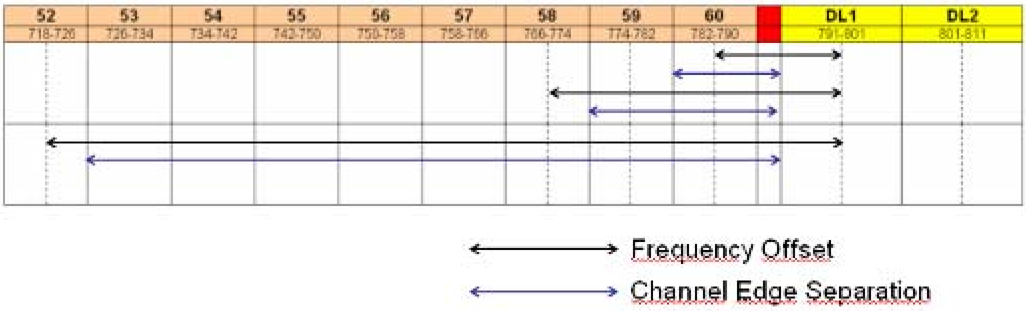

Figure 30: Frequency offset and channel edge separation for 10 MHz LTE signal

The protection ratio for a frequency offset of plus 65 MHz corresponds to the spurious response at the image frequency.

The following notes need to be consulted when using the values provided in the tables:

Note 1: PR is applicable unless the interfering signal is above the corresponding O_{th}. If the interfering signal level is above the corresponding O_{th}, the receiver will behave in a nonlinear way.

Note 2: At wanted signal level close to receiver sensitivity, noise should be taken into account, e.g. at 3 dB above receiver sensitivity threshold, 3 dB should be added to the PR.

Note 3: PR for different system variants and various reception conditions can be obtained using the correction factors in Table 4. The overloading threshold is independent of system variant and reception conditions.

Note 4: Treatment of overloading threshold in calculations when assessing interference from LTE into DVB-T is presented in Annex C to ECC Report 138.

Note 5: Using statistical analysis (assuming a Gaussian cumulative distribution) the 10th, 50th, and 90th percentile of all measured protection ratios and the 10th, 50th, and 90th percentile of all measured overloading thresholds for LTE interference into DVB-T were calculated. The information on the number of receivers used in this statistical analysis is provided in Annex D of Report 148 [6].

Note 6: The 90th percentile for the protection ratio value corresponds to the protection of 90% of receivers measured, with respect to the given frequency offset and parameter; whereas the 90th percentile for the overloading threshold value corresponds to overloading of 10% of receivers measured (i.e. the 10th percentile for the overloading threshold should be used to protect 90% of receivers measured).

Note 7: In some measurements of protection ratio from LTE UE, the ACLR of the interference signal was 70 dB, corresponding to a protection ratio of roughly -60 dB. Therefore, the actual protection ratio may be better than measured where the protection ratio is approaching this value.

Annex G of Report 148 [7] contains references to the source documents of all protection ratio measurements provided for the development of this report.

LTE Base Station interfering signal

The protection ratios and overloading thresholds obtained for LTE-BS interferer are listed in Table 17 and Table 18, respectively, for different receiver types and technologies.

DVB-T PR for 64-QAM 2/3 DVB-T signal (LTE BS, Constant Average Power)									
Channel edge separation (MHz)	**PR (dB)**								
	10th			**50th**			**90th**		
	Can STB/iDTV	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**
1	-44	-43	-43	-39	-37	-38	-33	-33	-33
9	-50	-47	-49	-46	-44	-45	-42	-40	-36
17	-51	-51	-48	-48	-46	-45	-39	-44	-36
25	-60	-55	-51	-59	-50	-46	-56	-48	-38
33	-67	-56	-50	-64	-51	-47	-63	-49	-42
41	-68	-56	-50	-59	-53	-46	-58	-50	-43
49	-70	-58	-51	-67	-53	-48	-66	-50	-43
57	-71	-59	-53	-68	-54	-48	-66	-52	-43
65	-56	-61	-50	-46	-52	-46	-39	-45	-44

Table 17: DVB-T PR values in the presence of a time-constant LTE BS interfering signal in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners

DVB-T O_{th} for 64-QAM 2/3 DVB-T signal (LTE BS, Constant Average Power)									
Channel edge separation (MHz)	**O_{th} (dBm)**								
	10th			**50th**			**90th**		
	Can STB/iDTV	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**
1	-12	-13	-25	-8	-8	-17	-1	-2	-3
9	-8	-7	-22	-2	-1	-12	4	4	0
17	-9	-6	-18	-1	2	-6	8	5	0
25	-10	3	-14	-6	4	-6	5	5	0
33	-7	3	-14	-2	4	-5	6	5	0
41	-7	2	-14	0	3	-5	8	4	0
49	-6	1	-14	1	3	-5	10	4	0
57	-7	0	-13	1	2	-2	11	4	0
65	-3	-5	-17	2	2	-12	11	5	0

Table 18: DVB-T O_{th} values in the presence of a time-constant LTE BS interfering signal in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners

The difference of PR values for a Gaussian channel and for a time-variant Rayleigh transmission channel is given in Table 19 for six receivers measured assuming LTE-BS interference. It can be noted that the correction factors listed in Table 16 are between 3.2-4.2 dB for portable reception and between 6.2-7.2 dB for mobile reception (depending on the system variant). A comparison of the measurement results with the correction factors listed in Table 16 shows that the time-variant Rayleigh channel is closer described if the correction factors for the mobile reception listed in Table 16 are used.

		Channel edge separation (MHz)								
		1.5	**9.5**	**17.5**	**25.5**	**33.5**	**41.5**	**49.5**	**57.5**	**65.5**
Difference (dB) Gaussian – time-variant Rayleigh channel	**Rx1**	8.5	9.1	9.3	8.9	7.9	8.5	9	8.7	8.6
	Rx2	9	10.9	8.8	10.8	11	10.5	9.9	9.7	8.7
	Rx3	9.9	9.8	7.9	6.8	6.8	8	8.9	10	7.3
	Rx4	10.2	8.3	8.2	8.1	7.5	8.5	8.3	5.4	9.9
	Rx5	8.7	9.4	8.5	15.6	8.3	9.1	8.4	8.2	20.6
	Rx6	8.4	8.2	7.6	14.8	8.4	8.2	7.7	7.4	6.9
	$\overline{Rx}$	**9.1**	**9.3**	**8.4**	**10.8**	**8.3**	**8.8**	**8.7**	**8.2**	**10.3**

Table 19: Difference of PR values for Gaussian and time-variant Rayleigh channel for LTE BS interference into DVB-T 64QAM 2/3

LTE User Equipment interfering signal

The protection ratios and overloading thresholds obtained for LTE-UE interferer are listed in Table 20 and Table 21, respectively, for different receiver types and technologies. The range of values corresponds to different sequences (see Annex B of ECC Report 148 [7] for details) for the UE signals used in different measurements.

Different sequences and different receivers show a spread in protection ratios and overload thresholds which is under investigation by industry. The protection ratios for interference signals with constant average power and no frequency variation were generally much lower than those for time varying interference signals such as the pulsed LTE UE waveform. The overload threshold for interference signals with constant average power and no frequency variation were generally much higher than those for time varying interference signals such as the pulsed LTE UE waveform.

DVB-T PR for 64-QAM 2/3 DVB-T signal (LTE UE TPC off)									
Channel edge separation (MHz)	**PR (dB)**								
	10th			**50th**			**90th**		
	Can STB/iDTV	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**
co-channel	13 … 18	13 … 18	NA	18 … 19	18 … 19	NA	20 … 22	19 … 22	NA
1.5	-28 … -14	-15 … -14	-28	-21 … -13	-14	-23	-14 … -12	-13	-18
9.5	-51	-51	-43	-48 … -47	-49 … -42	-37	-45 … -42	-46 … -32	-31
17.5	-56 … -55	-54 … -51	-45	-49 … -48	-51 … -43	-39	-43 … -40	-48 … -35	-32
25.5	-63 … -59	-56 … -55	-47	-61 … -57	-52 … -46	-39	-59 … -54	-48 … -36	-31
33.5	-70 … -62	-57 … -53	-49	-67 … -56	-54 …-45	-40	-63 … -50	-51 … -37	-31
41.5	-79 … -63	-61 … -52	-49	-73 … -56	-53 … -45	-40	-66 … -49	-45 … -38	-31
49.5	-76 … -66	-60 … -56	-49	-74 … -57	-56 … -48	-40	-71 … -47	-51 … -40	-30
57.5	-77 … -66	-62 … -55	-49	-78 … -59	-55 … -46	-40	-70 … -52	-48 … -37	-30
65.5	-63 … -54	-63 … -52	-47	-50 … -44	-55 … -45	-40	-38 … -33	-47 … -37	-32

Table 20: DVB-T PR values in the presence of a LTE-UE interfering signal without TPC in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners

DVB-T O_{th} for 64-QAM 2/3 DVB-T signal (LTE UE TPC off)									
Channel edge separation (MHz)	**O_{th} (dBm)**								
	90^{th}			**50th**			**10th**		
	Can STB/iDTV	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**	**Can STB/iDTV**	**Silicon STB/iDTV**	**Silicon USB**
1.5	-11 … 2	-14 … -9	-3	-16 … -11	-16 … -16	-15	-21 … -19	-23 … -17	-27
9.5	1 … 7	-10 … 9	-13	-6 … -2	-28 … 2	-30	-18 … -4	-46 … -5	-47
17.5	0 … 7	-5 … 12	-15	-16 … -10	-26 … 5	-32	-31 … -26	-47 … -2	-49
25.5	-7 … -6	-5 … 9	-18	-13 … -9	-25 … 2	-30	-19 … -11	-44 … -6	-42
33.5	-1 … 0	-5 … 10	-19	-9 … -4	-24 … 3	-30	-17 … -7	-43 … -5	-41
41.5	0 … 9	-16 … 7	-13	-9 … -2	-25 … 0	-25	-18 … -7	-41 … -7	-37
49.5	6 … 11	-3 … 13	-13	-3 … 2	-21 … 4	-25	-16 … -3	-39 ... -5	-37
57.5	4 … 10	-12 … 11	-17	-4 … 2	-21 … 2	-28	-16 … -3	-35 … -7	-39
65.5	5 … 10	-13 … 8	-10	-2 … 4	-23 … -1	-25	-9 … -3	-32 … -10	-40

Table 21: DVB-T Oth values in the presence of a LTE UE interfering signal without TPC in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners

The difference of PR values for a Gaussian channel and for a time-variant Rayleigh transmission channel is given in Table 22 for six receivers measured assuming LTE-UE interference. It can be noted that the correction factors listed in Table 16 are between 3.2-4.2 dB for portable reception and between 6.2-7.2 dB for mobile reception (depending on the system variant). A comparison of the measurement results with the correction factors listed in Table 16 shows that the time-variant Rayleigh channel is closer described if the correction factors for the mobile reception listed in Table 16 are used.

		Channel edge separation (MHz)								
		1.5	**9.5**	**17.5**	**25.5**	**33.5**	**41.5**	**49.5**	**57.5**	**65.5**
Difference [dB] Gaussian – time-variant Rayleigh channel	**Rx1**	7.5	6.2	5.5	5.2	6.3	6.4	6.4	6.4	6.3
	Rx2	9.8	7	7.8	8.5	7.7	7.7	9	9.5	8
	Rx3	8.1	9.1	10.5	11.9	12.3	11.1	14	9.3	6.4
	Rx4	7	9	7.5	9.2	8.8	6.7	8.5	7.3	8.4
	Rx5	7.8	5.8	6.1	3.1	0.4	1.5	-0.3	0.8	7.3
	Rx6	5.7	6.8	11	15	13.5	9.5	3	8.7	5.6
	$\overline{Rx}$	**7.7**	**7.3**	**8.1**	**8.8**	**8.2**	**7.2**	**6.8**	**7.0**	**7.0**

Table 22: Difference of PR values for Gaussian and time-variant Rayleigh channel for LTE UE interference into DVB-T 64QAM 2/3

ANNEX 2 : NATIONAL STUDIES ON AMOUNT OF SPECTRUM IN THE BAND 470-790 MHZ POTENTIALLY AVAILABLE FOR WHITE SPACE DEVICES

A.2.1 UK

Using the geolocation database methodology the numbers of available channels for white space devices are represented on the Figure 31. It is noted that this study has been established before any re-planning to free the band 790-862 MHz for mobile services.

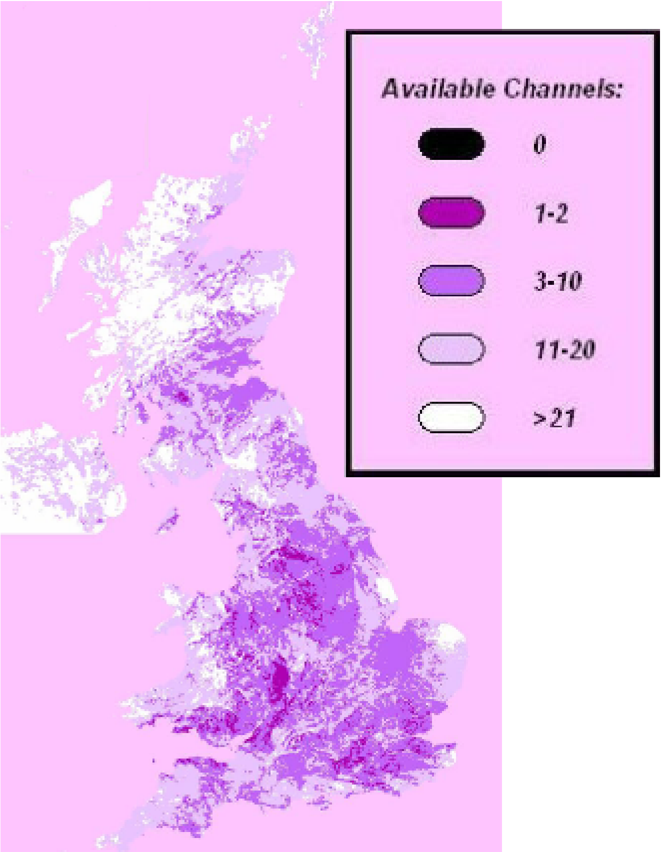

Figure 31: Ofcom, "Overall UHF Channel Availability Map" – http://www.ofcom.org.uk/consult/condocs/ddr/statement/statement2/

France

A.2.2.1. Introduction

In this section we provide an estimation of the spectrum potentially available as white space in 3 rural areas Morbihan, Creuse and Vosges in the 470-790 MHz band. These areas, represented in Figure 32, have been chosen due to their different topology characteristics, representing a coastal, a flat and a mountainous area. All three areas are further away from any border and there is natural terrain shielding towards other countries.

It should be noted that the PMSE were not taken into account in this study and the protection of Radio astronomy is assumed by the unavailability of the channel 38 for WSD. This study is based on a threshold-based approach as described in the section 10.1.1 and a database approach as described in section 10.1.2. Furthermore, overloading of DTT receivers which may lead to a loss of reception at any receiving channel has not been considered.

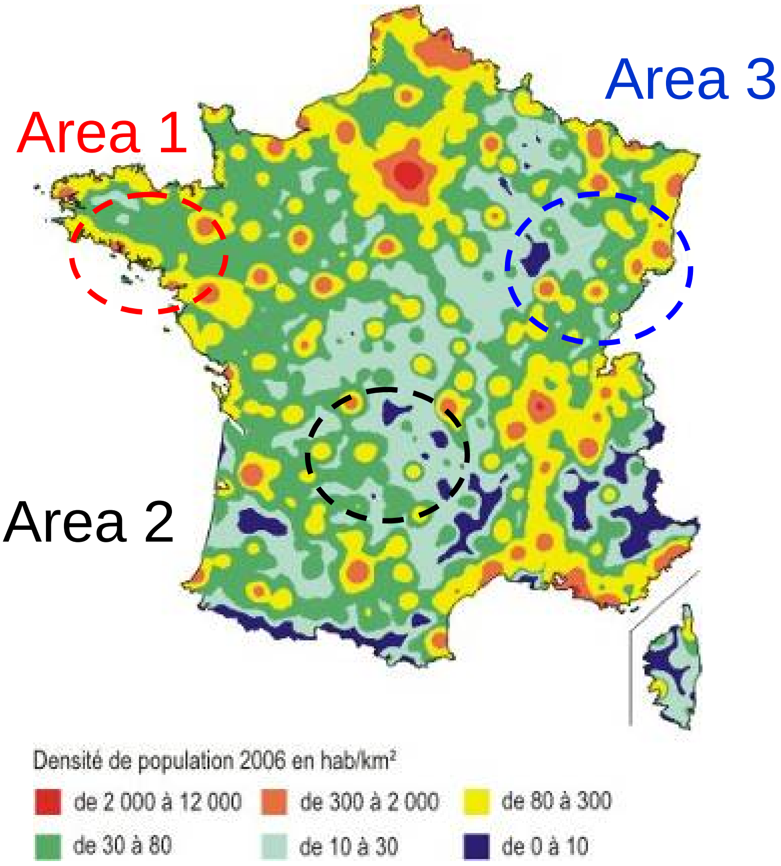

Figure 32: Representation of the areas

According to the report "France numérique 2012", available on the following website http://francenumerique2012.fr/, and especially action point n°20, 13 multiplexes are intended to be used in France after the DSO, 11 for fixed reception and 2 for mobile outdoor reception. For the purpose of this study, two alternative scenarios are also considered to assess the impact of various factors in the number of available channels. Therefore, a total of three scenarios are studied:

- 13 multiplexes, 11 for fixed reception and 2 for mobile outdoor reception (called "11+2 scenario")
- 8 multiplexes, 7 for fixed reception and 1 for mobile outdoor reception (called "7+1 scenario")
- 7 multiplexes, 7 for fixed reception (called "7 scenario")

A.2.2.2. Digital Terrestrial Television assumptions

The characteristics of the DTT considered in this study are listed below:

- DVB-T network planned to cover about 95 % of the population
- DVB-H network planned to cover about 70 % of the population
- Transmitters are extracted from the assignments of GE06 Plan or derived from the analogue assignments when GE06 is limited by an allotment description
- DVB-T reception threshold for planning: 56 dBµV/m (64 QAM, FEC 2/3) for 10 m agl
- DVB-H reception threshold for planning: 82 dBµV/m for 1,5m agl
- Co channel protection ratio = 21 dB
- Omnidirectional antenna with application of the GE06 constraints
- ERP of GE06 Plan for existing assignment and analogue ERP – 10 dB for the stations derived from the analogue plan (except from the RPC2 configuration)

Area 1 – Morbihan

48 DVB-T stations

342 DVB H stations

Area 2 - Creuse

109 DVB-T stations

747 DVB H stations

Area 3 - Vosges

155 DVB-T stations

466 DVB H stations

222 DVB-T foreign stations

Figure 33: DTT characteristics

A.2.2.3. White Space Devices assumptions

In this study, two types of WSD are considered:

- Mobile WSD @1.5m (agl) with an omnidirectional antenna (0 dBi)
- Fixed WSD @30m (agl) with an omnidirectional antenna (0 dBi).

A.2.2.4. Methodology

Both methodologies, sensing and database, presented in the chapter 10.1. of the report are used.

A.2.2.4.1 Sensing

According to the DTT planning configurations, the sensing thresholds, extracted from the table 4.3.1, used in this section are the following:

DTT	DTT fixed outdoor, planned for SubUrban area		Mobile TV (DVB-H) outdoor
Percentage location in the target detection area:	95%		90%
DTT receiver antenna height	@10 m		@1.5 m
WSD	Mobile Outdoor @1,5m	Fixed Outdoor @30m	Mobile Outdoor @1,5m
$P_{sense\ 1,5m}$	-117.71	-90.86	-100.91

Table 23: Sensing thresholds

The most restrictive sensing threshold for mobile outdoor operation @1.5m, e.g. for the protection of the fixed outdoor reception, is used.

The calculations are done on several test points representing the centre of each city of the considered area. The test points and associated populations are the following:

- Morbihan area : 261 test points and a population of 693 711 inhabitants
- Creuse area : 260 test points and a population of 123 401 inhabitants
- Vosges area : 515 test points and a population of 214 982 inhabitants

For each test points, the field strength provided by all the stations, described in Figure 35, on channels 21 to 60, are computed using ITU-R P 1546 at 50% of the time for 50% of the locations.
A channel is considered available on a test point for white space devices when all the computed field strengths are below the thresholds defined in Table 25.

For each area the results are represented by the cumulative distribution functions of the white space availability expressed as a % of locations and population with a given amount of spectrum.

This representation is given on a single channel basis, e.g. one channel available even if the two adjacent channels have field strength above the threshold, and on a two contiguous channel basis, e.g. at least on adjacent channel has field strength below the threshold.

🟧 At least one field strength computed with all the DTT stations is above the threshold

☐ All the field strength computed with all the DTT stations are below the threshold

Example:

🟧☐🟧☐☐🟧

Single channel basis : 3 channels -> 24 MHz
Two contiguous channels basis : 2 channels -> 16 MHz

For one DTT scenario a map of the area is given representing the amount of spectrum potentially available for white space devices for each test point. The 11+2 scenario is used for the map with white space devices operating at 1.5m.

A.2.2.4.1.1. Results for Morbihan

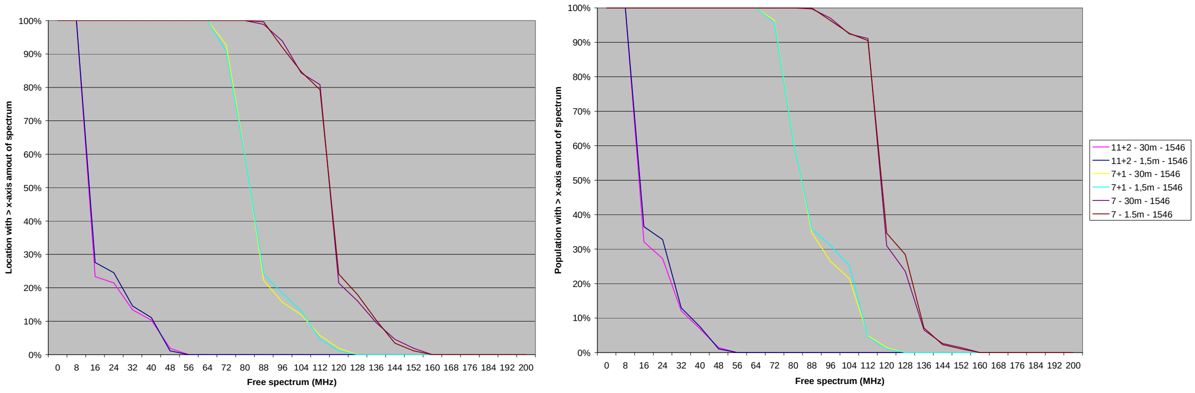

Figure 34: White space availability expressed as % of locations and population with a given amount of spectrum on a single channel basis

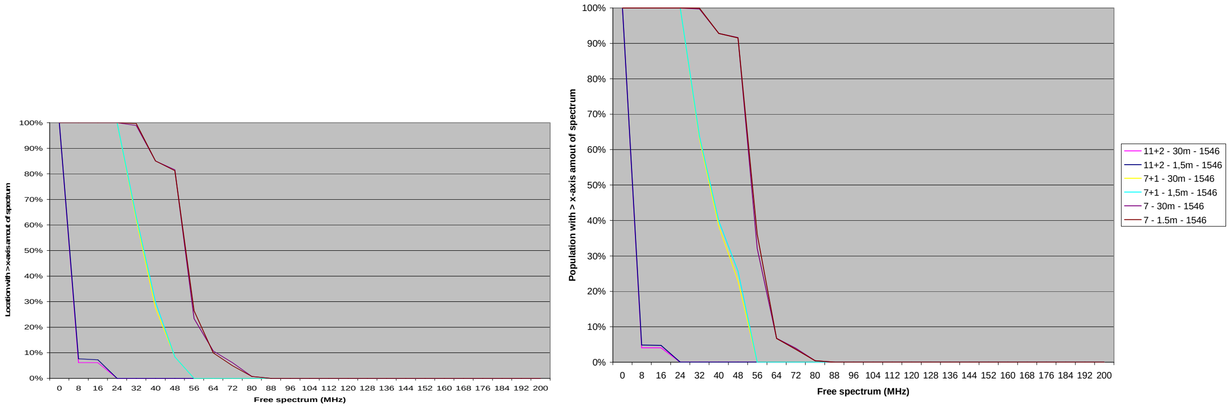

Figure 35: White space availability expressed as % of locations and population with a given amount of spectrum on a two adjacent channels basis

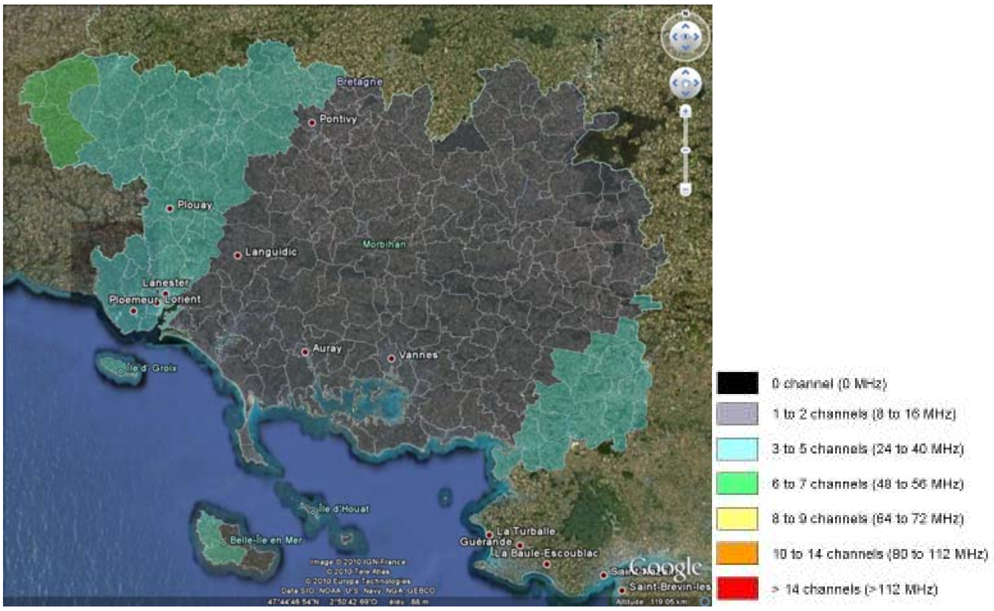

Figure 36: Representation of the "11+2 scenario" in Morbihan for WSD@1,5m

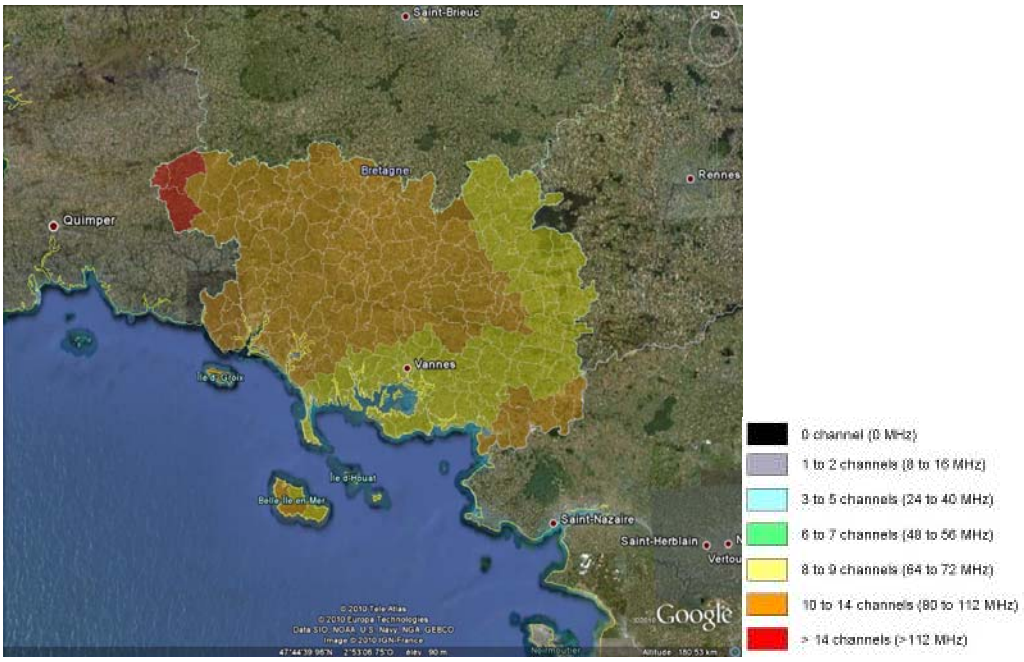

Figure 37: Representation of the "7+1 scenario" in Morbihan for WSD@1,5m

A.2.2.4.1.2. Results for Creuse

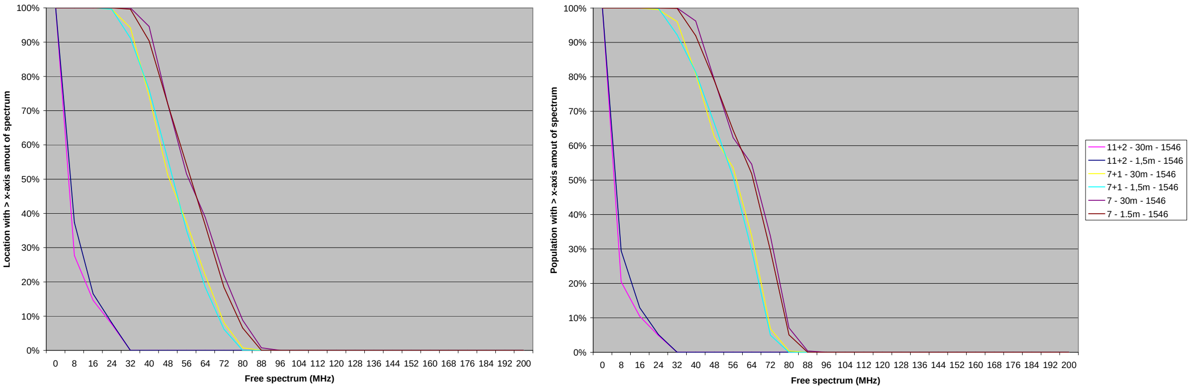

Figure 38: White space availability expressed as % of locations and population with a given amount of spectrum on a single channels basis

