ECC Report 261

Short Range Devices in the frequency range 862-870 MHz

Approved 27 January 2017

0 EXECUTIVE SUMMARY

This ECC report considers the situation with the use of the frequency band 863-870 MHz, such as to reflect on the policy, technological and market developments that took place since the development of the previous ECC Report 37 [1] “Compatibility of Planned SRD Applications with Currently Existing Radiocommunication Applications in the frequency band 863-870 MHz (2008)”. The main objective of this work is to review the applicable regulatory SRD requirements with the view on facilitating SRD innovation and more efficient use of the band with respect to new and existing services and (sub-) bands.

The report also looks at a closely related issue of feasibility of utilising the previous guard-band 862-863 MHz for SRDs, noting the changed conditions of use of the adjacent band below 862 MHz by the wideband cellular systems. Finally, the report considered the feasibility of introducing new proposed Narrowband/Wideband Networked SRD applications in the band 862-868 MHz.

In order not to duplicate the previous work, the report draws heavily on the previously published studies that are related to the use of SRDs in the subject frequency range, notably:

- ECC Report 37 “Compatibility of planned SRD applications with currently existing radio communications applications in the frequency band 863-870 MHz” (February 2004);
- ECC Report 181 “Improving spectrum efficiency in SRD bands” (September 2012) [2];
- ECC Report 200 “Coexistence studies for proposed SRD and RFID applications in the frequency 870-876 MHz/915-921 MHz” (September 2013) [3];
- ECC Report 207 “Adjacent band coexistence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz” (January 2014) [4];
- “Channel Access Rules for SRDs”, Study by IMST GmbH (November 2012) [5].

This report progressed by analysing information of the above referenced documents accordingly and developing new complementary analysis where and as necessary. In general it may be said that the methodology and assumptions used recently in the ECC Report 200 for similar studies in the bands 870-876/915-921 MHz were also used here, however noting the different scope of the envisaged SRD uses in respective bands. It is also worth noting that differently from “SRDs green field” approach applicable in the bands 870-876/915-921 MHz, the band 863-870 MHz had been already extensively used by SRDs for many years. Therefore this report had to start from certain reference scenarios referring to the existing status quo in the band. Also for the same reason, the sub-band 868-870 MHz was excluded early on from further analysis having noted that it was used most extensively and by some sensitive applications.

The publicly available software SEAMCAT (ver. 4.1.0) has been used for studies in this report, providing probabilistic assessment of interference as a result. The following analysis and conclusions are based on deployment assumptions (device density, activity factor, duty cycle, etc.) aiming to reflect average conditions over large population of devices instead of worst-case scenarios. Some further considerations as regards possible additional positive or negative impact of various assumptions made in the study are outlined in ANNEX 6: and ANNEX 7: respectively for adjacent band and intra-SRD coexistence prospects.

It should be also noted that ECC Report 249 [6] considered results of measurements of unwanted emissions of common radio systems and recommended that they be modelled in a statistical manner representing the phenomenon of spurious emissions domain "spikes" occurring on specific frequencies or at specific points in time. The probability of these occurrences can be defined as a distribution instead of modelling the spurious behaviour as being constant at the maximum permitted level across all frequencies and not varying with time, as typically specified in standards. This statistical approach can improve the accuracy of sharing/compatibility studies as it is based on more realistic assumptions.

For the sake of this report, constant spurious emissions levels were modelled as a simplifying assumption. Although it is recognised that this assumption is overly pessimistic, the results of this study are valid. The analysis may benefit from further future work once the recommendations in ECC Report 249 have been developed into an updated methodology.

The following lists the key findings and conclusions of this report, structured according the relevant bands. References to relevant sections of the report are given in brackets to guide to more detailed information for given issue.

Besides duty cycle (DC) and power level which are regulatory parameters, density, antenna height and deployment environment (indoor/outdoor) have also a significant impact on the results of the studies. In this report, the following assumptions have been considered:

- For 500mW Narrow Band Networked Short Range Devices (NBN SRDs):
  - Network Access Points (NAP): outdoor deployment with 5m for antenna height; DC 10% max/ 2.5% average;
  - Network Nodes (NN): outdoor deployment with 5m for antenna height; DC 2.5% max/0.7% average;
  - Terminal Nodes (TN): indoor deployment with 1.5m for antenna height, DC 0.1%;
  - All NBN SRD devices modelled with active APC.
- For 25 mW Wide Band Networked Short Range Devices (WBN SRDs):
  - AP: indoor deployment with 1.5m for antenna height, DC 10% max/2.5% average;
  - TN: indoor deployment with 1.5m for antenna height, DC 2.8% max/0.1% average.

This report has differentiated between certain applications in the frequency band 862-868 MHz.

- Typical SRDs;
- Wide Area Networks (WAN) based on 500 mW NBN SRDs;
- WANs based on TNs using 25 mW and sensitive NAP receivers (identified as LPWAN in this report and considered using a specific example of LORA™ WAN uplink use case in the band 865-868 MHz);
- Localised (indoor) deployment of 25 mW WBN SRDs.

This report specifically focuses on:

- case studies for intra-SRD coexistence in 862-868 MHz;
- 862-863 MHz: investigating possible conditions for introduction of SRDs;
- 865-868 MHz: investigating conditions under which the RFID interrogator channels could be liberalised to allow (up to) 500mW e.r.p. SRDs within the band;
- 863-865 MHz: investigating to which extent higher power, duty-cycle restricted SRD applications could co-exist with 10 mW analogue or digital audio devices/radio microphones;
- case studies for alignment of alarm parameters in 868-870 MHz based on TR 103 056 [7];
- impact of the newly proposed SRD arrangements on LTE below 862 MHz.

All CEPT Administrations should be also alerted to the emergence and wide spreading of the unlicensed use of LPWAN systems mostly in the band 865-868 MHz, such as the example of LORA™ WAN. Administrations wishing to protect LP WAN system s considered in this report should implement conclusions as given in the section on WAN (section 6.2.4). Other Administrations need not follow this restriction. With regard to the studied LP WAN case it should be noted that only network access point as a victim has been considered. The need for further studies may be considered once the ETSI system reference document on LP WAN is available.

Band 862-863 MHz:

- All NBN SRD network devices were simulated under conservative assumption of operating (1) with spectrum mask compliant with -54dBm/100kHz spurious emissions limits, (2) average and maximum DC and, (3) medium and highest density; (4), in order to achieve compatibility with incumbent applications in adjacent bands (Cordless Audio, Hearing Aids). The resulting adjacent band impact to LTE Uplink below 862 MHz would be very significant: leading to increased probability of bitrate loss from 5-8% up to 14-21% over the baseline case, depending on considered deployment densities and even with the unwanted emission mask Option 1. Such high probability of adjacent band interference to LTE operations would be clearly excessive (for details refer to sections 5.1.3 and 5.4 of the report). Additional sensitivity analysis was performed to test the option of reducing the NBN SRD output power to 100 mW across entire 862-863 MHz. However this allowed reducing the interference level by few percentage points only, with the risk of interference under high deployment density urban scenarios still being between 7-14%.

- Considering the results of simulations (table 87), reported in Section 5.1.3, it appears that implementation of NBN networks as presented in section 2.5.1 (with NAP/NN/TN) could create high probability of interference on LTE base stations below 862 MHz.
- Furthermore, some practical tests (Annex 8) have shown that deployment of NBN with 500 mW e.r.p above 862.4 MHz could potentially affect audio systems (in close proximity) above 863 MHz.
- Hence, operation in the band 862-862.4 MHz should be restricted to terminals with 500 mW e.r.p, low duty cycle (0.1%) and to terminals with 100 mW e.r.p, low duty cycle (0.1%) in the band 862.4-863 MHz, within specific networks (e.g. smart metering in rural or remote area and low density deployments). In all cases, unwanted emission mask of these terminals shall comply with mask option 1 (in Annex 1 figure 44).
- Non-specific SRD devices with e.r.p. of up to 25 mW and DC of up to 0.1% and with 350 kHz bandwidth were shown to have minimal interference to Cordless Audio devices in 863-865 MHz (see 5.2 and 5.3), and to LTE under the condition that the transmitters use emission mask Option 1, making their implementation is therefore feasible.
- WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters use emission mask Option 1 as described in ANNEX 1:, Figure 32, i.e. meeting the spurious emissions limit of -54dBm/100 kHz. Furthermore, although the studied worst case scenario to ensure protection of LTE 10 MHz channels operating below 862 MHz resulted by mask Option 1, some stakeholders were of the opinion that an additional restriction of 800 kHz guard band may need to be implemented between the frequency 862 MHz and the WBN lower band edge (i.e. 862.8 MHz). Given the minimum required channel bandwidth of 1 MHz, this effectively means that WBN SRD should not be introduced in 862-863 MHz.
- SRD vendors wishing to use the band 862-863 MHz should weigh the risks and accept responsibility for deciding themselves whether their specific applications shall be capable of operating in the presence of comparatively high ambient noise levels from LTE UEs' out-of-band emissions and design their products accordingly (see. 5.1.1).

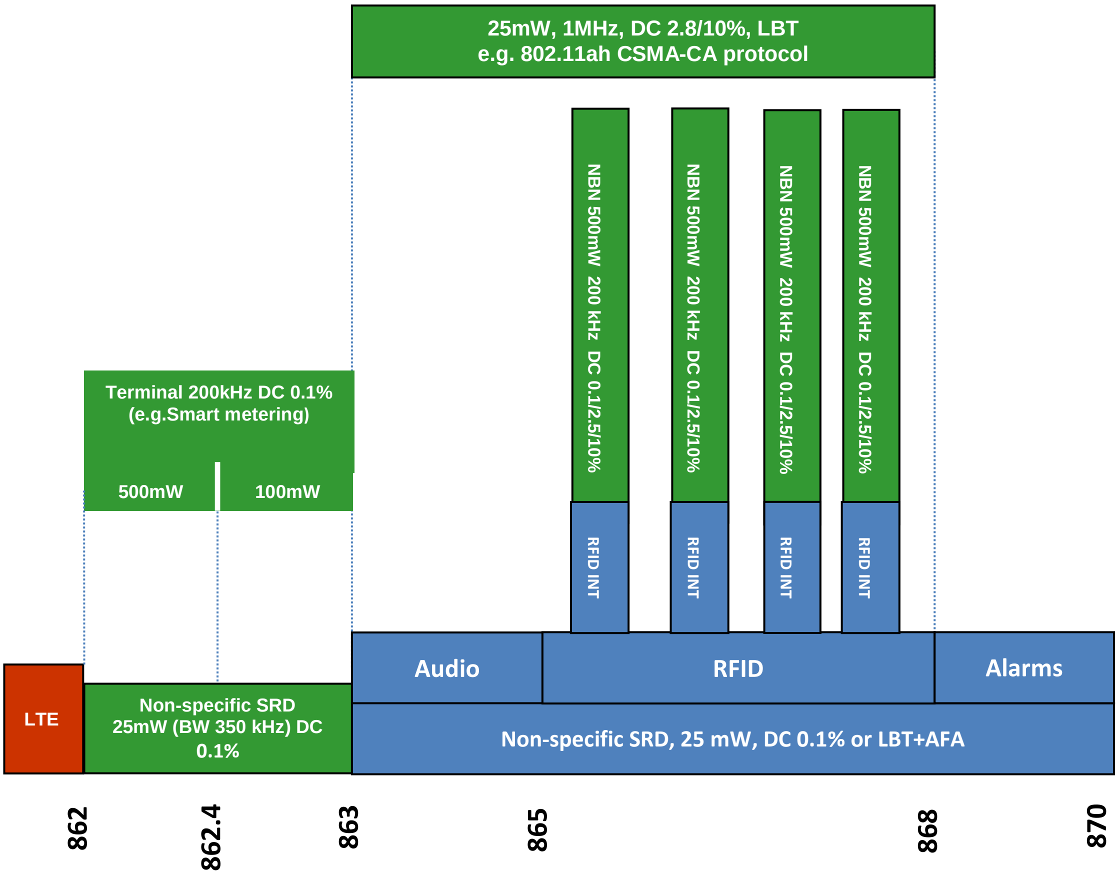
Band 863-865 MHz:

- Although SEAMCAT simulations have shown that additional NBN SRD 500 mW applications may coexist with cordless audio in the band (see 6.2.2) (i.e. for the medium density and average DC case the contribution of NBN SRD deployed over 863-868 MHz to audio SRDs in 863-865 MHz may be estimated to be around 2% to 4% of interference probability), practical tests have been carried out (see ANNEX 8:) showing that this coexistence would be difficult because of the expected up to 100% duty cycle nature of audio systems. Also simulations of adjacent band interference from NBN SRD in 863-865 MHz to LTE below 862 MHz (see 6.1) have shown That this band should not be recommended for NBN SRD.
- The SEAMCAT simulations have shown that WBN SRD applications may coexist with Cordless Audio in the band (see 7.2.2), even, as conservative approach, without introducing polite spectrum access technique such as CSMA/CA or equivalent as mitigation in the SEAMCAT simulations. Cordless Audio manufacturers noted and expressed concern that practical tests were not conducted, however it was considered by other parties that such tests were not obligatory. However, the use of LBT or equivalent technique may facilitate more reliable use of the spectrum in particular in order to mitigate any potential interference to cordless audio devices.
- WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters used emission mask Option 1 as described in ANNEX 1:, Figure 32.

Band 865-868 MHz:

- WBN SRDs;
  - WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters used emission mask Option 1 as described in ANNEX 1:, Figure 32;
  - WBN SRD applications are able to operate across the entire band 865-868 MHz without causing harmful interference to other SRDs in this band, as studied in this report (see 7.2.3 and 8);
- 500 mW NBN SRDs (as presented in section 2.5.1);
  - NBN SRDs are able to operate throughout the band 865-868 MHz without causing harmful interference to Cordless Audio applications as long as the existing Tx restrictions are obeyed, i.e. e.r.p.<100mW below 865.6 MHz (see 6.2.2);
  - NBN SRDs are able to operate throughout the band 865-868MHz without causing harmful interference to RFID provided that their duty cycle doesn't exceed 2.5 %. When the duty cycle of NAP of NBN SRDs exceeds 2.5%, it is preferable that these devices operate on the high-power RFID interrogator channels (see 6.2.3);
  - When considering LPWAN applications (e.g. LORA™) in the band 865-868 MHz, which are in current use in some European countries (see section 2.3.7), the available studies up to now show that sharing between NBN and LPWAN in the frequency band 865-868 MHz is possible if NBN SRDs were restricted to RFID interrogator channels.;
  - Considering the results of simulations, reported in Section 6.1 and recognising that this kind of operation would be more than 3 MHz offset from the LTE upper edge, it appears that implementation of NBN networks within "RFID interrogator channels" may create acceptable probability of interference to LTE base stations below 862 MHz;
- It may be also noted that the impact from NBN SRD and WBN SRD was studied separately in the report, i.e. the aggregated impact from both these systems - such as if deployed together in the same band(s) - to adjacent band below 862 MHz (LTE) and in respect to other incumbent SRDs in the band 863-868 MHz has not been considered. This was for the simple reason that it was not possible to make a meaningful a priori judgment as to the eventual preferred regulatory configuration and band choice for the respective proposed new systems.

The overall conclusions of the report may be illustrated by the following Figure 1 which depicts the proposed changes to the use of the subject frequency range.



Legend

- Proposed new SRD uses
- Main existing SRD

Note 1: SRDs utilising 862-863 MHz are to be capable of enduring high ambient noise from LTE UE's OOB emissions

Note 2: All SRDs to comply with spurious emissions limit of -54 dBm/100kHz

Note 3: WBN and NBN emissions to comply with mask option 1 (Annex 1 figures 32 and 43 respectively)

Note 4: The expression DC 0.1/2.5/10% means Duty Cycle of: 0.1 % for TN; 2.5% for NN; 10% for NAP.

Note 5: SRD uplinks terminal in the band 862-862.4 MHz should be restricted to 500 mW e.r.p. and in the band 862.4-863 MHz to uplink terminals with 100 mW e.r.p. within specific networks (e.g. smart metering in rural or remote area and low density deployments)

Figure 1: Proposed changes to the use of SRDs in the frequency range 862-870 MHz

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
AFA	Adaptive Frequency Agility
ALD	Assistive Listening Devices
AP	Access Point
BS	Base Station
CEPT	European Conference of Postal and Telecommunications Administrations
CSMA-CA	Carrier Sense Multiple Access protocol with Collision Avoidance
DC	Duty Cycle
dRSS	desired Received Signal Strength (term used in SEAMCAT)
EC	European Commission
ECC	Electronic Communications Committee
e.i.r.p.	equivalent isotropically radiated power
e.r.p.	effective radiated power (with reference dipole antenna)
ETSI	European Telecommunications Standards Institute
EFTA	European Free Trade Association
EU	European Union
FHSS	Frequency Hopping Spread Spectrum
FSU	Field Service Unit
GSM	Global System for Mobile Communications
IEEE	Institute of Electrical and Electronics Engineers
IL and ILK	Interfering Link
ILR	Interfering Link Receiver
ILT	Interfering Link Transmitter
IoT	Internet of Things
iRSS	interference Received Signal Strength (term used in SEAMCAT)
ISM	Industrial, Scientific and Medical
ISO	International Organization for Standardization
LBT	Listen Before Talk (Transmit)
LDC	Low Duty Cycle
LORA	Trademark name of one of LPWAN technologies, promoted by “LoRa Alliance”

Abbreviation	Explanation
LPRA	the Low Power Radio Association
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
M3N	Metropolitan Mesh Machine Networks
MCL	Minimum Coupling Loss
NAP	Network Access Points
NN	Network Nodes
NBN SRD	Narrowband Networked SRD
OBW	Operating (channel) Bandwidth
OFDM	Orthogonal Frequency Division Multiplexing
OMS	Open Metering Specification
PHY	Physical layer
PR-SMEP	Spectrum Requirements for Smart Metering European access profile Protocol
RF	Radio Frequency
RFID	Radio Frequency Identification
Rx	Receiver
SEAMCAT	Spectrum Requirements for Smart Metering European access profile Protocol
SM	Smart Metering
SRD	Short Range Device
TN	Terminal Nodes
TS	Terminal Station
Tx	Transmitter
UE	User Equipment
UHF	Ultra-High Frequency band (300-3000 MHz)
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VLK	Victim Link
VLR	Victim Link Receiver
WB	Wideband
WBN SRD	Wideband Networked SRDs
WLAN	Wireless

1 INTRODUCTION

This ECC report addresses the need for coexistence studies identified within the CEPT Roadmap for review of spectrum requirements for various SRD and RFID applications in the 863-870 MHz spectrum. It builds on the previous SRD and RFID coexistence studies in the UHF band. Most notably it can be seen as the continuation of work started with the ECC Report 37 [1]. The main objective of this new report is to analyse the applicable technical regulatory SRD requirements with the view to facilitating further SRD innovation and more efficient use of the band.

The report also looks at a closely related issue of feasibility of utilising the 862-863 MHz for SRDs that has been used by various Government services, noting the recent changed conditions of use of the adjacent band below 862 MHz from broadcasting to wideband cellular systems.

This report specifically focuses on:

- case studies for improved intra-SRD coexistence in 862-868 MHz;
- 862-863 MHz: investigating possible conditions for SRDs;
- 865-868 MHz: investigating conditions under which the RFID interrogator channels could be liberalised to allow (up to) 500 mW e.r.p. SRDs within the band;
- 863-865 MHz: investigating to which extent higher power, duty-cycle restricted SRD applications could co-exist with 10 mW analogue or digital audio devices/radio microphones;
- case studies for alignment of alarm parameters in 868-870 MHz based on TR 103 056;
- impact of the newly proposed SRD arrangements on LTE below 862 MHz.

Over and above the studies outlined, the report also investigates the potential use of wideband systems in the 862-868 MHz band. The ETSI Report ETSI TR 103 245 [8] requested spectrum access for wideband SRD in the bands 870-876 MHz and 915-921 MHz. Those studies were described in ECC Report 246 [9].

In order not to duplicate the previous work, the report draws heavily on the previously published studies that are related to the use of SRDs in the subject frequency range, namely:

- ECC Report 37 “Compatibility of planned SRD applications with currently existing radio communications applications in the frequency band 863-870 MHz” (February 2004) ;
- ECC Report 181 “Improving spectrum efficiency in SRD bands” (September 2012) [2];
- ECC Report 200 “Coexistence studies for proposed SRD and RFID applications in the frequency 870-876 MHz/915-921 MHz” (September 2013)[3];
- ECC Report 207 “Adjacent band coexistence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz” (January 2014) [4].
- “Channel Access Rules for SRDs”, Study by IMST GmbH (November 2012) [5].

2 CONSIDERED SRD APPLICATIONS, THEIR PARAMETERS AND USE SCENARIOS

2.1 CURRENT SRD REGULATIONS IN THE BAND 863-870 MHZ

The use of the band 863-870 MHz by SRD is already well established in Europe and is fully harmonised in the EU/EEA territory by the EC Decision 2006/771/EC [10] and its subsequent revisions. The key reference guiding SRD use in the band 863-870 MHz, as well as in many other bands, is ERC/REC 70-03 [11], which is being kept constantly updated by CEPT. Relevant provisions of its latest version will be summarised below. For a group of CEPT countries (EU/EEA member states) it is mandatory to implement the EC decisions listed in Appendix 2 of ERC/REC 70-03. The technical annexes of these EC Decisions state the frequency bands and the relevant essential regulatory parameters for SRDs. The parameters in the EC Decisions listed may be subject to derogation for an individual EU country and are detailed in Appendix 3 of ERC/REC 70-03.

A very significant additional level of standardisation of technical parameters of SRDs is provided by ETSI via a complement of technical reports and harmonised standards - European Norms (EN). Harmonized standards for radio equipment contain requirements relating to effective use of the spectrum and avoidance of harmful interference. These can be used by manufacturers as part of the conformity assessment process. With regard to SRDs, ETSI developed four generic standards: EN 300 220 [12], EN 300 330 [13], EN 300 440 [14] and EN 305 550 [15], as well as a number of specific standards covering specific applications. All ETSI standards relevant to SRDs are listed in Appendix 2 of ERC/REC 70-03.

A certain degree of global harmonisation for SRD use is also an objective, especially for personally carried devices. This is sought via the ITU-R activities and deliverables, such as Report ITU-R SM.2153 [16] on "Technical and operating parameters and spectrum use for short range radiocommunication devices" (07/2013), which replaced previous Recommendation ITU-R SM.1538 [17].

The regulatory provisions for SRDs in the band 863-870 MHz are established by ERC/REC 70-03 using grouping into several SRD application categories:

Table 1: Non-specific SRDs (Annex 1 of ERC/REC 70-03)

h1.1	863-870 MHz (notes 3 and 4)	25 mW e.r.p.	≤ 0.1% duty cycle or LBT (notes 1 and 5)	≤ 100 kHz for 47 or more channels (note 2)		FHSS
h1.2	863-870 MHz (notes 3 and 4)	25 mW e.r.p. Power density - 4.5 dBm/100 kHz (note 7)	≤ 0.1% duty cycle or LBT+AFA (notes 1, 5 and 6)	Not specified		DSSS and other wideband techniques other than FHSS
h1.3	863-870 MHz (notes 3 and 4)	25 mW e.r.p.	≤ 0.1% duty cycle or LBT+AFA (notes 1 and 5)	≤ 100 kHz, for 1 or more channels modulation bandwidth ≤ 300 kHz (note 2)		Narrow /wide-band modulation
h1.4	868.000-868.600 MHz (note 4)	25 mW e.r.p.	≤ 1% duty cycle or LBT+AFA (note 1)	Not specified, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
h1.5	868.700-869.200 MHz (note 4)	25 mW e.r.p.	≤ 0.1% duty cycle or LBT+AFA (note 1)	Not specified, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
h1.6	869.400-869.650 MHz	500 mW e.r.p.	≤ 10% duty cycle or LBT+AFA (note 1)	Not specified, for 1 or more channels		Narrow / wide-band modulation The whole stated frequency band may be used as 1 channel for high speed data transmission
h1.7	869.700-870.000	5 mW e.r.p.	No requirement	Not specified		Narrow / wide-band

	MHz (note 11)	25 mW e.r.p.	≤1% duty cycle or LBT+AFA (note 1)	for 1 or more channels		modulation. No channel spacing, however the whole stated frequency band may be used

Note 1: When either a duty cycle, Listen Before Talk (LBT) or equivalent technique applies then it shall not be user dependent/adjustable and shall be guaranteed by appropriate technical means. For LBT devices without Adaptive Frequency Agility (AFA), or equivalent techniques, the duty cycle limit applies. For any type of frequency agile device the duty cycle limit applies to the total transmission unless LBT or equivalent technique is used.
Note 2: The preferred channel spacing is 100 kHz allowing for a subdivision into 50 kHz or 25 kHz.
Note 3: Sub-bands for alarms are excluded (see ERC/REC 70-03 Annex 7).
Note 4: Audio and video applications are allowed provided that a digital modulation method is used with a max. bandwidth of 300 kHz. Analogue and digital voice applications are allowed with a max. bandwidth ≤ 25 kHz. In sub-band 863-865 MHz voice and audio conditions of Annexes 10 and 13 of ERC/REC 70 – 03 apply respectively.
Note 4bis: Audio and video applications are excluded. Analogue or digital voice applications are allowed with a max. bandwidth ≤ 25 kHz and with spectrum access technique such as LBT or equivalent. The transmitter shall include a power output sensor controlling the transmitter to a maximum transmit period of 1 minute for each transmission
Note 5: Duty cycle may be increased to 1% if the band is limited to 865-868 MHz.
Note 6: For other wide-band modulation than FHSS and DSSS with a bandwidth of 200 kHz to 3 MHz, duty cycle can be increased to 1% if the band is limited to 865-868 MHz and power to ≤10 mW e.r.p.
Note 7: The power density can be increased to +6.2 dBm/100 kHz and -0.8 dBm/100 kHz, if the band of operation is limited to 865-868 MHz and 865-870 MHz respectively.

Table 2: Alarms (Annex 7 of ERC/REC 70-03)

Frequency Band		Power / Magnetic Field	Spectrum access and mitigation requirements	Modulation/ maximum occupied bandwidth	ECC/ERC deliverable	Notes
a	868.600-868.700 MHz	10 mW e.r.p.	≤ 1.0 % duty cycle	25 kHz		The whole frequency band may also be used as 1 channel for high speed data transmissions
b	869.200-869.250 MHz	10 mW e.r.p.	≤ 0.1 % duty cycle	25 kHz		Social Alarms
c	869.250-869.300 MHz	10 mW e.r.p.	≤ 0.1 % duty cycle	25 kHz		
d	869.300-869.400 MHz	10 mW e.r.p.	≤ 1.0 % duty cycle	25 kHz		
e	869.650-869.700 MHz	25 mW e.r.p.	≤ 10 % duty cycle	25 kHz		

Table 3: Radio Microphone applications including Assistive Listening Devices (ALD) (Annex 10 of ERC/REC 70-03)

g	863-865 MHz	10 mW e.r.p.	No requirement	Not specified		Radio microphones including wireless audio and multimedia streaming devices. The frequency band is also identified in annex 1

Table 4: RFID (Annex 11 of ERC/REC 70-03)

a1	865.0-865.6 MHz	100 mW e.r.p.	No requirement	≤ 200 kHz		
a2	865.6-867.6 MHz	2 W e.r.p.	No requirement	≤ 200 kHz		
a3	867.6-868.0 MHz	500 mW e.r.p.	No requirement	≤ 200 kHz		

Table 5: Radio microphone applications including Assistive Listening Devices (ALD), Wireless audio and multimedia streaming systems (Annex 10 of ERC/REC 70-03)

g	863-865 MHz	10 mW e.r.p.	No requirement	Not specified		Radio microphones including wireless audio and multimedia streaming devices. The frequency band is also identified in annex 1

It may be seen from the above that the use of the band 863-870 MHz is based on two approaches:

- Generic access to the entire band (excluding sub-bands for Alarms);
- Application-specific access conditions in dedicated sub-bands.

In that sense the ERC/REC 70-03 [11] offers a balanced approach which is both technology-neutral and yet allows dedicated niches for specific technologies that might benefit of fulfilment of specific requirements, such as larger DC, higher reliability, lower latency etc.

2.2 EXTENT OF EXISTING SRD USE IN 863-870 MHZ

The ITU offers general considerations on SRD spectrum use measurements methods and objectives as provided in the ITU-R Reports SM.2154 [24] and SM.2179 [25]. However they do not report specific findings on spectrum utilisation, leaving this to national and regional investigations.

There are several surveys made by CEPT that can shed light on the actual use of SRDs in this band. One of these is the recent ECC Report 182 “Survey about the use of the frequency band 863-870 MHz” (September 2012) [26]. From the analysis there it emerges that the most numerous SRD applications, with more than 40 million units sold annually (whole conservative figure) in this band include the following:

- Sub-metering applications, i.e. intra-apartment collection of metering information from heating and similar devices;
- Home automation (incl. all kinds of remote controls);
- Alarms (incl. intrusion sensing);
- Automotive;
- Audio.

The survey results also showed that majority of devices rely on simple mitigation techniques such as DC, whereas more elaborate mechanisms such as LBT/AFA, FHSS, DSSS (by descending order) are less widely used.

Another important survey has been carried out by the ECC PT FM22 in 2011 as multi-stage monitoring campaign carried out in total of 12 European countries.

The following of its findings may be of relevance to this study:

- typical SRD channel bandwidths in use are 25 kHz in channelized sub-bands and an average of 150 kHz in parts of the bands that do not have prescribed channelization;
- the most occupied sub-bands are 863-865 MHz and 868-870 MHz with the largest concentration of SRD use observed in residential parts of the cities;
- the sub-band 865-868 MHz is mostly used by RFIDs, which are accordingly concentrated in industrial areas, logistic and shopping centres, including airports. Therefore the occupancy of this sub-band as seen across the cities is rather limited for instance.

These findings well correspond to observations in ECC Report 182 [26]. The first one relating to majority of devices being simple DC-based devices, the two latter findings correspond to observation that the list of most sold applications is dominated by home-based devices such as sub-metering, home automation, alarms and audio devices.

2.3 PARAMETERS AND SCENARIOS OF TYPICAL SRD APPLICATIONS IN 863-870 MHZ[1],[2]

2.3.1 Alarms

Alarm systems are designed to detect an event and to either distribute the alarm within the network or to pass the message to a central operation centre. There are numerous applications like smoke detection, fire alarm, intruder detection, or social alarms, which slightly differ with regards to their requirements.

Residential Smoke Detector systems typically concentrate on the message spreading, so that if one sensor detects smoke, the alarms will sound on all the detectors in the network, improving the chances that occupants will be alerted. While wired smoke detectors are regulated by EN 14604 [27], there are only

[1] The content of this section is largely based on material in “Channel Access Rules for SRDs” [5]

[2] For additional information regarding parameters and activity estimates of various SRDs please refer to ECC Report 181, i.e. Table 26 in Annex 7 therein [2]

national standards for wireless smoke detector networks. For example, VdS 3515 in Germany demands a battery lifetime of 10 years and alarm forwarding delay of not more than 30 seconds on a single link. A typical smoke detector system consists of up to 20 sensors (see ETSI TR 103 056) [7]. Table 6 below shows typical values for technical and implementation parameters of such systems.

Table 6: Technical and implementation parameters for smoke detector systems

Parameter	Comment
Packet size	Around 100 bits
Data rate	<500 kbps; 100 kbps decreases power consumption, ETSI TR 102 649-2 [20]
Max Duty cycle	0.1%
Average DC over one day	Approx. 0.0015% Note
Latency	Up to 30 seconds for a single link typically up to 60 seconds within a network
Installation	In buildings

Note: when there is an alarm, the DC could rise up to 0.1%, otherwise just some regular "battery live and all OK" checks could be taking place thus the average DC over one day would be much smaller than the limit

While smoke detector systems are typically installed in private residential buildings, fire alarm systems are widely deployed in commercial and industrial premises like shops, hotels or factories. The requirements for a fire alarm system as defined by CEN's EN 54 [21] are much more stringent, demanding regular network checks and high immunity to interference and site attenuation. A link failure needs to be detected within 300 s, which is usually addressed by requiring bi-directional communication between all network nodes in even shorter time periods. Furthermore, simultaneous forwarding of different alarms within the same systems as well as parallel operation of two independent alarm systems of the same manufacturer shall be possible without messages losses and a maximum messages spreading time of 10 seconds. The battery lifetime is reduced to a minimum period of 36 months. A fire alarm network might include up to 500 devices, widely spread within a large building (see TR 103 056 [7]). Table 7 below shows typical values for technical and implementation parameters of such systems.

Table 7: Technical and implementation parameters for fire alarm systems

Parameter	Comment
Packet size	System dependent
Data rate	<500 kbps; 100 kbps decreases power consumption, TR 102 649-2 [19]
Max Duty cycle	From <0.1% up to 1% or even more when including regular network checks for systems with large number of detectors; higher data traffic during alarm conditions
Latency	Up to 10 seconds within a network
Installation	In and around buildings

For *intruder alarm systems*, the alert is typically transmitted to a central unit, which, for example, sounds the siren outside the premises and optionally forwards the alert to a person or institution in charge (e.g. owner, surveillance centre, police). EN 50131 specifies four different grades of security with increasing requirements on immunity to intentional and unintentional manipulation and interference, packet throughput and link failure detection. A link failure shall be detected and reported within 240 minutes for a grade 1 device, while only 10 seconds are allowed for grade 4 resulting in a relatively stringent requirement for periodic transmission. Typical residential alarm systems have less than 50 sensor devices (see TR 103 056 [7]). Table 8 below shows typical values for technical and implementation parameters of such systems.

Table 8: Technical and implementation parameters for intruder alarm systems

Parameter	Comment
Packet size	Around 100 bits
Data rate	<500 kbps; 100 kbps decreases power consumption, ETSI TR 102 649-2 [20]
Max Duty cycle	From < 0.1% to 10% when including regular network checks in between 240 min (grade 1) down to 10s (grade 4), high data traffic during alarm conditions Note
Average DC over one day	Approx. 0.01 -0.001 % Note
Latency	Several seconds, ETSI TR 103 056
Installation	In and around buildings

Note: when there is an alarm, the DC could rise up to 10%, otherwise just some regular "battery live and all OK" checks could be taking place thus the average DC over one day would be much smaller than the limit

There is an increasing trend for elder people to live independently in their own homes despite of their physical handicaps. These systems for the so-called Ambient Assisted Living (AAL) offering social alarms are only responsive in the case of emergency. For example, a home electrocardiogram monitoring unit could communicate when limits are exceeded. A motion sensor could for example detect a collapse and initiate an automatic emergency call transmission. In an even simpler implementation the wearable transmitter just has an alarm button, which can be pressed in case of an emergency situation. EN 50134 [28] specifies the requirements for social alarms. The connection must be bi-directional allowing the health centre to confirm the alarm message and to communicate with the person in distress. Furthermore, alarm devices without controlled access to the frequency band shall use frequencies specifically dedicated to social alarm systems. Social alarms typically have a low duty cycle, but the requirements towards reliability during an alarm situation are high. Table 9 below shows typical values for technical and implementation parameters of such systems.

Table 9: Technical and implementation parameters for social alarm systems

Parameter	Comment
Packet size	Around 100 bits
Data rate	100 kbps, high data rate decreases power consumption, ETSI TR 102 649-2
Max Duty cycle	From <0.1% (checking the system) to 10% data traffic during alarm conditions due to communication function
Average DC over one day	Approx. 0.001% Note
Latency	Several seconds, ETSI TR 103 056, ECC Report 181 [2]
Installation	In and around buildings
Power consumption	Typically 10 years

Note: when there is an alarm, the DC could rise up to 10%, otherwise just some regular "battery live and all OK" checks could be taking place thus the average DC over one day would be much smaller than the limit.

Devices for social alarms will have limited size so that they can be easily worn on the body. Hence, alarm devices are not suited to frequencies below UHF. On the other side they should have a range of 20 m within buildings so that the higher frequencies above 1 GHz are not suitable due to the power limitations of a battery-powered device. More information can be found in ETSI TR 102 649-2 [20].

2.3.2 Cordless Audio and Radio Microphones

Cordless audio devices consist of radio microphones, assistive listening devices, speakers, and headphones. These applications significantly differ from the aforementioned applications due to their continuous transmission requirement. The majority of current equipment uses FM modulation with a 100% duty cycle. In addition baby Alarms use the 864.8-865 MHz band. There are no channelling or bandwidth limitations in ERC/REC 70-03 [11], which allows manufactures to optimise their spectrum efficiency in this band, which has increased from some two simultaneous radio microphones to four or in some cases five.

The ECC PT FM22 multi-stage monitoring campaign showed this band was one of two most heavily used sub bands.

Radio microphones and in-ear monitoring for professional users have a typical bandwidth of 200 kHz for analogue and digital audio transmissions, and up to 300KHz for some cordless audio and IEM, which use stereo transmissions. However, using digital processing, such as coding, inevitably introduces delays any bandwidth reduction is rarely achieved due the low latency requirements of less than a few milliseconds.

This is the only fully harmonised radio microphone band in the EC and is extensively used by peripatetic groups, lecturers and other exhibition use. In addition it is used as an “overflow” for professional productions using licenced spectrum especially for In Ear Monitors.

Many consumer devices use this band for a wide range of applications from video camera sound to wild life recording

Assistive listening devices (ALD) are used by hearing impaired persons, as an audio hearing aid. They consist of a microphone placed near the speaker and a loudspeaker, headphone, or hearing aid on the receiver side, which amplifies the speaker’s voice while suppressing the background noise. In recent years “ear to ear “communication has been used to balance the audio input especially where the user has only on ear capable of hearing

Tour guide systems use a single radio microphone to “broadcast” to persons receiving the same signal with a headset. These applications are standardised by EN 300 422 [29] or EN 301 357 [30]. Table 10 below shows typical values for technical and implementation parameters of such systems.

Table 10: Technical and implementation parameters for Cordless audio

Parameter	Comment
Bandwidth	Up to 2MHz, typically 200-300 KHz
Duty cycle	Up to 100% when Cordless Audio device is in operation
Average DC over one day	Depends on application: from 3 to18 hours of activity a day, (a show can be up to eight hours a day and ALDs 16-20 hours)
Latency	Few ms
Installation	In and around buildings, outdoors, marine and airborne

Wireless loudspeakers, headphones, in-vehicle audio devices, and consumer microphones are standardised by EN 301 357 or EN 300 422. Stereo equipment requires a bandwidth of >200 kHz, while multichannel audio equipment such as surround sound systems operating on a higher bandwidth, and use the 1785-1800 MHz band Baby Alarms use the 864.8-865 MHz band and are both analogue and digital they come under EN 300 220 [12] with a 50 kHz bandwidth, they are in universal use throughout the EC, this band having taken over from the 27 MHz and 49 MHz band for these devices due to a quieter noise floor and better in house propagation.

2.3.3 RFID

RFID systems allow reading data from tags attached to an object for the purposes of automatic identification and tracking. The majority of the tags are passive devices using the energy generated by the interrogator's antenna for responding. In passive backscatter RFID systems, the interrogator continuously transmits at a constant radio frequency power level, while the tag answers by modifying the amount of reflected power. Alternatively, battery powered RFID can be used allowing to significantly increase the communication range at the expense of tag costs and size.

Table 11 focuses on requirements of RFIDs in the UHF band.

Table 11: Technical and implementation parameters for UHF - RFID

Parameter	Comment
Packet size	100-250 bits
Data rate (return link)	10 - 40 kbps, ISO18000-6
Duty cycle	<1%: tag <10%: interrogator with active tags up to 100%: interrogator with passive tags
Average DC over one day	Approx. 5-30% (for interrogator, assuming 8 hours of activity a day)
Installation	Commercial, industrial environments

A tremendous growth is expected for RFIDs using UHF frequencies due to an even larger communication range up to 3 m and higher bandwidth, which is required to either increase data volume or to read a higher number of tags within the same time. UHF RFIDs are used for example in asset tracking, waste management, parking lot access, or logistic and supply chains. It is expected that the density of tags in logistics will significantly increase in the future, so that reading of up to 1500 tags in a single interrogation might be required (ETSI TR 102 649-2 [20]), while the current regulation with a 200 kHz bandwidth limitation allows for only 200 tag readings per second.

One significant reason for the success of the LF and HF-band is the worldwide availability of the frequency bands, while there is no harmonised regulation for the UHF band. An international standard (ISO's 18000 series) exists defining the parameters for air interface communications for passive backscatter RFID systems. The standard encompasses all four different frequency bands. ISO18000-2 covers parameters for communications below 135 kHz (LF-band), while ISO18000-3, ISO18000-4, and ISO18000-6 apply to 13.56 MHz (HF-band), 2.4 GHz, and 860-960 MHz, respectively. More information and a summary of RFID standards can be found in ETSI TR 102 449 [31].

2.3.4 Sub-metering applications

To date remote metering (electricity, gas, water and heat) is used either by suppliers or by sub-metering service providers to determine the energy or water consumption in private houses from the outside without the need to enter the building. Meters can be simple transmitters connected to a central database for data collecting. Repeaters can be used to extend the range of the network, which might be either infrastructure devices or meter devices with repeater functionality. The latter requires the use of transceivers instead of simple transmitters, which increases the cost of the meter and its power consumption due to the forwarding functionality, but significantly reduces the infrastructure costs. Nevertheless, the use of transceivers in the meter devices offer additional features like reading data on demand, remote meter configuration and maintenance, or scheduled transmissions for collision avoidance.

Table 12 below shows typical values for technical and implementation parameters of such systems.

Table 12: Technical and implementation parameters for metering systems

Parameter	Comment
Packet size	Hundreds of bits
Data rate	Typically from 32.768 kbps up to 100 kbps
Max Duty cycle	Typically <0.1%; up to 1% (for 868.3MHz)
Average DC over one day	Approx. 0.02%
Latency	Scheduled data transmission, ETSI TR 102 886 <1s on demand,
Installation	In and around buildings

Up to now remote metering has been done for billing purposes requiring a single measurement at the end of the year. The focus on energy efficiency (see Directive 2006/32/EC [33]) will dramatically change the attitude towards Automatic Meter Reading (AMR) requiring “intelligent” or smart metering with nearly real time data measurements. On the one hand it is expected that displaying the actual energy consumption will allow the customer to make smarter decisions about his energy usage most likely resulting in energy savings, while on the other hand the management and control of the power network will be supported by nearly real time information. Directive 2009/72/EC [34] for electricity and Directive 2009/73/EC [35] for gas extends the requirements towards intelligent metering systems assisting the active participation of consumers in the market. In March 2009, the European Commission issued mandate M/441 [36] for the standardization of smart metering functionalities and communication for electricity, gas, heat, and water applications. Despite the fact that the smart metering requires significantly shorter measurement intervals, the final report of M/441 issued in December 2009 still considers battery powered devices: “Battery powered meters do have limited power supply resources as the communication process needs to be operated over many years without changing the power supply battery (typically at least 10 years and effective business cases may require longer periods). For this issue, specific communication procedures have been developed that are different from the electricity meters communications.” Hence, most non-electricity meters are supposed to be battery powered and therefore limited with regards to their duty cycle. EN 13757-4 [37] specifies the requirements of parameters for the physical and the link layer for this kind of metering devices. Furthermore, the Open Metering Specification[3] (OMS) is increasingly used in Europe as a normative requirement for deployment of smart metering applications. The OMS references a sub-set of EN 13757-4, as well as some additional sources.

Smart meter working requirements can be found in ETSI TR 102 886 [32]. The reading intervals for gas and electricity are taken from Dutch Smart Meter specification and tender dossier NTA 8130 [42], which defines interval of 15 minutes for electricity and 60 minutes for gas meter. Other meters can be transmitting with different intervals, which can be significantly longer or shorter. Typically, there is one electricity or gas meter per flat resulting in up to a hundred devices in a multi-storey building. The number of sub-metering devices like heat cost allocators and water meters might be by a factor of 10 higher.

[3] See http://oms-group.org/

2.3.5 Automotive

In the automotive area several applications make use of SRD band frequencies, e.g. Keyless Entry systems, Remote Key, Car-2-Car, Vehicle Alarm, Personal Car Communication, or Tire Pressure Monitoring Systems. Common requirements for all automotive applications may be found in the ECE Regulations[4]. Although some of the mentioned applications have dedicated ECE regulations, all have to be compliant to the generic regulations, e.g. ECE R10 "Approval of Vehicles with regard to electromagnetic stability" [38]. The ECE regulations themselves refer to other standards, like EN 300 220 [12], EN 301 489 [39] or ERC/REC 70-03 [11], which have to be observed by automotive equipment.

Passive Entry/Go systems work typically at 433 or 868 MHz in Europe. The use case is to open the door lock as soon as the car driver approaches the car respectively close the door as soon as the driver leaves. Technically the car sends out a Low Frequency Signal (typically at 120-130 kHz) in order to wake up the key. After this an authentication handshake is performed between key and car at 433 or 868 MHz; it has to be detected very precisely if the key is inside or outside the car (location tracking). Therefore a communication between key and car is necessary as long as the key is nearby the car. This leads to the following requirements as summarised in Table 13.

Table 13: Technical and implementation parameters for Passive Entry systems

Parameter	Comment
Packet size	Around 250 bits
Data rate	No specific requirements
Max Duty cycle	<0.1%: in case the key is outside the communication range from the car, no communication is performed. <10%: whenever the key is brought within communication range to the car, the authentication handshake and location tracking of the key has to be performed
Installation	Outdoor

Remote Keyless Entry is the feature for wireless door locking systems. A key with a transmitter (might be transceiver) communicates with the receiver (might be transceiver) unit in the car. The system is only active, if the button on the key is pressed. Table 14 below shows typical values for technical and implementation parameters of such systems.

Table 14: Technical and implementation parameters for remote keyless entry systems

Parameter	Comment
Packet size	Around 100 bits
Data rate	No specific requirements
Max Duty cycle	<0.1%: only active if the button on the key is pressed
Average DC over one day	Approx. 0.002%
Installation	Outdoor

---

[4] http://www.unece.org/trans/main/wp29/wp29regs.html

With the “direct” type *Tire Pressure Monitoring Systems* (TPMS) the tire pressure is continuously monitored. The tire pressure is important for safety and fuel consumption of the car. The system periodically sends the measured values from the wheel sensors to a receiver unit inside the car. A TPMS is required to generate a warning message in case of a pressure loss within 10 minutes, if the car is moving. Therefore the transmission interval is at least around 10 minutes in case the car is driven. Table 15 below shows typical values for technical and implementation parameters of such systems.

Table 15: Technical and implementation parameters for car TPMS systems

Parameter	Comment
Packet size	Around 250 bits
Data rate	No specific requirements
Max Duty cycle	<10%: transmission in intervals of around 10 minutes in case the car is driving
Average DC over one day	Approx. 0.001%
Installation	Outdoor

2.3.6 Home and building automation

Building automation or home automation when installed in private houses, offices or SME premises, includes the remote control of a number of different applications like heating, air conditioning, lighting, shutter, television, garage doors, household appliances etc. In simple installations the lights are switched on when a person enters the room or the garage opens pressing a button on a separate device. Advanced systems will install manual or automatic sensors in a centralised or decentralised control allowing combining a number of different functionalities. For example, when a person enters the house, the garage door closes, the heating is turned up, the shutters are opened during the day or the light is switched on during the night, such providing improved convenience, comfort, and energy efficiency. Additionally, home and/or building automation might be combined with intruder or fire alarm systems or cooperate with smart metering systems. Devices should have a range of 20-40 m between two communicating elements of an installation within buildings and their surroundings, like garage etc., so that the higher frequencies above 1 GHz are not suitable due to excessive propagation losses and power limitations, especially for battery powered devices.

Radio communication link is established basically between sensors and actuators, and optionally from/to a central unit. In network terminology Home and Building Automation is seen to represent more a WSAN (Wireless Sensor Actuator Network) than a WSN (Wireless Sensor Network) like in metering applications. The typical relation of sensors to linked actuators is often close to 1:1 or 1:n, in contrast to domestic sub-metering application, where many sensors are linked to one data concentrator, e.g. the relation of sensors to data concentrator is n:1. In many cases only one sensor is actively transmitting in a given time interval. This has to be considered when setting up the SEAMCAT simulations.

Therefore Home Automation and Sub-Metering are different SRD applications and should be considered in coexistence studies separately. Table 16 below shows typical values for technical and implementation parameters of home and building automation systems.

Table 16: Technical and implementation parameters for home and building automation

Parameter	Comment
Packet size	Hundreds of bits
Data rate	Medium data rate is tens of kbps, ETSI TR 102 649-2 [20]
Max Duty cycle	Typical <1%

Parameter	Comment
	For future wideband Internet-of-Things type of devices: - up to 2.8% for terminal devices/sensors; - up to 10% for Access Point devices
Average DC over one day	Typ. 0.01% (for 868.30 MHz) Approx. 1% (863-868 MHz)
Installation	In and around buildings

2.3.7 Low Power Wide-Area Networks (LPWAN) with terminals using 25 mW and sensitive Network Access Points (NAP)/ Network Nodes (NN) receivers

Low-Power, Wide-Area Networks (LPWAN) are projected to support a major portion of the billions of devices forecasted for the Internet of Things (IoT). Different technologies already exist and are deployed in commercial uses in some European countries, known under various acronyms such as Low Throughput Networks, Ultra Narrow Band (UNB) LPWA, Direct Sequence Spread Spectrum (DSSS) LPWA, etc. Further tentative consideration of LPWAN in this report will use one specific example of DSSS LPWA technology marketed under the name of LoRa™.

Based on public information[5], the LoRa Alliance announced that LPWA networks are in use in some CEPT countries. Many other Field Trials are on-going but under confidentiality agreement. According to LoRa™ WAN Specification document published by LoRa Alliance [[6]], the primary (i.e. obligatory for any LoRa™ device) operating channels for LoRa™ WAN are channels 868.1 MHz, 868.3 MHz and 868.5 MHz, which may be used for both uplink and downlink by both TNs and NAPs (called respectively end-devices and gateways in LoRa™ specs). In some countries, LPWA has also used additional channels within the frequency band 865-868 MHz, as considered in this report. One further additional channel 869.525 MHz is used by LoRa™ WAN for secondary high-power downlink and for beaconing transmissions. However, only a case of uplink operation of LoRa™ WAN in the band 865-868 MHz is considered further in this report as one example of possible LPWAN operations in the range 863-870 MHz.

LoRaWAN networks typically are laid out in a star-of-stars topology in which gateways1 relay messages between end-devices and a central network server at the backend. Gateways are connected to the network server via standard IP connections while end devices use single-hop LoRa™ or FSK communication to one or many gateways. All communication is generally bi-directional, although uplink communication from an end-device to the network server is expected to be the predominant traffic. Communication between end-devices and gateways is spread out on different frequency channels and data rates. The selection of the data rate is a trade-off between communication range and message duration, communications with different data rates do not interfere with each other. LoRa data rates range from 0.3 kbps to 50 kbps. To maximize both battery life of the end-devices and overall network capacity, the LoRa network infrastructure can manage the data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) scheme.

Table 17 below focuses on the main signalling and packet payload parameters of proprietary LoRa™ WAN standard. More information regarding the technology could be found in the referenced LoRa™ WAN specification [6].

[5] https://www.lora-alliance.org/

[6] https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pdf

Table 17: Technical parameters for LPWAN

Data rate	Configuration	Indicative physical bit rate (bit/s)	End-device Duty Cycle (865-868 MHz)	Max payload max (bytes)
0	LoRa: SF12 / 125 kHz	250	< 1%	51
1	LoRa: SF11 / 125 kHz	440	< 1%	51
2	LoRa: SF10 / 125 kHz	980	< 1%	51
3	LoRa: SF9 / 125 kHz	1760	< 1%	115
4	LoRa: SF8 / 125 kHz	3125	< 1%	222
5	LoRa: SF7 / 125 kHz	5470	< 1%	222
6	LoRa: SF7 / 125 kHz	11000	< 1%	222
7	FSK: 50 kpbs	50000	< 1%	222

2.3.8 Representative typical SRD and LPWAN applications to be used for further studies

Based on the above information, this report will consider in coexistence studies the following typical examples of SRD devices, widely used in the band 863-870 MHz with their key technical parameters and operational assumptions as listed in Table 18. These parameters and assumptions had been aligned with the ones used recently for similar case studies in the band 870-876/915-921 MHz (see ECC Report 246 [9]). However it should be noted that the representative density numbers of various types of SRD devices are higher than those used in ECC Report 246 because of combining the historically accumulated numbers of legacy SRDs in the band 863-870 MHz with future deployment of new SRDs in this European harmonised SRD core band.

Table 18: Representative incumbent typical SRD and LPWAN applications to be used in coexistence studies

Parameter	Home Automation or other, e.g. Non-specific, automotive, etc. (Note 1)	Sub-Metering	Alarms	RFID interrogator (e.g. store item tagging)	Cordless Audio	Hearing Aids	LPWAN Rx
Frequency range	863-870	868.3, 868.95 (Note 2)	868.6-869.4	865.7, 866.3, 866.9, 867.5	864.9	863-865	865.175
Bandwidth (kHz)	350	300	25	200	200	600	125
Activity period maximum DC (%) Note 4	1	0.1	0.01	12.5	100	100	N/A (Note 7)
Average DC over one day (%)	0.01	0.0025	0.0015	2.5-12.5	<75	Up to 80	N/A (Note 7)

Parameter	Home Automation or other, e.g. Non-specific, automotive, etc. (Note 1)	Sub-Metering	Alarms	RFID interrogator (e.g. store item tagging)	Cordless Audio	Hearing Aids	LPWAN Rx
Receiver noise floor (dBm)	-113	-114	-123	-114	-114	-111	-120
NF (dB)	5	5	7	7	7	10	3
Sensitivity (dBm)	-104	-104	-112	-85	-97	-94	-137
Transmitter Output Power (dBm)	14	14	14	20	10	-6	14 (Note 7)
Antenna gain Rx/Tx (dBd)	-5	-5	-5	4	-5	-23	2.85
Typical indoor operating range (m)	20-40 (Note 5)	20-40 (Note 5)	20-40 (Note 5)	<3 m	20-30 (Note 5)	1	N/A (Note 7)
C/(I) objective (dB)	8	8	8	12	17	17	-14
Assumed range of device density per km2 in urban areas	800-1500	25000-50000	1000 - 3000	50-480 (Note 3)	40-100	12	N/A (Note 7)
Receiver parameters	Realistic Category 2 receiver, see Annex 1, Figure 46	Realistic cat. 2 receiver, see Annex 1, Figure 46	Realistic cat. 2 receiver, see Annex 1, Figure 46	EN 302 208, see Annex 1, Figure 48	Realistic cat. 2 receiver, see Annex 1, Figure 46	Realistic cat. 2 receiver, see Annex 1, Figure 46	See Annex 1, Figure 47
Tx mask	See Annex 1	See Annex 1	See Annex 1	See Annex 1, Note 6	See Annex 1	See Annex 1	N/A (Note 7)

(1) Home automation is assumed as most appropriate SRD example for typical considered dense in-building scenarios, whereas e.g. automotive devices would be operated in less dense outdoor environments;
(2) Sub-metering devices extensively use 868.3 MHz for mode S operation, and 868.95 MHz for mode T1 (ref. EN 13757-4) [37]
(3) LPRA estimates the long-term average density of RFID interrogators in this band at 50 units/sq.km; 480/km2 relates to hot-spots;
(4) “Activity period DC” values are to be understood as maximum DC limits to apply during highest activity periods of respective SRD application. However it should be noted that these high activity periods are not correlated between different applications and are not necessarily linked to human activity patterns, therefore it is not expected that the highest activity periods of different SRD applications would be converging on any specific diurnal “busy hours”;
(5) The lower operating range is used with higher wall attenuation values (wall loss option 2), the higher operating range is used with lower wall attenuation values (wall loss option 1); see more details in section 4.2
(6) The RFID mask is taken from EN 302 208 [43] and includes a step to comply with the limits for spurious emissions below 862 MHz
(7) In this report, LPWAN is considered as a victim. Hence, in SEAMCAT simulations, only transmit power in Tx parameters is considered for deriving maximum acceptable interference level.

As regards SRD transmitter masks, an important point that needs to be considered (especially for the case of adjacent band interference from SRDs to wideband system like LTE) is the level of emissions in spurious domain. The ERC/REC 74-01 [41] stipulates that SRD spurious emissions below 1 GHz should not generally exceed -36 dBm/100 kHz. There is still however an optional limit mentioned in the ERC/REC 74-01 of -54 dBm/100 kHz applicable in the (former) broadcasting bands, such as 470-862 MHz. It was set specifically for protection of domestic TV reception and is now proposed to be rescinded for band segments transferred to use by mobile services. Nevertheless, all the incumbent SRDs in the band 863-870 MHz were designed to respect the reduced spurious emissions limit. Therefore, throughout this report, two options for SRD unwanted emissions masks will be considered:

- Option 1 of "Reduced emissions mask" based on -54 dBm/100 kHz spurious limit;
- Option 2 of "Worst case emissions mask" based on -36 dBm/100 kHz spurious limit.

The specific parameters of the two mask options for different SRDs as used in simulations are given in ANNEX 1: of this report.

An additional set of valuable information describing state-of-the-art of SRDs in the band 863-870 MHz, including summary overview of their typical real transmission parameters in time domain, is provided in Annex 7 of ECC Report 181 [2].

Section 4 considers a reference scenario for the existing SRD usage in the band by applying MCL and SEAMCAT simulations.

2.4 POTENTIAL USE OF 862-863 MHZ FOR SRDS

The use of the band 862-863 MHz was hindered for a long time due to it being a guard band on the edge of the high power TV Band V. However with switchover of TV to digital formats and re-location of TV transmissions to lower parts of the TV UHF Bands, the band edge around 862 MHz became appealing for possible future SRD deployment.

Therefore the 862-863 MHz may be considered as a green-field deployment opportunity, provided there is feasibility of adjacent band coexistence with wideband digital cellular systems to be deployed instead of TV below 862 MHz.

A majority of administrations see a possibility to designate the frequency band 862-863 MHz for SRDs such as wireless metering / sub-metering and home automation applications utilising low duty cycle.

In particular compatibility studies with the adjacent band below 862 MHz (LTE) and with the cordless audio applications operating in 863-865 MHz are required to get information about which power levels / duty cycle / etc. combinations might be feasible for SRD installations in the frequency band 862-863 MHz.

Coexistence studies for scenario of using the band 862-863 MHz are provided in section 5.

2.5 NEWLY PROPOSED SRD APPLICATIONS FOR THE BAND 862-868 MHZ

During this review of SRD arrangements in the frequency band 862-870 MHz, several new applications and use scenarios were proposed within the range 862-868 MHz, aiming to further extend opportunities for SRD use in the sub-1 GHz UHF range. These requirements were therefore added to the consideration and studies presented in this report.

2.5.1 Narrowband Networked SRD applications

The first new requirement was to investigate possibilities for accommodating high power Narrowband Networked SRDs (NBN SRD) for fixed installations including smart meters infrastructure network equipment with up to 500 mW e.r.p. in the frequency range 862-868 MHz, see below.