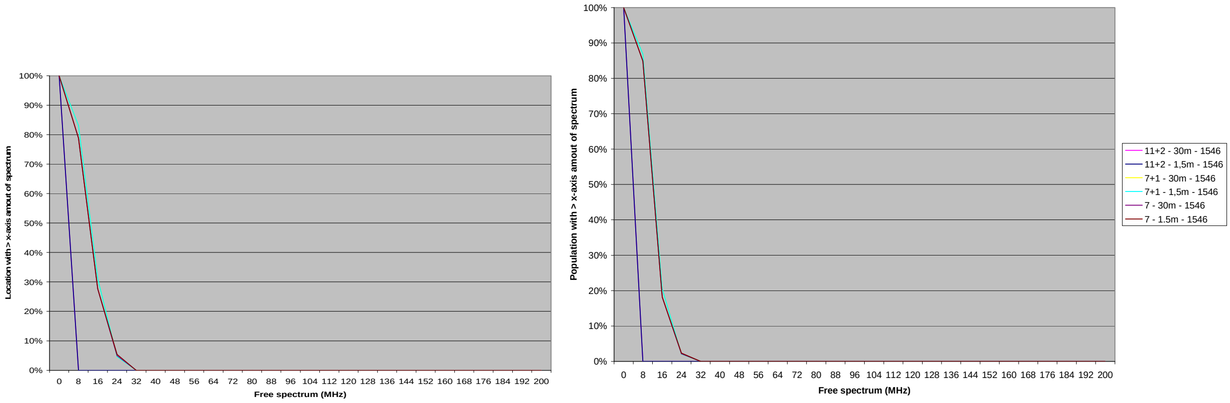

Figure 39: White space availability expressed as % of locations and population with a given amount of spectrum on a two adjacent channels basis

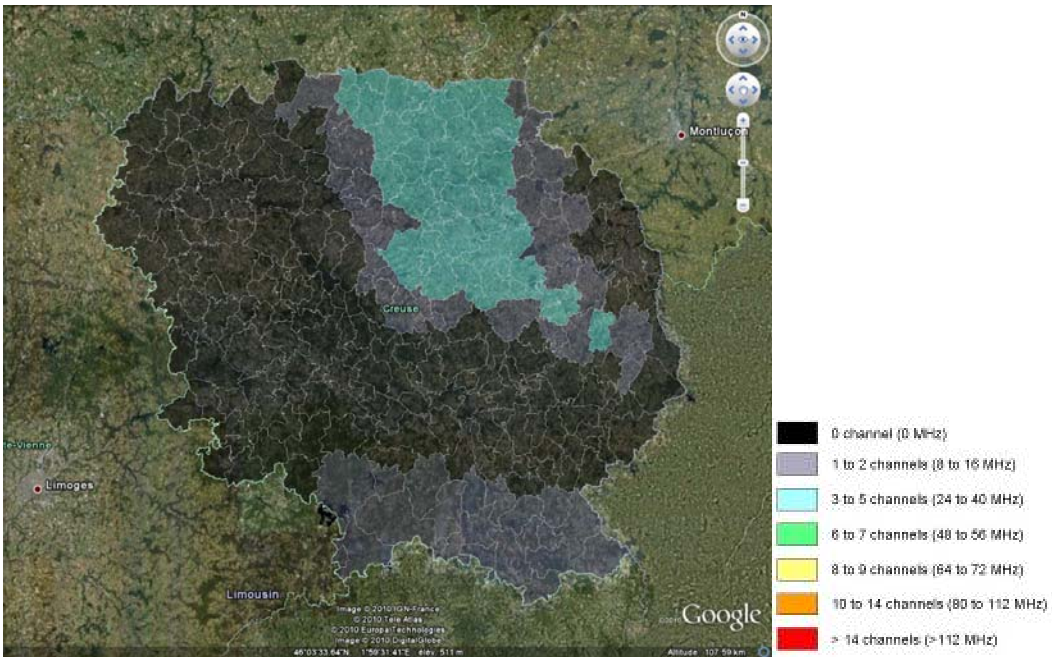

Figure 40: Representation of the "11+2" scenario in Creuse for WSD@1,5m

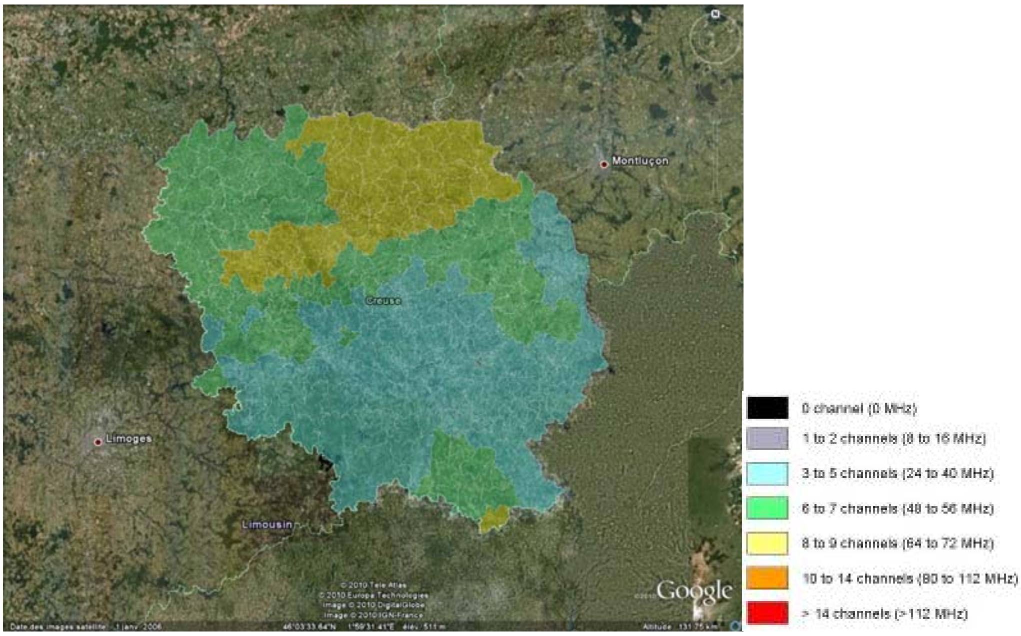

Figure 41: Representation of the "7+1" scenario in Creuse for WSD@1,5m

A.2.2.4.1.3. Results for Vosges

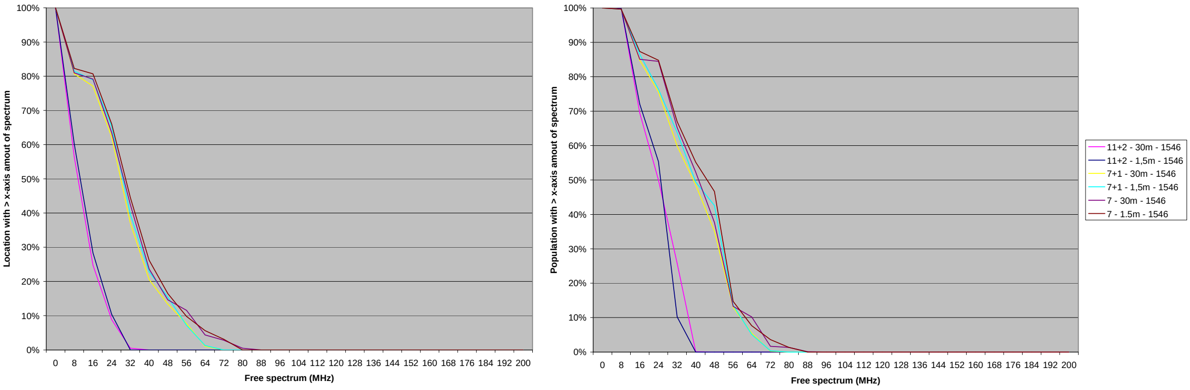

Figure 42: White space availability expressed as % of locations and population with a given amount of spectrum on a single channel basis

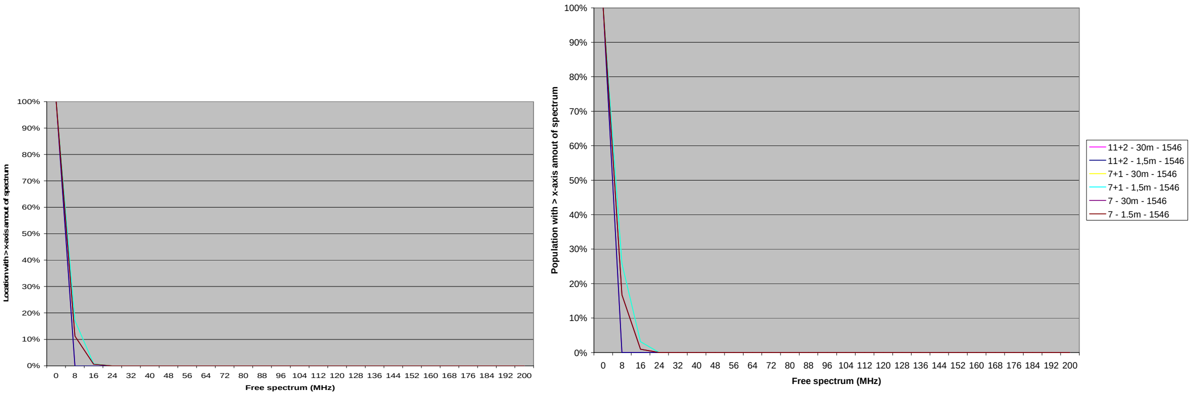

Figure 43: White space availability expressed as % of locations and population with a given amount of spectrum on a two adjacent channels basis

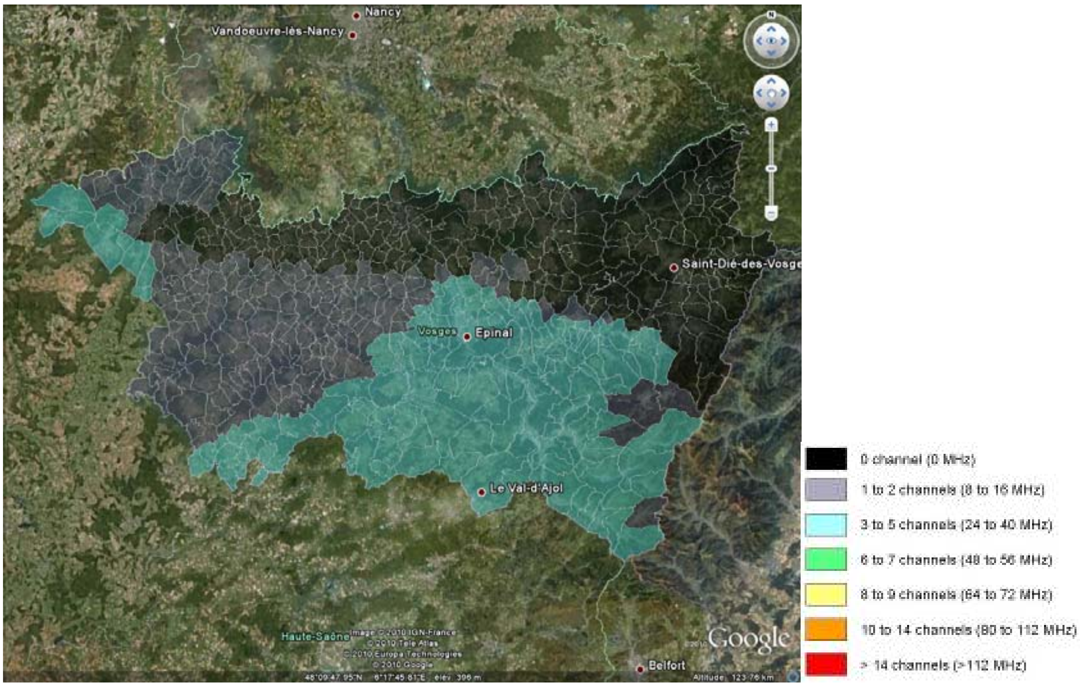

Figure 44: Representation of the "11+2 scenario" in Vosges for WSD@1,5m

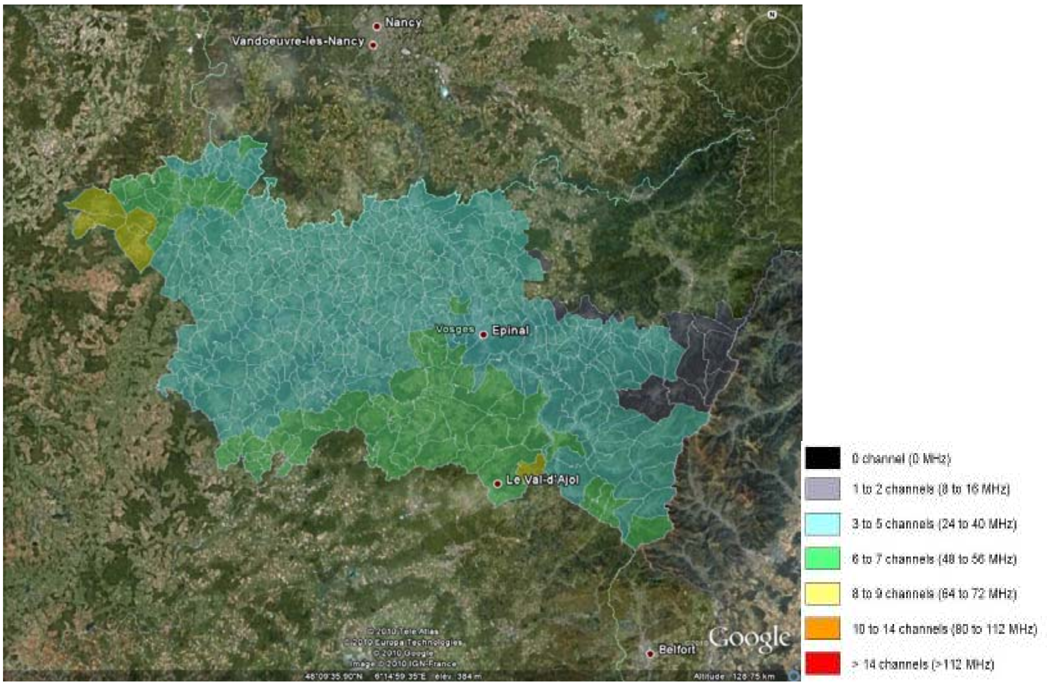

Figure 45: Representation of the "7+1 scenario" in Vosges for WSD@1,5m

A.2.2.4.2 Database approach

The approach of the section 4.3.4 is applied for the area of Morbihan for the "11+2 scenario" for the white space devices operating at 1.5m.

A.2.2.4.2.1. Mobile CR operation and fixed roof-top DTT reception

Figure 61 shows the relevant reference geometry. This geometry was also used in CEPT Report 30 for the calculation of the emission limits for mobile/fixed communication network terminal stations in the 800 MHz Digital Dividend band.

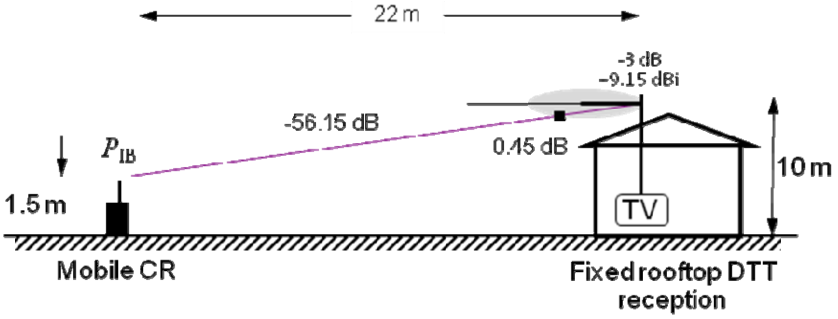

Figure 46: Reference geometry for mobile WSD. Shown path loss is for a carrier at 650 MHz

The DTT receiver antenna would provide a 3 dB polarisation discrimination with respect to a randomly oriented mobile WSD.

Portable CR geometry:

Coupling gain standard deviation $\sigma_{G\,(\mathrm{dB})} = 3.5$ dB.

Median path gain = -56.15 dB

DTT antenna gain = 9.15 dBi

DTT antenna angular discrimination = -0.45 dB

DTT antenna polar discrimination = -3 dB

Coupling gain median $m_{G\,(\mathrm{dB})} = -56.15 + 9.15 – 0.45 – 3 = -50.5$ dB.

Note that this reference geometry corresponds to a worst-case scenario for the following reasons:

- It is assumed that the WSD is located along the azimuth bore-sight of the DTT receiver's antenna.
- For a DTT antenna which complies with the ITU-R BT.419-3 directional pattern, the horizontal separation of 22 m results in the largest median coupling gain, $m_{G\ (\mathrm{dB})}$.

It can be assumed that this scenario doesn't occurred 50% of the time.

A.2.2.4.2.2. Other assumptions

For the purposes of the examples in this section, we assume:

- The median DTT received power and standard deviation are determined with the assumptions of the threshold approach
- $\Delta q = 0.01$
- $\mathrm{S}M_{(\mathrm{dB})} = 3$ dB

The protection ratios used in the study are derived from the ECC Report 148 for 50% and 90% of the receiver.

Channel edge separation (MHz)	PR 50%	PR 90%
0	19	21
1	-19	-17
9	-47	-39
17	-48	-41
25	-59	-46
33	-61	-50
41	-66	-50
49	-65	-54
57	-65	-50
65	-45	-38

Table 24: Protection ratio derived from ECC Report 148 [7].

From a statistical point of view, the final protection criteria for DTT used in this study is the degradation of the location probability by Δq in a case of a pixel composed by the 50 or 90% of the receiver (depending on the PR used) in a worst case situation which has his own probability of occurrence.

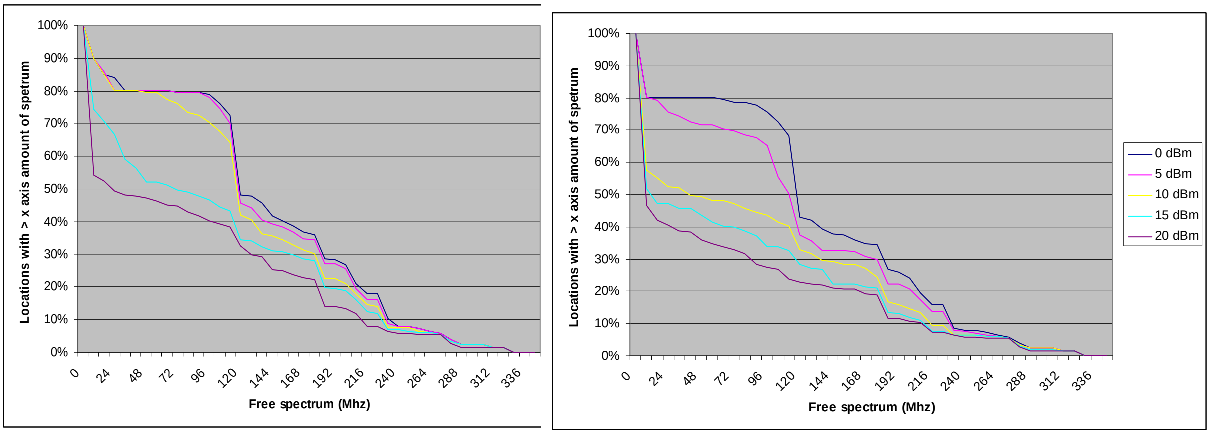

Figure 47: White space availability expressed as % of locations with a given amount of spectrum in a database operation with two set of PR, respectively for 50% and 90% of the receivers

A.2.2.5. Conclusion

Using the assumptions of the report, this study shows the amount of spectrum potentially available for two white space devices configurations in different areas and different DTT configurations.

It is shown that the amount of spectrum for white space devices decreases in a significant way when the spectrum is densely used for DTT in the surrounding areas. This situation may occurred in bordering areas between two countries, such as Vosges, or between to different planned regions.

It could be concluded that the amount of spectrum potentially available seems to be greater in a geolocation database operation. This can be explained by assuming the fact that for each location the level of DTT field strength is known. It should be noted that the inaccuracy of the location of the white space devices is not taken into account and thus the amount of spectrum is overestimated.

In addition, the amount of spectrum given in this study may be overestimated as the protection of the PMSE is not taken into account. However, the propagation model used does not take into account terrain model, which may underestimate the potential available spectrum.

A.2.2 Italy

A.2.2.1 Introduction

In this section we provide an estimation of the spectrum potentially available as white space in West Piedmont (Italy), where the digital switch-on has been completed in 2009, with a detection threshold-based approach.

In Italy the spectrum band ranging from 470 to 862 MHz is greatly utilized by broadcasting services, and thus it will be difficult to find some vacant channels to be used as white spaces.

Until now, only a part of the Italian regions have completed the digital switch-on, like Lazio, Sardinia, Aosta Valley, Campania, or West Piedmont, while Italy will be all digital by the end of 2012. Thus, in this contribution we apply the estimation procedure to the case of West Piedmont (Figure 48 Figure 48).

Also note that in Italy there are some channels that are already assigned to the Digital Dividend, which will start after the Italian digital switch-on; in regions like West Piedmont where the switch-on is completed, digital television broadcasters are not allowed to use these channels, so in this very moment they should result as vacant. Actually, as neighbouring regions are not all digital, transmitters covering these areas can still use the Digital Dividend channels, and so simulations show them as occupied (with low signal levels) even if they should not be such.

A.2.2.2 Methodology

The estimation process to evaluate White Spaces potentially available is performed according to the following steps:

- computation of the power received on a given channel and on a given pixel (600 m x 600 m) by a receiving omnidirectional antenna (0 dBi gain) mounted at a specific height above ground level. Recurring to database information containing ERP values and positions of each DTT transmitter covering West Piedmont, this computation was performed applying the Recomendation ITU-R P.1546;
- comparison of the received power against a specific threshold. The detection threshold has been set equal to -114 dBm and -120 dBm, as these values are consistent with those achievable with current technologies. For the purpose of this analysis detection thresholds should not be intended as a specific level of protection for DTT systems ;
- if the received power is under the detection threshold, the channel is considered as vacant;
- iterate the previous steps for all the channels from 21 to 60 and for all the pixels which describe the area.

In the following computations only DTT system has been considered. However the same procedure can be applied to other systems (e.g. PMSE) operating in the UHF band.

Figure 48: West Piedmont map

A.2.2.3 Results

This section provides the results obtained with a detection threshold set to -114 dBm and -120 dBm, and with a receiving antenna mounted at 1.5 m and 10 m. Figure 49 to Figure 52 show the West Piedmont area with the number of channels available for each pixel in these cases. With reference to Figure 48 which shows the West Piedmont map, it can be easily noted that areas where the WSDs actually have channels to operate on are mainly rural, in correspondence of mountains and valleys. More populated areas, near Torino or Cuneo, have little or no spectrum available as white space.