Table 19: Device types of proposed higher power NBN SRD within 862-868 MHz

NBN SRD Device types	Equivalent ETSI Doc	Max Power, e.r.p.	Max DC	Channel arrangement	Bandwidth
Infrastructure network nodes (Note)	TR 102 886 [32] TR 103 055 [45] EN 303 204 [44]	500 mW APC	2.5%	Not defined	200 kHz
Infrastructure network access points (Note)	TR 102 886 TR 103 055 EN 303 204	500 mW APC	10%	Not defined	200 kHz

Note: installation only by professionals – e.g. part of Smart Metering/M3N network

Both of the above listed types of devices represent infrastructure support devices with similar outdoor deployment by professional companies, with key difference being only the maximum value of DC. This would also suggest the varying density as these devices represent two different hierarchical layers of the tree-based network infrastructure. At the lowest hierarchical layer of a network there will be deployed a large number of predominantly indoor Terminal Nodes, such as individual metering devices of different kinds with DC of less than 0.1%. Therefore for the purpose of analysis in this report, different DC and density of devices at respective hierarchical layer will be considered in simulations as relevant, as further addressed in section 5.1.

The concept of Network Access Points (NAPs) was defined in ECC Report 200 [3] (Coexistence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz) as 'Devices deployed by professional organisations, such as utilities, to support wider operations, and thereby restricted in their deployment. Such devices will not be made available to the general public/consumers'.

It was proposed that the deployment of NAPs be described by following features:

- Low density of around 10 dev/sq.km ensured by regulatory means;
- Maximum DC of up to 10%;
- Outdoor mounting;
- Interconnection with WAN network (i.e. Internet) that may be used for supervision and automated configuration of NAPs;
- Professional installation and activation by utility companies' staff.

Further input to ECC Report 200 was provided by ETSI TR 102 886 (Technical characteristics of Smart Metering (SM) Short Range Devices (SRD) in the UHF Band; System Reference Document, SRDs, Spectrum Requirements for Smart Metering European access profile Protocol (PR-SMEP)), and highlighted the necessity for a band of at least 3MHz (or 15 x 200 kHz channels).

ECC Report 200 concluded that:

NAPs may be easily accommodated in most typical coexistence situations (except Cordless Audio), because their higher DC may be compensated by lower deployment figures. However, in the case of NAPs, there is a probability that the density may potentially be found to exceed assumptions, subject to market growth, spectrum access and competition issues. Therefore, some form of review mechanism should be considered as necessary, within the regulatory framework for SRDs with additional mitigation mechanisms, such as APC, which may be considered as a useful measure, e.g. for SRDs with transmit power of 100 mW and higher, as means of general reduction of in-band interference noise levels.

EN 303 204 [44] (Network Based Short Range Devices (SRD); Radio equipment to be used in the 870 MHz to 876 MHz frequency range with power levels ranging up to 500 mW) has set out in more detail the characteristics of such devices including APC details, transmission masks, timing limitations and polite spectrum access techniques.

The technical requirements and market scenarios for SRDs to be used in SM and M3N type of utility networks are described in ETSI TR 102 886 [32] and TR 103 055 [45], as illustrated in Figure 2.

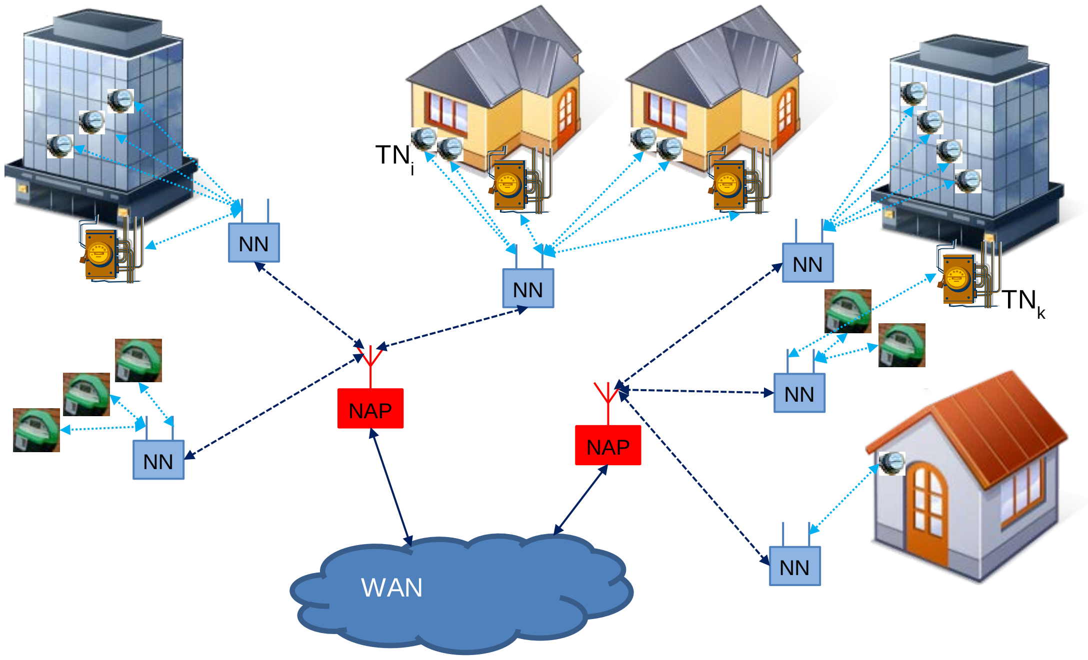


Figure 2: An illustrative example of M3N network hierarchy with Terminal Nodes (TN), Network Nodes (NN) and Network Access Points (NAP)

In relation to the hierarchical structure outlined in Figure 2, it is important to establish the respective densities of constituent network elements. In order to do that, the reference is made to the assumptions taken previously in the ECC Report 200 [3] for the composition of M3N/SM networks. The resulting set of assumptions for DC, densities and resulting number of potentially interfering transmitters to be considered representative of various layers of proposed NBN SRD applications is given in Table 20.

Table 20: Deployment assumptions for NBN SRDs in dense urban environment

Network Element	Max DC, %	Average DC, %	Max Density, 1/km2	Average Density, 1/km2
NAP	10	2.5	10	5
NN	2.5	0.7	90	45
TN	0.1	0.1	1900	950

Note that similarly to assumption of average DC for legacy SRDs operating in this band (see Table 37 in section 2.3), some average DC values are proposed for NBN SRD applications as well. While for legacy SRDs the average DC was assumed to be 10-100 times less than the maximum limit, in this instance it is proposed to approximate the average to be at ¼ of the maximum DC for NAPs and NNs, while for already low DC of TNs it is retained unchanged. Both maximum and average values of DC will be considered in the studies in this report.

According to these assumptions, all three types of NBN SRD network infrastructure devices will be considered jointly in the simulations. The number of potentially interfering devices will depend on the size of the considered impact area. For cases of intra-SRD interference, the simulation radii for the relevant victims are provided in ANNEX 4:. Whereas for cases of adjacent band interference to LTE base station receivers, a macro scale scenario with 500 m cell radius will be considered.

Coexistence studies for proposed NBN SRD applications are provided in section 6.

2.5.2 Wideband Networked SRD applications for Internet of Things

Second requirement for additional investigations is addressing the Wideband Networked SRD (WBN SRD) applications. It is linked to the emergence of new standards for wireless networking, such as exemplified by the widening IEEE 802.xx family of wireless networking standards (e.g. newly emerging IEEE 802.11ah [40]) for WLAN-type wideband “Internet of Things” (IoT) in the sub-1 GHz UHF range, as a complement to highly successful WLAN use of IEEE 802.11a-n standards (also known as “Wi-Fi”) in 2.4 GHz ISM range. These global developments are also being actively supported by ETSI with the recent development of SRDoc TR 103 245 [8] for IoT applications in UHF range, initially aiming for 870-876/915-921 MHz.

The industry behind the IoT standards development believes that ubiquitous compact wireless devices with wideband channels (bandwidth more than 200 kHz, e.g. 1 MHz proposed by TR 103 245) can enable many new applications by achieving higher data rates and opening up new use cases in Internet-of-Everything era. Coexistence with legacy and future applications can be facilitated through implementing Listen-before-talk (LBT)/Adaptive-frequency-agility (AFA), which in the case of IEEE 802.11ah takes form of so called Carrier Sensing Multiple Access protocol with Collision Avoidance (CSMA-CA). This procedure allows for a distributed control of channel access that aims to reduce collisions between transmissions while allowing for fairness in transmit opportunities. Additionally, the CSMA-CA protocol accounts for coexistence and spectrum sharing with non-IEEE 802.11ah technologies through the use of Energy Detection-based deferral. This procedure detects for all transmissions in the subject channel independent of transmission pattern, modulation type, etc., based on measured received energy.

The 802.11ah-based unified technical framework can pave the way for many new innovative WBN SRD applications and increase the economic value of the SRD frequency bands under consideration.

It is therefore proposed by the industry to extend the parameters definition of Non-specific SRD in the subject frequency range in order it could accommodate the 802.11ah standard equipment with the parameters shown in Table 21Table 15.

Table 21: Proposed new use for WBN SRD applications for IoT, e.g. based on TR 103 245 (IEEE 802.11ah), within 862-868 MHz

SRD Category	Equivalent ETSI SRDoc	Max Power, e.r.p.	Channel arrangement	Bandwidth
Non-specific	TR 103 245	25 mW	1 MHz	1 MHz

The 802.11ah equipment would employ the Orthogonal Frequency Division Multiplexing (OFDM) and it is believed that the general parameters and coexistence principles defined in ETSI EN 300 220 [12] could also apply to 802.11ah devices operating as non-specific SRDs.

The WBN SRD network may consist of two hierarchical layers of different devices: access points and terminal stations (also known as “end nodes”).

Their envisaged use scenarios include a variety of IoT applications. Currently the most advanced and best-formalised vision for IoT applications is described in Europe by ETSI TR 103 245 and globally by IEEE 802.11ah [40] networking standard. Similarly to widely known 802.11a/b/g/n family of standards operating in higher frequency bands, the vision promoted for IoT in the 862-868 MHz band is also based on network-centric deployment structures, as illustrated in the following Figure 3.

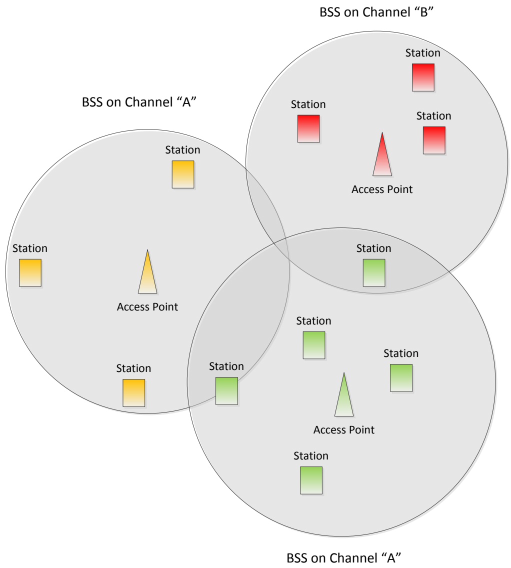


Figure 3: An illustrative example of network-centric deployment of proposed WBN SRD applications for IoT, using 802.11ah network depiction in ETSI TR 103 245

While the end-user Terminal Stations (TS) will include a wide plethora or sensors, actuators and any other kinds of IoT, it is expected that the Access Points (AP) will be the key drivers supporting operation of IoT networks and their constituent devices.

The key parameters characterising use of IoT APs will be the transmit e.r.p. of up to 25 mW (as requested by TR 103 245 [8]), DC of up to 2.5-10%, and channel bandwidth of up to 1 MHz. It may be noted that TR 103 056 [7] also requested to consider IoT devices with transmit power of up to 100 mW, however it was identified during early simulations that even deployment of WBN SRD devices with lower transmit power of 25 mW would be putting noticeable pressure on intra-SRD coexistence, therefore in order to avoid further confusion, the option of 100 mW was dropped from further consideration.

As regards deployment scenarios, it should be noted that it is expected that both TSs and APs of such networks would be deployed predominantly in the indoor environments.

Next it is important to agree on the respective densities of constituent network elements. Since TR 103 245 [8] did not provide specifics on expected densities of proposed WBN SRD devices, a reasonable starting point would be to assume densities similar to IoT-like applications such as SM/M3N networks discussed in 2.5.1 and ECC Report 200 [3], i.e. approx. 2000/km2 for terminal devices and 100/km2 for network nodes/access points in urban areas. However, noting that the prime target for deploying 802.11ah [40] devices remains the 870-876/915-921 MHz, it may be hypothesised that a complementary deployment of WBN SRD devices in the band 862-868 MHz would constitute half of that number, i.e. 1000/km2 active TSs and some 50/km2 APs. These numbers may be compared with European statistics on urban density of households, which indicate that for densely populated urban areas of EU-28 and EFTA countries there are on average 584 households/km^2. The absolute highest densities are found in the cities of Paris and London with 11067 and 4423 households/km^2.

The resulting set of assumptions for DC, densities and resulting number of potentially interfering transmitters to be considered representative of two layers of proposed WBN SRD networking applications is given in Table 22 below.

Table 22: Deployment assumptions for WBN SRDs in dense urban environment

WBN SRD Device type	Max DC %	Average DC %	Max Density 1/km2	Average density 1/km2
AP	10	2.5	50	25
TN	2.8	0.1	1000	500

As the device density numbers in Table 22 were derived based on predictions for dense urban environments, for suburban environments the number of active interfering devices may be halved, i.e. to respectively 500/km^2 for TSs and 25/km^2 for APs.

Note that similarly to assumption of average DC for legacy SRDs operating in this band (see Table 18 in section 2.3), some average DC values are proposed for WBN SRD applications as well. Following the review of available references discussing the state-of-the-art of deployment and design trends of IoT-type machine-to-machine-communication systems, it was noted that all sources stress that design and wireless access protocols of terminal nodes in such networks would be primarily focused on meeting the energy-constrained nature of deployment and operation of such devices. As a result of this constraint, coupled with bursty and occasional nature of operation of terminal IoT devices, the quoted long term average DC was typically ranging between 0.007-0.03%, and in rare cases up to 0.1%. Therefore it was proposed in this report to use the assumption of average DC for WBN SRD terminal being 0.1% as a conservative worst-case assumption.

At the time of writing this report there was not found available evidence as regards the realistic average DC of APs in the IoT-type networks, therefore for APs the average DC was arbitrarily assumed to be ¼ of the maximum value.

Both maximum and average values of DC will be considered in the studies in this report.

According to the above assumptions, both types of WBN SRD network infrastructure devices will be considered jointly in the following simulations. The number of potentially interfering devices will depend on the size of the considered impact area. For cases of intra-SRD interference the simulation radii are provided in ANNEX 4: For cases of adjacent band interference to LTE base station receivers, a macro scale scenario with 470/700 m impact radius will be considered.

Coexistence studies for proposed WBN SRD applications are provided in section 7.

2.5.3 Preferences manifested by LPRA for the future of the band 862-868 MHz

In order to identify SRD industry preferences for innovation in this band, the Low Power Radio Association (LPRA) collected views of its membership in July 2014. Based on that exercise the LPRA observed that in principle the SRD industry is generally content with the regulatory arrangements currently established for the band 863-870 MHz by the ERC/REC 70-03 [11]. However, in order to allow scope for future SRD innovation, the industry made the following recommendations for the additional types and densities of SRD devices to be considered in studies of long-term SRD coexistence, along with the existing typical SRD uses:

- 862-863 MHz:
  - Generic SRDs:
    - 100mW, max 10%DC or LBT+AFA, max OBW 1MHz;
    - Average density: 1 device per impact area of ~600 m² (i.e. up to 50 devices within 100 m radius).
- 863-865 MHz:
  - Generic SRDs:
    - 100mW, max 10%DC or LBT+AFA, max OBW 1MHz;
    - Average density: 2 devices per impact area;
  - High power SRDs:
    - 500mW APC, max 10%DC or LBT+AFA, max OBW 200 kHz;
    - Average density: 1 device per impact area.

- 865-868 MHz:
  - Generic SRDs:
    - 25mW, no restriction but LBT+AFA, max OBW 2MHz;
    - Average density: 25 devices per impact area;
  - High power SRDs:
    - 500mW APC, max 10%DC or LBT+AFA, max OBW 200 kHz;
    - Average density: 1 device per impact area.
- 868-870 MHz:
    - no change of the current regulation.

Accordingly, all new requirements discussed in sub-sections 2.5.1, 2.5.2 and 2.5.3 will be taken into account when analysing possible future changes to SRD arrangements between 862-868 MHz.

2.6 STUDY METHODS USED IN THE REPORT AND INTERPRETATION OF RESULTS

This report will use a combination of methods for analysing coexistence of various radiocommunication applications in the subject band 862-868 MHz:

- Minimum Coupling Loss (MCL) method:
  - used for establishing maximum impact distances between the established pairs of possibly interacting applications (see 4.1 and tables in ANNEX 4:);
- Enhanced MCL method:
  - used for analytical evaluation of probability of interference to RFID from NBN SRD and WBN SRD applications (see sub-sections 6.2.3.1 and 7.2.3.1 respectively);
- Monte Carlo simulations using CEPT's SEAMCAT tool:
  - for computational random sampling of established coexistence scenarios in order to derive statistical probability of interference (this method used widely throughout Chapters 6, 7 and 8).

A very thorough comparative evaluation of these three methods had been previously presented in ERC Report 101 [22]. The following represents a brief recap of some of the key points of that report in the context of the current study.

The distinctive features of the MCL method are:

- the result generated is isolation in dB, which may be converted into a physical separation by using an appropriate path loss formula;
- it is a worst case analysis and produces a spectrally inefficient result.

More elaborate derivatives of MCL method, called Enhanced MCL, may use some additional features of the analysed systems, e.g. not just single sensitivity threshold but a wider range of signal strength margin, and thus derive analytically some probability of interference metric based on some simplified assumptions, such as uniform distribution of interferers around the victim, certain path loss fading margin, fixed frequency offset, etc. It is important to note that the comparative application of E-MCL calculations often produce results that are of the same order of magnitude as those generated by the Monte Carlo method [19].

The most important characteristics of the Monte Carlo method are:

- it allows the user to model realistic scenarios and evaluate f.e. appropriate minimum frequency/distances separations;
- multiple interferers using multiple channels may be considered;
- the effect of features such as power control may be included.

When comparing those three methods, the following main points may be further considered:

- the MCL approach is relatively straight forward, modelling only a single interferer-victim pair. It provides a result which, although spectrally inefficient, guards against the worst case scenario;

- the Monte Carlo approach is a statistical technique, which models a victim receiver amongst a population of interferers. It is capable of modelling highly complex systems. The result is spectrally efficient but requires careful interpretation;
- the E-MCL approach provides a useful bridge between the MCL and Monte Carlo methodologies. For relatively simplistic scenarios the results of the E-MCL methodology are of the same order of magnitude as the Monte Carlo. However the methodology is not likely to compare so favourably for all interference scenarios e.g. complex scenarios with multiple variables and several interfering systems, incl. CDMA and OFDMA systems. As in the case of Monte Carlo, the result requires careful interpretation.

Each of the methodologies has its merits and drawbacks. The appropriate choice depends upon the criteria used and on the tool available to the user. The increasing penetration of wireless communications is leading to increased congestion in the radio spectrum. This indicates that one criterion should be the ability to evaluate spectrum efficiency. Radio systems are becoming more and more complex as the range of services offered is increased. This indicates that another criteria should be the ability to model complex scenarios realistically and with flexibility. Finally, the advent of high-density systems has led to the concept of soft capacity i.e. capacity is a function of inter and intra system interference, this concept is fundamental to the case of CDMA and LTE systems. Thus the last criteria is the ability to evaluate capacity in a system. In summary the criteria are:

- the ability of evaluating spectrum efficiency;
- ability to model complex scenarios realistically;
- flexibility;
- ability to evaluate system performance for high density and complex systems.

SEAMCAT (Spectrum Engineering Advanced Monte Carlo Tool) [19] is based on the Monte Carlo simulation method, to enable statistical modelling of different radio interference situations. It has been developed to deal with a complex range of spectrum engineering and radio compatibility problems. SEAMCAT is developed within the framework of the CEPT/ECC Working Group Spectrum Engineering (WGSE) within its sub-entity SEAMCAT Technical Group (STG).

The theoretical background of model is presented in the ITU-R Report SM.2028 [18].

It was thus long established in the CEPT that the Monte Carlo method is the most appropriate and versatile method that is best meeting the above stated criteria. Accordingly, the SEAMCAT tool was developed through the cooperation of CEPT administrations and wireless industry, which is aimed to provide a universal and reliable tool for use in Spectrum Engineering studies. This tool is now entering its Fifth generation, having seen constant development and improvement over the last two decades. So far, there were no reported instances when some regulatory decision taken based on SEAMCAT simulations would be later shown to result in inordinate interference in real life deployments of authorised systems. The exhaustive handbook for SEAMCAT use had been recently published in CEPT as ECC Report 252 [23]].

As regards the important issue of careful interpretation of results of Monte Carlo simulations, the ERC Report 101 [22] noted that “*what the Monte Carlo simulation is computing will depend upon the scenario being modelled. For simulations where the victims are all treated equally and do not have restrictions placed upon their positions, then each will experience the same level of interference. In this case the meaning of the result is that 100% of the users experience a P% probability of being disturbed.* For *simulations where the position of some or all of the victims is restricted then it is possible that some victims will experience more interference than others. In this case the meaning of the result will be somewhere between 100% of the users experiencing a P% probability of being disturbed and P% of users experiencing a 100% probability of being disturbed”*.

A Monte Carlo simulation is a set of statistical calculations based upon the consideration of several events (also called snapshots or trials), which are independent in time, space and frequency domains. For each event, a scenario is set out using a number of random variables that define the systems to be simulated (e.g. frequency, power, propagation loss, positioning of the transmitters and receivers, etc.).

SEAMCAT tool was designed to perform statistical simulations using the Monte Carlo method. Statistical simulations by definition imply variation of some or all parameters. The variation of a given parameter can be described as a random variable, which is used in the simulation. It can be appropriate to include both constant values for some parameters and random variables for others in a Monte Carlo simulation.

It is possible in SEAMCAT to obtain a single value of interference probability calculations as well as to analyse the entire vectors of wanted and unwanted signals per each event. An example below presents a typical intra-SRD simulation scenario with average interference probability of 10%.

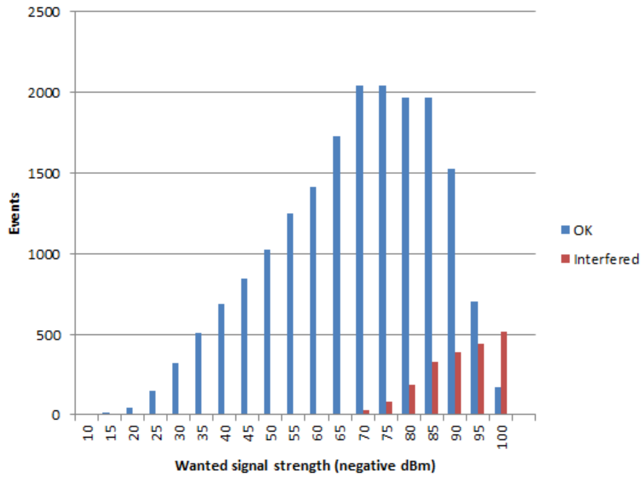


Figure 4: Example of wanted signal vector analysis (wanted signal is grouped in 5dB bins)

From Figure 4 it can be seen that victim devices receiving weakest signal from their transmitters (e.g. due to being in unfavourable geometry) will suffer interference the most. The following Figure 5 illustrates the proportion of devices experiencing different percentage of interference.

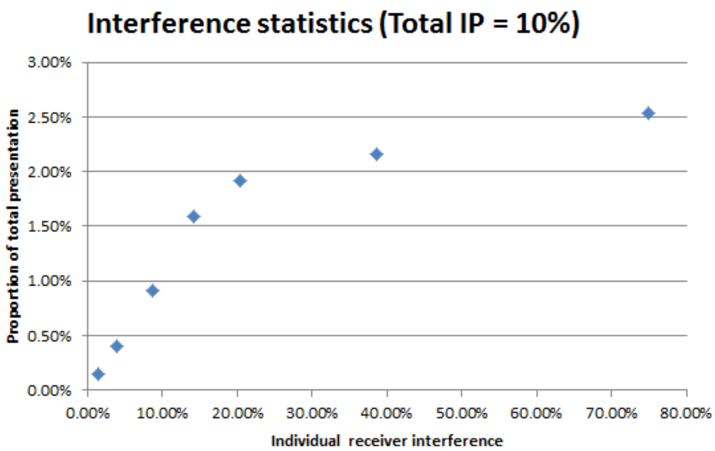


Figure 5: Detailed Interference statistics for total IP=10%

It can be seen from the figure that 2.5% of simulated events experience around 80% interference; whereas 1% of devices experience around 10% interference; and 0.4% have around 0.34% interference, giving overall interference for this case 10%.

3 PREVIOUS SHARING STUDIES PERTINENT TO THE BAND 863-870 MHZ

This section provides a summary of key previously published documents that are pertinent to the issue of SRD coexistence and most efficient utilisation of the subject band.

Other than the documents considered in greater detail below, there are other documents that have bearing on the analysis of the 863-870 MHz band, most notably:

- ECC Report 200 on Coexistence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz [3];
- ECC Report 207 on Adjacent band coexistence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz [4].

Although not directly concerned with internal organisation of the band 862/863-870 MHz, the complex studies reported in these two report as well as their findings should be very useful and relevant for this study. Most importantly, they provide a context that would help establishing overall band utilisation rules and SRD coexistence prospects as part of a bigger picture of cohesive development and co-habitation of various wireless systems and applications in the entire 800 MHz band range. These two latter reports may be also useful as precedents for establishing SRD deployment scenarios and applying appropriate coexistence analysis methods.

3.1 ECC REPORT 37

3.1.1 Conclusions

The conclusions from ECC Report 37 [1] (section 8) are as follows:

Quote:

“This report considers the impact of introducing new techniques in the band 863 to 870 MHz in accordance with the CEPT Strategic Plan 862 – 870 MHz. The results show that the probability of interference caused by the new techniques against existing applications is no greater than between existing applications. Receiver parameters of existing ETSI standards were used in this study.

The results from SEAMCAT simulations for existing Short Range Devices show that most of the probabilities of interference are well below 1%, with the exception of Social Alarms (4.5 %), Cordless Audio Applications (1 %, 5.2% and 11 % depending on sub-band) and Radio Microphones (6.8 % and 7 % depending on sub-band).

The new techniques include DSSS and FHSS. This report also considers the ”listen before each transmit” feature.

The probability of interference caused by these new techniques has been analysed using SEAMCAT simulations and MCL calculations.

Based on the results presented in section 6, the following conclusions were reached:

1. *New applications for non-specific SRDs within this band shall use “listen before each transmit” if their Duty Cycles are higher than the limits shown in table 8.1 below. The values of all other parameters shall not exceed the limits in table 8.1. Traditional Duty Cycle restrictions are unnecessary for equipment using “listen before each transmit”, provided the minimum transmit-off time and maximum transmit-on time are defined. This needs to be implemented within ETSI standards as a mandatory requirement.*

2. *Based on the advantages demonstrated in the analysis of LBT in section 7, it is recommended that administrations should encourage a migration by non-specific SRDs towards its use. The “listen before each transmit” feature can be applied to most existing SRDs as covered by ERC/REC 70-03. However “Listen before each transmit” may be inappropriate for one-way systems, e.g. social alarms*

3. *It should be noted that either duty cycle or LBT with AFA is a mandatory requirement for non-specific SRDs. This offers the following options to industry:*

   - *For SRDs without LBT or those with LBT but without AFA the duty cycle limit as defined in the table 8.1 shall not be exceeded.*
   - *For equipment with LBT and AFA, the traditional duty cycle restriction is not required. The net result in the event of high traffic, is a dynamic duty cycle limitation which is dependent on the loading of the channel.*

4. *The probability of interference caused by the new techniques to existing short range devices is considered acceptable. However, it should be noted that the results for the new techniques in Section 6 were simulated/calculated without taking into account the "listen before each transmit" feature.*

5. *Special consideration was given to the needs of Social Alarms. The study shows that the probability of interference caused by existing systems is 4.5% while for new systems it is less. Nevertheless, one manufacturer of these systems has declared that the only acceptable figure is one where the probability of interference is effectively zero.*

6. *Operation of RFID in accordance with the four channel plan described in Annex D.5 provides significant benefits to end-users and improves coexistence with SRDs using LBT and AFA. For the nearby SRDs without LBT and AFA that are co-channel with an RFID interrogator, the probability of interference will be increased. The probability will exceed the figures in Table A.1.2 for RFID 33 @ D.C. of 30%. (See also ETSI TR 102 649-1 [29]). This may make the operation of such SRDs impracticable in the four high power channels.*

A summary of the recommended limits for satisfactory operation of the different technologies within the band is provided in Table 8.1 below.

Application	Regulatory parameters	Comments
Non-specific SRD using DSSS	**sub band 865 – 868 MHz** - max radiated power = 25 mW e.r.p. - occupied bandwidth = 0.6 MHz - max power density = 6.2 dBm/100 kHz - max duty cycle = 1 % **sub band 865 – 870 MHz** - max radiated power = 25 mW e.r.p. - occupied bandwidth = 3 MHz - max power density = -0.8 dBm/100 kHz - max duty cycle = 0.1 % **sub band 863 – 870 MHz** - max radiated power = 25 mW e.r.p. - occupied bandwidth = 7 MHz - max power density = -4.5 dBm/100 kHz - max duty cycle = 0.1 %	Implementation of LBT is not considered possible for DSSS unless a narrow band receiver is used while in the listen mode. If LBT timing is used, the timing shall be determined within ETSI standards[1)]: Examples for such values are: TX on-time= 500 ms TX off-time= 15 ms
Non-specific SRD using FHSS	**sub band 865 – 868 MHz** - max radiated power = 25 mW e.r.p. - channel bandwidth = 50 kHz - number of hop channels = 60 [2)] - max duty cycle = 1 % or LBT [1)] **sub band 865 – 870 MHz** - max radiated power = 25 mW e.r.p. - channel bandwidth = 100 kHz - number of hop channels = 50 [2)]	If LBT timing is used, the timing shall be determined within ETSI standards[1)]: Examples for such values are: TX on-time= 500 ms TX off-time= 15 ms

	- max duty cycle = 0.1 % or LBT [1] **sub band 863 – 870 MHz** - max radiated power = 25 mW e.r.p. - channel bandwidth = 100 kHz - number of hop channels = 70 [2] - max duty cycle = 0.1 % or LBT [1]	
Non-specific SRD using other digital modulations [3]	**sub band 865 – 868 MHz** - max radiated power = 10 mW e.r.p. -200 kHz < occupied bandwidth < 3 MHz - max duty cycle = 1 % or LBT [1] **sub band 865.5 – 867.5 MHz** - max radiated power 25 mW e.r.p. - 50 kHz < occupied bandwidth < 200 kHz - max duty cycle = 0.1% or LBT [1]	If LBT timing is used, the timing shall be determined within ETSI standards[1]: Examples for such values are: TX on-time= 500 ms TX off-time= 15 ms
System for stolen cars using DSSS 4)	**sub band 865.5 – 867.5 MHz** - max radiated power = 2 W e.r.p. - occupied bandwidth = 2 MHz - max power density = 20 dBm/100 kHz - max duty cycle = 0.03 %	Effective implementation of LBT is not considered possible for DSSS. If LBT timing is used, the timing shall be determined within ETSI standards[1]: Examples for such values are: TX on-time= 500 ms TX off-time= 15 ms
System for tracking containers using FHSS	**sub band 865 – 868 MHz** - max radiated power = 500 mW e.r.p. - channel bandwidth = 25 kHz - min number of hop channels = 7 [2] - max duty cycle = 0.03 % or LBT [1]	If LBT timing is used, the timing shall be determined within ETSI standards[1]: Examples for such values are: TX on-time= 500 ms TX off-time= 15 ms
Generic RFID 5)	**sub band 865 – 868 MHz** - max radiated power = 20 µW e.r.p. except at **center frequencies of 865.7, 866.3, 866.9 and 867.5 MHz where the following parameters shall apply:** - max radiated power = 2 W e.r.p. - channel bandwidth = 200 kHz - maximum period of continuous transmit on a channel = 4 s	RFID tags may respond on any channel within the sub band. Interrogators shall not be required to use LBT in the four high power channels.

Table 8.1: Implementations considered feasible

Notes:

1) LBT = "Listen Before each Transmit" with defined max. TX on-time and min. TX off-time.
   It requires mandatory receiver parameters for sensitivity, adjacent channel selectivity and blocking response.
   Traditional Duty Cycle restrictions are unnecessary for equipment using LBT.

2) This number of hop channels has been used in combination with the channel bandwidth for the calculation of the probability of frequency collision. A minimum number of hop channels shall be implemented in an ETSI Standard. If the minimum number of hop channels is significantly less than the numbers used in this study the probability of interference shall be verified.

3) The outcome of ETSI studies on requirements for SRDs in the UHF band was that users wanted greater data rates and higher powers. To make greater data rates possible a larger bandwidth is proposed for digital modulations techniques. It should be noted that, due to the limited spreading range, none of the spread spectrum technique are able to achieve high data rates . To restrict the spectral density to an acceptable level the output power shall be limited to 10 mW.

4) For the purpose of this study the proposed ETSI transmitter spectrum mask has been changed (see the comment below the Figure 1-4-3-2)

5) As described in Annex D.5 generic RFIDs are simulated using that frequency for the victim, which is either the adjacent channel to a high power channel if applicable, or the closest channel of the adjacent sub-band.

"

Unquote

Comments:

It is not very clear whether the DC restriction is required for LBT only devices or not. It is mentioned under bullet 3 that LBT plus AFA is mandatory and that only this combination of LBT+AFA does not require additional DC restrictions. But in the table 8.1 only LBT is mentioned. In addition it is not clear what is meant with LBT+AFA in detail. To-date DC = 90s max / 1hour within 200 kHz portion of spectrum (practically DC 2.5% / hour).

3.1.2 Main findings and discussion

The main findings of ECC Report 37 [1] in the context of the current study may be summarised as follows:

- It is recommended that administrations should encourage a migration by non-specific SRDs towards using LBT;
  - DC restrictions for LBT without AFA are not very clear in ECC Report 37: either the DC limit from table 8.1 (see bullet 3) or minimum transmit-off time and maximum transmit-on time (see bullet 1, e.g. Ton< 500ms, Toff>15ms);
  - For LBT+AFA it is clearly suggested that no DC restriction is required (but possibly the above Ton/Toff limit is meant for this);
- Sharing with Cordless Audio and social alarm seems to be possible with the below restrictions for new techniques:
  - DSSS with additional restriction on PSD and DC (e.g. 25mW, -4.5 dBm/100kHz, 0.1% DC), and
  - FHSS with additional restriction of the hop channels and DC or LBT (e.g. 25mW, 70 hop channels with channel bandwidth of 100 kHz, 0.1% DC or LBT);
- LBT may be inappropriate for one-way systems, e.g. social alarms.

3.2 ECC REPORT 181

3.2.1 Summary/Conclusions

The Executive Summary from ECC Report 181 [2] is as follows:

Quote:

"Considering the development of SRDs applications, the development of new technologies and the experience gained toward the deployment of SRDs equipment, this ECC Report investigates possible ways of improving spectrum efficiency in the frequency bands used by Short Range Devices (SRDs).

It is important to distinguish between spectrum occupancy and spectrum efficiency. The value of using a particular part of spectrum comes from the utility it provides to users, which is not necessarily the same as the data traffic. A distinction should be made between the concepts of Single system Absolute spectrum Efficiency (SAE), which is based on the raw data transmitted, and Group Spectrum Efficiency (GSE), which is closer to the broader utility or service provided.

One conclusion is that some SRDs operating in "exclusive" bands might indeed benefit if those bands were to be low occupancy so that devices relying on access by duty cycle (DC) limits alone can operate effectively. At the same time, it would be wasteful and inefficient to operate all the spectrum identified for

SRDs in this way. In other sub-bands, whenever there is demand, occupancy and throughput levels will have to rise. Regulators and industry will have to devise means of achieving this. Since basic DC is only effective as a sharing mechanism up to relatively low levels of occupancy and throughput, this may require the introduction of more advanced sharing mechanisms.

A second conclusion is that different sub-bands should be optimised for different communication needs. Users of the SRD bands have a variety of needs and different criteria for a successful service, and this should be recognised in the management of the spectrum identified for SRDs. Access mechanisms and spectrum management should be based on sound technical foundations – the equivalent of "evidence based" rule making. This report initiated some work relating to the derivation of the technical parameters and spectrum management for a given SRD sub-band. This work should be continued and extended.

In addition, the following was concluded:

- *Spectrum occupancy is the parameter most visible to observers and monitors of the spectrum. Section 3.11 shows the relationship between occupancy levels and access techniques. For monitoring purposes on an application level the distinction between spectrum occupancy and channel occupancy needs to be made. In most general cases this is not necessary but when investigations are made in specific subbands, especially when considering application of new spectrum efficiency metrics proposed in this report and some advanced mitigation mechanism, this may be relevant.*
- *There is a need to optimise some of the SRD spectrum to achieve high reliability use. The amount of spectrum required for such usage might be relatively small.*
- *The aims of this report are entirely consistent with the principle of application neutrality set out in CEPT Report 14 (section 2.7 [19]). For instance, it may be better to designate a sub-band not for inherently safety related critical alarm systems, but instead as a sub-band where high reliability, low latency, low duty signalling is always possible. This is a clearer path for regulators to follow in order to provide a better service both to alarm manufacturers and to alarms users while remaining application neutral, thus not preventing further innovation in the given sub-band.*
- *The principle of application neutrality means the end of segregation by application – whereby sub–bands were designated exclusively to a particular application, primarily within the European SRDs generic frequency ranges. In order to preserve technical efficiency, a suitable replacement could be partitioning of the bands based on technical objectives – e.g., sub-bands for high reliability, for low latency, for high throughput. However, this may lead to more detailed definition being needed in describing the technical requirements and this may lead to a reduction in technology neutrality if not performed properly.*
- *At the same time it is worth noting that sometimes an SRD application may have very clear specific technical characteristics that may employ opportunistic sharing techniques to enable it to politely operate within spectrum allocated to radiocommunication services that otherwise would be interfered by generic SRDs. This may represent higher spectrum use efficiency, beneficial to both uses.*
- *The principle of technology neutrality is more difficult to realise and therefore may not always be realised by regulation without sacrificing spectrum use efficiency. It should be still possible to frame regulations so that, for instance, either analogue or digital modulation is allowed or a range of bandwidths is possible. In most cases, however, it is necessary to set specific technical conditions to allow successful sharing, so technology neutrality is at odds with spectrum efficiency. There may be a case for a Sandpit area, akin to the concept of bands identified for ISM, where technology neutrality is applied as far as possible, to assist the emergence of new technologies.*
- *Listen Before Talk (LBT) is well known mitigation technique in the SRD field whereby the transceiver performs sensing of the channel before each packet transmission. This report carried out an extensive modelling with the aim of quantifying the precise benefits of LBT in various sharing scenarios. It was shown that the LBT is not a silver-bullet in that it has its limitations and shortcomings, most notably as described by the hidden/exposed node problems.*
- *The report considered the benefits of two related concepts, namely those of Carrier Sensing (CS) and Collision Detection (CD), known as part of so called Aloha channel access protocol. CD is the detection of a collision after the event. This happens in all systems that work at the higher levels of the OSI model, such as analysis of message success rates. CS operates before the transmission with the aim of preventing collisions. It thus closely resembles LBT and sensing elements of more advance frequency agility mechanisms such as DAA, DFS and AFA. The notable conclusion of this report is that LBT and CS/CD require further studies in anticipation that some kind of hybrid mechanisms, involving both CD and CS aspects, would be necessary if wanting to achieve high levels of throughput and spectrum use efficiency in high channel occupancy scenarios.*
- *The traditional generic FHSS may be only truly effective in scenarios with lower levels of band occupancy; basically it spreads the traffic over a wide spectrum to reduce the per-channel traffic to low*

levels. Hybrid or adaptive FHSS need further study to see how effectively it overcomes the limitations of generic FHSS and what other types of spectrum access mechanisms it can most optimally share with. Noting the nature of FHSS as band-level, not channel-level access mechanism, it may be suggested that regulations should not make special provisions for FHSS, but should instead apply per-channel access rules taking into account the correlation of channel transmissions in the spatial domain.

- *Advanced technologies (FDMA, CR,…) for spectrum access may have received less attention and analysis to date in the SRD community than time domain techniques, mostly because of the higher involved complexities, including some of them needing central controlling entity with degree of intelligence etc., but they should be studied further as potential techniques for high occupancy, high traffic sub bands.*
- *It may be possible to achieve spectrum use efficiency gains and overall spectrum capacity increase by combining longer- and shorter-range deployment scales (still in the overall context of limited SRD range). This would resemble the principle of combined deployment of umbrella macro-cells and pico cells in the same area, even on the same channel. Systems operating with differing operating powers within sensible limits and ranges are able to effectively co-exist, thereby significantly increasing medium utilisation. The success of this mechanism depends on the typical usage scenarios and user expectation for the applications vying for coexistence. The achieved group spectrum efficiency depends on the choice of spectrum access parameters."*

Unquote

3.2.2 Main findings and discussion

The main findings of ECC Report 181 [2] in the context of the current study may be summarised as follows:

- some SRDs operating in "dedicated" sub-bands might indeed benefit if those sub-bands were to be low occupancy so that devices relying on access by duty cycle (DC) limits alone can operate effectively. At the same time, it would be wasteful and inefficient to operate all the spectrum identified for SRDs in this way;
- A second conclusion is that different sub-bands should be optimised for different communication needs. This report may be seen as specific for the 863-870 MHz, being an evolution of the work as started in ECC Report 181 which was not related to a specific frequency band;
- There is a need to optimise some of the SRD spectrum to achieve high reliability of use. The amount of spectrum required for such usage might be relatively small;
- it may be better to designate a sub-band not for specific application of safety related critical alarm systems, but instead a neutrally designated sub-band for high reliability, low latency, low duty signalling applications;
- there should not be special provisions for FHSS, but the limits (e.g. DC) should apply per-channel taking into account the correlation of channel transmissions in the spatial domain.

3.3 IMST STUDY

3.3.1 Summary/Conclusions

A complementary study "Channel Access Rules for SRDs" [5] was carried out in Germany in 2012 by IMST to establish the effect of various SRD parameters (power, DC, etc.) and different channel access schemes in facilitating efficient intra-SRD sharing of spectrum.

The conclusions and recommendations from the IMST Study (Chapter 7) are:

Quote:

'*The analysis of potential SRD applications in section 3 has shown that a large group of applications require only small packet sizes of a few hundred bits and low to medium duty cycles below 1% for data transfer. Furthermore, they typically have not very stringent latency requirements as even alarm systems can cope with a delay of few hundred milliseconds, but the requested link reliability might be high. Many applications are operated indoor and a number of independent systems might be simultaneously operated within the same building, so that coexistence must be possible. However, it sometimes will be the case that the same* *party is operating the different systems, so that adjustments in deployment may be possible in challenging scenarios. As the majority of the SRDs will be battery operated, robust, simple, and energy efficient access schemes will be required.*

Centralised resource control is known to provide a high resource utilisation, but a central control instance in one node will not be available in a scenario with simultaneously transmitting networks of different operators. Alternatively, resource allocation can be solved in a distributed manner defining a common control channel, which would be then used for neighbour detection and resource reservation. The air interface format and the protocols of the common channel need to be standardised, so that information can be exchanged between devices belonging to different networks. Nevertheless, it has to be taken into account that the number of devices might be quite large, while the duty cycle on a single link is typically small. Hence, listening to the resource allocation of the neighbour nodes and making own reservations prior to a short packet transmission might require much more energy than the transmission of the data packet itself. As the majority of the SRDs will be battery operated, the overhead required for resource control in general cannot be spent. Hence, this study focused on random access schemes.

Among the single carrier random access systems, ***DC based random access*** *using unidirectional links for data transmission is the simplest one. This access scheme is used by applications requiring extremely low cost, small size "transmitter only" devices with low reliability requirements. Calculations as well as simulations in section 5.6.1 have shown that the maximum achievable accumulated DC in the application layer is approximately 3% for a packet loss rate of 0.1% transmitting six packet copies for each data packet to increase reliability. Thereby, the accumulated DC is the product of the number of harmful interferers and the application duty cycle on the links. For example, 30 devices with an application duty cycle of 0.1% or, alternatively, 3 devices with an application duty cycle of 1% can transmit in parallel supposed that the band is exclusively dedicated to DC based random access users. The latency will be similar to the latency in ALOHA systems with a constant repetition interval. In both systems the time interval between packet copies should be randomly selected and large enough to avoid that the new packet copy will again collide if the previous has been already lost due to a collision. The poor performance of uni-directional DC based random access justifies a strong limitation of the duty cycle on a single link, so that only a small portion of channel access time is used by this low efficient access scheme. A transmit duty cycle of 0.1% at a transmit power level of 10 dBm is proposed and even smaller transmit duty cycles are recommended for higher transmit power levels. Section 6.1 provides a formula for the relationship of transmit duty cycles and transmit power as a function of the path loss exponent.*

Using a bi-directional protocol with an acknowledgement procedure can significantly increase the system performance. The device costs are slightly higher as a transceiver is required to establish the bi-directional link. Simulations presented in section 5.6.2 have shown that ALOHA achieves an up to 9 times higher accumulated application duty cycle than DC based random access systems for the same target packet loss rate and the same device constellation.

Additionally, the number of transmitted copies per data packet is significantly smaller if packets are only retransmitted if being lost. Hence, the power consumption for implementing the acknowledge procedure is more than compensated by the smaller number of packet transmissions, so that ALOHA outperforms DC based random access with regards to reliability and power consumption. Nevertheless, the ALOHA performance significantly depends on the scheduling algorithm for the retransmissions. The time offset in between packets should be always randomly selected, but if the mean offset is too short, the system can easily collapse. The implementation of a load dependent ***backoff*** *procedure (e.g. binary exponential backoff) is strongly recommended.*

The system capacity can be further increased using the receiver which is anyway required for the acknowledgment procedure of ALOHA systems to check the channel state prior to transmission. The assess scheme is then denoted as ***CSMA-ACK****, which uses the listen-before-talk (LBT) procedure to send packets only if the channel is free. This feature can be implemented with no additional hardware costs. Simulations presented in section 5.6.4 have shown that the number of harmful interferers which can be tolerated in the vicinity of the receiver can be increased by a factor of 2-3 compared to ALOHA with linearly increasing backoff for the considered parameter settings and simulation environment. Hence, CSMA-ACK increases the accumulated application duty cycle by a factor of 2-3 compared to ALOHA, while the packet loss rate in the application layer remains almost zero. Furthermore, the number of packet retransmissions is significantly smaller in CSMA-ACK systems than in ALOHA (see Figure 56) so that the additional power consumption for the CCA measurement of the LBT procedure is more than compensated.*

*Nevertheless, the performance of the LBT scheme significantly depends on the **LBT implementation parameters**, i.e. the minimum interferer measurement time and the dead time between the end of the channel measurement and the start of the packet transmission in case the channel has been detect as to be free. Even if the transmitter can detect all harmful interferers, a non-zero collision probability is observed as explained in section 5.6.3.*

*Additionally, any harmful interferer which cannot be measured by the desired transmitter significantly degrades the CSMA performance, as collisions with a packet of a so called **hidden node** cannot the actively avoided. The number of hidden nodes depends on the interferer detection method and the **detection threshold setting**. Hence, LBT implementation parameters as well as the interference detection threshold need to be properly upper limited in order to guarantee that LBT significantly lowers the packet collision rate on the channel compared to a non-LBT access scheme. Anyway, the effective channel packet loss rate in a realistic implementation will always be greater than zero so that CSMA-ACK experiences a performance limiting congestion similar to the ALOHA system although the corresponding traffic load is significantly higher. Hence, a load dependent **back-off** procedure is recommended to achieve a graceful degradation instead of a system collapse.*

While there is an easy trade-off between duty cycle and transmit power in non-LBT systems, the situation is more difficult in systems using LBT. In case transmitter and interferer are using the same transmit power, signal detection works equally in both directions. If the transmitter can detect the interferer, the interferer can detect the transmitter as well as the physical channel itself is reversible. This is no longer true using different transmit power levels. A low power transmitter will detect a large number of harmful interferers with a high transmit power, but only a few of them will be able to measure the signal of the low power transmitter. Hence, LBT successfully avoids a collision only if the interferer packet transmission starts prior to the scheduled transmission on the desired link, while any later start during the desired packet transmission will inevitably result in a packet collision. The performance degradation of LBT systems due to different power levels depends on the performance of the LBT itself. Hence, a common agreement on the LBT parameters and the scenario assumptions is required prior to a decision on the duty cycle limitation for high power links. Alternatively, the spectrum may be subdivided into different bands allowing LBT with specific transmit power levels within each band.

In general, the needed transmit bandwidth of an SRD is significantly smaller than the available bandwidth in the SRD band. Section 3 has shown that many SRD applications are using data rates in the order of ten to hundred kilobits per seconds, which often is a good compromise between transmission range and energy consumption for packet transmission. Hence, a typical bandwidth is in the order of 100 kbps. Using single-carrier access schemes has the disadvantage that the spectrum is not equally exploited. Some of the 100 kHz sub bands might be much more crowded than others. Hence, the use of systems with frequency agility shall be encouraged to obtain equal spectrum exploitation. Potential implementations of LBT&AFA have been described in section 4.8.

*In order to enable a high number of simultaneously operating devices, the duty cycle on a single link needs to be limited. For systems using single carrier, **DC based random access on unidirectional links** the duty cycle limit should be very low:*

- *Transmit DC of 0.1% might be reasonable for systems without LBT;*
- *Duty cycle is independent of the signal bandwidth;*
- *Allow higher transmit power at the cost of a lower duty cycle;*
- *Define maximum Ton and minimum Toff time.*

*In order to maintain the same number of devices, the duty cycle of **non-adaptive FH** should not be higher than the duty cycle of a single carrier system. In this case, the duty cycle on a hop frequency is equal to 0.1%/N, supposed that N is the number of hop frequencies and all frequencies are equally used. As FH helps to randomize the channel load over the frequency band, a higher duty cycle limit might be applied to promote FH systems and thus drive the resulting capacity increase. It is recommended to specify a minimum frequency separation in the order of the typical signal bandwidth of single carrier systems.*

- **Transmit DC of 0.1%, maybe higher to promote FH;**
- **Minimum frequency separation of 100 kHz recommended.**

*For systems using bi-directional links with **acknowledgement procedure** the following rules are proposed:*

- *ACK packets shall be allowed to be transmitted without LBT;*

- *ACK packet length and response time shall be added to the packet length of the transmitter for DC calculations;*
- *Application duty cycle shall be 0.1% including ACK;*
- *Number of retransmissions shall be limited by duty cycle restriction or load dependent back off procedures for packet retransmissions need to be defined;*
- *Define maximum communication time and minimum Toff time.*

*Systems should be encouraged to use **LBT** to increase the efficiency of resource usage. As the performance of the LBT procedure significantly depends on the interferer detection reliability and the implementation parameters, these parameters shall be specified.*

- *Energy detection is recommended as interferer detection method;*
- *Detection threshold shall be in the order of the typical receiver sensitivity level;*
- *Detection threshold shall be no function of the transmit power;*
- *It is recommended that the minimum required interference measurement time and the dead time are specified*
- *The duty cycle of LBT systems shall be 10 times higher than the duty cycle of non-LBT systems*

Different power levels lower the LBT performance. Duty cycle restrictions for high power devices shall be carefully selected and shall be more restrictive for LBT than for DC based random access systems. Alternatively, the SRD band needs to be separated into subbands with different power levels.

*It is expected that a significant part of SRD applications will be single-carrier systems due to cost and complexity limitations. In general, the SRD band is not equally exploited using single carrier systems. Hence, the resource usage can be significantly improved by adding systems with a combination of listen before talk and frequency agility (**LBT & AFA**), as they will increase the traffic load on sparsely used frequency bands. As frequency agility helps to protect fixed frequency access systems, it shall be promoted by a higher duty cycle limit.*

- **The duty cycle limit of LBT&AFA systems shall be higher than the duty cycle limit of LBT systems.**

In general, it is recommended that a maximum communication time (T_{ON}) followed by a quiet time period (T_{OFF}) time is defined to make sure that other users can intervene and start their own transmission during the quiet time period. The maximum TON time should consider the latency requirements of SRD applications.

- **TON shall be smaller than 50 ms.**

*Operation of high duty cycle **DSSS/ fast FH** in parallel to a LBT system is not recommended, as the threshold of the LBT should not be increased to cope with wideband signals. This would significantly degrade coexistence with other LBT devices.*

- **DSSS/ fast FH should be subject to transmit duty cycle limitations.**

Some applications cannot be operated in parallel to low duty cycle, random access schemes. For example, a separate band shall be foreseen for audio systems with 100% duty cycle transmissions. In order to exploit the frequency band in the absence of audio applications, LBT & AFA shall be allowed even in this special band.

Furthermore, SRD applications requiring low latency and high reliability (e.g. industrial automation) cannot be operated in parallel to random access schemes. Hence, the SRD band can be only used in protected areas, where the access of SRDs is controlled by the premises owner. Otherwise, high data rate standards with guaranteed access for example in the 2.4 GHz band should be used.

The situation is slightly different for alarm systems like fire or intruder alarm, because the latency requirements are less stringent. Lost packets can be retransmitted based on acknowledgement procedures. If necessary, one could even think about different backoff procedures for safetyrelated applications to reduce the collision probability with a standard SRD application. Alarm systems themselves can implement redundancy, so that an alarm can be received by different devices with typically different interference situations. Most importantly, frequency agility can be used to select less congested channels for system operation. Hence, in general it should be possible to design highly reliable alarm systems without assigning a dedicated frequency band.

Nevertheless, there is no guarantee in license-except bands, so there is always a certain channel load which will hamper a successful communication. Therefore, it might be reasonable to specify a small exclusive portion of the spectrum for very sensitive safety related applications like social alarms at the cost of a slightly lower spectral efficiency, which always results from splitting the SRD spectrum into different bands'.

Unquote

Comments:

When considering the IMST Study the following should be borne in mind:

- Some of the simulations are of quite specific situations, e.g. a device sending 6 packets with a requirement that at least one is successful, and results from these may not be applicable to all situations.
- Allowing higher power at the cost of lower DC is mentioned in the conclusions. It is clear in the text (eg., Section 6.1) that there is not a direct relationship between power and DC and trading one for the other only is only applicable in certain limited circumstances.
- The word "shall" is clearly not used in the same sense as in ECC and ETSI documents. In the IMST conclusions it should be read as a recommendation rather than an imperative.

3.3.2 Main findings and discussion

The main findings of the IMST Study in the context of the current study may be summarised as follows:

In relation to the communications link:

- Bi-directional communications are to be preferred over uni-directional.
- Spectrum access methods such as CSMA, LBT and LBT+AFA can offer advantages over DC based random access.
- It may be appropriate to encourage and reward bi-directional communications and advanced spectrum access methods, for instance by higher duty cycle or other means.
- The overall performance of spectrum access method can be dependent on details of parameters such as back off procedures.
- There is some study of populations with mixed spectrum access methods. Section 6.3 discusses coexistence between DC based random access and CSMA. This may be useful in the current study.
- Limits on maximum Ton and minimum Toff should be introduced for all spectrum access methods.
- Generally, different applications can share frequency bands, but it may be reasonable to specify small exclusive bands for sensitive safety related applications.

In relation to specific applications:

- Audio, PMSE: are not typical SRDs, due to the low latency requirements and the high DC (even digital systems require more than 10% DC); therefore placing them in exclusive sub-band like 863-865 MHz seems appropriate. But other SRDs might be also allowed in the same sub-band under specific conditions to ensure coexistence with audio/PMSE devices (e.g. DSSS and FHSS requirements established in ECC Report 37 [1]);
- Wireless industrial: are not typical SRDs, due to the low latency and high reliability requirements; their self-protection may be assumed thanks to certain geographical separation (installation requirements at industrial plants). However this application is anyway not considered an issue for the subject band due to high EMC emissions in industrial environments below 1 GHz;
- Social Alarms: it may be inappropriate for simple one-way systems such as social alarms to implement adaptive techniques. Therefore sufficiently high reliability may be achieved for these applications only by placing them in exclusive sub-band. Possibly very small exclusive sub-band(s) acting as "safe harbour" may be considered for these applications, while allowing them to tune across other sub-bands when manufacturers deem the risk of experienced interference acceptable. Overall this suggests that the number of dedicated sub-bands for alarms may be reduced compared with current situation; also the adaptivity in these applications, when possible, should be rewarded.

3.4 ANALYSIS OF PREVIOUS STUDIES

The most relevant findings of previous studies in the context of the current report may be summarised as follows:

- The use of adaptive techniques like LBT/AFA should be encouraged; however, the use of adaptive techniques may be inappropriate for one-way systems, e.g. social alarms
- There is a clear preference for application neutrality in regulations for SRD bands. In that sense the current SRD regulations for the band 863-870 MHz in ERC/REC 70-03 [11] already offer sufficient freedom through a very broad designation of the entire band for “Non-specific SRD” category. So this designation should be clearly retained;
- There is still the need for some application specific sub-bands, but there may be some room for reducing the amount of such spectrum (e.g. alarms).
- The introduction of max Ton and min Toff restriction should be considered, at least for some very specific types of applications, while noting that there is a wide variety of SRD applications and some in deployment today using Ton times up to 1 s. See several examples of addressing this issue in various documents summarised in Annex 5 of this report;
- FHSS: here a differentiation of fast and slow FHSS could be reasonable, because slow FHSS appears like a DC mitigation from the viewpoint of a narrowband receiver, and fast FHSS appears like a wide Gaussian noise. That could be solved by an appropriate definition of the required DC limits.
- ECC Report 181 [2] and the IMST Study differ slightly in one recommendation. ECC Report 181 states different sub-bands should be optimised for different communication needs, whereas IMST implies that band segregation always lowers spectrum efficiency. The resolution of this apparent conflict is explained in Report 181, which discusses different meanings of “efficiency”. The aim is not necessarily to optimise spectrum occupancy or data traffic.

4 REFERENCE SCENARIO INTRA-SRD COEXISTENCE IN 863-868MHZ

4.1 STATIC VIEW ON WHERE SRD COEXISTENCE STANDS TODAY

Before progressing to elaborate on any possible future re-arrangements, it is worth to stand back and take a measured look at where intra-SRD coexistence stands today. This would provide a means of establishing some reference basis. Noting that generally so far there was little evidence of intra-SRD coexistence problems reported, it might be assumed that the current situation could be used as a safe departure point in terms of expressing some coexistence criterions that ensure safe cohabitation of various SRD applications, if not the most efficient utilisation of common spectrum bands.