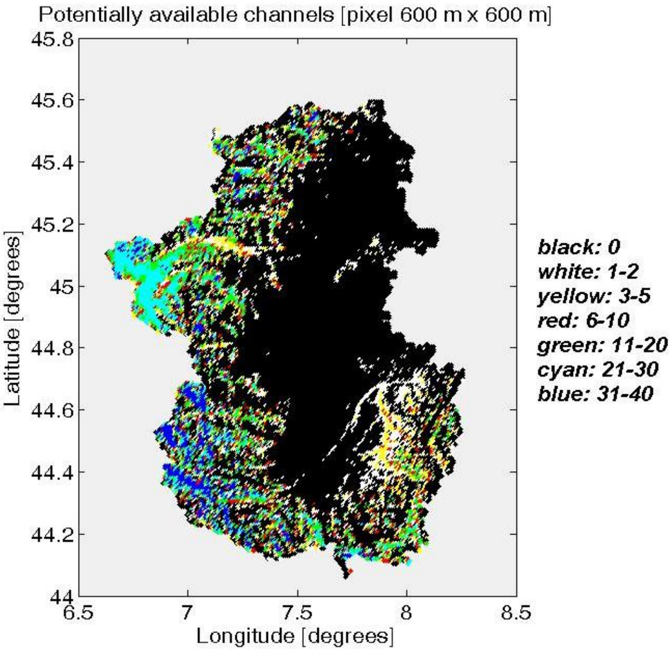

Figure 49: DT=-120 dBm , h=10 m

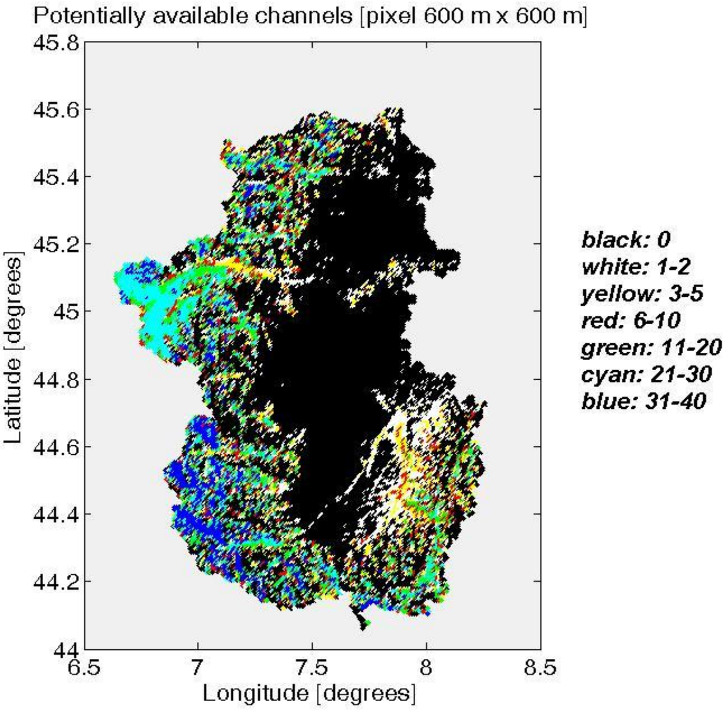

Figure 50: DT=-114 dBm , h=10 m

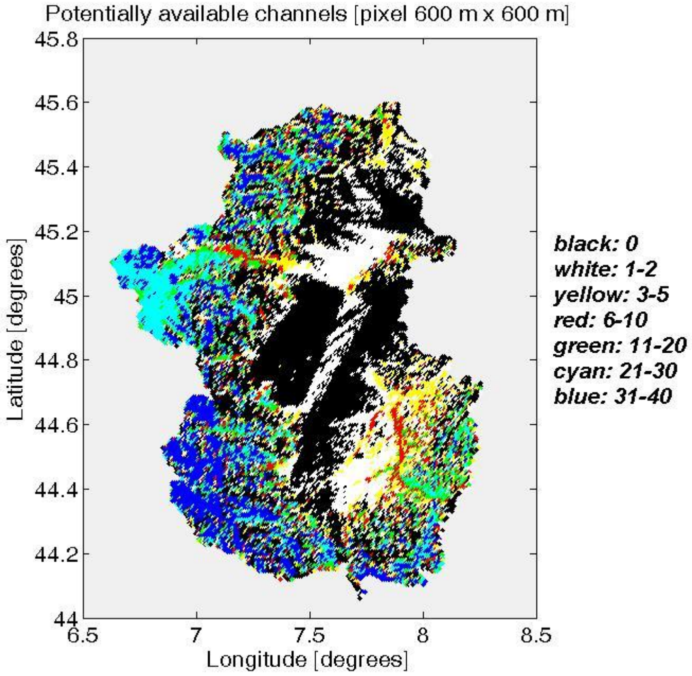

Figure 51: DT=-120 dBm , h=1.5 m

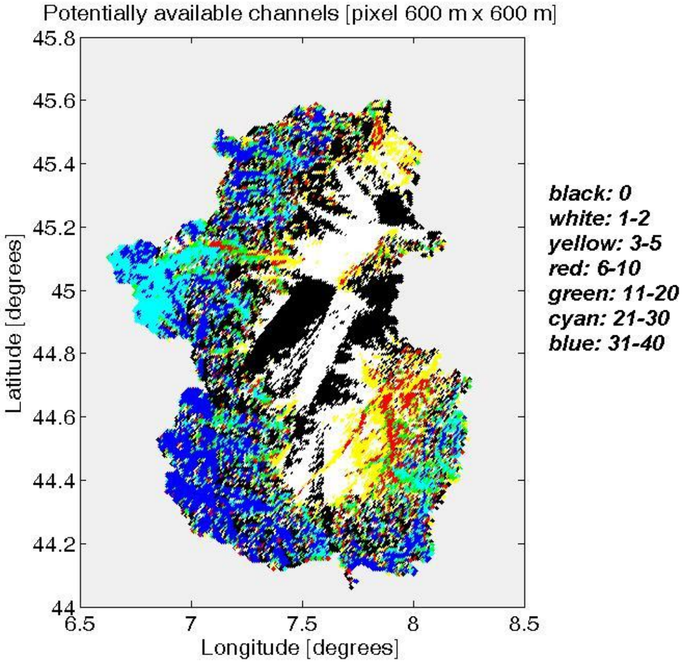

Figure 52: DT=-114 dBm , h=1.5 m

The amount of spectrum available as white space strongly depends on the detection threshold used by the WSD. As a matter of fact, with DT=-120 dBm and h=1.5 m the percentage of pixels where there is at least 1 available channel is 47.19%, while raising the detection threshold to -114 dBm this percentage becomes 56.99%. This is a key point.

The results provide in this section do not represent the effective amount of spectrum available as white space; actually, they probably are an overestimation, because even if the WSD detects a channel as vacant, it might not be allowed to use it because of the interference it will generate with its transmission for several reasons:

- the WSD might generate too much interference on an adjacent channel which is occupied;
- the interference generated by all of the WSDs detecting the channel as available might be too high on an adjacent channel or on the same channel in an adjacent pixel;
- even if the hidden node problem is taken into account with a margin inside the detection threshold, situations might still occur where the WSD experiences a shadowing higher than the margin itself, thus making a mistake when sensing the channel.

However, cooperation among the WSDs or the implementation of a sensing technique combined with the information provided by a geolocation database might allow the WSD to use a higher detection threshold, thus counter-balancing or even overwhelming the reduction of available channels due to the interference issues listed above. For example, if the gain due to cooperation is 15 dBm (DT=-105 dBm), the percentage of pixels where there is at least 1 available channel is 77.15%.

Figure 53and Figure 54 show the Complementary Cumulative Distribution Function (CCDF) of the estimated amount of spectrum available as white space. These Figures confirm the point that the areas where there are more available channels are rural, as the CCDF referring to the population percentage (Figure 54) is extremely fast in going to values under 5-10%, while the one referring to the location percentage (Figure 53) has a more gradual slope. For example, while almost 20% of locations have more than 64 MHz available with DT=-120 dBm and h=10 m, only 2% of population is actually in these areas.

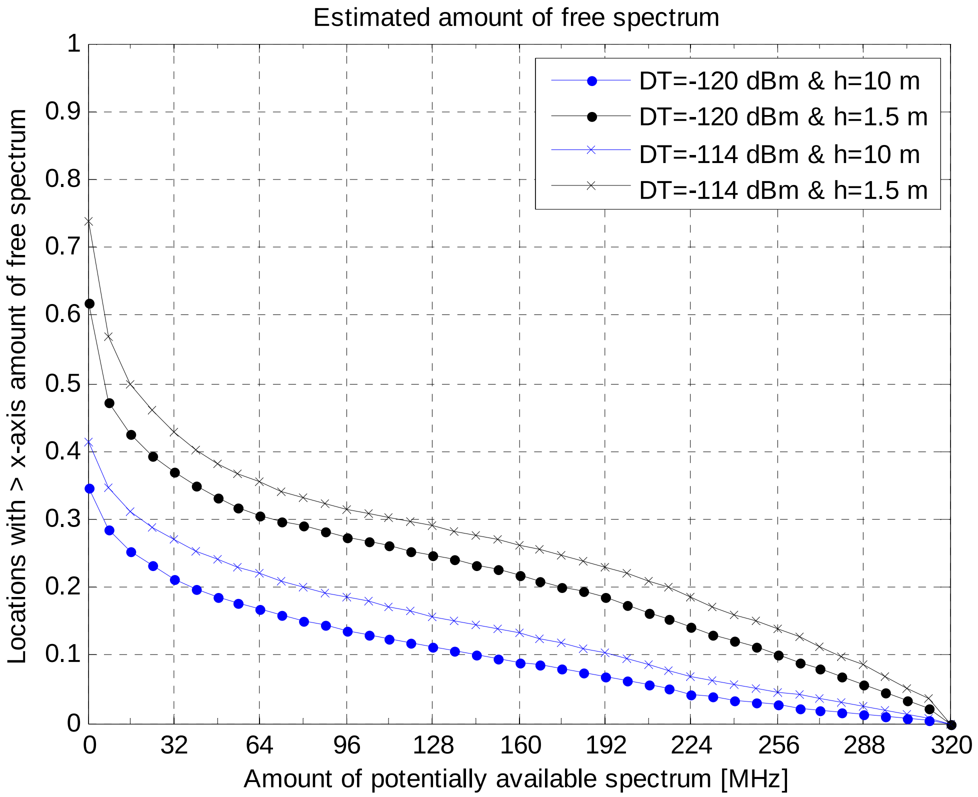

Figure 53: Cumulative Distribution Function of the amount of white space per pixel

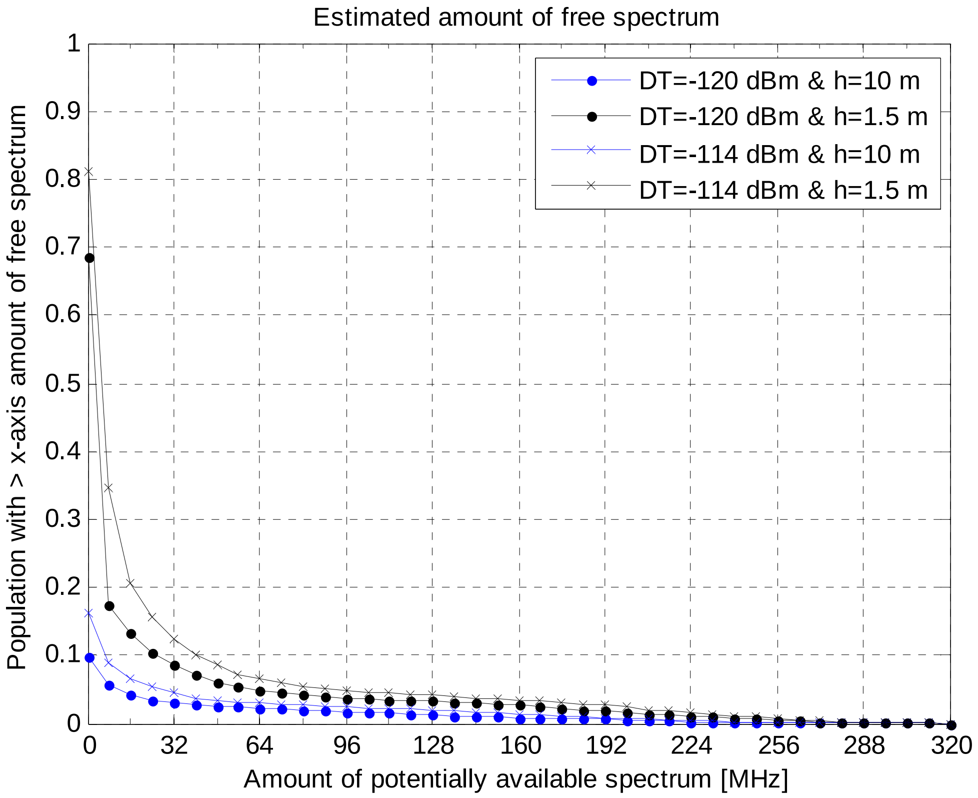

Figure 54: Cumulative Distribution Function of the amount of white space per population

ANNEX 3 : DEFINITION OF PR, ACS, ACLR AND RELATIONSHIP BETWEEN THEM

Radio frequency signal-to-interference ratio (C/I)

It is the ratio of the power of the wanted signal to the total power of interfering signals and noise, evaluated at the receiver input.

Usually, C/I is expressed as a function of the frequency offset $f_I - f_W$ between the wanted and interfering signals over a wide frequency range. For $f_I = f_W$, co-channel situation is considered; for $f_I \neq f_W$ adjacent channel situation takes place.

Radio frequency protection ratio (PR)

It is the minimum value of the signal-to-interference ratio required to obtain a specified reception quality under specified conditions at the receiver input.

Usually, PR is specified as a function of the frequency offset between the wanted and interfering signals over a wide frequency range.

Adjacent Channel Leakage Ratio (ACLR)

It is a measure of transmitter performance. It is defined as the ratio of the transmitted power to the power measured in the adjacent radio frequency evaluated at the output of a receiver filter.

Adjacent Channel Selectivity (ACS)

It is a measure of receiver performance. It is defined as the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent frequency.

Adjacent Channel Interference Ratio (ACIR)

It is a measure of over all system performance. It is defined as the ratio of the total power transmitted from an interfering source to the total interference power affecting a victim receiver, resulting from both transmitter and receiver imperfections.

These parameters have the following relationship (in linear domain):

$$\frac{1}{ACIR} = \frac{1}{ACLR} + \frac{1}{ACS}$$

$$ACIR = \frac{PR\,(f_I = f_W)}{PR\,(f_I \neq f_W)}$$

ANNEX 4 : HIDDEN NODE MARGIN (HNM)

Several alternative approaches were developed in order to derive values for the HNM. The first one (A.4.1) has derived some HNM figures by simulating a set of scenarios, followed by a set of measurements. A second study (A.4.2.) has considered an analytical approach, by taken into account the difference between the field strengths received at different heights. A second set of simulations were performed (A.4.3) in order to assess if the previous HN margins calculated are consistent for the considered context.

A.4.1 First Study

A.4.1.1 Scenarios

Two types of DTT operation are considered here.

- DTT External Antenna (typically rooftop mounted) with
  - WSDs in the street for urban environment
  - WSDs in the street for rural environment
  - WSDs in the street for suburban environment

- DTT Internal Antennas (typically mounted on top of the television) with
  - WSDs in the same building
  - WSDs in a different building

The case of indoor cognitive devices and DTT receiver in the same room is not considered to be the worst case scenario when looking at additional margins for hidden terminal problem as the fades occurring in different parts of the same room in general will only be a few dBs deep and will very rarely exceed the additional margins needed for other cases.

A.4.1.2 Simulation Parameters

A.4.1.2.1 DTT External Antenna

Simulation model was recreated for the following scenario:

- exact recreation of a 3 km^2 urban/suburban environment based on the London suburb of Croydon was created using building database with ± 15cm height resolution and 90m terrain resolution
- exact recreation of 9km^2 dense urban environment based on an area in Central London
- creation of 3km^2 of rural village representing Crawley Downs based on typical generic area consisting of a mix of building types

The TV transmitter was modelled as follows

- Bandwidth: 8MHz
- ERP: 20,000W (73dBm)
- Transmitter height: 202m above ground level
- Distance of TV transmitter and centre of building data: 5.7km

The propagation model used was

- Dominant path model[11] which is a variant of standard ray tracing techniques.
- The path loss exponent for line of sight (LOS) and non line of sight (NLOS) was adjusted by comparing with measurement data
- LOS path loss exponent 2.1 and 4 before and after Fresnel break point respectively
- NLOS path loss exponent 2.5 and 4 before and after Fresnel break point respectively

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[11] http://www.awe.communications.com It is noted that technical details of this model are not publicly available.

The building make-up within the 3 scenarios is as follows:

Environment	Building Type
Urban	Blocks of flats typically 3 to 8 storeys high
	Office buildings up to 20 storeys high
	Large Shopping complexes
Suburban	Rows of terraced houses with the road a different orientations, including roads along a radial from the transmitter and roads that are perpendicular to such radials
	Roads with semi-detached and detached houses
	2 to 3 storeys residential buildings
Rural	Small roads with a few semi-detached and detached houses

Table 25: Scenarios

The walls of the buildings were modelled as 30cm concrete and the material properties used are given below[12]:

Parameter	Value
Transmission loss- wall (dB)	5.2
Transmission loss- roof (dB)	5.2
Reflection loss (dB)	7.5
Minimum incident diffraction loss (dB)	12
Maximum incident diffraction loss (dB)	35
Diffraction loss (dB)	5
Relative permittivity	6
Relative Permeability	1
Conductivity (S/m)	0.018

Table 26: Material properties

A.4.1.2.2 DTT Internal Antenna

Simulation model was created to evaluate the transmission, reflection and diffraction effects in and around a typical housing environment for the following four paths as shown in Figure 55:

- Path 1 is a WSD at 1.5m to TV at 1.5m between two houses across the road from each other.
- Path 2 is a WSD at 1.5m to TV at 1.5m in different rooms in the same house.
- Path 3 is a WSD at 4.5m to TV at 4.5m between two houses across the road from each other.
- Path 4 is a WSD at 4.5m to TV at 4.5m in different rooms in the same house.

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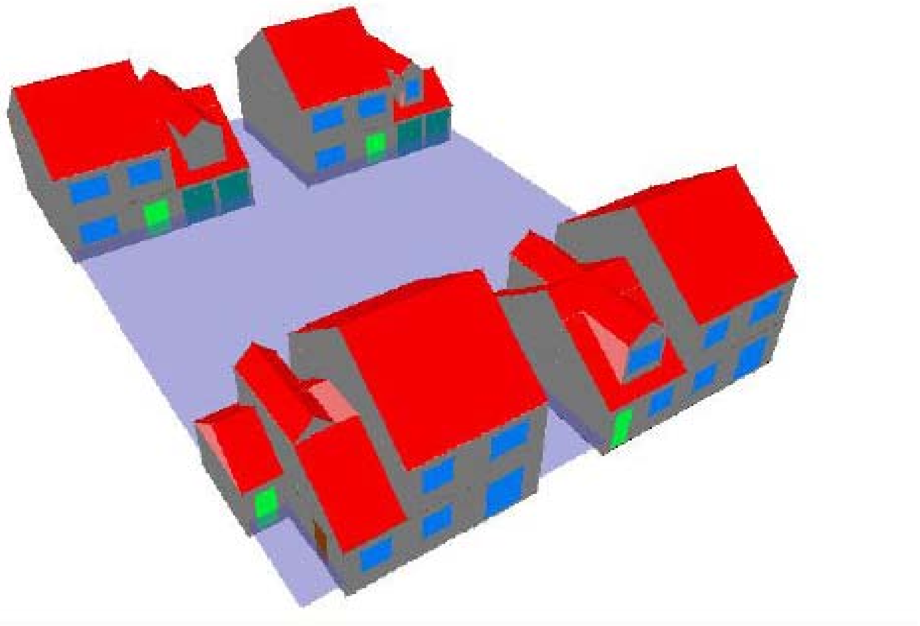
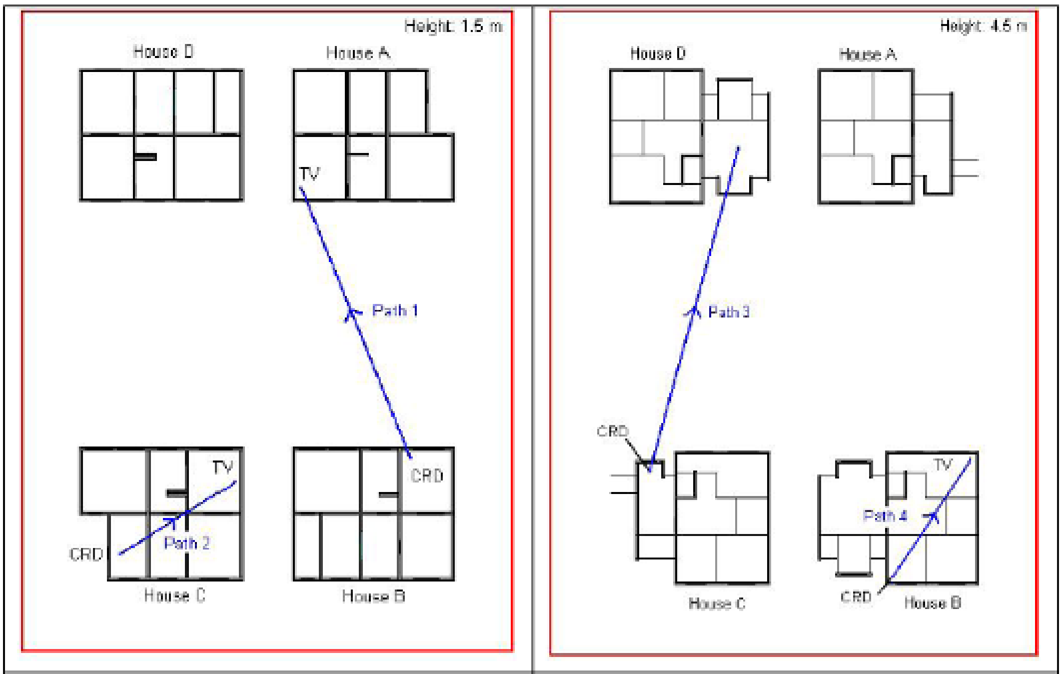
[12] Properties of concrete taken from AWEC Communications materials database for a frequency of 450 MHz.These parameters are based on the validation of their software tool using the ray tracing and the dominant path model with measurements.





a) CRD – TV path profile at 1.5 m

b) CRD – TV path profile at 4.5 m

Figure 55: Modeled paths

The houses were constructed as follows and the parameters of the electrical and RF properties of materials are given in the Table 27 below:

- External frame - 30cm thick brick wall cladding, 1cm thick clay roof top tiles
- Internal ground floor rooms – Concrete base floor and 10cm brick wall
- Internal first floor rooms – Wooden floor and 10cm thick plasterboard partitions
- 2mm thick glass windows, wood doors and 1mm thick garage metal doors

Parameter	**Brick Wall**	**Wooden 1st floor**	**Clay roof**	**Internal plasterboard partitions**	**Glass window**	**Garage metal doors**	**Concrete floor base**
Transmission loss – wall (dB)	1.64	0.49	0.8	1.84	1.69	56.31	5.2
Reflection loss (dB)	9.54	12.95	13	9.52	7.53	0.05	7.51
Minimum incident diffraction loss (dB)	12	10	9	12	12	12	12
Maximum incident diffraction loss (dB)	36	34	33	36	35	36	35
Diffraction loss (dB)	6	6	8	6	5	6	5
Relative permittivity	4	2.5	2.45	4	6	1	6
Relative permeability	1	1	1	1	1	20	1
Conductivity (S/m)	0.003	0.001	0.0045	0.01	0.001	2500	0.018

Table 27: Parameters of the electrical and RF properties of materials

Similar dominant path model as with the macro case is used, with the path loss exponent set to 2.5.

Note: The relation of all parameters in Table 28 to values which are used in broadcasting planning and interference consideration, e.g. a mean value of building penetration loss of 8 dB (see GE06 [5]), is unclear.

A.4.1.3 Validation Measurements

Measurements were conducted to validate modelling for the macro *urban/suburban* scenario in Croydon area, for external antennas as described in section A.4.1.2.1. It is noted that this does not cover the simulations explained in section A.4.1.2.2.

The above mentioned validation for external antennas was done based on measuring the received field strength for six digital TV channels at four different heights of 0.5m, 1.5m, 5m and 10m at 100 separate locations.

For heights at 5m and 10m, the received DTT signal strength was measured with UHF Yagi antenna with 10dBi gain, whereas for heights of 0.5m and 1.5m, a 2dBi gain omnidirectional antenna was used. Antenna orientations were made for both co-polar and cross-polar orientation as well as a third plane orthogonal to both orientation.

When calculating the hidden node, the gain and cable loss were taken out, thus eliminating any antenna dependency between the TV antenna and cognitive antenna. The minimum received signal between co-polar and cross-polar results at 1.5m was also used to ensure maximum sensitivity required for a potential cognitive device to detect a DTT signal.

The measurement data are then compared with the numerical results from the simulation of the urban/suburban scenario in Croydon area.

A.4.1.4 Results

A.4.1.5 Comparison of simulated results (external antennas) and measured data for 100 data points

Environment	**DTT hidden node margin (dB)**					
	90% of locations		**95% of locations**		**99% of locations**	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
Urban/suburban	30.5	28.5	31.4	30.4	32.5	33.7

Table 28: Comparison of simulated results (external antennas) and measured data

A.4.1.5.1 Summary of DTT hidden node margin values from simulations

DTT External Antennas

Environment	**No. of test points**	**DTT hidden node margin (dB)**		
		90% of locations	**95% of locations**	**99% of locations**
Densely urban	102,400	18.5	22.4	29.2
Urban	30,000	28.1	30.2	32.5
Suburban	30,000	30.5	31.4	32.9
Rural	30,000	14.9	15.6	16.6

Table 29: Results for DTT HNM from simulations

The absolute worst-case margin covering virtually 100% of locations in the sub-urban environment is around 35dB. This also includes allowance for misalignment of antennas (where the cognitive device's antenna is oriented in a different plane from the polarisation of the DTT transmitter's antenna.

DTT Internal Antennas

Scenario	**DTT hidden node margin (dB)**	
	1.5m	**4.5m**
A cognitive device in the front of a house furthest away from the TV transmitter and an indoor antenna in the front of a house across the street	15 (Path 1)	6 (Path 3)
A cognitive device and an indoor antenna in the same house	28 (Path 2)	11 (Path 4)

Table 30: Results for DTT HNM from simulations

Note: The methodology used in the study above is different from the methodology described in the GE06 Agreement

A.4.2 Second Study

An alternative theoretical method to determine the hidden node margin to provide comparison with the first study is to apply the following equation

$$HM = E_{med}(H_{DTT}) - E_{med}(H_{WSD}) + \mu_{99.9}\sigma$$

where the first part of the equation would be the differences in the field strength of TV reception and WSD at the required height and the second part is the location correction factor of 99.9% which would represent the % of location to be protected.

Using the following assumptions:

- Reception in an urban area;
- frequency = 800 MHz;
- ERP = 10 kW;
- H_{tx} = 300 m;
- Distance between the Tx and the Rx = 10 km;

the results for the hidden node margin for the differences in the various receive heights are shown below for the case of suburban clutter environment to provide comparison the first study.

Difference in received height between TV reception and WSD	Differences in field strength for different clutter environment (dB)			$\mu_{99.9}\sigma$ (dB)	Hidden node margin (dB) for suburban environment
	Dense Urban (30m)	Urban (20m)	Suburban/open (10m)		
30m to 1.5m	27.8	28.3	28.3	17	45.3
10m to 1.5m	2.7	5.2	18.2	17	**35.2**
30m to 10m	25.1	23.1	10.1	17	27.1

Table 31: Results for DTT HNM from Second Study

The hidden node margin of 35.2 dB between 10m to 1.5m is consistent with the 35dB value for the same scenario of the first study.

A.4.3 Second set of simulations

The two methodologies for the Hidden Node (HN) calculation, proposed in this Annex have been applied to a real scenario in the Italian city of Bologna. Only the case of DTT fixed reception, that is external antennas on rooftops, has been taken into account and different environments have been considered.

The aim of the work is to assess the proposed methodologies applied to a typical Italian urban scenario and verify if previous HN margins calculated are consistent with the analysed context.

A.4.3.1 Analysed scenario

The Hidden Node margin has been evaluated only for DTT fixed reception, that is external antennas typically rooftop mounted.

Inside the city area of Bologna three different environments have been considered (see Figure 56), which have been recreated by means of a building database. Terrain information has been disregarded, since the considered environments are in flat areas.

- Urban environment: exact recreation of a 4 km^2 square area (blue area in Figure 56), characterised by 2-6 storey high buildings with an average height of 10.5 m;
- Open environment: exact recreation of a 4 km^2 square area (green area in Figure 56). This area is in the neighbourhood of the city and is characterised by houses typically 2-3 storey high with an average height of 6 m. In this area there are few houses generally surrounded by wide gardens and some woods. This is the area closest to the DTT transmitter;
- Dense Urban environment: exact recreation of a 16 km^2 square area (pink area in Figure 56). In this area there is a business centre with several tower buildings surrounded by many office and residential blocks. The simulated area includes also part of the city centre, which is characterised by narrow streets with a radial orientation and some medieval towers and also several churches. The average building height is 12.2 m.

Cognitive devices have been considered both at street level (1.5 m) and at 10 m in urban and dense urban cases. In the open environment only cognitive devices at street level have been taken into account.

For the HN estimation, the DTT receiving antennas have been assumed at the reference levels of 10 m and 30 m.