In order to set out this reference static point of coexistence, the basic MCL check was used to analyse the “impact ranges” for different combinations of SRD applications. The results are reported in ANNEX 4:.

These results show the projected values of impact range - i.e. the maximum distance at which the signals may still create interference in case of collisions of transmitted packets. One most critical coexistence case stands out, namely with the case with RFID as interferer, which has impact ranges up to 200-500 m for co-channel and 30-70 m for adjacent coupling. This could create more coexistence concerns in those scenarios of industrial/business environments, where RFIDs might be co-located with other types of SRD applications on the same premises.

Otherwise, for most dominant residential and office environments, the impact ranges are from few tens of meters to at most 100-150 meters. Note that these results were obtained without assuming any additional losses such as from heavier partitions between the office floors, which means that if considering the impact on adjacent floors of multi-storey building, the impact ranges would be further reduced to maximum 10-50 m. This means that for majority of incumbent SRD applications using 863-870 MHz, their coexistence in typical residential/office environments could be considered to belong in the domain of “same premises”, where the owner of the premise could take actions to resolve an interference case.

In summary the MCL calculations are showing that under worst-case assumption interference can only be expected in the "same premises" scenarios.

Not considered in the MCL calculations are the time dimension and other dynamics in frequency and space (e.g. Duty cycle of the interferer, time variance of the wanted signal of the victim receiver). Those details will be analysed with SEAMCAT in the following sub-section to better understand the currently expected levels of intra-SRD interference and if there is any problem expected.

Also, the graphs of various relevant simulations of SRD coexistence in time domain, carried out for such scenarios and reported in [5] were shown above in section 3.3 of this report. They offer some valuable insights on comparative performance of different channel access schemes.

4.2 ADDITIONAL STATISTICAL SIMULATIONS OF LEGACY INTRA-SRD COEXISTENCE

To complement the static view provided in previous sub-section, it is also possible to carry out statistical Monte Carlo simulations of intra-SRD coexistence using the SEAMCAT tool. In this case the aim of analysis is establishing statistical interference potential amongst the different SRD families. This analysis had been derived from similar intra-SRD analysis done previously for neighbouring band 870-876 MHz in ECC Report 200 (see section 5.2 in [3]).

The analysis looks at the scenario of using different SRD applications within the same premises, since it was shown previously that the realistic impact ranges of most incumbent low power SRD applications are quite low, on the order of few tens to around one hundred meters. Therefore all interfering and victim devices shall be mixed in one random spot, as illustrated in the following Figure 6 that shows a screenshot of SEAMCAT simulation window for this scenario. Note that the spread of up to 300 m is due to high impact range of RFID devices, whereas all other types of interfering vs. victim SRD applications are placed within 40-150 m from each other, according to their respective mutual impact range as calculated with MCL in previous sub-section and provided in ANNEX 4:.

Figure 6: Example of a single snapshot in SEAMCAT simulation: Intra-SRD coexistence scenario

It should be also noted that SEAMCAT simulations model dynamics of possible physical movement, impact of differing mutual placement on respective link budgets, as well as possible collision of transmissions in time domain as a result of DC-based probability of transmission. The SEAMCAT simulations do not take into account possible mitigation effects from more sophisticated channel access methods, e.g. variants of ALOHA or CSMA-ACK mechanisms discussed previously. Therefore SEAMCAT results should be considered valid for simple DC-based access, although the used SEAMCAT version (4.1.0) has only simple and limited possibilities to consider time domain effects. When more sophisticated channel access mechanisms would be used, they should provide some additional mitigating effect and improve co-operative or interactive aspects of co-existence therefore a decrease of the predicted probability of interference is expected in real scenarios where at least part of SRDs is employing advanced channel access methods.

Of the available SEAMCAT's in-built propagation models, the Extended Hata-SRD model was used in this analysis, as it is well suited to model propagation in cluttered environment between similarly low placed transceivers. It was used with the ILT-VLR placement mode "None", whereas the maximum coverage radius was set differently for different interferer-victim configurations according to the respective impact ranges calculated with MCL method as reported in the previous sub-section. Except that for RFID case the impact range was limited to 300 m to correspond to maximum validity range of the model.

In addition to choice of the main propagation model, it was also discussed which values should be used for the wall/floor penetration. As a result of these discussions, it was determined that it may be impossible to settle on one set of specific values appropriate for broad range of buildings encountered in real life situations. Therefore it was agreed to make simulations using two sets of wall/floor losses:

- *Wall losses Option 1*: default SEAMCAT values of 5 dB for indoor-indoor wall penetration, 10 dB for indoor-outdoor and 18.3 dB for floor attenuation, to represent medium propagation losses, i.e. representing "optimistic indoor propagation conditions";
- *Wall losses Option 2*: alternative penetration loss values of 10 dB for indoor-indoor wall penetration, 20 dB for indoor-outdoor wall penetration and 25 dB for floor attenuation, i.e. representing "conservative indoor propagation conditions".

The option 2 values were suggested by the SRD community and are based on their practical experience in the field. The results for these two sets would thus allow establishing certain brackets for the range of probability of interference.

Other parameters, including the number of interferers active in a considered impact area were used as first established in 2.3.7, Table 18.

Since there exist a certain number of uncertainties, it appears reasonable to structure the simulated cases into a few distinct categories, i.e. based on these most critical assumptions:

- Medium Density Scenario vs. High Density Scenario: taking respectively the lower and upper limits of device deployment density ranges indicated in Table 18;
- High Activity Period vs. Average Activity: taking respectively the values of maximum DC (i.e. DC equal to maximum allowed limit in ERC/REC 70-03 [11]) and average DC over one day, as indicated in Table 18;
- Medium propagation losses (Wall losses Option 1 as described above) vs. High propagation losses (Wall losses Option 2): taking respectively wall/floor penetration losses as by default in SEAMCAT or some increased wall/floor loss factors.

Furthermore, in order to reduce the number of various combinations to be considered (e.g. 8 for the above three factors), it appears reasonable to try combining some options, for instance, by deducing that higher propagation losses may be linked to extreme urban environments and therefore higher path loss assumption could be linked with high deployment density scenario, whereas medium path losses would be more appropriate for less dense (e.g. suburban) environments, and therefore medium density assumption could be linked with medium path losses.

The Table 76 in ANNEX 10: shows detailed technical parameters for SEAMCAT simulation settings with different options for mixed SRD scenario with Home Automation SRD as example of a legacy SRD victim. Detailed settings for all tested scenarios and victim cases may be obtained by reviewing the accompanying SEAMCAT scenario files. The following Figure 7 shows an illustration of simulated scenario and it's constituent transceivers. The simulation radiuses of victim links are established according to assumptions in Table 18, while simulation radiuses (i.e. maximum impact distances) for interfering links are dependent on specific interferer-victim pair, as calculated in ANNEX 4:.

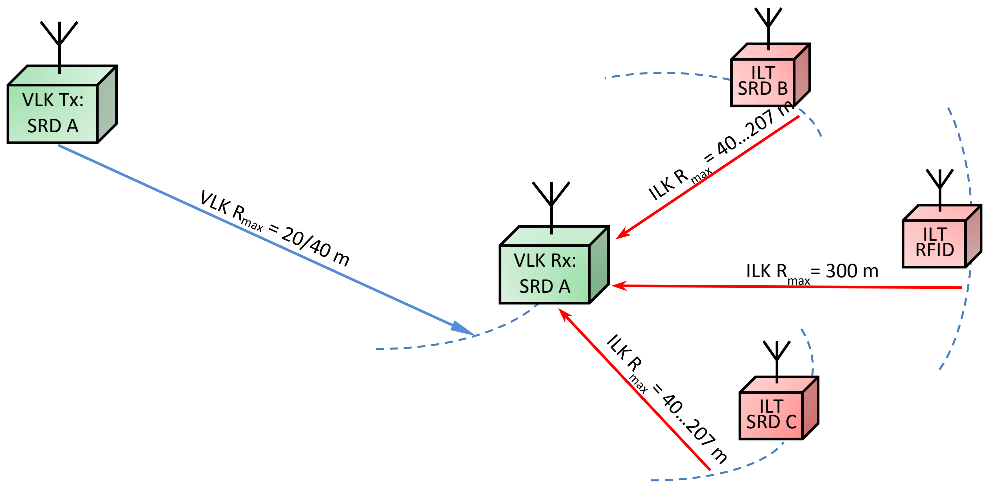


Figure 7: Intra-SRD coexistence scenario outline

The Table 77 in ANNEX 10: shows the summary of results of simulations for various scenarios with legacy SRD mix, with different SRD devices types considered a victim in turn.

The results of SEAMCAT simulations show that when assuming a realistic Cat. 2 filter in victim receivers, the risk of interference is generally low across the entire range of considered legacy scenarios. Only when assuming the worst case and rather unrealistic scenario configuration with all participating SRD transmitters operating at their maximum permitted DC, the probability of interference reaches to around 2-3% for unwanted interference and up to 5% if considering unwanted and blocking interference.

This means that already in the legacy SRD coexistence scenarios there may be marginal risk of blocking interference for some cases of very densely deployed and thus closely co-located devices.

Also note that the additional influence of background adjacent band interference from LTE uplink deployed below 862 MHz was not considered in this analysis of past-to-present situation, but will be considered in the next sections as part of future scenarios.

This observation further re-affirms the long standing understanding that the SRD industry should not slack the receiver quality parameters such as receiver selectivity and blocking performance, and supports the overall drive for implementing advanced channel access mechanisms as a recommended practice for any future applications that may see dense deployment.

5 FEASIBILITY OF USING THE BAND 862-863 MHZ FOR SRDS

There remain legacy radiocommunication services in the 862-863 MHz band in some CEPT administrations incl. EU member states. These are mostly communications systems used by Government agencies. They are listed in the European Table of Frequency Allocations and Utilisations (ERC Report 25 [49]) as a Mobile application with the Major utilisation being Defence Systems.

It is recognised that compatibility analysis will be necessary before SRD can be authorised for use in administrations where such Defence Systems operate. However, the use scenario and technical characteristics of these Defence Systems are often classified and were not made available to this study team.

Therefore this ECC Report does not include any in-band compatibility analysis against the Defence Systems in 862-863 MHz. Any compatibility analysis will need to be undertaken by individual administrations or collectives of administrations using similar Defence Systems.

However the existence of these Defence Systems in 862-863 MHz should be recognised when discussing later in this report the impact of future SRD, if deployed in this band, into Mobile systems operating below 862 MHz (LTE Base-Receive). Namely it should be remembered that the existing 862-863 MHz spectrum is not empty but instead have certain legacy use.

It is worth noting that until recently, the radiocommunication service immediately below 862 MHz was broadcasting. Broadcast receivers were often co-located in the same room as 863-865 MHz audio SRDs with 100% Duty Cycle (a common example being cordless Audio Headphones used to listen to the audio output from the very same television set that acts as potential victim receiver). These two systems operated side by side without undue interference.

With the change of use of the frequency band to LTE Base-Receive, the separation distance has typically increased, as compared to the above described same-room scenario. Such increase of separation distance might be expected to improve coexistence potential and thus compensate for reducing the frequency separation, i.e. moving lower edge of SRD band from 863 MHz down towards 862 MHz without causing undue harm to LTE Base receive function. This hypothesis provided the initial motivation and drive for the following statistical analysis of the mutual adjacent band impact of proposed SRD operations in the band extended down to 862 MHz.

5.1 REVIEW OF ADJACENT BAND SRD AND LTE COEXISTENCE

First it is needed to confirm the feasibility of adjacent band coexistence between current and emerging SRD applications in the band 862-870 MHz vis-à-vis LTE systems deployed below 862 MHz in the part of the UHF band vacated from analogue TV transmissions. Note that today the 862-863 MHz is not allocated to SRD and represents a potential new opportunity for SRDs as described in Section 2.4.

The material of this sub-section complements the previous studies of SRD vs. LTE OOB coexistence as reported in ECC Report 200 [3] and ECC Report 207 [4].

5.1.1 Impact of LTE 800 into SRDs using 862-863 MHz

This case study will consider a representative example of SRD Sub-metering application being deployed in the band 862 – 863 MHz as victim and LTE UE below 862 MHz as interferer. The same scenarios and assumptions will be used as previously in ECC Report 207, with changed frequency range and application type.

Used scenarios:

- Scenario 1 (same room), see Figure 8 a single LTE UE is located within 10 m range of an SRD receiver, in an indoor environment, to simulate the case of a person using their LTE UE in premises where an

SRD receiver is present. In general, it is expected that the LTE UEs and SRDs are likely to operate at the same premises:

- Scenario 1, approach 1: user defined dRSS with a mean dRSS 20dB (Gaussian distributed) above sensitivity. For metering dRSS = -84dBm with a standard deviation (std dev) of 10 dB;
- Scenario 1, approach 2: real distance simulation, distance up to typical operating distance depend on used category of SRD receiver. As a result of this approach, for Metering SRD victim the simulated dRSS had mean of -78 dBm with std dev 18 dB;

- Scenario 2 (macro): one single LTE UE and an SRD receiver are randomly located in a 3-cell network, with no specific assumptions on the relative position between LTE UE and SRD.

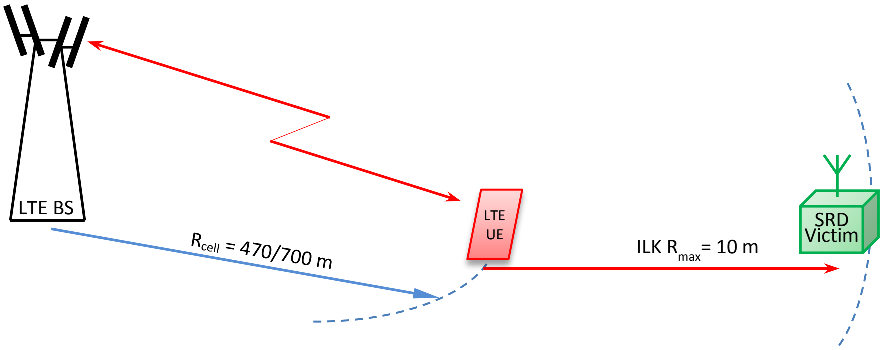


Figure 8: LTE UL to SRD interference scenario outline

The key SRD parameters used for this simulation are listed in the Table 78 and the results of SEACAT simulations are listed in Table 79.

With reference to studies reported in section 5.2.1 of the ECC Report 207 [4], identical SEAMCAT simulations were repeated here with only one change: the frequency of the victim link was changed to 862.1 MHz, in order to fall within the addressed band extension.

The results for **Scenario 1 with dRSS approach 1** can be found in Table 79. They show that were SRD victim receivers operate near their sensitivity thresholds, the risk of interference from a nearby operating LTE UE may be very high, i.e. around 8% to 22% for realistic 10 MHz LTE UE emissions mask interfering with Cat. 2 SRD victim receiver.

The results for **Scenario 1 with dRSS approach 2** can be found in Table 80. They show that when assuming average realistic deployment conditions for victim SRD applications with operating ranges of 20 to 40 m, they usually would have certain operational margin on their wanted signal which allows moderating impact of adjacent band interference from nearby LTE UEs. For example, for Cat. 2 victim SRD receiver operating within 20 m of its transmitter, the risk of interference from LTE UE with realistic mask is below 3%. However if the same victim SRD were to operate at up to 40 m range from its wanted transmitter, the reduced operating margin would lead to much higher risk of interference from LTE UE, up to 7-16%.

The results for **Scenario 2** (ref. section 5.2.2 of ECC Report 207) can be found in Table 81. In the “macro” Scenario 2 the probability of interference was found to be mostly below or around 1% (except for blocking impact on Cat. 3 SRD receivers) and therefore this case is not considered critical. Here one SRD receiver and 3 (when using 10 MHz channel) or 15 (when using 1.4 MHz channel) LTE UEs are randomly located within 300 m of victim SRD, as if working in a 3-cell LTE network, with random relative position between victim SRD and LTE UEs in indoor environment.

To summarise, for the same room scenario 1, where a single LTE UE is using one or more channels in block C (852-862 MHz) and is transmitting at the same time when the SRD is receiving and is located within 10 m range of the SRD receiver, in an indoor environment, the simulations indicate a challenging environment for SRD, with a significant level of interference unless the maximum operating range of victim SRD is reduced to around 20 m. It is expected that the design of new SRDs applications for the band 862-863 MHz will have to take into account the relatively high level of ambient interference from LTE UEs. For example, the ambient interference from LTE UEs would be seen by SRD as in-channel noise, therefore it could be detectable and avoided by using LBT or DAA-type techniques.

The fear of interference from LTE below 862 MHz may discourage some SRD applications from using the 862-863 MHz sub-band. There may be, however, some applications where such an interference threat would be of little or no relevance. This may be for various reasons, including:

- Devices that will be located physically separate from LTE UE devices. This may include, for instance, devices on top of streetlights, on unattended machinery or in remote locations;
- Devices for which latency is not important. The LTE UE transmissions will not generally continue uninterrupted for long times. In Home Automation, for example, heating control would fit this category, but in-building lighting control would not.

There are SRD applications that fit both of the above mitigating categories, such as remote control of street lighting. This example shows that there might be SRD applications who could make use of the band extension down to 862 MHz regardless of increased risk of interference spill-over from LTE UEs transmitting just below 862 MHz.

5.1.2 Impact of legacy SRDs using 862-863 MHz into LTE 800

In this case an LTE BS receiver operating below 862 MHz is considered as victim, whereas Sub-metering and Home Automation SRD transmitters in the band 862-863 MHz will act as representative SRD interferers. Similar to simulations reported in chapter 4.5 of ECC Report 200 [3], only LTE technology will be considered for Victim, and only Sub-Metering or Home Automation as SRD Interferers.

Macro Scenario will be considered where one single LTE BS and several SRD transmitters are randomly located in a circle with 500 meter radius with a minimum coupling loss of 70 dB between victim and interferer; Figure 9 illustrates the outline of this simulation scenario.

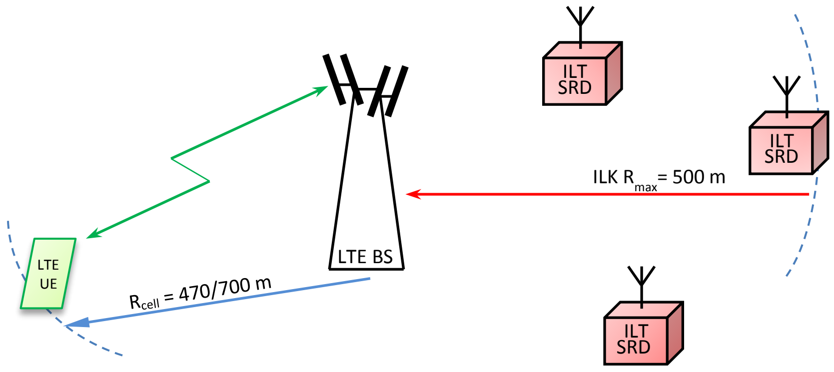


Figure 9: Legacy SRD to LTE UL coexistence scenario outline

The detailed technical parameters of SEAMCAT scenario are given in ANNEX 10:, Table 82 and Table 84 respectively for Home Automation SRD and Sub-metering SRD as respective interferers.

The results for this scenario with **Home Automation SRD acting as interferer** are given in Table 83. They show that the impact from 25 mW HA SRDs with reduced emissions mask (Mask Option 1, see ANNEX 1:) would be up to 1.6% for all considered cases. Only if assuming HA SRDs operating with worst case mask (Mask Option 2) and the unlikely occurrence of all simulated SRD transmitters operating constantly at their maximum allowed DC, the average throughput loss might reach 7-8%.

The results for this scenario with **Sub-Metering SRD acting as interferer** are given in Table 85. When looking at these results and comparing them with previous ones, it may be seen that the impact from Sub-metering SRDs with reduced emissions mask (Mask Option 1) would be higher than that from HA SRDs due to much larger deployment density of Sub-metering SRDs. Still it would be within acceptable limits, i.e. below

1% for scenarios with SRDs operating at average DC and up to 4-5% for the extreme and unlikely case of all SRDs operating at their maximum allowed DC. Only if assuming Sub-metering SRDs operating with worst case mask (Mask Option 2) and the unlikely occurrence of all simulated SRD transmitters operating constantly at their maximum allowed DC, the probability of interference would be unacceptable and may be reaching as high as 20-25%.

Note that this analysis did not see the need to consider the baseline case of current interference from SRD operating above 863MHz.

5.1.3 Impact of high power NBN SRDs in 862-863 MHz into LTE 800

Note that bringing into consideration of wide area network such as LTE, changes the geographical dimension and scale of analysis of proposed NBN SRD application. If in intra-SRD scenarios the appropriate interaction area is considered to be in the order of 100 m, the LTE with its powerful outdoor mounted base stations expands the impact area to the range of around 0.5-1 km, i.e. corresponding to a typical coverage range of one LTE cell. This expansion of impact area range brings into picture many more SRDs that may potentially interfere with an LTE base station. At the same time, expanding the scale of considerations brings into picture the full extent of diverse networking layers of the proposed new SRD applications, as illustrated in Figure 2 for the scenario of NBN SRDs used for M3N type utilities infrastructure. The respective densities of various constituent device types had been indicated in section 2.5.1.

The illustration of the considered coexistence scenario is given in Figure 10 below.

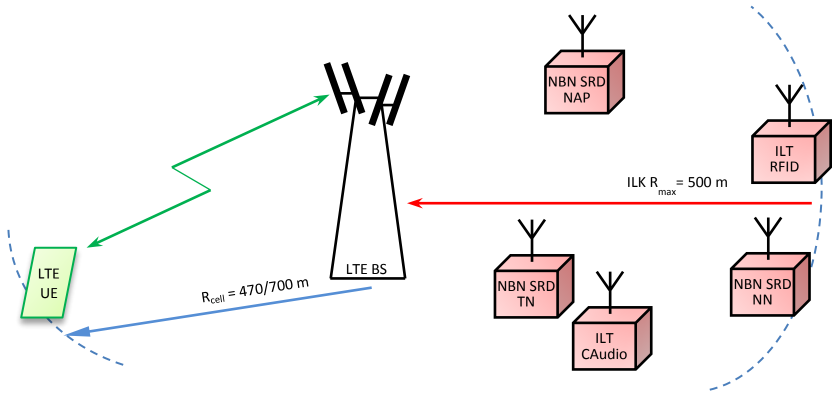


Figure 10: NBN SRD in 862-863 MHz to LTE UL coexistence scenario outline

The detailed technical parameters used in the SEAMCAT simulations for this scenario are provided in Table 86 in ANNEX 10:

The relevant results of the SEAMCAT simulations are summarised in Table 87 and Table 88 for respectively NBN SRD with reduced emissions (Mask Option 1, see ANNEX 1:) and worst case (Mask Option 2) unwanted emissions mask. These results show that for NBN SRDs with unwanted emissions compliant with reduced emissions mask, their deployment would create a significant additional increase of up to 5-20% of interference risk compared with the background level existent from legacy SRDs that already occupy the band 863-868 MHz.

Allowing NBN SRD unwanted emissions according to Option 2 mask specification would further increase the risk of additional interference up to 24% compared with baseline scenario.

In order to investigate feasibility of deploying new NBN SRD application in 862-863 MHz with reduced power as well as reduced unwanted emission level, an additional sensitivity analysis was performed by re-simulating a few most sensitive scenarios with unwanted emission mask Option 1 but with output power of all NBN SRD constituent device types (NAP, NN and TN) further reduced to 20 dBm and accordingly operational radius of Terminal Nodes reduced from 300 m to 100 m. The results of this sensitivity analysis are reported in Table 87bis. They show that reduction of NBN SRD output power to 100 mW would only minimally reduce the risk of interference. For most sensitive case of high density urban deployment, the probability of interference would be still 7-14%.

5.2 IMPACT OF SRDS 862-863 MHZ INTO CORDLESS AUDIO IN 863-865 MHZ

In this case a Cordless Audio device (e.g. consumer operated wireless headphones or wireless microphone used in PMSE) operating in the band 863-865 MHz was used as victim. Several metering SRDs operating in the band 862-863 MHz were considered as interferers. The carried out simulations were similar to those reported in ECC Report 207 [4], with audio as a victim and changed interfering link (metering instead of LTE as Interferer, metering parameters from ECC Report 200 [3]).

The simulated coexistence scenario entails one Cordless Audio victim receiver operating at user defined dRSS and affected by several interfering SRD transmitters, which are randomly located in a circle with either 10 or 500 meter radius around the victim, as illustrated in Figure 11 below.

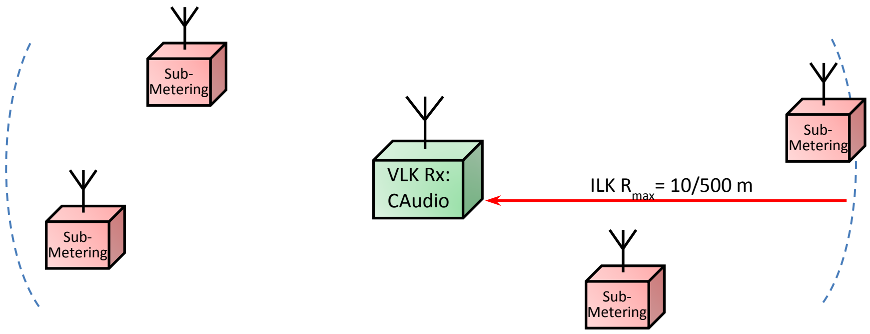


Figure 11: Scenario for SRD in 862-863 MHz impact on Cordless Audio in 863-865 MHz

The detailed technical parameters for SEAMCAT simulations are listed in Table 89 in ANNEX 10:. The results of simulations by SEAMCAT show that the combined (unwanted & blocking) probability of interference experienced by Cordless Audio victim receiver of Cat. 1 may be as follows:

- dRSS approach 1: 0.3% (500m radius), 1.0% (10m radius);
- dRSS approach 2: 0.15% (500m radius), 0.7% (10m radius).

The probability of interference (unwanted & blocking) experienced by Cordless Audio receiver of Cat. 2 would be:

- dRSS approach 1: 0.3% (500m radius), 1.0% (10m radius);
- dRSS approach 2: 0.2% (500m radius), 0.9% (10m radius).

These results show marginal risk of interference from SRDs in 862-863 MHz to Cordless Audio devices in 863-865 MHz. It may be surmised that the low DC of 0.1% of interferers is a key element to achieve this result.

Noting that analogue and digital Cordless Audio devices will operate with DC of 100%, a closer look is warranted at what exactly the 0.15…1.0% probability of interference might mean. As regards interpretation of the marginality of the risk of interference, the following might be considered:

- the above results should be interpreted as the probability that interfering SRD devices (each with DC of 0.1%) will happen to be close enough to adjacent band victim Cordless Audio receiver as to cause interference during interferer's Ton times;
- as regards the subsequent impact in time domain to given victim from a dominant nearby interferer, one might refer to Annex 7 of ECC report 181 [2] that offers a detailed breakdown of operational statistics of various SRDs. It shows that the transmission pattern of metering SRDs vary between 1 packet of 25 ms every day and 96 times 25 ms, But in all cases this would constitute the emissions much less that the DC limit of 0.1% in any hour. However, if assuming a DC of 0.1%, that would mean max 3.6s of Ton time in any given hour, or 144 packets of 25 ms in an hour (i.e. 2 packets per minute). This would mean that

Cordless Audio receiver might see an increase of noise due to OOB twice a minute for 25 ms duration, but only for the worst case that the DC limit of 0.1% per hour would be permanently exploited. This might be an unacceptable interference effect to an ALD or Radio microphone user.

A detailed discussion of interpretation of SEAMCAT results and probability of interference was provided in section 2.6 of this Report.

5.3 IMPACT FROM NBN IN 862-863 MHZ INTO SRDS

5.3.1 NBN Scenarios

Several scenarios have been considered in the following studies:

Table 23: Scenario 1: Initial scenario

	Max DC (%)	Average DC (%)	High Density	Medium Density	Simulation radius (m)	Antenna high
NAP	10	2.5	3	2	300	5
NN	2.5	0.7	25	13	300	5
TN	0.1	0.1	537	269	300	1.5

Table 24: Scenario 2: Specific duty cycles and specific densities

	DC (%) options	High Density (1)	Medium Density (1)	Low Density(2)	Very Low density (3)	Simulation radius (m)
NAP	0.1% or 1%	3	2	/	/	300
NN	0.1% or 1%	25	13	/	/	300
TN	0.1% or 1%	537	269	134	/	300
TN	1% or 10%	/	/	/	34	300

(1) Initial densities as used in the report.
(2) Additional density not yet considered in the studies to reflect a “low density” (475 devices /km2 – 134 in a 300m simulation radius).
(3) Additional density not yet considered in the studies to reflect a “very low density” (120 devices /km2 – 34 in a 300m simulation radius).

Table 25: Scenario 3: Combination of Tx power and duty cycles in different frequency bands

	TN	NN	NAP
Tx power (mW)	250	500	500
DC	0.1%	1%	1%
Frequency (MHz)	862-862.4	862.4-863	862.4-863
High density (1)	537	25	3
Medium density (1)	269	13	2
Low density	126	6	2

(1) Initial densities as used in the report.
Additional density not yet considered in the studies to reflect a “low density” (475 devices /km2 – 134 in a 300m simulation radius).

5.3.2 Compatibility with Cordless Audio in the band 863-865 MHz

Table 26: Baseline: Interferences on Cordless Audio with existing scenario, with no NBN implementation

Interfer	RFID (865-868) LTE 800 Cordless audio (863.9)	
	High density – Max DC	Medium density Average DC
Probability of interference (unwanted/unwanted + blocking)	12.62/20.16	7.7/11.32

- When considering the baseline scenario (without NBN implementation), simulations show high probability of interference.

Results for Scenario 1.

Table 27: Probability of interference (%) from NBN 500 mW to Cordless audio (Unwanted/Unwanted+Blocking)

Interferer	NBN 500 mW (Initial scenario)
Victim	Cordless audio 864.9 MHz
High density/Max DC	0.3/2.52
High density/Average DC	0.07/0.83
Medium density/Max DC	0.24/1.64
Medium density/Average DC	0.1/0.72

Table 28: Probability of interference (%) from NBN 250 mW to Cordless audio (Unwanted/Unwanted+Blocking)

Interferer	NBN 250 mW (Initial scenario) 862-863 MHz
Victim	Cordless audio 864.9 MHz
High density/Max DC	0.22/1.89
High density/Average DC	0.91/1.72
Medium density/Max DC	0.17/1.26
Medium density/Average DC	0.09/0.61

Results for scenario 2:

Table 29: Probability of interference (%) from NBN 500 mW to Cordless Audio (Unwanted/Unwanted+Blocking)

Interferer	NBN 500 mW DC : 1%	NBN 500 mW DC : 1%	NBN 500 mW DC : 0.1%	NBN 500 mW DC : 0.1%
Victim	Cordless audio 864.9 MHz	Cordless audio 863.2 MHz (1)	Cordless audio 864.9 MHz	Cordless audio 863.2 MHz (1)
High density	0.71/4.3	1.74/9.69	0.06/0.45	0.14/1.11
Medium density	0.6/4.25	1.5/9.37	0.05/0.37	0.16/1.12
Low density	0.34/2.17	0.85/4.73	0.01/0.18	0.04/0.42
Very Low density	/	0.2/1.12	/	/

(1) Worst case scenario not yet considered in the studies to show worst case scenario.]

Table 30: Probability of interference (%) from NBN 250 mW to Cordless Audio (Unwanted/Unwanted+Blocking)

Interferer	NBN 250 mW DC : 1% 862-863 MHz	NBN 250 mW DC : 1% 862-863 MHz	NBN 250 mW DC : 0.1% 862-863 MHz	NBN 250 mW DC : 0.1% 862-863 MHz
Victim	Cordless audio 864.9 MHz	Cordless audio 863.2 MHz (1)	Cordless audio 864.9 MHz	Cordless audio 863.2 MHz (1)
High density	0.51/3.24	1.45/8.22	0.03/0.3	0.15/0.89
Medium density	0.4/3.44	1.25/8.46	0.04/0.3	0.17/1.04
Low density	0.18/1.54	0.63/4.03	0.02/0.2	0.05/0.4

(1) Worst case scenario not yet considered in the studies to show worst case scenario.

Results for scenario 3:

Table 31: Probability of interference (%) from NBN to Cordless audio (Unwanted/Unwanted+Blocking)

Interferer	TN	NN	NAP
Tx power (mW)	250	500	500
DC	0.1%	1%	1%
Frequency (MHz)	862-862.4	862.4-863	862.4-863
High density Probability of interference (%) Victim : cordless audio 863.2 MHz	0.42/2.49		
Medium density Probability of interference (%) Victim : cordless audio 863.2 MHz	0.3/1.25		

5.3.3 Compatibility with Hearing Aids in the band 863-865 MHz

Table 32: Baseline: Interferences on Hearing Aids with existing scenario, with no NBN implementation

Interfer	RFID (865-868) LTE 800 Cordless audio (864.9)	
	High density – Max DC	Medium density Average DC
Probability of interference (unwanted/unwanted + blocking)	1.97/2.69	1.83/2.97

Results for scenario 1:

Table 33: Probability of interference (%) from NBN 500 mW to Hearing Aids (Unwanted/Unwanted+Blocking)

Interferer	NBN 500 mW (Initial scenario) 862-863 MHz
Victim	Hearing aids 863.3 MHz
High density/Max DC	0.13/1.11
High density/Average DC	0.11/0.54
Medium density/Max DC	0.13/1.34
Medium density/Average DC	0.07/0.48

Results for scenario 2:

Table 34: Probability of interference (%) from NBN 500 mW to Hearing Aids (Unwanted/Unwanted+Blocking)

Interferer	NBN 500 mW DC : 1% 862-863 MHz
Victim	Hearing aids 863.3 MHz
High density/DC 1%	0.24/1.58
Medium density/DC 1%	0.41/2.56
Low density/DC 1%	0.22/1.15

Results for scenario 3:

Table 35: Probability of interference (%) from NBN to Hearing Aids (Unwanted/Unwanted+Blocking)

Interferer	TN	NN	NAP
Tx power (mW)	250	500	500
DC	0.1%	1%	1%
Frequency (MHz)	862-862.4	862.4-863	862.4-863
High density Probability of interference (%) Victim : Hearing aids 863.3 MHz	0.08/0.55		
Medium density Probability of interference (%) Victim : Hearing aids 863.3 MHz	0.06/0.33		

5.3.4 Conclusion for compatibility between high power NBN in the band 862-863 MHz and incumbent applications in the band 863-865 MHz (Cordless audio and Hearing Aids in the band)

Table 36: NBN in 862-863 MHz compatibility with Cordless Audio and Hearing Aids at 863-865 MHz

	Scenario	High density	Medium density	Low density	Very low density
500 mW NBN	Initial			N/A	N/A
500 mW 1%	2			(TN only)	(TN only)
500 mW 0.1%	2			(TN only)	(TN only)
250 mW NBN	Initial			N/A	N/A
250 mW 1%	2			(TN only)	(TN only)
250 mW 0.1%	2			(TN only)	(TN only)
Combination of Tx power and duty cycles in different frequency bands	3				N/A

- As a general rule, it can be seen that compatibility with incumbent applications in the band 863-865 MHz is achieved when terminals are operating with a low duty cycle (0.1%). Indeed, by their own nature (low density), NBN NAP and NBN NN within networks such as described in section 2.5.1(initial scenario) have a low impact with regard to associated TN (NBN terminals) with 0.1% DC.

5.4 REGULATORY AND TECHNICAL CONDITIONS FOR SRDS OPERATIONS IN 862-863 MHZ

Based on analysis provided in the chapter, it may be recommended that the band 862-863 MHz is opened for some new SRD uses.

Namely, the use of non-specific SRD devices with e.r.p. of up to 25 mW and DC of up to 0.1% could be extended down to 862 MHz under the condition that the transmitters use emission mask Option 1. Even though it is acknowledged that when using the band 862-863 MHz the SRDs will have to contend with the high background noise due to spill over of LTE OOB emissions from the adjacent band below 862 MHz. Nevertheless, it would be up to SRD vendors to decide whether their specific application may be capable of operating in this noisy band.

It is therefore expected that the design of new SRDs applications for the band 862-863 MHz will have to take into account the relatively high level of ambient interference from LTE UEs. For example, the ambient interference from LTE UEs would be seen by SRD as in-channel noise, therefore it could be detectable and avoided by using LBT or DAA-type techniques. Alternatively, even typical legacy SRD technologies should be capable of operating in the band 862-863 MHz but with maximum operating ranges reduced to around 20 m.

The simulations have shown that it would not be feasible to allow new networked SRD applications in this band, such as the 500 mW NBN SRD used for Smart Metering. Even with output power reduced to 100 mW and assuming more stringent unwanted emission mask (Option 1), the adjacent band interference to LTE operations below 862 MHz would be unacceptably high.

Hence, as shown in table 87, operation in the band 862-862.4 MHz should be restricted to terminals with 500 mW e.r.p, low duty cycle (0.1%) and to terminals with 100 mW e.r.p, low duty cycle (0.1%) in the band 862.4-863 MHz, within specific networks (e.g. smart metering in rural or remote area and low density deployments). In all cases, unwanted emission mask of these terminals shall comply with mask option 1 (in Annex 1 figure 44).

6 FEASIBILITY OF IMPLEMENTING HIGH POWER NBN SRDS IN THE BAND 862-868 MHZ

This chapter will review the sharing feasibility of latest proposals for utilising NBN SRDs with transmit power of up to 500 mW in the band 862-868 MHz.

This section investigates the possibility of accommodating in the frequency range 862-868 MHz high power networked SRDs for fixed installations including smart meters with up to 500 mW e.r.p. and duty cycle restrictions (or other appropriate mitigations) as alternative and complementary option for the new entry for such devices in 870-875.6 MHz in Annex 2 of ERC/REC 70-03 [11]. Also possibilities for utilising other kinds of ad hoc professional digital SRD applications with e.r.p. of up to 500 mW was considered to be potentially useful.

A general description and essential parameters for proposed new higher power NBN SRD applications were discussed in section 2.5.1.

6.1 ADJACENT BAND STUDIES WITH PUBLIC CELLULAR SYSTEMS BELOW 862 MHZ

This sub-section will complement the analysis carried out previously in 5.1.3 by looking at the possible impact from proposed high power SRDs to LTE operation in adjacent band below 862 MHz. In this sub-section the impact of high power (500 mW with APC) new NBN SRD devices with a bandwidth of 200 KHz on LTE is analysed if they were deployed in sub-band 863-865 MHz or 865-868 MHz. In the latter case, the 500 mW NBN SRD operating frequencies had been restricted to 4x200 kHz channels overlapping with high power RFID interrogating channels.

As the only change here compared with previous scenario would be the shift of operating frequency band for proposed NBN SRD operations, the rest of assumptions will remain the same as shown in Table 86, including the application of two options of unwanted (OOB+spurious) masks for incumbent and proposed SRDs.

The results of SEAMCAT simulations for the scenario of 500 mW NBN SRD operating in 863-865 MHz are summarised in Table 90 and Table 91 for respectively NBN SRD with reduced emissions (Mask Option 1, see ANNEX 1:) and worst case (Mask Option 2) unwanted emissions masks. The results for 500 mW NBN SRD operating in high power RFID interrogator channels in 865-868 MHz are summarised in Tables 90bis (Mask Option 1) and 91bis (Mask Option 2). Recognising that this kind of operation would be more than 3 MHz offset from the LTE upper edge, it appears that implementation of NBN networks within "RFID interrogator channels" may create acceptable probability of interference to LTE base stations below 862 MHz.

6.2 INTRA SRD STUDIES

6.2.1 Impact on potential new SRDs in 862-863 MHz

This sub-section will review assumptions and results of simulations of coexistence of proposed new high-power NBN SRD applications in the band 862-863 MHz with legacy SRD applications deployed in the same band. Key technical parameters of NBN SRD and various deployment assumptions for simulations were taken from information in section 2.5.1.

The detailed technical parameters for SEAMCAT simulation of this scenario are given in Table 97 in ANNEX 10:. Graphical depiction of this scenario is given in Figure 12.

As this scenario addresses a newly developed “greenfield” band 862-863 MHz, as far as SRDs are concerned, a traditional SRD application of the type “Home Automation” will be considered a representative victim. In addition to previous studies related to implementation of 500mW SRD devices in 862-863 MHz, the following studies considered implementation of 250 mW NBN SRD in the band 862-863 MHz, with 0.1% duty cycle and very low density. It was considered that such characteristics could reflect specific SRDs deployment and act as mitigating circumstance to ensure the coexistence.

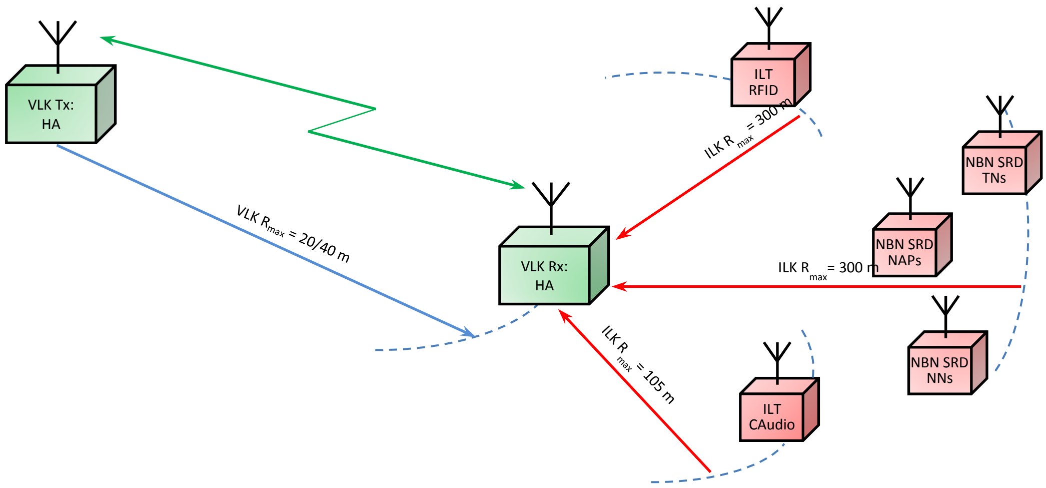


Figure 12: Scenario for NBN SRD co-existence with legacy SRDs in 862-863 MHz

The previous studies on operation of 500 mW narrowband SRDs in the band 862-863 MHz considered the impact on Home Automation system. Taking into account medium density and average duty cycle for each component of NBN SRD (Terminal nodes, Network nodes, Network Access Point), the results indicated interference probability of 6.5%/7.8% (unwanted/unwanted and blocking). Extending the analysis to most restrictive parameters (0.1% duty cycle for all NBN SRD components, very low density), it can be seen that sharing between high power (250 to 500 mW) NBN SRDs and Home Automation equipment is achievable with simulated probability of interference being around 1%.

6.2.2 Impact on Cordless Audio and Hearing Aids in 863-865 MHz

The first part of this sub-section is considering the impact of introducing NBN SRD in the range 862-863 MHz on Cordless Audio applications in 863-865 MHz, with scenario outline depicted in Figure 13.

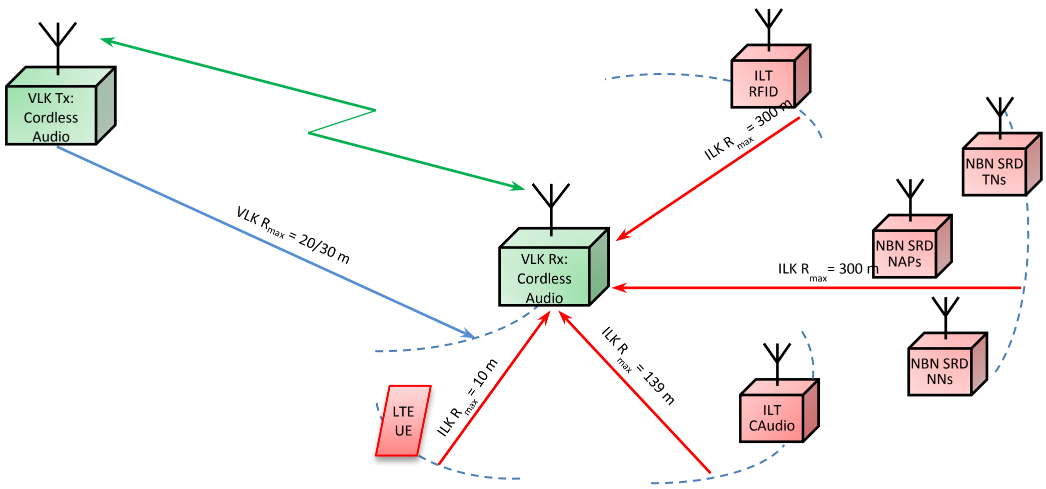


Figure 13: Scenario for NBN SRD co-existence with Cordless Audio SRDs in 863-865 MHz

The Table 97 in ANNEX 10: lists the key relevant parameters for this simulation while Table 98 provides the results of simulations. These results show that with regards to the current situation, the implementation of 500 mW NBN SRD in the band 862-863 MHz has only a very marginal impact on cordless audio devices in the band 863-865 MHz. It appears clearly from comparing different cases that unwanted emissions from LTE in adjacent band would be a major contributor in rising probability of interference.

The following part of this sub-section will consider the impact of introducing NBN SRDs in the range 863-868 MHz on Cordless Audio and Hearing Aids in 863-865 MHz. The general outline of this scenario for the case of Cordless Audio as victim remains the same as illustrated in Figure 13. Whereas when considering the Hearing Aids as a victim the simulated interaction radiuses will be different, see Figure 14, to reflect on different impact ranges in the case of Hearing Aid as victim (cf. ANNEX 4: for details).

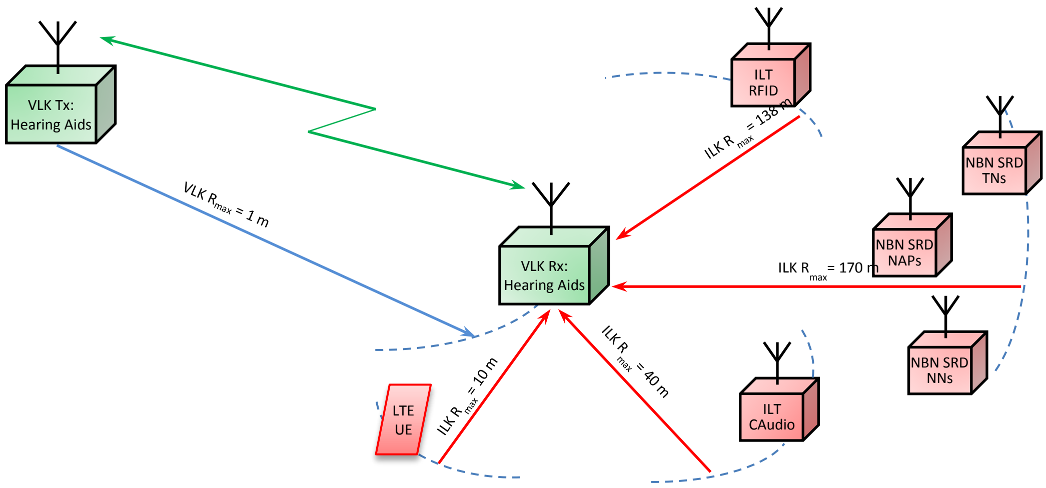


Figure 14: Scenario for NBN SRD co-existence with Hearing Aids SRDs as a victim

The detailed SEAMCAT simulation settings for this scenario are provided in Table 97 and Table 99 of ANNEX 10: respectively: first for the representative incumbent victim to be a Cordless Audio device, such as consumer cordless headphones or radio microphones and, secondly, a Hearing Aids device as a victim.

The relevant results of simulations of this scenario are given in Table 98 for victim Cordless Audio and in Table 100 for victim Hearing Aids. These results indicate that in general in the scenarios with NBN SRD using the band 863-865 MHz as part of their operating frequency range, the audio SRDs may experience probabilities of interference of up to 8-20%. However the major part of that would be due to ambient noise levels attributable to other interferers such as unwanted emissions from LTE in adjacent band. The contribution of NBN SRD alone may be up to 3-6% for highest density case with maximum allowed DC. For the medium density and average DC case the contribution of NBN SRD deployed over 863-868 MHz to audio SRDs in 863-865 MHz may be estimated to be around 2-4% of probability of interference.

6.2.2.1 Practical tests of the adjacent band impact of NBN SRDs

ANNEX 8: provides the summary of practical tests on the impact of Smart Metering NBN SRD systems built according to EN 303 204 [44] and working above 865 MHz on 4 audio systems working below 865 MHz. The results of the laboratory tests described in Annex 8 make it clear that operation of NBN devices in the band 863-865 MHz is not feasible. It further shows that under the selected conditions of adjacent band operation (500 mW e.r.p. above 865.6 MHz, 100 mW e.r.p. from 865-865.6 MHz) the coexistence with Cordless Audio is possible.

6.2.3 Impact on RFID and SRD systems in 865-868 MHz

6.2.3.1 Analytical evaluation of impact to RFID

Overview

This section investigates the potential impact of emerging applications in the band 863-870 MHz on RFID systems that are currently deployed in the band 865-868 MHz. This is an externally produced study and as such is different from and complementary to the statistical methodology adopted across this report. The statistical analysis of NBN SRD and RFID coexistence is provided later in subsection 6.2.3.2. The following Table 37 summarises the parameters used in this analytical study for RFID interrogators for two important applications – fixed infrastructure used for portals, vehicular access, and general area monitoring that operate at 2 W e.r.p.; and handheld (HH) devices that operate at 0.5 W e.r.p. that are often used in warehouses and retail shops for item-level inventory monitoring. The latter has become an especially common and important use of RFID equipment due to the benefits that high inventory accuracy affords to end users.

Table 37: RFID parameters assumed for analytical study

Parameter	RFID Application	
	Fixed Infrastructure	Hand-held (HH) devices
Frequency range (MHz)	865-868	865-868
Transmitter power, dBm	29.2	27.0
Tx antenna gain, dBi	6	2.2
Tx radiated power (e.r.p.), dBm	33	27
Rx antenna gain, dBi	6	2.2
Receiver bandwidth[7], kHz	400	400
Declared receiver sensitivity, dBm	-85	-80
C/I objective, dB	8	8

RFID systems that are the subject of this study consist of interrogators that operate with passive RFID tags. When RFID systems were introduced 10-15 years ago, the sensitivity of passive RFID tags was limited. This created a forward-link limited system where the power needed to energize a tag provided the tag with enough power that the backscatter energy received by the interrogator often exceeded the receiver sensitivity of the equipment by 5-10 dB or more. As RFID tag technology has improved, the forward and reverse links are now at parity, and to obtain 10 meters or more of read range requires an interrogator sensitivity of -85 dBm. As a result, a much higher percentage of RFID communications occurs close to the declared (threshold) reader sensitivity of the devices. It is worth noting that one characteristic of RFID tags is that since they have a threshold sensitivity of approximately -20 dBm, they are typically within close range of interrogators (10 m) and are less vulnerable to interference from other SRDs, cellular systems, WLAN, etc.

Another characteristic of RFID systems worthy of mention relates to the ISO/IEC 18000-6 protocol used by RFID interrogators in the 865-868 MHz band. This protocol has a built-in retry mechanism that improves the reliability of communications between the interrogator and the tag. However, if interference is present for

[7] An RFID interrogator receives tag transmissions in an upper and lower sideband, each with a bandwidth of approximately 200 kHz.

extended and continuous periods of time, then a tag that is transient and is within range of an interrogator only briefly may not benefit from the retry mechanism.

The parameters for NBN SRDs used in this study are according to description in section 2.5.1. Note that smart meter terminal nodes (TN) are not considered below as it is assumed that proximity of these devices with RFID installations is not common (or greater than 300 meters), or that site engineering techniques can be employed to mitigate against potential interference conditions. This may not be a universally valid assumption and may be re-visited at a later date.

Methodology

This analytical study uses traditional MCL analysis methods based upon transmission and receive parameters and path loss. In the process, worst-case scenarios for interference are defined and analysed.

The methodology further improves on standard MCL by incorporating statistical elements that attempt to provide more “real-world” predictions of interference. These methods are not intended to replace more sophisticated Monte Carlo techniques like those utilized in SEAMCAT. Instead, they are intended to provide insight into the mechanisms of interference, and to provide a “sanity check” against the more sophisticated methods that are highly dependent upon the assumptions and parameters that are inputs into those models. Moreover, the proposed method is explicitly designed to account for reception of RFID signals in upper and lower sidebands.

Technical Analysis

a) Calculation of Minimum Coupling Loss and Impact Range

The analysis of coexistence between interfering transmitters and victim receivers is based on the Friis transmission equation:

$$P_{Rx} = P_{Tx} * G_{Tx} * G_{Rx} * (\frac{\lambda}{4\pi R})^2$$

where PRx is the power at the (victim) receiver, PTx and GTx are the transmitter (interferer) power and antenna gain respectively, GRx is the receiver antenna gain, and the last term is the free space path loss with R as the distance between transmitter and receiver. Note, it is common to use the logarithmic version of the Friis equation, and to include a “path loss exponent”, Exp, that accounts for observed measurements found in typical wireless environments (indoor, urban, etc) where the attenuation of the signal due to path loss is often greater than that predicted in free space. Therefore, the transmission equation used in this study is given by:

$$P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - \left[20log\left(\frac{4\pi f}{c}\right) + 10 * Exp * \log(R)\right]$$

where the bracketed term in the above equation is the path loss, L.

To achieve “interference free” operation, an interfering transmitter signal arriving at the victim receiver must be no greater than the victim receive sensitivity minus its minimum C/I ratio. This power level is given by:

$$\mathrm{I_{max}} = \mathrm{P_{Rx,sensitivity}} - \mathrm{(C/I)_{min}}$$

Therefore, the minimum path loss for interference free operation is given by:

$$L_{min} = P_{Tx} + G_{Tx} + G_{Rx} - I_{max}$$

and the minimum range for interference free operation (impact range) if given by:

$$R_{min} = 10^{\frac{\left[L_{min} - 20log\left(\frac{4\pi f}{c}\right)\right]}{10*Exp}}$$

From this value, the impact area, Aimpact , can be determined.

One additional refinement that is applied in this analysis is to limit the impact range to 300 meters. This is consistent with the same approach used in other parts of this report.

Another refinement to the above model used in this study was to apply a bandwidth correction factor for cases where the interfering transmitter signal bandwidth BTx is greater than the victim receiver bandwidth BRx. In dB, this correction factor, F, is given by:

$$\mathbf{F = 10log\left(\frac{B_{Tx}}{B_{Rx}}\right)}$$

and is subtracted from PTx. This correction factor is necessary only for the WBN SRDs (WBS) that utilize a transmission bandwidth of 1 MHz.

b) Calculation of Probability of Interference

The general method of determining the probability of interference from an interfering transmitter to a victim receiver is to determine how many potential interferer devices (N) are within the impact range of a victim receiver and also the probability of transmission on an interfering channel. To compute N:

$$N = A_{impact} \; / \; A_{Interfering\ Device}$$

$$= A_{impact} * D_{Interfering\ Device}$$

where D is the density of interfering devices per square meter.

The probability of interference to a victim receiver is the probability that there is at least one active transmitter within its impact range and transmitting on an interfering channel. In the proposed coexistence arrangement between RFID and NBN SRDs, the SRDs will occupy one of fifteen 200 kHz channels in the 865 - 868 MHz band. The probability that the interfering device will choose an interfering channel is 4/15 (for example, tag sideband transmissions received by an RFID interrogator operating on channel 10 will be interfered with only if the SRD chooses to operate on channels 8, 9, 11, or 12). The probability that the SRD is active is simply its duty cycle, DC. Therefore, the probability of interference to a victim receiver when there are N devices within the impact range of the receiver is given by:

$$p_{interference} = \frac{4}{15} * DC * N$$

The above probability may not be valid for large N where simultaneous transmission by more than one device on the same channel is possible. In that case, the equation above will overstate the probability of interference. Later analysis will reveal that use of this simplified model is justified for NBN SRDs.

c) Further Refinements to the Statistical Analysis

Up to this point the probability of interference has been calculated based on the density and transmit power of interfering devices, and by the victim receiver sensitivity and resulting impact range. In reality the situation is more complex and the probability of interference given by the previous analysis is often pessimistic. The likelihood of interference in “real-world” deployments is typically less than the probability computed above for a variety of reasons. Some of the more common reasons are:

- Not all desired signal transmissions are received at the victim receiver at threshold sensitivity;
- The use of directional antennas (by either the interfering or victim devices);
- Additional path loss due to shielding, indoor-outdoor deployment scenarios, etc.;
- Other factors, including site engineering practices.

But of course, it is always possible that interference levels are higher in certain situations. Those cases are best left for site engineering or other remedies.

In this study we will directly address the first item from the above list where it is the typical case that there is margin above threshold sensitivity for the majority of signal transmissions. For RFID, a minimum signal occurs approximately 25% of the time. In this study, the DRSS cumulative distribution function shown in Figure 15 is applied to compute a more typical, “real-world” probability of interference. Intuitively, the impact range (and thus the probability of interference) is reduced when there is signal margin above threshold sensitivity in the victim receiver.

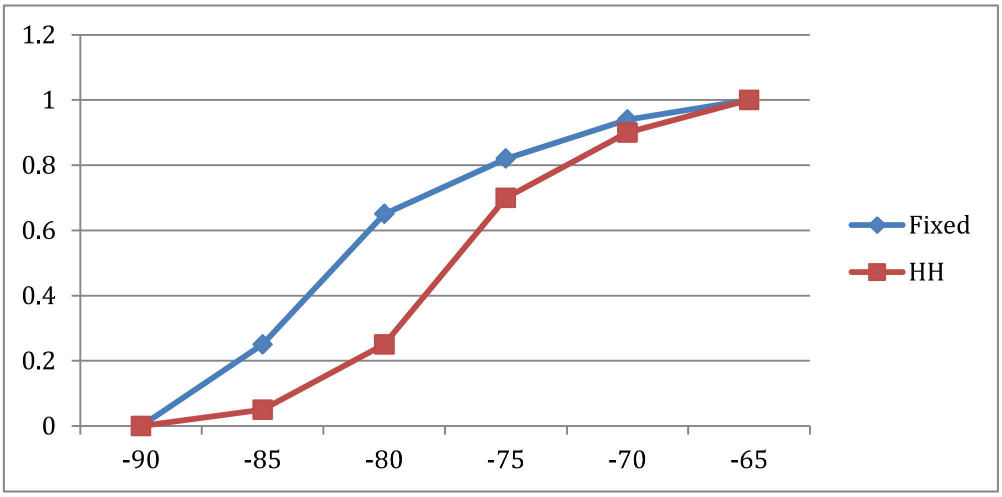


Figure 15: DRSS distributions of victim RFID receivers

The other items listed above are not directly addressed, however, they should be considered in the context of the overall deployment scenario and the probability predicted for each specific scenario.