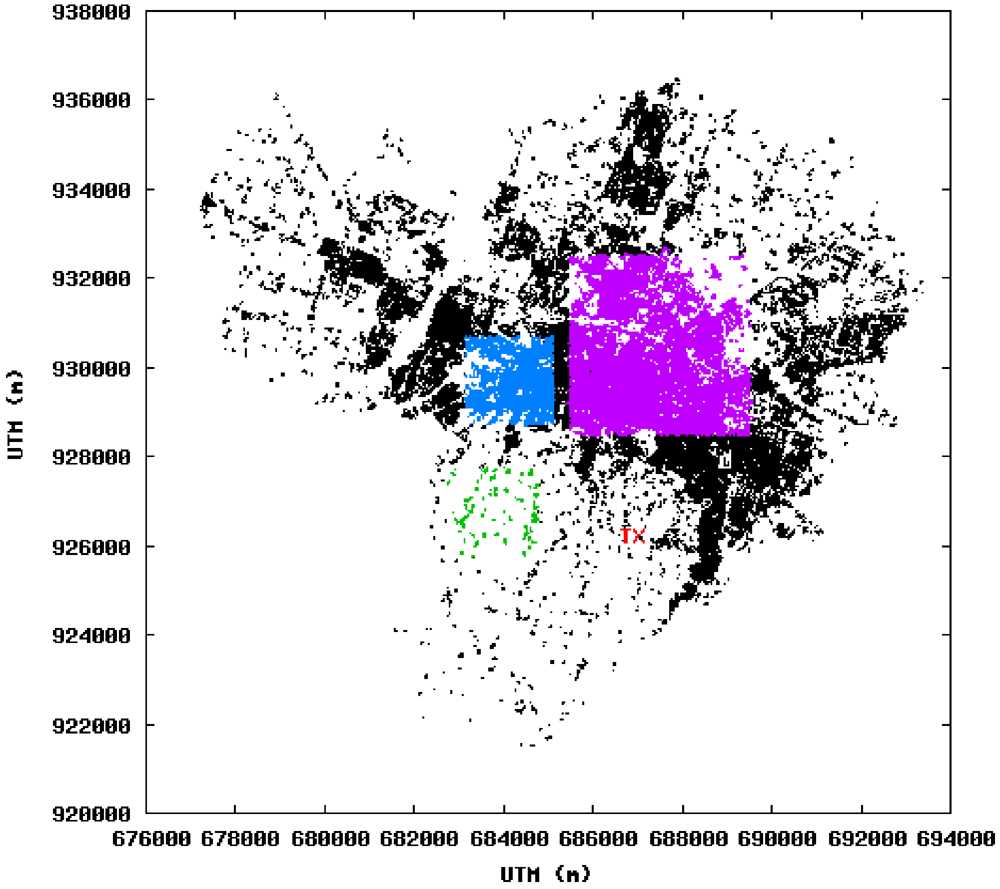


Figure 56: Simulation scenario

In each environment, the HN margin has been evaluated along several outdoor paths (see Figure 57, Figure 58 and Figure 59) with 1 m step. In each sample point the DTT signal strength has been estimated at different heights for HN calculation:

- Urban environment: 1765 test points;
- Open environment 3313 test points;
- Dense Urban environment: 1622 test points.

Figure 57: Simulated paths in the considered urban environment

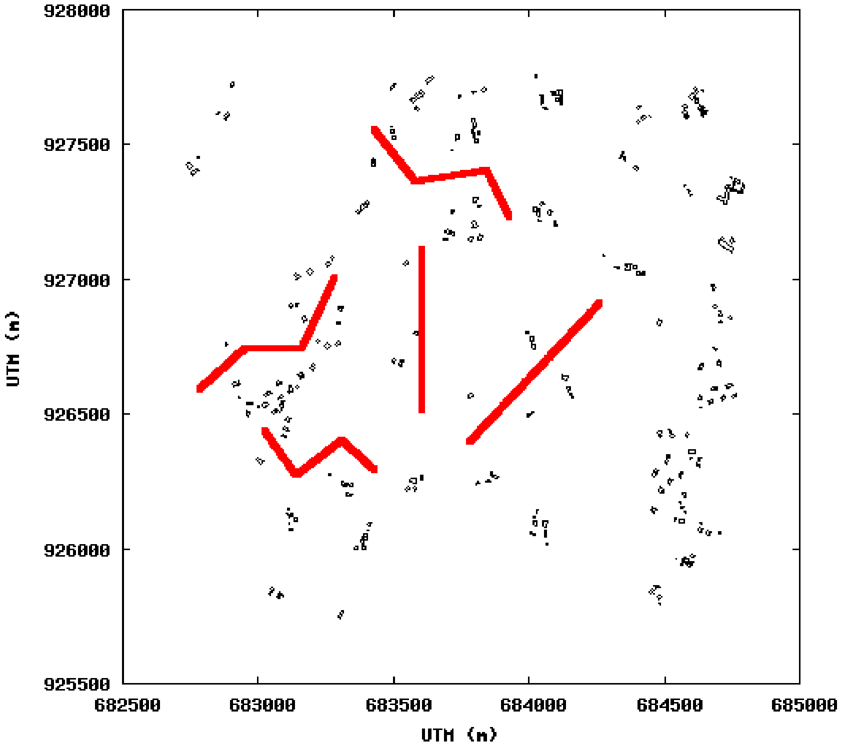


Figure 58: Simulated paths in the considered open environment

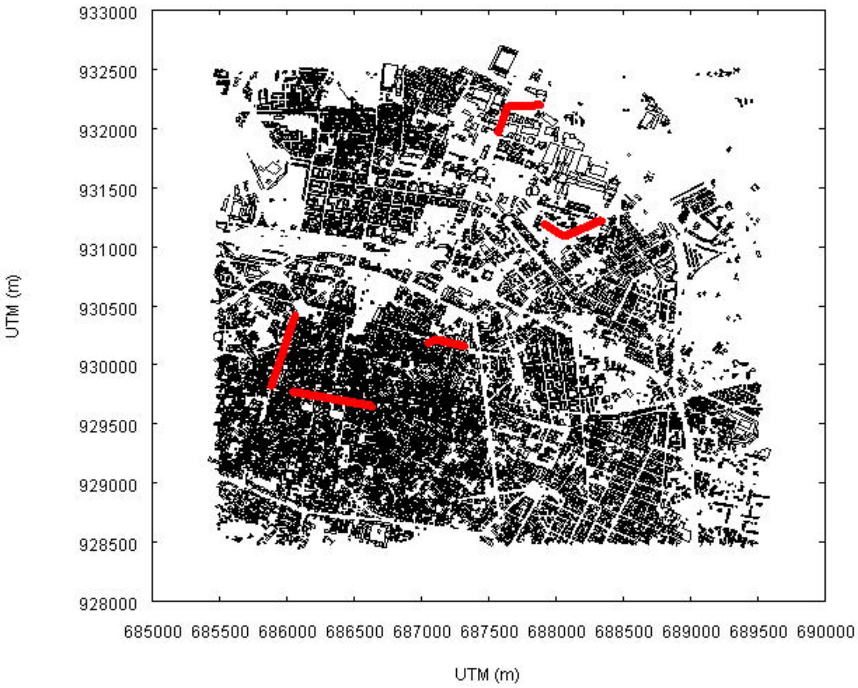


Figure 59: Simulated paths in the considered dense urban environment

The considered DTT transmitter is a real installation, located on the hills surrounding the city (see Figure 59) with the following characteristics:

- Distance from the analysed test points:
  - Urban environment: 3.4 - 4.7 km
  - Open environment: 2.5 - 3.9 km
  - Dense Urban environment: 3.4 - 6.1 km
- Frequency: 690 MHz
- Bandwidth : 8 MHz
- ERP: 81.11 dBm
- Transmitter height: 335 m above sea level.

For the HN calculations evaluated according to the methodology of Annex A.4.1, a propagation model based on a 3D ray-tracing simulator has been considered [14]. The ray-tracing tool considers diffractions, reflections and diffuse scattering, while transmission through walls and roofs is disregarded in the employed software version. Losses due to the interactions of the electromagnetic field with walls are computed assuming the following electromagnetic properties:

- Relative permittivity: 5
- Relative permeability: 1
- Conductivity (S/m): 0.01.

The previous values of the electromagnetic parameters are based on the validation of the software propagation tool against measurements [17]

For the HN calculations evaluated according to the methodology of Annex A.4.2 the ITU-R P.1546 model [15] has been considered. Both urban and dense urban scenarios have been mapped as urban environment for propagation analysis with ITU-R P.1546.

A.4.3.2 Results

A.4.3.2.1 HN margin calculated according to methodology of Annex A.4.1

Environment	No. of test points	Configuration	DTT hidden node margin (dB) for 99% of locations	DTT hidden node margin (dB) for 99.9% of locations*
Urban	1765	DTT@30m – WSD@1.5m	41.5	48.03
		DTT@30m – WSD@10m	30.63	44.68
		DTT@10m – WSD@1.5m	32.81	46.44
Open	3313	DTT@10m – WSD@1.5m	3.67	5.91
Dense urban	1622	DTT@30m – WSD@1.5m	43.2	54.55
		DTT@30m – WSD@10m	40.36	46.99
		DTT@10m – WSD@1.5m	26.7	34.8

*The HN margin has been evaluated also for 99.9% of locations in order to virtually obtain a full protection of DTT.

Table 32: Calculated Hidden Node margins

The obtained values of HN margins are consistent with those presented in Annex A.4.1 .

A.4.3.2.2 HN margin calculated according to methodology of Annex A.4.2

Environment	No. of test points	Configuration	DTT hidden node margin (dB) for 99.9% of locations**
Urban/Dense Urban	3387	DTT@30m – WSD@1.5m	43.83
		DTT@30m – WSD@10m	41.06
		DTT@10m – WSD@1.5m	19.76
Open	3313	DTT@10m – WSD@1.5m	32.60

**Given the geometry of the considered environments, predictions obtained applying ITU-R P.1546 present negligible variations. Thus, the reported HN margins are the mean values obtained in each configuration of the considered environment.

Table 33: Calculated Hidden Node margins

The obtained values of HN margins are consistent with those presented in Annex A.4.2.

ANNEX 5 : SPECIFIC SCENARIOS FOR DETECTION THRESHOLD CALCULATION

This annex presents additional calculations for detection threshold, considering specific scenarios, which takes into account some national and/or local planning assumptions, which are different than those used in Section 4.2.

The following tables presents results in three different sets of calculations:

- Consider some specific scenarios where the service is planned for 70% of locations;
- Consider the scenario of planning the DTT fixed reception with 30 m reference antenna height, instead of 10 m as it was considered in the reference scenario

  This is motivated by the fact that TV antenna height in urban and densed urban in general is larger than e.g. in rural areas, resulting in a larger height loss.

For each set of calculations, two sub-sets were taken onboard, by considering the case when WSD is at outdoor and when is indoor.

A.5.1 DTT is planned for 70% of locations

In many European countries, the 70% coverage contours is used to define the edge of the planned service. This is acceptable in practice as modern installations can be improved beyond the reference parameters used in GE06, e.g. due to lower DTT receiver noise figures.

A.5.1.1 Detection Threshold for Outdoor WSD

DTT	**DTT fixed outdoor, planned for Dense Urban area**			**DTT fixed outdoor, planned for SubUrban area**			**Portable outdoor**
Percentage location in the target detection area:	**70%**			**70%**			**70%**
DTT receiver antenna height	**@30 m**			**@10 m**			**@1.5 m**
WSD	**Mobile Outdoor @1,5m**		**Fixed Outdoor @30m**	**Mobile Outdoor @1,5m**		**Fixed Outdoor @30m***	**Mobile Outdoor @1,5m**
$E_{med,plan}$	50.02	40.02	50.02	50.02	40.02	50.02	47.00
$L_{HDTT - HWSD}$	26.87	26.87	0.00	17.01	17.01	-9.84	0.00
E_{med}	23.15	13.15	50.02	33.01	23.01	59.86	47.00
Sensing reliability	99,99%	99,99%	99,99%	99,99%	99,99%	99,99%	99,99%
$\sigma_{1,5m}$	5.50	5.50	5.50	5.50	5.50	5.50	5.50
μ_{sense}	3.72	3.72	3.72	3.72	3.72	3.72	3.72
$\mu_{sense}.\sigma_{1,5m}$	20.46	20.46	20.46	20.46	20.46	20.46	20.46
f_{sense}	650.00	650.00	650.00	650.00	650.00	650.00	650.00
G_{sense}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{pol} (Note 2)	3.00	3.00	3.00	3.00	3.00	3.00	3.00
L_{body_loss}	3.00	3.00	0.00	3.00	3.00	0.00	3.00
E_{sense}	2.69	-7.31	29.56	12.55	2.55	39.40	26.54
$P_{sense\_1,5m}$	-136.76	-146.76	-106.89	-126.90	-136.90	-97.05	-112.91

Table 34: Detection threshold for outdoor WSD when DTT is planned for 70% of locations

A.5.1.2 Detection Threshold for Indoor WSD

DTT deployment	**DTT fixed outdoor, at Dense Urban area**		**DTT fixed outdoor, at Rural area**		**Portable outdoor**	
Percentage location in the target detection area:	**70%**		**70%**		**70%**	
DTT receiver antenna height	**@30m**		**@10m**		**@1.5 m**	
WSD deployment	**Mobile indoor @1,5m**		**Mobile indoor @1,5m**		**Mobile indoor @1,5m**	
$E_{med,plan}$	50.02	40.02 *	50.02	40.02 *	47.00	dBuV/m
$L_{HDTT\text{ - }HWSD}$	26.84	26.84	17.01	17.01	0.00	dB
E_{med}	23.18	13.18	33.01	23.01	47.00	dBuV/m
$\sigma_{1,5m}$	5.50	5.50	5.50	5.50	5.50	dB
BPL **	11.00	11.00	11.00	11.00	11.00	dB
σ_{BPL}	5.00	5.00	5.00	5.00	5.00	dB
σ_{indoor}	0.00	0.00	0.00	0.00	0.00	dB
Sensing reliability	99.99%	99.99%	99.99%	99.99%	99.99%	
μ_{sense}	3.72	3.72	3.72	3.72	3.72	dB
$m_{sense}\sqrt{(\sigma^2_{1.5m}+\sigma^2_{BPL}+\sigma^2_{indoor})}$	31.72	31.72	31.72	31.72	31.72	dB
f_{sense}	650.00	650.00	650.00	650.00	650.00	MHz
G_{sense}	0.00	0.00	0.00	0.00	0.00	dBi
L_{pol} (Note 2)	3.00	3.00	3.00	3.00	3.00	dB
Lbody_loss	3.00	3.00	3.00	3.00	3.00	dB
E_{sense}	-15.46	-25.46	-5.63	-15.63	8.36	dBuV/m
$P_{sense\_1,5m}$	-154.9	-164.9	-145.1	-155.1	-131.1	dBm

Note *: In some countries local broadcasters, considering their need to expand geographical coverage rather than maximizing capacity, have decided to use 16-QAM. In other countries, e.g. Germany, fixed reception is used in practice where portable reception of the (more robust) 16-QAM signal is not possible anymore.

Note **: The BPL values and the associated standard deviations used in this table are taken from the document "BMCO link budgets white paper" for light indoor case. With these values, the term σ_{indoor}m is absorbed into an increased BPL term when compared to GE06 values used in the main body of this report. For the case of "deep indoor", values of 17 dB for BPL and 6 dB for σ_{indoor} would be appropriate.

Table 35: Detection threshold for outdoor WSD when DTT is planned for 70% of locations

A.5.2 DTT is planned for 95% of locations

A.5.2.1 Detection Threshold for Outdoor WSD

DTT	**DTT fixed outdoor, planned for Dense Urban area**		
Percentage location in the target detection area:	**95%**		
DTT receiver antenna height	**@30 m**		
WSD	**Mobile Outdoor @1,5m**	**Fixed Outdoor @30m***	
$E_{med,plan}$	56.21	56.21	dBuV/m
$L_{HDTT\text{ - }HWSD}$	26.87	0.00	dB
E_{med}	29.34	56.21	dBuV/m
Sensing reliability	99,99%	99,99%	%
$\sigma_{1,5m}$	5.50	5.50	dB
μ_{sense}	3.72	3.72	dB
$\mu_{sense} \cdot \sigma_{1,5m}$	20.46	20.46	dB
f_{sense}	650.00	650.00	MHz
G_{sense}	0.00	0.00	dBi
L_{pol} (Note 2)	3.00	3.00	dB
L_{body_loss}	3.00	0.00	dB
E_{sense}	8.88	35.75	dBuV/m
$P_{sense\_1,5m}$	-127.57	-100.70	dBm

Table 36: Detection threshold for outdoor WSD when DTT is planned for 95% of locations

A.5.2.2 Detection Threshold for Indoor WSD

DTT deployment	DTT fixed outdoor, at Dense Urban area	
Percentage location in the target detection area:	95%	
DTT receiver antenna height	@30m	
WSD deployment	Mobile indoor @1,5m	
$E_{med,plan}$	56.21	dBuV/m
$L_{HDTT\text{ - }HWSD}$	26.84	dB
E_{med}	29.37	dBuV/m
$\sigma_{1,5m}$	5.50	dB
BPL *	11.00	dB
σ_{BPL}	5.00	dB
σ_{indoor}	0.00	dB
Sensing reliability	99,99%	%
μ_{sense}	3.72	dB
$m_{sense}\sqrt{(\sigma^2_{1.5m}+\sigma^2_{BPL}+\sigma^2_{indoor})}$	31.72	dB
f_{sense}	650.00	MHz
G_{sense}	0.00	dBi
L_{pol}	3.00	dB
Lbody_loss	3.00	dB
E_{sense}	-9.27	dBuV/m
$P_{sense\_1,5m}$	-148.7	dBm
Note *: The BPL values and the associated standard deviations used in this table are taken from the document “BMCO link budgets white paper” for light indoor case. With these values, the term σ_{indoor}m is absorbed into an increased BPL term when compared to GE06 values used in the main body of this report. For the case of “Deep indoor”, values of 17 dB for BPL and 6 dB for σ_{indoor} would be appropriate.		

Table 37: Detection threshold for indoor WSD when DTT is planned for 70% of locations

The following notes apply to all tables:

Note 1: The detection thresholds are referenced to an omnidirectional receive antenna with a gain of 0 dBi. If a receive antenna with a minimum directional gain of less than 0 dBi is used, the detection threshold shall be reduced by the amount in dB that the minimum directional gain of the antenna is less than 0 dBi

Note 2: The detection thresholds are referenced to cross polar discrimination. If the receive antenna of the fixed WSD has a different polarization configuration, the detection threshold shall be reduced by 3dB if polarizations are the same and and it could be increased by 13 dB if polarizations are orthogonal.

A.5.3 Summary of the Detection Threshold values

The following table presents a summary of the calculated detection thresholds, based on the assumed scenarios.

	WSD outdoor
DTT outdoor	DTT Fixed @10m 95% – WSD Fixed @30m: **-90.86 dBm** DTT Fixed @10m 95% – WSD Mobile @1.5m: **-117.71 dBm**
	DTT Portable @1.5m 95% - WSD Mobile @1.5m: **-95.70 dBm** DVB-H @1.5 m 90% - WSD Mobile @1.5m: **-100.91 dBm**
	DTT Fixed @30m 70% – WSD Fixed @30m: **-106.89 dBm** DTT Fixed @30m 70% – WSD Mobile @1.5m: **-136.76 dBm** DTT Fixed @30m 70% – WSD Mobile @1.5m 16QAM: **-146.76 dBm** DTT Fixed @10m 70% – WSD Fixed @30m: **-97.05 dBm** DTT Fixed @10m 70% – WSD Mobile @1.5m: **-126.90 dBm** DTT Fixed @10m 70% – WSD Mobile @1.5m 16QAM: **-136.90 dBm**
	DTT Portable @1.5m 70% - WSD Mobile @1.5m: **-112.91 dBm**
	DTT Fixed @30m 95% – WSD Fixed @30m: **-100.70 dBm** DTT Fixed @30m 95% – WSD Mobile @1.5m: **-127.57 dBm**

Table 38: Summary of results for WSD located outdoor (70% and 95 % correspond to the planned DTT location probability)

	WSD indoor
DTT outdoor	DTT Fixed @10m 95% - WSD Mobile @1.5m: **-140.0 dBm**
	DTT Portable @1.5m 95% - WSD Mobile @1.5m: **-118.0 dBm** DTT Portable @1.5m 70% - WSD Mobile @1.5m: **-132.2 dBm** DVB-H @1.5 m 90% - WSD Mobile @1.5m: **-123.0 dBm**
	DTT Fixed @30m 70% – WSD Mobile @1.5m: **-154.9 dBm** DTT Fixed @30m 70% – WSD Mobile @1.5m 16QAM: **-164.9 dBm** DTT Fixed @10m 70% – WSD Mobile @1.5m: **-145.1 dBm** DTT Fixed @10m 70% – WSD Mobile @1.5m 16QAM: **-155.1 dBm**
	DTT Portable @1.5m 70% - WSD Mobile @1.5m: **-131.1 dBm**
	DTT Fixed @30m 95% – WSD Mobile @1.5m: **-148.7 dBm**

Table 39: Summary of results for WSD located indoor (70% and 95 % correspond to the planned DTT location probability)

Taking into account the results presented in the above tables, it can be concluded that:

For a Fixed located WSD with 30 m antenna height the detection threshold varies between:

- -90.86 dBm (to detect the reception of DTT fixed @10 m, planned for 95% of locations),
- -100.7 dBm (to detect the reception of DTT fixed @30 m, planned for 95% of locations).

It should be noted that scenario of detecting DTT fixed at 30 m, planned for 70% of locations leads to a detection threshold of -107 dBm but is considered as less relevant because 30 m receiving antenna height corresponds to urban environment whereas the location probability of 70% corresponds to rural areas.

For a mobile/portable WSD at 1.5 m (considering that *indoor* is the stringent scenario) the detection threshold varies between:

- -140.0 dBm (to detect the reception of DTT fixed @10 m, planned for 95% of locations – suburban areas)

- -155. 1 dBm (to detect the reception of DTT fixed @10 m, planned for 70% of locations).

It should be noted that scenario of detecting DTT fixed at 30 m, planned for 70% of locations leads to a detection threshold of -165 dBm but is considered as less relevant because 30 m receiving antenna height corresponds to urban environment whereas the location probability of 70% corresponds to rural areas.

ANNEX 6 : DESCRITION AND NUMERICAL EXAMPLES OF E.I.R.P. LIMITS OF WSD CALCULATED WITH MONTE CARLO SIMULATION (AS REFERRED TO IN SECTION 4.3.2)

NOTE: The calculations presented in this annex use protection ratios provided in ECC Report 148. These protection ratios were derived with LTE-test signals based on the technical characteristics (BEM) according to EC Decision 2010/267/EU, e.g. an ACLR of 59 dB for BS and 88 dB for TS. In case that WSDs will have ACLR values different from those used in ECC Report 148, the resulting in-block power limits will need to be adjusted accordingly.

A.6.1 Nuisance fields and power summation

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

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

where PR(Δf) is the required protection ratio for a given frequency offset, Δf, POL is the polarisation discrimination (if any), and DIR is the receive antenna discrimination (vis-à-vis the interfering signal, if any). We define the 'nuisance field', NU_{i1}, corresponding to the interfering field E_{i1} to be

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

The nuisance field, N_{UN}, for the noise, N, is[13]

$NU_N = N + C/N$,

where N is the noise equivalent field strength, and C/N is the required DTT carrier-to-noise ratio to ensure acceptable DTT reception in the presence of noise only.

If we take noise and a single interferer into account, then the requirement for an acceptable reception is

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

where ⊕ represents the power sum[14] of the nuisance fields, and $NU_{i1} \oplus NU_N$ is the 'summed nuisance field'.

If there are k interfering DTT signals, E_{i1}, E_{i2}, ..., E_{ik}, then the summed nuisance field (including noise) is

$NU_{i1} \oplus NU_{i2} \oplus ... \oplus NU_{ik} \oplus NU_N$.

And for an acceptable DTT reception,

$E_w > NU_{i1} \oplus NU_{i2} \oplus ... \oplus NU_{ik} \oplus NU_N$. (1)

Because multiple interfering WSD sources may be present, an appropriate margin should be included 'MI', and a 'safety margin', 'SM', might also be needed. So we also include an 'interference margin' IM = MI + SM. Then the nuisance field for the WSD interferer would be modified to incorporate the IM term.

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

If WSD interference is also added, then for an acceptable DTT reception,

$E_w > NU_{i1} \oplus NU_{i2} \oplus ... \oplus NU_{ik} \oplus NU_N \oplus NU_{WSD}$ (1′)

A.6.2 Monte Carlo simulation

In a Monte Carlo simulation, the statistical variations of the signals are taken into account.

We assume here the following value for the relevant parameters for any given pixel within the wanted DTT coverage area (assumed to be stored in the data base):

- median wanted DTT field strength and standard deviation: E_{W_med}, σ_W;

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[13] Sometimes the nuisance field for the noise is called the 'minimum field', E_{min}.

[14] The power sum of two fields, A and B, is calculated as $A \oplus B = 10 \log (10^{A/10} + 10^{B/10})$.

- ith median interfering DTT field strength and standard deviation: E_{Ii_med}, σ_{Ii};
- the appropriate protection ratios (or ACSs and ACLRs) corresponding to the relevant Δf;
- median WSD interfering field strength and standard deviation for the agreed interference scenario: E_{WSD_med}, σ_{WSD};
- the polarisation discrimination POL and receive antenna discrimination DIR for DTT to DTT and WSD to DTT, if applicable and depending on the configuration;
- The values for MI and SM depending on the number of WSDs to be considered simultaneously and the level of protection to be afforded to DTT from WSD are left open for the moment.

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 example, for the given WSD site, and the associated pixel, the following trials would be carried out, say 30 000 in number (this gives an accuracy of about 0.1 dB).

For each trial the following calculations are carried out and the results are stored in a table, such as the Table 40 shown below:

- a random wanted DTT field strength is calculated using

  $E_W = E_{W\_med}$ + random (Gaussian, σ_W) variation
- random interfering DTT field strengths are calculated using

  $E_{Ii} = E_{Ii\_med}$ + random (Gaussian, σ_{Ii}) variation;

The corresponding nuisance fields, NU_{Ii}, are calculated using equation (A) above and the relevant protection ratios, POL, DIR, etc;

- random interfering WSD field strength, for example starting from e.i.r.p. = 0 dBm, is calculated using

$E_{WSD\_0} = E_{WSD\_med\_0}$ + random (Gaussian, σ_{WSD}) variation

The corresponding nuisance field, NU_{WSD_0}, is calculated using equation (A′) above and the relevant protection ratios, POL, DIR, etc.;

- the power sums for the NU_{Ii} and NU_N are carried for each trial, leading to a value NU_{before}, which is compared to the trial value of E_w.
- The ratio of the number of trials where $E_W > NU_{before}$ to the total number of trials gives the location probability, P_{before}, in the presence of the interfering DTTs and the noise.
- For each trial, the power sum of NU_{before} and NU_{WSD_0} is carried out leading to a value NU_{after}.
- The ratio of the number of trials where $E_W > NU_{after}$ to the total number of trials gives the location probability, P_{after}, in the presence of the interfering DTTs, the noise, and the WSD interference.
- If $P_{before} – P_{after} = x\%$ (where x is the tolerable degradation in the DTT location probability of pixels), we are done: the maximum WSD e.i.r.p. = 0 dBm.
- If $P_{before} – P_{after} < x\%$, the WSD e.i.r.p. can be increased above 0 dBm.
- The calculated values are stored in a table (see the yellow marked columns in the Table below). It is only necessary to do an iteration on the values of NU_{WSD_0}, which were based on the initial assumption that e.i.r.p. = 0 dBm. If the e.i.r.p. = α dBm, the corresponding values in the column "NU_{WSD_0}" are increased by α, to give NU_{WSD_α} and the power sum $NU_{after\_\alpha} = NU_{before} \oplus NU_{WSD\_\alpha}$ is carried out for each trial, as before. With a few such iterations the maximum WSD e.i.r.p. can be found (i.e., when $P_{before} – P_{after} = x\%$).
- If $P_{before} – P_{after} > x\%$, the WSD e.i.r.p. must be decreased below 0 dBm.
- A similar type of iteration can be carried out on the e.i.r.p. as for $P_{before} – P_{after} < x\%$, reducing the maximum WSD e.i.r.p. to a value less than 0 dBm.