Analysis for NBN SRD

The following table summarizes the results using the analysis method discussed in the previous section. In the case of smart meter NAP devices, eight scenarios are analysed:

- NAP with maximum density and average duty cycle with fixed RFID interrogators;
- NAP with maximum density and maximum duty cycle with fixed RFID interrogators;
- NAP with maximum density and average duty cycle with handheld RFID interrogators;
- NAP with maximum density and maximum duty cycle with handheld RFID interrogators;
- NN with maximum density and average duty cycle with fixed RFID interrogators;
- NN with maximum density and maximum duty cycle with fixed RFID interrogators;
- NN with maximum density and average duty cycle with handheld RFID interrogators;
- NN with maximum density and maximum duty cycle with handheld RFID interrogators.

The maximum density of NAP and NN devices is assumed for the following reasons:

- Anticipation of future growth of these systems;
- Multiple systems operated by competing network operators or other professional systems operating according to the 500 mW standard.

Table 38: Analytical calculation of probability of interference from NBN SRDs to RFID

Interferer								
Type	NAP	NAP	NAP	NAP	NN	NN	NN	NN
IL Transmitter power, dBm	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2
IL Tx Antenna gain, dBi	0	0	0	0	0	0	0	0

Interferer BW, kHz	200	200	200	200	200	200	200	200
Max Density/km2	10	10	10	10	90	90	90	90
DC, %	2.5	10	2.5	10	0.7	2.5	0.7	2.5
Area, m2 per device	100000	100000	100000	100000	11111	11111	11111	11111
Victim								
Operating frequency, GHz	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865
Transmitter power, dBm	29.2	29.2	27	27	29.2	29.2	27	27
Tx Antenna gain, dBi	6	6	2.2	2.2	6	6	2.2	2.2
Tx radiated power (e.r.p.), dBm	33	33	27	27	33	33	27	27
Rx Antenna gain, dBi	6	6	2.2	2.2	6	6	2.2	2.2
Receiver bandwidth, kHz	400	400	400	400	400	400	400	400
Declared Rx sensitivity, dBm	-85	-85	-80	-80	-85	-85	-80	-80
Receive signal margin, dB	0	0	0	0	0	0	0	0
C/I objective, dB	8	8	8	8	8	8	8	8
Imax, dBm	-93	-93	-93	-93	-93	-93	-88	-88
BW correction factor, dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minimum path loss, dB	128	128	119	119	128	128	119	119
Propagation exponent	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Impact range, m	591	591	331	331	591	591	331	331
Impact range (limited to 300m)	300	300	300	300	300	300	300	300
Impact area, m2	282743	282743	282743	282743	282743	282743	282743	282743
Devices within Impact area	2.8	2.8	2.8	2.8	25.4	25.4	25.4	25.4
Probability of interference, %	1.9	7.5	1.9	7.5	4.8	17.0	4.8	17.0

Explanation of Results

In Table 38, the calculation of I_{max}, minimum path loss, impact range, etc. was done as described in the previous sub-section. Note the use of 3.5 for the propagation exponent (a commonly accepted value for this type of analysis and propagation environment). In general the impact range of handheld devices is less than that of fixed infrastructure. This is based on the lower receiver antenna gain and also the lower receive sensitivity of handheld devices, both reasonable assumptions due to the typically reduced size, performance, and read range of handheld RFID readers. However, since the impact range exceeds 300 meters in all cases, the impact area has been limited to π*3002 resulting in 2.8 potential NAP interferers within the impact range of an RFID interrogator and 25.4 potential NN interferers within the impact range of an RFID interrogator.

The probability of interference computed to this point still assumes all signal transmissions are at threshold sensitivity. This is a pessimistic assumption which we define as “worst-case”. A more rigorous statistical analysis that applies the DRSS distributions shown in the previous section will result in a more typical "real-world" probability of interference. Those results are summarized for NAP and NN devices operating at 500 mW e.r.p. in the following tables.

Table 39: Probability of interference to RFID assuming drSS distribution: 500 mW NAP interferer

Parameter	SRD Scenario	
	Smart meter NAP with Fixed RFID Interrogator	Smart meter NAP with HH RFID Interrogator
Frequency range (MHz)	865-868	865-868
Transmitter e.r.p., dBm	27.0	27.0
Assumed device density per km2	10	10
Assumed range of duty cycle, %	2.5 / 10	2.5 / 10
Worst case probability of interference, %	1.9 / 7.5	1.9 / 7.5
Typical probability of interference, %	1.7 / 6.8	1.2 / 4.7

Table 40: Probability of interference to RFID assuming drSS distribution: 500 mW NN interferer

Parameter	SRD Scenario	
	Smart meter NN with Fixed RFID Interrogator	Smart meter NN with HH RFID Interrogator
Frequency range (MHz)	865-868	865-868
Transmitter e.r.p., dBm	27.0	27.0
Assumed device density per km2	90	90
Assumed range of duty cycle, %	0.7 / 2.5	0.7 / 2.5
Worst case probability of interference, %	4.8 / 17.0	4.8 / 17.0
Typical probability of interference, %	4.3 / 15.3	2.9 / 10.5

The above Table 39 and Table 40 illustrate that the expected real-world probability of interference is improved when considering the drSS distribution function, although, not by as much as would be expected. This is due to the fact that the impact range was confined to 300 m in the worst-case analysis, when in fact it was much larger. Therefore, it took large amounts of receive signal margin to reduce the impact range of victim receivers, which for a given device density is ultimately what drives the probability of interference. It is also the case that the typical use of directional antennas in RFID interrogator applications could further improve the results, although, it is unlikely it would reduce the combined probability of interference to less than 10% at maximum DC for operation of both NAP and NN devices, which is an expected deployment scenario.

Based on the previous analysis it is clear that levels of interference will exist between RFID and emerging NBN SRD applications. However, at low duty cycles and expected device densities coexistence can be achieved without the need for mitigation techniques. However, for duty cycles that exceed 2.5%, interference could exceed acceptable levels unless some form of mitigation is employed.

With the objective of not imposing LBT or other DAA mechanisms, one suggestion mitigation method is that when duty cycle exceeds 2.5%, that either or both NAP and/or NN devices confine their transmissions to preferentially operate on the high-power RFID channels (provided those transmissions fall within the spectrum mask defined in EN 302 208). This eliminates SRD transmissions in the sideband channels where tag transmissions occur, resulting in interference free operation.

6.2.3.2 SEAMCAT simulation with RFID as victim (NBN SRD without sensing)

The use of RFID in the frequency band 865 to 868 MHz is shown in Figure 16.

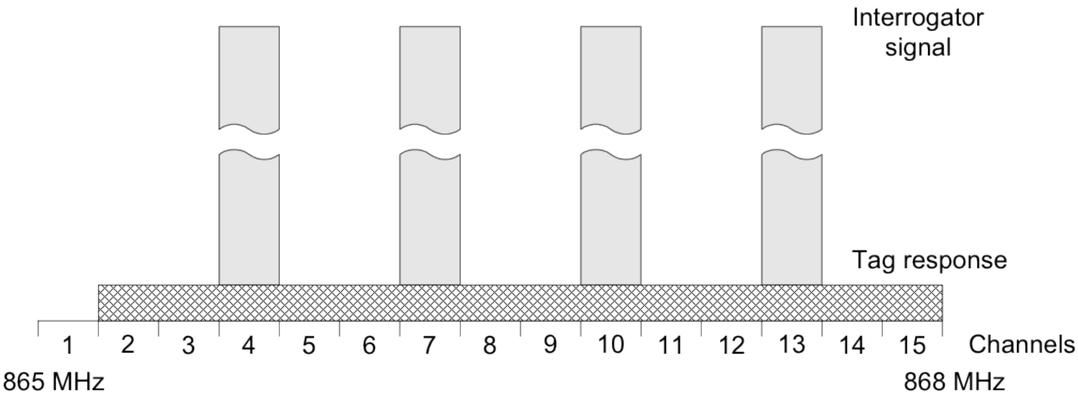


Figure 16: RFID Channel Plan in 865-868 MHz

The 3 MHz of spectrum is channelized into 15 channels of 200 kHz each. RFID interrogators use channel numbers 4, 7, 10 and 13. Interrogators are permitted to transmit with power of up to 33 dBm. RFID tags respond to the interrogator on the adjacent and next-to adjacent channels.

From Figure 14 it is therefore clear that channel 1 (865.0-865.2 MHz) remains unused by RFID.

The four interrogator channels are 865.6 to 865.8 MHz, 866.2 to 866.4 MHz, 866.8 to 867 MHz and 867.4 to 867.6 MHz.

Since it is difficult to model dRSS signal emanating from RFID tags, an empirically measured example of dRSS distribution provided by RFID community will be used in simulations, as illustrated in the following Figure 17.

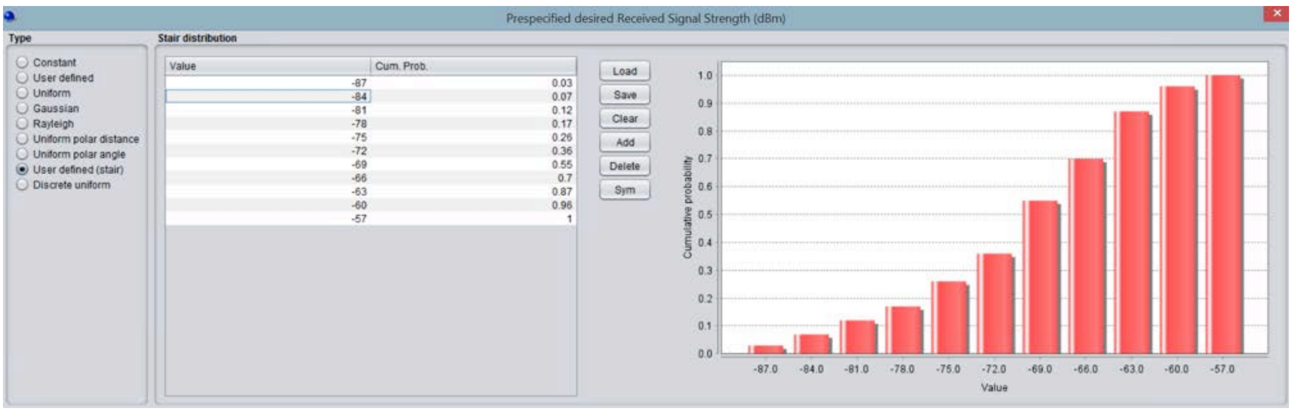


Figure 17: Distribution (CDF) of simulated wanted received signal in RFID reader

In the following simulations sharing is not considered in the RFID channels where the Tag Response operates. Sharing is only considered in the interrogator channels and the unused channel 1.

As a starting point for this consideration, the LPRA suggested in a liaison statement regarding the proposed operation of Network Access Points (NAP) at 500 mW in the band 862-868 MHz, that it is believed that NAP should be capable of sharing the four high power channels with RFID, provided some precautionary measures have been taken, such as:

- transmissions of NAP devices should fall within the spectrum mask at figure 3 of EN 302 208-1 v1.4.1. [43] This will ensure that transmissions by NAP do not interfere with the very low level responses from tags;
- received interfering power levels from 500 mW NAP devices measured at RFID interrogation zones are below -35 dBm;
- some form of mitigation technique might be considered, e.g. carrier sensing (DAA) to avoid frequency overlap between RFID and NAP devices in a given locality. Where a NAP senses that RFID is occupying a high power channel, it would need to find and select one that is unused;
- alternatively to using mitigation technique as DAA, NAP devices operating in excess of 100 mW may be restricted to outdoor operation only, which would ensure additional shielding by walls and thus offset the impact of higher transmit power.

The LPRA liaison statement concludes that provided these requirements can be met, it would seem probable that NAP can share the high power channels with RFID on a long-term basis.

In order to complement the analytical feasibility study of NBN SRDs sharing with RFID provided in previous sub-section 6.2.3.1, the statistical SEAMCAT simulation scenario was set up as illustrated in Figure 18.

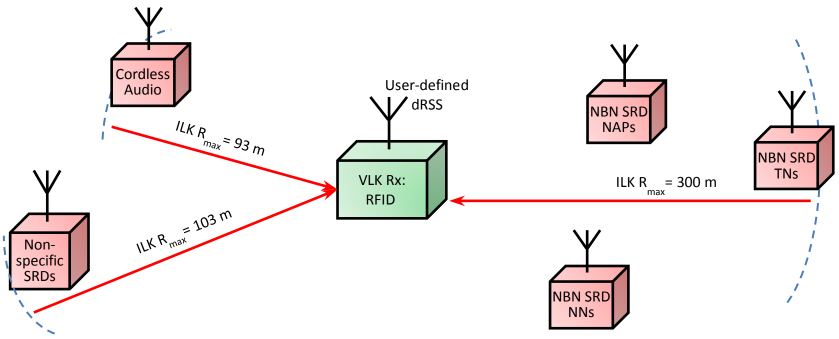


Figure 18: Scenario outline for NBN SRD and RFID coexistence in 865-868 MHz

The detailed technical parameter settings for this scenario are given in Table 101 in ANNEX 10: and the corresponding simulation results are provided in Table 102. These results show that NBN SRD deployed in the band 865-868 MHz are fulfilling a 5% interference probability already without any additional mitigation measures except employing the default mitigation factors of APC and DC limits stipulated by the original industry request for these new SRD applications (see section 2.5.1). Comparing the results for different simulated cases allows suggesting that restricting NBN SRDs to the “high power” RFID interrogator channels and one unused channel allows further decreasing the risk of unwanted interference.

However, the above results with RFID as victim might not represent the worst case. The above simulation considers that the given band is used by 2-3 NAP, 13-25 Network Nodes and 269-537 Terminals, all in radius of 300 m from the RFID receiver. However if in the future such Smart Metering applications becomes truly widespread it would be quite possible for these devices to be present in even higher densities, i.e. the same number of simulated devices would be concentrated in a smaller area. Therefore the feasibility of a sensing procedure to protect RFID systems will be analysed in the following section.

6.2.3.3 Sensing procedure to detect RFID systems

RFID deployments are not ubiquitous, and by using LBT, it may be possible to sense for RFID deployments and exploit a larger number of channels in the band.

NSRDs (network SRDs) could be deployed anywhere. NAPs – which will account for typically one in every 100-1000 devices – will be mounted on street furniture in external locations, as was assumed in the original ECC Report 200 [3] work.

RFID systems are usually deployed indoors and are typically used in retail or manufacturing environments. High power interrogator beams are directed at items fitted with RFID tags, and a small proportion of the power is returned in the adjacent channels either side (in the frequency domain) of the interrogator channels.

ANNEX 9:of this Report provides a study where the feasibility of a sensing procedure like LBT/AFA to protect RFID is analysed. This study indicates that for an SRD with output power of 500 mW e.r.p., it should be capable of detecting (via energy detection) the operation of RFID systems with sensitivity threshold of -89 dBm. The effected separation distance between active RFIDs and NBN SRDs are estimated approximately to be in the order of up to a few hundreds of meters.

This result opens the possibility of considering spectrum sharing techniques between NBN SRDs and RFIDs in band 865-868 MHz based on spectrum sensing, like LBT, DFS and AFA. This, in turn, makes it possible for NBN SRDs to share the same bandwidth on a geographical basis with RFIDs.

It should be noted that the analysis in ANNEX 9: only considered the detection of high power RFID channels. In the following the feasibility to avoid also the low power tag responses is analysed.

The challenge of attempting to coexist with RFID systems is the vanishingly low power at which the tag-return signal operates. Although the 2W interrogator channels can – with reasonable certainty - be detected, response signals will not be strong enough to be detected using conventional LBT. By exploiting the known characteristics of these types of systems, however, it is possible to imply occupation of the response channels, as shown in Figure 19 below.

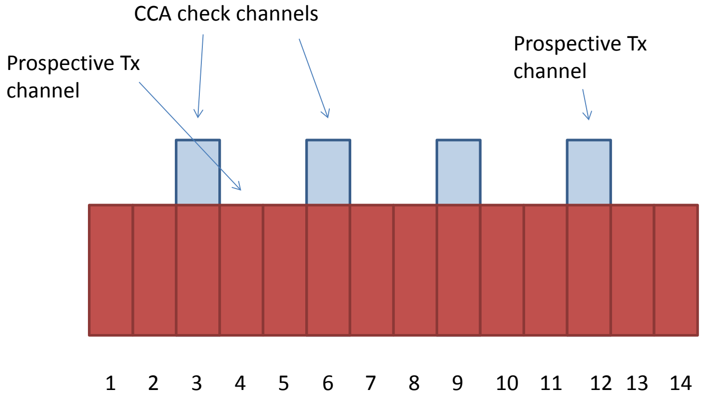


Figure 19: RFID channel detection configuration

Tags could respond in channels 4 and 5 from transmissions by interrogators on channels 3 or 6. In order to check that it is permissible for NSRDs to transmit on channels 4 and 5, they would have to carry out a CCA (Clear Channel Assessment)[8] of channel 3 then channel 6[9]. Transmission on an interrogator channel would be allowed without CCA operation.

The worst case interfering scenario, therefore, is when power received by the interrogator from the NSRD is just out of range of the receiver's LBT mechanism. Note: this is irrespective of the exact path (from free space to cluttered propagation), but it will be instructive to calculate the distance nevertheless.

---

[8] EN 303 204 [45] has a CCA time of 160 micro-seconds, but the RFID community has stipulated that, in order to ensure that NRPs can reliably detect interrogators transmitting on the same channel for periods of greater than 4 seconds, a listen time of at least 1 ms would be required

[9] i.e. at least 2 x 1 milli-second = 2 milli-seconds

An MCL calculation within the NSRD transmit channel is set out below:

Assuming the two systems to be on the interrogator bore sight, the path loss between the two systems is as follows:

> An RFID interrogator transmitting at 2W (+33dBm) e.r.p. via a 6dBi antenna towards an NSRD device which has a gain of 6dBi, then the path loss to achieve -81dBm at the input of the NSRD is:
>
> = +33 + 6 + 81 = 120dB
>
> Looking at the RF power in the opposite direction (at the point at which the LBT mechanism is ***just*** not triggered), the power received (from the up to 500mW e.r.p. transmission) by the receiver in the interrogator will be:
>
> = +27 – 120 +6 = -87dBm[10]

Assumptions being made in this report are that all usable dRSS power will be above -87dBm, with 88% of the signal being above -81dBm, which should – even under the worst-case conditions of MCL - give this technique headroom of 0 to 3dB.

SEAMCAT calculations, based on those in sub- section 6.2.3.2 above[11], confirm that the probability of interference to the RFID victims is acceptable. The detailed technical parameters used for this SEAMCAT simulation are provided in the Table 103 and the corresponding simulation results are provided in Table 104, showing the marginal risk of interference with probability not exceeding 2.3% even for most severe case of high density and maximum DC.

Figure 20 shows a snapshot from one of the simulation runs (High Density – Maximum DC) illustrating the effect of the LBT mechanism, whereas the active smart meter transmissions are kept away from the RFID victims.

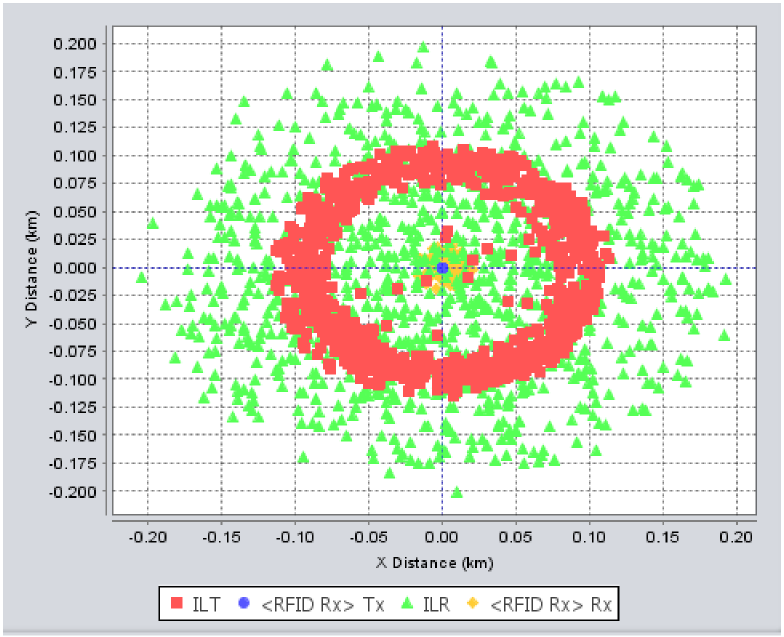


Figure 20: Illustration of geographical spacing resulting from LBT application

---

[10] Note further, that Annex 1 type devices are allowed to operate in this band at a power of 25mW. Assuming that they might operate within 10m of a receiver and have a gain of 0dBi, that would see power being received by RFID receiver being = +14dBm – 111db (free space loss at 865MHz) + 6 = -91dBm, which is very similar.

[11] Changes to the model are: Victim Link: Transmitter-Victim link receiver path: protection distance 0 > 90m (for all smart meter components); interfering transmitter: transmitter distribution – evenly distributed across 15 200 kHz channels from 865-868MHz.

Two residual risks exist with the above analysis:

- *NSRD shut out:* Operation close to an RFID system will inevitably hold NSRDs off from operation of one or more channels. Mesh networks, however, are designed to self-organize, and so the systems would tend to avoid sending traffic from neighbouring devices into these compromised nodes. Furthermore, the geographical limit of RFID deployments should leave large parts of a territory available, and sensible operators will ensure that NRPs are not located close to RFID hot-spots;
- *Low power RFID operation:* Analysis so far has assumed that RFID equipment will be operating at 2W, however, some handheld equipment operates at lower powers and so will be less easy to detect using LBT. Nevertheless, the operational range of this type of equipment is usually lower making interference into the interrogator less likely.

In summary, the acceptable protection for RFID systems is assumed to be achieved by 500mW applications in the band 865-868 MHz using LBT (CSMA-CA) with a threshold of -89 dBm.

It should be noted that the shielding of high power RFID installations (e.g. up to 16 dB) will improve the situation. However there are many other RFID applications, which operate at much reduced ranges and where there is no need for shielding.

According to RFID industry, a specific listening time for the detection mechanism might improve further the detection. However, to generalize the listening time would hamper the whole SRD industry whereas it might only improve co-located sites. For industrial premises where an RFID high level of service is expected, it’s also recommended to employ site engineering.

6.2.3.4 Impact of NBN SRDs in 865-868 MHz on Non-specific 25 mW SRDs

While the previous sub-sections considered an example of RFID as victim user in the band 865-868 MHz, this band can be also used by low powered non-specific SRDs. The latter use possibility is harmonised across the entire EU in accordance with EU SRD Decision and could not be neglected. This sub-section therefore reviews the simulations of coexistence of proposed 500 mW Network-based SRD applications against incumbent low power SRDs.

The technical parameters of NBN SRD application remain essentially the same as used in previous simulations reported in section 6.2.3.2, while low-power non-specific SRD is modelled by using data for representative example of Home Automation application as specified in Table 18. Graphical depiction of this scenario is given in the following Figure 21.

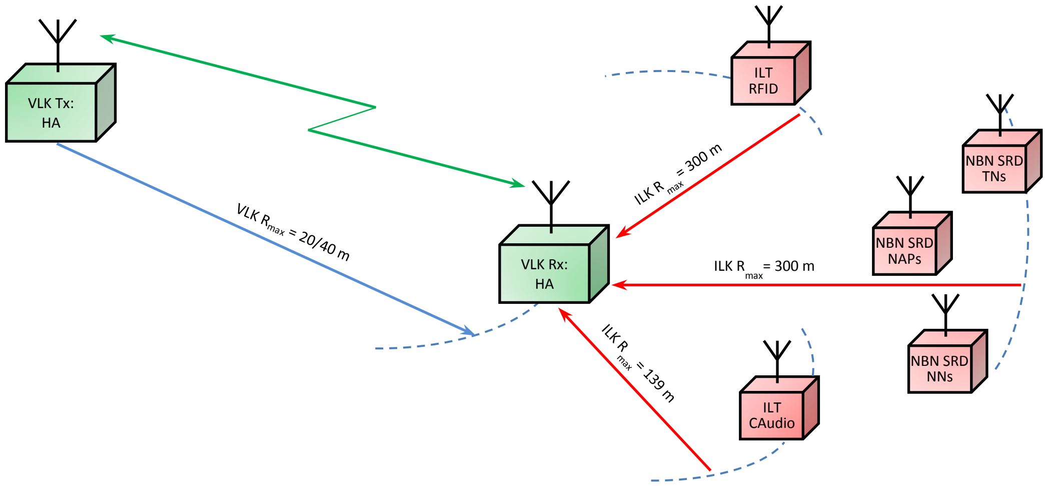


Figure 21: Scenario outline for NBN SRD impact on generic 25 mW SRDs in 865-868 MHz

Detailed simulation settings for SEAMCAT are outlined in Table 105 while the corresponding simulation results are given in Table 106. These results show that in most considered scenario configurations the use of

NBN SRDs in the band 865-868 MHz would create limited risk of interference to incumbent low power SRD applications.

6.2.4 Impact on Low-Power Wide Area Networks

The following studies consider impact of NBN implementation into existing Low-Power Wide Area Networks. This family of SRD technologies is an existing use within Europe and in numerous other countries to support Machine to Machine (M2M) and Internet of things (IoT) networking applications. Already implemented examples include such commercial technologies as LORA and SIGFOX. As a tentative representative example of LPWAN technologies, a case of DSSS LPWAN uplink in 865-868 MHz based on LoRa™ WAN specifications is considered further in this section.

6.2.4.1 Simulation assumptions for LPWAN

In the analysis below, the LPWAN network (e.g. LoRa™) uses 25 mW uplinks in the band 865-868 MHz and 500 mW downlinks in the band 869.4-869.65 MHz.

The following table shows LPWAN system characteristics taken into account in this study:

Table 41: Example of LPWAN system (LoRa)

LoRa Use Case	
Bandwith	125 kHz
NAP RECEIVER_BLOCKING_MASK	from EN 300 220 [12]
NAP Gain	5 dBi
NAP Noise Figure	3 dB
TN Gain	0 dBi
TN Tx Power	14 dBm
NAP Sensitivity	-137 dBm
Protection ratio	-17 dB
NAP High	25 m
TN High	1,5 m

6.2.4.2 Impact into LPWAN NAP in the band 865-868 MHz

Table 42: Probability of interference (%) from NBN in 865-868 MHz into LPWAN NAP (865.175 MHz) (Unwanted/Unwanted+Blocking)

Interferer		Victim LPWAN NAP (h=25m) 865.175 MHz Sensitivity: -137 dBm
NBN 500 mW 865-868 MHz TN/NN/NAP 865-868 MHz	High density/Max DC Simulation Radius (Number of devices)/DC NAP:1800m (101) /DC 10% NN:1800m (916)) /DC 2.5% TN:1562m (14581)) /DC 0.1%	93.3/93.8
	Medium density/Average DC Simulation Radius (Number of devices)/DC NAP:1800m (81)) /DC 2.5% NN:1800m (468)) /DC 0.7% TN:1562m (7306)) /DC 0.1%	51.5/53.9
SRD Generic BW 350 kHz (to reflect current situation) 865-868 MHz	High Density Simulation Radius:470 m Number of devices = (1038) 80% DC 0.1% (830) 20% DC 1% (208)	15.36/16.86
	Medium Density Simulation Radius:470 m Number of devices =(554) 80% DC 0.1% (443) 20% DC 1% (111)	9.4/9.69
	Medium Density Simulation Radius:470 m Number of devices = (554) DC 0.1%	2.86/2.92

It can be seen that sharing between NBN in the band 865-868 MHz and LPWAN NAP in the band 865-868 MHz is not feasible.

6.2.4.3 Proposal for implementation of NBN in the band 865-868 MHz

To give the opportunity to implement 500 mW NBN while ensuring protection to LPWAN in the band 865-868 MHz, the following scenario may be considered. The 500mW links may be used to implement NBN Networks in RFID interrogators.

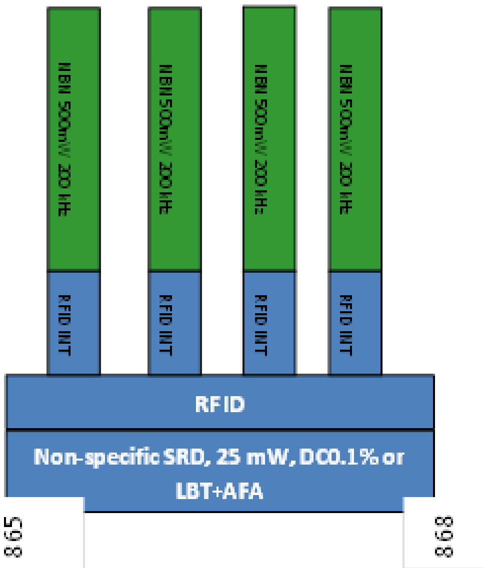


Figure 22: NBN in the band 865-868 MHz

Conclusions and Recommendations

- Considering the band 865-868 MHz, the studies show that sharing between NBN within networks described in section 2.5.1 and the considered LPWAN use case example is not feasible. LPWAN applications (e.g. LORA, SIGFOX) are are in current use within some European countries and aim to be widespread throughout Europe and with to view to not to hamper their current and predictable development, implementation of 500mW should be restricted in RFID interrogators for NBN deployment as described in section 2.5.1 (with indoor TN).

6.2.5 Complementary calculations of LBT threshold values for 500mW NBN SRDs

The below calculation in Table 43 is based on the approach presented in Annex 5 of ECC Report 246 [9] on how to derive a threshold value for LBT functionality. It shows the required threshold values for 500mW devices to detect Sub-Metering, RFID, Cordless audio and Hearing Aids. In addition the table contains the required link margin at the victim receiver where a LBT threshold of -75 dBm would be able to detect the victim link.

Table 43: LBT threshold values

Parameters	Cordless Audio	Sub-metering	RFID	Hearing Aids
Bandwidth, MHz	0.2	0.3	0.4	0.6
Transmit power, dBm	10	14	33	-6
Sensitivity, dBm	-97	-104	-85	-94
C/I, dB	17	8	12	17
Margin, dB	0	0	0	0
Imax, dBm	-114	-112	-97	-111
Interferer's e.r.p., dBm	27	27	27	27
Interferer's bandwidth, MHz	0.2	0.2	0.2	0.2

Parameters	Cordless Audio	Sub-metering	RFID	Hearing Aids
Interferer's power in victim's channel, dBm	27	27	27	27
Required separation distance, m (Note)	1369.51	1200.67	447.56	1124.22
LBT threshold, dBm/BW	-131	-125	-91	-144
Required margin above sensitivity with threshold of -75 dBm/MHz	56	50	16	69

Note: assuming propagation path loss exponent 3.5

The protection of the considered victims systems by an energy detection threshold of -75 dBm is possible if the victim links are working with a certain margin above sensitivity: cordless audio 56 dB, sub-metering 50 dB, RFID 16 dB and for hearing aids 69 dB. In real life scenarios the victim links are working with a margin above its sensitivity, and thus the energy detection threshold could improve the situation. But especially for Cordless Audio, Hearing Aids and Sub-metering SRD the LBT approach seems not able to improve the coexistence due to the huge required margin.

6.3 CONCLUSIONS ON POSSIBILITY OF IMPLEMENTING 500 MW DEVICES IN 862-868 MHZ

Conclusions on introduction of 500 mW NBN SRDs in the band 862-863 MHz are presented in section 5.4. Considering the impact of introducing 500 mW NBN SRDs in the band 863-868 MHz into LTE (below 862 MHz), audio systems (863-865 MHz) and legacy SRDs such as LPWAN NAP (865-868 MHz), the results of simulations show that coexistence is feasible when restricting their deployment within RFID interrogator channels in the band 865-868 MHz.

7 FEASIBILITY OF IMPLEMENTING WBN SRD IN THE BAND 862-868 MHZ

This chapter will review the proposal for deploying WBN SRDs with channel bandwidth of up to 1 MHz in the band 862-868 MHz. This consideration was initiated in response to industry indications that they would like having an option, additional to the use considered in ECC Report 246 [9], of deploying low power WBN SRD devices used for IoT applications in this band. This optional deployment should be seen in complement to using the bands 870-876/915-921 MHz for this type of applications, as described by ETSI System Reference Document TR 103 245 [8] with reference to 802.11ah networking standard. It is therefore anticipated that WBN SRDs proposed for deployment in the band 862-868 MHz would be technically identical to WBN SRDs deployed in 870-876/915-921 MHz in compliance with technical parameters and operational protocols described in TR 103 245.

A general descriptions and essential parameters for proposed WBN SRD applications in the band 862-868 MHz were presented in section 2.5.2.

The studies in this chapter are not considering in detail the CSMA-CA features of 802.11ah. Some insight in the efficiency of CSMA-CA as interference mitigation mechanism for WBN SRD is provided in section 3 of ECC Report 246.

7.1 ADJACENT BAND STUDIES WITH PUBLIC CELLULAR SYSTEMS BELOW 862 MHZ

This sub-section will complement the analysis carried out previously in 5.1.2 by looking at the possible impact from proposed WBN SRDs to LTE operation in adjacent band below 862 MHz. The general approach to considering this case of macro-scale adjacent band interference had been explained in section 6.1. This section shall apply the same differentiating principles as regards establishing the density of SRD devices (see 6.1) and also as regards observance of fulfilment of limits on spurious emissions, i.e. considering two possible options for SRD unwanted emission masks. The general scenario outline is provided in Figure 23.

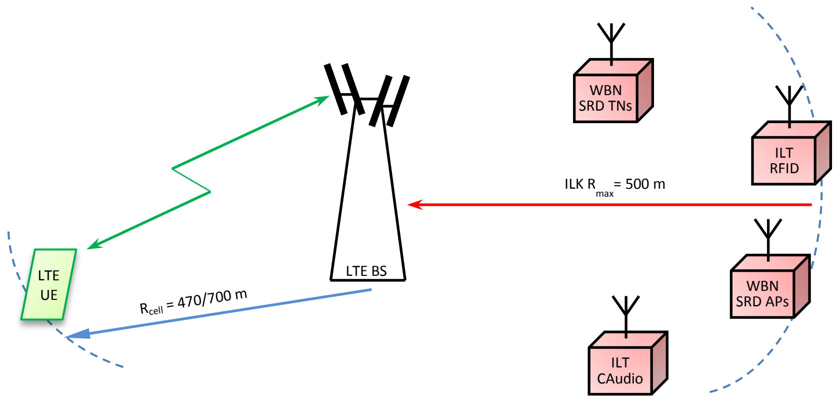


Figure 23: Scenario outline for analysing WBN SRD adjacent band impact on LTE BS

The technical parameters used in the SEAMCAT simulations are illustrated in Table 107 in ANNEX 10: and the corresponding results are outlined in Table 108 for WBN SRD reduced emissions mask (Option 1, see ANNEX 1:) and in Table 109 for WBN SRD mask Option 2 respectively.

The simulation results in Table 107 for evaluating the new WBN SRDs in the band 862-863 MHz with SRDs mask Option 2 “Worst case” show that for the case of maximum density and maximum DC and LTE power scaling factor of 0.99, LTE uplink suffers 35.3% data capacity loss due to interference from all of the existing regulated SRDs, the introduction of the new WBN SRDs increase an additional LTE uplink data capacity loss of 22%.

For the case of maximum density and maximum DC and LTE power scaling factor of 0,9, LTE uplink suffers 18,5% data capacity loss due to interference from all of the existing regulated SRDs, the introduction of the new WBN SRDs increase an additional LTE uplink data capacity loss up to 11.6%.

For the case of medium density and maximum DC and LTE power scaling factor of 0,99, LTE uplink suffers 26,2% data capacity loss due to interference from all of the existing regulated SRDs, the introduction of the new WBN SRDs increase an additional LTE uplink data capacity loss up to 19.2%.

For the case of medium density and maximum DC and LTE power scaling factor of 0,9, LTE uplink suffers 14% data capacity loss due to interference from all of the existing regulated SRDs, the introduction of the new WBN SRDs increase an additional LTE uplink data capacity loss up to 10%.

It is understood that not all of the WBN devices will transmit at the maximum duty cycle at the same period, the simulation results presented in the table 107 may over-estimate the impact on LTE uplink data capacity.

When SRD mask Option 1 “reduced Emissions” is assumed (cf. Table 108), the LTE uplink data throughput losses caused by SRDs are significantly reduced comparing to the respective cases with the worst case mask, as well illustrated by comparing the respective results in the two above tables.

Furthermore, although the studied worst case scenario to ensure protection of LTE 10 MHz channels operating below 862 MHz resulted by mask Option 1, some stakeholders are of the opinion that an additional restriction of 800 kHz guard band may be implemented between the frequency 862 MHz and the WBN lower band edge (i.e. 862.8 MHz).

The complementary simulations were carried out in order to extend the above analysis by checking possible impact to LTE operation in adjacent band below 862 MHz from proposed WBN SRDs if they were deployed in sub-band 863-865 MHz.

As the only change here compared with the above scenario would be the shift of operating frequency band for proposed WBN SRD operations, the rest of assumptions will remain the same, including the application of two options of unwanted (OOB+spurious) masks for incumbent and proposed SRDs. The summary of key technical parameters used in SEAMCAT simulations for this case is reiterated in the Table 110 and the corresponding results are outlined in Table 111 for WBN SRD reduced emissions mask (Option 1, see ANNEX 1:) and in Table 112 for WBN SRD mask Option 2 respectively.

When analysing the two latter tables and comparing them with the results obtained previously for the case of WBN SRD deployed in 862-863 MHz, it becomes clear that when deploying new WBN SRDs in the band of 863-865 MHz, the impact on LTE for all cases becomes smaller, as might be expected. In particular, the impact of the WBN SRDs with reduced emissions mask (Option 1), for the case of medium density and average DC the impact from WBN SRD is almost negligible.

Further elaboration of this adjacent band coexistence scenario would be to consider the case if WBN SRD were allowed to operate over the entire range, i.e. 863-868 MHz. This should further facilitate coexistence across the board due to wider tuning band and thus spreading of interference risk over wider range, including the anticipated reduction of adjacent band impact. To verify this assumptions an additional set of simulations was performed with WBN SRD tuning range set to 863-868 MHz while all the other technical parameters used in SEAMCAT simulations where the same as given in the Table 110.

The ultimate results are outlined in Table 113 for WBN SRD reduced emissions mask (Option 1, see ANNEX 1:) and in Table 114 for WBN SRD mask Option 2 respectively. These results demonstrate further, albeit already minor, reduction of the probabilities of adjacent band interference and confirm the feasibility of coexistence between WBN SRD compliant with reduced emissions mask and LTE in adjacent band below 862 MHz. For instance, for a typical case with WBN SRDs compliant with reduced emissions mask (Option 1) and operating near their average DC, the WBN SRD would be contributing just 0.2-0.6% of the probability of interference compared with the current baseline with legacy SRDs. Even when assuming the absolute worst case with WBN SRDs deployed at very high density and all of them operating at their maximum DC limit (which is quite unrealistic yet provided as a sake of theoretical worst case limit), the probability of interference from WBN SRD to LTE Uplink would not exceed 2.5-6.2%, depending on operational configuration of victim LTE network.

If WBN SRD were to made compliant just with worst case (Option 2) mask, the probability of interference generated for LTE operations would be tolerable in average DC scenarios (at around 0.7-2%), however denser deployment and increased activity of WBN SRD would increase probability of interference to some 9-20%, therefore using Option 2 mask for WBN SRD should not be recommended.

7.2 INTRA SRD STUDIES

7.2.1 Impact on potential new SRDs in 862-863 MHz

This sub-section will review assumptions and results of simulations of coexistence of proposed new WBN SRD applications in the band 862-863 MHz.

Key technical parameters and various deployment assumptions for simulations were taken from information in section 2.5.2 and some complementary documents, such as ETSI SRDoc TR 103 245 [8] that describes the proposed 802.11ah-based SRD applications [40].

The Table 115 in ANNEX 10: lists most essential SEAMCAT settings for the simulation of proposed WBN SRD applications. As this is a newly developed “greenfield” band as far as SRDs are concerned, the WBN SRD applications would be considered as interferer and a traditional SRD application (Home Automation) will be considered a representative victim. In addition, the list of simulated interferers will include some representative legacy SRD which may have impact on operation of devices in 862-863 MHz: non-specific SRDs as they may be also allowed into this new band, as well as RFID and Cordless Audio to consider possible adjacent band intra-SRD interference impact. Also the inherent impact of adjacent band interference from LTE operations below 862 MHz will be considered, based on observations in 5.1.1 that these operations will create significant ambient noise in the adjacent SRD bands above 862 MHz. The LTE uplink simulation will correspond to “same room/dRSS Option 2” scenario in 5.1.1, using realistic (BNetzA) 10 MHz LTE mask. The general scenario outline is shown in Figure 24 below.

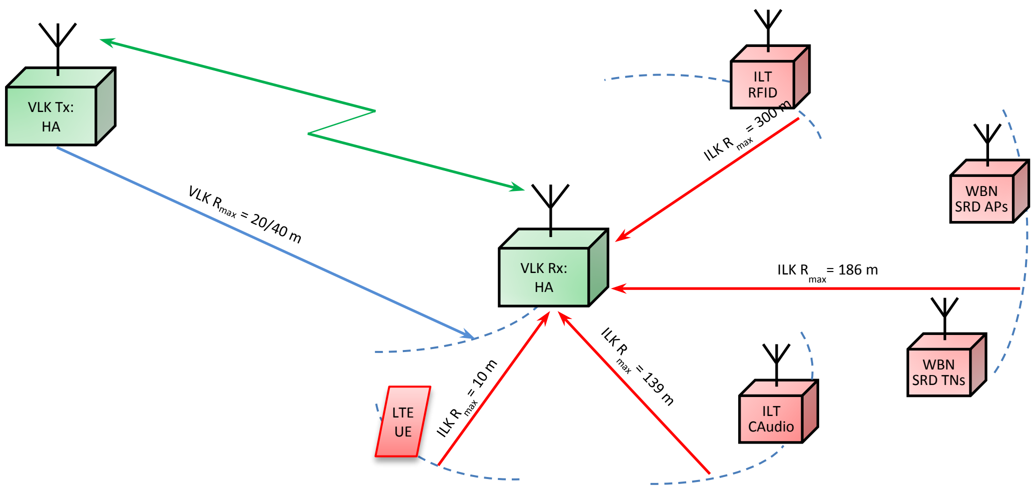


Figure 24: Scenario outline for analysing WBN SRD coexistence with SRDs in 862-863 MHz

Note that the simulations will consider WBN SRD to use transmit power (e.r.p.) of 25 mW based on requirements outlined in ETSI TR 103 245.

The detailed results of SEAMCAT simulations of this scenario are given in Table 116. These results show that introduction of WBN SRDs across the broader range beyond solely 862-863 MHz, such as over entire band 862-868 MHz would create tolerable additional risk of interference (around 2-5%) to SRD victims in 862-863 MHz compared with the baseline interference level in that band due to ambient noise from adjacent band OOB emissions from LTE uplink. Like was previously observed in 5.1.1 the operation of any SRDs in the band 862-863 MHz without additional mitigation measures would likely result in their reduced maximum operating ranges.

The above simulations results of impact of WBN SRD do not take into account additional mitigation of interference provided by utilisation of CSMA-CA channel access protocol in accordance with TR 103 245 or equivalent.

7.2.2 Impact on Cordless Audio and Hearing Aids in 863-865 MHz

This sub-section will consider intra-SRD impact of introducing wideband SRDs in the range 863-865 MHz. The SEAMCAT simulation settings for this case are provided in Table 117 and Table 119. In this case, the incumbent Cordless Audio and Hearing Aid devices would be considered as two representative victims and the corresponding scenario outlines are given in the following Figure 25 and Figure 26.

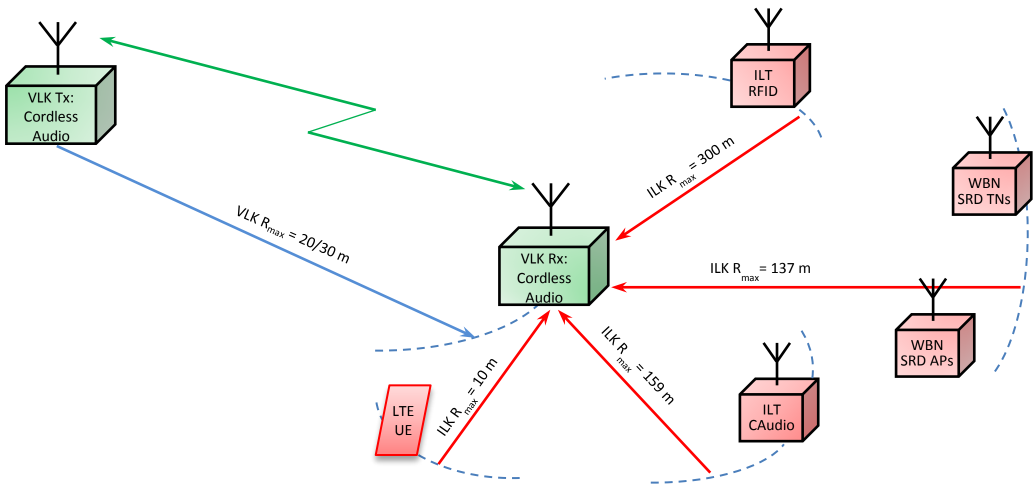


Figure 25: Scenario for NBN SRD co-existence with Cordless Audio SRDs in 863-865 MHz

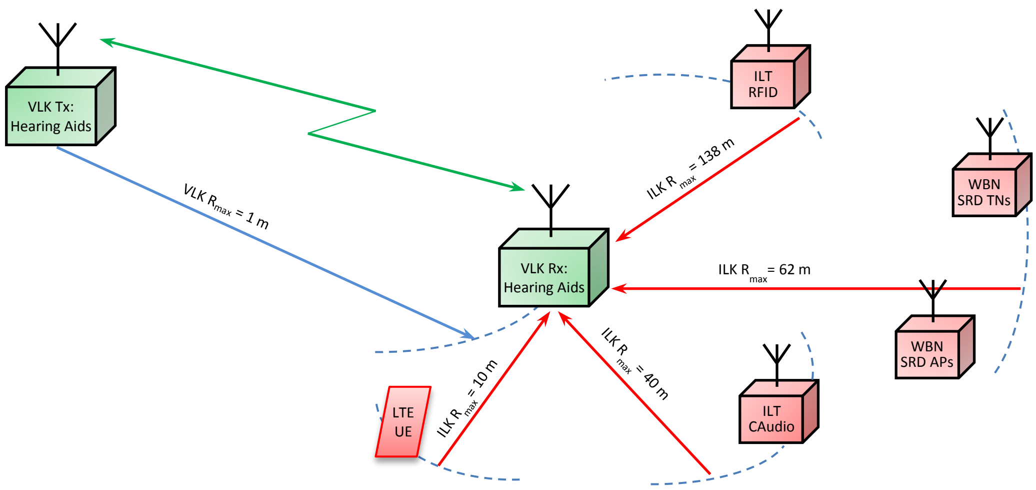


Figure 26: Scenario for NBN SRD co-existence with Hearing Aids SRDs in 863-865 MHz

The detailed results of SEAMCAT simulations are given in Table 118 for Cordless Audio as victim, and in Table 120 for victim Hearing Aids. These results indicate that introduction of WBN SRDs operating over the entire 862-868 MHz range would create marginal risk of unwanted interference to audio applications in 863-865 MHz. For the most realistic scenario of WBN SRD devices operating at their average DC levels (with worst case assumption for the latter value), the probability of interference to audio devices would be increased by 1-2% compared with the baseline scenario of ambient in-band noise due to adjacent band emissions. Even in the unlikely case of all devices operating at their maximum permitted DC, the additional interference risk would increase by up to 5-7% compared with baseline scenario.

The above discussed results of potential impact to Cordless audio and hearing aids as victim did not take into account the use by WBN SRD of CSMA-CA mitigation mechanism. On the other hand, if in the future such WBN SRD applications become truly widespread, it would be quite possible for these devices to be present in even higher densities, i.e. the same number of simulated devices would be concentrated in a smaller area. Therefore the importance of using LBT or equivalent mitigation technique such as CSMA-CA is very important and feasibility of a sensing procedure to protect audio systems is presented in section 7.2.4.

7.2.3 Impact on RFID and SRD systems in 865-868 MHz

7.2.3.1 Analytical evaluation of impact to RFID

This section extends the analytical study of interference to RFID by using enhanced MCL method that was previously described in section 6.2.3.1. In this instance, impact of proposed WBN SRDs is considered.

Overview

While the overall methodology remains exactly as described in 6.2.3.1, one differentiating analysis factor is taking account of wider bandwidth of interfering system, which makes different overlapping of RFID channel template.

In the proposed coexistence arrangement between RFID and WBN SRDs, the latter will occupy one of three 1 MHz channels in the 865-868 MHz band. In this case a single WBN SRD overlaps multiple RFID channels as shown in Figure 27 below. This figure shows that there is potential for WBN SRD to interfere with the operation of RFID even with the CSMA-CA process described in TR 103 245 [8].

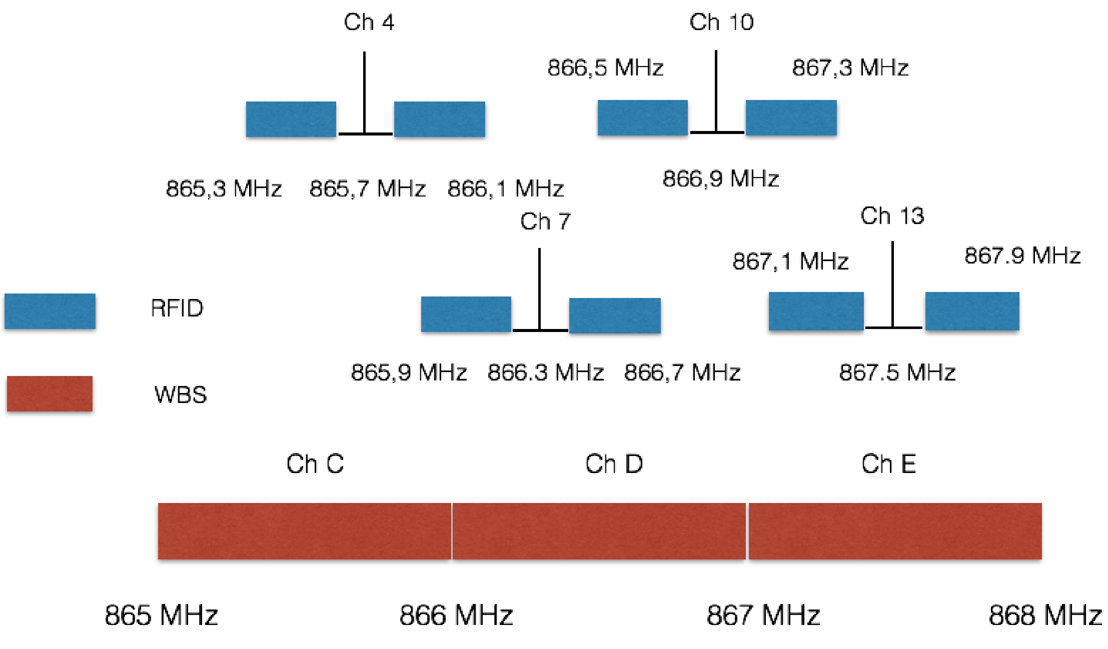


Figure 27: Overlap of WBN SRD channels vis-à-vis RFID channel pattern

To compute the probability of interference for WBN SRD, we assume that an RFID interrogator occupies one of the four high power channels with a uniform distribution. Therefore, the probability it will occupy channel 4, 7, 10, or 13 is 25%. From the figure the following interference scenarios can be identified:

RFID Channel 4 If the WBN SRD equipment makes a random selection and chooses to operate on Ch C, the CSMA-CA mitigation technique in the WBN SRD equipment will detect transmission by RFID on channel 4 and will then attempt to operate on Ch D or Ch E with equal (50%) probability. If the WBN SRD equipment chooses operation of Ch E, RFID operation will continue interference free. If the WBN SRD equipment chooses operation on Ch D, it will not detect RFID operating on channel 4 and it will begin transmission. In this case there will be 100 kHz overlap with WBN SRD transmissions which will enter the interrogator receiver (bandwidth correction factor F=10dB).

RFID Channel 7 If the WBN SRD equipment makes a random selection and chooses to operate on Ch D, the CSMA-CA mitigation technique in the WBN SRD equipment will detect transmission by RFID on channel 7 and will then attempt to operate on Ch C or Ch E with equal (50%) probability. If the WBN SRD equipment chooses operation of Ch E, RFID operation will continue interference free. If the WBN SRD equipment chooses operation on Ch C, it will not detect RFID operating on channel 7 and it will begin transmission. In this case there will be 100 kHz overlap with WBN SRD transmissions which will enter the interrogator receiver (bandwidth correction factor F=10dB).

RFID Channel 10 If the WBN SRD equipment makes a random selection and chooses to operate on Ch D, the CSMA-CA mitigation technique in the WBN SRD equipment will detect transmission by RFID on channel 10 and will then attempt to operate on Ch C or Ch E with equal (50%) probability. If the WBN SRD equipment chooses operation on Ch C, RFID operation will continue interference free. If the WBN SRD equipment chooses operation on Ch E, it will not detect RFID operating on channel 10 and it will begin transmission. In this case there will be 200 kHz overlap with WBN SRD transmissions which will enter the interrogator receiver (bandwidth correction factor F=7dB).

RFID Channel 13 If the WBN SRD equipment makes a random selection and chooses to operate on Ch E, the CSMA-CA mitigation technique in the WBN SRD equipment will detect transmission by RFID on channel 13 and will then attempt to operate on Ch C or Ch D with equal (50%) probability. In either case, RFID operation will continue interference free.

Therefore, the probability of interference is calculated as follows:

$$p_{interference} = \frac{1}{4} * p_{interference}\big|_{F=10dB} + \frac{1}{8} * p_{interference}\big|_{F=7dB}$$

$$= \frac{1}{4} * DC * N|_{F=10dB} + \frac{1}{8} * DC * N|_{F=7dB}$$

Note that the impact range is calculated with two different bandwidth correction factors, which in turn leads to two different values of N. In reality the probability of interference will be slightly higher due to the short (40 µs) duration of the carrier sense mechanism in the WBN SRD device. However, it is expected that this will be self-correcting through CCA, TXOP, etc., and will also have diminished impact due to the retry mechanism inherent in RFID.

The rest of methodology including the assumed drSS distribution of RFID are the same as was described in 6.2.3.1.

Analysis for Wideband SRDs

The methodology used in section 6.2.3.1 is now applied to the case of RFID and Wideband SRDs. The following four scenarios are analysed:

- WB AP with maximum duty cycle and fixed RFID interrogators;
- WB AP with maximum duty cycle and handheld RFID interrogators;
- WB TN with average duty cycle and fixed RFID interrogators;
- WB TN with average duty cycle and handheld RFID interrogators.

The maximum density of both AP and TN devices is assumed in anticipation of future growth of these systems. The maximum duty cycle for AP and average duty cycle for TN devices is assumed based on expected densities and distribution of the devices. The table on the following page shows that at maximum densities, on average there will be approximately 20 TN devices per AP device. If the maximum duty cycle of 10% of an AP is shared equally among 20 TN devices, each TN device would have 0.5% duty cycle. Therefore, use of 0.7% is justified.

The following summarizes the calculation results.

Table 44: Analytical calculation of probability of interference from WBN SRDs to RFID

Interferer								
Type	AP	AP	AP	AP	TN	TN	TN	TN
IL Transmitter power, dBm	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2
IL Tx Antenna gain, dBi	0	0	0	0	0	0	0	0
Interferer BW, kHz	1000	1000	1000	1000	1000	1000	1000	1000
Max Density/km2	50	50	50	50	1000	1000	1000	1000
DC, %	10	10	10	10	0.7	.7	0.7	.7
m2 per device	20000	20000	20000	20000	1000	1000	1000	1000
Victim								
Operating frequency, GHz	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865
Transmitter power, dBm	29.2	29.2	27	27	29.2	29.2	27	27
Tx Antenna gain, dBi	6	6	2.2	2.2	6	6	2.2	2.2
Tx radiated power (e.r.p.), dBm	33	33	27	27	33	33	27	27
Rx Antenna gain, dBi	6	6	2.2	2.2	6	6	2.2	2.2
Receiver bandwidth, kHz	100	200	100	200	100	200	100	200
Declared receiver sensitivity, dBm	-85	-85	-80	-80	-85	-85	-80	-80
Receive signal margin, dB	0	0	0	0	0	0	0	0
C/I objective, dB	8	8	8	8	8	8	8	8
Imax, dBm	-93	-93	-88	-88	-93	-93	-88	-88
BW correction factor, dB	10.0	7.0	10.0	7.0	10.0	7.0	10.0	7.0
Minimum path loss, dB	105	108	96	99	105	108	96	99
Propogation exponent	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Impact range, m	130	159	73	89	130	159	73	89
Impact area, m2	53255	79137	16730	24861	53255	79137	16730	24861
Devices within Impact area	2.7	4.0	0.8	1.2	53.3	79.1	16.7	24.9
Probability of interference, %	11.6		3.6		16.2		5.1	

Explanation of Results

Given that the transmit power of WBN SRD is 25 mW e.r.p. and this energy is spread across 1 MHz, and also given the various overlap scenarios between the RFID and WBS devices, the impact range and number of victim receivers within that impact range varies. The overall probability of interference is calculated as described in the previous section.

The values shown in the previous table are worst-case probabilities, and as before in section 6.2.3.1, applying a probability distribution function to the received signal strength will result in lower probability of interference. Applying the same cumulative distribution function as the previous section results in interference probabilities summarised in Table 44 and Table 45 below.

Table 45: Probability of interference to RFID assuming drSS distribution: WBN SRD AP interferer

Parameter	SRD Scenario	
	WB AP with Fixed RFID Interrogator	WB AP with HH RFID Interrogator
Frequency range (MHz)	865-868	865-868
Transmitter e.r.p., dBm	14.0	14.0
Assumed device density per km2	50	50
Assumed duty cycle, %	10	10
Worst case probability of interference, %	11.6	3.6
Typical probability of interference, %	6.1	2.0

Table 46: Probability of interference to RFID assuming drSS distribution: WBN SRD TN interferer

Parameter	SRD Scenario	
	WB TN with Fixed RFID Interrogator	WB TN with HH RFID Interrogator
Frequency range (MHz)	865-868	865-868
Transmitter e.r.p., dBm	14.0	14.0
Assumed device density per km2	1000	1000
Assumed duty cycle, %	0.7	0.7
Worst case probability of interference, %	16.2	5.1
Typical probability of interference, %	8.5	2.8

Recall that the above probabilities of interference are based on the assumption that the WBN SRD use the CSMA-CA process described in TR 103 245 [8] (-75 dBm / 1 MHz). Applying the Friis transmission equation in reverse will show that this is a reasonable assumption.

Conclusions and Recommendations

Based on the previous analysis it is clear that levels of interference will exist between RFID and emerging WBN SRD applications. However, even with conservative assumptions for device density and duty cycle, it appears that coexistence can be achieved. If, however, the proliferation of WBN SRD devices becomes greater than the assumptions used in this analysis, then it is possible that interference levels could become higher than those computed with commensurate negative impact on the performance of RFID (and other SRDs) that share the 865-868 MHz band.

7.2.3.2 SEAMCAT analysis

The use of RFID in the frequency band 865 to 868 MHz was already discussed in 6.2.3.1. The narrowband SRDs analysed in 6.2.3.1 have channel bandwidth of 200 kHz and therefore could interleave within RFID channel plan in order to avoid tag operation channels. In this case however the wideband SRDs have channel bandwidth of 1 MHz and would overlap the entire RFID channel plan without possibility to protect specific channels.

In order to analyse feasibility of introducing WBN SRD in coexistence with RFID, the simulation scenario was set up as shown in the following Figure 28.

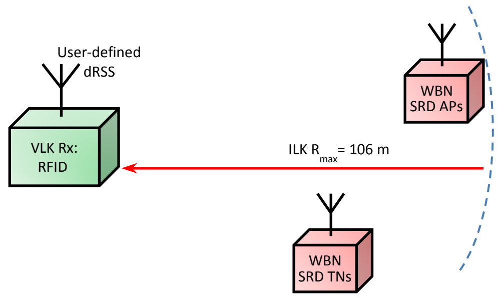


Figure 28: Scenario for WBN SRD co-existence with RFID in 865-868 MHz

The detailed technical parameters of SEAMCAT simulations for this scenario are given in Table 121 of ANNEX 10: and the corresponding results of simulations are given in Table 122. These results indicate low risk of interference from 25 mW WBN SRDs to RFID operations in 865-868 MHz.

However it should be noted that the performed SEAMCAT analysis only considered the impact of WBN SRD in the high power RFID channels. It should be noted that the shielding of high power RFID installations (e.g. up to 16 dB) is not considered in the above simulation. However there are many other RFID applications, which operate at much reduced ranges and where there is no need for shielding.

In addition, the above results with RFID as victim might not represent the worst case. The above simulation considers that the given band is used by up to 27 IoT devices within a radius of 106 m from victim RFID. However if in the future the IoT becomes truly widespread it would be quite possible for these devices to be present in even higher densities, i.e. the same number of simulated devices would be concentrated in a smaller area. Therefore the feasibility of a sensing procedure to protect RFID systems will be analysed in section 7.2.4.

ANNEX 7: provides an overview of various additional factors not considered in this report that may improve or worsen the simulation results.

In summary, acceptable protection for existing SRDs is assumed to be achieved by WBN SRDs in the band 865-868 MHz using LBT (CSMA-CA) with a threshold of -75 dBm.

According to RFID industry, a specific listening time for the detection mechanism might improve further the detection (see ANNEX 4:, e.g. at least 1ms). However, to generalize the listening time at 1ms would hamper the whole SRD industry whereas it might only improve co-located sites. For industrial premises where an RFID high level of service is expected, it's also recommended to resort to site engineering.

7.2.3.3 Impact of WBN SRDs in 865-868 MHz on Non-specific 25 mW SRDs

While the previous sub-sections considered an example of RFID as victim user in the band 865-868 MHz, this band can be also used by low powered non-specific SRDs. The latter use possibility is harmonised across the entire EU in accordance with EU SRD Decision and could not be neglected. This sub-section therefore reviews the simulations of coexistence of proposed WBN SRD applications against incumbent low power SRDs.

The technical parameters of WBN SRD application remain the same as used in previous simulations reported in 7.2.3.2, while low-power non-specific SRD is modelled by using data for representative example of Home Automation application as specified in Table 18; Figure 29 shows the outline of this scenario.

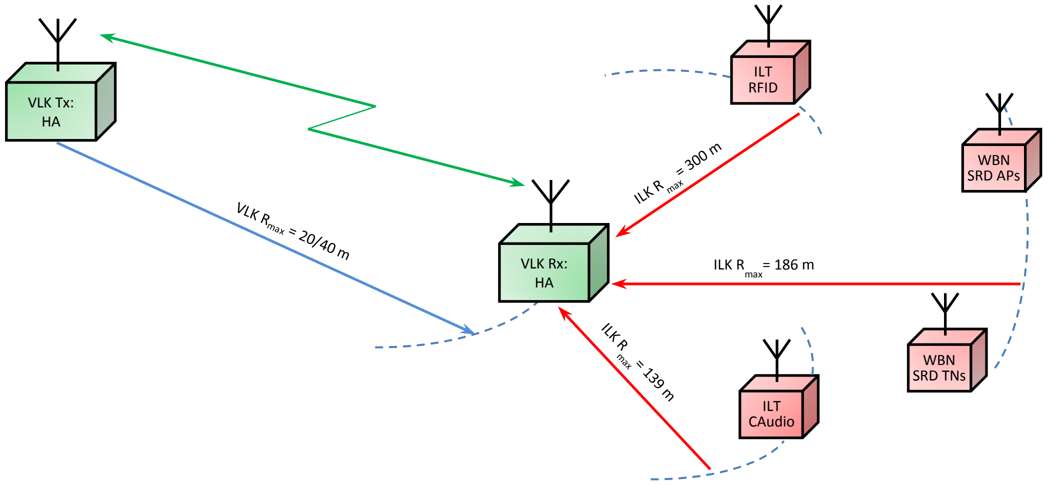


Figure 29: Scenario for WBN SRD co-existence with 25 mW Non-specific SRDs in 865-868 MHz

Detailed technical parameters and their settings for SEAMCAT simulations of this scenario are outlined in the Table 123 while the corresponding simulations results are given in Table 124.

These results show that for typical real-life cases with WBN SRDs operating near their average DC, the probability of combined interference to non-specific SRDs would be on the order of 1-4%, of which less than 1% would be attributable to WBN SRD, the rest being generated by ambient noise from other legacy SRDs in baseline scenario. Only if considering an extreme worst case with all SRDs operating at their maximum allowed DC, the probability of interference might increase to above 10% of which some 6-9% would be attributable to WBN SRD. However as was already noted before this worst case is quite unrealistic and therefore should be seen as giving absolute worst theoretical limit of possible interference.

7.2.4 Impact on LPWAN in 865-868MHz

This section continues the consideration started in 6.2.4 and here considers impact of WBN implementation into an example of LoRa™ LPWAN uplink use in 865-868 MHz.

7.2.4.1 Simulation assumptions for LPWAN

In the analysis below, the LPWAN network (e.g. LoRa™) uses 25 mW uplinks in the band 865-868 MHz and 500 mW downlinks in the band 869.4-869.65 MHz.

The following table shows LPWAN system characteristics taken into account in this study:

Table 47: Example of LPWAN system (LoRa)

LoRa Use Case	
Bandwith	125 kHz
NAP RECEIVER_BLOCKING_MASK	from EN 300 220
NAP Gain	5 dBi

LoRa Use Case	
NAP Noise Figure	3 dB
TN Gain	0 dBi
TN Tx Power	14 dBm
NAP Sensitivity	-137 dBm
Protection ratio	-17 dB
NAP Height	25 m
TN Height	1,5 m

The following table shows the impact of 25mW WBN SRDs on LPWAN system.

Table 48: Probability of interference from WBN SRDs into LPWAN

	Interferer : 25mW 802.11ah
High Density Max DC	90% (DC= AP: 10% / TN: 2.8%)
Medium Density Average DC	12% (DC= AP: 2.5% / TN: 0.1%)
Medium Density Low DC	7.16% (DC= AP: 1% / TN: 0.1%)

When restricting the duty cycles at 2.5% for Access Point and 0.1% for Terminal Nodes (such reflecting realistic scenarios for 802.11ah), compatibility with LPWAN could be achieved.

7.2.5 Complementary calculations of LBT threshold values for WBN SRDs

The following Table 49 contains the calculation of LBT threshold based on the approach presented in Annex 5 of ECC Report 246 [9] on deriving a threshold value for LBT functionality of CSMA-CA channel access mechanism. It shows the required threshold values for WBN SRD devices to detect Sub-metering, RFID, Cordless Audio and Hearing Aids. In addition, Table 49 elucidates the required link margin at the victim receiver where a LBT threshold of -75 dBm would be able to detect the victim link.

Table 49: LBT threshold values

Parameters	Cordless Audio	Sub-metering	RFID	Hearing Aids
Bandwidth, MHz	0.2	0.3	0.4	0.6
Transmit power, dBm	10	14	33	-6
Sensitivity, dBm	-97	-104	-85	-94
C/I, dB	17	8	12	17
Margin, dB	0	0	0	0
Imax, dBm	-114	-112	-97	-111

Parameters	Cordless Audio	Sub-metering	RFID	Hearing Aids
Interferer's e.r.p., dBm	14	14	14	14
Interferer's bandwidth, MHz	1	1	1	1
Interferer's power in victim's channel, dBm	7.01	8.77	10.02	11.78
Required separation distance, m (Note)	367.65	361.91	146.46	413.08
LBT threshold, dBm/BW	-111.01	-106.77	-74.02	-128.78
Required margin above sensitivity with threshold of -75 dBm/MHz	36	32	-1	54

Note: assuming propagation path loss exponent 3.5

The protection of the considered victims systems by an energy detection threshold of -75 dBm used by the WBN SRD device is possible if the victim links are working with a certain margin above sensitivity: Cordless Audio 36 dB, Sub-metering SRD 32 dB, RFID 1 dB and for Hearing Aids 54 dB. In real life scenarios the victim links are working with a margin above its sensitivity, and thus the energy detection threshold of IoT devices is expected to improve the situation. But especially for Hearing Aids the LBT approach seems not able to improve the coexistence due to the huge required margin.

7.3 CONCLUSIONS ON POSSIBILITY OF IMPLEMENTING WIDEBAND SRDS IN 863-868 MHZ

Considering the results of simulations reported in Chapter 7, the introduction of new WBN SRDs in the band 865-868 MHz with e.r.p. limited to 25 mW is feasible. The simulations were conducted without introducing polite spectrum access technique such as CSMA-CA in order to examine the worst case. However, the use of LBT or equivalent technique may facilitate more reliable use of the spectrum in particular in order to mitigate any potential interference to cordless audio devices.

It may be noted that allowing WBN SRD in 863-868 MHz might be seen to complement and clarify the previous allowance in Annex 1 of ERC/REC 70-03 (option h1.2) to operate any wideband (other than FHSS) non-specific SRDs across the entire range 863-870 MHz with e.r.p. of 25 mW (power density of -4.5 dBm/100 kHz) and no DC restriction if employing LBT+AFA or equivalent technique, such as CSMA-CA employed by IEEE 802.11ah-compliant devices [40]. So while the 25 mW/1 MHz e.r.p. of IEEE 802.11ah devices (equivalent to 1.4 dBm/100 kHz) would exceed the power density envisaged in option h1.2 of ERC/REC 70-03, any additional interference risk would be effectively contained by limiting the DC of proposed WBN SRDs and prohibiting their access to 868-870 MHz.

Some Cordless Audio stakeholders pointed out that the band 863-865MHz should not be used by WBN SRDs until practical tests are confirming theoretical studies that the coexistence between WBN SRD and ALDs and Cordless Audio is possible. However it was considered by other parties that such tests were not obligatory. However, the use of LBT or equivalent technique may facilitate more reliable use of the spectrum in particular in order to mitigate any potential interference to cordless audio devices.

8 MUTUAL COEXISTENCE OF NBN SRD VS. WBN SRD

This chapter shall consider mutual coexistence of NBN SRD vis-à-vis WBN SRD to provide for the case where both of these new applications may be allowed in the same frequency band. Based on the results of the studies reported in Chapters 6 and 7, it appears that the most likely scenario for coexistence of these two systems may be encountered in the band 865-868 MHz.

The first case will consider probability of interference from WBN SRD to a Terminal Node of NBN SRD. The general outline of this scenario is depicted in Figure 30.

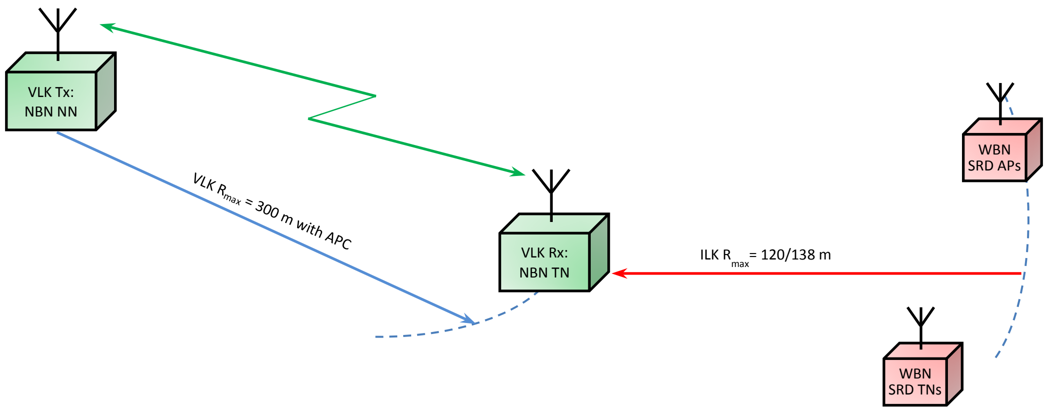


Figure 30: Scenario for mutual WBN SRD vs NBN SRD coexistence in 865-868 MHz: NBN TN as a victim

The detailed technical parameters for SEAMCAT simulation of this scenario are provided in Table 125 in ANNEX 10: and the corresponding results are given in Table 126. These results show that for the most realistic case with SRDs operating at near average DC, the probability of interference from solely WBN SRD to NBN SRD would less than 1%. Even for unrealistic worst case with all SRDs operating at their maximum allowed DC limit, the probability of interference would barely reach 4-5%.

In the other direction the risk of interference from 500 mW NBN SRD to WBN SRD Terminal Node receiver was considered as depicted in the following Figure 31.

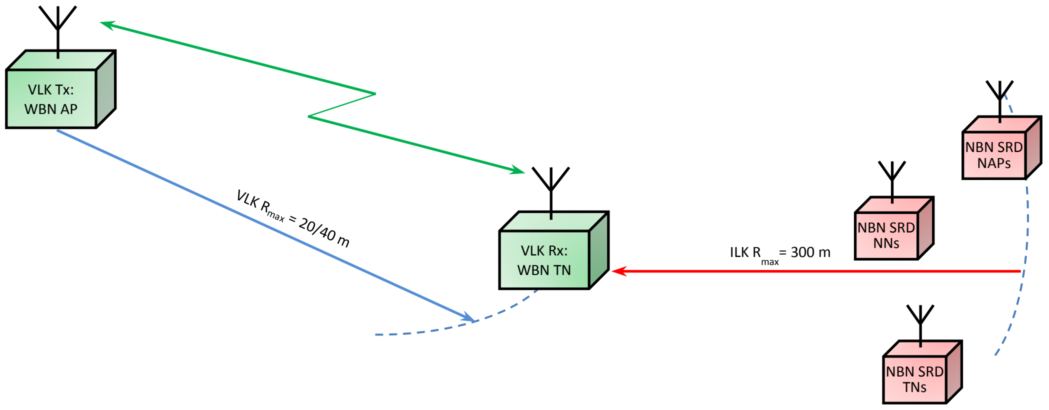


Figure 31: Scenario for mutual WBN SRD vs NBN SRD coexistence in 865-868 MHz: WBN TN as victim

The detailed technical parameters for SEAMCAT simulation of this scenario are provided in Table 127 in ANNEX 10: and the corresponding results of simulations are provided in Table 128. They show higher risk of interference than was demonstrated in the opposite direction, yet the risk would be still tolerable. For the typical real-life case with SRDs operating at their average DC and regardless of their deployment density, the probability of interference would be around 2-3%. Only for the unlikely case of all SRDs operating at their maximum permitted DC, the probability of interference would climb to around 5-8% depending on deployment density.

It should be further noted that neither of the above-simulated scenarios have considered mitigation effect of using CSMA-CA spectrum access mechanism implemented in WBN SRD.

To conclude, the two scenarios analysed in this chapter have demonstrated feasibility of mutual co-existence of 500 mW NBN SRD and WBN SRD for most realistic deployment assumptions.

9 CONCLUSIONS

This ECC report considers the situation with the use of the frequency band 863-870 MHz, such as to reflect on the policy, technological and market developments that took place since the development of the previous ECC Report 37 [1] "Compatibility of Planned SRD Applications with Currently Existing Radiocommunication Applications in the frequency band 863-870 MHz (2008)". The main objective of this work is to review the applicable regulatory SRD requirements with the view on facilitating SRD innovation and more efficient use of the band with respect to new and existing services and (sub-) bands.

The report also looks at a closely related issue of feasibility of utilising the previous guard-band 862-863 MHz for SRDs, noting the changed conditions of use of the adjacent band below 862 MHz by the wideband cellular systems. Finally, the report considered the feasibility of introducing new proposed Narrowband/Wideband Networked SRD applications in the band 862-868 MHz.

In order not to duplicate the previous work, the report draws heavily on the previously published studies that are related to the use of SRDs in the subject frequency range, notably:

- ECC Report 37 "Compatibility of planned SRD applications with currently existing radio communications applications in the frequency band 863-870 MHz" (February 2004);
- ECC Report 181 "Improving spectrum efficiency in SRD bands" (September 2012) [2];
- ECC Report 200 "Coexistence studies for proposed SRD and RFID applications in the frequency 870-876 MHz/915-921 MHz" (September 2013) [3];
- ECC Report 207 "Adjacent band coexistence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz" (January 2014) [4];
- "Channel Access Rules for SRDs", Study by IMST GmbH (November 2012) [5].

This report progressed by analysing information of the above referenced documents accordingly and developing new complementary analysis where and as necessary. In general it may be said that the methodology and assumptions used recently in the ECC Report 200 for similar studies in the bands 870-876/915-921 MHz were also used here, however noting the different scope of the envisaged SRD uses in respective bands. It is also worth noting that differently from "SRDs green field" approach applicable in the bands 870-876/915-921 MHz, the band 863-870 MHz had been already extensively used by SRDs for many years. Therefore this report had to start from certain reference scenarios referring to the existing status quo in the band. Also for the same reason, the sub-band 868-870 MHz was excluded early on from further analysis having noted that it was used most extensively and by some sensitive applications.

The publicly available software SEAMCAT (ver. 4.1.0) has been used for studies in this report, providing probabilistic assessment of interference as a result. The following analysis and conclusions are based on deployment assumptions (device density, activity factor, duty cycle, etc.) aiming to reflect average conditions over large population of devices instead of worst-case scenarios. Some further considerations as regards possible additional positive or negative impact of various assumptions made in the study are outlined in ANNEX 6: and ANNEX 7: respectively for adjacent band and intra-SRD coexistence prospects.

It should be also noted that ECC Report 249 [6] considered results of measurements of unwanted emissions of common radio systems and recommended that they be modelled in a statistical manner representing the phenomenon of spurious emissions domain "spikes" occurring on specific frequencies or at specific points in time. The probability of these occurrences can be defined as a distribution instead of modelling the spurious behaviour as being constant at the maximum permitted level across all frequencies and not varying with time, as typically specified in standards. This statistical approach can improve the accuracy of sharing/compatibility studies as it is based on more realistic assumptions.

For the sake of this report, constant spurious emissions levels were modelled as a simplifying assumption. Although it is recognised that this assumption is overly pessimistic, the results of this study are valid. The analysis may benefit from further future work once the recommendations in ECC Report 249 have been developed into an updated methodology.

The following lists the key findings and conclusions of this report, structured according the relevant bands. References to relevant sections of the report are given in brackets to guide to more detailed information for given issue.

Besides duty cycle (DC) and power level which are regulatory parameters, density, antenna height and deployment environment (indoor/outdoor) have also a significant impact on the results of the studies. In this report, the predominant following assumptions have been considered:

- For 500mW Narrow Band Networked Short Range Devices (NBN SRDs):
  - Network Access Points (NAP): outdoor deployment with 5m for antenna height; DC 10% max/ 2.5% average;
  - Network Nodes (NN): outdoor deployment with 5m for antenna height; DC 2.5% max/0.7% average;
  - Terminal Nodes (TN): indoor deployment with 1.5m for antenna height, DC 0.1%;
  - All NBN SRD devices modelled with active APC.
- For 25 mW Wide Band Networked Short Range Devices (WBN SRDs):
  - AP: indoor deployment with 1.5m for antenna height, DC 10% max/2.5% average;
  - TN: indoor deployment with 1.5m for antenna height, DC 2.8% max/0.1% average.

This report has differentiated between certain applications in the frequency band 862-868 MHz.

- Typical SRDs;
- Wide Area Networks (WAN) based on 500 mW NBN SRDs;
- WANs based on TNs using 25 mW and sensitive NAP receivers (identified as LPWAN in this report and considered using a specific example of LORA™ WAN uplink use case in the band 865-868 MHz);
- Localised (indoor) deployment of 25 mW WBN SRDs.

This report specifically focuses on:

- case studies for intra-SRD coexistence in 862-868 MHz;
- 862-863 MHz: investigating possible conditions for introduction of SRDs;
- 865-868 MHz: investigating conditions under which the RFID interrogator channels could be liberalised to allow (up to) 500mW e.r.p. SRDs within the band;
- 863-865 MHz: investigating to which extent higher power, duty-cycle restricted SRD applications could co-exist with 10 mW analogue or digital audio devices/radio microphones;
- case studies for alignment of alarm parameters in 868-870 MHz based on TR 103 056 [7];
- impact of the newly proposed SRD arrangements on LTE below 862 MHz.

All CEPT administrations should be also alerted to the emergence and wide spreading of the unlicensed use of LPWAN systems mostly in the band 865-868 MHz, such as the example of LORA™ WAN. Administrations wishing to protect LP WAN system s considered in this report should implement conclusions as given in the section on WAN (section 6.2.4). Other administrations need not follow this restriction. With regard to the studied LP WAN case it should be noted that only network access point as a victim has been considered. The need for further studies may be considered once the ETSI system reference document on LP WAN is available.

Band 862-863 MHz:

- All NBN SRD network devices were simulated under conservative assumption of operating (1) with spectrum mask compliant with -54dBm/100kHz spurious emissions limits, (2) average and maximum DC and, (3) medium and highest density; (4), in order to achieve compatibility with incumbent applications in adjacent bands (Cordless Audio, Hearing Aids). The resulting adjacent band impact to LTE Uplink below 862 MHz would be very significant: leading to increased probability of bitrate loss from 5-8% up to 14-21% over the baseline case, depending on considered deployment densities and even with the unwanted emission mask Option 1. Such high probability of adjacent band interference to LTE operations would be clearly excessive (for details refer to sections 5.1.3 and 5.4 of the report). Additional sensitivity analysis was performed to test the option of reducing the NBN SRD output power to 100 mW across entire 862-863 MHz. However this allowed reducing the interference level by few percentage points only, with the risk of interference under high deployment density urban scenarios still being between 7-14%.

- Considering the results of simulations (table 87), reported in Section 5.1.3, it appears that implementation of NBN networks as presented in section 2.5.1 (with NAP/NN/TN) could create high probability of interference on LTE base stations below 862 MHz.
- Furthermore, some practical tests (Annex 8) have shown that deployment of NBN with 500 mW e.r.p above 862.4 MHz could potentially affect audio systems (in close proximity) above 863 MHz.
- Hence, operation in the band 862-862.4 MHz should be restricted to terminals with 500 mW e.r.p, low duty cycle (0.1%) and to terminals with 100 mW e.r.p, low duty cycle (0.1%) in the band 862.4-863 MHz, within specific networks (e.g. smart metering in rural or remote area and low density deployments). In all cases, unwanted emission mask of these terminals shall comply with mask option 1 (in Annex 1 figure 44).
- Non-specific SRD devices with e.r.p. of up to 25 mW and DC of up to 0.1% and with 350 kHz bandwidth were shown to have minimal interference to Cordless Audio devices in 863-865 MHz (see 5.2 and 5.3), and to LTE under the condition that the transmitters use emission mask Option 1, making their implementation is therefore feasible.
- WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters use emission mask Option 1 as described in ANNEX 1:, Figure 32, i.e. meeting the spurious emissions limit of -54dBm/100 kHz. Furthermore, although the studied worst case scenario to ensure protection of LTE 10 MHz channels operating below 862 MHz resulted by mask Option 1, some stakeholders were of the opinion that an additional restriction of 800 kHz guard band may need to be implemented between the frequency 862 MHz and the WBN lower band edge (i.e. 862.8 MHz). Given the minimum required channel bandwidth of 1 MHz, this effectively means that WBN SRD should not be introduced in 862-863 MHz.
- SRD vendors wishing to use the band 862-863 MHz should weigh the risks and accept responsibility for deciding themselves whether their specific applications shall be capable of operating in the presence of comparatively high ambient noise levels from LTE UEs' out-of-band emissions and design their products accordingly (see. 5.1.1).

Band 863-865 MHz:

- Although SEAMCAT simulations have shown that additional NBN SRD 500 mW applications may coexist with cordless audio in the band (see 6.2.2) (i.e. for the medium density and average DC case the contribution of NBN SRD deployed over 863-868 MHz to audio SRDs in 863-865 MHz may be estimated to be around 2% to 4% of interference probability), practical tests have been carried out (see ANNEX 8:) showing that this coexistence would be difficult because of the expected up to 100% duty cycle nature of audio systems. Also simulations of adjacent band interference from NBN SRD in 863-865 MHz to LTE below 862 MHz (see 6.1) have shown That this band should not be recommended for NBN SRD.
- The SEAMCAT simulations have shown that WBN SRD applications may coexist with Cordless Audio in the band (see 7.2.2), even, as conservative approach, without introducing polite spectrum access technique such as CSMA/CA or equivalent as mitigation in the SEAMCAT simulations. Cordless Audio manufacturers noted and expressed concern that practical tests were not conducted, however it was considered by other parties that such tests were not obligatory. However, the use of LBT or equivalent technique may facilitate more reliable use of the spectrum in particular in order to mitigate any potential interference to cordless audio devices.
- WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters used emission mask Option 1 as described in ANNEX 1:, Figure 32.

Band 865-868 MHz:

- WBN SRDs;
  - WBN SRD application does not cause harmful interference to adjacent LTE operations below 862 MHz (see 7.1), on the condition the transmitters used emission mask Option 1 as described in ANNEX 1:, Figure 32;
  - WBN SRD applications are able to operate across the entire band 865-868 MHz without causing harmful interference to other SRDs in this band, as studied in this report (see 7.2.3 and 8);
- 500 mW NBN SRDs (as presented in section 2.5.1);
  - NBN SRDs are able to operate throughout the band 865-868 MHz without causing harmful interference to Cordless Audio applications as long as the existing Tx restrictions are obeyed, i.e. e.r.p.<100mW below 865.6 MHz (see 6.2.2);

  - NBN SRDs are able to operate throughout the band 865-868MHz without causing harmful interference to RFID provided that their duty cycle doesn't exceed 2.5 %. When the duty cycle of NAP of NBN SRDs exceeds 2.5%, it is preferable that these devices operate on the high-power RFID interrogator channels (see 6.2.3);
  - When considering LPWAN applications (e.g. LORA™) in the band 865-868 MHz, which are in current use in some European countries (see section 2.3.7), the available studies up to now show that sharing between NBN and LPWAN in the frequency band 865-868 MHz is possible if NBN SRDs were restricted to RFID interrogator channels.;
  - Considering the results of simulations, reported in Section 6.1 and recognising that this kind of operation would be more than 3 MHz offset from the LTE upper edge, it appears that implementation of NBN networks within "RFID interrogator channels" may create acceptable probability of interference to LTE base stations below 862 MHz;
- It may be also noted that the impact from NBN SRD and WBN SRD was studied separately in the report, i.e. the aggregated impact from both these systems - such as if deployed together in the same band(s) - to adjacent band below 862 MHz (LTE) and in respect to other incumbent SRDs in the band 863-868 MHz has not been considered. This was for the simple reason that it was not possible to make a meaningful a priori judgment as to the eventual preferred regulatory configuration and band choice for the respective proposed new systems.

The overall conclusions of the report may be illustrated in Figure 1, which depicts the proposed changes to the use of the subject frequency range.

ANNEX 1: UNWANTED EMISSION MASKS, RECEIVER SELECTIVITY AND OTHER PARAMETERS USED IN SEAMCAT SIMULATIONS

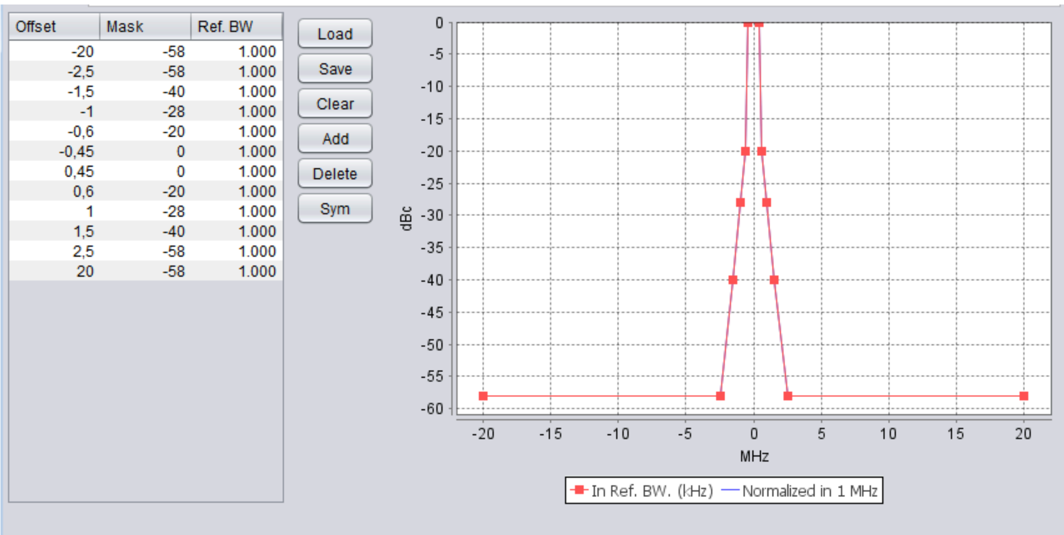
It is very important to carefully define the unwanted emissions masks for considered legacy as well as proposed future SRD applications. Traditionally these masks are focused on reflecting the OOB limits as they are dominant factor in most in-band studies. However this report also considered the case of adjacent band interference with cellular systems, where the interferer and victim were far removed in frequency, much beyond the OOB domain of unwanted emissions of narrowband SRD devices. Therefore in case of SRD to cellular interference the spurious domain emissions may become a predominant factor, which requires that the unwanted emission masks of SRD transmitters should be carefully defined to ensure that they properly reflect the suitable spurious emission limits.

As was described in sub-section 2.3.7, the simulations of adjacent band interference carried out in this report were based on two options for SRD unwanted masks:

- Option 1 representing "Reduced emissions mask" based on -54 dBm/100 kHz spurious limit;
- Option 2 representing "Worst case emissions mask" based on -36 dBm/100 kHz spurious limit.

ANNEX 3: provides an emission mask of a real 802.11ah [40] device obtained in the lab, which might not be representative for all devices.

The following figures show the specifics of the masks of both of the above options that were used in SEAMCAT simulations reported in this report. The remaining simulations concerned with in-band sharing scenarios were carried using reduced emissions mask option.



Offset	Mask	Ref. BW
-20	-58	1.000
-2,5	-58	1.000
-1,5	-40	1.000
-1	-28	1.000
-0,6	-20	1.000
-0,45	0	1.000
0,45	0	1.000
0,6	-20	1.000
1	-28	1.000
1,5	-40	1.000
2,5	-58	1.000
20	-58	1.000

Figure 32: WBN SRD Mask Option 1: Reduced Emissions Mask

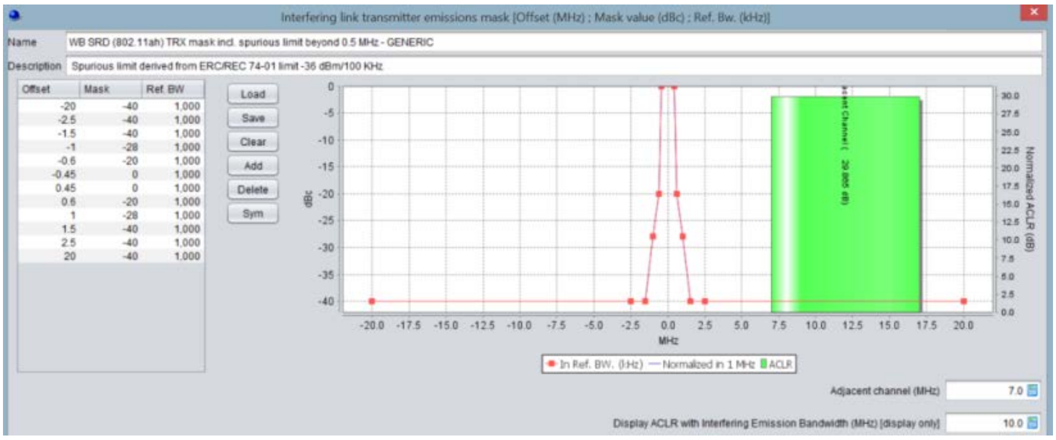


Figure 33: WBN SRD Mask Option 2: Worst Case Mask

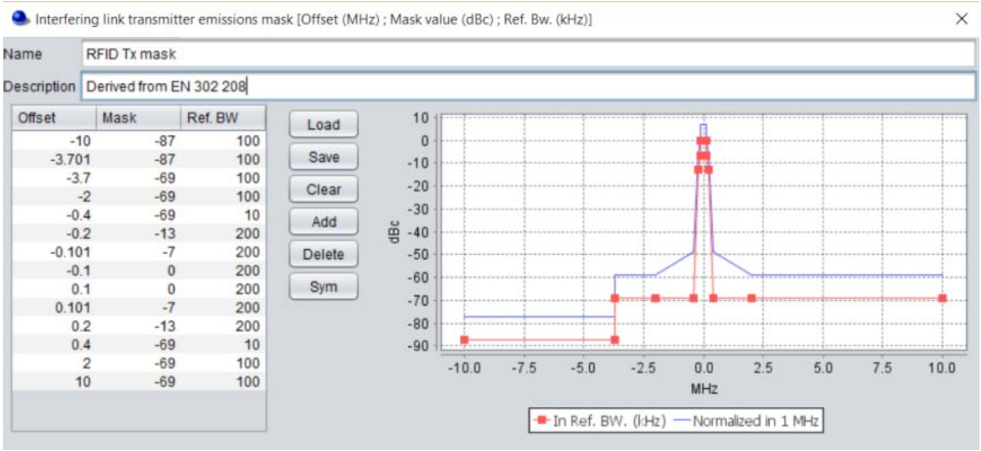
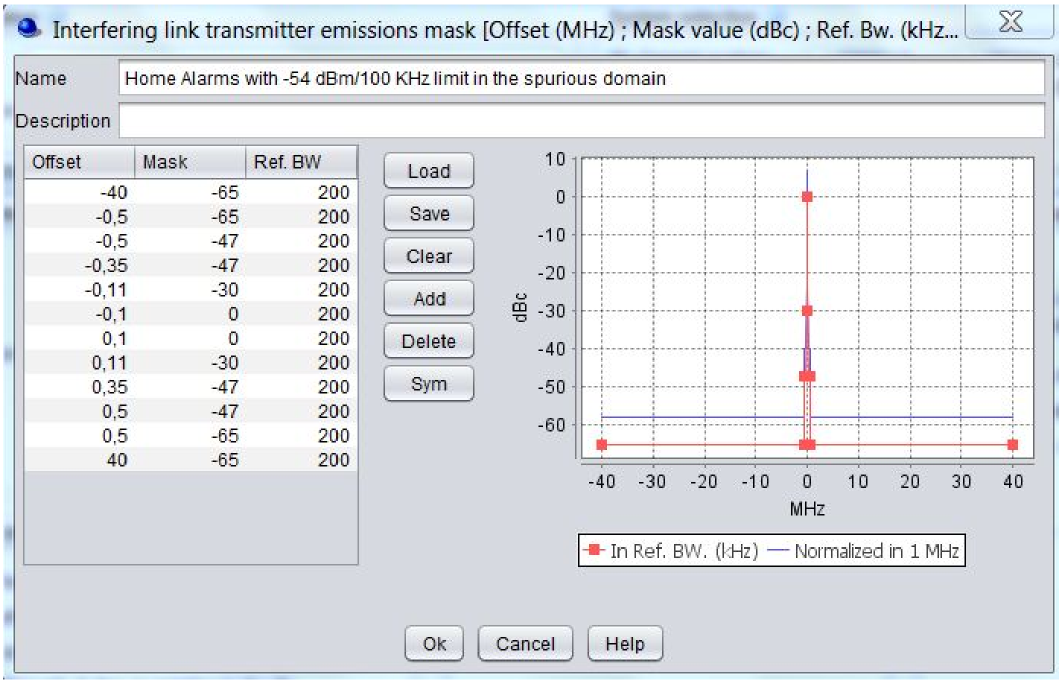
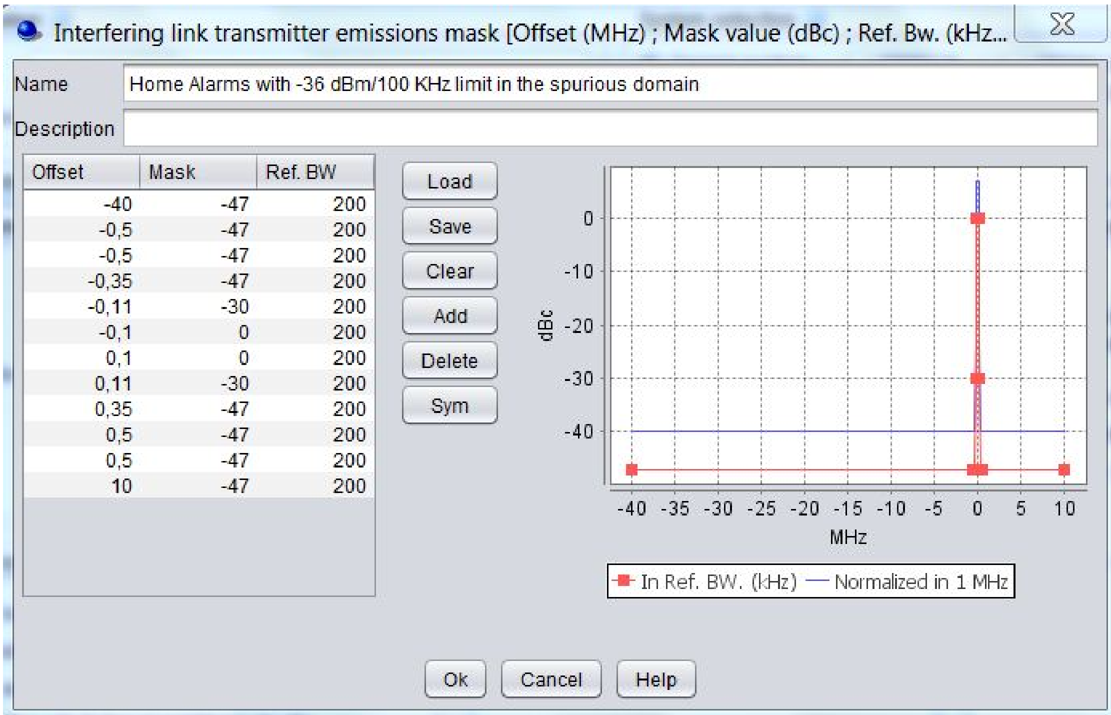


Figure 34: Emissions mask for RFID from EN 302 208 [43]: single option



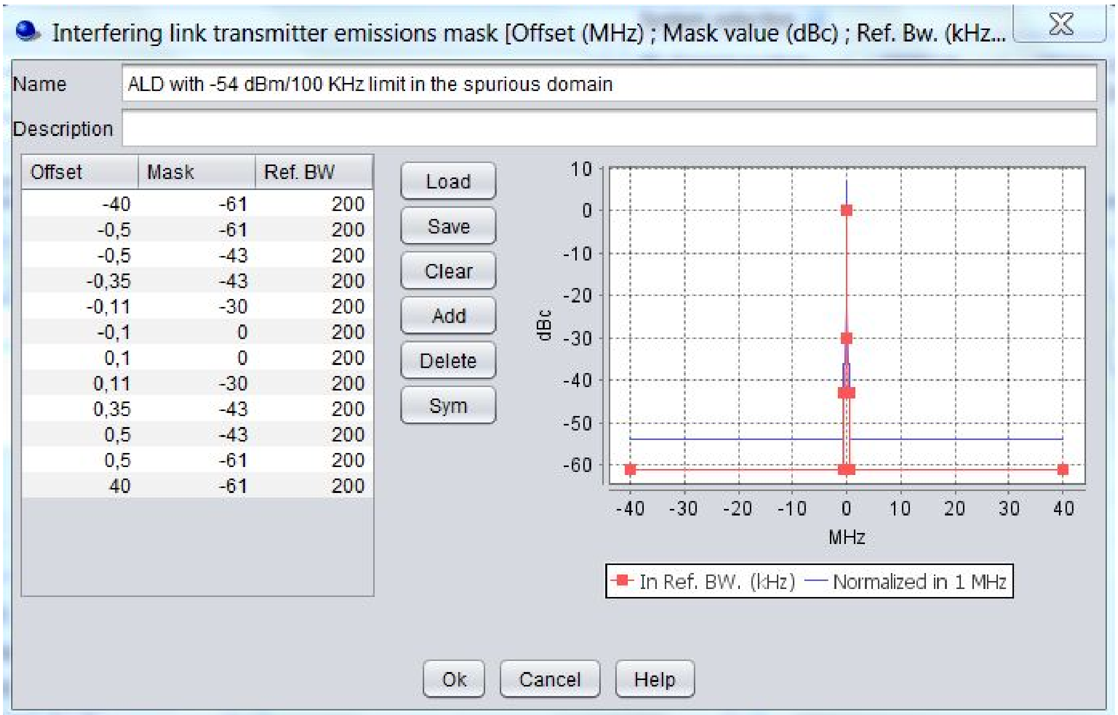
Offset	Mask	Ref. BW
-40	-65	200
-0,5	-65	200
-0,5	-47	200
-0,35	-47	200
-0,11	-30	200
-0,1	0	200
0,1	0	200
0,11	-30	200
0,35	-47	200
0,5	-47	200
0,5	-65	200
40	-65	200

Figure 35: HA SRD Mask Option 1: Reduced Emissions Mask



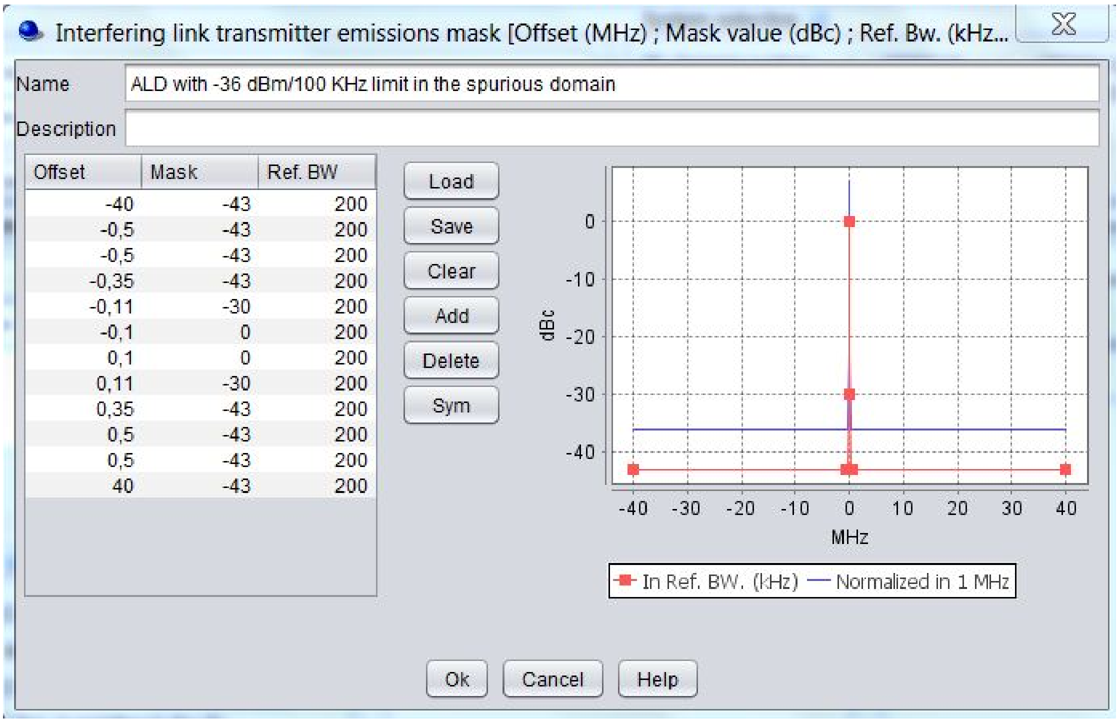
Offset	Mask	Ref. BW
-40	-47	200
-0,5	-47	200
-0,5	-47	200
-0,35	-47	200
-0,11	-30	200
-0,1	0	200
0,1	0	200
0,11	-30	200
0,35	-47	200
0,5	-47	200
0,5	-47	200
10	-47	200

Figure 36: HA SRD Mask Option 2: Worst Case Mask



Offset	Mask	Ref. BW
-40	-61	200
-0,5	-61	200
-0,5	-43	200
-0,35	-43	200
-0,11	-30	200
-0,1	0	200
0,1	0	200
0,11	-30	200
0,35	-43	200
0,5	-43	200
0,5	-61	200
40	-61	200

Figure 37: ALD SRD Mask Option 1: Reduced Emissions Mask



Offset	Mask	Ref. BW
-40	-43	200
-0,5	-43	200
-0,5	-43	200
-0,35	-43	200
-0,11	-30	200
-0,1	0	200
0,1	0	200
0,11	-30	200
0,35	-43	200
0,5	-43	200
0,5	-43	200
40	-43	200

Figure 38: ALD SRD Mask Option 2: Worst Case Mask

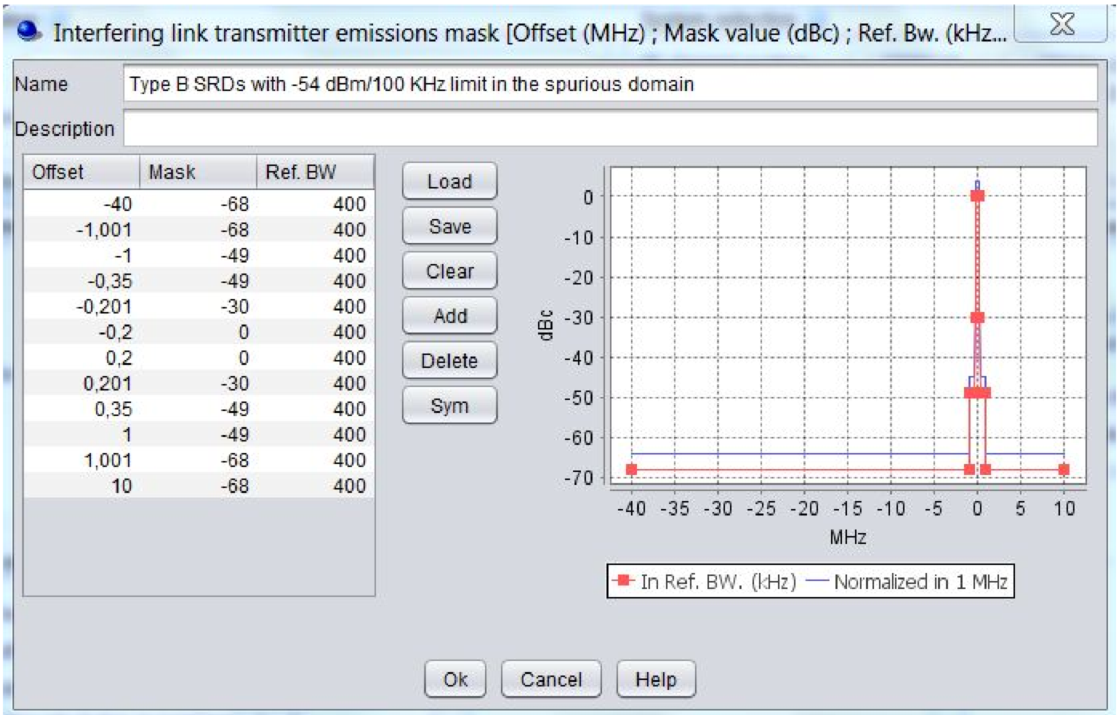


Figure 39: Type B SRD Mask Option 1: Reduced Emissions Mask

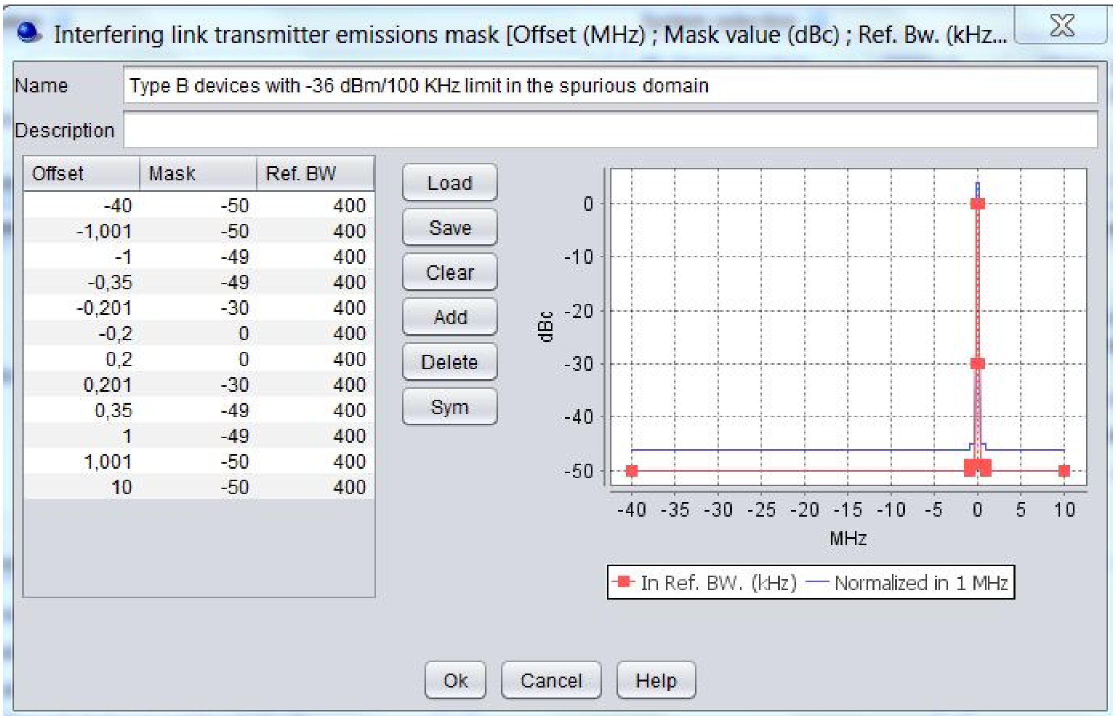
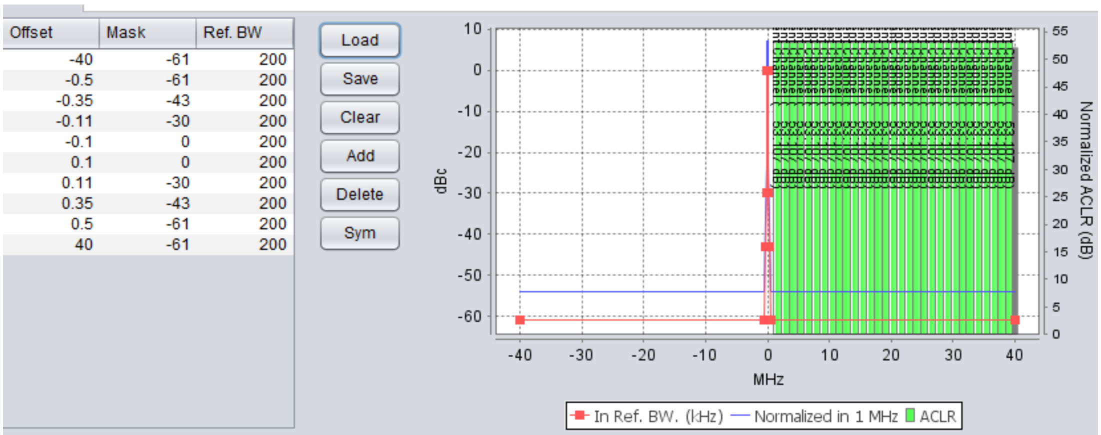
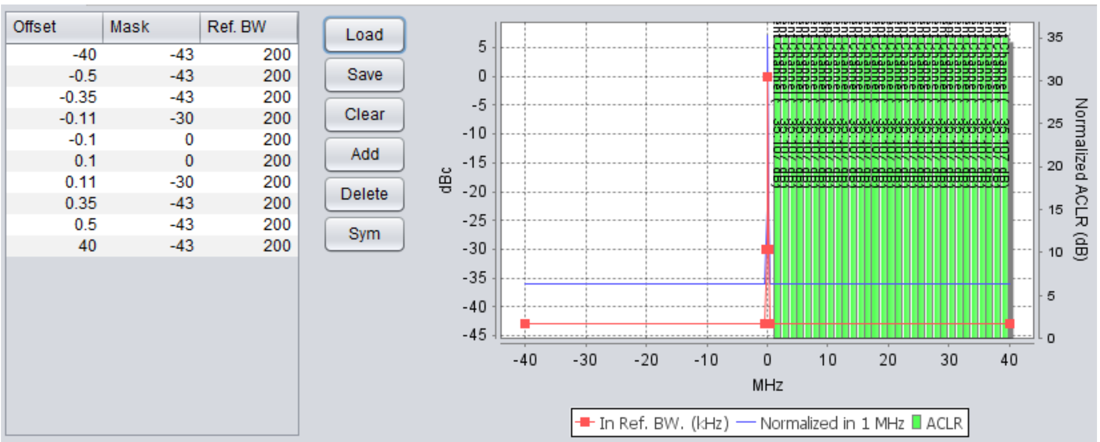


Figure 40: Type B SRD Mask Option 2: Worst Case Mask



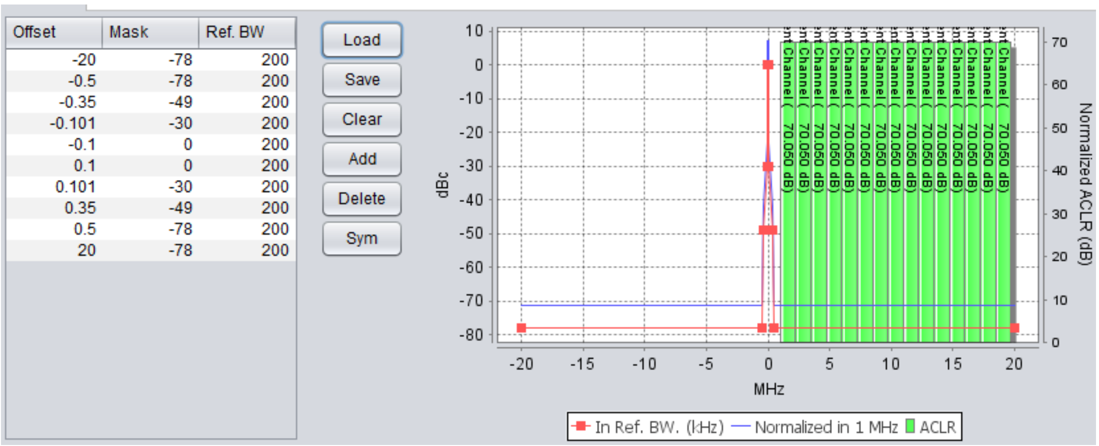
Offset	Mask	Ref. BW
-40	-61	200
-0.5	-61	200
-0.35	-43	200
-0.11	-30	200
-0.1	0	200
0.1	0	200
0.11	-30	200
0.35	-43	200
0.5	-61	200
40	-61	200

Figure 41: Cordless Audio SRD Mask Option 1: Reduced Emissions Mask



Offset	Mask	Ref. BW
-40	-43	200
-0.5	-43	200
-0.35	-43	200
-0.11	-30	200
-0.1	0	200
0.1	0	200
0.11	-30	200
0.35	-43	200
0.5	-43	200
40	-43	200

Figure 42: Cordless Audio SRD Mask Option 2: Worst Case Mask



Offset	Mask	Ref. BW
-20	-78	200
-0.5	-78	200
-0.35	-49	200
-0.101	-30	200
-0.1	0	200
0.1	0	200
0.101	-30	200
0.35	-49	200
0.5	-78	200
20	-78	200

Figure 43: 500mW SRD Mask Option 1: Reduced Emissions Mask

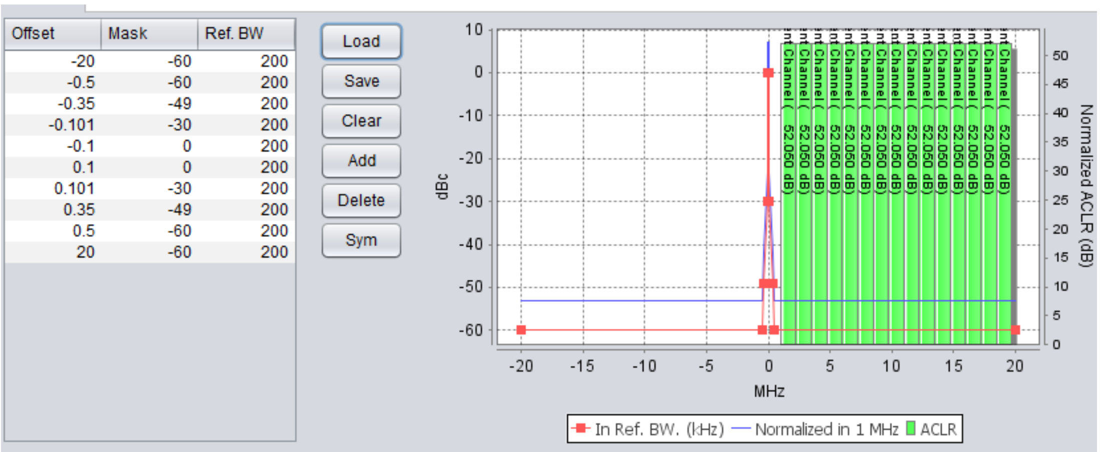


Figure 44: 500mW SRD Mask Option 2: Worst Case Mask

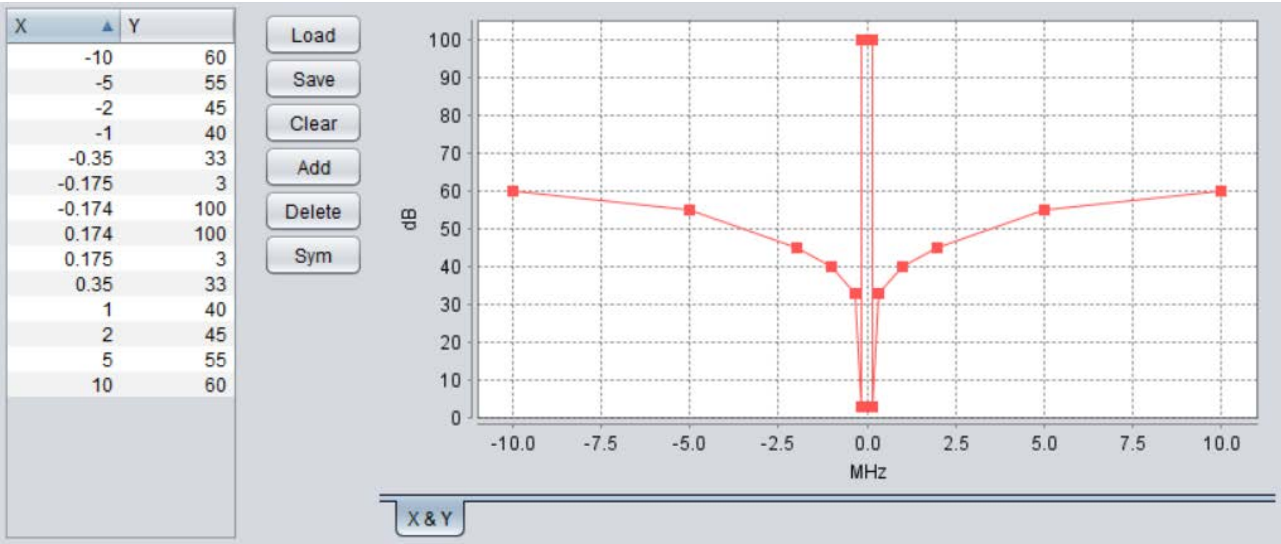


Figure 45: Example of a realistic selectivity mask used in studies for SRDs (realistic Cat.2 receiver 350 kHz channel bandwidth mask assumed in this report for Home Automation SRD)

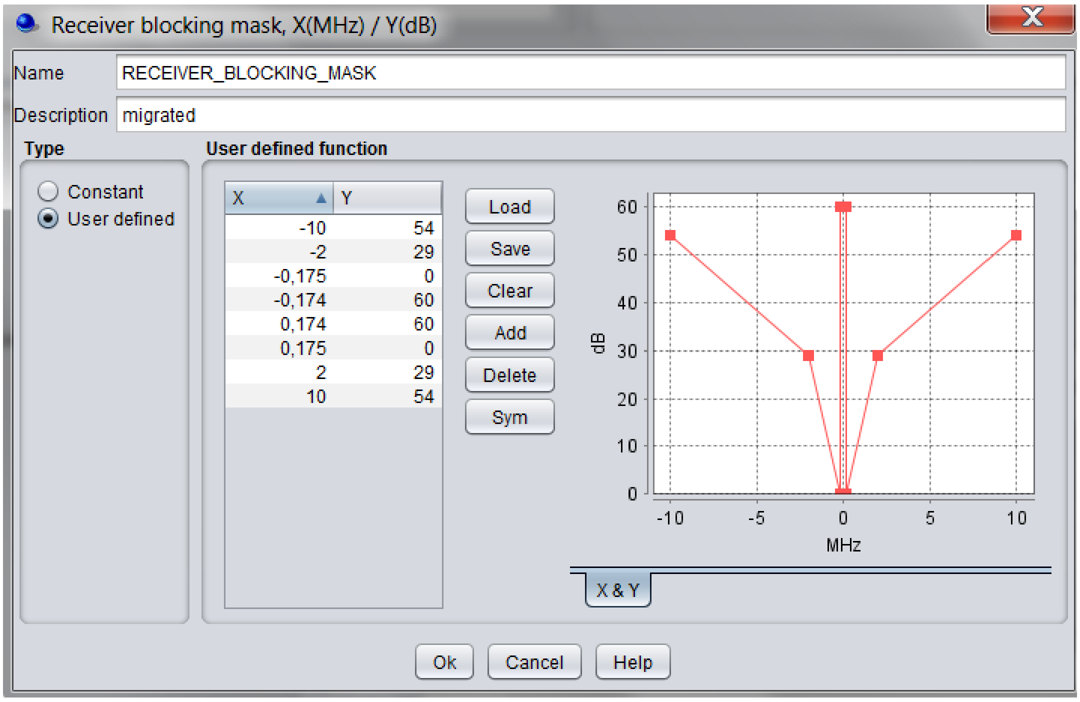


Figure 46: Example of a selectivity mask used in the studies for SRDs (Cat.2 receiver derived from EN 300 220 for 350 kHz channel bandwidth)

Note: the ACS and blocking values have to be chosen carefully. It is not correct to assume that the adjacent or out of band power reduced by the ACS or blocking value from the standard can be assumed as an equivalent co-channel interfering power; ACS is usually measured as the difference between adjacent power and wanted signal. Thus, the equivalent interfering power of the adjacent signal is the actual power reduced by the ACS/blocking value plus C/I. The values from EN 300 220 [12] are for Cat. 2 receivers 35dB-10log(BW/16kHz) at 2MHz offset from the center frequency and 60dB -10log(BW/16kHz). For the studies bandwidth of 350 kHz and a C/I of 8dB where assumed, resulting in 54dB at 10MHz and 29 dB at 2 MHz.