Using this procedure, only one Monte Carlo simulation is necessary, and the iteration needed for finding the maximum WSD e.i.r.p., is reduced to a simple iteration involving analytic calculations involving previously stored quantities only. Note: a Monte Carlo simulation, involving 30 000 trials, and 20 iterations to determine the e.i.r.p.$_{WSD\_MAX}$, takes less than 0.1 second calculation time on a laptop.

Trial #	E_W	NU_{I1}	NU_{I2}	…	NU_{Ik}	NU_N	$NU_{before} = \sum_{i=1}^{k} \oplus NU_{Ii} \oplus NU_N$	$NU_{WSD\ 0}$ (NU_{WSD_α})	$NU_{after} = NU_{before} \oplus NU_{WSD}$
1									
2									
3									
…									
…									
30000									

Table 40: Note: the columns marked in yellow are to be stored during the Monte Carlo simulation, in order to rapidly calculate NU_{after} for each iteration on e.i.r.p.$_{WSD}$.

The methodology and how this could applied in various interference scenarios are shown in Section 4.3.4.5 and Section 4.3.4.6. This should be considered as an example for guidance for Administrations intending to implement geo-location database operation of WSDs. However, other methodologies and interference scenarios can be considered depending on the DTT configuration to be protected in individual countries.

A.6.3 e.i.r.p. limits calculations

The examples of calculations using the methodology described in Annex A.6.4 with the set of parameters listed in Table 41 are provided in this ANNEX 6. It can be, however, noted that these calculations were based on the assumption that the minimum BS power at the BS receiver input should be protected. This requirement can be relaxed when a WSD operates inside the adjacent channels coverage area where an actual BS signal power can be significantly higher than the minimum BS power. This is done by using the actual BS power in the calculation and deriving the corresponding WSD e.i.r.p. and OOB levels. The implication is that, with the aid of a geo-location database, the permitted emission limits of a WSD can be significantly relaxed in areas where the received wanted BS signal power is high (i.e., where BS coverage quality is good).

A.6.4 Interference scenarios in case of geo-location database operation

Different interference scenarios, that impact the emission limits of WSDs, can take place in the reality depending on the DVB-T mode (as listed in Section 4.1) and on the type of CR applications used. In particular, these applications are classified to short range personal/portable devices and to longer range fixed/access devices (see CEPT Report 24). The impact of these applications on the broadcasting service need to be studies for situations when:

(i) the WSD is outside the co-channel DTT coverage area;

(ii) the WSD is outside the adjacent channel DTT coverage area;

(iii) the WSD is inside the adjacent channels DTT coverage area.

Due to the variety of interference scenarios it may appear reasonable to consider only those scenarios that would most probably represent the worst case situations in terms of their impact on the broadcasting service. Table 41 sets the values for different parameters considered within the methodology developed in Section 4.3.1 for some configurations within selected interference scenarios. These sets of parameters should be considered as examples only and are aimed merely to assist administrations in their national activities noting that different sets for different interference scenarios can be used on a national level.

	Portable WSD		Fixed WSD		Portable WSD
	Configuration 1	**Configuration 2**	**Configuration 3**	**Configuration 4**	**Configuration 5**
DVB-T Reception	fixed outdoor	portable indoor	fixed outdoor	fixed outdoor	fixed outdoor
Situation	outside co-channel coverage area	inside adjacent channels coverage area	outside co-channel coverage area	inside adjacent channels coverage area	inside adjacent channels coverage area
$P_{min}^{BS}(f_{BS})$ **(dBm)**	For 64QAM2/3 -77.1 dBm (Note 1)	For 16QAM2/3 -82.6 dBm	For 64QAM2/3 -77.1 dBm (Note 1)	For 64QAM2/3 -77.1 dBm (Note 1)	For 64QAM2/3 -77.1 dBm (Note 1)
σ_{BS} **(dB)**	5.5	7.8	5.5	5.5	5.5
σ_{CR} **(dB)**	Case 1: Okumura Hata use σ of function of distance Case 2: JTG prediction method, use 5.5	3.5	5.5	3	3.5
Location percentage (%)	95	95	95	95	95
D_{pol} **(dB)**	case A: 3 dB case B: 0 dB	0	case A: 3 dB case B: 0 dB	3	3
D_{dir} **(dB)**	case A: 0 dB case B: 16 dB	0	case A: 0 dB case B: 16 dB	0	0
G_i **(dB)**	12	2.15	12	12	12
L_f **(dB)**	3	0	3	3	3
Propagation prediction method	Case 1: Okumura Hata Case 2: JTG5/6	Free space	Rec. ITU-R-P.1546	Free space	Free space

Note 1 : this value of -77 dBm and -82.6 dBm is calculated using :

- Absolute noise temperature of 290°K
- Equivalent noise bandwidth of 7.61 MHz
- Receiver noise figure of 7 dB
- Minimum signal to noise ratio required by the system variant of 21 dB and 19 dB, respectively.
- the appropriate antenna gain and feeder losses (see G_i and L_f in the table)

Note 2: these distances are taken arbitrarily and are related to the direct distance between the DVB-T receiving roof top antenna and the fixed WSD antenna, both antennas assumed to be at the same height (no consideration of vertical antenna pattern).

Note 3: Different assumptions on the parameters can be used by different administrations.

Note 4: These values can be applied in case of a single BS transmitter, only; values to be applied in case of an SFN would be lower.

Table 41: Example interference configurations to be used in calculations of emission limits of WSDs assisted by a geo-location database. (Note 3)

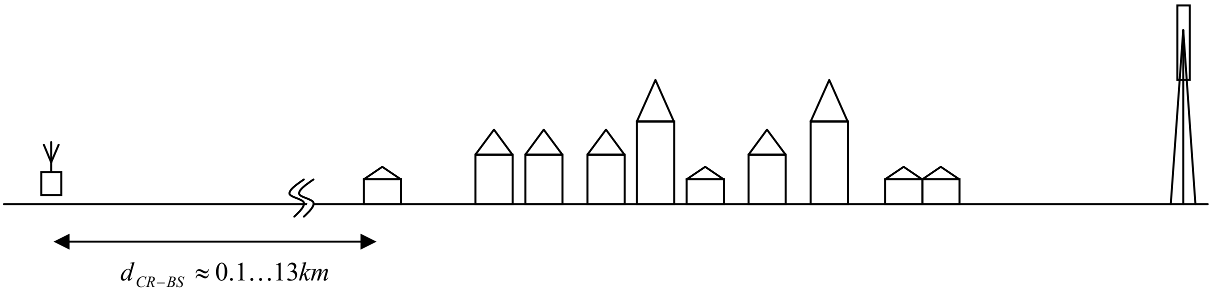
These studies are based on the assumption that only passive antennas are used to receive the DVB-T signals, i.e. no mast amplifiers for fixed reception and no active antennas in case of for portable indoor reception. However, if an active antenna is used, this may lead to an increased risk of overloading, due to the high gain of such antennas and their wideband characteristics.

A.6.4.1 Calculation examples for the configurations listed in Table 41

The calculations presented in this section are based on the minimum DTT power to be protected.

Configuration 1:

Portable WSD into fixed outdoor DVB-T reception in the situation where the WSD is located outside the co-channel DVB-T coverage area



DTT edge of coverage: E_{DTT_med} = 56.21 dBμV/m outside at 10 m
Freq = 600 MHz

- Example 1:

In this example the following assumptions were made:
SM = 19 dB
MI = 0 dB
No sensitivity degradation.
Co-channel protection ratio *PR*(0) = 23.1 dB (from [7])
Note: 23.1 = 22 (upper value of co-channel protection ratio range) + 1.1 (correction from Gaussian channel to fixed reception)

- Example 2:

In this example the following assumptions were made:
SM = 0 dB
MI = 6 dB
Sensitivity degradation of 3 dB was added to the protection ratio.
Co-channel protection ratio *PR*(0) = 22.1 dB (from [7])
Note: 22.1 = 21 (mean value of the protection ratio range for the 90th percentile of receivers) + 1.1 (correction from Gaussian channel to fixed reception)

Separation distance (km) (JTG 5/6 Propagation, 600 MHz)	**$P_{wsd\ max}$ (dBm)**		
	ΔLP = 0.1%	**ΔLP = 0.5%**	**ΔLP = 1%**
0.1	-80.2	-72.9	-69.9
0.2	-75.2	-58.0	-54.9
0.3	-56.5	-49.3	-46.1
0.4	-53.0	-43.0	-39.9
0.5	-45.3	-28.2	-35.1
0.6	-41.5	-34.3	-31.2
0.7	-38.2	-31.0	-27.9
0.8	-35.3	-28.1	-25.0
0.9	-32.8	-25.6	-22.4
1.0	-30.5	-23.2	-20.1
2.0	-20.2	-13.0	-9.9
3.0	-13.9	-6.7	-3.5
4.0	-9.1	-1.9	1.2
5.0	-5.3	1.9	5.0
6.0	-2.1	5.2	8.3
7.0	0.7	8.0	11.1
8.0	3.1	10.4	13.5
9.0	5.3	12.6	15.7
10.0	7.3	14.6	17.7
11.0	9.1	16.4	19.5
12.0	11.2	18.5	21.6
13.0	12.3	19.6	22.7

Table 42: Example 1 – Case A

For results for Example 1, Case B, add 13 dB to the results of Example 1, Case A.
For results for Example 2, Case A, add 11 dB to the results of Example 1, Case A.
For results for Example 2, Case B, add 24 dB to the results of Example 1, Case A.

Configuration 2:

Portable WSD into portable indoor DVB-T reception in the situation where the WSD is located inside adjacent channels DVB-T coverage area

Example 1:

DTT edge of coverage: E_{DTT_med} = 62.95 dBμV/m inside the building at 1.5 m, including 8 dB BPL; 7.78 dB standard deviation

WSD Body loss (BL): 0 dB
Safety margin (SM): 0 dB
Multiple interference margin (MI): 0 dB

The LP at the edge in the presence of noise only is 95%; in the presence of noise and 1 WSD interferer separated 2m from the DTT receiver is 94.9%, 94.5% or 94%, a 0.1%, 0.5% or 1% degradation, respectively, of the LP.

Channel edge separation (MHz)	**Protection ratio (dB)**	**P_{wsd_max} (dBm)**		
		ΔLP = 0.1%	**ΔLP = 0.5%**	**ΔLP = 1%**
1.5	-6.6	-60.8	-54.1	-50.8
9.5	-25.6	-41.8	-35.1	-31.8
17.5	-27.6	-39.8	-33.1	-29.8
25.5	-28.6	-38.8	-32.1	-28.8
33.5	-29.6	-37.8	-31.1	-27.8
41.5	-30.6	-36.8	-30.1	-26.8
49.5	-32.6	-34.8	-28.1	-24.8
57.5	-29.6	-37.8	-31.1	-27.8
65.5	-30.6	-36.8	-30.1	-26.8

Table 43: Configuration 2 – Example 1

Note: if a safety margin, SM, is taken into account, then the P_{wsd_max} values in the table above would be reduced by SM. For example, in the row corresponding to 1.5 MHz channel edge separation and the column corresponding to a 1% ΔLP, the table entry value for P_{wsd_max}, "-50.8", would become "-69.8" if SM were 19 dB.

OVERLOADING

NOTE: further study is needed to define a complete treatment of overloading in order to take account of the power sum of all fields, wanted as well as interfering, in a statistical manner (e.g. Monte Carlo simulation), when calculating the overall power entering a DTT receiver

In the meantime, in the following descriptions (in this configuration and in configuration 4), only one interfering WSD field is taken into account, which gives an upper bound to the maximum WSD e.i.r.p. to avoid overloading the DTT receiver.

Case a: Single interfering WSD (the WSD interfering power is assumed to be significantly higher than the wanted power at the DTT receiver).

Relation between received power and field strength at the DTT is

$$P_{DTT}\ (\text{dBm}) = E_{at\_DTT}\ (\text{dB}\mu\text{V/m}) + G_i - 20 \log f - 77.21, \text{ with}$$

$$G_i = 2.15 \text{ dB}, f = 650 \text{ MHz}$$

To determine the field strength corresponding to a specified overload threshold, P_{oth}, the transformation is used:

$$E_{at\_DTT} = P_{oth} - 2.15 + 56.26 + 77.21 = P_{oth} + 131.32$$

The (free space) field at 2 m produced by a WSD with e.i.r.p. P_{wsd} is

$$E_{wsd\_at\_2m} = P_{wsd}(\text{dBm}) + 44.75 - 20 \log .002$$

So to avoid overloading the DTT

$$P_{wsd} < P_{oth} + 131.32 - 44.75 + 20 \log .002 = P_{oth} + 32.6$$

To protect p% of the locations, the maximum median power of the WSD must be

$$P_{wsd\_max} = P_{wsd} - \mu_p\sigma = P_{oth} + 32.6 - \mu_p x3.5, \text{ where}$$

$$\mu_{99} = 2.326,\ \mu_{99.5} = 2.576,\ \mu_{99.9} = 3.091.$$

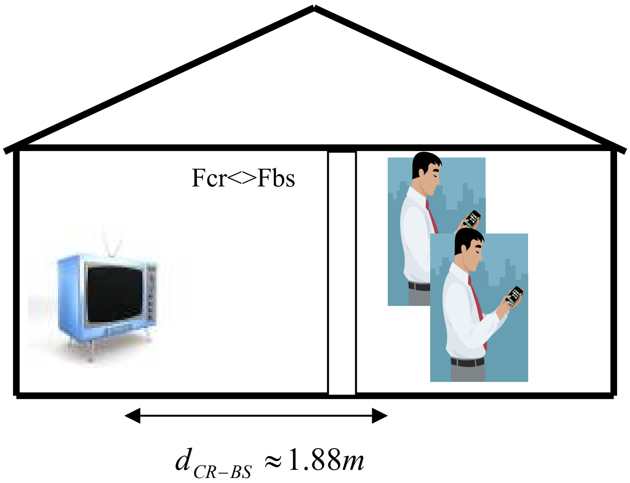
So $P_{wsd\_max\_99.9} = P_{oth} + 21.8$, $P_{wsd\_max\_99.5} = P_{oth} + 23.6$, $P_{wsd\_max\_99} = P_{oth} + 24.5$,

Channel edge separation (MHz)	Overload threshold (dBm)	$P_{wsd\ max}$ (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-25	-3.2	-1.4	-0.5
9.5	-38	-16.2	-14.4	-13.5
17.5	-36	-14.2	-12.4	-11.5
25.5	-35	-13.2	-11.4	-10.5
33.5	-33	-11.2	-9.4	-8.5
41.5	-35	-13.2	-11.4	-10.5
49.5	-32	-10.2	-8.4	-7.5
57.5	-31	-9.2	-7.4	-6.5
65.5	-33	-11.2	-9.4	-8.5

Table 44: Configuration 2 – Example 1 - Overloading

The maximum in-band power (PIBmax) calculated above is valid where only one interferer exists. If multiple WSD using simultaneously the same frequency or frequency with the same potential of interference on the DVB-T frequency then the individual PIBmax will have to be reduced by a margin to be defined.

Example 2: same as example 1 but with different set of parameters



Example 2:
In this example the following assumptions were made:
SM = 0 dB;
MI = 3 dB;
Sensitivity degradation of 3 dB was added to the protection ratio.
Body loss = 6 dB;
Wall loss = 8 dB;
Wall loss standard deviation = 5.5 dB
The protection ratios correspond to the mean value or the range for the 90th percentile of the receivers (excluding the Silicon USB)
The overloading threshold correspond to the mean value or the range for the 10th percentile of the receivers (excluding the Silicon USB)
The correction factor is -2 dB, corresponding to 16QAM2/3 for portable indoor

Channel edge separation (MHz)	**Minimum PR (dB)**	**Maximum PR (dB)**	**Correction factor**	**Protection ratios for calculation (dB)**	**PIB max_PR (dBm)**		
					ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-21	-12	-2	-19	-35.2	-28.3	-25.2
9.5	-46	-32	-2	-41	-13.2	-6.3	-3.2
17.5	-47	-34	-2	-43	-11.2	-4.3	-1.2
25.5	-56	-35	-2	-48	-6.2	-0.3	3.8
33.5	-63	-36	-2	-52	-4.2	3.7	7.8
41.5	-62	-37	-2	-52	-4.2	3.7	7.8
49.5	-69	-39	-2	-56	-0.2	7.7	11.8
57.5	-63	-36	-2	-52	-4.2	3.7	7.8
65.5	-46	-30	-2	-40	-14.2	-7.3	-4.2

Table 45: Configuration 2 – Example 2

OVERLOADING

NOTE: further study is needed to define a complete treatment of overloading in order to take account of the power sum of all fields, wanted as well as interfering, in a statistical manner (e.g. Monte Carlo simulation), when calculating the overall power entering a DTT receiver

In the meantime, in the following description, only one interfering WSD field is taken into account, which gives an upper bound to the maximum WSD e.i.r.p. to avoid overloading the DTT receiver.

Case a: Single interfering WSD (the WSD interfering power is assumed to be significantly higher than the wanted power at the DTT receiver)

Relation between received power and field strength at the DTT is

$$P_{DTT}\ (\text{dBm}) = E_{at\_DTT}\ (\text{dB}\mu\text{V/m}) + G_i - 20 \log f - 77.21, \text{ with}$$

$G_i = 2.15$ dB, f = 650 MHz

To determine the field strength corresponding to a specified overload threshold, P_{oth}, the transformation is used:

$$E_{at\_DTT} = P_{oth} - 2.15 + 56.26 + 77.21 = P_{oth} + 131.32$$

The (free space) field at 1.88 m produced by a WSD with e.i.r.p. P_{wsd} is (including 8 dB wall loss, standard deviation 5.5 dB and 6 dB body loss)

$$E_{wsd\_at\_2m} = P_{wsd}(\text{dBm}) + 44.75 - 20 \log .00188 - 8 - 6.$$

So to avoid overloading the DTT

$$P_{wsd} < P_{oth} + 131.32 - 44.75 + 20 \log .00188 + 8 + 6 = P_{oth} + 46.1$$

To protect p% of the locations, the maximum median power of the WSD must be

$$P_{wsd\_max} = P_{wsd} - \mu_p\sigma = P_{oth} + 46.1 - \mu_p x\sqrt{(3.5^2 + 5.5^2)}, \text{ where}$$

$$\mu_{99} = 2.326,\ \mu_{99.5} = 2.576,\ \mu_{99.9} = 3.091.$$

So $P_{wsd\_max\_99.9} = P_{oth} + 30.9$, $P_{wsd\_max\_99.5} = P_{oth} + 29.3$, $P_{wsd\_max\_99} = P_{oth} + 25.9$,

Channel edge separation (MHz)	Minimum Oth (dBm)	Maximum Oth (dBm)	Overload threshold (dBm)	P_{wsd_max} (dBm)		
				ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-23	-17	-20	10.9	9.9	5.9
9.5	-48	-4	-26	4.9	3.3	-0.1
17.5	-47	-2	-25	5.9	4.3	0.9
25.5	-44	-6	-25	5.9	4.3	0.9
33.5	-43	-5	-24	6.9	5.3	1.9
41.5	-41	-7	-24	6.9	5.3	1.9
49.5	-39	-3	-21	9.9	8.3	4.9
57.5	-35	-3	-19	11.9	10.3	6.9
65.5	-32	-3	-18	12.9	11.3	7.9

Table 46: Configuration 2 – Example 2 - Overloading

Example 3: Outdoor portable/mobile DTT reception at 1.5 m, portable/mobile WSD at 1.5 m

The following assumptions are made

DTT edge of coverage: E_{DTT_med} = 61.21 dBμV/m outside at 1.5 m
DTT C/N: 19 dB
DTT Rx antenna gain G_i: 2.15 dB; Rx antenna discrimination: 0 dB
WSD Propagation model: free space, standard deviation = 3.5 dB
WSD Body loss (BL): 0 dB
Safety margin (SM): 0 dB
Multiple interference margin (MI): 0 dB

The LP at the edge in the presence of noise only is 95%; in the presence of noise and 1 WSD interferer separated 2m from the DTT receiver is 94.9%, 94.5% or 94%, a 0.1%, 0.5% or 1% degradation, respectively, of the LP.

Channel edge separation (MHz)	Protection ratio (dB)	P_{wsd_max} (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-19	-48.1	-41.0	-38.1
9.5	-41	-26.1	-19.0	-16.1
17.5	-43	-24.1	-17.0	-14.1
25.5	-48	-19.1	-12.0	-9.1
33.5	-52	-15.1	-8.0	-5.1
41.5	-52	-15.1	-8.0	-5.1
49.5	-56	-11.1	-4.0	-1.1
57.5	-52	-15.1	-8.0	-5.1
65.5	-40	-27.1	-20.0	-17.1

Table 47: Configuration 2 – Example 3

OVERLOADING

NOTE: In the following description, only one interfering WSD field is taken into account, which gives an upper bound to the maximum WSD e.i.r.p. to avoid overloading the DTT receiver. Further studies is needed.

Relation between received power and field strength at the DTT is

$$P_{DTT}\ (\text{dBm}) = E_{at\_DTT}\ (\text{dB}\mu\text{V/m}) + G_i - 20 \log f - 77.21, \text{ with}$$

$$G_i = 2.15 \text{ dB}, f = 650 \text{ MHz}.$$

To determine the field strength corresponding to a specified overload threshold, P_{oth}, the transformation is used:

$$E_{at\_DTT} = P_{oth} - 2.15 + 56.26 + 77.21 = P_{oth} + 131.32$$

The (free space) field at 2 m produced by a WSD with e.i.r.p. P_{wsd} is

$$E_{wsd\_at\_2m} = P_{wsd}(\text{dBm}) + 44.75 - 20 \log .002$$

So to avoid overloading the DTT

$$P_{wsd} < P_{oth} + 131.32 - 44.75 + 20 \log .002 = P_{oth} + 32.6$$

To protect p% of the locations, the maximum median power of the WSD must be

$$P_{wsd\_max} = P_{wsd} - \mu_p\sigma = P_{oth} + 32.6 - \mu_p \text{ x}3.5, \text{ where}$$

$$\mu_{99} = 2.326,\ \mu_{99.5} = 2.576,\ \mu_{99.9} = 3.091.$$

So $P_{wsd\_max\_99.9} = P_{oth} + 21.8$, $P_{wsd\_max\_99.5} = P_{oth} + 23.6$, $P_{wsd\_max\_99} = P_{oth} + 24.5$,

Channel edge separation (MHz)	Overload threshold (dBm)	P_{wsd_max} (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-20	1.8	3.6	4.5
9.5	-26	-4.2	-2.4	-1.5
17.5	-25	-3.2	-1.4	-0.5
25.5	-25	-3.2	-1.4	-0.5
33.5	-24	2.2	-0.4	0.5
41.5	-24	2.2	-0.4	0.5
49.5	-21	0.8	2.6	3.5
57.5	-19	2.8	4.6	5.5
65.5	-18	3.8	5.6	6.5

Table 48: Configuration 2 – Example 3 - Overloading

Configuration 3:

Fixed WSD into fixed outdoor DVB-T reception in the situation where the WSD is located outside co-channel DVB-T coverage area

- Example 1:

In this example the following assumptions were made:
SM = 19 dB
MI = 0 dB
No sensitivity degradation.
Co-channel protection ratio *PR*(0) = 23.1 dB (from ECC Report 148 [7])
Note: 23.1 = 22 (upper limit of co-channel protection ratio) + 1.1 (correction from Gaussian channel to fixed reception)

- Example 2:

In this example the following assumptions were made:
SM = 0 dB;
MI = 6 dB;
Sensitivity degradation of 3 dB was added to the protection ratio.
Co-channel protection ratio *PR*(0) = 21 dB (from GE06)

Separation distance (km) H_{tx} = 10 m; H_{rx} = 10 m (JTG 5/6 Propagation, 600 MHz)	**$P_{wsd\ max}$ (dBm)**		
	ΔLP = 0.1%	**ΔLP = 0.5%**	**ΔLP = 1%**
1	-47.3	-40.1	-37.0
5	-22.1	-14.9	-11.8
10	-9.3	-2.3	0.8
15	-1.8	5.5	8.6
20	3.9	11.1	14.2
25	8.0	15.2	18.3
30	11.3	18.5	21.6
35	13.9	21.2	24.2
40	16.1	23.3	26.4
45	18.0	25.2	28.3
50	19.5	26.7	29.8

Table 49: Example 1 – Case A

For results of Example 1, Case B, add 13 dB to the results of Example 1, Case A.
For results of Example 2, Case A, add 12.1 dB to the results of Example 1, Case A.
For results of Example 2, Case B, add 25.1 dB to the results of Example 1, Case A.

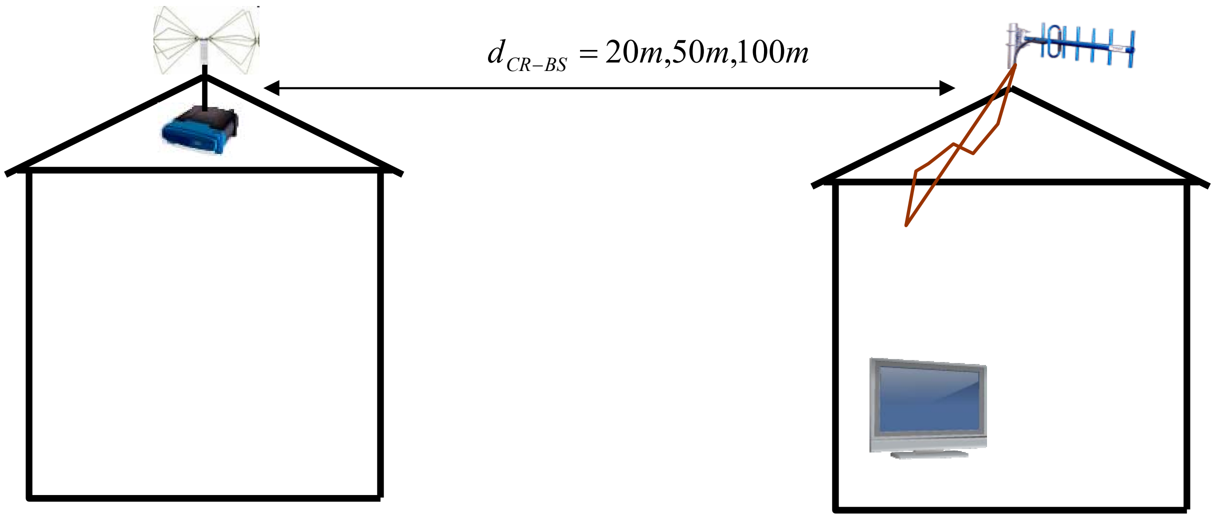
Separation distance (km) H_{tx} = 30 m; H_{rx} = 10 m (JTG 5/6 Propagation, 600 MHz)	**$P_{wsd\ max}$ (dBm)**		
	ΔLP = 0.1%	**ΔLP = 0.5%**	**ΔLP = 1%**
1	-50.9	-43.7	-40.6
5	-28.2	-21.0	-17.9
10	-16.5	-9.5	-6.4
15	-9.4	-2.1	1.0
20	-3.8	3.4	6.5
25	0.3	-0.2	2.9
30	3.7	10.9	14.0
35	6.5	13.8	16.8
40	8.9	16.1	19.2
45	11.1	18.3	21.4
50	12.9	20.1	23.2

Table 50: Example 1 – Case A

For results for Example 1, Case B, add 13 dB to the results of Example 1, Case A.
For results for Example 2, Case A, add 12 dB to the results of Example 1, Case A.
For results for Example 2, Case B, add 25 dB to the results of Example 1, Case A.