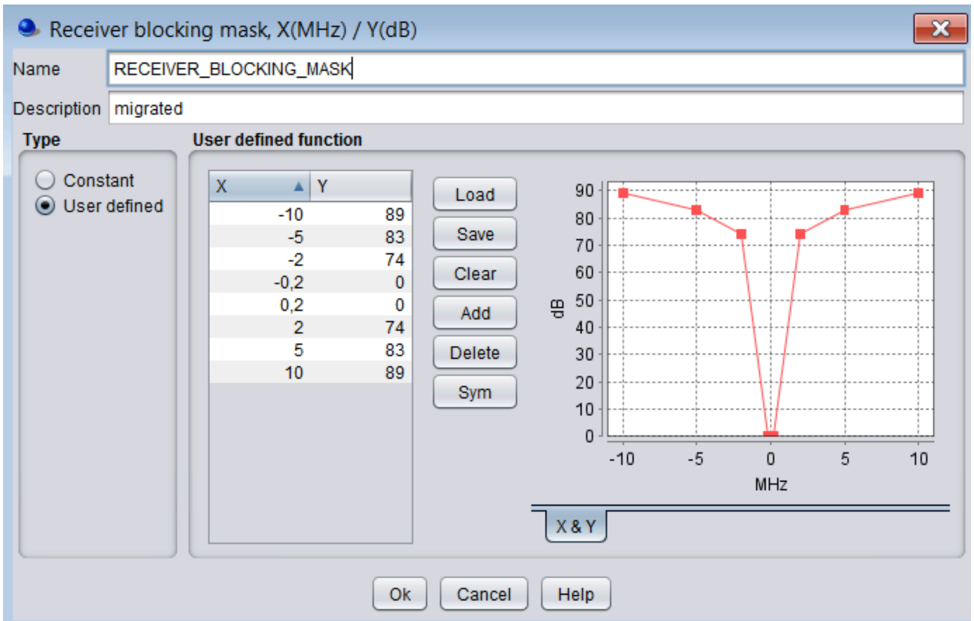


Figure 47: Selectivity used for RFID (derived from draft EN 302 208 [43])

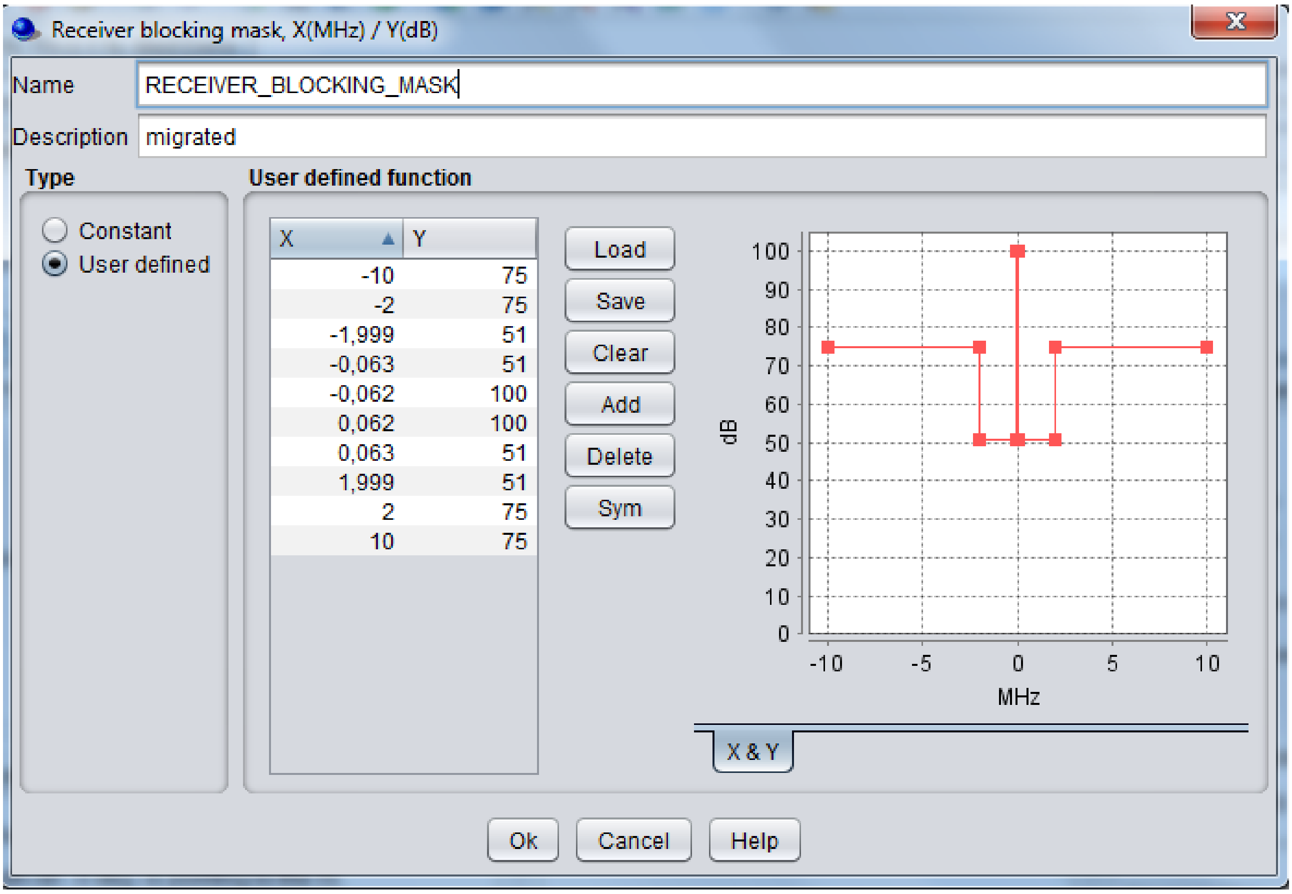


Figure 48: Selectivity used for LPWAN (derived from Table 13 and Table 16 of EN 300 220 [12])

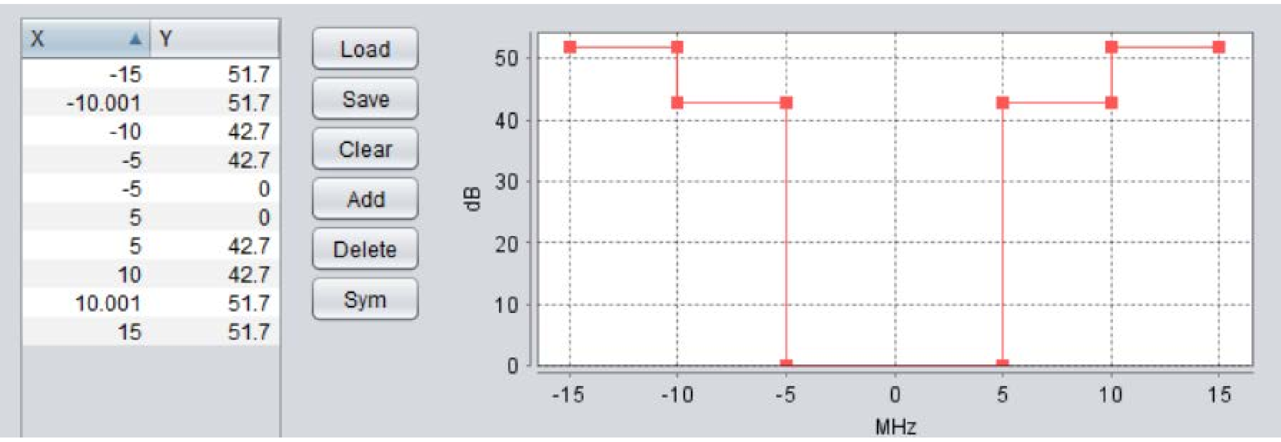


Figure 49: LTE BS receiver mask

A1.1 CONSIDERATION OF E.R.P. VS. E.I.R.P. AND RESULTING EXPRESSION OF ANTENNA GAIN IN SEAMCAT SIMULATIONS

Quite often antenna gain of various SRD products is loosely expressed by vendors and considered in compatibility studies in decibels, without explicit clarification as to whether it is an absolute gain relative to theoretical isotropic radiator (dBi) or gain relative to practical dipole (dBd). This distinction is however important, because in accordance with practice in ERC/REC 70-03 [11], the regulatory limits for power emission levels below 1 GHz are usually defined in "e.r.p." units. This power metric is traditionally defined as power effectively radiated from a half-way dipole.

Importantly for practical implementation of the SRD regulations such as ERC/REC 70-03, this definition of e.r.p. is also embedded in ETSI EN 300 220-1 [12] through combination of clauses 5.2.1 and 5.2.2, from where it becomes unambiguously clear that the antenna gain used for measuring e.r.p. of SRDs tested for compliance should be expressed related to dipole antenna.

Noting that the half-wave dipole has theoretical gain of 2.15 dBi, any ambiguity in definition of antenna gain in either dBi or dBd as used for simulations may introduce 2.15 dB error in definition of actual simulated emitted power. Therefore during studies of this report an additional investigation was carried out to clarify the antenna gain references and ensure that all SRD antennas in the report are uniformly defined in dBd and reflected in simulation settings accordingly. Because SEAMCAT does not have an option to distinguish e.r.p. emitted power and performs all calculations using e.i.r.p. reference. Therefore antenna gain used in SEAMCAT need to consider and possibly adjust for difference between dBd and dBi reference antennas in order to ensure that the modelled power level corresponds to relevant regulatory power limit (e.r.p. in the case of ERC/REC 70-03).

The following table summarises the antenna gains in dBd units for various SRDs considered in this report as well as their corresponding dBi values used in SEAMCAT simulations.

Table 50: SRD antenna gains used in the Report

SRD type	Nominal *Ga*	*Ga* used in SEAMCAT
HA/Non-specific	-5 dBd	-2.85 dBi
Sub-metering	-5 dBd	-2.85 dBi
Alarms	-5 dBd	-2.85 dBi
RFID	4 dBd	6 dBi
Cordless Audio	-5 dBd	-2.85 dBi
Hearing Aids	-23 dBd	-20.85 dBi
500 mW NAP	0 dBd	2.15 dBi
500 mW NN	0 dBd	2.15 dBi
500 mW TN	-2.15 dBd	0 dBi
WB SRD AP	0 dBd	2.15 dBi
WB SRD TN	-2.15 dBd	0 dBi

ANNEX 2: TIME DOMAIN CONSIDERATIONS

As noted previously, SEAMCAT does not model in detail the time behaviour aspects of the interaction between interferer and victim. The workaround of using the interferer DC as the Probability of Transmitting in SEAMCAT is not necessarily correct. One solution that has been proposed is the use of a correction factor to derive an adjusted Probability of Transmitting to be used as input parameter for the SEAMCAT simulations.

Section A2.1 is providing the mathematical formulas for the correction factor, Section A2.2 transmission times for different systems and Section A2.3 examples.

At the time of the preparation of this report there was no agreement on the correction factor for SEAMCAT simulations. Below are some concerns that remain unresolved:

- Any such method, the correction factor, and the subsequent results of simulation would be applicable to a very specific considered pair of interferer vs. victim device types, which may be dependent on proprietary (i.e. not specified in ETSI standards) technological solutions defining channel access and timing parameters of a specific product;
- the approach assumes that any short overlap in time destroys the packet or message, which is not necessarily the case. This is, however, the assumption made in ECC Report 181 [2], the IMST Study and most of the academic literature. SEAMCAT analyses whether the interfering packet is strong enough to destroy the victm packet and allows for that;
- the approach only looks at the DC aspect and does not account for real-time dynamics of interactions resulting from interference, i.e. LBT effects nor advanced channel access protocols such as CSMA-CA, packet acknowledgement/re-transmission, etc. In other words, it is not a complete solution to the problem of time domain analysis but a step along the way;
- in some cases, transmission times are dependent on the application and are different for every user: e.g. 802.11ah, max 27ms, but will seldom be used, min 1-2 ms; suitable values will need to be chosen; however, a way out could be to derive restrictions to the max transmission time from the simulation;
- The proposed corrections will always results in worse or equal results compared with SEAMCAT results using the existing workaround;
- With the correction we get a packet loss rate, therefore the criterion may need to be adjusted. E.g. if the acceptable interference probability is 5%, then the acceptable packet loss value could be 10%. The criterion will need to be assessed for each victim, but ideally we should already be doing that anyway. Interpretation of “probability of interference” is open to discussion;
- in some scenarios the correction factor results in very large changes; for example Cordless Audio as victim: large T_{vict}, small T_{int} with very small DC_{int}. This results in an interference probability of 1 with the analytical formula; but a low interference probability without it. Which result is correct? The current SEAMCAT results, not using the victims perspective, can be interpreted in a way that an interference prob of 1% could be seen as short annoying interruptions, e.g. 100ms every 10s. Is that harmful? Do we expect a 24h interference effect in that way, or is it more a time limited effect similar to an EMC interference, e.g. from a drilling machine use nearby? The scenario of digital interferer – analogue victim may be a case for special treatment, with or without the correction factor;
- a question was raised whether the connection of the analytical time domain approach with the current SEAMCAT tool is correct.

A2.1 USE OF PROBABILITY OF TRANSMITTING IN SEAMCAT

Suppose an interferer and a victim system are both on the same channel and within range of each other.

Section 4.2 of the IMST Study [19] states:

In case two users m and n are transmitting with random time offsets, the probability of a packet collision of user n depends on the two packet lengths Tx,m and Tx,n as well as the repetition interval Tint,m of user m.

$$P_{success}(n) = \max\left(0{,}1 - \frac{T_{Tx,m} + T_{Tx,n}}{T_{int,m}}\right)$$

Section 3.1 of ECC Report 181 states:

Suppose user 1 sends transmissions of duration T1, at a rate of F1. User 2 sends transmissions of T2 at F2, etc. Therefore their duty cycles are

$$\tau_1 = T_1 F_1 \; \tau_2 = T_2 F_2 \text{ etc}$$

The relative timings between users is random. User N sends a transmission of duration TN. The probability that this collides with a transmission from user m is

$$P_{COLL} = (T_m + T_N)F_n \text{ for } (T_m + T_N)F_n \le 1 \text{ otherwise } P_{COLL} = 1$$

It can be seen that the two formulae are the same, apart from a difference in notation.

For convenience, let us replace m and n or N with INT and VICT, then:

The probability that a transmission in the victim system suffers a collision with a transmission from the interferer is:

$$P_{COLL} = (T_{INT} + T_{VICT})F_{INT} \text{ for } (T_{INT} + T_{VICT})F_{INT} \le 1 \qquad \text{otherwise } P_{COLLV} = 1$$

SEAMCAT models the probability of interference on the assumption that the interferers and the victim are all 100% duty cycle systems. An accepted method of allowing for duty cycles of less than 100% is to use the Probability of Transmitting parameter, P_{TX}.

It is necessary, however, to choose the correct value for P_{TX}.

In the case above, with interferer and victim on the same channel and in range, a collision is certain if both devices are active at the same time and therefore SEAMCAT will model the probability of interference as:

$$P_{INT} = P_{TX}$$

Therefore, the value for the collision probability can be obtained by using a value for the interferer's probability of transmitting of:

$$P_{TX} = P_{COLL} = (T_{INT} + T_{VICT})F_{INT}$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT}$$

The above proposal is in agreement with:

- The IMST Study [19];
- ECC Report 181;
- ECC Report 234;

Subject to a maximum value for P_{TX} of 1.

The above approach assumes that any overlap in time is preventing reception of the entire packet, which is not always the case.

A2.2 TRANSMISSION DURATIONS

The table below lists some indicative example durations of a transmission from each type of device. It should be noted that transmission times are mostly dependent on the application and are changing dynamically. It should be noted that the values in the table are only examples.

Table 51: Examples for typical durations of a transmission from each type of device

Device	Information Source	Typical transmission (ms)	Comment
Wideband devices	TR 103 245 [8]	1-27 ms	802.11ah specifies 27.92 ms max, but will seldom be used, minimum 1-2 ms
Portable alarms	TR 103 056 [7] indicates 100 bits	35	Note 1
Fire/Smoke alarms	TR 103 056 indicates 100 bits	35	Note 1
Intruder Alarms	ECC Report 181 [2] Annex 7 TR 103 056 indicates 100 bits	25	Note 1
Social Alarms	STF 411 [46] TR 103 056 indicates 100 bits	35	Note 1
Smart Metering Terminals	EN 303 204 [44]	250	EN 303 204 specifies 400 ms max
Smart Metering Aps	EN 303 204	250	EN 303 204 specifies 400 ms max
Automotive	ECC Report 181 Annex 7	150	Range is 30 ms to 30 s.
Home Automation	ECC Report 181 Annex 7	50	Range is 10 ms to 36 s.
Lighting control	Measurements at GCD	8	Subset of HA requiring very low latency
Sub metering	ECC Report 181 Annex 7	25	Range is 25 ms to 1.2 s.
RFID		5	Time to read 1 tag
Cordless Audio		500 sec	Note 2
ALD		500 sec	Note 2
Non specific SRDs IoT Terminal		50	
Non specific SRDs		50	

Device	Information Source	Typical transmission (ms)	Comment
IoT APs			
Non specific SRDs Type B		50	
Non specific SRDs IoT Terminal		50	
GSM Uplink		25	
UMTS Uplink		25	
LTE Macro Uplink		1	

Notes:

There is a particular consideration here, especially for uni-directional alarms. A device may embed a number of packets into one transmission. When the device is considered as an interferer it is the total transmission duration that is important. When it is considered as a victim it is the duration of an embedded packet that is important. The value listed is the embedded packet.

These systems are effectively continuous operation. The value listed is based on the user's reasonable expectation of a period of uninterrupted use.

A2.3 EXAMPLES OF DERIVING THE P_{TX}

This section lists some examples of how to derive the Probability of Transmitting parameter in various cases.

It can be seen that the use of the correction factor sometimes results in small changes, sometimes in large ones.

A2.3.1 Case 1: Equal transmission durations

Interferer: Sends transmissions of 50 ms at average rate of 1 per 50 secs

DCINT = 0.1%

Victim: Uses packets of 50 ms duration

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.05 + .05) \times .01 = 0.002$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.05 + .05}{.05} \times .001 = 0.002$$

A2.3.2 Case 2a: Unequal durations – Long transmission by victim, short by interferer

Interferer: Sends transmissions of 25 ms at average rate of 1 per 25 secs

DCINT = 0.1%

Victim: Uses packets of 100 ms duration

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.025 + .1) \times .04 = 0.005$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.025 + .1}{.025} \times .001 = 0.005$$

A2.3.3 Case 2b: Unequal durations – Short transmission by victim, long by interferer

Interferer: Sends transmissions of 100 ms at average rate of 1 per 100 secs

DCINT = 0.1%

Victim: Uses packets of 25 ms duration

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.025 + .1) \times .01 = 0.00125$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.025 + .1}{.1} \times .001 = 0.00125$$

A2.3.4 Case 3: Almost certain collision

Interferer: Sends transmissions of 50 ms at average rate of 2 per sec

DCINT = 10%

Victim: Uses packets of 700 ms duration

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.05 + .7) \times 2 = 1.5$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.05 + .7}{.05} \times .1 = 1.5$$

In this case PTX should be set to 1 representing an almost certain collision if the two systems coincide in space and frequency.

Note: if the interfering transmissions are randomly timed then there is a tiny probability that a victim signal does get through, but it is negligible for practical purposes.

A2.3.5 Case 4: Audio transmission by victim

Interferer: Sends transmissions of 100 ms at average rate of 1 per 20 secs

DCINT = 0.5%

Victim: Listens continually. Let’s assume he listens to music tracks of 300 secs duration.

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.1 + 300) \times .05 = 15.005$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.1 + 300}{.1} \times .005 = 15.005$$

In this case PTX should be set to 1 representing an almost certain interruption of each music track if the two systems coincide in space and frequency.

A2.3.6 Case 5a: Concatenated packets sent by victim

Interferer: Sends transmissions of 200 ms at average rate of 1 per 20 secs

DCINT = 1%

Victim: An alarm system that sends transmissions of 200 ms, but consisting of a 50 ms packet repeated 4 times.

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.2 + .05) \times .05 = 0.0125$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.2 + .05}{.2} \times .01 = 0.0125$$

In this case the duration of the individual packets in the victim system is used rather than the overall transmission duration. This will lead to the Packet Loss Rate experienced by the victim. The probability that all 4 packets in a transmission will be lost is different and beyond the remit of this discussion.

A2.3.7 Case 5b: Concatenated packets sent by interferer

Interferer: An alarm system that sends transmissions of 200 ms, but consisting of a 50 ms packet repeated 4 times. The transmissions are sent at an average rate of 1 per 20 secs.

DCINT = 1%

Victim: Uses packets of 200 ms duration.

$$P_{TX} = (T_{INT} + T_{VICT})F_{INT} = (.2 + .2) \times .05 = 0.02$$

or

$$P_{TX} = \frac{T_{INT} + T_{VICT}}{T_{INT}} \cdot DC_{INT} = \frac{.2 + .2}{.2} \times .01 = 0.02$$

In this case the duration of whole transmission is used rather since this is what the victim will experience.

A2.4 EXAMPLES

The DC values used in this report could be corrected using the time domain parameters from Table 51. The corrected DC values could be then used as input for the SEAMCAT simulations. The below Table 52 shows examples of calculating P_{TX} with an alarm system as victim.

Table 52: Examples of time domain correction

Victim: Alarm						
	SM Term	SM AP	IoT Term	IoT AP	Automotive	HA
Ton_int, s	0.25	0.25	0.02	0.02	0.15	0.05
Ton_vict, s	0.03	0.03	0.03	0.03	0.03	0.03
DC_int, %	2.5	10	2.5	10	0.1	0.0025
Ptx	2.8	11.2	6.25	25	0.12	0.004

ANNEX 3: 802.11AH SPECTRUM EMISSION MASK LAB MEASUREMENTS

This Annex provides an emission mask of a real IEEE 802.11ah device [40] obtained in the lab, which might not be representative for all devices. The goal of this measurement was to understand which of the two spectrum emission masks adopted in this report (see ANNEX 1:) is more realistic in terms of modelling real device behaviour. The above-mentioned masks are depicted in the following Figure 50 for the case of 14 dBm max output power.

As it can be observed from the Figure 50, the in-band region is the same as the one described in ETSI TR 103 245 [8]. The two masks plotted in black and red differ in the spurious domain region. The black curve represents the IEEE mask, where the spurious level has a floor at -40 dBr, i.e. 14 dBm/MHz - 40 dBr=-26 dBm/MHz as shown in the Figure 50. The red curve shows instead the case when an absolute value of -54 dBm/100 kHz at 2.5 MHz offset to the carrier frequency (-44 dBm/1MHz in the Figure 50).

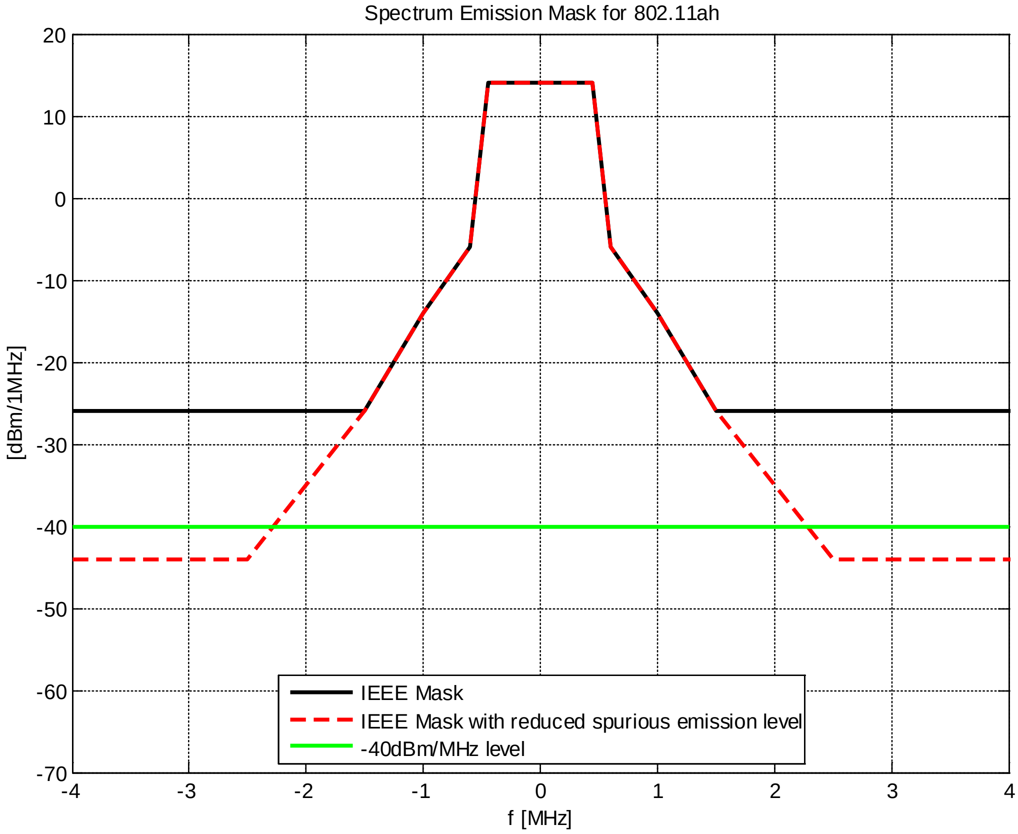


Figure 50: Spectrum emission masks adopted in this Report (red and black curves)

Since these two masks are used to determine the power leakage into adjacent channels, we want to get a better understanding of what would be the emission of a real device transmitting IEEE 802.11ah waveform in 900 MHz. In the next sub-section we will present the emission level obtained by testing a power amplifier driven by IEEE 802.11ah waveform operating in 900 MHz band.

A3.1.1 Lab Measurements

Tests were performed in a lab under the following conditions:

- Power Amplifier (PA) only test (no RFIC and Front End);
- Carrier frequency: 915 MHz;
- PA driven to 17.5 dBm to compensate 3.5 dB front end loss, 14 dBm would be available at antenna;

- PA driven using 11ah waveforms;
- Lab equipment: Agilent E4438C with Agilent PXA.

Results of the lab measurement are reported in the following Figure 51, which shows the emission mask observed with spectrum analyser. In order to correctly interpret the results, we would like to point out the following observations:

- Resolution bandwidth is 91 kHz;
- Yellow plot represents the emission considering PA driven @17.5dBm. This means that the real output power at the antenna would be attenuated by the front end loss. Assuming that this loss is mainly due to insertion loss, we expect attenuation flat in the frequency domain. This means that the antenna emission can be obtained by shifting down the yellow curve by a factor of 3.5 dB (the estimated front end loss);
- Red line represents the -36 dBm/100kHz limit (note that in picture this value is slightly scaled down due to the different resolution bandwidth, i.e. resulting value is -36 dBm/100kHz + 10*log10(91/100) ~-36.4 dBm/91kHz;
- Magenta line represents the -40dBm/1MHz limit (note that in picture this value is slightly scaled down due to the different resolution bandwidth, i.e. resulting value is -40dBm/1000kHz + 10*log10(91/1000) ~-50.4dBm/91kHz;
- Green line represents the -54 dBm/100KHz limit (note that in picture this value is slightly scaled down due to the different resolution bandwidth, i.e. resulting value is -54 dBm/100kHz + 10*log10(91/100) ~ -54.4 dBm/91kHz;
- Blue lines represent ±1.5MHz and ±2.5MHz offset with respect to the carrier frequency.

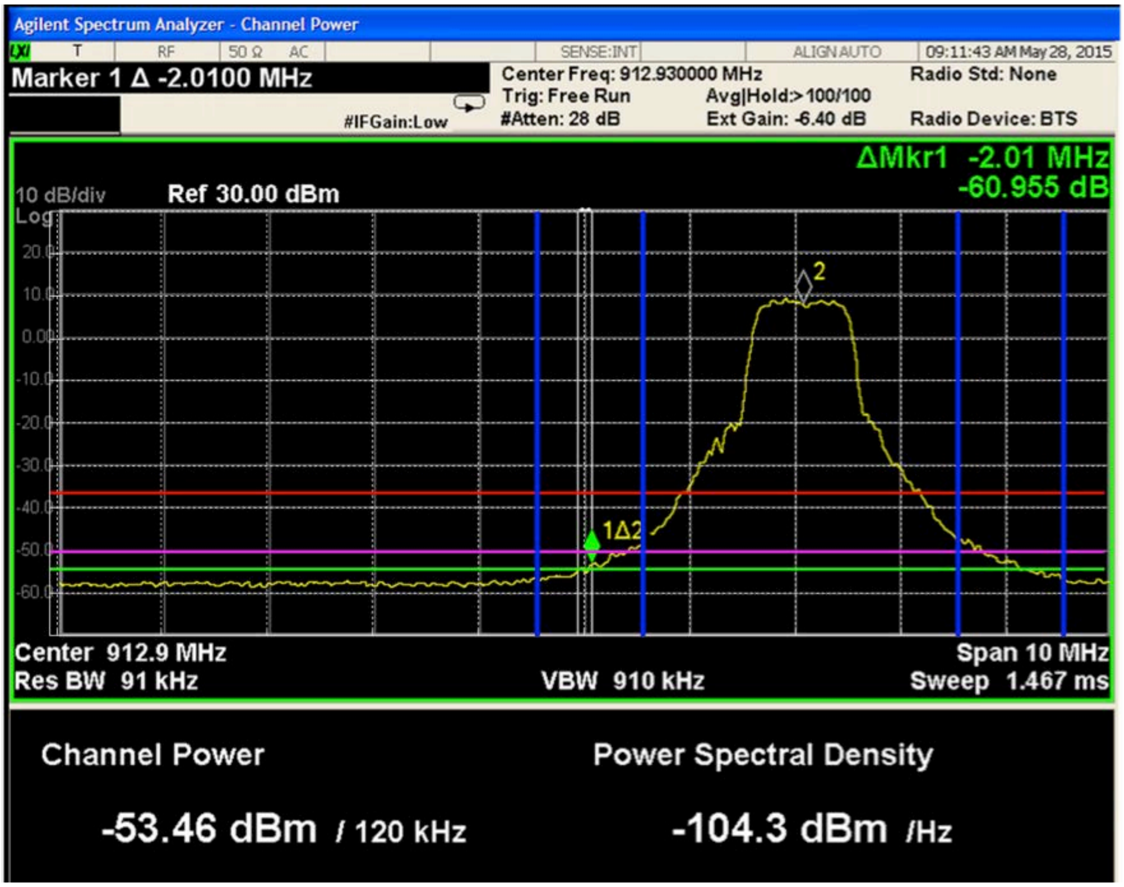


Figure 51: Spectrum emission of device under testing

By analysing the data the following observations can be made:

- @±1.5MHz offset with respect to the carrier frequency a value of -40 dBm/MHz can be reached (note that emission at antenna will be 3.5 dB lower compared to the yellow curve);
- @±2.5MHz offset with respect to the carrier frequency a value of -54 dBm/100kHz can be reached;
- The emission floor is below the -54 dBm/100kHz value.

Of course, when analysing this data several factors need to be taken into account:

- Test have been obtained with only one PA vendor, other factors such as phase noise, baseband noise/linearity, and digital baseband processing can contribute to the final emission which cannot be characterised here;
- PA from different vendors can behave differently;
- PA from the same vendor can have statistical variation in terms of performance;
- Behaviour of same devices can vary depending on ambient temperature.

However, based on the above information the following will be concluded for this report:

- The emission floor of -54 dBm/100kHz can be achieved by 802.11ah devices operating @900MHz;
- The emission mask based on ETSI TR 103 245 [8] specification is pessimistic. This implies that results obtained through that mask must be interpreted as a worst case scenario;
- It is not possible to define a specific mask based on one set of measurement results because of the intra-vendor and inter-vendors performance variation. However, the data provided here gave a strong indication of the capability of 802.11ah devices operating in 900 MHz band.

ANNEX 4: SIMULATION RADII AND NUMBER OF TRANSMITTERS USED IN THE STUDIES

It is important for SEAMCAT simulations to place interfering devices within certain suitable distances vis-à-vis victim devices. These maximum distances are accordingly used to set "simulation radius" parameters in SEAMCAT scenarios, depending on specific set of victim and interferer.

It had been a long accepted practice (see e.g. ECC Report 200 [3]) to define simulation radiuses through use of Minimum Coupling Loss (MCL) method to calculate maximum distance where given interfering device could still have impact on a given victim device. Based on derived maximum impact range, it then possible to calculate size of the area where interfering transmitters are to be dropped in simulations and their corresponding number as function of estimated device density.

This annex therefore contains a collection of MCL tables detailing calculation of impact range, and hence SEAMCAT simulation radii as well as number of interfering transmitters to be simulated, for different pairs of interferers and victims. The tables are structured in self-explanatory manner and their number corresponds to the number of various interferer-victim combinations as considered in simulations reported in Chapters 6 and 7 of this report.

Note that the path loss is estimated using FSL model with propagation exponent of 3.5, which corresponds to propagation in dense urban conditions.

Table 53: Interferer: HA

Interferer	**Home Automation or Non-specific SRD**									
Transmitter power, dBm	14									
Antenna gain, dBi	-2.85									
Interferer's BW, kHz	350									
Interferer's NFD, dB	30									
	Representative victim system:									
	Sub-metering		**Alarms**		**RFID**		**Cordless Audio**		**Hearing Aids**	
Operating frequency, GHz	0.868		0.869		0.865		0.864		0.864	
Receiver bandwidth, kHz	350		25		200		200		600	
Receiver noise figure, dB	5		7		7		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-113**		**-123**		**-114**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-85		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		17		17	
Imax, dBm	**-102.0**		**-110.0**		**-87.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**0**		**-11**		**-2**		**-2**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**110.3**	**80.3**	**106.8**	**76.8**	**101.7**	**71.7**	**109.9**	**79.9**	**91.3**	**61.3**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**181**	**25**	**144**	**20**	**103**	**14**	**177**	**25**	**52**	**7**
Impact area, sq. km	0.103068826	0.001989947	0.065278234	0.001260325	0.033460952	0.00064603	0.097909923	0.001890345	0.008505613	0.000164218
Density medium estimate, dev/sq.km	800									
Density high estimate, dev/sq.km	1500									
Active TRx in impact area: medium estir	**82**	**2**	**52**	**1**	**27**	**1**	**78**	**2**	**7**	**0**
Active TRx in impact area: high estimate	**155**	**3**	**98**	**2**	**50**	**1**	**147**	**3**	**13**	**0**

Table 54: Interferer: Sub-metering SRDs

Interferer	Sub-metering									
Transmitter power, dBm	14									
Antenna gain, dBi	-2.85									
Interferer's BW, kHz	300									
Interferer's NFD, dB	30									
	Representative victim system:									
	HA		Alarms		RFID		Cordless Audio		Hearing Aids	
Operating frequency, GHz	0.868		0.869		0.865		0.864		0.864	
Receiver bandwidth, kHz	350		25		200		200		600	
Receiver noise figure, dB	5		7		7		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-113**		**-123**		**-114**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-85		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		17		17	
Imax, dBm	**-102.0**		**-110.0**		**-87.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**0**		**-11**		**-2**		**-2**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**110.3**	**80.3**	**107.5**	**77.5**	**102.4**	**72.4**	**110.5**	**80.5**	**91.3**	**61.3**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**181**	**25**	**151**	**21**	**108**	**15**	**184**	**26**	**52**	**7**
Impact area, sq. km	0.103068826	0.001989947	0.071289194	0.001376379	0.036542108	0.000705518	0.10692568	0.002064412	0.008505613	0.000164218
Density medium estimate, dev/sq.km	25000									
Density high estimate, dev/sq.km	50000									
Active TRx in impact area: medium estir	**2577**	**50**	**1782**	**34**	**914**	**18**	**2673**	**52**	**213**	**4**
Active TRx in impact area: high estimate	**5153**	**99**	**3564**	**69**	**1827**	**35**	**5346**	**103**	**425**	**8**

Table 55: Interferer: Alarm SRDs

Interferer	Alarms									
Transmitter power, dBm	14									
Antenna gain, dBi	-2.85									
Interferer's BW, kHz	25									
Interferer's NFD, dB	30									
	Representative victim system:									
	Sub-metering		HA		RFID		Cordless Audio		Hearing Aids	
Operating frequency, GHz	0.868		0.868		0.865		0.864		0.864	
Receiver bandwidth, kHz	300		350		200		200		600	
Receiver noise figure, dB	5		5		7		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-114**		**-113**		**-114**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-104		-85		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		17		17	
Imax, dBm	**-101.9**		**-102.0**		**-87.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**0**		**0**		**0**		**0**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**110.2**	**80.2**	**110.3**	**80.3**	**104.2**	**74.2**	**112.3**	**82.3**	**91.3**	**61.3**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**180**	**25**	**181**	**25**	**121**	**17**	**207**	**29**	**52**	**7**
Impact area, sq. km	0.102274706	0.001974615	0.103068826	0.001989947	0.04606989	0.00088947	0.134804874	0.002602675	0.008505613	0.000164218
Density medium estimate, dev/sq.km	1000									
Density high estimate, dev/sq.km	3000									
Active TRx in impact area: medium estir	**102**	**2**	**103**	**2**	**46**	**1**	**135**	**3**	**9**	**0**
Active TRx in impact area: high estimate	**307**	**6**	**309**	**6**	**138**	**3**	**404**	**8**	**26**	**0**

Table 56: Interferer: RFIDs

Interferer	RFID									
Transmitter power, dBm	20									
Antenna gain, dBi	6									
Interferer's BW, kHz	200									
Interferer's NFD, dB	30									
	Representative victim system:									
	Sub-metering		Alarms		HA		Cordless Audio		Hearing Aids	
Operating frequency, GHz	0.868		0.869		0.863		0.864		0.864	
Receiver bandwidth, kHz	300		25		350		200		600	
Receiver noise figure, dB	5		7		5		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		-2.85		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-114**		**-123**		**-113**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-104		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		8		17		17	
Imax, dBm	**-101.9**		**-110.0**		**-102.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**0**		**-9**		**0**		**0**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**125.1**	**95.1**	**124.1**	**94.1**	**125.2**	**95.2**	**127.2**	**97.2**	**106.2**	**76.2**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**479**	**67**	**449**	**62**	**483**	**67**	**550**	**76**	**138**	**19**
Impact range limited to maximum 300 m	**300**	**67**	**300**	**62**	**300**	**67**	**300**	**76**	**138**	**19**
Impact area, sq. km	0.282743339	0.013933299	0.282743339	0.012244273	0.282743339	0.014134498	0.282743339	0.018365016	0.060017379	0.001158754
Density medium estimate, dev/sq.km	50									
Density high estimate, dev/sq.km	480									
Active TRx in impact area: medium estir	**14**	**1**	**14**	**1**	**14**	**1**	**14**	**1**	**3**	**0**
Active TRx in impact area: high estimate	**136**	**7**	**136**	**6**	**136**	**7**	**136**	**9**	**29**	**1**

Table 57: Interferer: Cordless Audio SRDs

Interferer	Cordless Audio									
Transmitter power, dBm	10									
Antenna gain, dBi	-2.85									
Interferer's BW, kHz	200									
Interferer's NFD, dB	30									
	Representative victim system:									
	Sub-metering		Alarms		RFID		HA		Hearing Aids	
Operating frequency, GHz	0.868		0.869		0.865		0.868		0.864	
Receiver bandwidth, kHz	300		25		200		350		600	
Receiver noise figure, dB	5		7		7		5		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-114**		**-123**		**-114**		**-113**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-85		-104		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		8		17	
Imax, dBm	**-101.9**		**-110.0**		**-87.0**		**-102.0**		**-101.0**	
BW correction factor, dB	**0**		**-9**		**0**		**0**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**106.2**	**76.2**	**105.3**	**75.3**	**100.2**	**70.2**	**106.3**	**76.3**	**87.3**	**57.3**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**139**	**19**	**130**	**18**	**93**	**13**	**139**	**19**	**40**	**6**
Impact area, sq. km	0.060422239	0.001166571	0.053097717	0.001025156	0.027217344	0.000525485	0.060891392	0.001175629	0.005024978	9.70171E-05
Density medium estimate, dev/sq.km	40									
Density high estimate, dev/sq.km	100									
Active TRx in impact area: medium estir	**2**	**0**	**2**	**0**	**1**	**0**	**2**	**0**	**0**	**0**
Active TRx in impact area: high estimate	**6**	**0**	**5**	**0**	**3**	**0**	**6**	**0**	**1**	**0**

Table 58: Interferer: "Internet of Things" WBN SRDs (e.g. IEEE 802.11ah [40])

Interferer	IoT WB SRD AP									
Transmitter power, dBm	14									
Antenna gain, dBi (for AP)	2.15									
Interferer's BW, kHz	1000									
Interferer's NFD, dB	30									
	Representative victim system:									
	HA		Alarms		RFID		Cordless Audio		Hearing Aids	
Operating frequency, GHz	0.868		0.869		0.865		0.864		0.864	
Receiver bandwidth, kHz	350		25		200		200		600	
Receiver noise figure, dB	5		7		7		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-113**		**-123**		**-114**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-85		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		17		17	
Imax, dBm	**-102.0**		**-110.0**		**-87.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**-5**		**-16**		**-7**		**-7**		**-2**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**110.7**	**80.7**	**107.3**	**77.3**	**102.2**	**72.2**	**110.3**	**80.3**	**94.1**	**64.1**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**186**	**26**	**148**	**21**	**106**	**15**	**182**	**25**	**62**	**9**
Impact area, sq. km	0.109221735	0.002108742	0.069175154	0.001335563	0.035458473	0.000684596	0.10375486	0.002003193	0.012264481	0.00023679
Density Access Points, dev/sq.km	50									
Density Terminal Stations, dev/sq.km	1000									
Active TRx in impact area: APs	**5**	**0**	**3**	**0**	**2**	**0**	**5**	**0**	**1**	**0**
Active TRx in impact area: TSs	**82**	**2**	**52**	**1**	**27**	**1**	**78**	**2**	**9**	**0**

Table 59: Interferer: "Smart Metering" NBN SRDs

Interferer	500 mW SRD NAP/NN									
Transmitter power, dBm	27									
Antenna gain, dBi (for NAP/NN)	2.15									
Interferer's BW, kHz	200									
Interferer's NFD, dB	30									
	Representative victim system:									
	HA		Alarms		RFID		Cordless Audio		Hearing Aids	
Operating frequency, GHz	0.868		0.869		0.865		0.864		0.864	
Receiver bandwidth, kHz	350		25		200		200		600	
Receiver noise figure, dB	5		7		7		7		10	
Receiver antenna gain, dBi	-2.85		-2.85		6		-2.85		-20.85	
N = kTBF, receiver thermal noise, dBm	**-113**		**-123**		**-114**		**-114**		**-106**	
Declared receiver sensitivity, dBm	-104		-112		-85		-97		-94	
Wanted receive signal margin, dB	**10**		**10**		**10**		**10**		**10**	
C/I requirement, dB	8		8		12		17		17	
Imax, dBm	**-102.0**		**-110.0**		**-87.0**		**-104.0**		**-101.0**	
BW correction factor, dB	**0**		**-9**		**0**		**0**		**0**	
Coexistence case:	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**	**Co-channel**	**Adjacent**
Minimum path loss, dB	**128.3**	**98.3**	**127.3**	**97.3**	**122.2**	**92.2**	**130.3**	**100.3**	**109.3**	**79.3**
Propagation exponent:	3.5									
Impact range (FSL with above exp), m	**592**	**82**	**553**	**77**	**396**	**55**	**677**	**94**	**170**	**24**
Impact range limited to max 300 m	**300**	**82**	**300**	**77**	**300**	**55**	**300**	**94**	**170**	**24**
Impact area, sq. km	0.282743339	0.021252648	0.282743339	0.018532457	0.282743339	0.009499547	0.282743339	0.027796576	0.090839979	0.001753845
Density Network Access Points, dev/sq.km	10									
Density Network Nodes, dev/sq.km	90									
Density Terminal Nodes, dev/sq.km	1900									
Active TRx in impact area: NAPs	**3**	**0**	**3**	**0**	**3**	**0**	**3**	**0**	**1**	**0**
Active TRx in impact area: NNs	**25**	**2**	**25**	**2**	**25**	**1**	**25**	**3**	**8**	**0**
Active TRx in impact area: TNs	**537**	**30**	**537**	**27**	**537**	**14**	**537**	**40**	**130**	**3**

Table 60: Interferer: NBN and WBN

Victim system	LoRa NAP	LoRa NAP	LoRa NAP	LoRa NAP	LoRa NAP
Operating frequency, MHz	868	868	868	868	868
Receiver bandwidth, kHz	125	125	125	125	125
Receiver antenna gain, dBi	5	5	5	5	5
Declared sensitivity, dBm	-137	-137	-137	-137	-137
Wanted receive signal margin, dB	10	10	10	10	10
C/I requirement, dB	-14	-14	-14	-14	-14
Imax, dBm	-113	-113	-113	-113	-113
Interferer	**500 mW NAP**	**500 mW NN**	**500 mW TN**	**WB AP**	**WB TN**
Transmitter power, dBm	27	27	27	14	14
Antenna gain, dBi	2,15	2,15	0	2,15	0
Interfer's BW, kHz	200	200	200	1000	1000
BW correction factor, dB	-2,041199827	-2,041199827	-2,041199827	-9,03089987	-9,03089987
Minimum Path Loss, dB	145,1088002	145,1088002	142,9588002	125,1191001	122,9691001
n (FSL exponent)	3,5	3,5	3,5	3,5	3,5
Impact Range (FSL with exp =3,5), m	1800,458101	1800,458101	1562,983696	483,3355421	419,5851998
Density High estimate,dev/sq km	10	90	1900	50	1000
Active TRx in impact area, High estimate	101	916	14581	36	553
Density Medium estimate,dev/sq km	8	46	952	25	500
Active TRx in impact area, High estimate	81	468	7306	18	276

ANNEX 5: T_{ON}/T_{OFF} PATTERN

This annex is a collection of material related to Ton/Toff pattern as polite channel access.

A5.1 ECC REPORT 37

The conclusion of ECC Report 37 [1] contains a table of feasible implementations (Table 8.1 of ECC Report 37). Each entry contains the comment:

If LBT timing is used, the timing shall be determined within ETSI standards1):

- Examples for such values are:
  - TX on-time= 500 ms;
  - TX off-time= 15 ms.

Recommendations for Max Ton and Min Toff are only made for the case where LBT is used.

The 15 ms off time appears to be a nominal value to allow another waiting device to take the channel in turn.

The 500 ms on time derives from the discussion in Annex J of ECC Report 37, which is an example generic scheme for dynamic channel allocation. In this example the 500 ms on time with short breaks is designed so that in the uncongested case a single user can operate at a high duty cycle, and in the congested case use of the channel is shared equitably between users.

The example scheme caters for both short and long messages and the 500 ms on time is not related to any particular message length or traffic requirement.

Following Report 37 a broadly similar access scheme (LBT+AFA) was introduced in the 863-870 MHz SRD band.

A5.2 ECC REPORT 181

ECC Report 181 [2] is a wide-ranging study of possible techniques for intra-SRD sharing. Of particular importance in the current context is section 3, Annexes 4 and 5. In section 3, the effects of techniques such as DC limits and Listen Before Talk (LBT) are analysed. Annex 5 extends this analysis to the case of multiple devices on a channel.

ANNEX 4: 4 presents the results of a computer model based on the equations in ANNEX 5:. It models the success rate of attempting to get a message through in a certain time on a shared channel, and in particular examines the effect of applying rules such as short term DC, Max Ton and Min Toff.

Figure 52 (reproduced below) in ECC Report 181 is one result from this model.

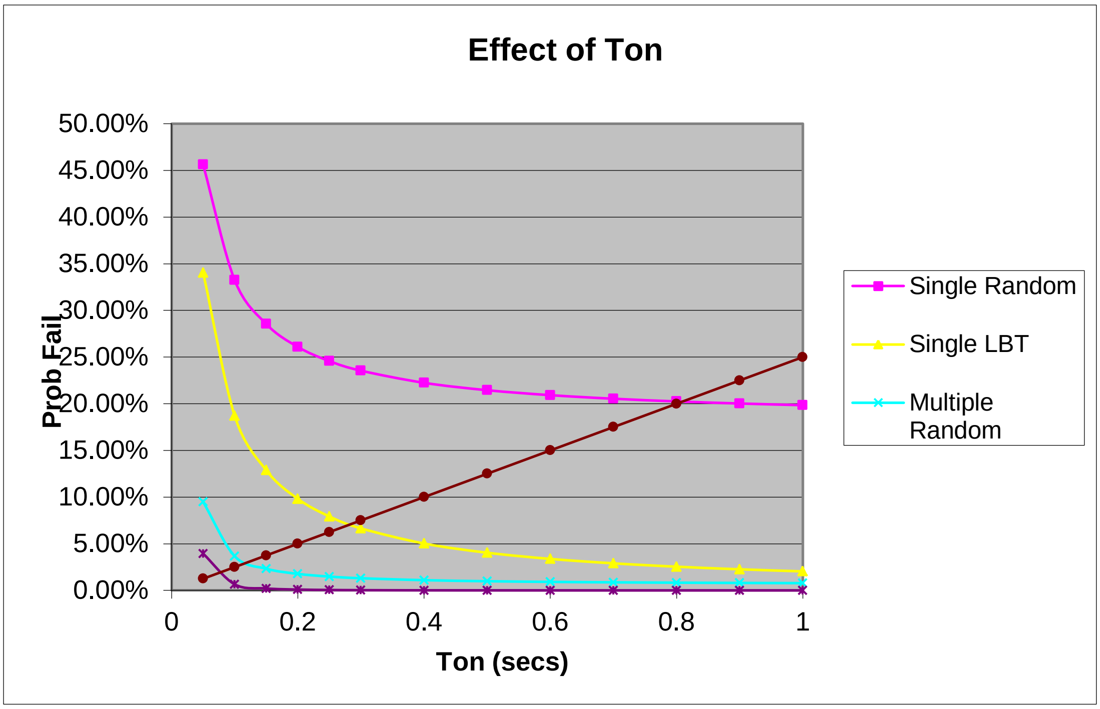


Figure 52: Effect of Ton

This is a case where the wanted message or packet is 50 ms long and the channel is moderately congested. A Min Toff of 200 ms is applied and the chart shows the effect of applying a Max Ton limit to the competing traffic

As discussed in ECC Report 181 [2], if Max Ton is set too low there is a sharp rise in the collision rate. This is because the traffic is broken up into a large number of small packets. On the other hand, if it is set too high then the latency scales up in proportion. The straight line in the chart is the expected average LBT wait time; the maximum wait time is equal to or greater than Max Ton.

There is not an obvious optimum; it depends on the relative importance of latency and success probability. But Max Ton should clearly not be less than 2 times the packet length (0.1 s in this example) and there are diminishing returns in setting it above 6 to 8 times the packet length (0.3 to 0.4 s).

A5.3 IMST REPORT

The IMST report contains extensive study and modelling of a variety of systems and spectrum sharing methods. In section 7 (Conclusions and Recommendations) it recommends:

For DC based random access unidirectional links and for systems using bi-directional links with acknowledgement procedure:

Define maximum Ton and minimum Toff time.

and

In general, it is recommended that a maximum communication time (TON) followed by a quiet time period (TOFF) time is defined to make sure that other users can intervene and start their own transmission during the quiet time period. The maximum TON time should consider the latency requirements of SRD applications.

Ton shall be smaller than 50 ms.

It is not clear how the 50 ms value is derived, or whether it is based on latency or traffic effects. It should be noted, though, that the simulations of complex situations in the report consistently use packet lengths of 20 ms. Thus the recommendation could be interpreted as 2.5 times the packet length.

A5.4 ETSI TR 103 056

Section 8.4.1 of ETSI TR 103 056 [7] is titled “Proposal for dedicated frequency ranges for alarm and social alarms/applications”. This proposal gives an indicative DC for some sub-bands of:

- Max Transmitter On Time / per single transmission: 700 ms;
- Min Transmitter Off Time between two transmissions: 400 ms;
- Sum of Ton times / minute = DC/min 2,5%/min;
- Sum of Ton times / hour = DC/hr: 0.1%/hr.

In the final version, these values are in square brackets and note continues with the statement that the Duty Cycle/Low Duty Cycle requirement is to be further studied.

TR 103 056 does not analyse the effects of Max Ton and Min Toff limits and does not state how the indicative values were derived.

A5.5 ETSI STF 411

ETSI STF 411[46] concluded that the definition of DC measured over 1 hour should be augmented by means to control the short term timing behaviour of devices. It considered applying DC limits over 1 minute or 1 second, but concluded that Max Ton and Min Toff limits were more effective. They allowed sharing but also allowed high short term DC where needed.

Practical tests

Results of tests conducted on various SRDs to measure the effects of applying a short term DC limit and/or Max Ton and Min Toff limits are summarised below.

Two of systems under test were social alarms from major manufacturers. It is not reported in the document, but these were similar in operation. They were both 25 kHz channel systems. The transmitters send frames of 800 to 1200 ms length, but these frames consist of packets of length around 30 to 40 ms repeated many times. The receiver only has to receive a small number of packets to register the message.

The following figure shows results of a test on one of these social alarms, showing the effect of applying a Max Ton limit to the other signal on the channel (the interference).