Configuration 4:

Fixed WSD into fixed outdoor DVB-T reception in the situation where the WSD is located inside the adjacent channels DVB-T coverage area



- **Example 1:**

The following assumptions are made

DTT edge of coverage: E_{DTT_med} = 56.21 dBµV/m at 10 m
DTT C/N: 21 dB
DTT Rx antenna gain G_i: 9.15 dB; polarisation discrimination : 0 or 16 dB
WSD Propagation model: free space, standard deviation = 3.5 dB
WSD Body loss (BL): 0 dB
Safety margin (SM): 0 dB
Multiple interference margin (MI): 0 dB

The protection ratios correspond to the upper value of the range for the 90th percentile of the silicon receivers (STB/iDTV)
The overloading threshold correspond to the lower value of the range for the 10th percentile of the silicon receivers (STB/iDTV)
The correction factor is 1.1 dB, corresponding to 64QAM2/3 for fixed reception.

The LP at the edge in the presence of noise only is 95%; in the presence of noise and 1 WSD interferer separated 2m from the DTT receiver is 94.9%, 94.5% or 94%, a 0.1%, 0.5% or 1% degradation, respectively, of the LP.

WSD to DTT separation: 20 m							
Channel edge separation (MHz)	Protection ratio (dB)	P_{wsd_max} (dBm)					
		ΔLP = 0.1%		ΔLP = 0.5%		ΔLP = 1%	
		POL = 0	POL = 16	POL = 0	POL = 16	POL = 0	POL = 16
1	-31.9	-20.2	-4.2	-13.4	2.6	-10.2	5.8
9	-38.9	-13.2	2.8	-6.4	9.6	-3.2	12.8
17	-42.9	-9.2	6.8	-2.4	13.6	0.8	16.8
25	-46.9	-5.2	10.8	1.6	17.6	4.8	20.8
33	-47.9	-4.2	11.8	2.6	18.6	5.8	21.8
41	-48.9	-3.2	12.8	3.6	19.6	6.8	22.8
49	-48.9	-3.2	12.8	3.6	19.6	6.8	22.8
57	-50.9	-1.2	14.8	5.6	21.6	8.8	24.8
65	-43.9	-8.2	7.8	-1.4	14.6	1.8	17.8

Table 51: Configuration 4 – Example 1

Note: for a 50 m WSD to DTT separation, the P_{wsd_max} values in the above table should be increased by 20 log (.05/.02) = 8 dB, and by 20 log(0.1/.02) = 14 dB for a 100 m WSD to DTT separation.

OVERLOADING

Note: In the following description, only one interfering WSD field is taken into account, which gives an upper bound to the maximum WSD e.i.r.p. to avoid overloading the DTT receiver. As noted before, further is required to define a complete treatment with respect to the overloading threshold.

Relation between received power and field strength at the DTT is

P_{DTT} (dBm) = E_{at_DTT} (dBµV/m) + G_i – 20 log f – 77.21, with

G_i = 2.15 dB, f = 650 MHz

To determine the field strength corresponding to a specified overload threshold, P_{oth}, the transformation is used (assuming a 0 dB polarisation discrimination):

$E_{at\_DTT} = P_{oth} - 9.15 + 56.26 + 77.21 = P_{oth} + 124.32$

The (free space) field at 2 m produced by a WSD with e.i.r.p. P_{wsd} is

$E_{wsd\_at\_2m} = P_{wsd}(\text{dBm}) + 44.75 - 20 \log .02$

So to avoid overloading the DTT

$P_{wsd} < P_{oth} + 124.32 - 44.75 + 20 \log .02 = P_{oth} + 45.6$

To protect p% of the locations, the maximum median power of the WSD must be

$P_{wsd\_max} = P_{wsd} - \mu_p\sigma = P_{oth} + 45.6 - \mu_p \text{x}3.5$, where

$\mu_{99} = 2.326$, $\mu_{99.5} = 2.576$, $\mu_{99.9} = 3.091$.

So $P_{wsd\_max\_99.9} = P_{oth} + 34.8$, $P_{wsd\_max\_99.5} = P_{oth} + 36.6$, $P_{wsd\_max\_99} = P_{oth} + 37.5$,

Channel edge separation (MHz)	Overload threshold (dBm)	P_{wsd_max} (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1	-13	21.8	23.6	24.5
9	-7	27.8	29.6	30.5
17	-6	28.8	30.6	31.5
25	3	37.8	39.6	40.5
33	3	37.8	39.6	40.5
41	2	36.8	38.6	39.5
49	1	35.8	37.6	38.5
57	0	34.8	36.6	37.5
65	-5	29.8	31.6	32.5

Table 52: Configuration 4 – Example 1 - Overloading

Configuration 5:

Portable/mobile WSD into fixed DVB-T reception where the WSD is located inside adjacent channel DVB-T coverage area

Example 1: Fixed DTT reception at 10 m, portable/mobile WSD at 1.5 m

The following assumptions are made

DTT edge of coverage: E_{DTT_med} = 56.21 dBµV/m outside at 10 m
DTT C/N: 21 dB
WSD Body loss (BL): 0 dB
Safety margin (SM): 0 dB
Multiple interference margin (MI): 0 dB
The LP at the edge in the presence of noise only is 95%; in the presence of noise and 1 WSD interferer separated 22 m from the DTT receiver is 94%, a 1% degradation of the LP.

The LP at the edge in the presence of noise only is 95%; in the presence of noise and 1 WSD interferer separated 22 m from the DTT receiver is 94.9%, 94.5% or 94%, a 0.1%, 0.5% or 1% degradation, respectively, of the LP.

Channel edge separation (MHz)	Protection ratio (dB)	P_{wsd_max} (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1	-31.9	-15.7	-8.9	-5.9
9	-38.9	-8.7	-1.9	1.1
17	-42.9	-4.7	2.1	5.1
25	-46.9	-0.7	6.1	9.1
33	-47.9	0.3	7.1	10.1
41	-48.9	1.3	8.1	11.1
49	-48.9	1.3	8.1	11.1
57	-50.9	3.3	10.1	13.1
65	-43.9	-3.7	8.1	6.1

Table 53: Configuration 5 – Example 1

Relation between received power and field strength at the DTT is

P_{DTT} (dBm) = E_{at_DTT} (dBμV/m) + G_i – POL - Rx_{disc} – 20 log f – 77.21, with

G_i = 9.15 dB; POL = 3 dB, Rx disc = 0.45 dB, f = 650 MHz.

To determine the field strength corresponding to a specified overload threshold, P_{oth}, the transformation is used:

$E_{at\_DTT} = P_{oth} – 9.15 + 3 + .45 + 56.26 + 77.21 = P_{oth} + 124.77$

The (free space) field at 2 m produced by a WSD with e.i.r.p. P_{wsd} is

$E_{wsd\_at\_2m} = P_{wsd}$(dBm) + 44.75 – 20 log .022

So to avoid overloading the DTT

$P_{wsd} < P_{oth} + 124.77 – 44.75 + 20 \log .022 = P_{oth} + 46.9$

To protect p% of the locations, the maximum median power of the WSD must be

$P_{wsd\_max} = P_{wsd} – \mu_p\sigma = P_{oth} + 46.9 – \mu_p$ x3.5, where

To protect p% of the locations, the maximum median power of the WSD must be

$P_{wsd\_max} = P_{wsd} – \mu_p\sigma = P_{oth} + 46.9 – \mu_p$ x3.5, where

$\mu_{99} = 2.326$, $\mu_{99.5} = 2.576$, $\mu_{99.9} = 3.091$.

So $P_{wsd\_max\_99.9} = P_{oth} + 36.1$, $P_{wsd\_max\_99.5} = P_{oth} + 37.9$, $P_{wsd\_max\_99} = P_{oth} + 38.8$,

Channel edge separation (MHz)	Overload threshold (dBm)	P_{wsd_max} (dBm)		
		ΔLP = 0.1%	ΔLP = 0.5%	ΔLP = 1%
1.5	-20	16.1	17.9	18.8
9.5	-26	10.1	11.9	12.8
17.5	-25	11.1	12.9	13.8
25.5	-25	11.1	12.9	13.8
33.5	-24	12.1	13.9	14.8
41.5	-24	12.1	13.9	14.8
49.5	-21	15.1	16.9	17.8
57.5	-19	17.1	18.9	19.8
65.5	-18	18.1	19.9	20.8

Table 54: Configuration 5 – Example 1 - Overloading

ANNEX 7 : DESCRIPTION AND NUMERICAL EXAMPLES OF E.I.R.P. LIMITS OF WSD CALCULATED USING APPROXIMATED ANALYTICAL METHOD (AS REFERRED TO IN SECTION 4.3.2)

In this section we describe the approximated analytical methodology presented in Section 4.3.2 and illustrate its workings through a number of numerical examples. It should again be emphasised that the numerical values of the parameters used in a geo-location database can be specified independently by different member states based on their particular circumstances and policies. The database parameter values presented in this report are for illustration purposes only.

A.7.1 Approximate analytic calculation of Equation 4.3-4 in section 4.3.2

An approximation of the exact calculation can be performed as described below.

Here, the terms $P_{\mathrm{S\ (dBm)}}$ and $U_{\mathrm{(dBm)}}$ are modelled as Gaussian random variables with medians $m_{\mathrm{S\ (dBm)}}$ and $m_{\mathrm{U\ (dBm)}}$, and standard deviations $\sigma_{\mathrm{S\ (dB)}}$ and $\sigma_{\mathrm{U\ (dB)}}$, respectively. The terms $m_{\mathrm{U\ (dBm)}}$ and $\sigma_{\mathrm{U\ (dB)}}$ can be derived via numerical techniques such as the Schwartz-Yeh algorithm or Monte Carlo simulations. The relationship between parameters q_1, $P_{\mathrm{S\ (dBm)}}$ and $U_{\mathrm{(dBm)}}$ in a pixel is illustrated in Figure 60 below.

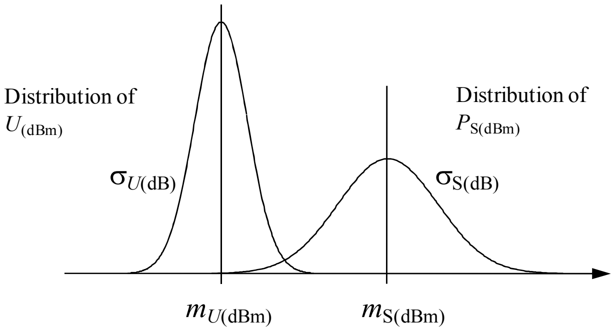


Figure 60: Distributions of wanted DTT power and DTT-to-DTT interference power in a pixel.

From Equation (4.3-4), and based on the approximation explained above, the location probability can be readily expressed in closed form as

$$q_1 = 1 - \frac{1}{2}\mathrm{erfc}\left\{ \frac{1}{\sqrt{2}} \frac{m_{\mathrm{S(dBm)}} - m_{U(\mathrm{dBm})}}{\sqrt{\sigma^2_{\mathrm{S(dB)}} + \sigma^2_{U(\mathrm{dB})}}} \right\}. \qquad \text{(A.7.1-1)}$$

Numerical examples are presented below.

A.7.2 Approximate analytic calculation of WSD in-block emission limit for a specific degradation in location probability

As for the case of q_1, an approximation can made in order to derive q_2 analytically. By expanding Equation (4.3-6), we have

$$
\begin{aligned}
q_2 &= \Pr\left\{P_\mathrm{S} \geq P_\mathrm{S,min} + \sum_{i=1}^{K} r_{\mathrm{U},k} P_{\mathrm{U},k} + r(\Delta f)\, G P_\mathrm{IB}^\mathrm{CR}\right\} \\
&= \Pr\left\{P_\mathrm{S} \geq U + r(\Delta f)\, G P_\mathrm{IB}^\mathrm{CR}\right\} \\
&= \Pr\left\{r(\Delta f)\, G P_\mathrm{IB}^\mathrm{CR} \leq P_\mathrm{S} - U\right\} \\
&= \Pr\left\{r(\Delta f)\, G P_\mathrm{IB}^\mathrm{CR} \leq Z\right\} \\
&= \Pr\left\{P_\mathrm{IB}^\mathrm{CR} \leq \frac{1}{r(\Delta f)\, G} Z\right\} \\
&= \Pr\left\{P_{\mathrm{IB}\ (\mathrm{dBm})}^\mathrm{CR} \leq Z_{(\mathrm{dBm})} - G_{(\mathrm{dB})} - r(\Delta f)_{(\mathrm{dB})}\right\}
\end{aligned}
\qquad \text{(A.7.2-1)}
$$

Then assuming that $Z_{(\mathrm{dBm})}$ is a Gaussian random variable with a median value, $m_{Z\,(\mathrm{dBm})}$, and a standard deviation $\sigma_{Z\,(\mathrm{dB})}$, the immediate implication of Equation (A.7.2-1) is that (in the logarithmic domain) the maximum permitted WSD in-block e.i.r.p. is given by

$$
P_{\mathrm{IB}\ (\mathrm{dBm})}^\mathrm{CR} \leq m_{Z\,(\mathrm{dBm})} - m_{G\,(\mathrm{dB})} - r(\Delta f)_{(\mathrm{dB})} - \mu(q_2)\sqrt{\sigma_{Z\,(\mathrm{dB})}^2 + \sigma_{G\,(\mathrm{dB})}^2} - \mathrm{IM}_{(\mathrm{dB})} \qquad \text{(A.7.2-2)}
$$

The term $\mathrm{IM}_{(\mathrm{dB})}$ is a *safety margin* which can be judiciously set by the database to provide an additional margin of protection to DTT services[15]. The term $\mu(q_2)$ represents the number of standard deviations between the median wanted and unwanted power levels which would allow a location probability of q_2 to be achieved. In other words

$$
1 - q_2 = \frac{1}{2}\mathrm{erfc}\left\{\frac{\mu}{\sqrt{2}}\right\} \quad \text{or} \quad \mu(q_2) = \sqrt{2}\,\mathrm{erfc}^{-1}\left\{2(1-q_2)\right\}. \qquad \text{(A.7.2-3)}
$$

Note that the median $m_{Z(\mathrm{dBm})}$ and standard deviation $\sigma_{Z(\mathrm{dB})}$would need to be derived via numerical techniques such as the Schwartz-Yeh algorithm [8] or Monte Carlo simulations.

Equation A.7.2-2 assumes that the shadow fading is lognormally distributed with standard deviation σ_G. If then for example the median path gain m_G is calculated using the free space formula, it would be necessary to set $\sigma_G = 0$, since the free space formula assumes ideal radio propagation without any multipath propagation or shadowing and thus represents a theoretical lower bound for the path loss. If it is desirable to use non-zero shadowing standard deviation, other models than free space have to be used for calculating the median path gain.

A.7.3 Reference geometries

Different member states may use different reference geometries in the context of co-existence between WSDs and DTT services within the same pixel. For example, in one member state only the protection of fixed roof-top DTT reception might be considered, whereas in another member state DTT reception with set-top aerials might be protected.

In this report we examine the two geometries described below.

A.7.3.1 Mobile WSD operation and fixed roof-top DTT reception

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[15] The value of this margin might, for example, be increased in response to a proliferation of WSDs and an increase in the potential for aggregate interference to DTT services.

Figure 61 shows the relevant reference geometry. This geometry was also used in CEPT Report 30 for the calculation of the emission limits for mobile/fixed communication network terminal stations in the 800 MHz Digital Dividend band.

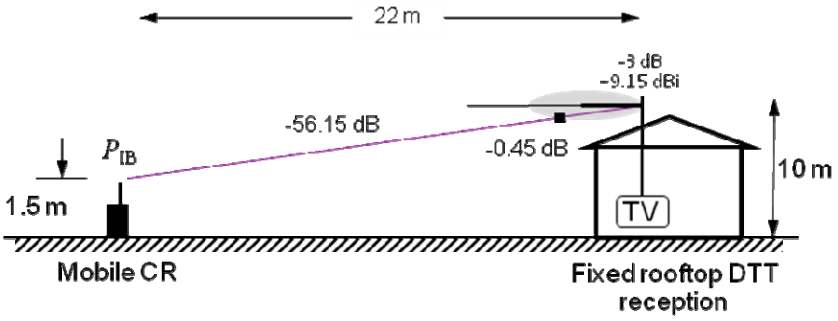

Figure 61: Reference geometry for mobile WSD. Shown path loss is for a carrier at 650 MHz

The DTT receiver antenna would provide a 3 dB polarisation discrimination with respect to a randomly oriented mobile WSD.

Note that this reference geometry corresponds to a worst-case scenario for the following reasons:

- It is assumed that the WSD is located along the azimuth bore-sight of the DTT receiver's antenna.
- For a DTT antenna which complies with the ITU-R BT.419-3 directional pattern, the horizontal separation of 22 m results in the largest median coupling gain, $m_{G(\mathrm{dB})}$.

A.7.3.2 Fixed roof-top WSD transmission and fixed roof-top DTT reception

Figure 62 shows the relevant reference geometry. This corresponds to Configuration 4 of Table 41.

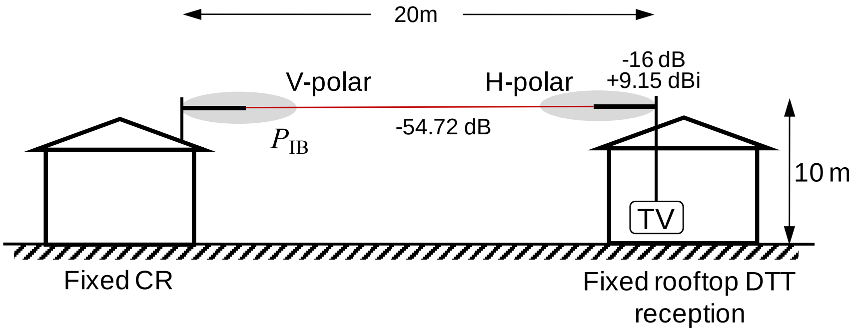

Figure 62: Reference geometry for mobile WSD. Shown path loss is for a carrier at 650 MHz

The DTT receiver antenna would provide a 16 dB polarisation discrimination with respect to a opposite-to-DTT polarised fixed WSD transmitter.

A.7.3.3 Interference margin

Depending on their specific circumstances and policies, member states may adopt different values for the interference margin, $\mathrm{IM}_{(\mathrm{dB})}$, in Equation (A.7.2-2). In one possible realisation, the interference margin could be set dynamically in order to account for the short-term temporal variation in the number of WSDs operating within any pixel. In another possible realisation, the interference margin could be adjusted based on the long-term increase in the number of WSDs, or even based on the number of complaints received by viewers of the DTT service.

For the purposes of the examples in this section, we assume $\mathrm{IM}_{(\mathrm{dB})} = 3$ dB.

A.7.4 Summary of parameter values

Table 55 below summarises the values of the various parameters used in the numerical examples of this section. Different member states may adopt different parameter values.

Parameter	Description and value
$m_{Z\,(\text{dBm})}$, $\sigma_{Z\,(\text{dB})}$, q_1	The median and standard deviation of $Z_{(\text{dB})}$ derived for each pixel via the DTT network planning model.
Δq , q_2	Δq is the tolerable degradation in location probability within a pixel. We assume $\Delta q = 0.01$. $q_2 = q_1 - \Delta q$ is then calculated for each pixel.
f_{DTT}	DTT carrier frequency, 650 MHz.
Δf	Frequency offset between WSD carrier and DTT carrier. We consider the example of 16 MHz.
ACLR_{WSD}	Portable WSD: ACLR is set to 36 dB, compatible with ACLR_2 of a LTE terminal station (as specified in 3GPP TS 36.101). Fixed WSD: ACLR is set to 45 dB, compatible with ACLR of a LTE base station (as specified in 3GPP TS 36.104).
ACS_{DTT}	Derived from measurements of protection ratio. Specifically, for Δf = 16 MHz, we assume that: ACS_{DTT} = 61, 58, 42, 35, and 28 dB for m_S = -70, -50, -30, -20, and -12 dBm, respectively. The dependence of the ACS on the wanted signal power implicitly models the non-linear behaviour (overload) of the DTT receiver. To model receiver overload implicitly, we assume that: for $m_S >$ -12 dBm, ACS_{DTT} = -500 dB, and for $m_S <$ -12 dBm, ACS_{DTT} = 61 dB.
$r(\Delta f)$	Derived from the DTT receiver ACS and the WSD ACLR. $r(0)$ = 16 dB (based on measurements).
$\text{IM}_{(\text{dB})}$	Interference margin of 3 dB.
$G_{(\text{dB})}$	Portable WSD geometry: Coupling gain standard deviation $\sigma_{G\,(\text{dB})}$ = 3.5 dB. Median path gain = -56.15 dB DTT antenna gain = 9.15 dBi DTT antenna angular discrimination = -0.45 dB DTT antenna polar discrimination = -3 dB Coupling gain median $m_{G\,(\text{dB})}$ = -56.15 + 9.15 – 0.45 – 3 = -50.5 dB. Fixed WSD geometry: Coupling gain standard deviation $\sigma_{G\,(\text{dB})}$ = 3.5 dB. Median path gain = -54.72 dB DTT antenna gain = 9.15 dBi DTT antenna angular discrimination = 0 dB DTT antenna polar discrimination = -16 dB Coupling gain median $m_{G\,(\text{dB})}$ = -54.72 + 9.15 – 0 – 16 = -61.6 dB.

Table 55: Parameter values

A.7.1 Numerical results

Table 56 shows the DTT wanted signal power and DTT interference powers, at a frequency of 650 MHz, and for a cluster of 9 adjacent pixels at a specific location in the UK. These values are derived from the UK DTT planning model. The location probabilities here are close to unity, implying excellent DTT coverage at this location. Note that $P_S >> U$, implying a noise-limited environment.

Pixel no.	Pixel coordinates		DTT wanted power, $P_{S\,(dBm)}$		DTT self-interference, $U_{(dBm)}$		DTT location probability, q_1
	x (m)	y (m)	Median $m_{S\,(dBm)}$	STD $\sigma_{S\,(dBm)}$	Median $m_{S\,(dBm)}$	STD $\sigma_{S\,(dBm)}$	
1	421700	200200	-34.56	5.50	-66.36	4.20	1.00
2	421800	200200	-34.46	5.50	-66.36	4.20	1.00
3	421900	200200	-34.46	5.50	-66.26	4.10	1.00
4	421700	200100	-34.46	5.50	-66.16	4.10	1.00
5	421800	200100	-34.36	5.50	-66.06	4.10	1.00
6	421900	200100	-36.86	5.50	-66.16	4.20	1.00
7	421700	200000	-34.46	5.50	-66.16	4.10	1.00
8	421800	200000	-36.96	5.50	-66.26	4.10	1.00
9	421900	200000	-36.86	5.50	-66.16	4.00	1.00

Table 56: Output of the DTT network planning model

Table 57 shows the resulting maximum permitted mobile WSD in-block and out-of-block emission levels in the 9 pixels for a 16 MHz carrier-to-carrier separation between the WSD and the nearest-frequency DTT channel (n+2). Here, we assume a maximum tolerable decrease in location probability of 1%, a median coupling gain of -50.5 dB (mobile WSD), a coupling loss standard deviation of 3.5 dB, an interference margin of 3 dB, a WSD ACLR of 36 dB, and a DTT receiver co-channel protection ratio of 16 dB. For $q_2 = 0.99$, we have $\mu(q_2) = 2.326$.

Note that the noise-limited environment means that $Z = P_S - U \approx P_S$. This will generally not be the case, and DTT self-interference, U, will affect the maximum permitted WSD emissions.

Pixel no.	Pixel coordinates		$Z_{(dBm)}$ where $Z = P_S - U$		ACS(Δf) (dB)	PR(Δf) (dB)	WSD emission limits	
	x (m)	y (m)	Median $m_{Z\,(dBm)}$	STD $\sigma_{Z\,(dBm)}$			$P_{IB\,(dBm)}$	$P_{OOB\,(dBm)}$
1	421700	200200	-34.55	5.53	45.65	-19.55	17.27	-18.73
2	421800	200200	-34.47	5.51	45.57	-19.54	17.40	-18.6
3	421900	200200	-34.48	5.49	45.57	-19.54	17.41	-18.59
4	421700	200100	-34.47	5.52	45.57	-19.54	17.37	-18.63
5	421800	200100	-34.37	5.52	45.49	-19.54	17.46	-18.54
6	421900	200100	-36.89	5.53	47.49	-19.70	15.09	-20.91
7	421700	200000	-34.49	5.50	45.57	-19.54	17.40	-18.6
8	421800	200000	-36.98	5.53	47.57	-19.71	15.01	-20.99
9	421900	200000	-36.87	5.51	47.49	-19.70	15.15	-20.85

Table 57: Output of the geo-location database calculations for mobile WSDs and a 16 MHz carrier-to-carrier separation from DTT

As it happens, the most stringent emission requirements correspond to pixel 8. The in-block and out-of-block emission limits for the cognitive device in pixel 5 may then be set to 15 dBm and -37 dBm respectively.

Table 58 shows the resulting maximum permitted fixed WSD in-block and out-of-block emission levels in the 9 pixels for a 16 MHz carrier-to-carrier separation between the WSD and the nearest-frequency DTT channel. Here, we assume a maximum tolerable decrease in location probability of 1%, a median coupling loss of -61.6 dB (fixed WSD), a coupling loss standard deviation of 3.5 dB, an interference margin of 3 dB, a WSD ACLR of 45 dB, and a DTT receiver co-channel protection ratio of 16 dB.

Pixel no.	Pixel coordinates		$Z_{(\text{dBm})}$ where $Z = P_S - U$		ACS(Δf) (dB)	PR(Δf) (dB)	WSD emission limits	
	x (m)	y (m)	Median $m_{Z\ (\text{dBm})}$	STD $\sigma_{Z\ (\text{dBm})}$			$P_{\text{IB (dBm)}}$	$P_{\text{OOB (dBm)}}$
1	421700	200200	-34.55	5.53	45.65	-26.30	35.12	-9.88
2	421800	200200	-34.47	5.51	45.57	-26.26	35.22	-9.78
3	421900	200200	-34.48	5.49	45.57	-26.26	35.23	-9.77
4	421700	200100	-34.47	5.52	45.57	-26.26	35.19	-9.81
5	421800	200100	-34.37	5.52	45.49	-26.23	35.25	-9.75
6	421900	200100	-36.89	5.53	47.49	-27.06	33.54	-11.46
7	421700	200000	-34.49	5.50	45.57	-26.26	35.22	-9.78
8	421800	200000	-36.98	5.53	47.57	-27.09	33.49	-11.51
9	421900	200000	-36.87	5.51	47.49	-27.06	33.60	-11.4

Table 58: Output of the geo-location database calculations for fixed WSDs and a 16 MHz carrier-to-carrier separation from DTT

Again, the most stringent emission requirements correspond to pixel 8. The in-block and out-of-block emission limits for the cognitive device in pixel 5 may then be set to 33 dBm and -37 dBm respectively.

ANNEX 8 : CALCULATION OF WSD EMISSION LIMITS BASED ON MCL ANALYSIS

A.8.1 Calculation of WSD emission limits as a function of guard band

The regulatory emission limits for a WSD must be specified as a function of the guard band (frequency separation) between the channel where a WSD intends to transmit and DTT services. This is due to the dependence of the DTT receiver ACS on the frequency offset of the interferer. Therefore, the permitted WSD emission levels can only be established once the available guard band with respect to the used DTT channels in its proximity has been identified.

In the studies undertaken in SE42, the MFCN TS in-block e.i.r.p. limit was fixed at 23 dBm for consistency with the peak e.i.r.p. specified in 3GPP LTE specifications. There is no such constraint for a WSD, and the in-block and out-of-block e.i.r.p. limits must be jointly specified.

However, the ACLR specified in SE42 was 88 dB, a value which is much higher than the value used in these studies. This value will be reached in reality only because of the frequency separation of more than 42 MHz, between the LTE uplink and the highest DTT channel.

WSDs are intended to operate in white spaces throughout the VHF/UHF TV band (470- 790 MHz). For this reason, the use of additional filtering at the DTT receiver is not an option and the non-filtered adjacent channel selectivity (ASC) of DTT receivers would need to be taken into account.

Based on the above, a calculation of the regulatory emission limits for a WSD as a function of the guard band with respect to DTT services can be performed.

Let P_{I} be the interference power experienced by a victim DTT receiver. Then we may write (in the linear domain)

$$P_{\mathrm{I}} = G\left(P_{\mathrm{OOB}} + \frac{P_{\mathrm{IB}}}{\mathrm{ACS}}\right), \qquad (1)$$

where G is the *aggregate coupling gain* between the WSD transmitter and the DTT receiver, P_{IB} is the in-block e.i.r.p. of the WSD, P_{OOB} is the out-of-block e.i.r.p. of the WSD, and ACS is the adjacent channel selectivity of the DTT receiver. Re-writing and re-ordering, we have

$$\left(P_{\mathrm{OOB}} + \frac{P_{\mathrm{IB}}}{\mathrm{ACS}}\right) = P_{\mathrm{IB}}\left(\frac{P_{\mathrm{OOB}}}{P_{\mathrm{IB}}} + \frac{1}{\mathrm{ACS}}\right) = P_{\mathrm{IB}}\left(\frac{1}{\mathrm{ACLR}} + \frac{1}{\mathrm{ACS}}\right) = \frac{P_{\mathrm{I}}}{G} \qquad (2)$$

where ACLR is the adjacent channel leakage ratio of the WSD.

A.8.2 Results

In this section, results of studies on WSD emission limits are provided based on MCL-calculations following the methodology described above.

All calculations were carried out for a frequency of 650 MHz and free-space path loss.

A certain ACS-value of the DVB-T receiver has been assumed. The resulting out-of-band emission limit was calculated as a function of the ACLR-value the WSD has to reach in order to be allowed to realize a certain e.i.r.p..

Results are displayed for different I/N-ratios.

A.8.2.1 Results for portable reception and a separation distance of 2m

In these studies an antenna gain of 2.15 dBi has been assumed for DTT reception (portable reception; according to Configuration 2 in Table 41).

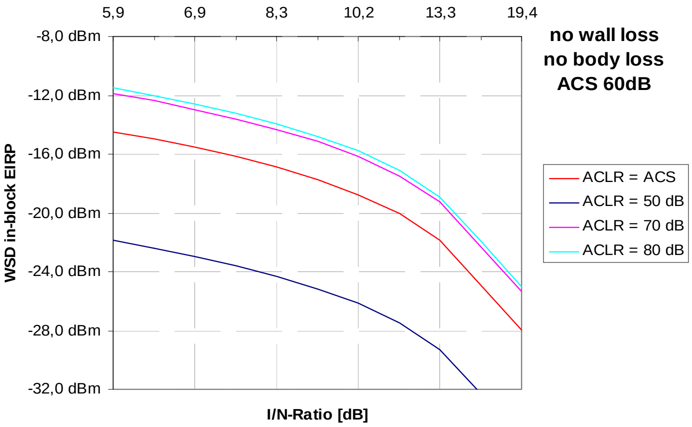

Figure 63: WSD in-block e.i.r.p. for a DVB-T receiver with an ACS of 60 dB, no wall loss and no body loss, for a separation distance of 2m

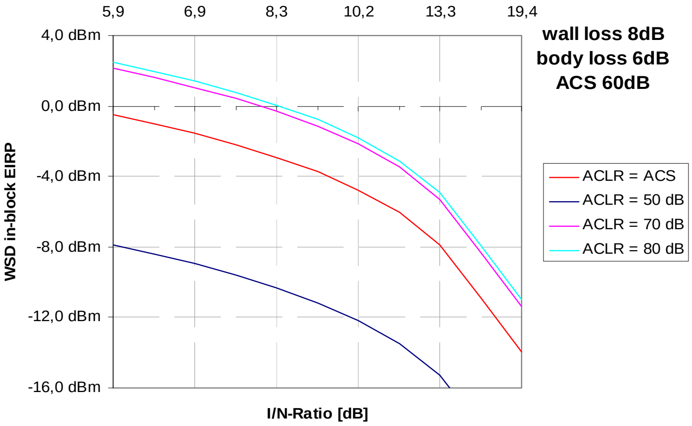

Figure 64: WSD in-block e.i.r.p. for a DVB-T receiver with an ACS of 60 dB, wall loss and body loss was taken into account, for a separation distance of 2m

It can be seen from results above that wall loss and body loss goes linearly into this analysis, i.e. values with a wall of 8dB and a body loss of 6 dB the resulting WSD in-block power would be by 14 dB higher than the one without any losses.

In the following, results without both losses are presented, only.

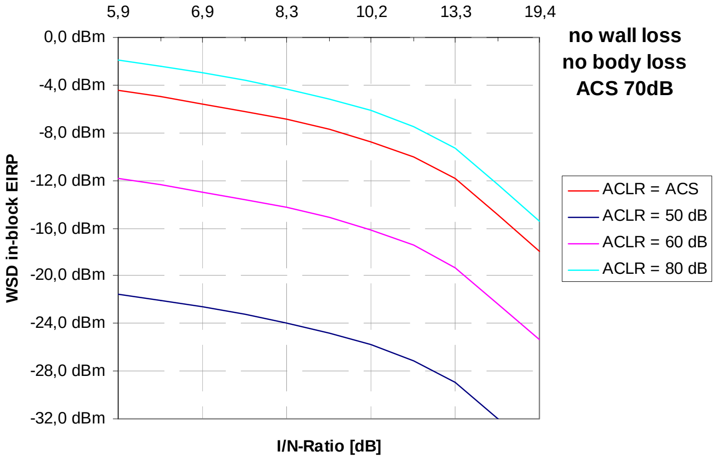

Figure 65: WSD in-block e.i.r.p. for DVB-T receiver ACS of 70 dB, separation distance of 2m

A.8.2.2 Results for fixed reception and separation distances of 20m, 50m and 100m

In these studies an antenna gain of 12 dBi has been assumed for DTT reception (fixed reception, according to Configuration 2 in **Table 41**).

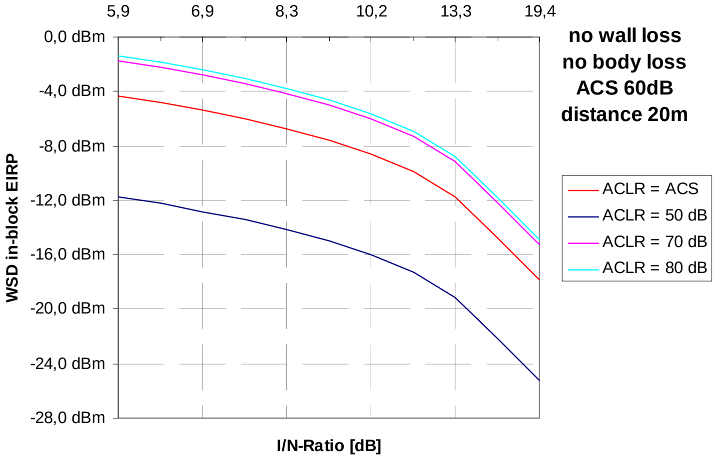

Figure 66: WSD in-block e.i.r.p. for DVB-T receiver ACS of 60 dB, separation distance 20m

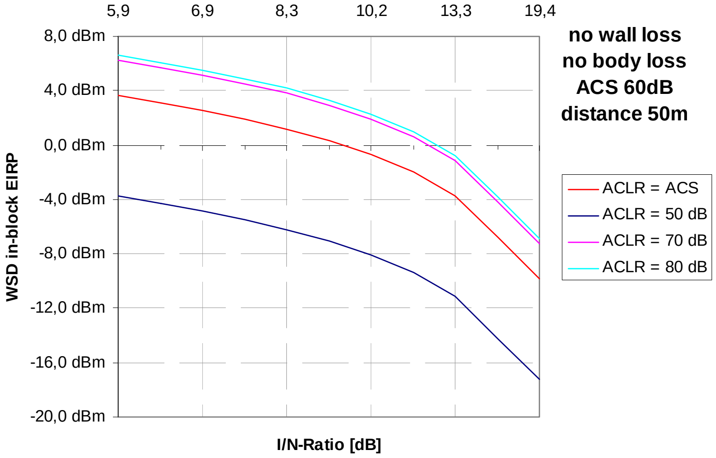

Figure 67: WSD in-block e.i.r.p. for DVB-T receiver ACS of 60 dB, separation distance 50m

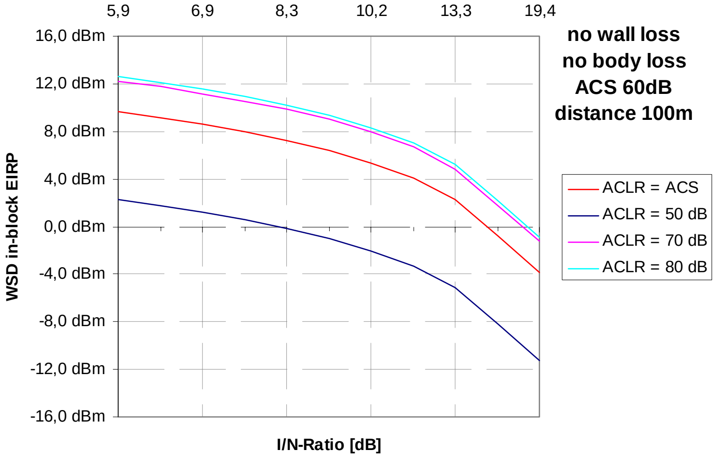

Figure 68: WSD in-block e.i.r.p. for DVB-T receiver ACS of 60 dB, separation distance 100m

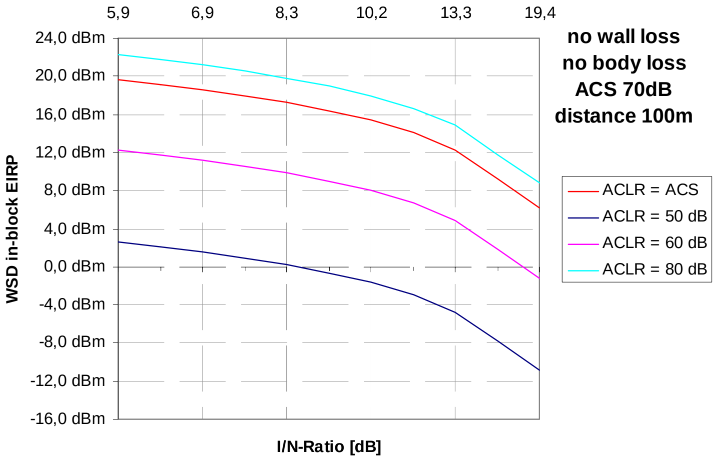

Figure 69: WSD in-block e.i.r.p. for DVB-T receiver ACS of 70 dB, separation distance100m

ANNEX 9 : SEAMCAT SIMULATIONS

The approach currently implemented within the SEAMCAT in order to assess interference from WSDs into radiocommunication services is given below. It is noted, however, that the work is still ongoing. Therefore, the results of simulations with the SEAMCAT need to be considered with caution.

STEP 1: *Identification of the frequencies to be tested.*

It is assumed that the frequency of the interfering WSD is in the same frequency range defined as the victim. This means that when the Cognitive Radio module is activated, the interfering frequency function dialog box is deactivated.

When the victim frequency is constant, it is equal to the interferer frequency. The number of channel *M* is 1. For discrete frequencies, the possible WSD frequencies are those defined by the user. This means that *M* equals to the number of discrete inputs.

For distributed victim frequencies between f_{min} and f_{max}, the possible WSD frequencies are in the range from f_{min}+(M-1)*victim bandwidth to f_{max} (f is the center frequency). The below algorithm is to extract the *M* WSD channels.

STEP 2: *Assigned the WSD with a frequency*

This algorithm is followed for each events and under the condition that the dRSS > sensitivity.

for each WSDs, **STEP 2.1** to **STEP 4.2** is performed.

from channel m = 1 to M+1 (i.e. over all the WSD channels)

STEP 2.1: Calculate the sRSS: $sRSS(f_m) = P_{Wt}(f_m)+G_{Wt\rightarrow It}+ G_{It\rightarrow Wt} + L$.

The illustration of the calculations of the sRSS is shown in Figure 70.

STEP 2.2: Identification of "available" channels

The algorithm detects if a WSD is allowed to transmit (i.e. compare to threshold), then it stores the channels that are or are not accessible as vector *available_channel* or *non_available_channel*;

STEP 3: *Probability of Failure (if activated)*

If there is a failure in the detection process, *non_available_channel* will be seen by a given WSD as available and the WSD may transmit on this channel.

STEP 4: *Select an available channel / determination of the WSD channel*

If all the channels are available and no frequency is blocked, then the max e.i.r.p of the WSD is considered and the WSD is placed randomly among the *available_channel.*

In case all the channels are blocked then, the algorithm will try another WSD (i.e. back to *STEP 2.1*) and store the number of inactive WSD).

If not all the channels are blocked, then the algorithm goes to *STEP 4.1.*

STEP 4.1: *Apply the Table of Constraints*

For each of the *non_available_channel*, the algorithm consider the associated predefined "vector" of constraints which is defined based on the victim system protection criterion, for which the "co-channel" row is synchronised to the non-available channel. Based on this, it generates a table of e.i.r.p. / channels. Then, for each of the *available_channel*, SEAMCAT extracts the smallest e.i.r.p from this table in order to make sure that the protection criterion of the victim is met. This gives the vector *available channel* (f_i) per e.i.r.p.

STEP 4.2: *Determination of the WSD channel /e.i.r.p*

From the resulting vector *available channel* (f_i) per e.i.r.p extract the couple (f_i, "max e.i.r.p").

In case several channels are associated with the same "max e.i.r.p", the WSD is placed randomly among those channels.

STEP 5: *Aggregated e.i.r.p.*

After *STEP 4*, all the active WSDs are assigned a frequency and a given e.i.r.p.. *STEP 5* calculates the cumulated impact resulting from all the active WSDs.

The SEAMCAT calculations which are shown in an usual way for each active WSDs. The calculation of the $iRSS_{unwanted}$ (i.e. victim at f_v), $iRSS_{blocking}$ (i.e. victim at fv), $iRSS_{overloading}$ from the interfering WSD at the victim receiver of DTT.

STEP 6*: Calculate* the Interference

The interference is calculated for each of the event and the corresponding interference probability is determined.

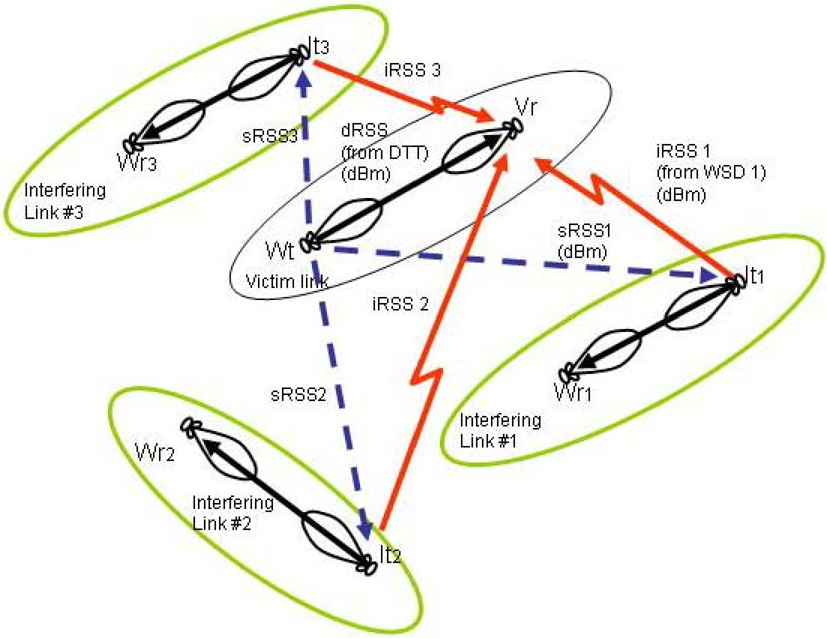

Figure 70: Illustration of operation of three WSDs and a victim system

ANNEX 10 : EXAMPLES A TRANSLATION PROCESS FOR THE PROTECTION OF DTT

A.10.1 Translation process according to the methodology described in Section 4.3.2.1

An example algorithm that can be implemented for the protection of DTT according to the methodology described in Section 4.3.2.1 is provided in the Figure 71.

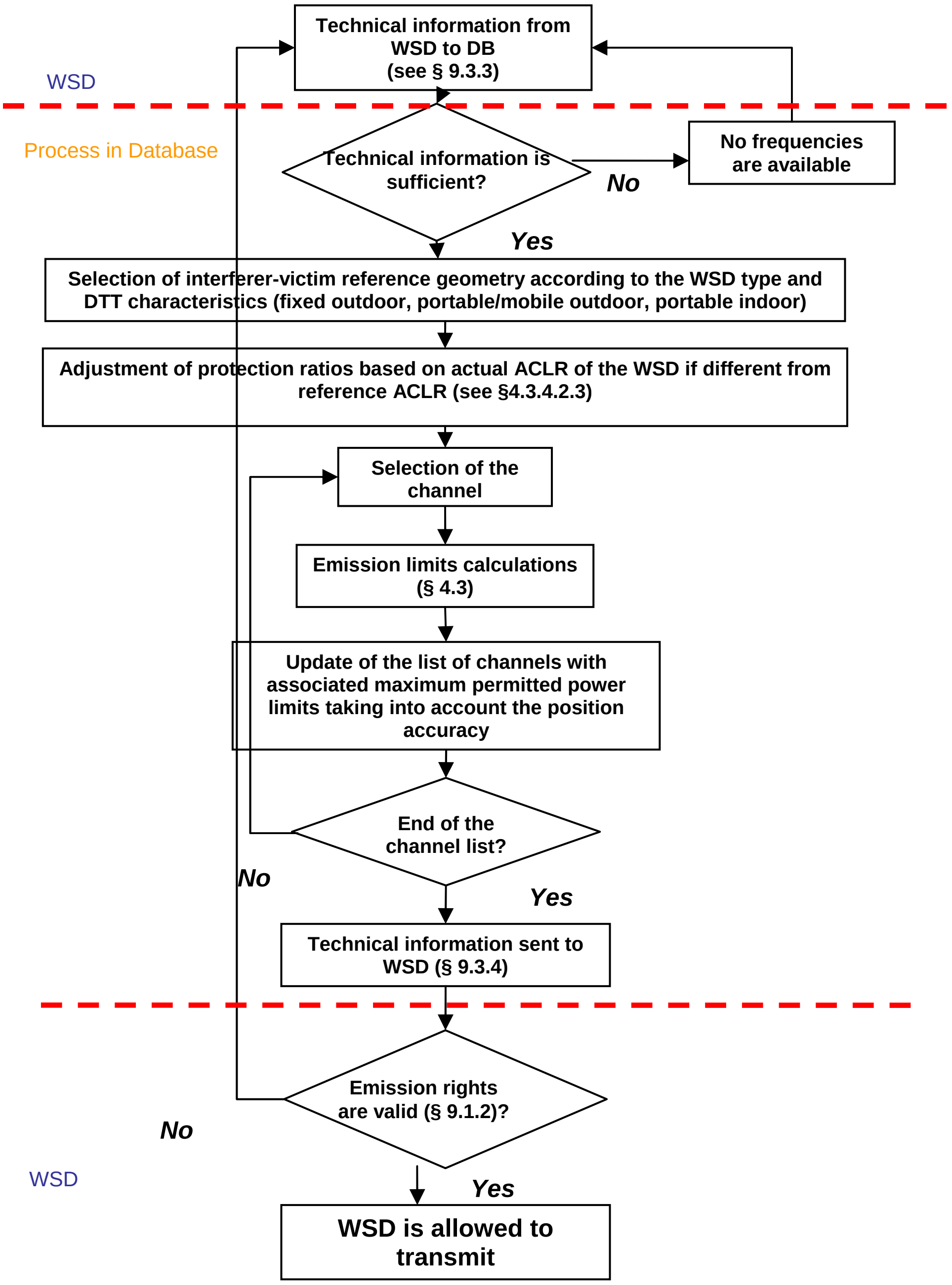

Figure 71: Example flowchart to determine available channels for WSD whilst protecting DTT. Above and below dashed red lines the treatment is made in the WSD and between these lines the treatment is done by the database

The translation process shown in Figure 71 requires real time computation capabilities inside the geo-location database. It may not be always necessary as in some cases the high volume of computations needed to determine available frequencies and associated maximum allowed e.i.r.p. can be performed with specific routines outside the database. The geo-location database will be then populated with the results of these computations. Data exchange between the database and WSDs will be then in real time.

In this case, the flowchart of Figure 71 can be reshaped as shown in Figure 72. The computation steps are provided in Figure 73.

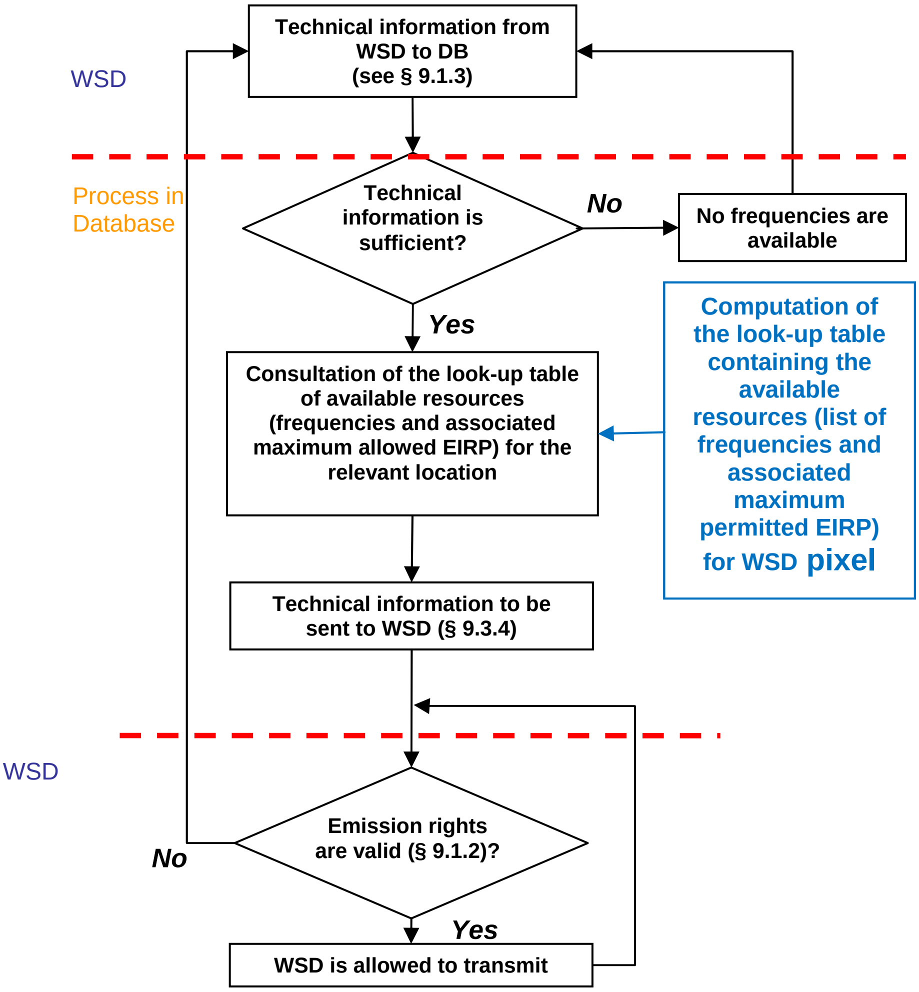

Figure 72: Example flowchart to determine available channels for WSD whilst protecting DTT with computations left outside the geo-location database

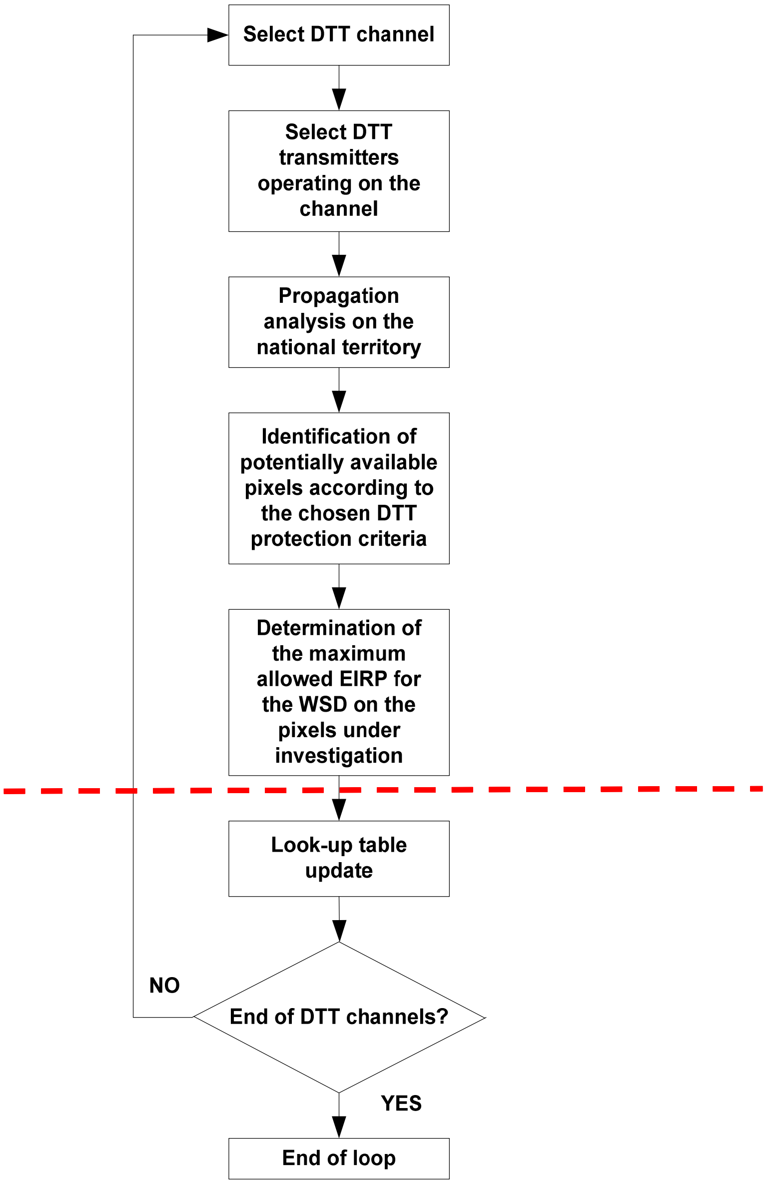

Figure 73: Example flowchart of the computation of the look-up table to fill the geolocation database

A.10.2 Translation process for the protection of DTT for the case of a master/slave configuration with low complexity

The WSD master transmits a single geo-location database query for its entire service area (covering the positions of all attached slave WSDs). The database calculates, e.g. according the method of section 4.3, and replies with the transmit power limits $\underline{\mathcal{P}_m^{MAX}(f_{WSD})}$ for each pixel m that covers the master WSD service area, see Figure 75 in ANNEX 11, and for each possible white space channel f_{WSD}

The master ensures that each slave WSD comply with the appropriate limit, depending on the slave WSD location within the master WSD service area (which is known at the master WSD by queries to the slave WSDs or by network positioning methods). That is; if a slave WSD (WSD_j) is located in the pixel m' then the maximal transmit power (e.i.r.p.) on f_{WSD} of that slave WSD will be

$$\underline{\mathcal{P}_j^{MAX}(f_{WSD}) = \mathcal{P}_{m'}^{MAX}(f_{WSD})}\ .$$

Another example is that, as above, the master WSD queries the geo-location database for its entire service area. The geo-location database calculates the maximal transmit powers e.g. according the method of Section 4.3, for all pixels *m* that covers the service area of the master WSD and obtains $\underline{\mathcal{P}_m^{MAX}(f_{WSD})}$ for all pixels *m* covering the service area of the master WSD.

The geo-location database returns in its reply to the master WSD only the lowest allowed e.i.r.p. out of all $\underline{\mathcal{P}_m^{MAX}(f_{WSD})}$, i.e., the geo-location database returns

$$\underline{\mathcal{P}^{MAX}(f_{WSD}) = \min_m \mathcal{P}_m^{MAX}(f_{WSD})}$$

for each channel f_{WSD}. This information is then used by the master WSD as the maximum allowed transmit power for channel f_{WSD} for all slave WSDs.

A.10.3 Translation process for the protection of DTT for the case of master/slave configuration that allows control of the aggregated interference at critical positions

In this example implementation the geo-location database constructs maximally allowed interference levels at worst case (critical) positions for each white space channel. The master WSD uses this information to construct conditions for its power and channel allocation algorithm that ensures that the total aggregated interference at the critical positions are kept below the maximally allowed interference level at each critical position.

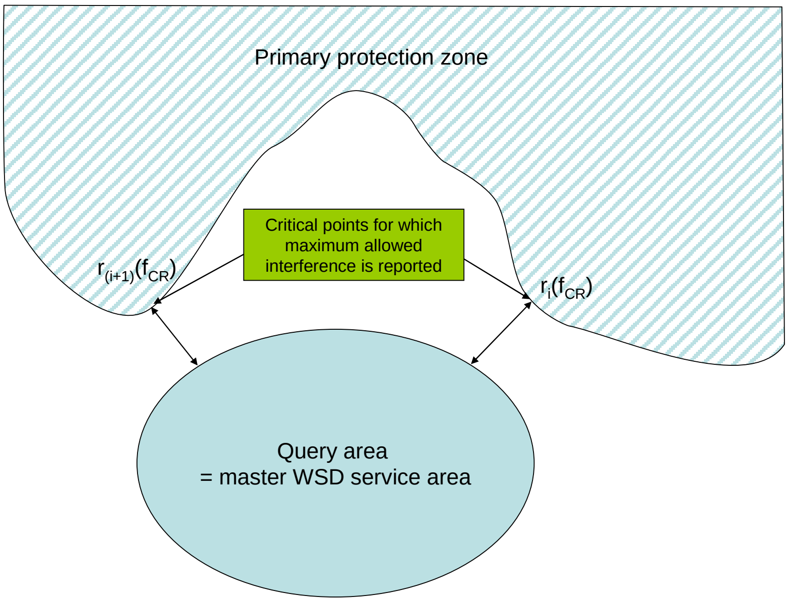

Figure 74: Illustration of two sets of critical points associated with a primary protection zone and a master WSD service area for a particular channel f_{WSD}.

The geo-location database replies by sending for each channel f_{WSD}, considered in the database as allowed for secondary usage, a list of $N_{citical}(f_{WSD})$ critical positions $\underline{\vec{r}_i(f_{WSD}), i = 1,\ldots\mathcal{N}_{critical}(f_{WSD})}$ and corresponding information that allows the master WSD to calculate constraints that needs to be respected by the power and channel allocation of the slave WSDs. Two such sets of critical points are illustrated in Figure 74 above.

For each critical position $\underline{\overset{\rightarrow}{r_i}\,\vec{r}(f_{WSD}), i = 1,\ldots\mathcal{N}_{critical}(f_{WSD})}$ for each channel f_{WSD} the following information is provided to the master WSD in the reply:

- The maximally allowed total interference at the critical position $I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})$ that may in some implementations (inspired by equation (4.3-1)) be calculated as

$$\begin{aligned} I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})) = \mathcal{P}_{\min}^{\mathcal{BS}}(f_{\mathcal{BS}}) + \mu\sigma_{\mathcal{BS}} - \mathcal{PR}(f_{\mathcal{WSD}} - f_{\mathcal{BS}}) - q\sqrt{(\sigma_{\mathcal{BS}}^2 + \sigma_{\mathcal{WSD}}^2)} \\ - \mathcal{MI} - \mathcal{SM} + \mathcal{D}_{dir} + \mathcal{D}_{pol} - \mathcal{G}_i + \mathcal{L}_f \end{aligned}, \tag{G.1}$$

  (where the notation is according to the ones used in equation (4.3) in Section 4.3) using the data available in the database and the information provided in the query from the master WSD. Other means of calculating the allowed interference may be based on, e.g., equation (4.3-8).

- $\mathcal{H}_{\Pr imary,i,f_{WSD}}$ being the (assumed) receiver antenna height at the critical position $\vec{r}_i(f_{\mathcal{WSD}})$

- Thus the reply from the geo-location database, includes the following data: $\left\{f_{\mathcal{WSD}}, \left\{\vec{r}_i(f_{\mathcal{WSD}}), I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})), \mathcal{H}_{\Pr imary,i,f_{WSD}}\right\}_{i=1}^{\mathcal{N}_{Critical}(f_{\mathcal{WSD}})}\right\}_{\forall f_{\mathcal{WSD}}}$

The master WSD uses the data in the reply to calculate a condition to be respected by its channel and power allocation of the slave WSDs.

The master WSD calculates the maximally allowed e.i.r.p. for each slave WSD, guided e.g. by equation (4.3-1), by combining the following information:

- Information received from the geo-location database, i.e., the set of data $\left\{f_{\mathcal{WSD}}, \left\{\vec{r}_i(f_{\mathcal{WSD}}), I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})), \mathcal{H}_{\Pr imary,i,f_{WSD}}\right\}_{i=1}^{\mathcal{N}_{Critical}(f_{\mathcal{WSD}})}\right\}_{\forall f_{\mathcal{WSD}}}$
- The location $\vec{p}_j$ and associated accuracy e_{pj} of each slave WSD (*WSD$_j$*), that were obtained by queries to the slave WSDs or by other positioning methods
- The transmit antenna heights of each the slave WSD, H_{WSD}
- A pre-defined path loss model (standardized by regulation, possibly the same as used in equation (4.3)):
  $L_{WSD(H_{WSD})-BS(H_{\Pr imary})}(d_{WSD-\Pr imary})$
  indicating the propagation path loss between a slave WSD transmit antenna with height $H_{WSD,j}$ and a primary receiver antenna at with height $H_{Primary}$at a distance $d_{WSD\text{-}Primary}$..

To derive the conditions on transmit powers for the slave WSD ($\mathcal{WSD}_j,\ j=1,\ldots,\mathcal{N}_{slaves}$), each channel f_{WSD} and each critical position $\vec{r}_j,\ j=1,\ldots,\mathcal{N}_{Critical}$ in the channel the master WSD performs the following:

- The master WSD calculates the distance between *WSD$_j$*and the critical position $\vec{r}_i(f_{\mathcal{WSD}})$:
  $d_{ij} = \left|\vec{r}_{\mathcal{WSD}} - \vec{r}_i(f_{\mathcal{WSD}})\right|$
  In this distance calculation the positioning accuracy e_{pj} of *WSD$_j$* is included to make a worst case assumption.
- The master WSD calculates the path loss between *WSD$_j$* and $\vec{r}_i(f_{WSD})$, using the knowledge of the slave WSD transmit antenna height $H_{WSD,j}$, the receiver antenna height $H_{Primary,i}$ and the location of the slave WSD by using the specified path loss model:
  $L_{WSD\ j(H_{WSD},j)}(d_{ij})$
- The master WSD use the $I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}}))$, provided by the geo-location database, to construct (calculate) constraints for the power and channel allocation optimization process. Let $P_j(f_{WSD})$ be the power allocated to WSD *WSD$_j$*,in channel f_{WSD}. The constraints

$10\log_{10}\sum_{j=1}^{\mathcal{N}_{slaves}} 10^{\left(\mathcal{P}_j(f_{\mathcal{WSD}})-\mathcal{L}_{\mathcal{WSD}\,j}(\mathcal{H}_{\mathcal{WSD},j})-\mathcal{BS}(\mathcal{H}_{\Pr imary,i})(d_{ij})\right)/10} \leq I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})),$ are to be respected $\forall f_{\mathcal{WSD}}, i=1,\ldots,\mathcal{N}_{critical}(f_{\mathcal{WSD}})$ by the power and channel allocation procedure in the master/slave configured communication system. This set of constraints ensures that the master/slave configured system does not cause too much aggregated interference to any critical position.

This approach takes into account the actual transmit power used by the slave WSDs to ensure that the total aggregated interference is accurately controlled. However the approach may only ensure that the master/slave configured system does not interfere too much with the primary system. If other WSDs are present the responsibility of keeping the aggregated interference under control lies with the geo-location database. As such it would be beneficial to allow only a single network of master/slave configured WSD systems to access a set of white space channels, as this would allow controlling the aggregated interference by the above outlined method.

The above outlined approach implies that we may remove, or at least lower the value of, the multiple interference margin *MI* in the calculation of the total allowed aggregated interference level $I_{tot}^{\mathcal{MAX}}(f_{\mathcal{WSD}},\vec{r}_i(f_{\mathcal{WSD}})$ in equation (G.1). This would provide the optimization process of the master/slave configured system with more total transmit power to allocate, while ensuring protection of the primary system. Hence, better capacity of the secondary links while providing the same primary protection.

A.10.4 Possible list of the required harmonised set of parameters for the calculation of WSD location specific power limits

Degradation in the location probability (%)

Minimum separation distance for the fixed WSD case vs fixed rooftop DTT reception (m)

Minimum separation distance for the portable/mobile WSD case vs portable/mobile DTT reception (m)

Minimum separation distance for the portable/mobile WSD case vs fixed rooftop DTT reception (m)

Body loss for the portable/mobile WSD case (dB)

Wall loss for the portable/mobile WSD case (dB)

Safety margin (dB)

Multiple Interference margin (dB)

ANNEX 11 : EXAMPLES FOR MASTER-SLAVE OPERATION OF GEOLOCATION DATABASE

The master-slave concept has, depending on the actual implementation, a possible impact on the communication protocol and the information exchanged between WSDs and the geolocation database. In the following some possible schemes are described.

In the simplest version of a WSD master/slave configuration the master WSD makes one query for each of its slave WSDs and the master WSD receives one response for each slave. The master WSD relays the responses to the slave WSDs who are, as above, obliged to operate according to the geo-location database response. The WSD master is assumed to transmit in each query the location of the respective slave WSD, this location may be obtained by either simply querying the slave WSD or, alternatively, via some network positioning method.

Alternatively the WSD master may, to reduce the number of queries to the geo-location database, transmit a single geo-location database query for its entire service area (covering the positions of all attached slave WSDs). In the following, first ideas on general principles how such a query for an area could be treated by a database implementation are presented. These ideas will need further detailed consideration in order to provide adequate protection to services to which the band is allocated.

In one implementation the database would determine what pixels are within the master WSD service area and would determine the “worst case” pixel (the pixel that allows the least output power) in it. The e.i.r.p. limit for this pixel would denote the e.i.r.p. limit for the whole service area, and the master would have to ensure that all slave WSDs comply with this limit.

In another implementation the database would return transmit power limits for each pixel within the master WSD service area, illustrated in Figure 75. The master would have to ensure that each slave WSD always complies with the appropriate limit, depending on the slave WSD location within the master WSD service area (which is known at the master WSD by queries to the slave WSDs or by network positioning methods).

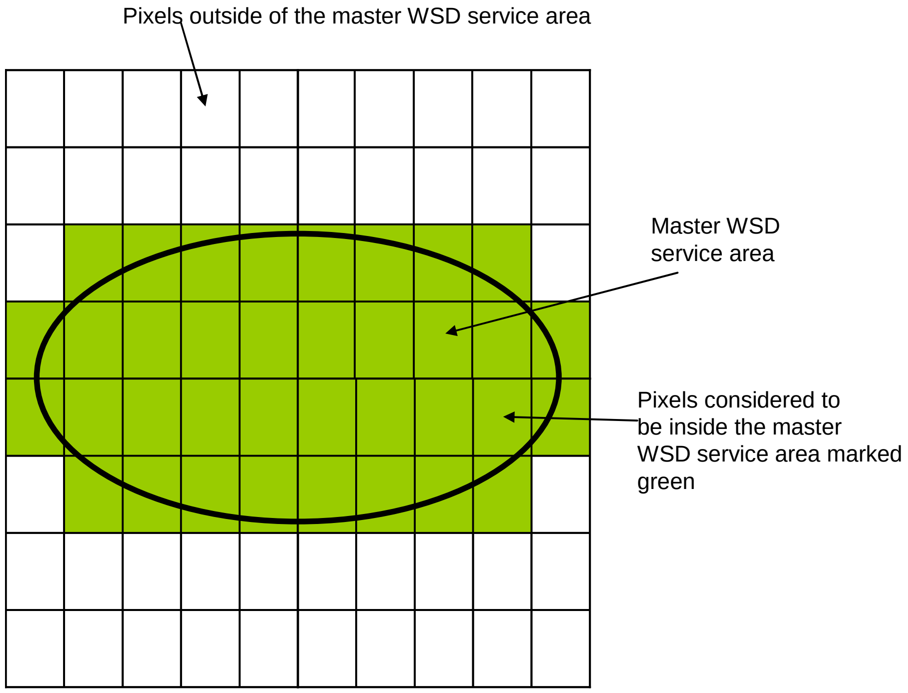

Figure 75: Illustration of a master WSD service area and pixels (marked green) for which the geo-location database returns maximum allowed transmit powers

The setting where the access point executes direct control over the spectrum access of WSDs it is serving is a more sophisticated WSD master/slave configuration. In this setting it would be possible to have the master WSD doing the database queries and assigning channels to and controlling corresponding maximum transmit powers of the associated WSD slaves using the results from a geo-location database query. This could be done so that the aggregated interference at the critical locations where primary receivers might be located (which would be specified by the geo-location database in its query response) is kept below specified levels, but the actual maximum transmit powers of the slave WSDs could be set and dynamically controlled by the master WSD according to e.g. the load situation and possible movements of the slave WSDs.

The master/slave configuration ensures that the aggregated interference can be accurately controlled by adapting the methods specified in the case where the WSD master/slave network is the only one operating on the white space channels; this may be ensured by for example issuing exclusive secondary licenses.

In this case of a master/slave configuration

- the master WSD queries the geo-location database for its entire area
- the reply contains critical positions (worst case locations that will experience the highest interference levels from a WSD located within the master WSD service area) and associated maximal allowed caused interference at these locations. The reply also contains relevant parameters for path loss calculation between a slave WSD location and the critical position.
- The master dynamically performs channel and power allocation for its slave WSDs
- The master WSD performs interference calculations to ensure that the total aggregated interference of all slave WSDs at the critical positions stays below the specified limits of allowed interference. This calculation is performed according to calculation methods and parameters configured by the geo-location database.

The main advantage with allowing the master WSD to dynamically set the allowed transmit power for the slaves while ensuring that the total generated interference does not exceed a predetermined threshold is that it may incorporate this calculation as a constraint in its power allocation optimization process and thus only interference generated by slave WSDs that are actually transmitting on a channel will contribute to the aggregated interference. This is possible since the master WSD, in this setting, has information on what channels and associated transmit powers that the slave WSDs are using for transmission at specific times. As the geo-location database has no information on what channels the slave WSDs are actually transmitting on (it has only information on the transmit power limits) it is thus only possible to specify a rough protection margin (in Section 4.3 referred to as the multiple interference margin, MI) if the geo-location database would try to implement the same feature. By the above master/slave approach this multiple interference margin may be lowered or completely removed if e.g., the only white space system operating on the frequencies is a master/slave configured network of access points serving associated slave WSDs.

The following additional information will be communicated by the geo-location database to the master WSD in case of master-slave operation:

- List of critical positions for each available frequency (optional requirement): The geo-location database uses the service area of the master WSD to determine the critical positions that will experience the most interference from slave WSDs located somewhere in the service area of the master WSD. This is illustrated below.
- Maximum allowed interference power caused by the slave WSDs at critical positions (optional requirement): This is the interference that is allowed to be caused by the master/slave configured system to a primary receiver at a critical position.
- Parameters that are needed for the master WSD to calculate path loss (optional requirement): This information is needed by the master WSD to accurately calculate the path loss between a slave WSD and a primary receiver at a critical position. The calculation is to be performed in a standardized fashion e.g. following the prescriptions of the path loss in equation (4.3-1). This information is in some implementations (as the one in equation (4.3-1)) only the height of the primary receiver antenna at the critical position.

Possible impact on information returned by the database

The following additional information may be communicated by the geo-location database to the master WSD in case of master-slave operation:

- List of critical positions for each available frequency: The geo-location database uses the service area of the master WSD to determine the critical positions that will experience the most interference from slave WSDs located somewhere in the service area of the master WSD. This is illustrated above in ANNEX 10 Figure 74.

- Maximum allowed interference power caused by the slave WSDs at critical positions: This is the interference that is allowed to be caused by the master/slave configured system to a primary receiver at a critical position.

- Parameters that are needed for the master WSD to calculate path loss: This information is needed by the master WSD to accurately calculate the path loss between a slave WSD and a primary receiver at a critical position. The calculation is to be performed in a standardized fashion e.g. following the prescriptions of the path loss in equation (4.3-1). This information is in some implementations (as the one in equation (4.3-1)) only the height of the primary receiver antenna at the critical position.

ANNEX 12 : RESULTS OF ANALYSIS OF PROTECTION REQUIREMENTS FOR MOBILE/FIXED SERVICES IN THE BAND ABOVE 790 MHZ

This Annex provides the calculated maximum in-block e.i.r.p. for white space devices operating at different frequency offsets in order to protect the mobile service above 790 MHz. The power levels are shown for different assumed baseline levels over frequencies above 790 MHz, for the four WSD deployment scenarios described in Section 8.1.1

- **WSD deployed as macro BS**

	WSD max. In-block e.i.r.p.				**Resulting WSD required ACLR**			
baseline level	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**
dBm	**dBm**	**dBm**	**dBm**	**dBm**	**dB**	**dB**	**dB**	**dB**
-30	2.33	2.59	14.59	43.59	32.33	32.59	44.59	73.59
-31	3.27	3.52	15.52	44.52	34.27	34.52	46.52	75.52
-32	3.89	4.14	16.14	45.14	35.89	36.14	48.14	77.14
-33	4.32	4.58	16.58	45.58	37.32	37.58	49.58	78.58
-34	4.64	4.90	16.90	45.90	38.64	38.90	50.90	79.90
-35	4.88	5.14	17.14	46.14	39.88	40.14	52.14	81.14
-36	5.06	5.32	17.32	46.32	41.06	41.32	53.32	82.32
-37	5.20	5.45	17.45	46.45	42.20	42.45	54.45	83.45
-38	5.30	5.56	17.56	46.56	43.30	43.56	55.56	84.56
-39	5.38	5.64	17.64	46.64	44.38	44.64	56.64	85.64
-40	5.45	5.71	17.71	46.71	45.45	45.71	57.71	86.71
-41	5.50	5.76	17.76	46.76	46.50	46.76	58.76	87.76
-42	5.54	5.80	17.80	46.80	47.54	47.80	59.80	88.80
-43	5.57	5.83	17.83	46.83	48.57	48.83	60.83	89.83
-44	5.60	5.85	17.85	46.85	49.60	49.85	61.85	90.85
-45	5.62	5.87	17.87	46.87	50.62	50.87	62.87	91.87
-46	5.63	5.89	17.89	46.89	51.63	51.89	63.89	92.89
-47	5.64	5.90	17.90	46.90	52.64	52.90	64.90	93.90
-48	5.65	5.91	17.91	46.91	53.65	53.91	65.91	94.91
-49	5.66	5.92	17.92	46.92	54.66	54.92	66.92	95.92
-50	5.67	5.92	17.92	46.92	55.67	55.92	67.92	96.92

Table 59: WSD required ACLR as function of WSD in-block e.i.r.p. (WSD as macro BS)

- **WSD deployed as micro BS**

	WSD max. in-block e.i.r.p.				**Resulting WSD required ACLR**			
baseline level	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**
dBm	**dBm**	**dBm**	**dBm**	**dBm**	**dB**	**dB**	**dB**	**dB**
-44	-10.57	-10.32	1.68	30.68	33.43	33.68	45.68	74.68
-45	-9.83	-9.57	2.43	31.43	35.17	35.43	47.43	76.43
-46	-9.32	-9.06	2.94	31.94	36.68	36.94	48.94	77.94
-47	-8.95	-8.70	3.30	32.30	38.05	38.30	50.30	79.30
-48	-8.68	-8.43	3.57	32.57	39.32	39.57	51.57	80.57
-49	-8.48	-8.22	3.78	32.78	40.52	40.78	52.78	81.78
-50	-8.32	-8.07	3.93	32.93	41.68	41.93	53.93	82.93
-51	-8.20	-7.95	4.05	33.05	42.80	43.05	55.05	84.05
-52	-8.11	-7.85	4.15	33.15	43.89	44.15	56.15	85.15
-53	-8.04	-7.78	4.22	33.22	44.96	45.22	57.22	86.22
-54	-7.98	-7.73	4.27	33.27	46.02	46.27	58.27	87.27
-55	-7.94	-7.68	4.32	33.32	47.06	47.32	59.32	88.32
-56	-7.90	-7.65	4.35	33.35	48.10	48.35	60.35	89.35
-57	-7.87	-7.62	4.38	33.38	49.13	49.38	61.38	90.38
-58	-7.85	-7.60	4.40	33.40	50.15	50.40	62.40	91.40
-59	-7.84	-7.58	4.42	33.42	51.16	51.42	63.42	92.42
-60	-7.82	-7.57	4.43	33.43	52.18	52.43	64.43	93.43
-61	-7.81	-7.56	4.44	33.44	53.19	53.44	65.44	94.44
-62	-7.80	-7.55	4.45	33.45	54.20	54.45	66.45	95.45

Table 60: WSD required ACLR as function of WSD in-block e.i.r.p. (WSD as micro BS)

- **WSD deployed as FWA CPE**

	WSD max. in-block e.i.r.p.				**Resulting WSD required ACLR**			
baseline level	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**	**7.5 MHz offset**	**10 MHz offset**	**15 MHz offset**	**85 MHz offset**
dBm	**dBm**	**dBm**	**dBm**	**dBm**	**dB**	**dB**	**dB**	**dB**
-46	-11.51	-11.25	0.75	29.75	34.49	34.75	46.75	75.75
-47	-10.92	-10.66	1.34	30.34	36.08	36.34	48.34	77.34
-48	-10.50	-10.24	1.76	30.76	37.50	37.76	49.76	78.76
-49	-10.19	-9.94	2.06	31.06	38.81	39.06	51.06	80.06
-50	-9.97	-9.71	2.29	31.29	40.03	40.29	52.29	81.29
-51	-9.79	-9.54	2.46	31.46	41.21	41.46	53.46	82.46
-52	-9.66	-9.40	2.60	31.60	42.34	42.60	54.60	83.60
-53	-9.56	-9.30	2.70	31.70	43.44	43.70	55.70	84.70
-54	-9.48	-9.22	2.78	31.78	44.52	44.78	56.78	85.78
-55	-9.41	-9.16	2.84	31.84	45.59	45.84	57.84	86.84
-56	-9.37	-9.11	2.89	31.89	46.63	46.89	58.89	87.89
-57	-9.33	-9.07	2.93	31.93	47.67	47.93	59.93	88.93
-58	-9.30	-9.04	2.96	31.96	48.70	48.96	60.96	89.96
-59	-9.27	-9.02	2.98	31.98	49.73	49.98	61.98	90.98
-60	-9.25	-9.00	3.00	32.00	50.75	51.00	63.00	92.00
-61	-9.24	-8.98	3.02	32.02	51.76	52.02	64.02	93.02
-62	-9.23	-8.97	3.03	32.03	52.77	53.03	65.03	94.03
-63	-9.22	-8.96	3.04	32.04	53.78	54.04	66.04	95.04
-64	-9.21	-8.95	3.05	32.05	54.79	55.05	67.05	96.05
-65	-9.20	-8.95	3.05	32.05	55.80	56.05	68.05	97.05

Table 61: WSD required ACLR as function of WSD in-block e.i.r.p. (WSD as CPE)

- **WSD deployed as residential access point or portable device**

	WSD max. in-block e.i.r.p.				Resulting WSD required ACLR			
baseline level	7.5 MHz offset	10 MHz offset	15 MHz offset	85 MHz offset	7.5 MHz offset	10 MHz offset	15 MHz offset	85 MHz offset
dBm	dBm	dBm	dBm	dBm	dB	dB	dB	dB
-69	-35.71	-35.45	-23.45	5.55	33.29	33.55	45.55	74.55
-70	-34.95	-34.69	-22.69	6.31	35.05	35.31	47.31	76.31
-71	-34.42	-34.17	-22.17	6.83	36.58	36.83	48.83	77.83
-72	-34.05	-33.79	-21.79	7.21	37.95	38.21	50.21	79.21
-73	-33.77	-33.51	-21.51	7.49	39.23	39.49	51.49	80.49
-74	-33.56	-33.31	-21.31	7.69	40.44	40.69	52.69	81.69
-75	-33.40	-33.15	-21.15	7.85	41.60	41.85	53.85	82.85
-76	-33.28	-33.03	-21.03	7.97	42.72	42.97	54.97	83.97
-77	-33.19	-32.93	-20.93	8.07	43.81	44.07	56.07	85.07
-78	-33.11	-32.86	-20.86	8.14	44.89	45.14	57.14	86.14
-79	-33.06	-32.80	-20.80	8.20	45.94	46.20	58.20	87.20
-80	-33.01	-32.76	-20.76	8.24	46.99	47.24	59.24	88.24
-81	-32.98	-32.72	-20.72	8.28	48.02	48.28	60.28	89.28
-82	-32.95	-32.69	-20.69	8.31	49.05	49.31	61.31	90.31
-83	-32.93	-32.67	-20.67	8.33	50.07	50.33	62.33	91.33
-84	-32.91	-32.65	-20.65	8.35	51.09	51.35	63.35	92.35
-85	-32.89	-32.64	-20.64	8.36	52.11	52.36	64.36	93.36
-86	-32.88	-32.63	-20.63	8.37	53.12	53.37	65.37	94.37
-69	-35.71	-35.45	-23.45	5.55	33.29	33.55	45.55	74.55
-70	-34.95	-34.69	-22.69	6.31	35.05	35.31	47.31	76.31
-71	-34.42	-34.17	-22.17	6.83	36.58	36.83	48.83	77.83
-72	-34.05	-33.79	-21.79	7.21	37.95	38.21	50.21	79.21
-73	-33.77	-33.51	-21.51	7.49	39.23	39.49	51.49	80.49

Table 62: WSD required ACLR as function of WSD in-block e.i.r.p. (WSD as residential Access point or portable device)

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