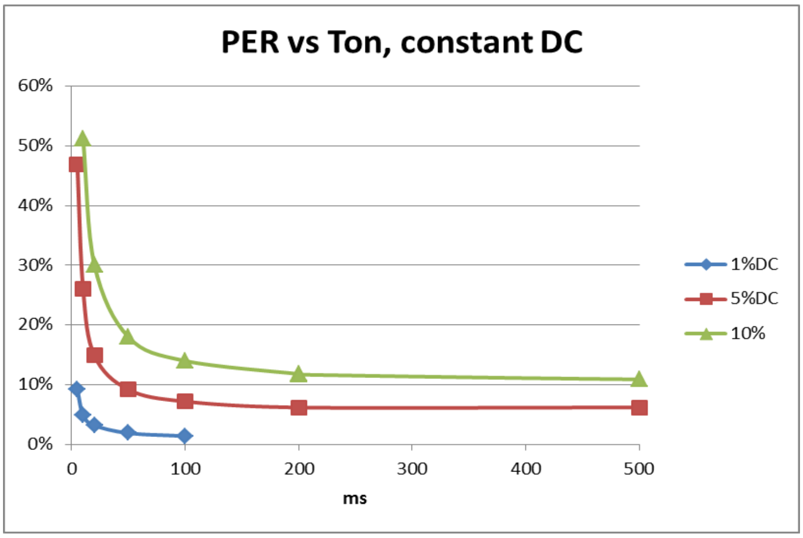


Figure 53: Packet Error Ratio as function of Ton at constant DC

This practical result is remarkably similar to the theoretical one in ECC Report 181 [2], but for this scenario it would suggest a suitable range for Max Ton of 70 to 200 ms, or 2 to 6 times the packet length.

Tests were also done to find the effect of Min Toff, and the results for the social alarms are shown below.

Social Alarm 1 869.2125 MHz

Radiated measurement approx 5 m range

Interferer is co-channel radiated signal strong enough to disrupt completely if 100% duty cycl

Interferer operated at Ton and Toff in table below.

Radio button activated 3 times and number of times received is recorded

		Ton (ms)				
	Score/3	10	20	40	80	160
Toff (ms)	10	0	0	0	0	0
	20	0	0	0	0	0
	30	0	0	0	0	0
	35	1	1	1	0	1
	40	3	3	3	3	3
	80	3	2	3	2	3
	160	3	3	3	3	3

Social Alarm 2 869.2125 MHz

Conducted measurement, with signal set to 6 dB above minimum

Interferer is co-channel signal 10 dB above wanted signal

Interferer operated at Ton and Toff in table below.

Packet Error Rate over 1000 packets recorded

		Ton (ms)				
	PER	10	20	40	80	160
Toff (ms)	10	0.999	1.000	1.000	1.000	1.000
	20	1.000	1.000	1.000	1.000	1.000
	30	0.991	0.993	0.993	0.993	1.000
	35	0.971	0.977	0.976	0.982	0.988
	40	0.966	0.943	0.963	0.968	0.994
	80	0.570	0.600	0.678	0.760	0.839
	160	0.284	0.368	0.396	0.503	0.626

Note: 1.000 or 100% means no packets received during test.

In test with 10 ms on, 10 ms off, system reported 1 packet received

Figure 54: Summary of results of testing social alarms for effect of Min Toff

In these results, the effect of T_{off} is much more important than T_{on}. The tables all show a weak effect as T_{on} varies but a very strong dependence on T_{off}, with a noticeable threshold effect.

The dominant effect is the relation between T_{off} and the packet length. If T_{off} is too short, no packets are received, but as soon as T_{off} exceeds the packet length there is a probability of one getting through. There is a noticeable improvement when T_{off} reaches 2 times the packet length. That PER continues to fall as T_{off} increases, but in this experiment that is partly because increasing T_{off} also decreases the duty cycle.

This experiment does not indicate an optimum value for T_{off}, but it does indicate that it should be a minimum of 2 times the packet length.

Choosing T_{on} and T_{off}

Some of the above studies are of cases where all devices on the channel are using LBT and therefore concentrate on the effect of Max T_{on} on the grounds that Min T_{off} needs only to be a small value.

The ETSI STF 411 [46] results show that Min T_{off} is important when not all devices are using LBT.

The above results indicate that both Max T_{on} and Min T_{off} should be a minimum of 2 times the shortest practical packet length. They should not be too long as this affects latency. The upper limit is less critical but there appears to be limited benefit in going beyond 6 to 8 times the packet length.

Where not all devices are using LBT, there is a clear benefit to setting Max T_{on} and Min T_{off} equal to each other. This then allows one system (using LBT) to fit its operation into the gaps left by another system.

TR 103 056 [7] section 7.2.1 7.2.1 states that an alarm system transmission is s generally packaged into a message of 100 bits. The duration of such a packet at various data rates is shown in the following Table 61.

Table 61: Packet duration as function of data rate

Data Rate kbps	Duration of 100 bit packet ms
1.2	83.3
2.4	41.7
9.6	10.4
10	10
20	5
50	2
100	1

In wider channels it is possible to use shorter packets (ETSI STF 411 [46] measured packet lengths of 8 ms in some home automation systems). One idea is that T_{on} and T_{off} could be scaled according to the bandwidth. This, however, leads to difficulties where systems of different bandwidths share a band.

A value of 50 ms, as proposed by IMST, would be greater than 2 times the packet length for all except the two slowest data rates listed, while also not being likely to cause latency effects.

There is a way of accommodating both those who want to do a rapid fire interchange, eg. with 10 ms packets, and those who want longer transmissions. This is to set the T_{on} and T_{off} limits relatively long, eg. 200 ms but to allow subdivision of the T_{on} period.

The definitions in TS 103 060 [47] allow for the T_{on} period to be split up into shorter transmissions. All that is required is that a Toff is performed at the right time.

Eg., with T_{on}=200 ms, T_{off}=200 ms, a device could do rapid fire for 200 ms, then change channel and continue. It would only take 2 channels for “continuous” operation.

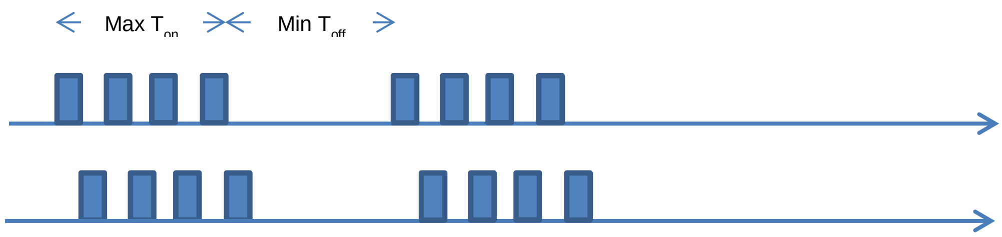


Figure 55: Example of 2 devices communicating with short packets

ANNEX 6: FURTHER CONSIDERATIONS THAT MAY WORSEN OR IMPROVE THE COEXISTENCE IN ADJACENT BAND STUDIES WITH LTE

The following considerations may worsen or improve the adjacent band coexistence compared with results of relevant simulations presented in sections 5.1, 6.1 and 7.1 of this report.

Table 62: Considerations that may have impact on analysed adjacent band coexistence

Issues	Considerations that may worsen the coexistence further	Considerations that may improve the coexistence further
LTE	It should be noted that the OFDMA setting used for setting 2 assumes 3 UEs, whereas 1 UE was assumed in both setting 1 and ECC Report 200 [3]. Issues related to having more than 1 UE for OFDMA systems in the current version of SEAMCAT has been reported. Assuming 3 UEs may lower the probability of interference by ~50% compared to having 1 UE in case of Worst case mask and ~10-60% in case of reduced emissions mask.	The used receiver masks do not include the filtering effect of the duplex filter. Further mitigation effects are expected due to better blocking characteristics of public cellular networks' BS in real systems compared to the assumed requirements from the standard.
Tx power and antenna		All SRD devices were assumed to transmit with max allowed Tx power and antenna gain, which is another worst case assumption. For instance, many of the sensors do not have power amplifier and have very inefficient antennas, meaning that achievable maximum transmit power would be less than the allowed regulatory limit.
DC assumption		The DC for all simulated devices was set to the maximum allowed limit, which is absolute worst case assumption as it may be otherwise assumed that in real life not all devices would be reaching their DC limit for most of the time.
SRD device Density assumptions	Statistics on the number of households per square kilometre used figures up to ~5000 and 11000 households per square kilometre respectively for inner London and Paris city. These figures together with the assumptions made in this report on the number of devices per square kilometre could be translated into number of devices per household to provide an indication on the level of the assumed device density in this report, which may be underestimated for dense cities even in the densest case. The LBT/CSMA mechanism employed by WBN SRD devices may increase the traffic due to the additional signalling (e.g. RTS-CTS, TWT, RAW, etc…), which in itself may increase the risk of channel collisions.	Results presented in this report do not take into account the mitigating effect of LBT/CSMA mechanism employed by WBN SRD devices. As described in Chapter 3, due to reduced number of simultaneous co-channel transmissions, the amount of interference created by WBN SRD nodes may be further reduced when CSMA mechanism are taken into consideration.

ANNEX 7: CONSIDERATIONS THAT MAY WORSEN OR IMPROVE THE INTRA-BAND COEXISTENCE STUDY RESULTS

The following considerations may worsen or improve the intra-SRD coexistence compared with simulation results presented in the main body of this report.

SEAMCAT results are based on assumptions of random distributions in time and space, and do not take into account any intelligent mitigation behaviour by either interferer or victim.

Table 63: Considerations that may have impact on analysed intra-SRD coexistence

Effect	Considerations that may worsen the results	Considerations that may improve the results
Devices are not randomly distributed in space Devices tend to be indoors more than outdoors. This creates patterns in the distribution on the scale of 10s of m and 100s of m	Local concentration in some “hot spots” may be higher than the average	If interferer and victim are in different rooms or indoor vs outdoor, then there is an additional mitigation of interference due to wall loss
Some devices are concentrated in particular locations For instance, RFID in warehouses; social alarms in homes for elderly or infirm people. This creates patterns in the distribution on the scale of kms and 10s of kms	Local concentration in some “hot spots” may be higher than the average	If interferer and victim are in different locations, then probability of collisions trying access the same channel decreases due to physical separation
Activity periods are not random Devices associated with human behaviour will vary their activity levels throughout the day. They can be expected to show both a di-urnal and a “rush hour” effect	If interferer and victim have the same rush hour, then probability of coincidence increases	If interferer and victim have different rush hours, then probability of coincidence decreases
Transmissions in the active periods are not random in time Packets tend to be clustered in groups. It is common for a uni-directional device to send a series of packets instead of just one. Bi-directional devices may initiate a transaction composed of a series of packets	There is a conditional probability effect. If one packet suffers interference, the probability that the next one suffers is much higher than the probability for the random case.	
Use of LBT/CSMA	The use of LBT/CSMA is unlikely in itself to increase interference probabilities; however: - It displaces transmissions in time, so it may create correlation effects. - There is a risk that benefits may be assumed that are not realised in practice.	LBT/CSMA can provide reductions in packet collision probability, but it can be difficult to quantify the effects, especially for dissimilar systems
Variations in system requirements: the commonly used criterion of 5% interference probability may not be	Audio devices require a period of uninterrupted operation, however this may be mitigated by using	Some systems could tolerate higher degree of interference (especially

Effect	Considerations that may worsen the results	Considerations that may improve the results
appropriate for all systems	digitally compressed and packetised transmission	speaking of bursty interference) thanks to non-real time operation with relaxed latency requirements that allow re-transmission of lost packets
Use of higher level features: some systems are designed to deal with a certain packet loss rate, by means of acknowledgements and repeats or redundancy coding		System level failure is lower than packet loss rate
Tx power and antenna		All SRD devices were assumed to transmit with max allowed Tx power and antenna gain, which is another worst case assumption. For instance, many of the sensors do not have power amplifier and have very inefficient antennas, meaning that achievable maximum transmit power would be less than the allowed regulatory limit
DC assumption		The DC for all simulated devices was set to the maximum allowed limit, which is absolute worst case assumption as it may be otherwise assumed that in real life not all devices would be reaching their DC limit for most of the time

ANNEX 8: ADJACENT BAND TESTING BETWEEN NETWORKED SRD DEVICES (865-868 MHZ) AND AUDIO DEVICES (863-865 MHZ)

This Annex describes a measurement campaign to investigate the compatibility of a frequency agile (frequency hopping) Smart Metering NBN SRD technology prototype devices manufactured by Silver Spring Networks (SSN) and operating in the 865-868 MHz band, with Assisted Listening Devices (ALDs), radio microphones and cordless headphones operating in the band 863-865MHz.

According to ECC Report 200 [3] and ECC Report 246 [9] operation of smart meters in the 870-876 MHz band (maybe allowed in some countries with a Duty Cycle (DC) of 2.5% (or 10% with Network Relay Points, equivalent to Access Points) and an e.r.p. of up to 500mW with mandatory (Automatic Power Control) APC. This work has been designed to examine the feasibility for similar operations in the 865-868 MHz band. However, during these measurements, interfering transmitters were operated at a DC of 100% and with no APC, representing worst-case conditions.

A8.1 SMART METERING EQUIPMENT

An SSN bridge modified to operate in the band 865-868MHz was used. The bridge contains a Network Interface Card (NIC) that is identical to that which would be installed inside a smart electricity, water or gas meter, Access Point (AP) or IoT Router. The bridge is capable of providing a wired Ethernet connection between two such devices, although for the purposes of this measurement campaign, the MAC and PHY layers of the radio were manipulated to transmit in both typical and extreme modes with respect to traffic and channel dwell duration.

For the tests, the bridge was connected to a PC and controlled via an Ethernet cable. An additional unit – a Field Service Unit (FSU) – was also connected to the PC which allowed messages to be sent to the bridge wirelessly. This was used to receive the RF Ping messages sent by the bridge when carrying out channel agile measurements (see below). The bridge was fitted with an omni-directional ‘rubber ducky’ antenna with a gain of approximately 3dB.

The SSN devices’ transmission properties comply with harmonised standard EN 303 204 [44] (Networked SRDs), with the exception that they were operating outside of the intended 870-876MHz band, at 100% DC and APC was not enabled ie transmissions were initially at a full 500mW.

Figure 56: SSN Field Service Unit and Bridge

The bridge was capable of operating in (normal) agile mode, where messages are transmitted on one of the 15 available 200 kHz channels between 865 and 868MHz. The bridge operating system chooses a channel to transmit on pseudo-randomly; or can be set to transmit on a fixed channel for a defined period of time.

An image of the signal produced on a fixed channel from a Marconi Instruments 2390 spectrum analyser are shown below. A similar measurement determined the power being transmitted to be +26.0dBm (conducted) or +26.85dBm e.r.p. P out of the antenna (484mW e.r.p.), fractionally less than the 500mW allowed in the channels above 865.6MHz.

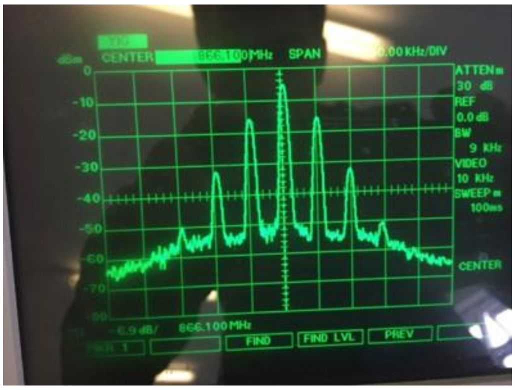


Figure 57: SSN bridge single channel transmission signature

A WiSpy scanner (by Metageek) and the Marconi spectrum analyser were used to sample the signals received over the air.

A8.2 CORDLESS AUDIO TEST EQUIPMENT

Various victim transmitter/receiver pairs were investigated. Each has a typical operating range of 50m transmitting <10mW and is described below.

A8.2.1 System 1: Radio microphone AKG SR 40

A single fixed channel radio microphone which is for musical instrument or voice, market segment: houses of worship, gyms and Band applications using the ETSI EN 301 357 standard [30]. Transmitter operated by a single AA battery. Mean RF Power 7mW.

Figure 58: AKG SR400 radio microphone

The transmission characteristics of the system are shown below.

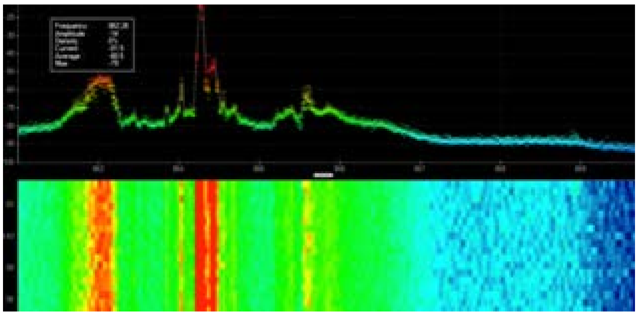


Figure 59: AKG SR40 radio microphone transmission signature

The WiSpy trace comprises two parts:

- The upper trace displays the power spectrum averaged over 10s;
- The lower trace displays sub-one-second variations in power for the previous ten seconds.

A8.2.2 System 2: Comfort Audio Digisystem

System designed for the teaching and education market, the DM30 microphone also contains a receiver so that the teacher can receive the Children's transmissions and a receive-only unit DH10 which receives the 864 MHz transmission and transposes it into the inductive neck loop for the children's Telecoil in the hearing instrument.

Figure 60: Comfort Audio

Two systems where in simultaneous use during their part of the testing.

The transmission characteristics of the system are shown below (single and double transceiver pairs).

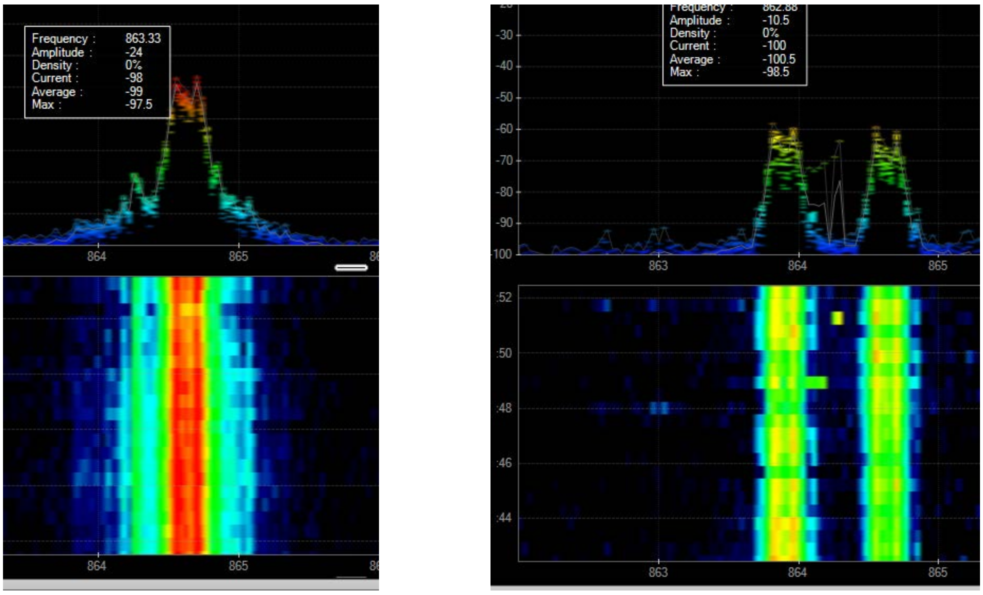


Figure 61: Comfort Audio transmission signature

A8.2.3 System 3: Cordless headphones (Sennheiser cordless audio - RS130)

FM stereo transmission powered by two AA rechargeable batteries has three selectable channels 863.3, 864 and 864.7; the 864.7 channel was used for testing. The unit complies with EN 301 357 [30]

Figure 62: Sennheiser cordless audio headphones

The transmission characteristics of the system are shown below.

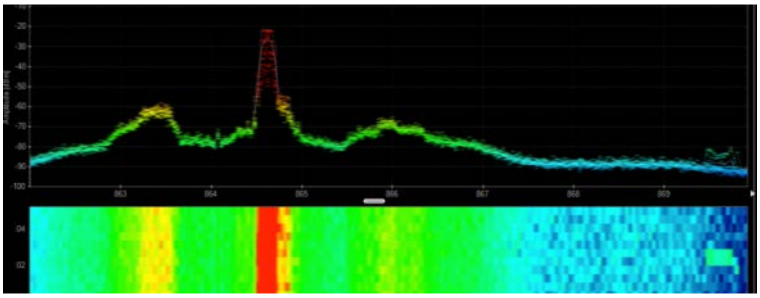


Figure 63: Sennheiser cordless audio headphones transmission signature

A8.2.4 System 4: ALD (Starkey Surf Link)

The main unit can have either Bluetooth input or via built-in microphone. Pairing with music devices and mobile phones results in a phone call overriding the music. In-built microphones can be surround-sound or directional (e.g. a person speaking). The ALD on-ear unit picks up transmissions directly in the 864MHz band at a power of <8.8dBm. This equipment complies with ETSI EN 300 422 [29]

Figure 64: Starkey Surf Link

The transmission characteristics of the system are shown below.

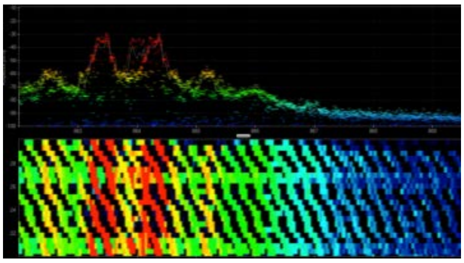


Figure 65: Starkey Surf Link transmission signature

A8.3 TESTING METHODOLOGY

The experimental set up was as shown below.

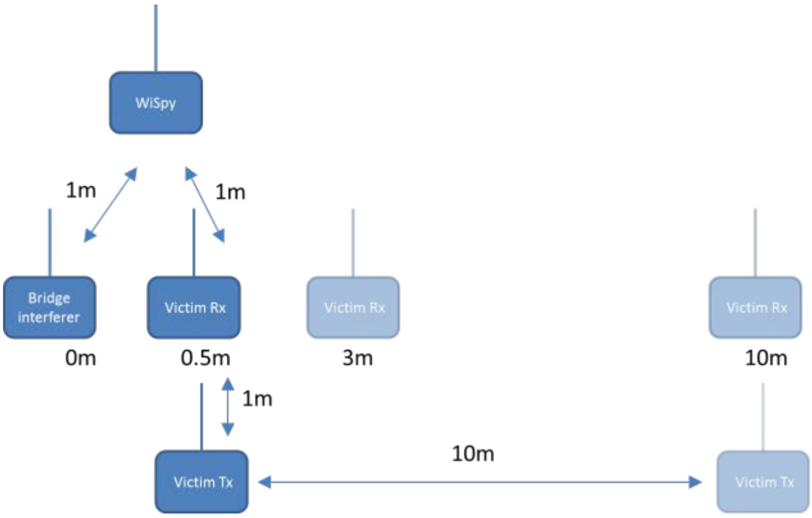


Figure 66: Experimental set up

Two sets of tests were carried out: channel agile mode and single channel. For each, the interference to the audio link (playing either a continuous audio tone or voice loop) was noted (see Table 64 and Table 65 below).

Channel agile measurements: The SSN bridge was set to transmit in 300 ms bursts (the maximum allowed according to ERC/REC 70-03 [11] being 400ms) before moving on to the next pseudo-random channel. Channels between 865 and 868 MHz were used (top- and bottommost channel centres being 865.1MHz and 867.9MHz). The interference was noted with a variety of physical separations between the victim Tx, Rx and (SSN bridge) interfering device.

Single channel measurements: The (SSN bridge) interfering device was set to transmit continuously (modulated) on chosen channels and the interference was noted. The physical separation between the victim Rx and the interferer was kept at 1m, and the victim Tx to Rx separation set to 1m or 10m. For the three lowest channels (below 865.6MHz) a 6dB attenuator was inserted to ensure that the e.r.p. limit of 100mW was respected.

A8.4 TEST RESULTS

A8.4.1 System 1: Radio microphone (AKG SR400)

- Victim Rx frequency = 864.6MHz;
- Channel agile measurements (Interferer Tx at 865-868 MHz).

Table 64: Interferer (SSN bridge) Tx power 500mW

	Victim Tx-Victim Rx	0.5m	10m
Intf Tx-Victim Rx			
<2cm		Slight clicking	Audible clicking – tone still intelligible
0.5m		No noticeable interference	Audible clicking – tone still intelligible
3m		No noticeable interference	No noticeable interference
10m		No noticeable interference	No noticeable interference

Table 65: Interferer (SSN bridge) Tx power 100mW

	Victim T-Victim Rx	0.5m	10m
Intf Tx-Victim Rx			
<2cm		Slight clicking	Audible clicking – tone still intelligible
0.5m		No noticeable interference	Occasional click
3m		No noticeable interference	No noticeable interference
10m		No noticeable interference	No noticeable interference

A8.4.2 System 2: Comfort Audio Digisystem

- Victim Rx frequency = 864.6MHz;
- Channel agile measurements (Interferer Tx at 865-868 MHz);
- Interferer (SSN bridge) Tx power – 500mW.

Table 66: Single victim system

	Victim T-Victim Rx	0.5m	10m
Intf Tx-Victim Rx			
<2cm		Audible clicking – audio still intelligible	Audible clicking – audio difficult to understand
0.5m		No interference	Audible clicking – audio still intelligible
3m		No interference	No interference
10m		No interference	No interference

Table 67: Two victim systems in use (864.6MHz & 863.9MHz)

	Victim T-Victim Rx	0.5m	10m
Intf Tx-Victim Rx			
<2cm	Audible clicking – audio still intelligible	Audible clicking – audio difficult to understand	Audible clicking – audio still intelligible
0.5m	No interference	Audible clicking – audio still intelligible	No interference
10m	No interference	No interference	No interference

Single channel measurements:

Table 68: Single victim system (864.6MHz) 1m from interferer – victim Tx 10m away

Interfering channel	Centre Frequency (MHz)	Observation	Notes
20	865.1	Channel blocked	100mW, Figure 67
24	865.5	Channel blocked	100mW
28	865.9	Channel blocked	500mW
32	866.3	Channel blocked	500mW, Figure 68
36	866.7	Channel blocked	500mW

Interfering channel	Centre Frequency (MHz)	Observation	Notes
40	867.1	Channel blocked	500mW
44	867.5	Channel blocked	500mW
48	867.7	No noticeable interference	500mW, Figure 15

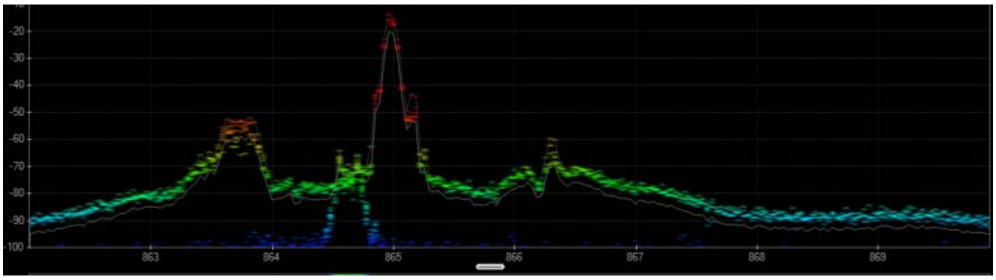


Figure 67: Interfering channel 20

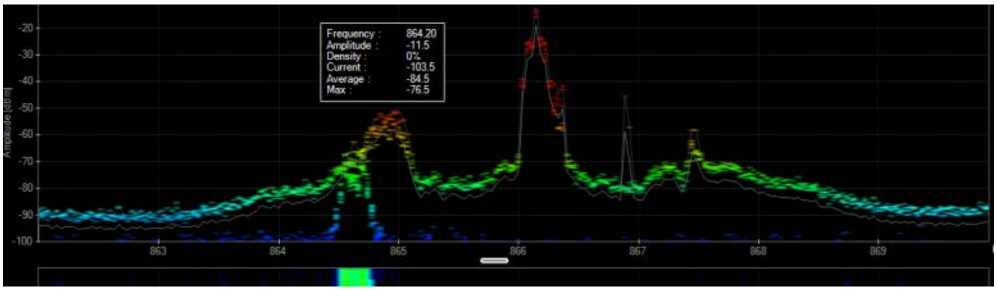


Figure 68: Interfering channel 32

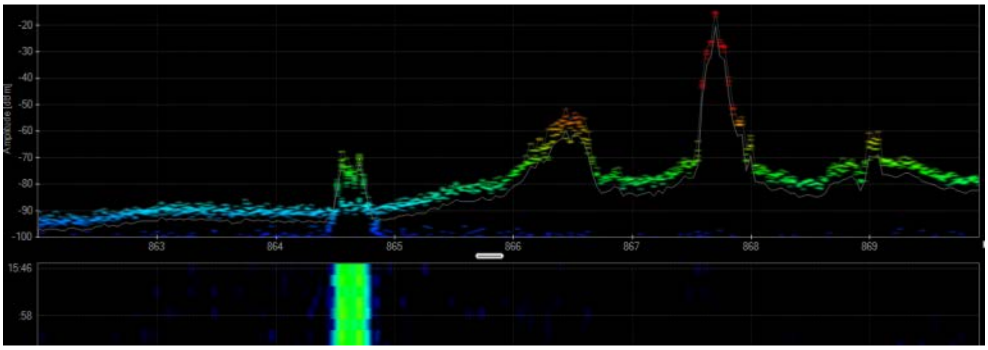


Figure 69: Interfering channel 48

Table 69: Single victim system (864.6MHz) 1m from interferer – victim Tx 1m away

Interfering channel	Centre Frequency (MHz)	Observation	Notes
20	865.1	Channel blocked	100mW, Figure 70
22	865.3	Noticeable interference - audible	100mW
24	865.5	Slight interference	100mW
26	865.7	No noticeable interference	500mW
28	865.9	No noticeable interference	500mW
32	866.3	No noticeable interference	500mW, Figure 71
36	866.7	No noticeable interference	500mW
40	867.1	No noticeable interference	500mW
44	867.5	No noticeable interference	500mW
48	867.7	No noticeable interference	500mW, Figure 72

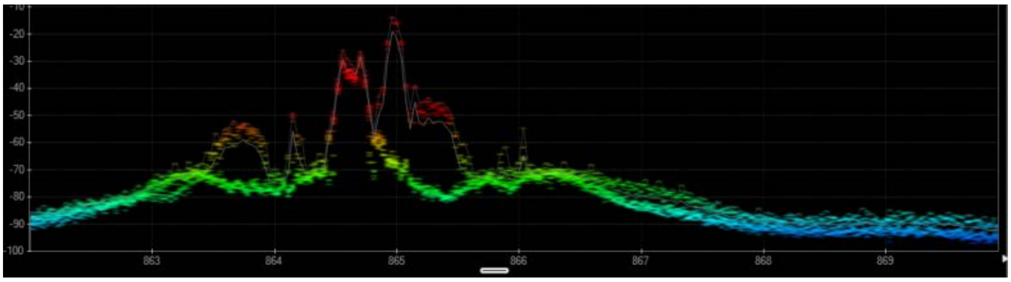


Figure 70: Interfering channel 20

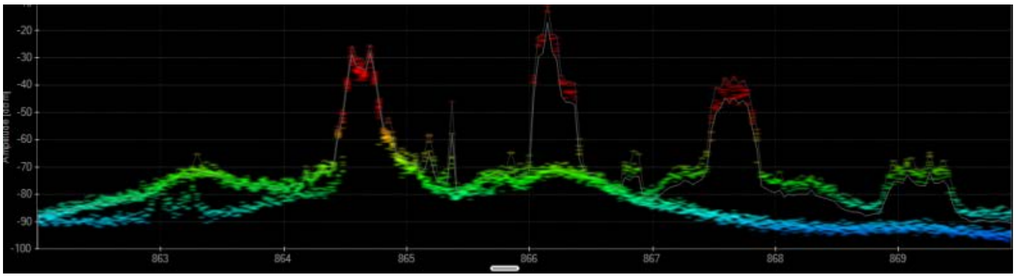


Figure 71: Interfering channel 32

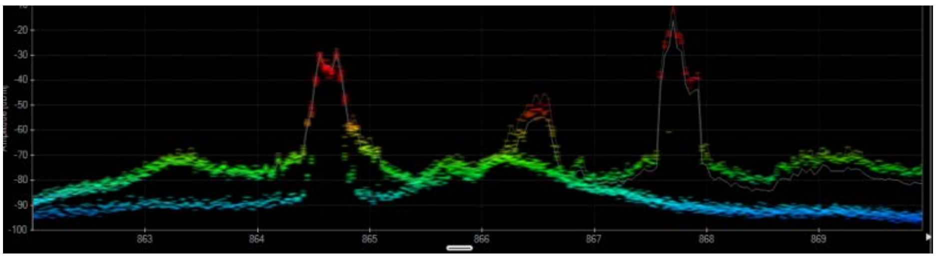


Figure 72: Interfering channel 48

A8.4.3 System 3: Cordless headphones (Sennheiser cordless audio - RS130)

- Victim Rx frequency = 864.6 MHz
- Channel agile measurements (Interferer Tx at 865-868 MHz)

Table 70: Interferer (SSN bridge) Tx power –100mW

	Victim T-Victim Rx	0.5m	10m
Intf Tx-Victim Rx			
<2cm		No interference	Occasional clicks
0.5m		No interference	No interference
3m		No interference	No interference
10m		No interference	No interference

Table 71: Interferer (SSN bridge) Tx power – 500mW

	Victim T-Victim Rx	0.5m	10m
Intf Tx-Victim Rx (m)			
<2cm		No interference	Occasional clicks
0.5m		No interference	No interference
3m		No interference	No interference
10m		No interference	No interference

A8.4.4 System 4: ALD (Starkey Surf Link)

- Victim Rx frequency = 864.3 & 863.4 MHz
- Channel agile measurements (Interferer Tx at 865-868 MHz)

Table 72: Interferer (SSN bridge) Tx power – 500 mW

	Victim T-Victim Rx	0.5m	10m
I_{ntf} Tx-Victim Rx			
<2cm		No interference	Very slight clicking
0.5m		No interference	No interference
3m		No interference	No interference
10m		No interference	No interference

Single channel measurements:

Table 73: Single victim system - 1m from interferer – victim Tx 1m away

Interfering channel	Centre Frequency (MHz)	Observation	Notes
20	865.1	No noticeable interference	100mW
24	865.5	No noticeable interference	100mW
28	865.9	No noticeable interference	500mW
32	866.3	No noticeable interference	500mW, Figure 73
36	866.7	No noticeable interference	500mW
40	867.1	No noticeable interference	500mW
44	867.5	No noticeable interference	500mW
48	867.7	No noticeable interference	500mW, Figure 74

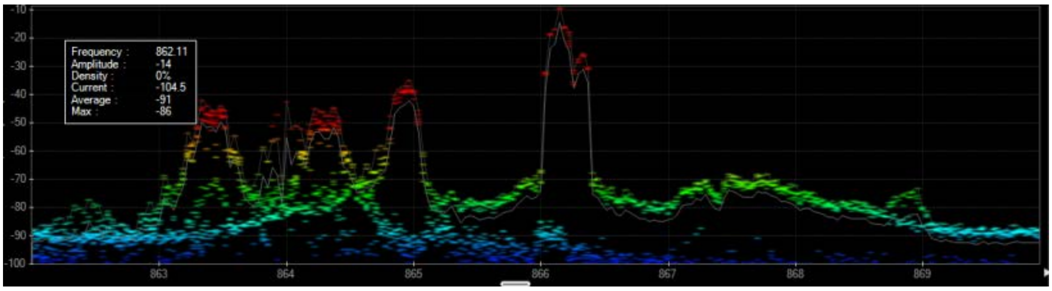


Figure 73: Interfering channel 32

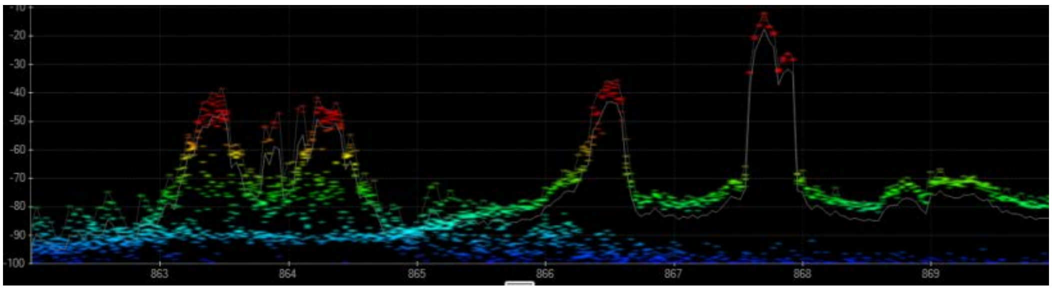


Figure 74: Interfering channel 48

Single victim system (864.6MHz) 1m from interferer – victim Tx 10m away

Table 74: Channel 20 (865.1 MHz)

Interfering channel	Centre Frequency (MHz)	Observation	Notes
20	865.1	Link lost	100mW, Figure 75
22	865.3	Fractional distortion	100mW
24	865.5	Fractional noise increase	100mW

Interfering channel	Centre Frequency (MHz)	Observation	Notes
26	865.7	No noticeable interference	500mW
28	865.9	Click on transition – slight audio distortion	500mW
32	866.3	Breaks link, sometimes	500mW, Figure 76
36	866.7	No noticeable interference	500mW
40	867.1	No noticeable interference	500mW
44	867.5	No noticeable interference	500mW
48	867.7	Fractional increase in background noise	500mW, Figure 77

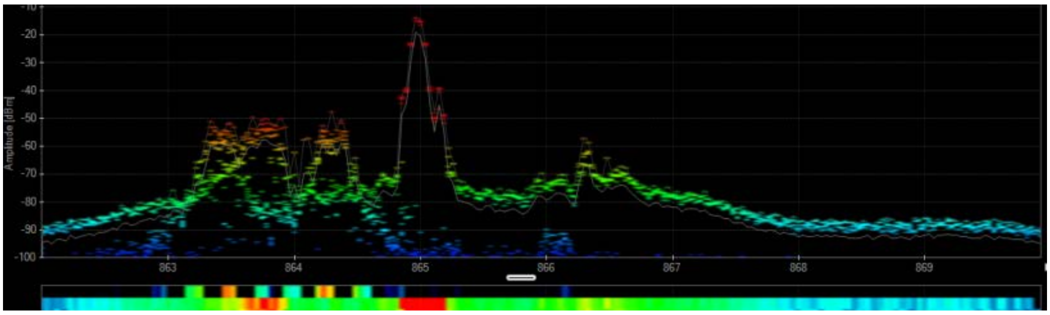


Figure 75: Interfering channel 20

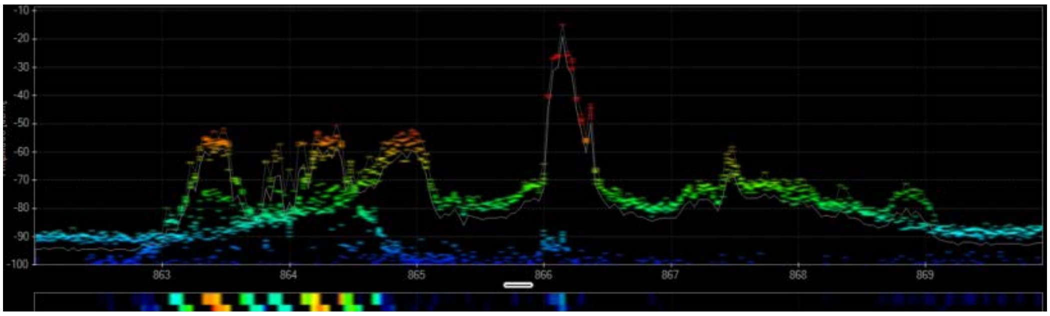


Figure 76: Interfering channel 32

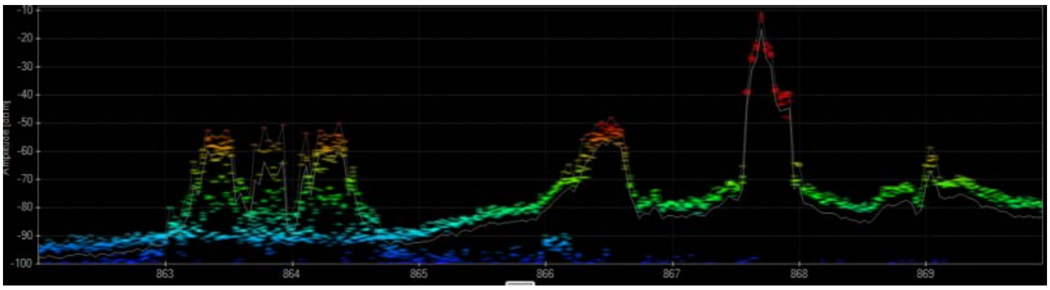


Figure 77: Interfering channel 48

A8.5 DISCUSSION

A set of compatibility measurements have been carried out to investigate the impact that Networked SRDs designed to EN 303 204 [44] operating in the 865-868MHz band would have on typical audio devices in the band 863-865 MHz, with a view to assessing the feasibility of operating these types of systems in these adjacent bands.

The Interferer (SSN bridge) was operated under conditions of heavy traffic[12] (channel agile measurements) and extreme (single channel) conditions. The interferer was operated at powers that would be anticipated in a new entry into ERC/REC 70-03 [11] (ie 100 mW e.r.p. 865-865.6 MHz & 500 mW e.r.p. above 865.6, terminating at 868 MHz), but no APC (as set out in EN 303 204) was used, which would be anticipated under the new entry.

A range of relative separations between interferer, victim Tx and victim Rx was investigated.

The measurements showed that, when channel agile mode was used, severe interference was only noted under the most extreme geometries.

When a transmitter was operated on a single channel (at 100% DC) in the lower part of the band, severe interference was noted under extreme circumstances ie a relatively large victim link length or three closest channels.

Access Points/ Network Relay Points are, operationally, unlikely to come with 3m of a victim.

Conclusions

The results of the measurements made thus far suggest that:

- interference from a 500mW (with 100mW below 865.6MHz) channel agile system is likely to be very low under most realistic scenarios;
- devices operating in this band need to be channel agile, or avoid the lower half of the band when transmitting at high powers (500mW);
- transmission durations on a single channel need to be kept to below 400ms on any one given channel before moving on;
- importance of channel agility for the report is not clear.

[12] In effect, a DC of 100% (whereas 2.5%/10% would be the maximum allowed operationally).

ANNEX 9: FEASIBILITY OF SPECTRUM SENSING FOR THE DETECTION OF RFID SYSTEMS

In this Annex we consider feasibility of sensing an RFID signal in the band 865-868 MHz, for the purpose of implementing a DFS/AFA technique. More precisely, the aim of the study is to investigate whether it is possible to implement a sensing mechanism in SRDs, so that they would be able to detect the operation of RFID systems and be able to avoid transmitting and avoid interfering with them.

In order to appreciate the scope of this study, let's assume there are two applications sharing the same band via spectrum sensing:

- Application A is an incumbent (in our case RFIDs) that does not apply spectrum sensing; it simply transmits when it needs to;
- Application B is a new comer (in our case NBN SRD), that applies spectrum sensing to avoid interfering into the reception of application A.

In this scenario, a comprehensive study on the feasibility of spectrum sensing as a coexistence technique needs to check the following three issues:

Issue 1: Application B must be able to reliably detect the emission of application A. This conditions means ensuring that the sensing mechanisms is sufficient to ensure that devices of type B dot not create interference into devices of type A. By reliably we mean to conditions:

With a sufficiently low probability of missed detection (and possibly of false alarm)

The detection need not to be reliable in absolute, but in situation when the emission of device B could create harmful interference into the RX of application A

Issue 2: the reliability of mechanism needs to be appreciated also the other way round, i.e. whether a device of class A may go undetected by a device of type B and create interference into it. In fact, this case is also possible: a device of class B performs spectrum sensing, the procedure indicates that the spectrum is free (no class A device is detected) and therefore the type B device starts transmitting. If issue 1 is positively resolved, the emission of device B will not create harmful interference into the A type device, but it is still possible that the A type device, while unnoticed, is transmitting and causing interference into the reception of the class type B receiver.

Issue 3: how much white space is available for type B applications?

RFID parameters

The RFID main parameters were provided in Table 18. It should be noted that two values are given for the sensitivity of the RFID interrogator:

- The value -75 dBm corresponds to typical sensitivity of RFID systems deployed today;
- The value -85 dBm corresponds to a hypothetical future improvement of RFID technology.

Protection criteria for the RFID systems

In order to derive a realistic protection criterion for the RFID interrogator, one needs to consider the link budget of a RFID system. Two cases are considered:

- The typical existing system, whose sensitivity is -75 dBm;
- A future system whose sensitivity if -85 dBm.

Over a bandwidth of 200 kHz, the thermal noise is KTBF= -114 dBm (F=7 dB). The sensitivity of the RFID interrogator receiver is in fact not determined by the thermal noise level of the receiver, but by other noise sources like the phase noise induced by the oscillators and the interference level from other RFID. In order to derive a crude protection criterion for the RFID, it is considered that RIFD typically employ a modulation an ASK modulation, that requires a C/N of around 12 dB for a satisfactory BER. The overall equivalent noise level (considering thermal noise, phase noise and intra-system interference) at the RFID interrogator receiver should therefore be around 12 dB below the declared sensitivity, namely at -75-12=-87 dBm and -85-12=-97 dBm.

Considering a criterion of I/N=-6 dB, one gets a value of -93 dBm and -103 dBm respectively. These two values are supposed to be, in this study, the maximum level of interfering power into the RFID interrogator that should not be exceeded. It should be noted that a less conservative (more realistic) protection criterion should be to calculate the actual C/(N+I) ratio at the interrogator receiver and check that the interfering power from the generic SRD does not impairs it beyond and acceptable level.

Calculation of the required sensing threshold

The Figure 78 below shows the situation:

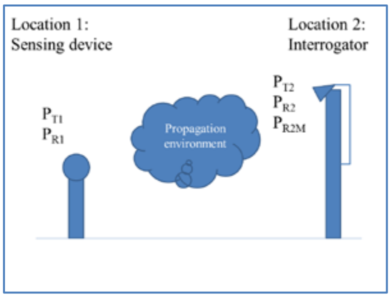


Figure 78: Sensing scenario

In Figure 78 above:

- PT1 is the power emitted by the device that is performing spectrum sensing to detect the presence of the interrogator;
- PR1 is the power, emitted by the interrogator and received by the sensor. This signal is the one available for performing the sensing;
- PT2 is the power emitted by the interrogator;
- PR2 is the interfering power, received by the interrogator from the sensing device (the receiver side of PT1);
- PR2M is the maximum interfering power admissible into the receiver of the RFID interrogator.

The average power received from the sensor is given by the equation:

$$P_{R2} = P_{T1} + G_1 + G_2 - Loss - \chi - L_{shield} - L_{build} + \gamma \qquad \text{Eq.1}$$

where:

- G_1 is the gain of the sensing device in the direction of the RFID interrogator;
- G_2 is the gain of the RFID interrogator in the direction of the sensing device;
- Loss is the basic transmission loss between the reader and the sensor, as given by the propagation model, without considering the building propagation loss;
- L_{shield}: is the loss to be considered because of the fact that the RIFD reader is installed between metallic fences that are required to protect it from inter-systems interference. 20 dB;
- L_{build} is the building propagation loss (indoor to outdoor loss). To be noted that in the case of an outdoor RFID reader the loss is obviously zero;
- γ is a model to take into account the fading, i.e. the variation of the actual propagation loss around the average estimated by the propagation model;
- χ: is the polarization mismatch.

At the same time, the power received by the sensing device from interrogator, is given by:

$$P_{R1} = P_{T2} + G_1 + G_2 - Loss - \chi - L_{shield} - L_{build} + \gamma \qquad \text{Eq.2}$$

The terms relating to the propagation, are the same in the two equations, because of reciprocity of the propagation medium.

If we consider the condition when the interfering power PR2 equals the maximum admissible threshold we get:

$$P_{R2M} = P_{R2} = P_{T1} + G_1 + G_2 - Loss - \chi - L_{shield} - L_{build} + \gamma \qquad \text{Eq. 3}$$

Extracting the term $-Loss - \chi - L_{shield} - L_{build} + \gamma$ in both equations gives:

$$P_{R1} = P_{T2} - P_{T1} + P_{R2M} \text{ Eq.4}$$

In other words, the sensor must be able to detect a power equal to:

$$P_{sens} = P_{T2} - P_{T1} + P_{R2M} \qquad \text{Eq. 5}$$

Values of the sensing threshold

If one assumes that PT1 is a variable parameter (corresponding to an erp of 100 mW, 200 mW an d 500 mW as indicated in the ERC/REC 70-03 [11]), one gets the following sets of curves representing P_{sens} versus P_{R2M}.

Considering the 2W e.r.p.:

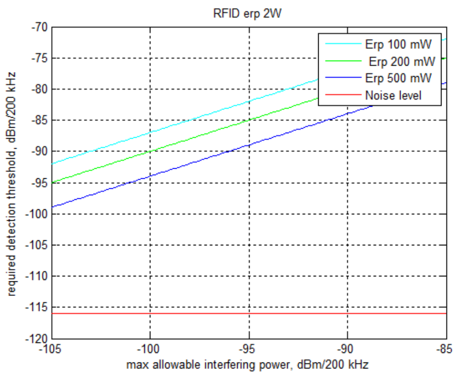


Figure 79: Detection threshold required for a sensing device in case of a 2W e.r.p. RIFD as a function of the maximum permissible interference level into of the RFID interrogator receiver

The following Figure 80 considers instead an RFID interrogator whose erp is 200 mW.

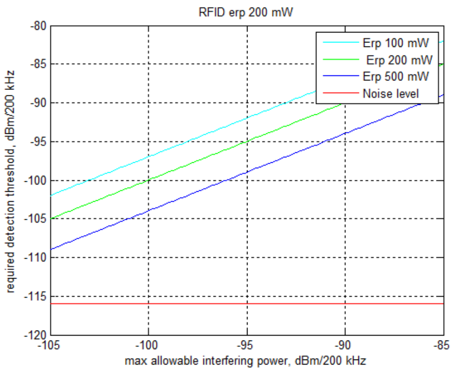


Figure 80: Detection threshold required for a sensing device in case of a 200 mW e-r.p. RIFD as a function of the maximum permissible interference level into of the RFID interrogator receiver

The following Figure 81 considers instead an RFID interrogator whose e.r.p. is 100 mW.

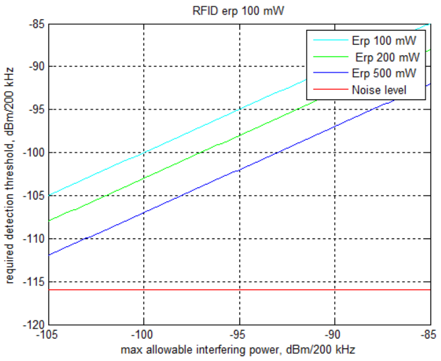


Figure 81: Detection threshold required for a sensing device in case of a 100 mW e.r.p. IFD as a function of the maximum permissible interference level into of the RFID interrogator receiver

Sensing mechanism

Energy detection is the easiest technique to implement. It does not require the knowledge of the structure of the signal to be detected. The probability of detection depends in this case on the available signal to noise ration and the observation time.

The following cases need to be distinguished:

- RFID with power 2W. The sensing threshold, considering a future system with improved sensitivity, is around 17 dB above noise. Considering an actual system with sensitivity -75 dBm the sensing threshold is 27 dB above noise. These favourable signals to noise ratios make possible an easy detection of the reader by the sensing device.
- RFID with power 200 mW. In this case, the signal to noise ratio is still positive, but lower than the case of a 2 W RFID. In the case of a future system with sensitivity set a -85 dBm, the required sensing threshold is about 7 dB above the noise level. In the case of an actual system with sensitivity -75 dBm, the sensing threshold is about 17dB above noise. It should be noted that the 200 mW e.r.p. RFID are intended for handheld use and therefore it is expected that the issue of improving the sensitivity will not impact them.
- RFID with power 100 mW. In this case, the signal to noise ratio is still positive, but lower than the case of a 200mW RFID. In the case of a future system with sensitivity set a -85 dBm, the required sensing threshold is about 4 dB above the noise level. In the case of an actual system with sensitivity -75 dBm, the sensing threshold is about 14 dB above noise. It should be noted that the 100 mW erp RFID are intended for handheld use and therefore it is expected that the issue of improving the sensitivity will not impact them.

Amount of available 'white space'

Considering that it is possible for the SRD device to detect the operation of RFID systems and avoid interfering with them, the question that remains whether the case can happen that the SRD is not interfering with the RFID reception, and therefore is using the spectrum, and at the same time the reception of its signal is interfered by the RFID operation. The answer is yes and it is explained considering the following situation (Figure 82):

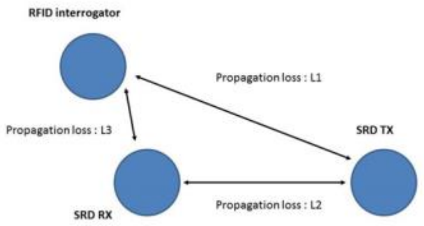


Figure 82: Sensing scenario

The case may happen that the SRD Tx is sufficiently far away from the RFID interrogator so that he detects no operation, starts transmitting (without causing harmful interference into the RFID interrogator reception) and at the same time the SRD receiver is sufficiently close to the RFID interrogator so that the reception of the SRD useful signal is interfered with. One can better appreciate this scenario by considering the case when, with reference to figure 5, L1>>L3.

Another issue related to this one, is what would be the separation distance that an RFID would impose to SRDs applying a sensing mechanism.

In order to investigate the issues above mentioned, the following Monte Carlo simulation was performed:

- N SRDs links are randomly cast in the proximity of a RFID device.
- For each SRD transmitter, assuming it has an embedded spectrum sensor it is tested whether the power received from RFID interrogator would force it to avoid transmitting.
- For each SRD receiver, it is calculated whether the interference from the RFID receiver would violate a given protection criterion.

The combination of the two last points above is equivalent to assess in a statistical way the area around the RFID where the operation of the SRD employing spectrum sensing as a sharing mechanism would be precluded.

The details of the simulation are given in the Table below.

Table 75: Simulation Parameters

RFID	
Bandwidth	200 kHz
E.i.r.p. max	2W
Antenna	70° aperture, modelled with ITU-R. F699
SRD	
Bandwidth (communication)	200 kHz
Bandwidth (spectrum sensor)	200 kHz
E.i.r.p. max	500 mW

Receiver antenna	Omni
Spectrum Sensor antenna	Omni
Noise figure (receiver)	5 dB
Noise figure (sensor)	5 dB
C(N+I) target (receiver)	5 dB
C/N required, sensor	3dB
Propagation model	
802.11 as in ECC Report 131. In the simulation a fast fading term modelled with a Gaussian variability of 15 dB has ben added after the break point.	

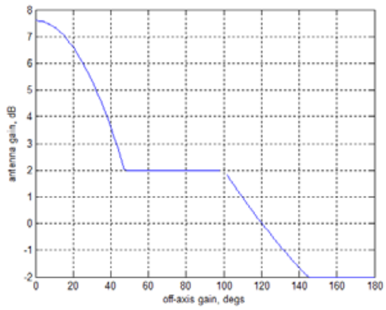


Figure 83: Antenna diagram assumed for the RFID interrogator

Figure 84 shows the propagation loss given by the model as a function of the distance, including the effect of the slow fading but without that of fast fading.

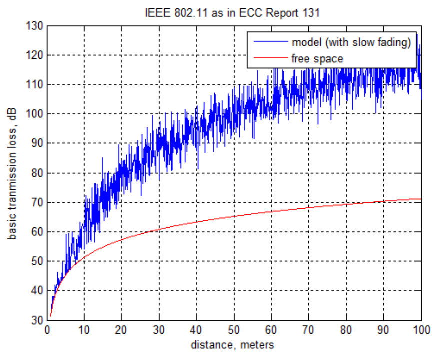


Figure 84: Propagation path loss with slow fading only

The Figure 85 shows the propagation loss given by the model as a function of the distance, including the effect of both slow fading and fast fading.

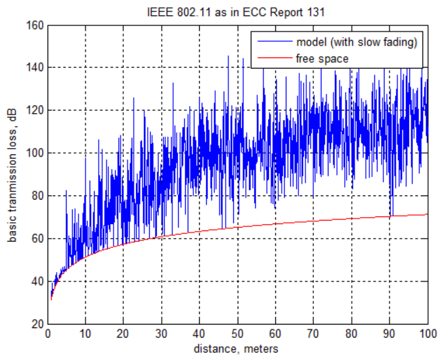


Figure 85: Propagation path loss with both slow and fast fading

Figure 86 below shows the area where the sensing mechanism would mute the SRD transmitter.

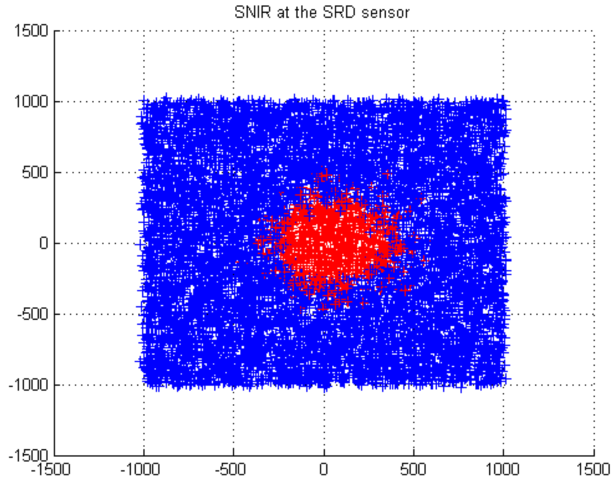


Figure 86: Cases where spectrum sensing mutes the SRD transmitter are in red

Figure 87 below shows the area where the SRD receiver would be interfered by the RFID interrogator.

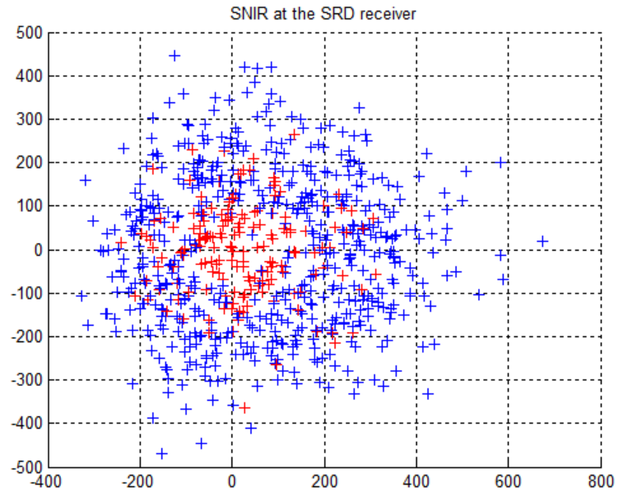


Figure 87: SNIR at the SRD receiver. Cases where the SNIR is not attained are in red. Cases where the SNIR is attained are in blue

ANNEX 10: TABLES OF SEAMCAT SIMULATION PARAMETERS

A10.1 SIMULATIONS FOR LEGACY SRD SCENARIOS

The following tables contain the detailed listing of key technical parameters of victim and interfering systems for SEAMCAT simulations and their detailed results, as referred to in Chapter 4 of this report.

Table 76: Simulation settings for intra-SRD scenario: Home Automation SRD as a victim

Simulation input/output parameters	Settings/Results
VL: HA SRD	
Frequency	869.3 MHz
VLR sensitivity	-104 dBm/350 kHz
VLR selectivity	Realistic Cat. 2 compliant mask
VLR C/I threshold	8 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/350 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km
IL1: Sub-metering	
Frequency	868.3 or 868.95 MHz (ref. Table 18)
ILT transmitter output power	14 dBm/300 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	0.1/0.0025 % (Note 1)
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	1 m/30 dB
ILT → VLR positioning mode	None (simulation radius 181 m)
Number of transmitters in impact area (Medium/High estimate)	2577/5153 (Note 1)
IL2: Alarms	
Frequency	868.6-869.4 MHz, 25 kHz channels
ILT transmitter output power	14 dBm/25 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	0.01/0.0015 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	1 m/30 dB
ILT → VLR positioning mode	None (simulation radius 181 m)
Number of transmitters in impact area (Medium/High estimate)	103/309

Simulation input/output parameters	Settings/Results
IL3: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 % (Note 2)
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL4: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6

Note 1: due to very high number of Sub-metering devices, in order to limit simulation time the number of active devices used in simulations is reduced by factor of 10 while their probability of transmission (DC) is increased by the same factor.

Note 2 in Table 18 the average DC of RFIDs is indicated to be within the range of 2.5-12.5%, a median of that range (7.5%) is used in SEAMCAT simulations.

Table 77: Summary of simulated probabilities of interference in 863-870 MHz for incumbent intra-SRD mix

Simulation assumptions	Probability of interference, % (unwanted / unw&blocking)					
	Victim SRD device					
	HA	Sub-metering	Alarms	RFID	Cordless Audio	Hearing Aids
High density & path loss, maximum DC	2.7 / 4.2	2.3 / 3.2	0.7 / 2.7	0.1 / 0.3	2.1 / 5.1	0.3 / 0.3
High density & path loss, average DC	0.8 / 1.1	0.8 / 1.1	0.3 / 0.7	0.0 / 0.0	0.1 / 1.5	0.0 / 0.1
Medium density & path loss, max DC	2.9 / 4.7	2.7 / 3.2	1.0 / 3.7	0.1 / 0.5	1.8 / 2.7	0.3 / 0.4
Medium density & path loss, avrg DC	0.8 / 1.0	0.7 / 0.9	0.3 / 0.5	0.0 / 0.1	0.1 / 0.3	0.0 / 0.0
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask						

High density & path loss, maximum DC	2.6 / 23	2.1 / 9.3	0.7 / 14.0	0.2 / 1.4	2.1 / 20.1	0.3 / 1.1
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling (Note)						
High density & path loss, maximum DC	1.8 / 3.1	1.7 / 2.4	0.5 / 1.7	0.1 / 0.3	2.1 / 5.4	0.2 / 0.2

Note: by default the standard deviation of indoor-indoor wall loss modelling is 10 dB, whereas it was suggested by industry members that the smaller value of 5 dB might be more appropriate for modelling wall losses in modern buildings

A10.2 SIMULATIONS FOR ESTABLISHING FEASIBILITY OF USING 862-863 MHZ BAND

The following Table 78 and Table 79 provide technical parameters for SEAMCAT simulations and their detailed results, as referred to in Chapter 5.

Table 78: SRD parameters and values used in simulations of LTE800 UL interference to SRD in 862-863 MHz

Parameter	Sub-metering SRD
Bandwidth, kHz	200
DC, %	0.1
Receiver noise, dBm	-112
NF, dB	9 dB
Sensitivity, dBm	-104
Transmitter Output Power, dBm	14
Antenna gain Rx, dBi	-2.85
Assumed maximum indoor operating range, m	20/40
C/(I) objective, dB	8
Selectivity, ACS, blocking	EN 300220-1

Note: the rest of SEAMCAT settings for this scenario are retained from the identical simulations done in ECC Report 207 [4], cf. section 5.2.1 therein

Table 79: Probability of exceeding a C/I objective (unwanted/unwanted&blocking) for SRD due to interference from LTE UL: Scenario 1 “same room”, user-defined dRSS approach 1

LTE UE mask	SRD receiver (Sub-metering)		
	Cat. 1	Cat. 2	Cat. 3
TS 136 101: 10 MHz	41.5/41.7	41.5/41.8	41.5/48.2
TS 136 101: 5 MHz	-	30.7/31.5	-
TS 136 101: 3 MHz	-	23.2/25.1	-
TS 136 101: 1.4 MHz	14.3/14.3	14.3/22.2	14.3/35.8
Real mask (BNetzA static): 10 MHz	8.6/8.6	8.6/21.4	8.6/43.2

Table 80: Probability of exceeding a C/I objective (unwanted/unwanted&blocking) for SRD due to interference from LTE UL: Scenario 1 “same room”, simulated dRSS approach 2

LTE UE mask	SRD receiver (Sub-metering)		
	Cat. 1	Cat. 2	Cat. 3
TS 136 101: 10 MHz	30.8/30.8	30.8/31.2	30.8/36.4
TS 136 101: 1.4 MHz	10.9/10.9	10.9/16.8	10.9/27.5
Real mask (BNetzA static): 10 MHz	6.6/6.6	6.6/15.7	6.6/32.8
Sensitivity analysis for the case of victim SRD limited to max operating range of 20 m (Note)			
Real mask (BNetzA static): 10 MHz	0.6/0.6	0.6/2.9	0.6/9.9

Note: for this case the resulting simulated dRSS had mean of -59 dBm and std dev of 13 dB

Table 81: Probability of exceeding a C/I objective (unwanted/unwanted&blocking) for SRD due to interference from LTE UL: Scenario 2

LTE UE mask	SRD receiver (Sub-metering)		
	Cat. 1	Cat. 2	Cat. 3
TS 136 101: 10 MHz	1.1/1.1	1.1/1.1	1.1/1.8
TS 136 101: 1.4 MHz	1.3/1.3	1.3/4.1	1.3/7.5
Real mask (BNetzA static): 10 MHz	0.1/0.1	0.1/0.2	0.1/1.2

Table 82: Simulation settings: Home Automation to LTE Uplink/Urban Cell in adjacent band

Simulation input/output parameters	Settings/Results	
VL: LTE Macro uplink		
Frequency	857 MHz, 10MHz channel	
VLR selectivity	see Annex 1.2 of ECC Report 200 [3]	
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional	
VLR antenna gain and height a.g.l.	18 dBi, 30 m, 65^{O} sector, Recommendation ITU-R F.1336-3 [48]	
VLR antenna feeder loss	3 dB	
Power Scaling Threshold	0.99	
VL Tx power e.i.r.p	-40 to 23 dBm	
VL Tx → Rx path	Extended-Hata, urban, Indoor-Outdoor/above roof, R=0.7/0.47 km	
IL: Home Automation		
Frequency	862.175MHz	
ILT power e.i.r.p.	14 dBm/350 kHz	
ILT mask	Reduced Emissions	Worst Case

Simulation input/output parameters	Settings/Results	
ILT antenna	-2.85dBi	
ILT probability of transmission (Maximum/Average DC)	1%/0.01%	
ILT density (Medium / High Density)	800/km^2	1500/km^2
ILT distance (macro)	500 m	
ILT number of transmitters in impact area (Medium / High Density)	628	1178
General settings for all ILs		
ILT → VLR positioning mode	None	
ILT → VLR interfering path	Extended-Hata, urban, indoor- outdoor /above roof	

Table 83: Simulation results for probability of interference: Home Automation to LTE Uplink/Urban Cell

Simulation case for Interferer: Home Automation	LTE Uplink: bitrate loss in reference cell [%]
Mask Option 1 – High Density - Maximum DC	1.6
Mask Option 1 – High Density - Average DC	0.03
Mask Option 1 – Medium Density - Maximum DC	1.2
Mask Option 1 – Medium Density - Average DC	0.02
Mask Option 2 – High Density - Maximum DC	8.3
Mask Option 2 – High Density - Average DC	0.1
Mask Option 2 – Medium Density - Maximum DC	6.8
Mask Option 2 – Medium Density - Average DC	0.1

Table 84: Simulation settings: Sub Metering to LTE Uplink/Urban Cell in adjacent band

Simulation input/output parameters	Settings/Results
VL: LTE Macro uplink	
Frequency	857 MHz, 10 MHz channel
VLR selectivity	see Annex 1.2 of ECC Report 200 [3]
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLR antenna gain and height a.g.l.	18 dBi, 30 m, 65^O sector, Recommendation ITU F.1336-3 [48]
VLR antenna feeder loss	3 dB
Power Scaling Threshold	0.99
VL Tx power e.i.r.p	-40 to 23 dBm
VL Tx → Rx path	Extended-Hata, urban, Indoor-Outdoor/above roof,

Simulation input/output parameters	Settings/Results	
	R=0.7/0.47 km	
IL: Sub-Metering		
Frequency	862.15MHz	
ILT power e.i.r.p	14 dBm/300 kHz	
ILT mask	Reduced Emissions	Worst Case
ILT antenna	-2.85 dBi	
ILT probability of transmission (Maximum/Average DC)	0.1%/0.0025%	
ILT density (Medium / High Density)	25000/km^2	50000/km^2
ILT distance (macro)	500 m	
ILT number of transmitters in impact area (Medium / High Density)	19635	39270
General settings for all ILs		
ILT → VLR positioning mode	None	
ILT → VLR interfering path	Extended-Hata, urban, indoor- outdoor /above roof	

Table 85: Simulation results for probability of interference: Sub-Metering to LTE Uplink/Urban Cell

Simulation case for Interferer: Sub-Metering SRD	LTE Uplink: bitrate loss in reference cell [%]
Mask Option 1 – High Density - Maximum DC	5.1
Mask Option 1 – High Density - Average DC	0.2
Mask Option 1 – Medium Density - Maximum DC	3.9
Mask Option 1 – Medium Density - Average DC	0.09
Mask Option 2 – High Density - Maximum DC	25.1
Mask Option 2 – High Density - Average DC	0.8
Mask Option 2 – Medium Density - Maximum DC	20.5
Mask Option 2 – Medium Density - Average DC	0.6

Table 86: SEAMCAT settings for simulating probability of interference of the 500 mW NBN SRD applications in 862-863 MHz to LTE uplink in 852-862 MHz

Simulation input/output parameters	Settings/Results
VL: LTE Macro uplink	
Frequency	857, 10MHz channel
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLR antenna gain and height a.g.l.	15 dBi, 30 m, 65^{O} sector, ITU-R F.1336-3 [48]
VLR antenna feeder loss, dB	3
VLR selectivity	See Figure 50 in Annex 1
VL UL power control	Yes (power scaling threshold 0.9 or 0.99)
VL Tx power e.i.r.p	-40 to 23 dBm
VL Tx → Rx path (Medium/High estimate)	Extended-Hata, urban, Indoor-Outdoor/above roof, R=0.7/0.47 km
IL1.A: NBN SRD: Network Access Point Tx	
Frequency	862-863 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT mask (OOB & spurious)	Two options, see ANNEX 1:
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, operating R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-outdoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	4/8
IL1.B: NBN SRD: Network Node Tx	
Frequency	862-863 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT mask (OOB & spurious)	Two options, see ANNEX 1:
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, operating R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-outdoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	36/71
IL1C: NBN SRD: Terminal Node Tx	
Frequency	862-863 MHz

Simulation input/output parameters	Settings/Results
ILT transmitter output power	27 dBm/200 kHz
ILT mask (OOB & spurious)	Two options, see ANNEX 1:
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, operating R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Extended-Hata, urban, indoor-outdoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	746/1492
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT mask (OOB & spurious)	One option, see ANNEX 1:
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	40/377
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT mask (OOB & spurious)	Two options, see ANNEX 1:
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75%
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	32/79

Table 87: SEAMCAT results for adjacent band interference to LTE from the new 500mW SRDs in 862-863 MHz: SRDs Mask Option 1 "Reduced Emissions"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.8/ 4.4	20.5 / 13.5	28.5 / 16.9
High Density, Average DC	7.8 / 3.3	7.7 / 4.5	15.2 / 7.2
Medium Density, Max DC	6.1 / 2.3	7.0 / 4.2	12.5 / 6.4
Medium Density, Average DC	4.8 / 1.8	2.5 / 1.4	6.8 / 3.2
Medium Density, 500 mW SRD terminals with DC 0.1%	- / -	1.0 / 0.8	- / -

Table 87bis: Sensitivity analysis for above scenario with NBN SRD Mask Option 1 but output power reduced to 20 dBm

Simulation case	LTE Uplink: bitrate loss in reference cell [%]	
	Impact from IL1 with 27 dBm LTE Power Scaling Threshold: 0.99 / 0.9	**Impact from IL1 with 20 dBm** LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	20.5 / 13.5	13.4 / 7.0
High Density, Average DC	7.7 / 4.5	4.4 / 2.0

Table 88: SEAMCAT results for adjacent band interference to LTE from the new 500mW SRDs in 862-863 MHz: SRDs Mask Option 2 "Worst case"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	39.3 / 20.9	23.6 / 14.9	51.5 / 31.9
High Density, Average DC	30.7 / 16.5	8.6 / 5.7	35.1 / 20.7
Medium Density, Max DC	27.8 / 15.8	7.7 / 4.7	33.7 / 19.2
Medium Density, Average DC	23.0 / 12.6	3.0 / 1.5	24.5 / 13.2

Table 89: Simulation settings: SRDs in 862-863 MHz to Cordless Audio in 863-865 MHz band

Simulation input/output parameters	Settings/Results
VL: Cordless Audio	
Frequency	863.1 MHz
VLR selectivity	EN 301357-1 (Cat. 1 or Cat. 2), see Annex 1 of ECC Report 207 [4]
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLR antenna gain and height a.g.l.	-2.85 dBi, 1.5 m, non-directional
VLR antenna feeder loss	0 dB
VL Tx power e.i.r.p	10 dBm
VL Tx → Rx path	dRSS approach 1 and 2 from ECC Report 207
IL: Sub-Metering SRD	
Frequency	862.95 MHz
ILT power e.i.r.p. (worst case / typical case)	14 dBm/100 kHz
ILT mask	Full mask (See Annex 2.5 of ECC Report 200 [3])
ILT antenna	-2.85 dBi
ILT Duty Cycle (considered as power distribution with 99.9% with -200dBm and 0.1% with 14 dBm)	0.001
ILT density	250/km^2
ILT –VLR distance	10 m/ 500 m
ILT number of transmitters	10 / 196
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof

A10.3 SIMULATIONS FOR NBN SRD

The following tables provide technical parameters for SEAMCAT simulations and their detailed results, as referred to in Chapter 6.

Table 90: SEAMCAT results for adjacent band interference to LTE from the new 500mW NBN SRDs in 863-865 MHz: SRDs Mask Option 1 “Reduced Emissions”

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.8 / 4.4	20.0 / 13.2	29.9 / 16.5
High Density, Average DC	7.8 / 3.3	7.5 / 4.3	14.8 / 7.0
Medium Density, Max DC	6.1 / 2.3	7.0 / 4.1	12.0 / 6.0
Medium Density, Average DC	4.8 / 1.8	2.5 / 1.3	6.5 / 3.0

Table 91: SEAMCAT results for adjacent band interference to LTE from the new 500mW NBN SRDs in 863-865 MHz: SRDs Mask Option 2 “Worst case”

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	39.3 / 20.9	23.0 / 13.2	50.7 / 29.3
High Density, Average DC	30.7 / 16.5	8.5 / 4.7	35.0 / 20.0
Medium Density, Max DC	27.8 / 15.8	7.5 / 4.1	33.1 / 16.5
Medium Density, Average DC	23.0 / 12.6	3.0 / 1.5	24.0 / 13.0

Table 92: SEAMCAT results for adjacent band interference to LTE from the new 500mW NBN SRDs operated in 865-868 MHz (RFID interrogator channels): SRDs Mask Option 1 “Reduced Emissions”

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.8 / 4.4	18.6 / 11.4	25.8 / 14.7
High Density, Average DC	7.8 / 3.3	6.5 / 3.7	13.4 / 6.8
Medium Density, Max DC	6.1 / 2.3	5.9 / 3.4	11.4 / 5.5
Medium Density, Average DC	4.8 / 1.8	2.3 / 1.2	6.5 / 2.9

Table 93: SEAMCAT results for adjacent band interference to LTE from the new 500mW NBN SRDs operated in 865-868 MHz (RFID interrogator channels): SRDs Mask Option 2 “Worst case”

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	39.3 / 20.9	20.2 / 12.9	49.5 / 29.2
High Density, Average DC	30.7 / 16.5	8.1 / 4.6	34.5 / 19.5
Medium Density, Max DC	27.8 / 15.8	7.0 / 4.0	32.4 / 16.5
Medium Density, Average DC	23.0 / 12.6	2.9 / 1.3	23.8 / 12.8

Table 94: SEAMCAT settings for simulating probability of interference in 862-863 MHz for proposed high-power NBN SRD applications (victim: Home Automation)

Simulation input/output parameters	Settings/Results
VL: HA SRD	
Frequency	862.175 MHz
VLR sensitivity	-104 dBm/350 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2 equivalent)
VLR C/I threshold	8 dB
VLR/Tx antenna	-5 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/350 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km
IL1: 250 mW NBN SRD Terminal Nodes	
Frequency	862-863 MHz
ILT transmitter output power	24 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	10
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (During high activity period/Average over one day)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	

Simulation input/output parameters	Settings/Results
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-5 dBi
APC	None
ILT probability of transmission (During high activity period/Average over one day)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 105 m)
Number of transmitters in impact area (Medium/High estimate)	1/3

Table 95: SEAMCAT settings for simulating probability of interference in 863-865 MHz for proposed NBN SRD applications in 862-863 MHz, victim: Cordless Audio

Simulation input/output parameters	Settings/Results
VL: Cordless Audio Rx	
Frequency	864.9 MHz
VLR sensitivity	-97 dBm/200 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2)
VLR C/I threshold	17 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	10 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.03 km
IL1A: NBN SRD Network's NAP Tx (outdoor)	
Frequency	862-863 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: NBN SRD Network's NN Tx (outdoor)	

Simulation input/output parameters	Settings/Results
Frequency	862-863 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	13/25
IL1C: NBN SRD Network's TN Tx (indoor)	
Frequency	862-863 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	269/537
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863.9 MHz, 200 kHz channel
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %

Simulation input/output parameters	Settings/Results
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 96: SEAMCAT results interference probability, unwanted/ (unwanted&blocking), victim: Cordless audio

	Case 1	Case 2	Case 3	Case 4
Interferer A	RFID(IL2), Cordless audio(IL3), LTE800(IL4)	RFID(IL2), Cordless audio(IL3), LTE800(IL4)	RFID(IL2), Cordless audio(IL3), LTE800 (847 MHz)	RFID(IL2), Cordless audio(IL3)
Interferer B		500mW at 862-863 MHz (IL1 A,B,C)	500mW at 862-863 MHz (IL1 A,B,C)	500mW at 862-863 MHz (IL1 A,B,C)
Scenario for SRD 500mW		Medium density Average DC	Medium density Average DC	Medium density Average DC
Interference probability unwanted/unwanted and blocking	7.04/11.2	7.52/11.89	3.43/9.52	1.76/4.57

Notes:
Medium density and average DC are presented as typical case to show the impact of LTE.
Description of the different cases (in italic the parameters changing compared with previous cases):

- Case 1:
  - Victim: Cordless audio at 864.9 MHz.
  - Interferers:
    - RFID 20 dBm between 865-868 MHz (14 active transmitters – simulation radius: 300m);

        - Cordless audio at 863.9 MHz (2 active transmitters - simulation radius: 139m);
        - LTE Uplink at 857 MHz (1 active transmitter – simulation radius: 10m).
- Case 2:
    - Victim: Cordless audio at 864.9 MHz.
    - Interferers:
        - RFID 20 dBm between 865-868 MHz (14 active transmitters – simulation radius: 300m);
        - Cordless audio at 863.9 MHz (2 active transmitters - simulation radius: 139m);
        - LTE Uplink at 857 MHz (1 active transmitter – simulation radius: 10m).
    - 500mW Networked SRD between 862-863 MHz:
        - Terminal Node (269 active transmitters – simulation radius: 300m – DC: 0.1%);
        - Network Node (13 active transmitters – simulation radius: 300m – DC: 0.7%);
        - Network Access Point (2 active transmitters – simulation radius: 300m – DC: 2.5%).
- Case 3:
    - Victim: Cordless audio at 864.9 MHz.
    - Interferers:
        - RFID 20 dBm between 865-868 MHz (14 active transmitters – simulation radius: 300m);
        - Cordless audio at 863.9 MHz (2 active transmitters - simulation radius: 139m);
        - LTE Uplink at 847 MHz (1 active transmitter – simulation radius: 10m).
    - 500mW Networked SRD between 862-863 MHz:
        - Terminal Node (269 active transmitters – simulation radius: 300m – DC: 0.1%);
        - Network Node (13 active transmitters – simulation radius: 300m – DC: 0.7%);
        - Network Access Point (2 active transmitters – simulation radius: 300m – DC: 2.5%).
- Case 4:
    - Victim: Cordless audio at 864.9 MHz
    - Interferers:
        - RFID 20 dBm between 865-868 MHz (14 active transmitters – simulation radius: 300m);
        - Cordless audio at 863.9 MHz (2 active transmitters - simulation radius: 139m).
    - 500mW Networked SRD between 862-863 MHz:
        - Terminal Node (269 active transmitters – simulation radius: 300m – DC: 0.1%);
        - Network Node (13 active transmitters – simulation radius: 300m – DC: 0.7%);
        - Network Access Point (2 active transmitters – simulation radius: 300m – DC: 2.5%);
        - No LTE interferer.

Table 97: SEAMCAT settings for simulating probability of interference in 863-865 MHz for proposed NBN SRD applications, victim: Cordless Audio

Simulation input/output parameters	Settings/Results
VL: Cordless Audio Rx	
Frequency	864.9 MHz
VLR sensitivity	-97 dBm/200 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2)
VLR C/I threshold	17 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	10 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.03 km

Simulation input/output parameters	Settings/Results
IL1A: NBN SRD Network's NAP Tx (outdoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: NBN SRD Network's NN Tx (outdoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	13/25
IL1C: NBN SRD Network's TN Tx (indoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	269/537
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof

Simulation input/output parameters	Settings/Results
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863.9 MHz, 200 kHz channel
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 98: SEAMCAT results interference probability, unwanted/ (unwanted&blocking), victim: Cordless audio

	Existing adjacent applications				
	RFID, cordless audio, LTE800	RFID, cordless audio, LTE800	/	/	/
New applications:	Baseline without new SRDs	500 mW ILT 863-868 MHz	500 mW ILT 863-868 MHz	500 mW ILT 864.9 MHz	500 mW ILT 865-868 MHz

	Existing adjacent applications				
High density & path loss, maximum DC	11.5/18.5	13.9/21.7	3.2/6.0	36.4/36.4	1.0/3.8
High density & path loss, average DC	10.8/16.5	12.0/18.2	1.1/2.4	17.0/17.0	0.4/1.5
Medium density & path loss, maximum DC	8.2/13.8	9.1/15.3	2.1/4.4	28.7/28.7	0.7/2.9
Medium density&path loss, average DC	7.5/12.2	8.2/13.1	1.0/2.0	13.7/13.7	0.4/1.4
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask					
High density & path loss, maximum DC	11.6/43.2	14.0/48.3			
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling					
High density & path loss, maximum DC	12.7/20.5	15.0/24.4			
Sensitivity analysis for the case of VLK maximum operating range reduced from 20 m to 10 m					
High density & path loss, maximum DC	1.1/2.3	2.1/3.5			

Table 99: SEAMCAT settings for simulating probability of interference in 863-865 MHz for proposed NBN SRD applications, victim: Hearing Aids

Simulation input/output parameters	Settings/Results
VL: Hearing Aids Rx	
Frequency	864.1 MHz
VLR sensitivity	-94 dBm/600 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2)
VLR C/I threshold	17 dB
VLR/Tx antenna	-20.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	-6 dBm/600 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.001 km
IL1A: NBN SRD Network's NAP Tx (outdoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	None (simulation radius 170 m)
Number of transmitters in impact area (Medium/High estimate)	1/1
IL1B: NBN SRD Network's NN Tx (outdoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz

Simulation input/output parameters	Settings/Results
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 170 m)
Number of transmitters in impact area (Medium/High estimate)	4/8
IL1C: NBN SRD Network's TN Tx (indoor)	
Frequency	863-868 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 170 m)
Number of transmitters in impact area (Medium/High estimate)	65/130
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 138 m)
Number of transmitters in impact area (Medium/High estimate)	3/29
IL3: Cordless Audio	
Frequency	864.9 MHz
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 40 m)

Simulation input/output parameters	Settings/Results
Number of transmitters in impact area (Medium/High estimate)	1 / 1
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 100: SEAMCAT results interference probability, unwanted/ (unwanted&blocking), victim: Hearing Aids

	Existing adjacent applications	
	RFID, cordless audio, LTE800	RFID, cordless audio, LTE800
New applications:	Baseline without new SRDs	500 mW ILT 863-868 MHz
High density & path loss, maximum DC	1.8/2.7	3.1/4.4
High density & path loss, average DC	1.5/2.4	2.1/3.1
Medium density & path loss, maximum DC	1.5/2.7	2.9/4.5
Medium density & path loss, average DC	1.3/2.3	2.4/3.9
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask		
High density & path loss, maximum DC	1.5/24.0	3.2/15.2
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling		
High density & path loss, maximum DC	0.6/1.4	2.1/3.0

Table 101: SEAMCAT settings for simulating interference to RFID in 865-868 MHz from proposed NBN SRD applications

Simulation input/output parameters	Settings/Results
VL: RFID interrogator receiver	
Frequency	865.5; 866.1; 866.7; 867.3; 200 kHz channels (1st adjacent to interrogator's transmit channels)
VLR sensitivity	-85 dBm/200 kHz

Simulation input/output parameters	Settings/Results
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	12 dB
VLR/Tx antenna	6 dBi, directional
VLR/Tx antenna height	1.5 m
VLR dRSS	User defined -87…-57 dBm, see Figure 15
IL1A: 500 mW NBN SRD NAP Tx	
Frequency	Three options: 863-868 MHz; 865-868 MHz; 865.1, 865.7, 866.3, 866.9, 867.5 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: NBN SRD NN Tx (outdoor)	
Frequency	Three options: 863-868 MHz; 865-868 MHz; 865.1, 865.7, 866.3, 866.9, 867.5 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	13/25
IL1C: NBN SRD TN Tx (indoor)	
Frequency	Three options: 863-868 MHz; 865-868 MHz; 865.1, 865.7, 866.3, 866.9, 867.5 MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	269/537

Simulation input/output parameters	Settings/Results
IL2: Cordless Audio	
Frequency	863.9 MHz
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 93 m)
Number of transmitters in impact area (Medium/High estimate)	1/3
IL3: Non-specific SRDs	
Frequency	865.1-867.9 MHz, 8x350 kHz channels
ILT transmitter output power	14 dBm/350 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	1/0.01 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 103 m)
Number of transmitters in impact area (Medium/High estimate)	27/50

Table 102: Results of interference probability from NBN SRD to RFID in 865-868 MHz, unwanted/ (unwanted&blocking)

	Existing adjacent applications			
	Cordless audio, HA	/	Cordless audio, HA	Cordless audio, HA
New applications:	/	500 mW ILT 863-868 MHz	500 mW ILT 865.1, 865.7, 866.3, 866.9, 867.5 MHz	500 mW ILT 865-868 MHz
High density & path loss, maximum DC	0.4 / 0.8	0.5 / 2.1	0.7 / 4.6	1.2 / 4.2
High density & path loss, average DC	0.1 / 0.1	0.1 / 0.8	0.1 / 1.6	0.4 / 1.6
Medium density & path loss, maximum DC	0.5 / 1.4	0.5 / 1.9	0.8 / 4.6	1.3 / 4.7
Medium density & path loss, average DC	0.1 / 0.1	0.2 / 0.9	0.2 / 1.5	0.4 / 1.5
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling				

	Existing adjacent applications			
High density & path loss, maximum DC	0.4 / 0.8	0.5 / 2.2	0.6 / 4.5	1.1 / 4.4

Table 103: SEAMCAT settings for simulating interference to RFID in 865-868 MHz from proposed NBN SRD applications assuming effect of LBT mechanism

Simulation input/output parameters	Settings/Results
VL: RFID interrogator receiver	
Frequency	865.5; 866.1; 866.7; 867.3; 200 kHz channels (1st adjacent to interrogator's transmit channels)
VLR sensitivity	-85 dBm/200 kHz
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	12 dB
VLR/Tx antenna	6 dBi, directional
VLR/Tx antenna height	1.5 m
VLR dRSS	User defined -87…-57 dBm, see Figure 15
IL1A: NBN SRD NAP Tx	
Frequency	15x 200kHz channels starting at a channel centred on 865.1MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=100 m
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR positioning mode	Protection distance of 90m (simulation radius 100 m)
Number of transmitters in impact area (Medium/High estimate)	1/1
IL1B: NBN SRD NN Tx (outdoor)	
Frequency	15x 200kHz channels starting at a channel centred on 865.1MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=100 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	Protection distance of 90m (simulation radius 100 m)
Number of transmitters in impact area	2/3

Simulation input/output parameters	Settings/Results
(Medium/High estimate)	
IL1C: NBN SRD TN Tx (indoor)	
Frequency	15x 200kHz channels starting at a channel centred on 865.1MHz
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=100 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	Protection distance of 90m (simulation radius 100 m)
Number of transmitters in impact area (Medium/High estimate)	29/57
IL2: Cordless Audio	
Frequency	863.9 MHz
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/15 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 105 m)
Number of transmitters in impact area (Medium/High estimate)	1/2
IL3: Non-specific SRDs	
Frequency	865.1-867.9 MHz, 8x350 kHz channels
ILT transmitter output power	14 dBm/350 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	1/0.01 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 103 m)
Number of transmitters in impact area (Medium/High estimate)	27/50

Table 104: Results of interference probability to RFID in 865-868 MHz from NBN SRD assuming impact of its LBT mechanism

Simulated probability of interference, unwanted/(unwanted&blocking)	
High density & clutter, maximum DC	0.5/1.3%
Medium density, low clutter, maximum DC	0.1/0.3%
High density & clutter, Average DC	0.8/2.3%
Medium density, low clutter, Average DC	0.1/0.2%

Table 105: SEAMCAT settings for simulating probability of interference of proposed NBN SRD applications on Non-specific 25 mW SRDs

Simulation input/output parameters	Settings/Results
VL: Non-specific 25 mW SRD	
Frequency	865.175 MHz
VLR sensitivity	-104 dBm/350 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2 equivalent)
VLR C/I threshold	8 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/350 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km
IL1A: NBN SRD NAP Tx (outdoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5%
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: NBN SRD NN Tx (outdoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof

Simulation input/output parameters	Settings/Results
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	13/25
IL1C: NBN SRD TN Tx (indoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	269/537
IL2: RFID interrogators	
Frequency	865.7, 866.3, 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6

Table 106: SEAMCAT results interference probability from NBN SRD, unwanted/ (unwanted&blocking), victim: non-specific SRDs in band 865-868 MHz

	Existing adjacent applications			
	Cordless audio, RFID	Cordless audio, RFID	Cordless audio, RFID	/
New applications:	Baseline without new SRDs	500 mW ILT 865-868 MHz	500 mW ILT 863-868 MHz	500 mW ILT 865-868 MHz
High density & path loss, maximum DC	2.2 / 4.3	6.4 / 9.3	5.4 / 8.6	4.3 / 5.6
High density & path loss, average DC	1.6 / 3.0	3.4 / 5.3	3.0 / 4.8	1.8 / 2.4
Medium density & path loss, maximum DC	2.1 / 3.4	5.5 / 7.9	4.5 / 7.2	3.9 / 5.0
Medium density & path loss, average DC	1.3 / 2.3	3.1 / 4.3	2.6 / 4.1	1.7 / 2.2
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask				
High density & path loss, maximum DC	2.2 / 22.8	6.5 / 30.5	4.9 / 30.4	4.6 / 12.2
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling				
High density & path loss, maximum DC	1.7 / 3.4	5.9 / 8.4	4.9 / 8.0	4.6 / 5.7

A10.4 SIMULATIONS FOR WBN SRD

The following tables provide technical parameters for SEAMCAT simulations and their detailed results, as referred to in Chapter 7.

Table 107: SEAMCAT settings for simulating probability of interference of the new WBN SRD applications in 862-863 MHz to LTE Uplink in 852-862 MHz

Simulation input/output parameters	Settings/Results
VL: LTE Macro uplink	
Frequency	857, 10MHz channel
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLR antenna gain and height a.g.l.	18 dBi, 30 m, 65^{O} sector, ITU-R F.1336-3 [48]
VLR antenna feeder loss	3
VLR selectivity	See Figure 50 in Annex 1
VL UL power control	Yes (power scaling threshold 0.9 or 0.99)[13]
VL Tx power e.i.r.p	-40 to 23 dBm
VL Tx → Rx path (Medium/High estimate)	Extended-Hata, urban, Indoor-Outdoor/above roof, R=0.7/0.47 km

[13] Two different LTE power scaling threshold settings, i.e. 0.99 and 0.9 (SEAMCAT default). 3GPP has defined two sets of power control parameter values represented by the 0.99 and 0.9 values), however the 0.99 setting is the most relevant for LTE deployments.

Simulation input/output parameters	Settings/Results
IL1.A: WBN SRD Access Point Tx	
Frequency	862.5 MHz
ILT transmitter output power	14 dBm/1000 kHz
ILT mask (OOB and spurious)	Two options, see ANNEX 1:
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	20/40
IL1.B: WBN SRD Terminal Node	
Frequency	862.5 MHz
ILT transmitter output power	14 dBm/1000 kHz
ILT mask (OOB and spurious)	Two options, see ANNEX 1:
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Extended-Hata, urban, Indoor-outdoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	393/786
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT mask	One option, see ANNEX 1:
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	40/377

Simulation input/output parameters	Settings/Results
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT mask	Two options, see ANNEX 1:
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75%
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	32/79

Table 108: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 862-863 MHz: SRDs Mask Option 1 "Reduced Emissions"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.02 / 3.91	11.08 / 5.16	19.07 / 8.47
High Density, Average DC	7.01 / 2.62	1.09 / 0.41	7.59 / 3.05
Medium Density, Max DC	3.26 / 1.36	5.99/ 2.42	9.40 / 3.90
Medium Density, Average DC	3.76 / 1.47	0.78 / 0.39	4.37 / 1.82

Table 109: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 862-863 MHz: SRDs Mask Option 2 "Worst case"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	35.30 / 18.46	22.07 / 11.62	47.86 / 26.41
High Density, Average DC	28.86 / 15.05	2.254 / 0.98	30.26 / 15.45
Medium Density, Max DC	26.28 / 14.03	19.25 / 10.03	38.19 / 14.03
Medium Density, Average DC	20.84 / 9.96	2.02 / 0.79	21.17 / 11.33

Table 110: SEAMCAT settings for simulating probability of interference of the new WBN SRD applications in 863-865 MHz to LTE Uplink in 852-862 MHz

Simulation input/output parameters	Settings/Results
VL: LTE Macro uplink	
Frequency	857, 10MHz channel
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLR antenna gain and height a.g.l.	18 dBi, 30 m, 65^{O} sector, ITU-R F.1336-3 [48]
VLR antenna feeder loss	3
VLR selectivity	See Figure 50 in Annex 1
VL UL power control	Yes (power scaling threshold 0.9 or 0.99)[14]
VL Tx power e.i.r.p	-40 to 23 dBm
VL Tx → Rx path (Medium/High estimate)	Extended-Hata, urban, Indoor-Outdoor/above roof, R=0.7/0.47 km
IL1.A: WBN SRD Access Point Tx	
Frequency	863.5MHz or 864.5MHz
ILT transmitter output power	14 dBm/1000 kHz
ILT mask (OOB and spurious)	Two options, see ANNEX 1:
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	20/40
IL1.B: WBN SRD Terminal Node	
Frequency	863.5MHz or 864.5MHz
ILT transmitter output power	14 dBm/1000 kHz
ILT mask (OOB and spurious)	Two options, see ANNEX 1:
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Extended-Hata, urban, Indoor-outdoor /above roof

[14] Two different LTE power scaling threshold settings, i.e. 0.99 and 0.9 (SEAMCAT default). 3GPP has defined two sets of power control parameter values represented by the 0.99 and 0.9 values), however the 0.99 setting is the most relevant for LTE deployments.

Simulation input/output parameters	Settings/Results
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	393/786
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT mask	One option, see ANNEX 1:
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	40/377
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT mask	Two options, see ANNEX 1:
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75%
ILT → VLR interfering path	Extended-Hata, urban, outdoor-indoor /above roof
ILT → VLR minimum distance/MCL	70 dB
ILT → VLR positioning mode	None (simulation radius 500 m)
Number of transmitters in impact area (Medium/High estimate)	32/79

Table 111: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 863-865 MHz: SRDs Mask Option 1 “Reduced Emissions”

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.02 / 3.91	7.49 / 3.21	15.63 / 6.63
High Density, Average DC	7.01 / 2.62	0.70 / 0.25	7.45 / 3.10

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
Medium Density, Max DC	3.26 / 1.36	4.10 / 1.57	7.16 / 2.94
Medium Density, Average DC	3.76 / 1.47	0.49 / 0.22	4.25 / 1.65

Table 112: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 863-865 MHz: SRDs Mask Option 2 "Worst case"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	35.30 / 18.46	20.68 / 10.62	47.04 / 26.16
High Density, Average DC	28.86 / 15.05	1.99 / 0.922	30.08 / 15.72
Medium Density, Max DC	26.28 / 14.03	18.25 / 9.58	37.57 / 20.73
Medium Density, Average DC	20.84 / 9.96	1.67 / 0.71	21.77 / 10.94

Table 113: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 863-868 MHz: SRDs Mask Option 1 "Reduced Emissions"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	10.0 / 3.9	6.2 / 2.5	14.6 / 6.0
High Density, Average DC	7.0 / 2.6	0.6 / 0.2	7.4 / 3.1
Medium Density, Max DC	4.5 / 1.4	5.0 / 2.1	10.0 / 4.1
Medium Density, Average DC	3.8 / 1.5	0.5 / 0.2	4.2 / 1.6

Table 114: SEAMCAT simulation results for adjacent band interference to LTE from the new 25 mW WBN SRD applications in 863-868 MHz: SRDs Mask Option 2 "Worst case"

Simulation case	LTE Uplink: bitrate loss in reference cell [%]		
	Baseline: IL2&IL3; LTE Power Scaling Threshold: 0.99 / 0.9	Impact from only IL1; LTE Power Scaling Threshold: 0.99 / 0.9	Combined impact from all ILs; LTE Power Scaling Threshold: 0.99 / 0.9
High Density, Maximum DC	35.3 / 18.5	20.3 / 10.1	46.2 / 26.8
High Density, Average DC	28.9 / 15.1	2.1 / 0.9	28.0 / 15.6
Medium Density, Max DC	26.3 / 14.0	17.2 / 9.4	37.2 / 19.9
Medium Density, Average DC	20.8 / 10.0	1.7 / 0.7	21.4 / 11.2

Table 115: SEAMCAT settings for simulating probability of interference to SRDs in 862-863 MHz from new WBN SRD applications

Simulation input/output parameters	Settings/Results
VL: HA SRD	
Frequency	862.175 MHz
VLR sensitivity	-104 dBm/350 kHz
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	8 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/350 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km
IL1A: WBN SRD Access Point Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 186 m)
Number of transmitters in impact area (Medium/High estimate)	3/5
IL1B: WBN SRD Terminal Node Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 186 m)
Number of transmitters in impact area (Medium/High estimate)	41/82
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %

Simulation input/output parameters	Settings/Results
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 116: SEAMCAT results of interference probability for WBN SRD coexistence with SRDs in 862-863 MHz, unwanted/ (unwanted&blocking), victim: HA

	Existing adjacent applications			
	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	/
New applications:	Baseline without new SRDs	WBN SRDs ILT 862-868 MHz	WBN SRDs ILT 862-863 MHz	WBN SRDs ILT 862-863 MHz
High density & path loss, maximum DC	10.9 / 12.9	13.6 / 15.4	24.8 / 26.2	17.5 / 17.5
High density & path loss, average DC	10.5 / 12.5	10.6 / 12.6	12.0 / 13.8	1.5 / 1.5
Medium density & path loss, maximum DC	9.8 / 12.1	15.6 / 17.7	34.3 / 35.4	28.7 / 28.7
Medium density & path loss, average DC	9.8 / 12.0	10.0 / 12.0	11.8 / 13.5	3.0 / 3.0
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask				
Medium density & path loss, max DC	9.8 / 22.8	15.3 / 29.1	33.6 / 44.5	28.1 / 32.4
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling				
Medium density & path loss, max DC	9.7 / 11.8	17.2 / 19.5	35.6 / 37.0	28.9 / 28.9
Sensitivity analysis for the case of victim SRD limited to max operating range of 20 m				
Medium density & path loss, max DC	0.7 / 1.1	2.9 / 3.3	11.9 / 12.2	11.4 / 11.4

Table 117: SEAMCAT settings for simulating probability of interference in 863-865 MHz from new WBN SRD applications: victim Cordless Audio

Simulation input/output parameters	Settings/Results
VL: Cordless Audio Rx	
Frequency	864.9 MHz
VLR sensitivity	-97 dBm/200 kHz
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	17 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	10 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.03 km
IL1A: WBN SRD Access Point Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi
APC	None

Simulation input/output parameters	Settings/Results
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 137 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: WBN SRD Terminal Node Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 137 m)
Number of transmitters in impact area (Medium/High estimate)	29/59
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863.9 MHz, 200 kHz channel
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 159 m)
Number of transmitters in impact area	3/8

Simulation input/output parameters	Settings/Results
(Medium/High estimate)	
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 118: Probability of interference from WBN SRD to Cordless Audio in 863-865 MHz, unwanted/ (unwanted&blocking)

	Existing adjacent applications			
	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800
New applications:	Baseline without new SRDs	WBN SRDs ILT 862-868 MHz	WBN SRDs ILT 862-863 MHz	WBN SRDs ILT 865-868 MHz
High density & path loss, maximum DC	11.5/18.5	17.5/24.5	12.2/19.3	15.4/21.9
High density & path loss, average DC	10.7/16.5	11.5/17.4	11.1/17.1	11.0/16.8
Medium density & path loss, maximum DC	8.3/13.8	16.0/21.0	9.3/15.2	13.7/18.7
Medium density & path loss, average DC	7.5/12.2	7.9/12.2	7.4/12.0	7.9/12.4
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask				
High density & path loss, maximum DC	11.6/43.2	17.5/48.2		
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling				
High density & path loss, maximum DC	12.7/20.5	19.2/26.7		
Sensitivity analysis for the case of VLK maximum operating range reduced from 20 m to 10 m				
High density & path loss, maximum DC	1.1/2.3	2.7/4.0		

Table 119: SEAMCAT settings for simulating probability of interference in 863-865 MHz from new WBN SRD applications: victim Hearing Aids

Simulation input/output parameters	Settings/Results
VL: Hearing Aids Rx	
Frequency	864.1 MHz
VLR sensitivity	-94 dBm/600 kHz
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	17 dB
VLR/Tx antenna	-20.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	-6 dBm/600 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.001 km
IL1A: WBN SRD Access Point Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 62 m)
Number of transmitters in impact area (Medium/High estimate)	1/1
IL1B: WBN SRD Terminal Node Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 62 m)
Number of transmitters in impact area (Medium/High estimate)	5/9
IL2: RFID interrogators	
Frequency	865.7 or 866.3 or 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %

Simulation input/output parameters	Settings/Results
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 138 m)
Number of transmitters in impact area (Medium/High estimate)	3/29
IL3: Cordless Audio	
Frequency	864.9 MHz, 200 kHz channel
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 40 m)
Number of transmitters in impact area (Medium/High estimate)	1/1
IL4: LTE800 UL	
Frequency	857 MHz, 10 MHz channel
ILT transmitter output power	20 dBm mean (Gaussian distr., std. dev. 1 dB)
ILT antenna gain	0 dBi
APC	Threshold -98.5 dBm, range 63 dB, step 1 dB
ILT probability of transmission (Maximum/Average DC)	100/100 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 10 m)
Number of transmitters in impact area (Medium/High estimate)	1/1

Table 120: Probability of interference from WBN SRD to Hearing Aids in 863-865 MHz, unwanted/ (unwanted&blocking)

	Existing adjacent applications			
	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800	Cordless audio, RFID, LTE800
New applications:	Baseline without new SRDs	WBN SRDs ILT 862-868 MHz	WBN SRDs ILT 862-863 MHz	WBN SRDs ILT 865-868 MHz
High density & path loss, maximum DC	1.8/2.8	2.9/3.9	1.6/2.7	1.8/2.9
High density & path loss, average DC	1.5/2.4	1.6/2.4	1.5/2.4	1.5/2.4
Medium density & path loss, maximum DC	1.5/2.7	4.4/5.7	1.7/3.1	2.0/3.3
Medium density & path loss, average DC	1.3/2.3	1.8/2.9	1.4/2.5	1.5/2.5
Sensitivity analysis for the case of minimum specification for victim receiver selectivity mask				
Medium density & path loss, max DC	1.5/24.0	4.4/27.1		
Sensitivity analysis for the case of 5 dB standard deviation for indoor-indoor wall loss modelling				
Medium density & path loss, max DC	0.6/1.4	3.4/4.3		

Table 121: SEAMCAT settings for simulating interference to RFID in 865-868 MHz from new WBN SRD applications

Simulation input/output parameters	Settings/Results
VL: RFID interrogator receiver	
Frequency	865.5; 866.1; 866.7; 867.3; 200 kHz channels (1st adjacent to interrogator's transmit channels)
VLR sensitivity	-85 dBm/200 kHz
VLR selectivity	35 dB @ dF=2 MHz
VLR C/I threshold	12 dB
VLR/Tx antenna	6 dBi, directional
VLR/Tx antenna height	1.5 m
VLR dRSS	**User defined -87…-57 dBm, see** Figure 15
IL1A: WBN SRD AP Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %

Simulation input/output parameters	Settings/Results
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 106 m, protection distance 3 m)
Number of transmitters in impact area (Medium/High estimate)	1/2
IL1B: WBN SRD Terminal Node Tx	
Frequency	862-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 106 m)
Number of transmitters in impact area (Medium/High estimate)	14/27

Table 122: SEAMCAT results interference probability from WBN SRD to RFID in 865-868 MHz, unwanted/ (unwanted&blocking)

	Existing adjacent applications	
	None	None
New applications:	WBN SRDs ILT 862-868 MHz	WBN SRDs ILT 865-868 MHz
High density & path loss, maximum DC	0.7 / 1.1	1.1 / 1.9
High density & path loss, average DC	0.1 / 0.1	0.1 / 0.2
Medium density & path loss, maximum DC	0.9 / 1.4	1.9 / 3.0
Medium density & path loss, average DC	0.2 / 0.4	0.4 / 0.7

Table 123: SEAMCAT settings for simulating probability of interference of the new WBN SRD applications to Non-specific 25 mW SRDs

Simulation input/output parameters	Settings/Results
VL: Non-specific 25 mW SRD	
Frequency	865.175 MHz
VLR sensitivity	-104 dBm/350 kHz
VLR selectivity	35 dB @ dF=2 MHz (Cat. 2 equivalent)
VLR C/I threshold	8 dB
VLR/Tx antenna	-2.85 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/350 kHz

Simulation input/output parameters	Settings/Results
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km
IL1A: WBN SRD AP Tx	
Frequency	863-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 186 m)
Number of transmitters in impact area (Medium/High estimate)	3/5
IL1B: WBN SRD Terminal Node Tx	
Frequency	863-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 162 m)
Number of transmitters in impact area (Medium/High estimate)	41/82
IL2: RFID interrogators	
Frequency	865.7, 866.3, 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None

ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6

Table 124: SEAMCAT results interference probability from WBN SRD, unwanted/ (unwanted&blocking), victim: non-specific SRDs in band 865-868 MHz

	Existing adjacent applications			
	Cordless audio, RFID	Cordless audio, RFID	Cordless audio, RFID	/
New applications:	Baseline without new SRDs	WBN SRD ILT in 865-868 MHz	WBN SRD ILT in 863-868 MHz	WBN SRD ILT in 863-868 MHz
High density & path loss, maximum DC	2.0 / 4.1	9.6 / 11.5	8.3 / 10.2	6.0 / 6.2
High density & path loss, average DC	1.5 / 2.9	2.9 / 4.1	2.5 / 4.0	1.0 / 1.0
Medium density & path loss, max DC	2.2 / 3.4	12.0 / 13.2	10.3 / 11.8	9.0 / 9.3
Medium density & path loss, average DC	1.5 / 2.5	2.4 / 3.4	2.2 / 3.2	0.8 / 0.8

A10.5 SIMULATIONS FOR WBN SRD VS. NBN SRD

The following tables provide technical parameters for SEAMCAT simulations and their detailed results, as referred to in Chapter 8.

Table 125: SEAMCAT settings for simulating interference from WBN SRD to NBN SRD applications in 865-868 MHz

Simulation input/output parameters	Settings/Results
VL: NBN SRD Terminal Node Receiver	
Frequency	865-868 MHz/200 kHz channels
VLR sensitivity	-99 dBm/200 kHz
VLR selectivity	Realistic Cat. 2, 45 dB @ dF=2 MHz
VLR antenna gain and height	0 dBi, Non-directional, 1.5 m
VLR C/I threshold	8 dB
VLTx antenna gain and height	2.15 dBi, Non-directional, 5 m
VLTx power	27 dBm/200 kHz
VLTx-Rx path	Hata-SRD, 300 m, outd-indoor
IL1A: WBN SRD AP Tx	
Frequency	863-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	2.15 dBi

Simulation input/output parameters	Settings/Results
APC	None
ILT probability of transmission (Maximum/Average DC)	10/2.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 138 m, protection distance 3 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: Wideband SRD Terminal Node Tx	
Frequency	863-868 MHz, 1 MHz chs.
ILT transmitter output power	14 dBm/1000 kHz
ILT antenna gain	0 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	2.8/0.1 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR positioning mode	None (simulation radius 120 m)
Number of transmitters in impact area (Medium/High estimate)	23/45

Table 126: SEAMCAT results of interference probability from WBN SRD to NBN SRD Terminal Node in 865-868 MHz

Scenario assumptions	Probability of Interference, % (Unwanted / Unwanted & Blocking)
High density & path loss, maximum DC	3.8 / 4.0
High density & path loss, average DC	0.3 / 0.3
Medium density & path loss, maximum DC	4.3 / 4.6
Medium density & path loss, average DC	0.4 / 0.4

Table 127: SEAMCAT settings for simulating probability of interference of NBN SRD to WBN SRD applications in 865-868 MHz

Simulation input/output parameters	Settings/Results
VL: WBN SRD Terminal Node Rx	
Frequency	863-868 MHz/1000 kHz channels
VLR sensitivity	-99 dBm/1000 kHz
VLR selectivity	Realistic Cat. 2, 45 dB @ dF=2 MHz
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/1000 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.02/0.04 km

Simulation input/output parameters	Settings/Results
IL1A: NBN SRD Network's NAP Tx (outdoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	10/2.5%
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	2/3
IL1B: NBN SRD Network's NN Tx (outdoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	2.15 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission (Maximum/Average DC)	2.5/0.7 %
ILT → VLR interfering path	Hata-SRD, urban, **outd**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	13/25
IL1C: NBN SRD Network's TN Tx (indoor)	
Frequency	865-868 MHz, 200 kHz channels
ILT transmitter output power	27 dBm/200 kHz
ILT antenna gain	0 dBi
APC	Threshold -89 dBm, 20 dB range, R=300 m
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, **ind**-ind/below roof
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	269/537
IL2: RFID interrogators	
Frequency	865.7, 866.3, 866.9 or 867.5 MHz
ILT transmitter output power	20 dBm/200 kHz
ILT antenna gain	6 dBi (directional)
APC	None
ILT probability of transmission (Maximum/Average DC)	12.5/7.5 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof

Simulation input/output parameters	Settings/Results
ILT → VLR minimum distance/MCL	10 m/60 dB
ILT → VLR positioning mode	None (simulation radius 300 m)
Number of transmitters in impact area (Medium/High estimate)	14/136
IL3: Cordless Audio	
Frequency	863-865 MHz, 200 kHz channels
ILT transmitter output power	10 dBm/200 kHz
ILT antenna gain	-2.85 dBi
APC	None
ILT probability of transmission (Maximum/Average DC)	100/75 %
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance/MCL	3 m/40 dB
ILT → VLR positioning mode	None (simulation radius 139 m)
Number of transmitters in impact area (Medium/High estimate)	2/6

Table 128: SEAMCAT results of interference probability from 500 mW NBN SRD WBN SRD Terminal Node in 865-868 MHz

Scenario assumptions	Probability of Interference, % (Unwanted / Unwanted & Blocking)
High density & path loss, maximum DC	5.5 / 8.0
High density & path loss, average DC	2.2 / 3.3
Medium density & path loss, maximum DC	4.9 / 7.3
Medium density & path loss, average DC	2.1 / 3.2

ANNEX 11: LIST OF REFERENCES

[1] ECC Report 37: Compatibility of planned SRD applications with currently existing radiocommunications applications in the frequency band 863-870 MHz.
[2] ECC Report 181: Improving spectrum efficiency in SRD bands (September 2012)
[3] ECC Report 200: Coexistence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz, September 2013
[4] ECC Report 207: Adjacent band coexistence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz Approved 31 January 2014
[5] "Channel Access Rules for SRDs", Study by IMST GmbH (November 2012), see: http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Koexistenzstudie_EN.pdf?__blob=publicationFile&v=2
[6] ECC Report 249: Unwanted emissions of common radio systems: measurements and use in sharing/compatibility studies
[7] ETSI TR 103 056 V1.1.1. Technical characteristics for SRD equipment for social alarm and alarm applications
[8] ETSI TR 103 245: Technical characteristics and spectrum requirements of wideband SRDs with advanced spectrum sharing capability for operation in the UHF 870-876 MHz and 915-921 MHz frequency bands
[9] ECC Report 246: Wideband and Higher DC Short Range Devices in 870-875.8 MHz and 915.2-920.8 MHz (companion to ECC Report 200)
[10] EC Decision 2006/771/EC: Commission Decision of 9 November 2006 on the harmonisation of the radio spectrum for use by short-range devices
[11] ERC Recommendation 70-03: Relating to the Use of Short Range Devices (SRD)
[12] ETSI EN 300 220-1 V2.4.1 (2012-05): Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW
[13] ETSI EN 300 330: Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz
[14] ETSI EN 300 440: Radio equipment to be used in the 1 GHz to 40 GHz frequency range
[15] ETSI EN 305 550: Radio equipment to be used in the 40 GHz to 246 GHz frequency range
[16] Report ITU-R SM.2153: Technical and operating parameters and spectrum use for short range radiocommunication devices (07/2013)
[17] Recommendation ITU-R SM.1538: Technical and operating parameters and spectrum requirements for short-range radiocommunication devices
[18] ITU-R Report SM.2028: Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems
[19] Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) software - free download and user manual available at: www.seamcat.org
[20] ETSI TR 102 649-2 V1.3.1: System Reference Document for Radio Frequency Identification (RFID) and SRD equipment; Part 2: Additional spectrum requirements for UHF RFID, non-specific SRDs and specific SRDs
[21] CEN EN54-x: Fire detection and fire alarm systems (multi-part). Available from: http://standards.cen.eu/
[22] ERC Report 101: A comparison of the minimum coupling loss method, enhanced minimum coupling loss method, and the Monte Carlo simulation, Approved May 1999.
[23] ECC Report 252: SEAMCAT Handbook, Approved April 2016
[24] ITU-R Report SM.2154: Short-range radiocommunication devices spectrum occupancy measurement techniques
[25] ITU-R Report SM.2179: Short-range radiocommunication devices measurements
[26] ECC Report 182: Survey about the use of the frequency band 863-870 MHz (September 2012)
[27] CEN EN 14604 Smoke alarm devices. Available from: https://standards.cen.eu/
[28] CENELEC EN 50134-x Alarm systems - Social alarm systems. Available from https://www.cenelec.eu
[29] EN 300 422**:** Wireless microphones in the 25 MHz to 3 GHz frequency range
[30] ETSI EN 301 357: Cordless audio devices in the range 25 MHz to 2 000 MHz
[31] ETSI TR 102 449: Telecommunications and Internet converged Services and Protocols for Advanced Networking (TISPAN); Overview of Radio Frequency Identification (RFID) Tags in the telecommunications industry
[32] ETSI TR 102 886: Technical characteristics of Smart Metering (SM) Short Range Devices (SRD) in the UHF Band;
[33] Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC

[34] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC

[35] Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC

[36] In March 2009, the European Commission issued mandate M/441 for the standardisation of smart metering functionalities and communication for electricity, gas, heat, and water applications

[37] CEN EN 13757-4 Communication systems for meters and remote reading of meters - Part 4: Wireless meter readout (Radio meter reading for operation in SRD bands). Available from: https://standards.cen.eu/

[38] ECE R10 “Approval of Vehicles with regard to electromagnetic stability

[39] ETSI EN 301 489: ElectroMagnetic Compatibility (EMC) standard for radio equipment and services

[40] IEEE 802 ah: License-exempt IEEE 802.11 wireless networks in frequency bands below 1 GHz

[41] ERC Recommendation 74-01: Unwanted Emissions in the Spurious Domain

[42] NTA 8130: Minimum set of functions for metering of electricity, gas and thermal energy for domestic customers

[43] ETSI EN 302 208: Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W and in the band 915 MHz to 921 MHz with power levels up to 4 W

[44] ETSI EN 303 204: Network Based Short Range Devices (SRD); Radio equipment to be used in the 870 MHz to 876 MHz frequency range with power levels ranging up to 500 mW

[45] ETSI TR 103 055: System Reference document (SRdoc): Spectrum Requirements for Short Range Device, Metropolitan Mesh Machine Networks (M3N) and Smart Metering (SM) applications

[46] ETSI STF 411: Method for a harmonized definition of Low Duty Cycle Transmission (LDC) as a passive mitigation technique used by short range devices and related conformance test methods

[47] ETSI TS 103 060: Method for a harmonized definition of Duty Cycle Template (DCT) transmission as a passive mitigation technique used by short range devices and related conformance test methods

[48] Recommendation ITU-R F.1336-3 (03/2012) Reference radiation patterns of omnidirectional, sectoral of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz

[49] ERC Report 25: The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz