ECC Report 200

Co-existence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz

September 2013

0 EXECUTIVE SUMMARY

This ECC report addresses the need for co-existence studies identified within the CEPT Roadmap for designating additional spectrum for SRD/RFID applications in the UHF spectrum, notably in the 870-876 MHz and 915-921 MHz bands.

The report has analysed a broad range of SRD and RFID uses that ETSI proposed to be deployed in the subject frequency bands (see Table 2) alongside several civil and non-civil radiocommunications services and systems that are already in situ or proposed in CEPT countries. The report also considers systems/services operating in adjacent bands. The studies have relied on a combination of methods: including Minimum Coupling Loss link budget calculations to statistical Monte-Carlo based simulations performed with SEAMCAT.

The main goal of this report has been the assessment of the impact of the requested SRD and RFID uses in respect to the primary radio services used in the same and adjacent bands. Some consideration has been given to intra-SRD investigations.

Analysis of trends (ANNEX 1:) indicates that the pattern of current and planned use of the subject bands varies greatly across the CEPT region. This varied use has resulted in different sharing opportunities dependent on the type of systems studied and the results have been structured to enhance the sharing possibilities with each country's combination of services. In some cases SRD equipment will need to be class 2 to ensure the best spectrum efficiency whilst protecting the primary service.

Note that except for some explicit provisions mentioned below, all conclusions are based on SRD/RFID parameters (e.g. channel bandwidths, DC and transmit power ranges) as derived from respective ETSI SRDocs (see chapter 3 and ANNEX 2:).

A. Countries where bands 870-876/915-921 MHz are used for TRR and/or UAS:

Countries where bands 870-876/915-921 MHz or parts of the band are used for TRR and/or UAS may consider introduction of SRD/RFIDs only with certain additional considerations, such as:

- For countries that in the time of peace restrict the use of TRR to designated military exercise areas, adequate physical separation between SRD/RFID and TRR must be ensured. Under these conditions sharing with SRD/RFIDs may be feasible and further aided by requiring SRDs to use APC.
- For countries that in time of peace allow the use of TRR anywhere across their territory, especially in urban areas,
  - sharing between SRD (band 870-876 MHz) and TRR may be feasible subject to specific conditions. In particular, these conditions must impose limitations on SRDs covering emitted power, DC and the density of SRDs per square km, as indicated in the studies. Irrespective, there will be some residual level of interference and the overall noise level to TRR will be increased;
  - sharing between RFID (band 915-921 MHz) and TRR will not be feasible.
- For countries that allow use of UAS anywhere across their territory, especially in urban areas,
  - co-frequency sharing between SRD (870-876 MHz) and UAS may be feasible subject to specific conditions. In particular, these conditions impose limitations on the emitted power of SRDs, their DC and the density of SRDs per square km, as indicated in the studies. Irrespective, there will be some residual level of interference and the overall noise level to UAS will be increased;
  - co-frequency sharing between RFID (915-921 MHz) and UAS will not be feasible in general.
- The countries that use the subject bands for TRR and/or UAS systems in the band 870-876 MHz may allow SRDs as Class 2 devices provided they comply with limits on power and duty cycle. Furthermore there must be certainty that the estimate for the density of devices is not exceeded;
- Sharing conditions may be improved if SRD/RFID could employ additional, more sophisticated mitigation mechanisms, such as DAA[1].

[1] The analysis presented in ANNEX 4: proves that, with simple power sensing on the candidate operational frequency, DAA may only work with very low detection threshold values (in some cases below the noise floor) or for high SNR margins at the victim link receiver. The situation would be improved if the SRD could monitor the emission at the same position where the victim receiver is located. However this would require knowledge about the TRR/UAS duplexing and channel arrangement which cannot be

B. Countries where the bands 873-876/918-921 MHz may be used for ER-GSM:

- The subject bands include sub-bands 873-876/918-921 MHz that are allocated as an extension for pan-European GSM-R systems (referred to as the ER-GSM bands). They may be used by countries that have a heavy railways infrastructure requiring additional network capacity in addition to that provided by the main GSM-R bands 876-880/921-925 MHz;
- Co-frequency sharing with ER-GSM is not generally possible without addition mitigation. It is therefore proposed that countries with plans for using 873-876/918-921 MHz for ER-GSM, may consider the following regulatory arrangements for introducing SRD/RFIDs:
  - Within the bands 870-873/915-918 MHz the considered SRDs/RFIDs may be allowed with the parameters assumed in this report (see Table 2);
  - Within the bands 873-876/918-921 MHz, administrations wishing to avoid harmful interference in both typical and worst case scenarios should introduce the option 1 and/or option 2 timing restrictions for SRDs in Table 1 below. Administrations willing to disregard the high risk of interference for worst case scenarios, and accepting interference probabilities in the average case simulations in the order of 5%, do not require these restrictions;
  - A further option to use ER-GSM bands for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the ER-GSM bands (see Option 3 in Table 1).

Table 1: Options for sharing with ER-GSM

	Option 1: For devices with high deployment figures	Option 2: For devices where low deployment is ensured by regulatory means (e.g. access points) (Note 2)	Option 3: Cognitive approach (Note 1 and Note 3)
DC limit in a bandwidth of 200 kHz	▪ Short term DC limit Max Ton 5ms, Min Toff 995ms, and ▪ Long term DC of around 0.01% per 1 hour	Short term DC limit Max Ton 5ms, Min Toff 995ms	NA
Max Tx power	25 mW	500mW	For RFID at 36 dBm (4W) and SRD at 27 dBm (500 mW). A frequency offset of 100kHz from GSM-R channels is applicable

Option 1 and Option 2 should be considered as lower and upper regulatory boundaries.

Note 1: The requirements for this cognitive approach with ER-GSM are analysed for the band 918-921 MHz in ANNEX 6: and are provided in TS 102 902 V1.2.2 and ETSI TS 102 903 V1.1.1 (2011-08). The latter document also describes the various compliance tests necessary to verify proper operation of the proposed mitigation technique for inclusion in an ETSI standard. The effectiveness of this approach was not tested against non-GSM systems (e.g. 4G, 5G).

Note 2: Low deployment means about 1 device per km^2

Note 3: The DAA mechanism considered and tested for coexistence between ER-GSM and RFID devices in the 918-921 MHz band (see ANNEX 6:) could be also adapted to identify channels not being used by ER-GSM in the vicinity of SRDs in the 873-876 MHz band

C. Countries that deploy Wind Profiler Radars and other than above mentioned services in 870-876 / 915-921 MHz:

It was noted that UK and Isle of Man each have one remote site with a Wind Profiler Radar that are in constant use. However these administrations considered that the Wind Profiler Radars would be adequately

generally assumed. Therefore DAA as a method of operation is not very promising for the protection of TRR and UAS links. Note that due to very low threshold levels DAA may only be possible in cases with prior knowledge of the TRR frequency plan (TDD or FDD with dual band sensing).

protected from the assumed SRD applications (see Table 2). They also considered that any interference events could be managed due to the very low number of WPR in operation, their remote situation and if necessary, the size of any exclusion zone that would be required to provide protection to their WPRs.

D. Countries that do not use the bands 870-876/915-921 MHz:

The adjacent band co-existence between candidate SRD/RFIDs and GSM/GSM-R may be feasible with the SRD/RFID applications and parameter settings assumed in this report.

Other than consideration of coexistence with other services in the subject bands, this study also addressed the feasibility of intra sharing for the envisaged broad variety of SRD and RFID uses as requested by ETSI. This is of primary importance to countries that do not use the bands. Some consideration has been given to this exercise.

As a general conclusion, this study found that intra-SRD sharing of the investigated uses in the bands 870-876 MHz is feasible, assuming the SRD parameters set out in the relevant SRDocs (see Table 2). Even Network Access Points (NAPs) with up to 10% DC may be easily accommodated in most typical co-existence situations, 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.

A similar conclusion on the feasibility of general intra-SRD/RFID sharing of the investigated uses may be drawn also for the band 915-921 MHz assuming the following frequency arrangements:

- Higher-power SRDs and RFIDs are placed in four “high power” channels;
- Lower-power SRDs are interleaved between the “high power” channels;
- Assistive Listening Devices (ALD) with DC up to 25% is also placed in the four RFID channels, assuming co-location is unlikely.

However, manufacturers of devices using the band 915-921 MHz should be aware that the channels 916.3, 917.5, 918.7 and 919.9 MHz may be used by high power SRDs/RFIDs with channel bandwidths of up to 400 kHz.

For countries that do not use the bands 870-876/915-921 MHz, the summary of assessed technical assumptions and parameters for SRDs and RFIDs being deployed in 870-876 MHz and 915-921 MHz bands is provided in the following table.

Table 2: Summary of assessed technical parameters for SRDs and RFIDs for countries that do not use the bands 870-876/915-921 MHz

Frequency Band	SRD Category	Equivalent ETSI SRDoc	Max Power	Max DC	Channel arrangement	Bandwidth
870-876 MHz	Non-specific (low power)	TR 102 649-2	25 mW	1%	870-876 MHz	Up to 600 kHz
	Personal wearable devices (e.g. alarms)	TR 103 056	25 mW	0.1%	870-876 MHz	25 kHz
	Indoor stationary devices (e.g. low duty cycle Home Automation and Sub-Metering)	TR 102 649-2 TR 102 886	25 mW	0.1%	870-876 MHz	Up to 200 kHz
	Automotive	TR 102 649-2	500 mW (2) (3)	0.1%	870-876 MHz	Up to 500 kHz
	Infrastructure network nodes (4)	TR 102 886 TR 103 055	500 mW (3)	2.5%	870-876 MHz	200 kHz
	Infrastructure network access points (4)	TR 102 886 TR 103 055	500 mW (3)	10%	870-876 MHz	200 kHz
915-921 MHz	Non-specific (low power)	TR 102 649-2	25 mW	1%	915-921 MHz	Up to 600 kHz
	Non-specific (medium power)	TR 102 649-2	100 mW	1%	4 channels in 915-921 MHz (1)	Up to 400 kHz
	Indoor stationary devices (e.g. low duty cycle Home Automation and Sub-Metering)	TR 102 649-2 TR 102 886	25 mW	0.1%	915-921 MHz	Up to 200 kHz
	Indoor stationary devices (e.g. high duty cycle Assistive Listening Devices)	TR 102 791	10 mW	25%	4 channels in 915-921 MHz (1)	Up to 400 kHz (6)
	RFID (interrogators)	TR 102 649-2	4 W	2.5% (5)	4 channels in 915-921 MHz (1)	Up to 400 kHz

Note 1: four channels: 916.3, 917.5, 918.7 and 919.9 MHz
Note 2: for Vehicle-to-Vehicle applications only; <100 mW for in-vehicle applications
Note 3: APC always required for applications to reduce unnecessary emission levels.
Note 4: Installation only by professionals – e.g. operator of Smart Metering/M3N network
Note 5: For RFID, a DC of 2.5% is assumed for the hot-spot scenario. In less dense scenarios higher DCs are possible.
Note 6: All ALD simulations were carried out with 200 kHz. If ALD share the channel plan with RFID, the bandwidth permitted may be 400 kHz.

Table 2 provides an example of a possible solution for SRD sharing in countries that do not use the bands 870-876/915-921 MHz and may not necessarily represent the final solution. Not considered were for example broadband SRDs using direct sequence or other spread spectrum techniques and sophisticated channel access techniques such as LBT and AFA.

Where the interrelationship between power, DC and deployment density has been used further consideration may be necessary in developing regulations

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
AF	Activity Factor
AFA	Adaptive Frequency Agility
ALD	Assistive Listening Device
ARFCN	Absolute Radio Frequency Channel Number, a unique channel number in GSM
BCCH	Broadcast Control Channel (of GSM-R base station)
BTS	Base Transmitting Station (feeder station serving a cell in mobile radio system)
BWA	Broadband Wireless Access
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CSMA	Carrier Sensing Multiple Access
DC	Duty Cycle
dRSS	desired Received Signal Strength (term used in SEAMCAT)
DVB-T	Digital Video Broadcasting – Terrestrial
ECC	Electronic Communications Committee
ER-GSM	Extended (in frequency) Railways' GSM
ETSI	European Telecommunications Standards Institute
FHSS	Frequency Hopping Spread Spectrum
HA	Home Automation SRD family, incl. Sub-metering applications
IL	Interfering Link
ILT	Interfering Link Transmitter
iRSS	interference Received Signal Strength (term used in SEAMCAT)
ITS	Intelligent Transport Systems
LBT	Listen Before Talk (Transmit)
LDC	Low Duty Cycle
M3N	Metropolitan Mesh Machine Networks
MCL	Minimum Coupling Loss
MS	Mobile Station (user terminal)
NAP	Network Access Point, infrastructure device in Smart Metering/Smart Grid network
PAMR	Public Access Mobile Radio (e.g. trunking system such as TETRA or similar)
PMR	Private Mobile Radio
RF	Radio Frequency
RFID	Radio Frequency Identification System
R-GSM (GSM-R)	Railways' GSM
SM	Smart Metering
SRD	Short Range Device
TRR	Tactical Radio Relay links (systems used in military environments)
UAS	Unmanned Aircraft Systems
UHF	Ultra High Frequency band (300-3000 MHz)
VL	Victim Link
VLR	Victim Link Receiver
WPR	Wind Profiler Radar

1 INTRODUCTION

This ECC report addresses the need for co-existence studies identified within the CEPT for designating additional spectrum for various SRD and RFID applications in the UHF spectrum. It builds on the previous SRD and RFID co-existence studies in the UHF band. Most notably it could be seen as continuation of work started with the ECC Report 37 [2] related to SRDs and RFID in 863-870 MHz band.

1.1 CURRENT SITUATION IN THE BAND 870-876 / 915-921 MHz

Up to now the European Common Allocations table designated this band for the following applications and users:

- Defence systems;
- Digital land mobile (PMR/PAMR), duplex: 870-876 MHz (uplink) paired with 915-921 MHz (downlink).

The CEPT questionnaire conducted in May-June 2012 with responses from 39 administrations revealed the following picture of how the bands 870-876 / 915-921 MHz were used or planned to be used across Europe:

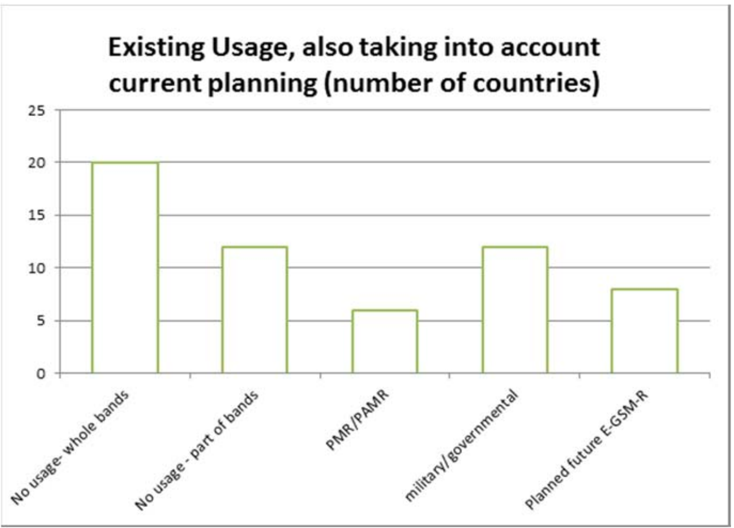


Figure 1: Use of bands 870-876 MHz and 915-921 MHz in 39 European countries (June 2012)

The PMR/PAMR designation in 870-876 / 915-921 MHz was meant to provide an additional paired band for wide-area digital PMR networks, e.g. utilising TETRA or CDMA PAMR band class 12. However, as of today, no PMR/PAMR installations exist in European countries at these frequencies. The ETSI technical committee responsible for TETRA have informed ERM that they have no plans to use these bands.Instead TETRA prefers to operate at lower frequencies. Currently the frequency range 915-921 MHz serves as a guard band between GSM uplink and downlink emissions.

Seeing this prolonged vacancy the European railways' digital system, known as “GSM for Railways” (GSM-R) requested an extension of their operating frequencies to include the paired bands 873-876 MHz and 918-921 MHz. Subsequently CEPT agreed to this request. The additional frequencies are referred to as ER-GSM (Extended Railways GSM) band (see ECC/DEC(04)06 [35]). Already some European countries have issued licenses for the operation in the ER-GSM bands and ER-GSM-enabled systems are expected to appear on the market by 2013. It is envisaged, that ER-GSM will be deployed mostly at locations with high railway use, e.g. shunting areas, urban areas or for high speed trains. In other more remote areas, or in some countries with no dense railways infrastructure, ER-GSM may be not used at all.

ANNEX 1: provides a summary and parameters of radiocommunications systems that may be used in the subject and adjacent bands in accordance with existing regulatory provisions and which therefore warrant protection from new proposed uses, such as SRDs.

1.2 FUTURE SRD/RFID REQUIREMENTS WITHIN THE BAND 870-876/915-921 MHZ

SRD devices are already in operation in the adjacent band 863-870 MHz and their use is steadily growing. To make provision for this expansion, ETSI has developed a System Reference Document (SRDoc) TR 102 649-2 [1] that requests additional frequencies for SRD applications (incl. RFID and other types of specific and non-specific SRD applications). The bands 870-876/915-921 MHz were identified as the prime candidates since they were assumed to be unused and also due to the proximity of the band 870-876 MHz to the existing SRD designation of 863-870 MHz. Also the frequency range 915-921 MHz is widely used by SRDs and RFID in many countries outside Europe, which makes it an attractive band for systems deployed on an international basis.

SRD devices are already installed in large numbers across a wide range of applications within Europe and their use is expected to grow rapidly over the next decade. It is anticipated that the current designations of spectrum for RFID and SRDs will be inadequate to meet their future needs. Several relevant ETSI SRDocs contain descriptions of constantly developing traditional SRD application families (such as automotive, home and building automation, alarms, etc.) as well as some newly emerging SRD applications. The ETSI SRDocs contain independent marketing data that predicts considerable market growth in RFID and SRDs and offers the following justification for new SRD/RFID band designation:

- The SRD industry has expanded considerably over recent years and has now developed into a number of different industrial sectors. These include metering, automotive applications, alarms, and in wider terms, non-specific SRDs such as home and building automation, telemetry, data transmissions, etc. It is anticipated that the present trend in diversification and expansion will continue. An indication of the potential size of the market for SRDs is provided in annex A of ETSI TR 102 649-2 [1];
- New emerging applications are being constantly developed, such as SRDs for Smart Metering (SM), described in ETSI TR 102 886 [3], Metropolitan Mesh Machine Networks (M3N) in TR 103 055 [4], Assistive Listening Devices in TR 102 791 [5] and new Social Alarms and Alarms in TR 103 056 [6]. Based on these recent developments and predictions of market growth contained in the referenced SRDocs, it is very evident that additional spectrum will be necessary for a plethora of emerging new SRD application families;
- Market predictions show robust growth potential for RFID applications. Already the sale of RFID tags in 2010 significantly exceeded the early market predictions. As the commercial benefits of RFID become more widely recognized, the technology will be adopted by many new industries. Some of these applications will require improvements to existing RFID performance. Typical examples include greater reading range, improved reading performance, faster data rates and the use of sensors (e.g. temperature, pressure, etc.) within tags. These requirements can only be met by the provision of additional spectrum. The RFID community is contributing to this process by developing novel methods for co-existence, such as the techniques described in the recently adopted ETSI report TS 102 902 [7].

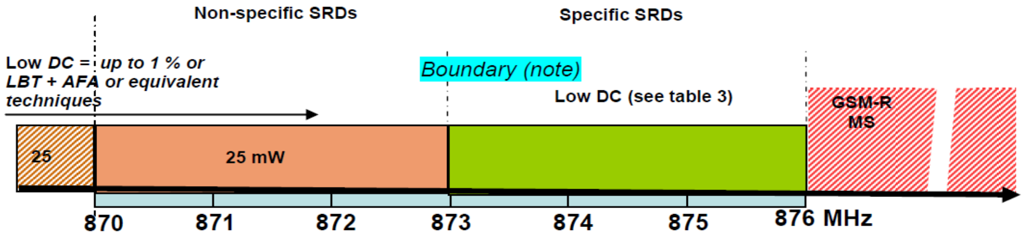
The necessity of finding additional spectrum for SRD and RFID applications was already identified in November 2006 in CEPT Report 14 [8] in response to a mandate from the European Commission. This document developed a strategy to improve the effectiveness and flexibility of the spectrum designation for SRDs and RFID. The CEPT Report 14 recommended that:

- All services in the subject band make more efficient use of spectrum and that full opportunity is taken of possibilities for sharing. Regulators can promote this by providing suitable incentives for spectrum efficiency;
- CEPT should ensure that only the minimum regulations are specified in ERC/REC 70-03 [9] and, where appropriate, the application-specific constraints to spectrum use are removed;
- New bands should preferably be extensions of SRD bands or close to them;
- Any efficiency benefit possibly accrued from the introduction of co-existence techniques such as LBT and/or AFA may be short lived if the anticipated growth in SRDs occurs. Therefore the identification of new spectrum for SRDs employing these techniques is important.

In accordance with these strategic guidelines, CEPT held a public workshop on the future use of UHF spectrum for SRDs and RFID on 4-5 April 2011 at Mainz, Germany. As a result of this consultation, the CEPT has developed a Roadmap for studies and actions aimed at designating additional spectrum for various SRD and RFID applications at UHF. The band 870-876 / 915-921 MHz was named in this roadmap as the prime candidate for co-existence studies.

Although RFID may be seen as part of the SRD family, some of their operational features, most notably their comparatively high transmit power, make them a distinctive application. The TR 102 649-2 [1] notes that it would be desirable to separate the high power transmissions of devices like RFID from the lower power levels generally associated with SRDs. It therefore proposes that the band 870-876 MHz is designated for use by SRDs with transmit powers at less than 100 mW (or little bit higher depending on the study results). The band 915-921 MHz is identified for high power devices such as RFID.

Initially, it was considered in TR 102 649-2 to possibly divide the band 870-876 MHz into two segments. One of these segments would cover devices which use duty cycle up to 1 % or LBT with AFA (or equivalent techniques). The other segment is aimed at SRDs that transmit intermittent very short bursts of power and rely on duty cycle for mitigation. The originally proposed band plan is shown in Figure 2: below.



NOTE: It is expected that the boundary between non-specific and specific SRDs will lie somewhere between 873 MHz and 874 MHz. The exact frequency will be determined following the compatibility study when the impact of GSM-R on the upper part of the band has been quantified. It should be noted that specific SRDs have a minimum requirement for 2 MHz of usable spectrum.

Figure 2: Tentative band plan for 870-876 MHz originally proposed in TR 102 649-2 [1]

However the originally proposed boundary may be affected by the requirement to accommodate ER-GSM and military applications. This represents an important issue for this co-existence study, because this band split is just a hypothetical proposal contained in TR 102 649-2 [1]. If this study shows that there is no reason for a band split, then this report could recommend a different band arrangement.

In that the principle of sub-dividing the band into segments for different SRD applications is now discouraged (see CEPT Report 44 [10]) but dividing into segments (if necessary) based on different signal types and/or access methods is possible. Therefore this approach is a valid option for consideration in this study.

In somewhat similar manner, the TR 102 649-2 also originally proposed a band-plan for RFID in the frequency range 915-921 MHz. Following subsequent feasibility studies between ER-GSM and RFID, the centre frequencies of the four proposed high power RFID channels were amended to give a 100 kHz offset from the centre frequencies of the GSM-R channels. This change gave an additional protection margin of 9 dB [11]. The latest version of the amended band plan is shown in Figure 3: below.

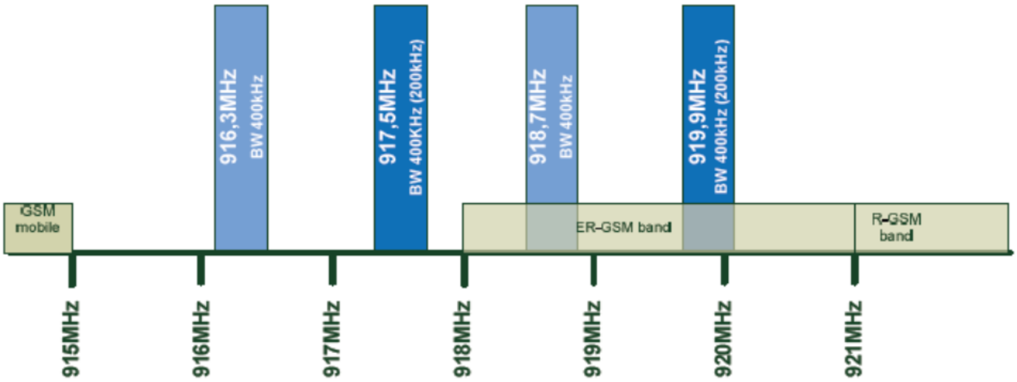


Figure 3: Tentative band plan for 915-921 MHz, based on amended TR 102 649-2 [2] proposal

Feasibility studies have been undertaken within ETSI between RFID and the railway operators to investigate whether sharing of the band is feasible. The results from this work were provided as inputs to this study ([11], [12] and [13]). These studies have subsequently been validated by some practical tests which are available in TS 101 602.

The proposed sharing of the band 915-921 MHz between RFID and non-specific SRD would provide additional spectrum reserve for SRD applications and will be of particular benefit in situations where higher powers are required (e.g. some kinds of automotive or smart metering SRDs that may require higher output powers) or where the candidate SRD applications are unlikely to be present in the same locality as RFID.

A summary of envisaged SRD and RFID applications is provided in section 3 of this report, and their detailed technical parameters in ANNEX 2:.

1.3 PROPOSED APPROACH FOR THE CO-EXISTENCE STUDY

When considering the co-existence study two issues should be taken into account:

- Power coupling aspects, i.e. the primary physical fact of whether the considered interferer has sufficient transmit power to overcome propagation loss from interference and interact with the victim receiver. In itself, this aspect may have two components: individual interference when interferer is a single device, or group interference from multiple devices, such as many SRDs deployed in a limited geographic area.
- Time domain aspects, i.e. given that there is a risk of direct power coupling between the interferer and the victim, to consider what will be the protracted effect of interference over reasonable periods of time. This could be expressed by statistical measures such as probability of interferer's and victim's packet collisions in time, BER on the victim link, voice quality deterioration, etc. This aspect may be especially relevant for the case of interference from SRDs that often operate with a very low Duty Cycles. Their effect may be but a transient glitch on a victim link that could be possibly corrected by the error correction layers of the receiver application.

The first of the above aspects, the power coupling and interference noise generation, should be considered by traditional link-budget oriented interference simulation tools. In view of the highly dispersed and irregular deployment of SRD applications, it was decided that the best approach for the co-existence study was to adopt statistical modelling using the SEAMCAT ([14] and [15]). However, where appropriate, the MCL method was also considered useful e.g. for the analysis of some identified critical co-existence scenarios and the general identification of some boundary-conditions. Such boundary conditions could be either in terms of adjacent frequencies or physical separation, or verifying the maximum range of interference.

Then, for the identified critical cases where there is shown to exist a risk of interference due to sufficient power coupling on the interference link, the time domain aspects must be considered. An example of such recent analysis applied to the case of SRD vs. ER-GSM is reported in [13]. This shows that even with direct power coupling the effect of interference from SRD to ER-GSM may be negligible due to combined effects of DC of less than 2.5% and exploiting channel coding, such as using single Tx bursts of less than 20-25 ms. A complementary analysis is provided in Annex 5.

The purpose of co-existence study is therefore first to check whether the existing and proposed applications can co-exist both power level wise and time domain wise. If they are shown to co-exist without problems, the goal is achieved and the study may stop. But if incompatibility is detected, then a discussion on improving the co-existence potential (and hence increasing spectrum efficiency) is a logical next step.

Given the high complexity of investigating so many applications in the proposed bands, it was decided to structure the study in several stages.

Firstly, addressing the situation in 870-876 MHz:

- In-band inter-system co-existence studies between SRD and ER-GSM use – this establishes the possibility and scope for sharing and any impact on the overall range of SRD use within the limits of 870-876 MHz as well as the proposed splitting into two sub-bands for SRD use as shown in Figure 2:;
- Adjacent-band inter-system co-existence studies at 876 MHz between SRD and R-GSM. The need for this aspect of investigation becomes clear after completion of the first stage;
- Intra-SRD sharing (i.e. between different SRD applications, including Smart Metering and M3N) studies within 870-876 MHz – this stage focuses on different SRD applications in order to establish the minimum mechanisms necessary (LBT/AFA, DC, FHSS, etc.) for their co-existence;
- In-band intra-system studies with any other residual uses of the band, such as defence systems - Tactical Radio Relay links, UAS and nationally implemented CDMA and similar Broadband Wireless Access (BWA) networks – subject to national requests and provision of suitable information;

Secondly, addressing the 915-921 MHz band[2]:

- In-band inter-system co-existence studies between SRD/RFID and ER-GSM – this establishes the potential for sharing and the types of SRD/RFID use within the band 915-921 MHz;
- Adjacent-band inter-system co-existence studies below 915 MHz between SRD/RFID and GSM/LTE and above 921 MHz between SRD/RFID and R-GSM;
- Intra-SRD sharing (i.e. between RFID and SRD applications) studies within 915-921 MHz in order to establish suitable mitigation techniques (AFA, DC, etc.) for their internal co-existence;
- In-band intra-system studies with any other residual users of the band, such as defence systems and nationally implemented BWA networks – subject to national requests and provision of suitable information.

The structure of the report therefore reflects the above proposed approach. Additionally, ANNEX 3: outlines some of the principal methods and tools used to develop this report.

[2] For the benefit of potential world-wide harmonisation of SRD & RFID use, it may be useful to compare possible options for 915-921 MHz band with the existing regulatory provisions for the 902-928 MHz ISM band in the USA

2 DEFINITIONS

Term	Definition
APC	“Automatic Power Control” is a technique employed by a wireless transceiver device in order to minimise energy consumption and at the same time reduce overall interference level to other terminals of the same system as well as to different systems/users of the band. The essence of APC functioning is that the receiver constantly monitors the level of received wanted signal and if that level exceeds certain threshold of sufficient signal level (e.g. C/I over sensitivity threshold), the peer transmitter is instructed to reduce its transmit power level accordingly. The technical parameters (threshold, dynamic range, power adjustment step size, timing, etc.) are to be established in relevant normative technical specifications, such as harmonised standard for a given family of devices.
DAA	“Detect and Avoid” is a technique employed by a wireless transceiver device for mitigating interfering impact on other (primary) users of the band. The essence of DAA functioning is that before first transmission and then at regular intervals during operation, the device scans the entire operational frequency range and “blacklists” the channels where other transmissions had been identified. The sensitivity threshold for DAA detecting function is normally linked to sensitivity threshold of receivers, whereas other technical parameters (listening time, power detection mechanism, repeat cycle, etc.) are to be established in relevant normative technical specifications, such as harmonised standard for a given family of devices.
DC	Duty Cycle: in the context of this report the Duty Cycle is understood to refer broadly to ratio of transmitter’s ON and OFF times. Any more specific timing considerations, such as duration of measurement cycle and whether ON time is constituted by single transmission burst or several transmission bursts within the measurement cycle, etc. is left to be defined in relevant ETSI standards, unless explicitly mentioned among sharing conditions defined in this report.
ER-GSM	Reference to GSM-R extension band 873-876 / 918-921 MHz.
GSM-R	“Railways GSM” refers to radiocommunications network that uses GSM technology to provide closed user group mobile communications services for railways, by connecting trains and railway workers to their respective controlling entities. It is deployed along the railway tracks and railway hubs/logistics centres.
R-GSM	Reference to frequency band 876-88 0 / 921-925 MHz currently used by GSM-R systems.
SRD	“Short Range Devices” refers to radio transmitters, which provide either unidirectional or bi-directional communication, and which have low capability of causing interference to other radio equipment (ECC/REC 70-03). Important to note that by themselves SRDs are not considered a distinctive “Radio Service” in the meaning established by ITU Radio Regulations.
TRR	“Tactical Radio Relay” is a radiocommunications system used in military operations to provide connectivity between various army units. Once deployed it acts as fixed link, however its terminal points may be randomly re-deployed to new places at any time, depending on tactical requirements.
UAS	“Unmanned Aircraft Systems” are pilot-less small aircraft, normally operated at the heights of up to 300 m, and used by public agencies for ad hoc air reconnaissance and surveillance, especially in urban environments, such as observation of public order, tracking of persons and objects, etc.

3 CHARACTERISTICS OF STUDIED SYSTEMS AND APPLICATIONS

The detailed technical parameters and operational scenarios of various radiocommunications systems, whose co-existence is studied in this report, are provided in ANNEX 1:.

This study has considered a range of SRD and RFID technologies and applications. The details of the systems and their characteristics have been derived from a series of five[3] SR Documents submitted to CEPT from ETSI ERM. The systems contained within these documents are described in more detail in ANNEX 2: and are summarized below.

3.1 SPECIFIC SHORT RANGE DEVICES

Five specific SRD applications have been considered as part of this study:

3.1.1 Alarms

Alarm & Social Alarm SRD applications have requested spectrum access arrangements characterised by high reliability for these socially important applications, with powers of up to 25-100 mW and flexible channel bandwidth with low DC (e.g. 0.1%).

3.1.2 Smart Metering and Smart Grid

Smart Metering and Smart Grid applications are intended to support smart utility networks e.g. electricity grid installation, and require greater operating ranges in order provide acceptable indoor-to-outdoor communication. To achieve this, the community has requested the following parameters: transmit power 100 - 500 mW; channel BW of 200 kHz; DC up to 2.5% (i.e. ETSI TR 102 886 in particular).

Smart meter protocols can be complex and the activity of devices can vary from time to time and from node to node in the network, depending on its mode of operation and the number of other nodes with which it communicates. Therefore only a small proportion of smart meters will need to operate at full peak DC, especially in dense deployment scenarios. The SEAMCAT simulations are conservative in this regard.

A typical smart meter at a customer’s premises would normally exhibit much lower average activity than peak when communicating with the network. This case was therefore considered by the present study, by offering an allowance for the peak to mean ratio of the actual Smart meter duty cycle.

This fulfilled the peak DC limit at 2.5% requested in the ETSI SRDoc to permit the small number of meters that operate at that level of activity.

It may be additionally noted that the nature of smart metering and smart grid applications may call for establishing a certain network infrastructure, i.e. a small number of access gateways to sink data collected from across various terminal nodes into fixed infrastructure maintained by a utility company. Due to acting as traffic aggregators, the activity on these nodes will be higher than on the terminal nodes. The industry therefore requested to define separate SRD device type that may be referred to as “Network Access Point (NAP)” and described as follows:

“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.”

This report considers whether the introduction of NAPs with transmit DC of up to 10% would have any significant impact on co-existence prospects of proposed SRD applications. It should be noted that such devices will, typically, receive similar levels of aggregated traffic from a large number of serviced nodes.

[3] TR 102-649-2 Generic SRD, RFID, and Automotive SRD, TR 102 886 Sub-metering / Smart Meters and Smart Grid, TR 103 055 Metropolitan Mesh Machine Networks (M3N) applications, TR 103 056 Alarm and Social Alarm systems, TR 102 791 Assistive Listening Devices.

3.1.3 Home Automation and sub-metering

Home Automation (HA) and sub-metering have been merged into one category due to their similar parameters. A transmit power of 25 mW and a channel BW of 200 kHz have been requested. The duty cycle of these devices is typically very low because they support a high density of devices within single dwellings. From consideration of the many relevant applications a duty cycle of 0.0025% has been assumed for the simulations. Any reference made to home automation throughout this report should be considered as a reference to both home automation and sub-metering.

3.1.4 Automotive applications

Automotive applications requested include both intra- and inter-vehicle applications, including tyre pressure monitoring systems, security applications, crash warning and truck-to-trailer communications. Technical characteristics requested include 100 mW and higher transmit powers, channel BW up to 500 kHz, DC up to 0.1%.

Automotive applications may require using NAPs for information exchange between cars and road infrastructure.

3.1.5 M3N

Metropolitan Mesh Machine Networking (M3N) will enable the sharing of several services on a single network, allowing interaction between devices of different services. M3N will allow various devices to be connected to different city automation & monitoring services over a single network - a first step toward the Internet of Things. When comparing the emerging Automotive, SM/SG and M3N requirements it becomes clear that this study needs to determine acceptable DC limits at different power levels up to 500 mW.

This is another type of professionally deployed networks with wider coverage; therefore it may be anticipated that NAPs also will be used in M3N network applications.

3.1.6 ALDs

Assistive Listening Devices (ALD) using digital technology will be installed indoors in public buildings only (stations, museums, etc.) and employ up to 400 kHz per channel each of up to 10 mW.

3.2 RFID

Five different scenarios are considered representative of the way in which RFID might be used. These include:

- “Hotspot”: multiple RFID interrogators in a hotspot such as a large warehouse/distribution centre (dense interrogator scenario);
- “Airport”: RFID readers on conveyors at airport terminals for baggage handling (e.g. a baggage handling hall in an airport terminal building. Such systems would be carefully designed and have to satisfy the requirements of the airport frequency management department);
- “Store”: a line of interrogators at the check-outs of a store (a row of check-out counters at a supermarket; due to shorter distances only 500 mW e.r.p. is assumed);
- “Other”: a typical concentration of RFID interrogators in an outdoor environment (any other usage not specially defined);
- “Item tagging”: RFID in a store, i.e. an additional variation of the store scenario, in which individual items are tagged so that they may be identified.

It is proposed that SRD & RFID should operate in the band 915 to 921 MHz. The parameters of SRDs for this band would generally conform to those described in previous sub-sections, and any band-specific deviations are addressed during simulations.

To enable multiple RFID interrogators to transmit simultaneously in the same geographic space and to minimise possible interference with other users of the same spectrum, it is proposed in ETSI TR 102 649-2 [1] to use a 4-channel plan. The transmit signal from an RFID interrogator would be at a power level of up to

4 W e.r.p. and occupy one of the high power channel of 400 kHz. The two channels on each side of the high power channel would be reserved for the backscatter response from the tag. Typically tags will respond at offset frequencies of approximately 600 kHz or 300 kHz, which is set by the configuration of the interrogator. The power level of the response from a tag will be –10 dBm e.r.p. or less depending on its distance between the tag and interrogator and the nature of the material to which it is attached.

RFID defines this form of operation as the dense interrogator mode. It separates the high power transmission of the interrogator from the low power signals of the tags, which improves system performance. It also permits transmissions from multiple interrogators on the same channel. In fact provided that an adequate minimum working distance is maintained between adjacent interrogators, there is no upper limit to the number of interrogators that may simultaneously operate at the same frequency. In all high density applications alternate interrogators will operate on different channels. Typically no more than two channels would be in use at a given time/place.

RFID transmit using directional antenna with a resulting e.r.p. of up to +36 dBm, however, in most cases they will be deployed in a semi-shielded environment, and pointed downwards, meaning that their environmental emission levels should be comparable to those from an SRD transmitting with e.r.p. of +20 dBm.

3.3 GENERIC SRDS

Non-specific SRDs applications are defined within Annex 1 of ERC/REC 70-03 [9] to be those not explicitly identified. Typical non-specific SRD applications will include Home and Building automation; Telemetry and telecommand; Mixed speech and data; Access control; Machine to Machine; Aviation and Maritime applications.

The technical characteristics of these types of devices will be many and varied, but typical characteristics will be 25-100mW, DCs up to 1% and an occupied bandwidth of up to 600 kHz. For the purposes of the study in the 915-921 MHz band, two categories of SRD have been defined:

- Non-specific SRDs Type A: 25 mW, 1% DC;
- Non-specific SRDs Type B: deployed with power up to 100 mW in the same 4 “high-power” channels as assigned to RFIDs.

Further details on parameters of studied SRD applications are provided in ANNEX 2:.

4 COMPATIBILITY WITH EXISTING SYSTEMS

4.1 COMPATIBILITY WITH UNMANNED AIRCRAFT SYSTEMS (UAS)

4.1.1 Co-existence with systems for Telecommand to UAS in 870-876 MHz

4.1.1.1 Parameters and use of UAS devices in 870-876 MHz

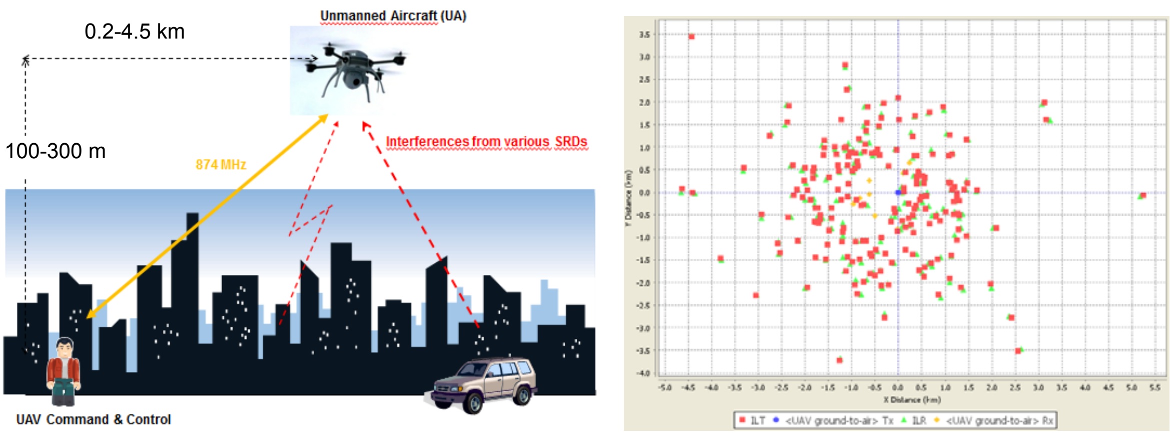
The UAS use was not up to now widely known nor were there any provisions for such use in the European Table of Common Frequency Allocations. However at the commencement of this study some countries reported the use of wireless communications to UAS in subject band as being an existing governmental application. The technical parameters of UAS transceivers are described in Annex A1.4, along with reference to Report ITU-R M.2171 [16] that describes a range of various frequencies outside the 870-876 MHz that may be used for providing communications with unmanned aircraft.

The considered UAS in subject frequency band are envisaged to be mainly used by the Police forces, especially in urban environments for various surveillance operations such as during international summits, observation of public order or tracking of dangerous people on a case by case basis. The same type of UAS could be also used by military, normally over military training grounds but also possibly over civil population areas during crisis periods.

It is to be expected that the use of UAS (and also terrestrial robots and maritime unmanned vehicles) will increase in the near future. For example, the customs may use mini UAS for maritime and terrestrial surveillance (illegal traffic, control of maritime routes, suspicious movements near borders) and civil security authorities could use UAS for fire surveillance or rescue operations in difficult access areas.

4.1.1.2 UAS vs. SRD co-existence scenarios in 870-876 MHz

The following simulations consider an interference scenario where ground-based SRD devices create interference to the UAS-mounted victim receiver, as depicted in the following figure. In this case an example of SRD use is shown to simplify the picture.



(a) (b)

Figure 4: Scenario of SRD vs. UAS co-existence in 870-876 MHz: (a) – general vision in urban environment, (b) – snapshot view in SEAMCAT with 10 active interferers

The altitude of the flying UAS poses the most critical challenge, as it ensures the line of sight visibility to large areas on the ground.

Otherwise, the overall set-up of SRD-UAS co-existence simulations scenario follow the configuration and principles that were used for SRD-TRR scenario in the preceding sub-section, except that in this case the SEAMCAT scenario settings assume an urban deployment environment.

Given that some countries may require exceptional protection for the operation of governmental systems, this report considers two cases when analysing scenarios of co-existence between SRDs and governmental systems:

- **Case A: “Typical Scenario”**, which may be characterised by assuming average conditions balancing out the pros and cons for co-existence;
- **Case B: “Critical Scenario”**, which may be characterised by assuming the worst case for co-existence and thus ensuring a high level of protection for governmental use.

According to these principles, the co-existence scenarios are tuned to represent a typical situation and the worst case.

4.1.1.3 Results of simulations – MCL single entry in 870-876 MHz

The high altitudes of UAS operation mean that the Line-of-sight conditions could not be disregarded even at a larger distances. In such situations even a single interfering device could have good power coupling conditions on the interference path and may potentially affect the operation of UAS. In order to check what kind of impact distances could be considered for such case, first of all the MCL analysis is applied for the case of single interferer. The Table below provides results of calculations for a set of interfering SRD devices. The respective radio parameters of UAS and SRDs are in accordance with what was described in ANNEX 1: and ANNEX 2:.

Note that by its very nature of static representation of unwavering interference coupling link, the application of MCL analysis may be seen as providing ultimate theoretical limit on interference for Case B – Critical Scenario configuration.

Table 3: Results of single entry MCL analysis for interference to UAS

Victim system: UAS receiver						
Operating frequency	MHz	874				
Bandwidth (IF)	MHz	0.2				
Ga (in the direction of Interferer)	dBi	0				
System noise temperature	degK	290				
Noise figure	dB	5				
Noise	dBm	-115.99				
I/N protection criterion		-6				
Max interference at receiver input	**dBm**	-122.0				
	dBm/MHz	-115.0				
Additional attenuation (wall loss)	dB	0	10	0	0	10
Interfering systems: SRD transmitters						
		Non-spec SRDs	**Home auto-mation**	**Portable alarms**	**Auto-motive**	**Metro utilities (SM/M3N)**
Nominal output power	dBm	14	14	20	20	27
Reference bandwidth	MHz	0.6	0.2	0.025	0.5	0.2
Transmitter output power density	dBm/MHz	18.77	14.00	10.97	23.98	27.00
Antenna gain	dBi	0	0	0	0	0
Interferer e.i.r.p. density	dBm/MHz	18.77	14.00	10.97	23.98	27.00
Impact range calculation:						

Victim system: UAS receiver						
Required Minimum Coupling Loss margin	dB	133.8	119.0	126.0	139.0	132.0
Impact range using FSL model	km	133.4	24.3	54.3	242.9	108.8
Impact range using Hata Suburban model	km	>30	>30	>30	>30	>30
Impact range using Hata Urban model	km	22	9	14	30	21

As may be seen from these results, the worst case static impact ranges for SRD to UAS interference could be very large.

4.1.1.4 Results of simulations – SEAMCAT analysis without mitigation in 870-876 MHz

In order to complement the static MCL analysis reported in the previous sub-section, it is worth also performing the statistical simulations. These would evaluate the dynamic and random conditions observed in real life, such as the sporadic nature of SRD transmissions and their random scattering in the interference area.

The selected overall scenario outline represents the operation of UAS in urban area, with geographical extent as illustrated in Figure 4: above. The choice of urban operation will have an impact both on the SRD deployment densities and the propagation path losses. The same area of SRD and UAS deployment is considered, given the previously described UAS pattern of use in civil environments.

As described above, two cases are considered with some distinctive specifics:

- Case A “Typical Scenario” is for SRD vs. UAS co-existence characterised by assuming that UAS control console is located on street level with Non-LOS condition to UAS, similarly NLOS condition may be assumed for SRD to UAS path, with path loss modelled by Hata-Extended model;

- Case B “Critical Scenario” for SRD vs. UAS co-existence is characterised by assuming LOS conditions on both wanted and interfering link, such as may be the case when UAS is operated over open space (e.g. over large park area). The path loss in this case would be modelled by Free Space Loss model.

The representative mix of SRD device families and their respective deployment densities for urban scenario will be identical to those derived for specific SRDs vs. GSM-R simulations in section 4.4.2.4.

Table 4: Simulation results: mix of SRDs to UAS telecommand link (Case A: Typical Scenario)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	874.00 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL1: Metropolitan utilities (Smart Metering/M3N)	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
IL → VL interfering path	Indoor-outdoor/below roof

Simulation input/output parameters	Settings/Results
ILT density	2000/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	38
IL2: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	50000/km^2
ILT probability of transmission	0.000025
ILT: number of active transmitters	3
IL3: Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	12/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	1
IL4: Automotive (high power variety)	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
IL → VL interfering path	Outdoor-Outdoor/below roof
ILT density	80/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	7
General settings for all ILs	
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Extended Hata, urban mode
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-94 (10)
Probability of interference, C/I = 15 dB, %	**38**
Probability of interference, I/N = -6 dB, %	**99**

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim

Table 5: Simulation results: mix of SRDs to UAS telecommand link (Case B: Critical Scenario)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	874.00 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)

Simulation input/output parameters	Settings/Results
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL1: Metropolitan utilities (Smart Metering/M3N)	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	2000/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	38
IL2: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	50000/km^2
ILT probability of transmission	0.000025
ILT: number of active transmitters	3
IL3: Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	12/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	1
IL4: Automotive (high power variety)	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
IL → VL interfering path	Outdoor-Outdoor/below roof
ILT density	80/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	7
General settings for all ILs	
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Free Space Loss model (variations 5 dB)
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-51 (8)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-65 (8)
Probability of interference, C/I = 15 dB, %	**58**
Probability of interference, I/N = -6 dB, %	**100**

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim

The simulation results indicate clearly the high interference levels for both Typical and Critical Cases. Unless some additional co-existence arrangements and interference mitigation techniques were employed, this situation may only allow introducing some very specific low power (up to 25 mW) SRD devices with low deployment figures and low DC. For example, the probability of interference for only alarm applications with 25 mW (IL3 in Table 5) would be for the typical scenario about 0.1% for C/I 15dB and 2% for I/N -6 dB.

4.1.1.5 Results of simulations – SEAMCAT analysis with APC in 870-876 MHz

The following table reports the results of interference simulation for the case if SRDs were required to employ APC.

Table 6: Simulation results: mix of SRDs with APC to UAS (Case A: Typical Scenario)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	874.00 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL1: Metropolitan utilities (Smart Metering/M3N)	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Indoor-Outdoor/below roof
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	2000/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	38
IL2: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.01 km, ind-ind/below roof
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	50000/km^2
ILT probability of transmission	0.000025
ILT: number of active transmitters	3
IL3: Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
APC threshold and range/step	-95 dBm/25 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Outdoor-Outdoor/below roof
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	12/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	1

Simulation input/output parameters	Settings/Results
IL4: Automotive (high power variety)	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
APC threshold and range/step	-82 dBm/500 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Outdoor-Outdoor/below roof
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	80/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	7
General settings for all ILs	
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Extended Hata, urban mode
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-100 (12)
Probability of interference, C/I = 15 dB, %	**26**
Probability of interference, I/N = -6 dB, %	**96**

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim

Table 7: Simulation results: mix of SRDs with APC to UAS (Case B: Critical Scenario)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	874.00 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL1: Metropolitan utilities (Smart Metering/M3N)	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Indoor-Outdoor/below roof
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	2000/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	38
IL2: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz

Simulation input/output parameters	Settings/Results
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.01 km, ind-ind/below roof
IL → VL interfering path	Indoor-Outdoor/below roof
ILT density	50000/km^2
ILT probability of transmission	0.000025
ILT: number of active transmitters	3
IL3: Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
APC threshold and range/step	-95 dBm/25 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Outdoor-Outdoor/below roof
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	12/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	1
IL4: Automotive (high power variety)	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
APC threshold and range/step	-82 dBm/500 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Outdoor-Outdoor/below roof
IL → VL interfering path	Outdoor-Outdoor/above roof
ILT density	80/km^2
ILT probability of transmission	0.001
ILT: number of active transmitters	7
General settings for all ILs	
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Free Space Loss model (variations 5 dB)
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-51 (8)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-70 (10)
Probability of interference, C/I = 15 dB, %	41
Probability of interference, I/N = -6 dB, %	100

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim.

These results indicate that introducing APC requirement on SRDs would have insufficient effect in both considered cases.

4.1.1.6 Analytical study of DAA to facilitate sharing between SRD and UAS

Please refer to ANNEX 4: for discussion of DAA threshold computation theory and how it may be considered to apply to the case of UAS operation. It is shown there that this mitigation technique would not improve the co-existence prospects between UAS and SRD as the correct operation would require DAA sensing threshold below the thermal noise level.

4.1.1.7 Summary of UAS vs. SRD co-existence studies in 870-876 MHz

For UAS deployed in the same areas as an assumed mix of SRD applications with high deployment figures, the simulation results clearly indicate a high risk of interference.

The consideration of APC shows small improvement compared with scenario without mitigation, but also here the simulation results indicate a high risk of interference.

Consideration of DAA shows that this technique would not be helpful to improve co-existence between SRDs and UAS.

4.1.2 Co-existence with systems for Telecommand to UAS in 915-921 MHz

As discussed in annex A1.4, the UAS may be considered in use in some countries also in the band 915-921 MHz. Therefore this section had considered co-existence of envisaged RFID/SRD applications with UAS systems in subject band.

All scenario settings and technical parameters for UAS systems shall be as discussed in section 4.1.1. Clearly the impact for mixed SRD applications would be comparable as was already shown in 4.1.1, therefore the following focuses solely on SEAMCAT simulations for RFID trying to establish an overall probability of interference in dynamic real-life settings.

4.1.2.1 Results of simulations – SEAMCAT analysis with RFID in the band 915-921 MHz

The interfering RFID parameters correspond to assumptions described in Annex A2.5. Because UAS is using just one 200 kHz channel, there may be two cases considered: when one of interfering RFID channels overlaps with victim UAS channel, and when RFID and UAS channels do not overlap. These may be then assigned to be considered as part of respectively Case B (overlapping) and Case A (non-overlapping) scenarios. The results of respective SEAMCAT simulations are reported in the two following tables.

Table 8: Simulation of RFID to UAS in 915-921 MHz (Case A: Scenario w/o channel overlap)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	916.2 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL: RFID	
Frequency	**917.5; 918.7; 919.9 MHz**; 400 kHz channels
ILT power e.i.r.p.	20 dBm (antenna pattern according Figure 29: in A2.5)
IL → VL interfering path	indoor-outdoor
ILT density	480/km^2
ILT probability of transmission	0.025

Simulation input/output parameters	Settings/Results
ILT: number of active transmitters	12
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Hata Extended model, urban mode
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-138 (7)
Probability of interference, C/I = 15 dB, %	**0.0**
Probability of interference, I/N = -6 dB, %	**2.2**

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim

Table 9: Simulation of RFID to UAS in 915-921 MHz (Case B: Scenario with channel overlap)

Simulation input/output parameters	Settings/Results
VL: UAS Telecommand link (airborne receiver)	
Frequency	916.2 MHz
VLR sensitivity	-90 dBm/200 kHz
VLR antenna	0 dBi
VLR height	100-300 m (uniformly distributed)
VL Tx power e.i.r.p.	43 dBm
VL Tx → Rx path	Uniform (distance/polar angle), R=0.2…4.5 km
IL: RFID	
Frequency	**916.3; 917.5; 918.7; 919.9 MHz**; 400 kHz channels
ILT power e.i.r.p.	20 dBm (antenna pattern according Figure 29: in A2.5)
IL → VL interfering path	indoor-outdoor
ILT density	480/km^2
ILT probability of transmission	0.025
ILT: number of active transmitters	12
ILT → VLR positioning mode	Uniform density around VLR position
ILT → VLR minimum distance	200 m (1)
VL Tx → Rx & ILT → VLR path loss	Free Space Loss (variations 5 dB)
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-51 (8)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-41 (14)
Probability of interference, C/I = 15 dB, %	**97**
Probability of interference, I/N = -6 dB, %	**100**

1. Minimum (protection) distance corresponds to average 200 m vertical separation between ground based interferer and airborne victim

4.1.2.2 Summary of UAS vs. SRD and RFID co-existence studies in 915-921 MHz

For UAS deployed in the same areas as an assumed mix of SRD applications with high deployment figures, the simulation results clearly indicate a high risk of interference.

The consideration of APC shows small improvement compared with scenario without mitigation, but also here the simulation results indicate a high risk of interference.

When considering operation of UAS in the same areas where RFID are deployed, the simulations show that for typical scenarios co-existence in general is not feasible unless it is possible to ensure that RFID and UAS operate on non-overlapping channels (1.3 MHz offset assumed in the studies).

It may be conjectured that APC/DAA effect would be identical as estimated in 4.1.1 and ANNEX 4:, not offering significant benefits for protection of UAS.

4.2 COMPATIBILITY WITH TACTICAL RADIO RELAY (TRR)

4.2.1 Co-existence with Tactical Radio Relays in 870-876 MHz

This sub-section considers the co-existence of SRD applications with the legacy Tactical Radio Relay (TRR) systems that are used in some s countries. Similarly as was introduced in previous section on UAS, two cases of co-existence scenarios are considered here as well: Case A Typical Scenario and Case B Critical Scenario.

4.2.1.1 Parameters and use of TRR

The main radio parameters of TRR systems were given in Annex 0, with reference to STANAG – an interoperability agreement for use of specific equipment type (not to be mixed up with the ETSI standard). As regards the operational usage, the TRR systems are used exclusively by military, i.e. for establishing tactical transportable links to the remote military units. As such, during times of peace such systems would be mostly used for military exercises in designated but not necessarily enclosed/fenced areas and also for Public Protection & Disaster Relief operations in public areas.

It may be possible in some cases that (i.e. not war, nor military exercise area, nor some disaster) the use of TRR and civil radiocommunications devices would be geographically separated. This concept was introduced for TRR co-existence studies reported in ECC Report 34 [17] under the name of “population pockets”, see figure 5 below for illustration. This case will be considered appropriate for Case A “Typical Scenario”.

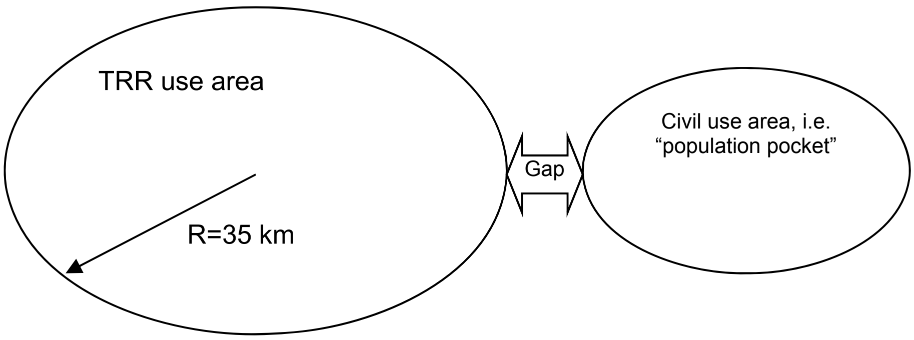


Figure 5: Illustration of civil-use “population pockets” vs. TRR use areas

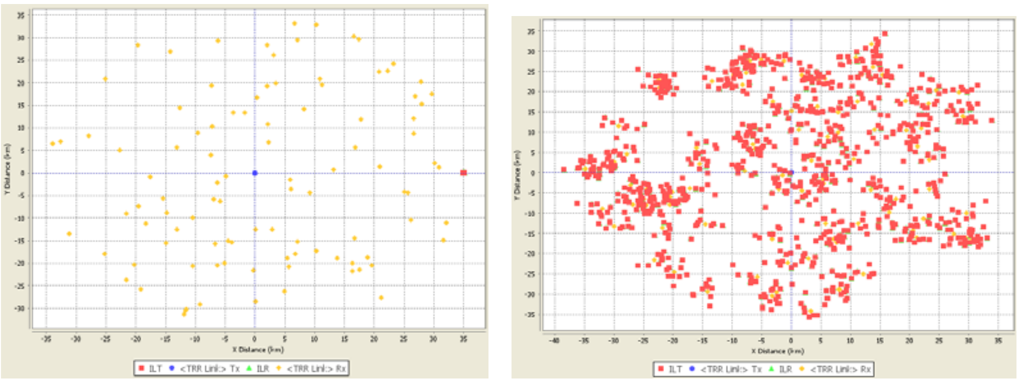
The radius of TRR deployment area is chosen at 35 km, which corresponds to typical link distance.

4.2.1.2 TRR vs. SRD co-existence scenarios

In order to analyse co-existence between TRR and SRD, this study would have to consider the case of in-band (co-channel) operation of TRR and SRD within the band 870-876 MHz. Two principal scenarios are considered to judge the boundaries of the co-existence problem. First scenario – Case A Typical –is based on the concept of “population pockets”, as illustrated in Figure 5: above. Previous studies had addressed different gap sizes. As a reasonable assumption, the Case A Typical scenario in this study it was proposed to consider gap size of 1 km, primarily because in dense European environments the military exercise areas may be very closely interspersed with civil areas so 1 km may be considered as reasonable minimalistic separation.

In order to model Case B – Critical Scenario – the TRR user community contributing to this study indicated that TRR links may be established to the predefined spots that are outside the military exercise areas. To model such an occurrence, the Case B scenario is used where the victim receiver of the stationary TRR link is placed right in the middle of the SRD deployment area, similar to that considered for the GSM-R BTS same area deployment in section 4.4.1.1. Also the link distance will be increased to 70 km in order to create conditions of very low margin on wanted signal.

The resulting representation of two scenarios in SEAMCAT is illustrated by simulation window screenshots in the figure below.



(a) (b)

Figure 6: Illustration of TRR vs. SRD simulation scenarios: (a) Case A: SRD civil-use “population pockets” vs. TRR in military exercise area; (b) Case B: TRR victim surrounded by SRD devices

Note that in the first screenshot of this figure the interferers – the pocket of SRD use – registers just as one large red dot, due to very large scale of the simulation field.

In order to model such displaced operational areas, in the first Case A scenario with “population pockets” the Interferer to Victim placement has to follow the so called “Correlated” modes in SEAMCAT scenario setting. In this placement mode each modelled Interfering link can only have one active transmitter. So for this scenario only one transmitter is active in each link, but they are made to operate with DC=100%, thus effectively representing a larger population of devices, e.g. for SRD devices with nominal DC=0.1% this would represent a populace of 1000 active devices.

For the second Case B scenario with TRR victim surrounded by the SRD devices, the Uniform placement mode could be used. The corresponding numbers of simultaneously active devices of the representative mix of SRD families were assumed to be 1/3 of the values derived for simulations in of specific SRDs section 4.4.2.4. This was to account for the fact that in this scenario we consider rural/sub-urban case as opposed to urban case considered for specific SRD simulations in 4.1.2.2. Except for the automotive applications, since the roads are omnipresent and the used value of SRD density is based on a pan-European average.

4.2.1.3 Results of SEAMCAT simulations without mitigation in 870-876 MHz

The following table describes the SEAMCAT scenario settings and corresponding results of simulations of interference from mixed SRD use into a TRR link for the two above described deployment scenarios: SRDs operating in "population pocket" immediately adjacent to military exercise area (Case A Typical Scenario) and the TRR victim being in the centre of the SRD deployment area (Case B Critical Scenario).

Table 10: Simulation results: mix of SRDs to TRR links in 870-876 MHz

Simulation input/output parameters	Settings/Results	
	Case A (Typical Scenario)	Case B (Critical Scenario)
VL: TRR Link (reference type as per STANAG-4212 agreement [18])		
Frequency	875.25 MHz	
VLR sensitivity	-100 dBm/1500 kHz	
VLR antenna	16 dBi	
VLR height	25 m	
VL Tx power e.i.r.p.	37 dBm	
VL Tx → Rx path	Extended-Hata, rural, Outdoor-Outdoor/above roof	
VL Tx → Rx distance	R=35 km	Constant 70 km
IL1: Metropolitan utilities (Smart Metering/M3N)		
Frequency	870-876 MHz, 0.2 MHz steps	
ILT power e.i.r.p.	27 dBm/200 kHz	
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	1000/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	19
IL2: HA		
Frequency	870-876 MHz, 0.2 MHz steps	
ILT power e.i.r.p.	14 dBm/200 kHz	
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density around VLR
ILT density	Not applicable	17000/km^2
ILT probability of transmission	1.0	0.000025
ILT: number of active transmitters	1	1
IL3: Alarms		
Frequency	870-876 MHz, 0.025 MHz steps	
ILT power e.i.r.p.	20 dBm/25 kHz	
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	12/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	1
IL4: Automotive (high power variety)		
Frequency	870-876 MHz, 0.5 MHz steps	

Simulation input/output parameters	Settings/Results	
	Case A (Typical Scenario)	Case B (Critical Scenario)
ILT power e.i.r.p.	27 dBm/500 kHz	
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/above roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	80/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	7
Simulation results		
dRSS, dBm/1500 kHz (Std.dev., dB)	-50 (11)	-75 (9)
$iRSS_{unwanted}$, dBm/1500 kHz (Std.dev., dB)	-150 (20)	-78 (9)
Probability of interference, C/I = 15 dB, %	**0.0**	**82**
Probability of interference, I/N = -6 dB, %	**3.5**	**100.0**
Probability of interference, I/N = -20 dB, %	**20.0**	**100.0**

1. STANAG-4212 is an agreement, which defines interoperability parameters and is often the least common denominator between TRR equipment of different nations. National systems can differ significantly from a STANAG as long as they can fulfil the STANAG requirements.

If TRR were to be deployed in the same areas as SRD (Case B in the above table), the simulation results indicate clearly the high interference levels, unless some additional co-existence arrangements and interference mitigation techniques are implemented. The impact could only be reduced if the TRR usage could be restricted to dedicated military exercise areas (Case A). Note that the result for the interference criteria of I/N=-20 dB may be seen as a conservative assumption, given the anticipated immunity of TRR equipment to withstand the hostile interference environments of modern warfare.

Based on that analysis it may be concluded that unless some additional mitigation technique were found and proven feasible, only very specific applications with low deployment values and low DC may be imaginable in countries that want to safeguard unrestricted operation of TRR (i.e. corresponding to Case B critical scenario); for example the probability of interference for Case B but assuming only alarm applications (IL3 in above Table 10) with 25mW would be about 5% for C/I 15dB and 21% for I/N -6 dB.

4.2.1.4 Results of SEAMCAT simulations with APC in 870-876 MHz

The first additional SRD interference mitigation measure that could be considered is introduction of Automated Power Control (APC), which is logical precaution mechanism especially for the cases of SRDs allowed higher power up to 500 mW. To model the effect of this mechanism on interference potential, the APC range of 20 dB was assumed for SRDs, with sensitivity threshold set to (RX_{sens}+10 dB). The results of simulations with APC are shown in the below table.

Table 11: Simulation results: mix of SRDs with APC to TRR links

Simulation input/output parameters	Settings/Results	
	Case A (Typical scenario)	Case B (Critical Scenario)
VL: TRR Link (reference type as per STANAG-4212 agreement[18])		
Frequency	875.25 MHz	
VLR sensitivity	-100 dBm/1500 kHz	
VLR antenna	16 dBi	
VLR height	25 m	
VL Tx power e.i.r.p.	37 dBm	

Simulation input/output parameters	Settings/Results	
	Case A (Typical scenario)	Case B (Critical Scenario)
VL Tx → Rx path	Extended-Hata, rural, Outdoor-Outdoor/above roof	
	R=35 km	Constant 70 km
IL1: Metropolitan utilities (Smart Metering/M3N)		
Frequency	870-876 MHz, 0.2 MHz steps	
ILT power e.i.r.p.	27 dBm/200 kHz	
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB	
ILT → ILR path	0…0.3 km, rural, Indoor-Outdoor/below roof	
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	1000/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	19
IL2: HA		
Frequency	870-876 MHz, 0.2 MHz steps	
ILT power e.i.r.p.	14 dBm/200 kHz	
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB	
ILT → ILR path	0…0.01 km, Rural, ind-ind/below roof	
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density around VLR
ILT density	Not applicable	17000/km^2
ILT probability of transmission	1.0	0.000025
ILT: number of active transmitters	1	1
IL3: Alarms		
Frequency	870-876 MHz, 0.025 MHz steps	
ILT power e.i.r.p.	20 dBm/25 kHz	
APC threshold and range/step	-95 dBm/25 kHz; range 20 dB, step 2 dB	
ILT → ILR path	0…0.3 km, Rural, Outdoor-Outdoor/below roof	
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	12/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	1
IL4: Automotive (high power variety)		
Frequency	870-876 MHz, 0.5 MHz steps	
ILT power e.i.r.p.	27 dBm/500 kHz	
APC threshold and range/step	-82 dBm/500 kHz; range 20 dB, step 2 dB	
ILT → ILR path	0…0.3 km, rural, Outdoor-Outdoor/below roof	
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/above roof	
IL → VL positioning mode	Correlated:	Uniform density, 1 km

Simulation input/output parameters	Settings/Results	
	Case A (Typical scenario)	Case B (Critical Scenario)
	VLT → ILR = 36 km	protection distance
ILT density	Not applicable	80/km^2
ILT probability of transmission	1.0	0.001
ILT: number of active transmitters	1	7
Simulation results		
dRSS, dBm/1500 kHz (Std.dev., dB)	-50.2 (11)	-75 (9)
$iRSS_{unwanted}$, dBm/1500 kHz (Std.dev., dB)	-167 (20)	-92 (11)
Probability of interference, C/I = 15 dB, %	**0.0**	**42.0**
Probability of interference, I/N = -6 dB, %	**0.3**	**100**
Probability of interference, I/N = -20 dB, %	**3.0**	**100**

It may be seen that for Case A scenarios APC mechanism provides significant improvement and drives the interfering noise from SRD below TRR impact levels. However for administrations wishing to consider same area use under Case B scenarios, use of APC on SRD side would not provide sufficient benefit to ensure co-existence.

As former administrations may also encounter the situations were SRDs are used to form utilities networks (SM, M3N), as described in Annex A2.4, the following table report the results of co-existence simulations with NAPs and high DC user nodes introduced in the original representative mix as part of SM/M3N network.

So the following table is an appropriately modified version of a Case A as it was considered in the previous table. Note again that due to the way that TRR scenario is modeled, the interfering links are anyway transmitting with 100% DC, i.e. assuming that the remote TRR victim receiver perceives the entire SRD populace as one big hot spot where it is reasonable to assume that at least one transmitter may be active at any time. Therefore in this first instance there is no need to introduce differentiation of DCs.

Table 12: Simulation results: mix of SRDs incl. NAPs (with APC) to TRR links

Simulation input/output parameters	Settings/Results
	Case A (Typical scenario) with SRD NAPs
VL: TRR Link	
Frequency	875.25 MHz
VLR sensitivity	-100 dBm/1500 kHz
VLR antenna	16 dBi
VLR height	25 m
VL Tx power e.i.r.p.	37 dBm
VL Tx → Rx path	Extended-Hata, rural, Outdoor-Outdoor/above roof
	R=35 km
IL1: Metropolitan utilities (Smart Metering/M3N)	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, rural, Indoor-Outdoor/below roof
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof
IL → VL positioning mode	Correlated: VLT → ILR = 36 km

Simulation input/output parameters	Settings/Results
	Case A (Typical scenario) with SRD NAPs
ILT density	Not applicable
ILT probability of transmission	1.0
ILT: number of active transmitters	1
IL1bis: Metropolitan Utilities' NAPs	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, rural, outd-ind/above roof
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/above roof
IL → VL positioning mode	Correlated: VLT → ILR = 36 km
ILT density	Not applicable
ILT probability of transmission	1.0
ILT: number of active transmitters	1
IL2: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.01 km, Rural, ind-ind/below roof
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof
IL → VL positioning mode	Correlated: VLT → ILR = 36 km
ILT density	Not applicable
ILT probability of transmission	1.0
ILT: number of active transmitters	1
IL3: Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
APC threshold and range/step	-95 dBm/25 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, Rural, Outdoor-Outdoor/below roof
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/below roof
IL → VL positioning mode	Correlated: VLT → ILR = 36 km
ILT density	Not applicable
ILT probability of transmission	1.0
ILT: number of active transmitters	1
IL4: Automotive (high power variety)	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
APC threshold and range/step	-82 dBm/500 kHz; range 20 dB, step 2 dB
ILT → ILR path	0…0.3 km, rural, Outdoor-Outdoor/below roof
IL → VL interfering path	Extended Hata, rural, Outdoor-Outdoor/above roof
IL → VL positioning mode	Correlated: VLT → ILR = 36 km
ILT density	Not applicable
ILT probability of transmission	1.0

Simulation input/output parameters	Settings/Results
	Case A (Typical scenario) with SRD NAPs
ILT: number of active transmitters	1
Simulation results	
dRSS, dBm/1500 kHz (Std.dev., dB)	-50 (11)
$iRSS_{unwanted}$, dBm/1500 kHz (Std.dev., dB)	-164 (19)
Probability of interference, C/I = 15 dB, %	**0.0**
Probability of interference, I/N = -6 dB, %	**0.3**
Probability of interference, I/N = -20 dB, %	**3.2 (reference scenario = 3.0%)**

These results show that for considered Case A scenario the introduction of networked SRD elements with higher DC would not have significant additional impact compared with baseline scenario.

This configuration is not considered for Case B scenario since even its baseline probability of interference is too high for considering co-existence with SRDs.

4.2.1.5 Analytical study of DAA to facilitate sharing between SRD and TRR

The analysis presented in ANNEX 4: proves that with simple power sensing on the candidate operational frequency, the DAA may only work with very low detection threshold values (in some cases below the noise floor) or for high SNR margins at the victim link receiver. The situation would be improved if the SRD might monitor the emission from the same location where the victim receiver is located, but then the knowledge about the TRR duplexing and channel arrangement would be required. But this cannot be generally assumed and therefore this DAA method of operation is not very promising method to protect operation of TRR links.

Note that the calculated very low DAA sensing thresholds imply that it may be realised only in cases of knowing beforehand TRR frequency use arrangements (TDD or FDD with dual band sensing) or by employing advanced discovery methods, such as distributed sensing or real-time coordination with central Geolocation database

4.2.1.6 Summary of TRR vs. SRD co-existence studies in 870-876 MHz

The co-existence between TRR and proposed SRD applications would strongly depend on the considered TRR deployment scenarios:

- Simulations shown for Case A – Typical scenario – show that co-existence may be feasible, especially if SRDs were required to implement APC;
- Simulations shown for Case B – Critical scenario – show that co-existence is generally not feasible, with or without APC on SRDs.

As regards the situation for Case B – Critical scenario, additional analysis of applying DAA (see ANNEX 4:) showed that DAA would be effective only in some configurations (e.g. high margin on wanted signal link) or if the interferers could know the duplex and channelling arrangements of TRR and could carry out sensing across both receive and transmit bands. However since the latter may not be generally assumed, the use of DAA does not seem to offer significant benefits.

4.2.2 Co-existence with TRR in 915-921 MHz

This sub-section shall describe the results of technical co-existence analysis between SRD/RFID devices and TRR operating in the band 915-921 MHz. The technical parameters of these systems are as defined in ANNEX 2: and annex 0 respectively.

The scenarios of TRR vs. SRD/RFID co-existence shall be the same as were described in section 4.2.1 on TRR vs. SRD co-existence in 870-876 MHz. Since all TRR stations operate in full duplex mode, there is no differentiation between the uplink-downlink types of deployment as is the case with cellular mobile systems.

Since the results for the SRD co-existence cases are assumed to be similar to the results in section 4.2.1, only simulations with RFID are provided in this section.

The following table provides the results of SEAMCAT simulations for the two considered scenarios: Case A – typical scenario – with RFIDs operating in "population pocket" adjacent to military exercise area and, Case B – critical scenario – the TRR victim being in the centre of the RFID deployment area. For the Case B, the density of RFID interferers was taken from Annex A2.4 for the Hotspot scenario (in this situation the antenna pattern shown in Figure 29: should be used). This leads to total number of 480 interferers in a single area of around one square kilometre, and assuming DC of 2.5% on any given channel. This means up to 12 simultaneously active interferers per channel.

Table 13: Simulation results: RFID to TRR links in 915-921 MHz

Simulation input/output parameters	Settings/Results	
	Case A (Typical Scenario)	Case B (Critical Scenario)
VL: TRR Link (reference type as per STANAG-4212 agreement [18])		
Frequency	917.25 MHz	
VLR sensitivity	-100 dBm/1500 kHz	
VLR antenna	16 dBi	
VLR height	25 m	
VL Tx power e.i.r.p.	37 dBm	
VL Tx → Rx path	Extended-Hata, rural, Outdoor-Outdoor/above roof	
VL Tx → Rx distance	R=35 km	Constant 70 km
IL: RFID		
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels	
ILT power e.i.r.p.	20 dBm (antenna pattern according Figure 29: in A2.5)	
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof	
IL → VL positioning mode	Correlated: VLT → ILR = 36 km	Uniform density, 1 km protection distance
ILT density	Not applicable	480/km^2
ILT probability of transmission	1.0	0.025
ILT: number of active transmitters	1	12
Simulation results		
dRSS, dBm/1500 kHz (Std.dev., dB)	-50.5 (11)	-75 (9)
iRSS, dBm/1500 kHz (Std.dev., dB)	-176 (35)	-63 (14)
Probability of interference, C/I = 15 dB, %	**0.0**	**95**
Probability of interference, I/N = -6 dB, %	**5.6**	**100**
Probability of interference, I/N = -20 dB, %	**16.5**	**100**

Given that RFID interrogators may be using one of four pre-defined frequencies, starting above 916 MHz, the centre frequency of victim TRR would be set to 917.25 MHz so as to overlap with one of the RFID channels.

The results of simulations provided in the above table indicate that similarly as in the band 870-876 MHz, if the TRR use was restricted to separate military areas (Case A), then the interference risk would be moderate on the C/I criterion, although TRR receivers' noise level would suffer noticeable increases. However if RFIDs were to be deployed in the same areas as TRR (Case B), the simulation results across all criteria indicate clearly the high interference potential.

Analysis of possibility to use DAA provided in ANNEX 4: would be also appropriate for the case if DAA sensing was to be implemented in RFID. It showed no significant benefits for considering DAA to protect operation of TRR.

4.2.2.1 Summary of TRR vs. SRD/RFID co-existence studies in 915-921 MHz

The results of simulations indicate that similarly as in the band 870-876 MHz, if the TRR use was restricted to separate military areas (Case A), then the interference risk would be moderate based on the C/I criterion, although the TRR receivers' noise level would increase significantly. However if SRD/RFIDs were to be deployed in the same areas as TRR (Case B), the simulation results across all criteria indicate clearly the high interference potential.

Analysis of possibility to use DAA provided in ANNEX 4: showed no significant benefits for considering DAA to protect operation of TRR.

4.3 COMPATIBILITY WITH GSM-R

4.3.1 Adjacent band interference from SRD to GSM-R around 876 MHz

4.3.1.1 Description of co-existence scenario

It would appear that the scenario of adjacent band co-existence around 876 MHz will represent a simplified sub-set of the same case of the ER-GSM case detailed in section 4.4. Indeed in this scenario the interference is again between R-GSM uplink and the SRDs and the only difference would be the shift of MS transmissions and BTS Victim receiver to adjacent R-GSM frequency. Otherwise the description of scenarios would be identical to what is depicted in Figure 7: and Figure 8:.

It may be therefore suggested that it should be sufficient to test here only one (the most severe in terms of interference potential) co-existence case of the different ones studied in section 4.4. It would appear natural to use for that the Mixed SRD case, as reported in section 4.4.2.4.

4.3.1.2 Results of simulations

The results of simulations of the Mixed SRD use case in configuration of adjacent band interference are presented in Table below. The only difference in scenario settings from that of in-band interference in section 4.4.2.4 was that the operating frequency of R-GSM BTS victim receiver was set to 876.2 MHz, i.e. the nearest adjacent channel of the original R-GSM band.

Table 14: Simulation results: mix of SRDs to GSM-R Urban Cell in ADJACENT BAND

Simulation input/output parameters	Settings/Results	
	SRD in 873-876 MHz	SRD in 870-876 MHz
Victim Link (VL): ER-GSM uplink		
Frequency	876.2 MHz	
VLR N	-116 dBm/200 kHz	
VLR C/(N+I) threshold	9 dB	
VLR BS antenna (incl. feeder/splitter loss)	12 dBi, 30^{o}	
VLR BS height	20 m	

Simulation input/output parameters	Settings/Results	
	SRD in 873-876 MHz	SRD in 870-876 MHz
VLT power e.i.r.p.	33 dBm	
VLT → VLR path	Extended-Hata, urban, Outdoor-Outdoor/below roof, R=2 km	
Interfering Link (IL) #1: Smart Metering		
Channel bandwidth	200 kHz	
ILT power e.i.r.p.	27 dBm/200 kHz	
ILT density	**2000**/km^2	
ILT number of active transmitters	15	
ILT probability of transmission	0.001	
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof	
IL2: HA		
Channel bandwidth	200 kHz	
ILT power e.i.r.p.	14 dBm/200 kHz	
ILT density	**50000**/km^2	
ILT number of active transmitters	2	
ILT probability of transmission	0.01	
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof	
IL3: Alarms		
Channel bandwidth	25 kHz	
ILT power e.i.r.p.	20 dBm/25 kHz	
ILT density	**12**/km^2	
ILT number of active transmitters	1	
ILT probability of transmission	0.001	
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof	
IL4: Automotive		
Channel bandwidth	500 kHz	
ILT power e.i.r.p.	27 dBm/500 kHz	
ILT density	**80**/km^2	
ILT number of active transmitters	1	
ILT probability of transmission	0.001	
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof	
General settings for all ILs		
ILT → VLR positioning mode	Uniform density	
ILT → VLR minimum distance	100 m	
IL frequency range	873-876 MHz	870-876 MHz
Simulation results		
dRSS, dBm/200 kHz (Std.dev., dB)	-88.5 (12.3)	
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-137 (11)	-137 (11)
Probability of interference, C/(N+I), %	**0.8**	**0.8**
Probability of interference, C/(N+I), % + blocking	**0.9**	**0.9**

As seen in the table, the modelling shows that the probability of SRD interference to ER-GSM reception in the adjacent band is around 1% and does not depend on the size of SRD operational sub-bands in the 870-

876 MHz range. These results correlate well with the results of practical testing [19] which showed that GSM-R receiver can tolerate presence of adjacent interfering signals exceeding the wanted signal by up to 25 dB in the first adjacent channel and up to 65 dB in the following, which corresponds to GSM-R selectivity mask settings used in this simulation.

4.3.2 Adjacent Band Co-existence around 921 MHz

4.3.2.1 Description of co-existence scenario

In this scenario the SRD&RFID mix in the band 915-921 MHz may interfere across the band edge of 921 MHz into the GSM-R downlink.

Only the case of victim handheld GSM-R mobile terminal is considered in the following simulations, due to understanding (confirmed by intermediate simulations) that it is more susceptible to interference than the train-mounted mobile terminal, due to obvious observation that the latter may enjoy better quality of reception of wanted signal and hence more favourable C/I conditions.

4.3.2.2 Results of simulations

The results of simulations of the Mixed SRD use case in configuration of adjacent band interference are presented in this section. First of all the suitable numbers of active interferers had to be established, using same calculation methodology as used previously throughout the report. The results of these calculations are reported below.

Table 15: Estimating number of active interferers for the case of SRD/RFID vs. GSM-R Downlink/Urban cell in adjacent band

	Non-specific A	Non-specific B	ALD	Home automation	RFID
Input fields					
f/GHz	0.921	0.921	0.921	0.921	0.921
SRD/RFID definition					
Tx power mW	25	100	10	25	100
Tx mask, dB, dF ≥0.2 MHz	-30	-30	-30	-30	-30
Adjacent band Tx power dBm/Bwi	-16.02	-10.00	-20.00	-16.02	-10.00
Receiver Bandwith BWi kHz	600	400	200	500	400
Uniform density / km^2	250	250	40	25000	480
Duty Cycle	1.00%	1.00%	25.00%	0.0025%	2.5000%
Victim definition: GSM –R downlink					
Sensitivity dBm/BWv	-102	-102	-102	-102	-102
BWv kHz	200	200	200	200	200
Signal level above Sens dB	7	7	7	7	7
SIR dB	9	9	9	9	9
Feeder loss dB	0	0	0	0	0
Splitter loss dB	0	0	0	0	0
Max permissible interf dBm/BWv	-104	-104	-104	-104	-104
Reception antenna gain dBi	0	0	0	0	0
BWCF dB	4.771212547	3.010299957	0	3.97940009	3.01029996

	Non-specific A	Non-specific B	ALD	Home automation	RFID
Interference assessment					
Propagation exponent n (Note 1)	3.5	3.5	3.5	3.5	3.5
Additional wall loss aw dB (Note 1)	0	0	0	0	0
Protection distance rp, m (Note 1)	29.46	49.15	31.03	31.03	49.15
Interference area Ai, km^2	0.00	0.01	0.00	0.00	0.01
Transmitters in interference area	0.68	1.90	0.12	75.65	3.64

Note 1: Propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+aw

Using the obtained numbers of active interferers, the following table reports the SEAMCAT settings as well as the ultimate results of interference.

Table 16: Simulation results: mix of SRDs to GSM-R downlink across the 921 MHz band: victim Handheld MS in Urban Cell

Simulation input/output parameters	Settings/Results
VL: GSM-R Handheld MS	
Frequency	921.2, 0.2 MHz channel
VLR sensitivity	-102 dBm/200 kHz
VLR selectivity	Cf. Table 55/Sensitivity mode
VLR C/(N+I) threshold	10 dB
VLR antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLT antenna gain and height a.g.l.	18 dBi, 20 m, 32^{O} sector
VL Tx power	40 dBm/200 kHz (including 3dB splitter loss and 3dB feeder loss)
VL Tx → Rx path	Hata, urban, outd-outd/below roof, R=2 km
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	0.01
ILT → VLR interfering path	Extended-Hata, urban, ind-outd/below roof
ILT density	$250/km^2$
ILT number of active transmitters	1
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	0.01
ILT → VLR interfering path	Extended-Hata, urban, ind-outd/below roof
ILT density	$250/km^2$
ILT number of active transmitters	2
IL3: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz channels

Simulation input/output parameters	Settings/Results
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	0.25
ILT → VLR interfering path	Extended-Hata, urban, ind-outd/below roof
ILT density	40/km^2
ILT number of active transmitters	1
IL4: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.000025
ILT → VLR interfering path	Extended Hata, urban, ind-outd/below roof
ILT density	25000/km^2
ILT number of active transmitters	75
IL5: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	0.025
ILT → VLR interfering path	Extended Hata, urban, ind-outd/below roof
ILT density	480/km^2
ILT number of active transmitters	4
General settings for all ILs	
ILT → VLR positioning mode	None
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-76 (12)
$iRSS_{unwanted}$, dBm/200 kHz (Std.dev., dB)	-225 (88)
$iRSS_{blocking}$, dBm/200 kHz (Std.dev., dB)	-245 (78)
Probability of interference (unwanted and blocking modes), C/(N+I), %	**2.6**

The results of this analysis demonstrate that adjacent band interference from SRD operation in the band 915-921 MHz into the adjacent GSM-R downlink in the band above 921 MHz would be at marginal levels and therefore could be disregarded.

4.4 COMPATIBILITY WITH ER-GSM

4.4.1 In-Band Co-Existence of proposed SRD and ER-GSM in 870-876 MHz

4.4.1.1 Description of co-existence scenario in 870-876 MHz

In this case the proposed SRD applications would have to co-exist with GSM-R deployment in the uplink part of “ER-GSM” frequency band 873-876 MHz. Illustration of the situation with the interference coupling paths is shown below (only two units and two types of SRD devices are shown to keep the picture simpler).

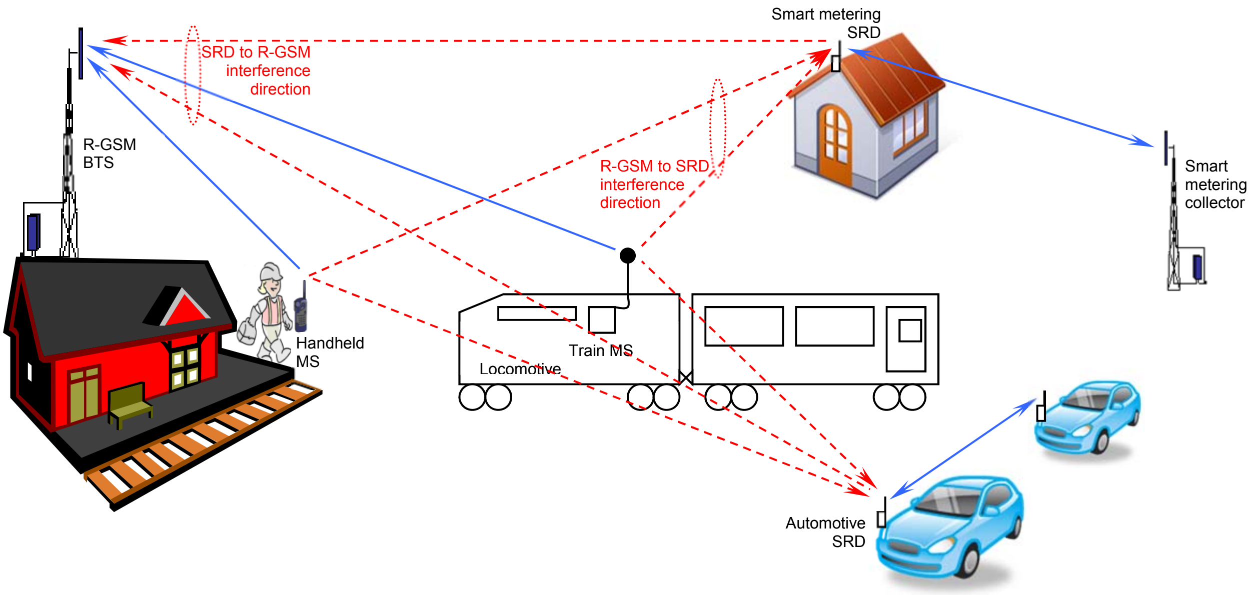


Figure 7: In-band SRD vs. ER-GSM co-existence: wanted and interfering paths in 873-876 MHz

This means that the following two interference directions will exist:

- Multiple SRDs to ER-GSM band BTS Rx;
- Multiple ER-GSM band MS (appropriate mix of handheld and train-mounted units) to SRD Rx.

However only interference to ER-GSM is studied in this report as being the more critical to protect sensitive public services, whereas SRDs would be introduced on a non-protected basis.

Then, similarly as was done with UAS and TRR studies, also two cases are considered:

Case A – Typical Scenario: the planning requirements recommended from UIC are considered here (dRSS ≥-98dBm should be ensured for 95% of cases). Case A simulations indicate the percentage of potentially impacted railway tracks supplied with ER-GSM.

Case B – Critical Scenario: a worst case indication on the impact in the hand-over region (dRSS=-98 dBm)

Geographically the simulation of ER-GSM vs SRD co-existence could be modelled as a number of MSs (VLT) and SRDs (ILT and ILR) operated within a coverage sector (cell) of ER-GSM band BTS (VLR), as shown in the figure below.

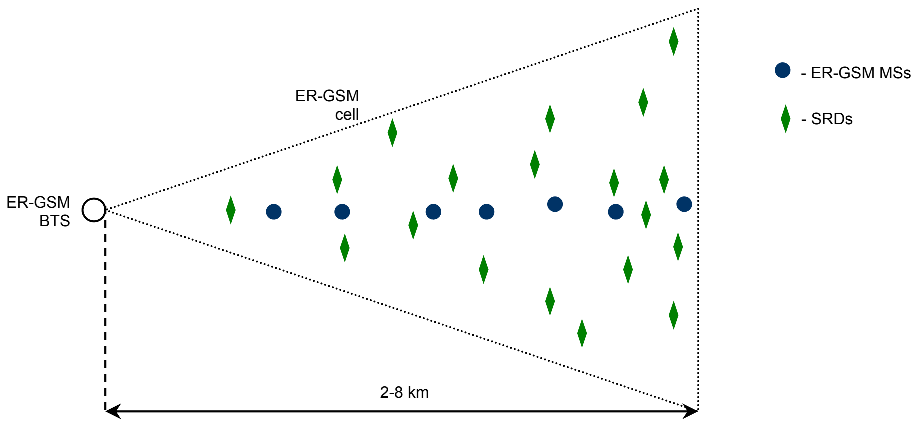


Figure 8: Geographic representation of SRD vs. ER-GSM co-existence scenario in SEAMCAT

Note that in this scenario modelling the ER-GSM MS devices are being clustered along a single line representing the railway track. An example of how the above scenario would appear after being programmed in SEAMCAT is presented below.

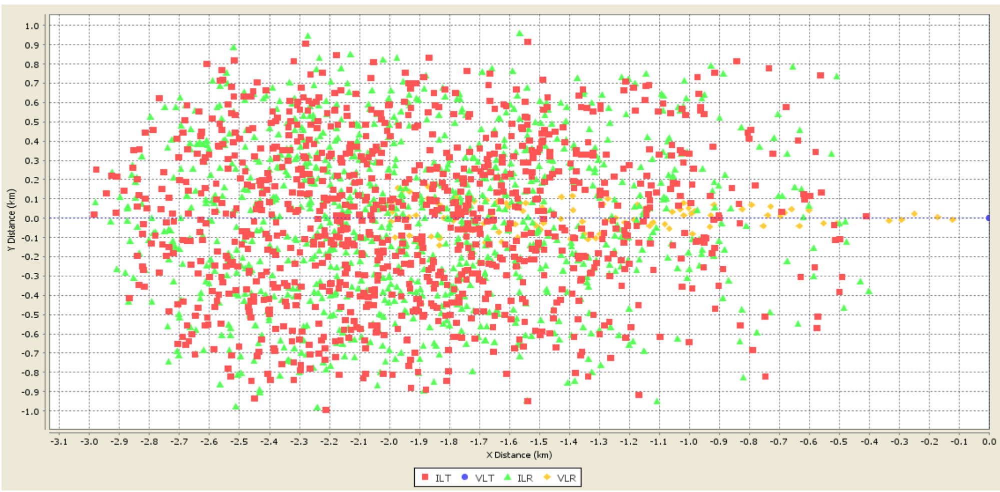


Figure 9: Example of SEAMCAT simulation window: SRD to ER-GSM

It may be seen from the picture that the victim receivers are positioned along the central line with interfering devices clustered around them in the limits of the cell. Note that due to specific peculiarity of SEAMCAT (namely, that in graphical rendering the position of VLT is taken to correspond to (0;0) coordinates), it appears that BTS is moving with respect to the MS, not the other way around. This has no impact on the simulation results, because the true essence of simulations is the changing link distance and configuration, regardless of which transceiver in the pair moved and which was stationary.

In order to evaluate sensitivity of interference scenario to different types and densities of SRDs, the simulations first look at interference from single type of SRD for a set of different densities. This would be then followed by a mixed scenario where several types of SRDs are sharing the same band.

4.4.1.2 Results of SEAMCAT simulations in 870-876 MHz

This sub-section describes the results of SEAMCAT simulations in power-level domain of the above described scenario of in-band interference between the different kinds of SRDs and ER-GSM.

Non-specific SRDs in the band

This case reflects upon the original vision in TR 102 649-2 [1] for placing non-specific SRDs in the lower part of the band 870-876 MHz, i.e. around 870-873…874 MHz (see Figure 2: and Figure 37: in ANNEX 2:), with the upper limit to be determined by the requirements derived from this sharing study. Therefore the following analysis attempts to investigate the sensitivity of this sharing scenario to the changing upper limit of the operational range for non-specific SRDs by testing three upper limit values: 873 MHz, 874 MHz and 876 MHz.

Direction of interference: SRD to ER-GSM BTS receiver, no LBT used by SRD. The SRD transmitter parameters used in simulations correspond to those outlined in Annex 2 Table 17, including the DC of 1% and channel bandwidth of 600 kHz. It was assumed that non-specific SRDs would be predominantly deployed indoors, with deployment density in the order of 10-1000/km^2. Accordingly the lower bound was used for rural scenario and upper bound for urban as a baseline scenario corresponding to Density Option I of these SRDs being used in only one band of 870-876 MHz (see Annex A2.3). Then the Density Option II, with non-specific SRDs being deployed across both 870-876 MHz and 915-921 MHz would mean that alternative scenario may be also considered with device density reduced by a factor of two.

The Table 17 below provides calculation of impact area and respective numbers of active interferers according to the procedure in annex A2.3. Note that in this calculation the assumption of Case A (typical) vs. Case B (critical) manifests via modelling of operating margin of victim receiver. Case A simulations indicate the percentage of potentially impacted railway tracks, as the resulting dRSS distribution represents the planning requirements recommended by UIC (dRSS ≥-98dBm should be ensured for 95% of cases). Case B simulation shows a worst case indication on the impact in the hand-over region.

Table 17: Estimating impact area and number of active transmitters for Non-specific SRD

Parameter	Rural scenario		Urban scenario	
	Case A	Case B	Case A	Case B
Frequency, f, GHz	0.873	0.873	0.873	0.873
SRD interferer				
Tx power, mW	25	25	25	25
Receiver bandwidth, BWi, kHz	200	200	200	200
Tx power normalised, dBm/BWi	13.98	13.98	13.98	13.98
SRD uniform density, 1/sq.km	10	10	1000	1000
Duty Cycle, %	1	1	1	1
GSM-R BS victim				
Receiver bandwidth, BWv, kHz	200	200	200	200
Sensitivity threshold, dBm/BWv	-104	-104	-104	-104
Useful signal level above sensitivity, dB	**25**	**9**	**25**	**9**
S/(I+N), dB	9	9	9	9
Feeder loss, dB	3	3	3	3
Splitter loss, dB	3	3	3	3
Max permissible interference, dBm/BWv	-82	-98	-82	-98
Receiver antenna gain, dBi	18	18	18	18
Impact range and active interferers				
Propagation exponent *n* (1)	2.5	2.5	3.5	3.5
Additional wall loss, *Aw* (1), dB	0	0	0	0

Parameter	Rural scenario		Urban scenario	
	Case A	Case B	Case A	Case B
Calculated impact range (simulation radius), *R* (1), m	2024	8835	230	659
Impact area, sq. km	12.9	255	0.17	1.36
Number of active transmitters for Density Option I (2)	2	25	2	14

1. Propagation model PL (dB) = 32.5 + 20*log(f [GHz])+n*10*log(R [m])+ Aw
2. Calculated as: Density (1/km^2) x ImpactArea (km^2) x DutyCycle

Note that in order to ensure consistency with SEAMCAT simulations, propagation exponents (2.5 for rural case and 3.5 for urban case) were chosen based on comparison with mean path loss curves obtainable from Extended Hata rural and urban models respectively, see Figure 10: below. Note that the chosen propagation exponent also takes into account the impact of wall loss, therefore this parameter set to zero in the above table.

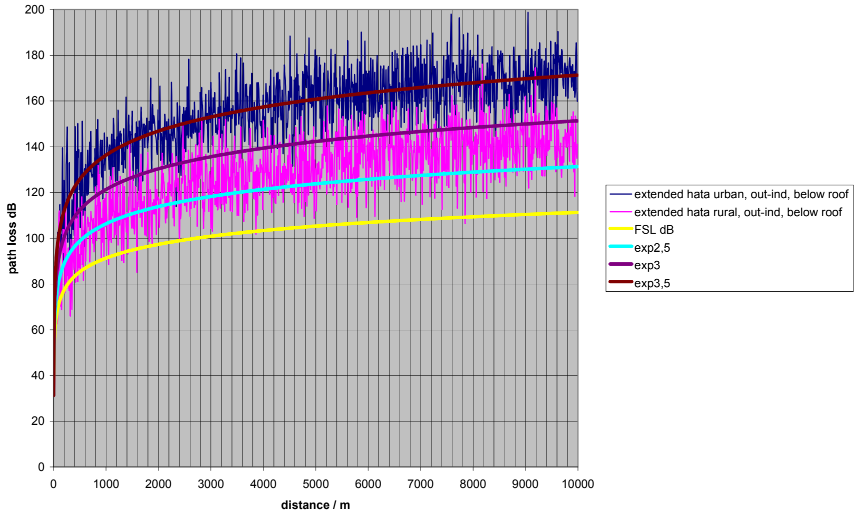


Figure 10: Choosing propagation exponents to represent Extended Hata rural and urban modes

The complete results of the simulations for non-specific SRDs interference to ER-GSM are reported below, first for rural cell, then for urban cell configurations.

In order to simulate Case A the ER-GSM cell radius was set to 10 km in rural scenario and 1 km in urban scenario in order to arrive at dRSS value of approx. -79 dBm, or 25 dB above sensitivity threshold, whereas for Case B – critical scenario, the dRSS operating margin was set constant at -98 dBm to correspond to the requirement for hand-over areas at cell edges.

Table 18: Simulation results: non-specific SRDs to ER-GSM in RURAL Case A: Typical Scenario

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
VLR BS antenna (incl. feeder/splitter losses)	12 dBi		
VLR BS height	45 m		
VLR BS antenna down tilt	3°		
VLT power e.i.r.p.	33 dBm		
VLT → VLR path	Extended-Hata, rural, Outdoor-Outdoor/above roof, R=10 km		
Interfering Link (IL): Non-specific SRD			
IL Channel bandwidth	600 kHz		
ILT power e.i.r.p.	14 dBm/600 kHz		
ILT density	**10**/km^2		
Simulation radius	2.5 km		
ILT probability of transmission	0.01		
ILT → VLR interfering path	Extended Hata, rural, Indoor-Outdoor/below roof		
ILT → VLR positioning mode	Uniform density		
ILT → VLR minimum distance (1)	100 m		
IL: frequency range, MHz	870-873	873-876	870-876
ILT: number of active transmitters for Deployment Density Option I	2	2	2
ILT: number of active transmitters for Deployment Density Option II	1	1	1
Simulation results			
dRSS, dBm/200 kHz (Std.dev., dB)	-79 (12)		
Probability of interference, C/(N+I), % (including blocking) for Density Option I	**0.7**	**6.8**	**3.8**
Probability of interference, C/(N+I), % (including blocking) for Density Option II	**0.7**	**4.9**	**2.8**

1. minimum distance is also elsewhere in this report and within SEAMCAT settings referred to as “protection distance”, e.g. in this case as may be ensured by BTS’ and railways safety enclosures

Table 19: Simulation results: non-specific SRDs to ER-GSM in RURAL Case B: Critical Scenario

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		
VLR BS antenna (incl. feeder/splitter losses)	12 dBi		
VLR BS height	45 m		
VLR BS antenna down tilt	3°		
VLT power e.i.r.p.	33 dBm		
VLR dRSS	Constant -98 dBm (2)		
Interfering Link (IL): Non-specific SRD			
IL Channel bandwidth	600 kHz		

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
ILT power e.i.r.p.	14 dBm/600 kHz		
ILT density	**10**/km^2		
Simulation radius	8.9 km		
ILT probability of transmission	0.01		
ILT → VLR interfering path	Extended Hata, rural, Indoor-Outdoor/below roof		
ILT → VLR positioning mode	Uniform density		
ILT → VLR minimum distance	100 m		
IL: frequency range, MHz	870-873	873-876	870-876
ILT: number of active transmitters for Deployment Density Option I	25	25	25
ILT: number of active transmitters for Deployment Density Option II	13	13	13
Simulation results			
dRSS, dBm/200 kHz (Std.dev., dB)	-98		
Probability of interference, C/(N+I), % (including blocking) for Density Option I	**5.3**	**58**	**36**
Probability of interference, C/(N+I), % (including blocking) for Density Option II	**5.0**	**48**	**29**

1. the lower bound increased to make up the whole number of 600 kHz channels
2. dRSS set to correspond to required protected power level in hand-over area at cell edge

Table 20: Simulation results: non-specific SRDs to ER-GSM in URBAN Case A: Typical Scenario

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		
VLR BS antenna (incl. feeder/splitter losses)	12 dBi, 30^o		
VLR BS height	20 m		
VLR BS antenna down tilt	3^o		
VLT power e.i.r.p.	33 dBm		
VLT → VLR path	Extended-Hata, urban, Outdoor-Outdoor/below roof, R=1 km		
Interfering Link (IL): Non-specific SRD			
IL Channel bandwidth	600 kHz		
ILT power e.i.r.p.	14 dBm/600 kHz		
ILT density	**1000**/km^2		
Simulation radius	0.23 km		
ILT probability of transmission	0.01		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
ILT → VLR positioning mode	Uniform density		

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
ILT → VLR minimum distance	100 m		
IL: frequency range, MHz	870-873	873-876	870-876
ILT: number of active transmitters for Density Option I	2	2	2
ILT: number of active transmitters for Density Option II	1	1	1
Simulation results			
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)		
Probability of interference, C/(N+I), % (including blocking) for Density Option I	**1.4**	**7.7**	**4.5**
Probability of interference, C/(N+I), % (including blocking) for Density Option II	**0.9**	**4.8**	**2.9**

Table 21: Simulation results: non-specific SRDs to ER-GSM in URBAN Case B: Critical Scenario

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		
VLR BS antenna (incl. feeder/splitter losses)	12 dBi, 30°		
VLR BS height	20 m		
VLR BS antenna down tilt	3°		
VLT power e.i.r.p.	33 dBm		
VLR dRSS	Constant -98 dBm		
Interfering Link (IL): Non-specific SRD			
IL Channel bandwidth	600 kHz		
ILT power e.i.r.p.	14 dBm/600 kHz		
ILT density	**1000**/km^2		
Simulation radius	0.67 km		
ILT probability of transmission	0.01		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
ILT → VLR positioning mode	Uniform density		
ILT → VLR minimum distance	100 m		
IL: frequency range, MHz	870-873	873-876	870-876
ILT: number of active transmitters for Density Option I	14	14	14
ILT: number of active transmitters for Density Option II	7	7	7
Simulation results			
dRSS, dBm/200 kHz (Std.dev., dB)	-98		
Probability of interference, C/(N+I), %	**8.5**	**51**	**32**

Simulation input/output parameters	Settings/Results		
	SRD in 870-873 MHz	SRD in 873-876 MHz	SRD in 870-876 MHz
(including blocking) for Density Option I			
Probability of interference, C/(N+I), % (including blocking) for Density Option II	**7.9**	**41**	**26**

1. the lower bound increased to make up the whole number of 600 kHz channels

The first observation that could be made from the above tables is that if the non-specific SRDs were allowed to infringe across the 873 MHz border line of ER-GSM sub-band, then it would make more sense to allow them operating across the entire band 870-876 MHz (in other words, upper limit of 876 MHz would be better than the considered previously 874 MHz). This may be explained by the fact, that the larger tuning range the non-specific SRDs have, the more evenly their random transmissions would be spread, thus minimising impact on any specific ER-GSM channel.

Also the urban scenario of interference appears slightly more critical and therefore it shall be used in future simulations as a reference worst-case scenario.

As conclusion of this sub-section, it may be noted that the probability of interference would greatly depend on the assumption of the ER-GSM wanted signal:

- For Case A, representing an average ER-GSM frequencies use case (e.g. railways shunting yards), the results are between 4 % if the whole 6 MHz can be used by SRDs and 8 % if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870-873 MHz then the probability of interference is in the order of 1%.
- For Case B, representing a worst case indication on the impact in the hand-over region of ER-GSM, the results are between 30 % if the whole 6 MHz can be used by SRDs and 60 % if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870-873 MHz then the probability of interference is between 5 % and 8 %.

Specific SRDs in the band

In this case we consider the scenario envisaged to develop in the upper part of the band, where a mix of various specific SRD families is expected to co-exist (see Figure 37: in ANNEX 2:). The table below lists the modelled representative mix of four different types of SRD, each having different output powers, bandwidth and DCs. It was prepared with due note of the overview of SRD requirements and typical deployment densities as discussed in annex A2.2 and A2.3. Note that in order to reflect the most pessimistic scenario, the applications with higher powers were chosen in a mix, with DC chosen as per principles shown in ANNEX 2:.

Table 22: Simulated mix of different types of SRD in the band 870-876 MHz

Interferer set	Power, mW	BW, kHz	Density, 1/km^2	DC, %	Deployment
Alarms	100	25 (1)	12	0.1	Outdoor
Automotive (high power variety)	500	500 (2)	80	0.1	Outdoor
Home automation/Sub-metering	25	200	50000 (3)	0.0025	Indoor
Metropolitan utilities (Smart Metering)	500	200	2000	0.1	Indoor

1. Emissions mask according Fig. B.4 in [1]
2. Emissions mask according Fig. B.5 in [1]
3. Baseline density for Density Option I (see A2.3). The density for Option II will be reduced by a factor of 2.

The respective sizes of impact areas and numbers of active devices to be used in the SEAMCAT simulations were derived in Table 23 and Table 24 below according to the procedure in annex A2.3 and noting urban deployment scenario, which was identified as more critical during simulations in previous sub-section.

Table 23: Estimating number of active transmitters for Specific SRDs: Case A – Typical Scenario

Parameter	Alarms	Home Automation	Smart Metering	Automotive high power
Frequency, f, GHz	0.873	0.873	0.873	0.873
SRD interferer				
Tx power, mW	100	25	500	500
Receiver bandwidth, BWi, kHz	200	200	200	200
Tx power normalised, dBm/BWi	20	13.98	26.99	26.99
SRD uniform density, 1/sq.km	12	50000	2000	80
Duty Cycle, %	0.1	0.0025	0.1	0.1
GSM-R BS victim				
Receiver bandwidth, BWv, kHz	200	200	200	200
Sensitivity threshold, dBm/BWv	-104	-104	-104	-104
Useful signal above sensitivity, dB	**25**	**25**	**25**	**25**
S/(I+N), dB	9	9	9	9
Feeder loss, dB	3	3	3	3
Splitter loss, dB	3	3	3	3
Max interference level, dBm/BWv	-82	-82	-82	-82
Receiver antenna gain, dBi	18	18	18	18
Impact range and active interferers				
Propagation exponent *n* (1)	3.5	3.5	3.5	3.5
Additional wall loss, *Aw* (1), dB	0	0	0	0
Calculated impact range, *R* (1), m	340	230	540	540
Impact area, sq. km	0.4	0.2	1	1
Number of active transmitters(2)	0	1	2	1

Table 24: Estimating number of active transmitters for Specific SRDs: Case B – Critical Scenario

Parameter	Alarms	Home Automation	Smart Metering	Automotive high power
Frequency, f, GHz	0.873	0.873	0.873	0.873
SRD interferer				
Tx power, mW	100	25	500	500
Receiver bandwidth, BWi, kHz	200	200	200	200
Tx power normalised, dBm/BWi	20	13.98	26.99	26.99
SRD uniform density, 1/sq.km	12	50000	2000	80
Duty Cycle, %	0.1	0.0025	0.1	0.1
GSM-R BS victim				
Receiver bandwidth, BWv, kHz	200	200	200	200
Sensitivity threshold, dBm/BWv	-104	-104	-104	-104
Useful signal above sensitivity, dB	**9**	**9**	**9**	**9**

Parameter	Alarms	Home Automation	Smart Metering	Automotive high power
S/(I+N), dB	9	9	9	9
Feeder loss, dB	3	3	3	3
Splitter loss, dB	3	3	3	3
Max interference level, dBm/BWv	-98	-98	-98	-98
Receiver antenna gain, dBi	18	18	18	18
Impact range and active interferers				
Propagation exponent *n*	3.5	3.5	3.5	3.5
Additional wall loss, *Aw*, dB	0	0	0	0
Calculated impact range, *R*, m	980	660	1551	1551
Impact area, sq. km	3	1.36	7.6	7.6
Number of active transmitters (1)	1	2	15	1

1. the number of active transmitters corresponds to Density Option I. The Option II was not considered in simulations reported in this sub-section as it would only affect the number of HA devices from 2 to 1, which would obviously have marginal effect.

The following figure depicts outline of simulated SEAMCAT scenario.

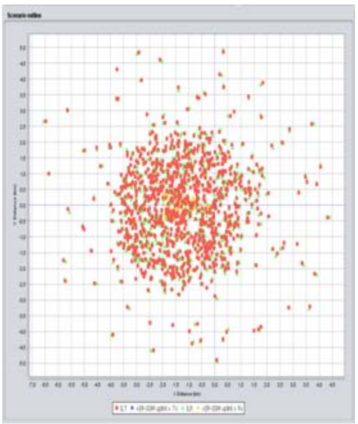


Figure 11: Outline of SEAMCAT simulations reported in this section

The results of simulations are reported in the following table. Noting the observation in the previous sub-section that extending operational range to the maximum might positively impact co-existence, it was decided to test here two cases of operational frequency range: one where specific SRDs were limited in the upper sub-band 873-876 MHz and the other one with using the entire band 870-876 MHz.

Again as in previous sub-section for Case A the ER-GSM cell radius was set to 1 km to arrive at dRSS value of -79 dBm, or around 25 dB above sensitivity threshold, whereas for Case B – critical scenario, the dRSS operating margin was set constant at -98 dBm to correspond to the requirement for hand-over areas at cell edges.

Table 25: Simulation results: mix of SRDs to ER-GSM URBAN Case A – Typical Scenario

Simulation input/output parameters	Settings/Results		
	SRDs in 870-873 MHz	SRDs in 873-876 MHz	SRDs in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		
VLR BS antenna (incl. feeder/splitter losses)	12 dBi, 30°		
VLR BS height	20 m		
VLT power e.i.r.p.	33 dBm		
VLT → VLR path	Extended-Hata, urban, Outdoor-Outdoor/below roof, R=1 km		
Interfering Link (IL) #1: Metropolitan utilities (Smart Metering/M3N)			
Channel bandwidth	200 kHz		
ILT power e.i.r.p.	27 dBm/200 kHz		
ILT density	**2000**/km^2		
ILT number of active transmitters	2		
ILT probability of transmission	0.001		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
IL2: HA			
Channel bandwidth	200 kHz		
ILT power e.i.r.p.	14 dBm/200 kHz		
ILT density	**50000**/km^2		
ILT number of active transmitters	1		
ILT probability of transmission	0.000025		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
IL4: Automotive (high power variety)			
Channel bandwidth	500 kHz		
ILT power e.i.r.p.	27 dBm/500 kHz		
ILT density	**80**/km^2		
ILT number of active transmitters	1		
ILT probability of transmission	0.001		
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof		
General settings for all ILs			
ILT → VLR positioning mode	Uniform density		
ILT → VLR minimum distance	100 m		
IL frequency range	870-873 MHz	873-876 MHz	870-876 MHz
Simulation results			
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)		
Probability of interference, C/(N+I), % including blocking	**0.7**	**8.2**	**4.0**

Table 26: Simulation results: mix of SRDs to ER-GSM URBAN: Case B – Critical Scenario

Simulation input/output parameters	Settings/Results		
	SRDs in 870-873 MHz	SRDs in 873-876 MHz	SRDs in 870-876 MHz
Victim Link (VL): ER-GSM uplink			
Frequency	873.2 MHz		
VLR N	-116 dBm/200 kHz		
VLR C/(N+I) threshold	9 dB		
VLR BS antenna (incl. feeder/splitter losses)	12 dBi, 30°		
VLR BS height	20 m		
VLR dRSS	Constant -98 dBm		
Interfering Link (IL) #1: Metropolitan utilities (Smart Metering/M3N)			
Channel bandwidth	200 kHz		
ILT power e.i.r.p.	27 dBm/200 kHz		
ILT density	**2000**/km²		
ILT number of active transmitters	15		
ILT probability of transmission	0.001		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
IL2: HA			
Channel bandwidth	200 kHz		
ILT power e.i.r.p.	14 dBm/200 kHz		
ILT density	**50000**/km²		
ILT number of active transmitters	2		
ILT probability of transmission	0.000025		
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof		
IL3: Alarms			
Channel bandwidth	25 kHz		
ILT power e.i.r.p.	20 dBm/25 kHz		
ILT density	**12**/km²		
ILT number of active transmitters	1		
ILT probability of transmission	0.001		
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof		
IL4: Automotive (high power variety)			
Channel bandwidth	500 kHz		
ILT power e.i.r.p.	27 dBm/500 kHz		
ILT density	**80**/km²		
ILT number of active transmitters	1		
ILT probability of transmission	0.001		
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof		
General settings for all ILs			
ILT → VLR positioning mode	Uniform density		
ILT → VLR minimum distance	100 m		
IL frequency range	870-873 MHz	873-876 MHz	870-876 MHz
Simulation results			

Simulation input/output parameters	Settings/Results		
	SRDs in 870-873 MHz	SRDs in 873-876 MHz	SRDs in 870-876 MHz
dRSS, dBm/200 kHz (Std.dev., dB)	-98 (0)		
Probability of interference, C/(N+I), % including blocking	**3.0**	**47.4**	**25.2**
Results without smart metering link: Probability of interference, C/(N+I), % including blocking	**0.3**	**10.5**	**5.3**

To assess the impact of the different ILs the smart metering link was removed and the simulations repeated. The result is shown in the above table.

By considering results reported in the above tables, it may be again clearly seen that prospects of co-existence with SRD would strongly depend on the type of ER-GSM deployment considered:

- For Case A, representing an average ER-GSM frequencies use case (e.g. railways shunting yard), the results are between 4 % if the whole 6 MHz can be used by SRDs and 8 % if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870-873 MHz then the probability of interference is in the order of 1%.
- For Case B, representing a worst case indication on the impact in the hand-over region of ER-GSM, the results are between 25 % if the whole 6 MHz can be used by SRDs and 50 % if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870-873 MHz then the probability of interference is about 3 %.
- When analysing the possibilities to improve the co-existence in critical scenario Case B, the Smart Metering application was identified as the one contributing most to the risk of interference, so the probability of interference would be reduced by a factor of 5 if the smart metering application could be removed or it’s interference to ER-GSM avoided, e.g. by implementing the DAA mechanism as discussed for RFID in 918-921 MHz band.

As Case A situations may promise co-existence potential with SRDs in countries that would consider that case relevant, it was decided to test it against the aforementioned possibility of deploying networked SRD devices, such as in professional utility networks (SM/M3N). The following simulation therefore presents an appropriately modified version of analysis of Case A of ER-GSM urban cell deployment, but with introduction of SM/M3N infrastructure devices (see Annex A2.4). The required for this simulation number of additional active interfering transmitters for NAP is calculated first, followed by the resulting SEAMCAT simulations report.

Table 27: Number of active NAP transmitters vs. ER-GSM, URBAN Case A – Typical Scenario

Parameter	Utilities network nodes (SM, M3N)		
	Low DC terminal	High DC terminal	NAP
Frequency, f, GHz	0.873		
SRD interferer			
Tx power, mW	500		
Receiver bandwidth, BWi, kHz	200		
Tx power normalised, dBm/BWi	26.99		
SRD uniform density, 1/sq.km	1900	100	10
Duty Cycle, %	0.1	2.5	10
GSM-R BS victim			
Receiver bandwidth, BWv, kHz	200		

Parameter	Utilities network nodes (SM, M3N)		
	Low DC terminal	High DC terminal	NAP
Sensitivity threshold, dBm/BWv	-104		
Useful signal above sensitivity, dB	**25**		
S/(I+N), dB	9		
Feeder and splitter losses, dB	6		
Max interference level, dBm/BWv	-82		
Receiver antenna gain, dBi	18		
Impact range and active interferers			
Propagation exponent *n*	3.5		
Calculated impact range, *R*, m	540		
Impact area, sq. km	0.92		
Number of active transmitters	**2**	**2**	**1**

Table 28: Simulation results: mix of SRDs with NAPs to ER-GSM URBAN Case A – Typical Scenario

Simulation input/output parameters	Settings/Results
	SRDs in 870-876 MHz
Victim Link (VL): ER-GSM uplink	
Frequency	873.2 MHz
VLR N	-116 dBm/200 kHz
VLR C/(N+I) threshold	9 dB
VLR BS antenna (incl. feeder/splitter losses)	12 dBi, 30°
VLR BS height	20 m
VLT power e.i.r.p.	33 dBm
VLT → VLR path	Extended-Hata, urban, Outdoor-Outdoor/below roof, R=1 km
Interfering Link (IL) #1.A: Metropolitan utilities (Smart Metering/M3N)	
Channel bandwidth	200 kHz
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT density	**1900**/km^2
ILT number of active transmitters	2
ILT probability of transmission	0.001
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof
IL1.B: Metropolitan utilities' higher DC terminal nodes	
Channel bandwidth	200 kHz
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT density	**90**/km^2
ILT number of active transmitters	5
ILT probability of transmission	0.025
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof
IL1.C: Metropolitan utilities' NAP	
Channel bandwidth	200 kHz

Simulation input/output parameters	Settings/Results
	SRDs in 870-876 MHz
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT density	**10**/km^2
ILT number of active transmitters	1
ILT probability of transmission	0.1
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/above roof
IL2: HA	
Channel bandwidth	200 kHz
ILT power e.i.r.p.	14 dBm/200 kHz
ILT density	**50000**/km^2
ILT number of active transmitters	1
ILT probability of transmission	0.000025
ILT → VLR interfering path	Extended Hata, urban, Indoor-Outdoor/below roof
IL4: Automotive (high power variety)	
Channel bandwidth	500 kHz
ILT power e.i.r.p.	27 dBm/500 kHz
ILT density	**80**/km^2
ILT number of active transmitters	1
ILT probability of transmission	0.001
ILT → VLR interfering path	Extended Hata, urban, Outdoor-Outdoor/below roof
General settings for all ILs	
ILT → VLR positioning mode	Uniform density
ILT → VLR minimum distance	100 m
IL frequency range	870-876 MHz
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-78 (13)
Probability of interference, C/(N+I), % including blocking	**5.1 (reference scenario = 4%)**

The provided results of simulation show that if introduced into the SRD mix, higher DC terminals and NAPs would increase the probability of interference by one-two percentage points.

4.4.1.3 Results of practical measurements in 870-876 MHz

A set of tests were carried out in Berlin in November 2012 to investigate the feasibility of coexistence between SRDs and GSM-R radios (to complement those carried out at BNetzA's Kolberg test facility in 2009). Those results are complementary to the simulations provided in the previous sections.

This testing campaign focused on call set up and data integrity measurements for both voice and data bearers. All of the tests were carried out in a real GSM-R network in operation but under static propagations conditions.

Investigations into the feasibility of sharing between SRDs and GSM-R bearers have shown that generally, signalling channels seem to be more sensitive to interference in GSM-R systems than traffic channels. The impact of interference on signalling channels is to extend call set up times, which is an important requirement for railway operations.
For transparent data Bearer service 25 (TCH full-rate with 4.8 kbps), aggregate interference activity that can be withstood (both setting up calls and established bearers) into a victim operating towards the limit of its

performance envelope lies between 15% and 25% (leading to extended call set times from 10s without interference to 11 seconds with 15% and 15s with 25 %,, and corresponding to 30 and 50 interferers each transmitting at 5ms every 1 second). Thus an aggregated DC limit of 15 % will be used later on to derive a long term DC limit for the protection of GSM-R (see Annex 5.2). This appears to be true irrespective of the interfering power. The impact of the duration of individual transmissions is inconclusive, but keeping transmissions below 20ms would appear to be sensible (leading to an extended call set time of around 1 second).

Operation (up to 100% duty cycle) in adjacent and next adjacent channels is feasible, but the protection ratio (C/I) for the former should be at most -25dB (eg -65dBm adjacent channel interferer into a victim receiving -90dBm) in order for calls to be able to be set up reliably. The protection ratio for next adjacent channel is -65dB.

For voice bearers, aggregate interference activity that can be withstood (both setting up calls and established bearers) into a victim operating towards the limit of its performance envelope lies around 10%. This appears to be true irrespective of the interfering power. Again, the impact of the duration of individual transmissions is inconclusive, but transmissions of up to 40ms appear feasible depending on the required RXQual-value and with the TXoff time set to 500 ms. Operation (up to 100% duty cycle) in adjacent and next adjacent channels is feasible with a protection ratio of at least -65dB.

Executive summary of the report from Berlin tests is reproduced in Annex A5.1.

Based on the results of practical testing a complementary theoretical post-processing modelling was performed in order to simulate the impact of interference from larger populaces of DC SRDs deployed in co-channel sharing scenario with ER-GSM. These are reported in detail in Annex A5.2.

This modelling indicates that 25mW non-specific SRD devices with deployment figures of up to 1000/km2 may coexist with ER-GSM if a specific short term DC limit could be fulfilled (Ton < 5 ms, Toff ≥ 995 ms, DC 0.5%/s). A small risk of interference remains at the hand-over region of ER-GSM, for the case that these 1000 devices per km2 are deployed around the ER-GSM base station. An additional long term DC limit of 0.1% per hour could solve that problem.

The assumed mix of specific SRD applications is more critical, as much higher deployment figures and higher power levels are assumed for some applications. This mix of applications would require a very low long term DC limit for most applications on top of the short term limit (e.g. below 0.03%). For some specific applications there are possibilities with the short term limit and without any additional long term DC restrictions (e.g. alarms, automotive) due to the expected low deployment figures. If the uniform density and other parameters could be changed for the mix of specific applications (especially home automation and smart metering applications), then there may be a possibility for all applications.

If the Tx power for all SRD applications would be reduced to 25mW, then only for home automation and smart metering a long term limit would be needed. This scenario reflects a mix of non-specific SRDs and is consistent with the non-specific scenario above, as both shows a possibility up to certain deployment figures.

For devices with high deployment figures it could be imaginable to restrict only for applications where we expect high deployment figures (i.e. more than 1 per household) the long term DC of around 0.03% (on top of the short term DC limit). It needs to be discussed if this could be claimed in the regulation.

It should be noted that all simulations heavily rely on the SRD device density assumptions. Since administrations would have no opportunity to control the practical deployment densities of SRDs in the real life, this means that the above conclusion are conditional on the understanding that the ETSI and industry predicted long term SRD deployment densities are well justified.

A possibility for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the E-GSM-R bands. This seems to be feasible as those devices are assumed to be installed by a service provider (e.g. for energy suppliers/smart grid) and not by the consumer. Additional cognitive approach, like solution by the RFID could allow higher device densities in areas with ER-GSM deployment.

4.4.1.4 Overall conclusions on GSM-R vs. SRD sharing in 870-876 MHz band

Overall it may be concluded that the co-existence of proposed SRD applications in the band 870-876 MHz with ER-GSM use in the sub-band 873-876 MHz would greatly depend on the scenario of ER-GSM use:

- For Case A, representing an average ER-GSM frequencies use case (railways shunting yards and similar traffic hot spots that require increase of railway network capacity), the results are between 4% if the whole 6 MHz can be used by SRDs and 8% if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870-873 MHz then the probability of interference is in the order of 1%;
- For Case B, representing a worst case indication on the impact in the hand-over region of ER-GSM, the results are between about 25 % if the whole 6 MHz can be used by SRDs and 50 % if only the band 873-876 MHz can be used by SRDs. If SRDs are deployed adjacent in the band 870 to 873 MHz then the probability of interference is between 3% and 8%;
- The results for non-specific SRDs and a mix of specific SRDs are similar, because the product of power, uniform density and Duty cycle are under the consideration of the bandwidth similar (Non-specific 25x1000x0.01=250 with 600 kHz, Smart metering 500x2000x0.001=1000 with 200 kHz).
- Administrations wishing to avoid harmful interference in both typical and worst case scenarios should introduce the option 1 and/or option 2 timing restrictions for SRDs in Table 1. Administrations willing to disregard the high risk of interference for worst case scenario B, and being able accepting interference probabilities in average case A simulations in the order of 5%, are not requiring those restrictions.
- A further option to use E-GSM-R bands for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the E-GSM-R bands (see Option 3 in Table 29).

Table 29: Options for sharing with ER-GSM

	Option 1: for devices with high deployment figures	Option 2: for devices where low deployment is ensured by regulatory means (e.g. access points) (Note 2)	Option 3: Cognitive approach (Note 1 and Note 3)
DC limit in a bandwidth of 200 kHz	▪ Short term DC limit Max Ton 5ms, Min Toff 995ms, and ▪ Long term DC of around 0.01% per 1 hour	Short term DC limit Max Ton 5ms, Min Toff 995ms	NA
Max Tx power	25 mW	500mW	For RFID at 36 dBm (4W) and SRD at 27 dBm (500 mW). A frequency offset of 100kHz from GSM-R channels is applicable

Note 1: The requirements for this cognitive approach with ER-GSM are analysed for the band 918-921 MHz in Annex 6 and are provided in TS 102 902 V1.2.2 and ETSI TS 102 903 V1.1.1 (2011-08). The latter document also describes the various compliance tests necessary to verify proper operation of the proposed mitigation technique for inclusion in an ETSI standard.
Note 2: Low deployment means about 1 device per km^2
Note 3: The DAA mechanism considered and tested for coexistence between ER-GSM and RFID devices in the 918-921 MHz band (see Annex6) could be also adapted to identify channels not being used by ER-GSM in the vicinity of SRDs in the 873-876 MHz band.

4.4.2 In-Band Co-Existence of proposed SRD/RFID and ER-GSM applications in 915-921 MHz

4.4.2.1 Co-existence of ER-GSM and RFID

Full details of the analysis between ER-GSM and RFID are shown at ANNEX 6:. One of the most important aspects of this study was to consider sharing of the band 915-921 MHz between ER-GSM and RFID using

DAA as a mitigation technique. The study was performed for the downlink of the GSM-R system using both analytical and SEAMCAT techniques. A brief summary of the main conclusions are summarised below:

4.4.2.2 Coexistence without mitigation techniques 915-921 MHz

Co-channel operation of the RFID interrogators and the ER-GSM downlink in the band 918-921 MHz needs to be avoided due to the large protection distances required;

For the protection of ER-GSM mobiles from RFID interrogators a frequency offset of ≥ 700 kHz is required assuming a separation distance of more than 20m;

For the protection of ER-GSM mobiles from RFID tags protection distances of up to some 60 m are necessary (see annex A6.1.1. This may be seen as acceptable as the use of RFID applications is predominantly indoors;

No impact is expected from the two proposed high power RFID channels in the band 915-918 MHz (916.3 and 917.5 MHz) on ER-GSM mobiles (NB: the centre frequency of the lowest ER-GSM channel is 918.2 MHz);

Also no harmful interference is expected to the GSM band below 915 MHz due to the frequency separation;

The results of some practical tests at an operational site between ER-GSM and RFID are reported in TS 101 602 [20]. These tests were carried out with modified interrogators that were fitted with DAA operating in accordance with the proposed mitigation technique. The results showed that RFID can share the band with ER-GSM without causing unacceptable interference.

4.4.2.3 Downlink detection

The results show that, with a threshold value of -98 dBm, the ER-GSM mobile is protected in most cases.

4.4.2.4 Co-existence of a mix of SRDs with ER-GSM operations in 915-921 MHz

In this case the simulation scenario would be in principle similar to what was modelled for the mix of specific SRD in the lower band 870-876 MHz (see section 4.4.1.2), except that in the band 915-921 MHz the ER-GSM duplex link direction is reversed and it is required to consider mobile GSM-R terminal as victim. This direction of interference would be identical to what was modelled in adjacent case around 921 MHz band edge in section 4.3.2. So the same assumptions is used here, such as considering only the handheld mobile station of ER-GSM as the likely more susceptible victim due to closer potential placement to SRDs.

One important difference from the sharing situation considered in section 4.4.1.2 is that the band 915-921 MHz would have different populace of SRD devices, as shown in ANNEX 2:

- Non-specific SRDs Type A: 25 mW, 1% DC;
- Non-specific SRDs Type B: deployed with power up to 100 mW in the same 4 “high-power” channels as assigned to RFIDs;
- Home Automation (HA) such as Home Alarms and Sub-metering, 200 kHz channels, 25 mW, 0.0025% DC;
- Assistive Listening Devices (ALDs), 10 mW, up to 25% DC, deployed in the same 4 “high-power” channels as assigned to RFIDs.

Note that since the band 915-921 MHz anyway assumes pre-defined placement of some “high-power” channels, as made necessary for RFID placement, it may be logically assumed that other systems may be placed taking due note of those channels. For instance, the higher power non-specific SRD Type B and ALD’s having high DC of up to 25% may use the same “polluted” channels as designated for RFID interrogators. Other SRDs (Non-specific Type A and HA) are in this simulation assumed to be spread across the entire band 915-921 MHz.

The simulation scenario is identical with the one considered in 4.3.2.1 However, in this case of in-band sharing, a more thorough analysis is carried out by analysing separately Cases A (typical) and B (critical) as discussed in previous sections.

Another important related element is the derivation of number of active interfering transmitters within impact area of victim. The approach used here is similar to what was used previously, and similarly assuming two different device user Density Options I and II (see Annex A2.3).Furthermore, for non-specific SRDs, the resulting total density could be equally partitioned between the low-power Type A and high-power Type B. The resulting calculations are given in the following table.

Table 30: Number of active transmitters for Specific SRDs to ER-GSM in 915-921 MHz: Case A

	Non-specific A	Non-specific B	ALD	Home automation
Input fields				
f/GHz	0.915	0.915	0.915	0.915
SRD definition				
Tx power mW	25	100	10	25
Tx power dBm/Bwi	13.98	20.00	10.00	13.98
Receiver Bandwith BWi kHz	600	400	200	500
Uniform density / km^2	500	500	40	50000
Duty Cycle	1.00%	1.00%	25.00%	0.0025%
Victim definition: GSM –R MS				
Sensitivity dBm/BWv	-102	-102	-102	-102
BWv kHz	200	200	200	200
Signal level above Sens dB	25	25	25	25
SIR dB	9	9	9	9
Feeder loss dB	0	0	0	0
Splitter loss dB	0	0	0	0
Max permissible interf dBm/BWv	-86	-86	-86	-86
Reception antenna gain dBi	0	0	0	0
BWCF dB	4.771212547	3.010299957	0	3.97940009
Interference assessment				
Propagation exponent n (Note 1)	3.5	3.5	3.5	3.5
Additional wall loss aw dB (Note 1)	0	0	0	0
Protection distance rp, m (Note 1)	65.12	108.65	68.60	68.60
Interference area Ai, km^2	0.01	0.04	0.01	0.01
Active transmitters	0.07	0.19	0.15	0.02

Note 1: Propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+aw

Table 31: Number of active transmitters for Specific SRDs to ER-GSM in 915-921 MHz: Case B

Input fields	Non-specific A	Non-specific B	ALD	Home automation
Input fields				
f/GHz	0.915	0.915	0.915	0.915
SRD definition				
Tx power mW	25	100	10	25
Tx power dBm/Bwi	13.98	20.00	10.00	13.98

Input fields	Non-specific A	Non-specific B	ALD	Home automation
Receiver Bandwith BWi kHz	600	400	200	500
Uniform density / km^2	500	500	40	50000
Duty Cycle	1.00%	1.00%	25.00%	0.0025%
Victim definition: GSM –R MS				
Sensitivity dBm/BWv	-102	-102	-102	-102
BWv kHz	200	200	200	200
Signal level above Sens dB	7	7	7	7
SIR dB	9	9	9	9
Feeder loss dB	0	0	0	0
Splitter loss dB	0	0	0	0
Max permissible interf dBm/BWv	-104	-104	-104	-104
Reception antenna gain dBi	0	0	0	0
BWCF dB	4.771212547	3.010299957	0	3.97940009
Interference assessment				
Propagation exponent n (Note 1)	3.5	3.5	3.5	3.5
Additional wall loss aw dB (Note 1)	0	0	0	0
Protection distance rp, m (Note 1)	212.81	355.08	224.19	224.19
Interference area Ai, km^2	0.14	0.40	0.16	0.16
Active transmitters	0.71	1.98	1.58	0.20

Note 1: Propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+aw

Due to close physical placement of interferers and victims and noting that various SRD families will have different output power levels, the study also considers the possibility of RF blocking interference mode.

As done in lower band, for Case A the scenario should lead to dRSS approximately around 25 dB above the sensitivity threshold, whereas for Case B a constant dRSS is set to -98 dBm.

The results of this simulation are reported in the following Tables.

Table 32: SRD co-existence with ER-GSM in 918-921 MHz, URBAN Case A – Typical Scenario

Simulation input/output parameters	Settings/Results
VL: ER-GSM downlink	
Frequency	918.2, 0.2 MHz channel
VLR sensitivity	-102 dBm/200 kHz
VLR selectivity	Cf. Table 55/Sensitivity mode
VLR C/(N+I) threshold	10 dB
VLR antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLT antenna gain and height a.g.l.	18 dBi, 20 m, 32^{O} sector
VL Tx power	40 dBm/200 kHz (incl. 6 dB splitter and feeder loss)
VL Tx → Rx path	Hata, urban, Outdoor-Outdoor/below roof, R=2 km
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz

Simulation input/output parameters	Settings/Results
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	500/250
Number of transmitters	1
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	500/250
Number of transmitters	1
IL3: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz with 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density	40/km^2
Number of active transmitters	1
IL4: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	50000/25000
Number of active transmitters	1
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-76 (12)
Probability of interference (unwanted and blocking modes), Device Density Options I and II, C/(N+I), %	**3**

Table 33: SRD co-existence with ER-GSM in 918-921 MHz, URBAN Case B - Critical

Simulation input/output parameters	Settings/Results
VL: ER-GSM downlink	
Frequency	918.2, 0.2 MHz channel
VLR sensitivity	-102 dBm/200 kHz
VLR selectivity	Cf. Table 55/Sensitivity mode
VLR C/(N+I) threshold	10 dB
VLR antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional
VLT antenna gain and height a.g.l.	18 dBi, 20 m, 32^O sector
VL Tx power	40 dBm/200 kHz (incl. 6 dB splitter and feeder loss)
VL Rx dRSS	Constant -98 dBm
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	500/250
Number of active transmitters	1
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	500/250
Number of active transmitters	2/1
IL3: ALD	
Frequency	915.0-916 MHz; 5 x 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	uniform density
ILT density	40/km^2
Number of active transmitters	2
IL4: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m

Simulation input/output parameters	Settings/Results
ILT → VLR positioning mode	uniform density
ILT density (Density Options I/II), dev/km^2	50000/25000
Number of active transmitters	1
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-98
Probability of interference (unwanted and blocking modes), Device Density Option I, C/(N+I), %	**14**
Probability of interference (unwanted and blocking modes), Device Density Option II, C/(N+I), %	**9**

4.4.2.5 Overall conclusions on ER-GSM vs. SRD sharing in 918-921 MHz band

It may be seen that the simulation and measurement results for ER-GSM vs. SRD co-channel sharing in 918-921 MHz band show broadly similar trends to those obtained for the band 873-876 MHz. Therefore the co-existence options and overall conclusions as outlined for the band 873-876 MHz in clause 4.4.1.4 retain their relevance to the sharing possibilities in the band 918-921 MHz as well.

4.5 COMPATIBILITY WITH PUBLIC CELLULAR SYSTEMS (ADJACENT BAND CO-EXISTENCE AROUND 915 MHz)

Description of co-existence scenario

This section reviews the co-existence prospects of proposed SRD/RFID applications in the band 915-921 MHz with the uplink of public cellular systems operated in the adjacent band 880-915 MHz.

This study currently considers GSM, UMTS and LTE as the technologies for public cellular systems (see Annex 1.2 for technical details). The following scenarios have been considered:

- Mixed SRDs to GSM BTS Rx;
- Mixed SRDs to UMTS Macro/Pico BS Rx;
- Mixed SRDs to LTE Macro BS Rx.

Results of simulations

The results of simulations of the Mixed SRD use case in configuration of adjacent band interference are presented in this section. First the simulation radius has to be determined; for this coexistence case a fixed simulation radius of 500m for macro scenarios and 50m for pico scenarios were selected. Secondly the suitable numbers of simulated interferers are selected based on simulation radius (see Table 34 below).

Table 34: Simulation Radius and Number of simulated SRD/RFID interferers vs. public cellular systems in adjacent band

GSM, UMTS marco and LTE	RFID (worst case)	RFID (typ.)	ALD	HA	Type A	Type B
Radius km	0.5	0.5	0.5	0.5	0.5	0.5
Density	480	20	40	25000	250	250
No of devices	376.99	15.71	31.42	19634.95	196.35	196.35
No of devices per 120 sector	125.66	5.24	10.47	6544.98	65.45	65.45

GSM, UMTS marco and LTE	RFID (worst case)	RFID (typ.)	ALD	HA	Type A	Type B
UMTA pico	**RFID**	**RFID**	**ALD**	**HA**	**Type A**	**Type B**
Radius km	0.05	0.05	0.05	0.05	0.05	0.05
Density	480	20	40	25000	250	250
No devices	3.77	0.16	0.31	196.35	1.96	1.96

Using the obtained numbers of interferers, the following table reports the SEAMCAT settings of simulations.

Table 35: Simulation settings: mix of SRDs to GSM/UMTS/LTE Uplink/Urban Cell in adjacent band

Simulation input/output parameters	Settings/Results	
VL: GSM uplink		
Frequency	914.8, 0.2 MHz channel	
VLR sensitivity	-110 dBm/200 kHz	
VLR blocking sensitivity	see Annex 1.2	
VLR C/I threshold	9 dB	
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 Rec. F.1336-3	
VLR antenna feeder loss	3 dB	
VL Tx → Rx path	User defined dRSS, See Annex 1.2	
VL: UMTS uplink		
Frequency	912.5, 5 MHz channel	
VLR selectivity	see Annex 1.2	
VLR noise figure	Macro: 5 dB Pico: 19 dB	
VLT antenna gain and height a.g.l.	0 dBi, 1.5 m, non-directional	
VLR antenna gain and height a.g.l., Macro	18 dBi, 30 m, 65^{O} sector, ITU Rec. F.1336-3	
VL Voice activity factor	1	
VLR antenna gain and height a.g.l., Pico	6 dBi, 3 m, non-directional	
VLR antenna feeder loss	3	
VL Tx power e.i.r.p	23 dBm	
VL Tx → Rx path , Macro	Extended-Hata, urban, outd-outd/above roof, R=500m	
VL Tx → Rx path , Pico	IEEE 802.11 model C, breakpoint distance 5m, R= 50m	
VL: LTE Macro uplink		
Frequency	910, 10MHz channel	
VLR selectivity	see Annex 1.2	
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 Rec. F.1336-3	
VLR antenna feeder loss	3	
VL Tx power e.i.r.p	23 dBm	
VL Tx → Rx path	Extended-Hata, urban, outd-outd/above roof, R=1.5km	
IL1: Non-specific SRD Type A		
Frequency	915.3-920.7 MHz, 0.6 MHz steps	
ILT power e.i.r.p.	14 dBm/600 kHz	
ILT mask (worst case / typical)	Full mask	20dB reduced in the spurious

Simulation input/output parameters	Settings/Results	
	(See Annex 2.5)	domain
ILT antenna	0 dBi	
ILT probability of transmission	0.01	
ILT → VLR interfering path	GSM/ LTE Macro/ UMTS Macro: Extended-Hata, urban, ind-outd/above roof UMTS Pico : IEEE 802.11 model C	
ILT density	250/km^2	
ILT impact distance (macro / pico)	500m / 50m	
ILT number of transmitters (macro / pico)	65 / 2	
IL2: Non-specific SRD Type B		
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels	
ILT power e.i.r.p.	20 dBm/400 kHz	
ILT mask (worst case / typical)	Full mask (See Annex 2.5)	20dB reduced in the spurious domain
ILT antenna	0 dBi	
ILT probability of transmission	0.01	
ILT density	250/km^2	
ILT distance (macro / pico)	500 m / 50 m	
ILT number of transmitters (macro / pico)	65 / 2	
IL3: ALD		
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz	
ILT power e.i.r.p.	10 dBm/200 kHz	
ILT mask (worst case / typical)	Full mask (See Annex 2.5)	20dB reduced in the spurious domain
ILT antenna	0 dBi	
ILT probability of transmission	0.25	
ILT density	40/km^2	
ILT distance (macro / pico)	500 m / 50 m	
ILT number of transmitters (macro / pico)	11 / 1	
IL4: HA		
Frequency	915.1-920.9 MHz, 0.2 MHz steps	
ILT power e.i.r.p.	14 dBm/200 kHz	
ILT mask (worst case / typical)	Full mask (See Annex 2.5)	20dB reduced in the spurious domain
ILT antenna	0 dBi	
ILT probability of transmission	0.000025 (Note 1)	
ILT density	25000/km^2	
ILT distance (macro / pico)	500 m / 50m	
ILT number of transmitters (macro / pico)	6545 / 196 (Note 1)	
IL5: RFID		
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels	
ILT power e.i.r.p. (worst case / typical case)	20 dBm/400 kHz	27 dBm/400 kHz
ILT mask (worst case / typical)	Full mask (See Annex 2.5)	20dB reduced in the spurious domain

Simulation input/output parameters	Settings/Results	
ILT antenna (worst case / typical)	0 dBi	8 dBi (Type 3) (see Annex 2.5)
ILT probability of transmission (worst case / typical case)	0.025	0.125
ILT density (worst case / typical)	480/km^2	20/km^2
ILT distance (macro / pico)	500 m / 50 m	
ILT number of transmitters(macro / pico)	126 / 4	5 / 1
General settings for all ILs		
ILT → VLR positioning mode	None	
ILT → VLR interfering path	GSM/ LTE Macro/ UMTS Macro: Extended-Hata, urban, ind-outd/above roof. UMTS Pico : IEEE 802.11 model C	

Note 1: to limit the simulation time the device number for home automation was reduced by a factor of 10 and the DC increasing by the same factor.

Two sets of simulation results are provided:

- A worst case simulation with an OOB and spurious emissions exploiting the maximum allowed mask and worst case RFID parameters; It has to be noted that the RFID density of 480/km^2 assumed for the worst case scenario is limited to a very few locations. The assumption that the OOB mask is exploited constantly over the full frequency band is also only of low relevance in practice.
- A typical simulation with typical OOB and spurious emissions and typical RFID parameters

For UMTS the voice activity factor determines the possible ratio a base station can have between talking (active) users and silent (inactive) users. If the numbers of active users have to be dropped due to external interference, the base station will also reduce the number of inactive users (to keep the activity factor constant). In SEAMCAT, there is no removal of inactive users, therefore any value different from 1 (activity 100 %) will artificially decrease capacity loss value. Therefore the value of 1 has been used.

To account for the fact that ALDs are not expected to be used at the same location as RFID, the simulations were only run with one of these two applications at any one time.

Table 37 shows the summary of the performed simulations.

Table 36: Simulation results: mix of SRDs to GSM/UMTS/LTE Uplink/Urban Cell

	GSM (Note 1 and 4) Probability of exceeding the C/I objective (unwanted and blocking)	UMTS pico (Note 2) Average capacity loss reference cell (%)	UMTS macro (Note 2) Average capacity loss reference cell (%)	LTE macro (Note 5) Average bitrate loss reference cell (%)
Mix of SRDs without RFID (worst case)	9.5 % (29.2 %)	10.2 % (0.4%)	22.1 % (13.9%)	16.6 % (9.5%)
Mix of SRDs without RFID (typical case) Note 3	1.2 % (4 %)	3.6 % (0.1%)	6.8 % (2.9%)	2.9 % (1.4%)
Mix of SRDs without ALD (worst case)	17 % (43.5 %)	9.8 % (0.5%)	33.1 % (19.8%)	28.2 % (18.9%)

	GSM (Note 1 and 4) Probability of exceeding the C/I objective (unwanted and blocking)	UMTS pico (Note 2) Average capacity loss reference cell (%)	UMTS macro (Note 2) Average capacity loss reference cell (%)	LTE macro (Note 5) Average bitrate loss reference cell (%)
Mix of SRDs without ALD (typical case) Note 3	1.1 % (4.3 %)	2.9 % (0.1%)	6.2 % (2.5%)	2.9 % (1.2%)

Note 1: fist value: C/I 9dB (3dB degradation), second result C/I 19 dB (0.1 dB degradation)
Note 2: first results cell noise rise selection 0.01 dB, Second result with 1dB. The 'target cell noise' parameter is a threshold which determines if a snapshot should be analysed for impact of interference or not. A low number will analyse all snapshots while a high number may exclude snapshots having impact of interference.
Note 3: For the typical scenario only the RFID deployment figures were adjusted compared to the worst case, although those numbers are also high and maybe not representative of a typical scenario; if the deployment figures for the other 4 application types were reduced by a factor of 10, then the interference probability would be essentially removed e.g. for typical case and GSM with C/I 19 dB from 4 % to <1% and for UMTS macro from 6 % to 1%)
Note 4: the results for GSM are based on a wanted signal distribution at the GSM BS with a mean value of -104 dBm (see also Annex 1.2), which is assumed to be valid for a full loaded GSM network; in real life this mean value might be higher and would reduce the risk of interference.
Note 5: first result obtained with the LTE power scaling threshold setting 0.99, second result with threshold setting of 0.9 (SEAMCAT default). 3GPP has defined two sets of power control parameter values represented by the 0.99 and 0.9 values).

The results for the so called “worst case” simulation are only provided for completeness and have no practical relevance.

The results of the typical scenario are summarised below:

- GSM: The probability of interference in the “typical scenario” with a C/I of 19 dB (0.1 dB degradation) is ~4% and with C/I of 9dB ~1% (3dB degradation). A further reduction to values below 1% is expected when considering that for the typical scenario only the RFID deployment figures were adjusted compared to the worst case, although the deployment figures for the other SRD applications are also high and may not be representative of a typical scenario. The impact is mainly caused by the unwanted emissions and the blocking effect can be neglected (0%). GSM is usually working in a frequency hopping mode which was not considered in the simulations and may reduce the impact further. It has to be noted that the assumed dRSS distribution is based on a fully loaded GSM system and the average dRSS is 6dB above sensitivity.

- LTE macro: In the “typical scenario”, when SRD OOB signal levels are reduced by 20dB, iRSS blocking signal dominates. However, the used LTE receiver mask does not include the filtering effect of the duplex filter. In an attempt to include the impact of a duplex filter the “typical scenario” degradation was reduced with ~50%. For the “typical scenario” “No RFID” and “No ALD” have similar results. The expected bitrate degradation of LTE Macro BS in the “typical scenario” due to SRD interference is within the range 1.5-3%. A further reduction to about 1% is expected when considering that for the typical scenario only the RFID deployment figures were adjusted compared to the worst case, although the deployment figures for the other SRD applications are also high and may not be representative of a typical scenario. It has to be noted that the LTE simulations show an average capacity loss of 0%, which only considers that no UE was dropped at the reference cell and not the bitrate degradation at the UE.

- UMTS macro: In the “typical scenario”, when SRD OOB signal levels are reduced by 20dB, iRSS blocking signal dominates. However, the used LTE receiver mask does not include the filtering effect of the duplex filter. In an attempt to include the impact of a duplex filter the “typical scenario” degradation was reduced with ~50%. For the “typical scenario” “No RFID” and “No ALD” have similar results. The expected capacity loss of UMTS Macro BS in the “typical scenario” due to SRD interference is up to 7%. A further reduction to about 1% is expected when considering that for the typical scenario only the RFID deployment figures were adjusted compared to the worst case, although the deployment figures for the other SRD applications are also high and may not be representative of a typical scenario.

- UMTS pico: In the “typical scenario”, when SRD OOB signal levels are reduced by 20dB, iRSS blocking signal dominates. However, the used LTE receiver mask does not include the filtering effect of the duplex filter. In an attempt to include the impact of a duplex filter the “typical scenario” degradation was reduced with ~50%. For the “typical scenario” “No RFID” and “No ALD” have similar results. The expected capacity loss of UMTS Pico BS for the “typical scenario” due to SRD interference is up to 4%. A further reduction to about 1% is expected when considering that for the typical scenario only the RFID deployment figures were adjusted compared to the worst case, although the deployment figures for the other SRD applications are also high and may not be representative of a typical scenario.

Further mitigation effects are expected due to better blocking characteristics public cellular network BS in real systems compared to the assumed requirements from the standard.

In summary we may conclude that the simulations on the impact of a mix of SRD and RFID applications used in the band 915-921 MHz on public cellular systems used below 915 MHz show that there may be a low risk of interference in real life scenarios (typical scenario).

4.6 COMPATIBILITY WITH WIND PROFILER RADARS

4.6.1 Description of co-existence scenario

The technical parameters of Wind Profiler Radars are described in annex A1.6.

There are just two sites in Europe where Wind Profiler Radars operate at 915 MHz. One is based at Camborne in the UK near Lands End in Cornwall and the second is on a hill next to a sewage works on the Isle of Man. At present it is believed that it is unlikely that any additional sites would operate within Europe within this band, indeed in Europe this frequency is not used elsewhere since the preferred band for UHF Wind Profiler Radars in Europe is the 1270-1295 MHz band.

To investigate possible interference from ALDs and RFID into Wind Profiler Radars, some practical feasibility tests were performed by representatives from ETSI ERM_TG17 and ERM_TG34 at the UK Met Office site at Camborne in February 2013. Full details of the investigation are contained in ETSI TR 103 151 [21]. The results showed that when ALD was positioned at the perimeter of the site, it was just detectable by Wind Profiler Radar. With RFID operating at 4 W e.i.r.p. in the same position and directed at the Wind Profiler Radar, it experienced a significant level of interference in its lower mode. However when the transmitted power of RFID was reduced to 100 mW, the level of interference to Wind Profiler Radar was on the margin of being acceptable. As recommended in A2.5 for the purposes of simulations, the emission levels from an RFID hotspot are typically just below 20 dBm.

4.6.2 Results of simulations

The following table provides the results of SEAMCAT simulations for the above discussed scenario. The density of RFID interferers was taken from Table 8 for the Hotspot scenario. This leads to total number of 480 interferers in a single area of around one square kilometre, and assuming DC of 2.5% on any given channel, this means up to 12 simultaneously active interferers per channel.

Table 37: Simulation results: RFID to Wind Profiler Radar at 915 MHz

Simulation input/output parameters	Settings/Results
VL: Wind Profiler Radar installation (see section A1.6)	
Frequency	915 MHz
VLR noise floor	-112.2 dBm/2500 kHz
VLR user-defined dRSS	-100 dBm/2500 kHz
VLR antenna gain in horizontal plane	-18.7 dBi
VLR antenna metallic enclosure loss	10 dB

Simulation input/output parameters	Settings/Results
VLR antenna effective gain ($G_{horiz} – L_{enclosure}$)	-28.7 dBi
VLR height, a.g.l.	1 m
IL: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20dBm (antenna pattern according Figure 29: in annex A2.5)
IL → VL interfering path	Extended Hata, rural, Indoor-Outdoor/below roof
IL → VL positioning mode	Uniform density, 1 km protection distance
ILT density	480/km^2
ILT probability of transmission	0.025
ILT: number of active transmitters	12
Simulation results	
iRSS, dBm/2500 kHz (Std.dev., dB)	-104.5 (14)
Probability of interference, I/N = -6 dB, %	4.66

The results reported in the above table shows an interference probability of around 5% from RFID to Wind Profiler Radars. However, if a further shielding of 10dB were added to the enclosure of the Wind Profiler Radars, the probability of interference would fall to 0.49%.

For these scenarios SEAMCAT assumed a total of 480 interrogators positioned at random within a radius of 1 km of the Wind Profiler Radar installation with each interrogator operating at a duty cycle of 0,25 %. This is representative of the maximum level of activity that occurs at a cluster of four distribution centres. Such high activity typically is restricted to the period between 03:00 hrs. and 06:00 hrs. when trucks are being loaded before leaving for the retail outlets.

4.7 CONCLUSIONS OF THE COMPATIBILITY STUDIES WITH EXISTING SYSTEMS

The first part of this report has considered possibility of co-existence between proposed SRD/RFID applications as described in section 3 and ANNEX 2: with existing systems in the bands 870-876 MHz and 915-921 MHz and in adjacent bands.

In general it may be observed that some challenges have been identified for sharing the bands 870-876 MHz / 915-921 MHz with some existing and future systems. The adjacent band coexistence appears possible.

The ECO document on *Results of the questionnaire regarding the existing usage in the frequency bands 870-876 MHz / 915-921 MHz* dated 28 June 2012 (available from www.efis.dk) shows that out of the 48 countries, these scenarios are not a common occurrence. Combining this with the results from the compatibility studies gives the summary in Table 38, below.

Table 38: Overview of SRD sharing possibilities with existing systems

Systems	Co-existence Challenge	Countries adversely affected *	Frequency affected (MHz)	Comments
UAS	YES	≤12	870-876 915-921	Sharing may only be feasible for SRDs if very low deployment figures can be enforced (see section 4.1). Sharing with RFID not feasible.
TRR	YES	≤12	870-876 915-921	Sharing may only be feasible for SRDs if TRR deployment is restricted to separate exercise areas or if very low deployment figures for SRDs can be enforced (see section 4.2). Sharing with RFID is not

				feasible.
Wind Profiler Radars	NO	1	915	Only 2 locations in Europe on remote sites
ER-GSM	YES	8	873-876 918-921	Sharing is feasible with ER-GSM with specific mitigation techniques (see section 4.4.1.4)
* Taken from ECO document on *Results of the questionnaire regarding the existing usage in the frequency bands 870-876 MHz / 915-921 MHz* dated 28 June 2012				

However these challenges may occur in some locations within a CEPT administration and it is likely that it will not be possible to create a fully harmonised situation across CEPT. It is likely that, should these bands be used for SRD and RFID that it would need to be addressed as operating under a Class 2 regulatory environment, over at least part of each of the two spectrum bands. It may be possible to harmonise the use of spectrum for SRD and RFID over parts of the 870-876 MHz and 915-921 MHz bands.

5 INTRA SRD COMPATIBILITY

5.1 DESCRIPTION OF CO-EXISTENCE SCENARIO

In this co-existence case the subject of study is the interference potential amongst the different SRD families. Again taking stance in the studies reported in previous section, it would appear logical to shortcut the initial deliberations of partial cases and start the analysis from the most complex of considered scenarios, namely, the co-existence within the dense mix of several SRD device families.

Therefore this study continues using the previous example of Mixed-SRD scenario in a dense urban environment but further considers one of the subject SRDs as the victim, while three other SRD families act as in-band interferers. Differently from the case of co-existence with ER-GSM, in this situation all interfering and victim devices shall be mixed in one random spot, as illustrated in the following figure that shows a screenshot of SEAMCAT simulation window for this scenario.

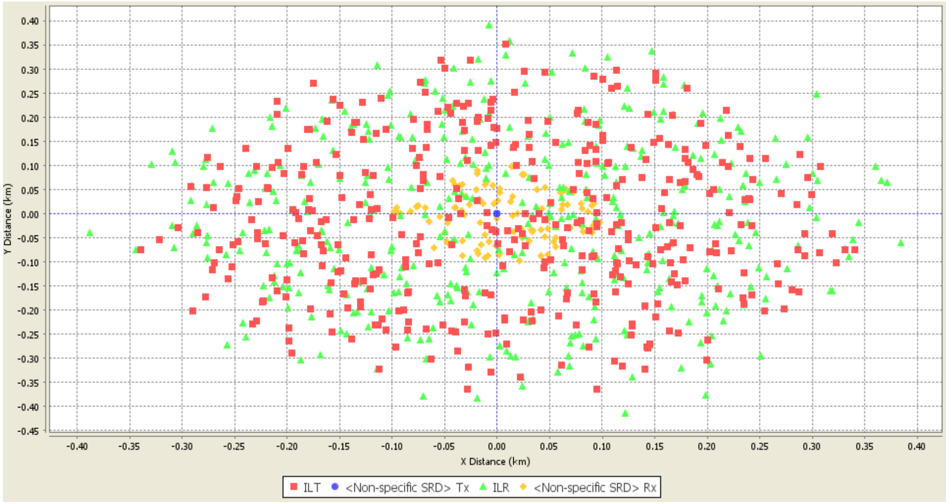


Figure 12: Example of SEAMCAT simulation window: Intra-SRD co-existence scenario

Hata-SRD propagation path loss model shall be used in this scenario, as it is well suited to model propagation in cluttered environment between similarly low placed transceivers. However, when using this model it is required to set a hard ceiling on the maximum simulation distances, as this model is defined only up to 300 m (which is also natural assumption for upper limit of intra-SRD impact range). Therefore in SEAMCAT scenario settings the "None" ILT-VLR placement mode was used because only this mode allows user to define maximum radius of simulations.

However, it was observed that the simulation radius may need to be further adjusted taking into account the power of interferer, so that the simulations do not create unbalanced situation by overestimating the impact of the low power types of SRDs.

Another important related element is the derivation of number of active interfering transmitters within impact area of victim. The calculations of respective impact areas and numbers of active interferers were carried out with a method similar to what was used when analysing the extent of the SRD impact to existing systems in section 4. The following table provides an example of calculating the impact area and number of interferers for one case.

Table 39: Impact area and number of active transmitters for the case of Non-specific SRD as victim

Parameter	Portable Alarms	Home Automation	Smart Metering		Automotive high power
Frequency, f, GHz	0.873	0.873	0.873		0.873
SRD interferer					
Tx power, mW	100	25	500		500
Receiver bandwidth, BWi, kHz	25	200	200		200
Tx power normalised, dBm/BWi	20	13.98	26.99		26.99
Baseline SRD uniform density, 1/sq.km	12	50000	1900	90	80
Duty Cycle, %	0.1	0.0025	0.1	2.5	0.1
Victim: Non-specific SRD					
Receiver bandwidth, BWv, kHz	600				
Sensitivity threshold, dBm/BWv	-91				
Useful signal above sensitivity, dB	19				
SIR, dB	8				
Max interference level, dBm/BWv	-80				
Receiver antenna gain, dBi	0				
Impact range and active interferers					
Propagation exponent *n*	3.5	3.5	3.5		3.5
Calculated impact range, *R*, m	91.68	61.70	145.21		145.21
Impact area, sq. km	0.03	0.012	0.07		0.07
Number of transmitters in impact area for Density Option I	1	600	125	6	5
Number of transmitters in impact area for Density Option II	1	300	125	6	5

Due to close physical placement of interferers and victims and noting that various SRD families will have different output power levels, the study also considers the possibility of RF blocking interference mode.

Note that in all following simulations no activity-periods/DC impact was considered on the victim, i.e. it was “receptive to interference” constantly, without any sleep time or similar inactivity periods.

Further particular details of the various parameter settings are reported in the simulation tables in the following section.

5.2 INTRA-SRD SHARING IN 870-876 MHz

5.2.1 Non-specific SRD as a victim

The following tables show the results of simulations for urban Mixed SRD scenario by considering different representative non-specific and specific SRD families as victims.

Note that for the sake of consistency with previously introduced notion of SM applications used in networked configuration; all simulations in this section include the same networking complement of SM devices.

Table 40: Intra-SRD co-existence simulation results: *Non-specific SRD as a victim*

Simulation input/output parameters	Settings/Results
VL: Non-specific SRD	
Frequency	870-876 MHz, 0.6 MHz steps
VLR sensitivity	-91 dBm/600 kHz
VLR selectivity	42 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	14 dBm/600 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1.A: Smart Metering – low DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 145 m)
ILT density	1900/km^2
Number of transmitters	125
IL1.B: Smart Metering – high DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 145 m)
ILT density	90/km^2
Number of transmitters	6
IL1.C: Smart Metering – NAPs	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	10%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 145 m)
ILT density	10/km^2
Number of transmitters	1
IL2: Portable Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz

Simulation input/output parameters	Settings/Results
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 90 m)
ILT density	12/km^2
Number of transmitters	1
IL3: Automotive	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 145 m)
ILT density	80/km^2
Number of transmitters	5
IL4: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 60 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters	600/300
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-72 (18)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**1.4**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**1.2**

It has to be noted that is has been assumed in all simulations, that all SRD applications working with a margin of about 20dB above sensitivity and all are randomly choosing there channel out of the available 6 MHz.

5.2.2 Specific SRD as a Victim

This sub-section reviews the results of intra-SRD interference modelling for the considered representative mix of specific SRDs in the band 870-876 MHz.

Table 41: Intra-SRD co-existence simulation results: *Portable Alarms SRD as a victim*

Simulation input/output parameters	Settings/Results
VL: Portable Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
VLR sensitivity	-105 dBm/25 kHz

Simulation input/output parameters	Settings/Results
VLR selectivity	50 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	20 dBm/25 kHz
VL Tx → Rx path	Hata-SRD, urban, Indoor-Outdoor/below roof, R=0.1 km
IL1.A: Smart Metering – Low DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 300 m)
ILT density	1900/km^2
Number of transmitters	795
IL1.B: Smart Metering – high DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 300 m)
ILT density	90/km^2
Number of active transmitters	38
IL1.C: Smart Metering – NAPs	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	10%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 300 m)
ILT density	10/km^2
Number of active transmitters	4
IL2: Non-specific SRDs	
Frequency	870-876 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 155 m)
ILT density, Options I/II	1000/500 1/km^2

Simulation input/output parameters	Settings/Results
Number of transmitters, Options I/II	75/38
IL3: Automotive	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 300 m)
ILT density	$80/km^2$
Number of active transmitters	33
IL4: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 155 m)
ILT density, Options I/II	$50000/25000\ 1/km^2$
Number of active transmitters. Options I/II	3770/1885
Simulation results	
dRSS, dBm/25 kHz (Std.dev., dB)	-66 (15)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**3.6**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**2.5**

Table 42: Intra-SRD co-existence: Home Automation SRD as a victim

Simulation input/output parameters	Settings/Results
VL: HA	
Frequency	870-876 MHz, 0.2 MHz steps
VLR sensitivity	-96 dBm/200 kHz
VLR selectivity	47 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	14 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1: Portable Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m

Simulation input/output parameters	Settings/Results
ILT → VLR positioning mode	None (simulation radius 130 m)
ILT density	12/km^2
Number of transmitters	1
IL2: Non-specific SRDs	
Frequency	870-876 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	1000/500 1/km^2
Number of transmitters, Options I/II	23/12
IL3.A: Smart Metering – low DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 200 m)
ILT density	1900/km^2
Number of transmitters	243
IL3.B: Smart Metering – high DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 200 m)
ILT density	90/km^2
Number of transmitters	12
IL3.C: Smart Metering – NAPs	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	10%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 200 m)
ILT density	10/km^2
Number of transmitters	1
IL4: Automotive	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz

Simulation input/output parameters	Settings/Results
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 200 m)
ILT density	80/km^2
Number of transmitters	10
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-72 (18)
Probability of interference (unwanted and blocking modes) , Density Option I, C/I, %	**2.1**
Probability of interference (unwanted and blocking modes) , Density Option II, C/I, %	**1.5**

Table 43: Intra-SRD co-existence simulation results: *Smart Metering SRD as a victim*

Simulation input/output parameters	Settings/Results
VL: Smart Metering	
Frequency	870-876 MHz, 0.2 MHz steps
VLR sensitivity	-96 dBm/200 kHz
VLR selectivity	47 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	27 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, Indoor-Outdoor/below roof, R=0.2 km (1)
IL1: Portable Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 130 m)
ILT density	12/km^2
Number of transmitters	1
IL2: Non-specific SRDs	
Frequency	870-876 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	1000/500 1/km^2
Number of transmitters, Options I/II	23/12

Simulation input/output parameters	Settings/Results
IL3: Automotive	
Frequency	870-876 MHz, 0.5 MHz steps
ILT power e.i.r.p.	27 dBm/500 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 200 m)
ILT density	80/km^2
Number of transmitters	10
IL4: HA	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters	1154/577
Simulation results	
dRSS, dBm/200 kHz (Std.dev., dB)	-75 (19)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**3.4**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**1.6**

Note 1: note that in this case victim's normal operational (simulation) radius is extended from 40 m to 200 m in order to justify requested increased power of 27 dBm

Table 44: Intra-SRD co-existence simulation results: *Automotive SRD as a victim*

Simulation input/output parameters	Settings/Results
VL: Automotive	
Frequency	870-876 MHz, 0.5 MHz steps
VLR sensitivity	-92 dBm/500 kHz
VLR selectivity	43 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	0.5 m
VL Tx power e.i.r.p.	27 dBm/500 kHz
VL Tx → Rx path	Hata-SRD, urban, Outdoor-Outdoor/below roof, R=0.2 km (1)
IL1: Portable Alarms	
Frequency	870-876 MHz, 0.025 MHz steps
ILT power e.i.r.p.	20 dBm/25 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof

Simulation input/output parameters	Settings/Results
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 100 m)
ILT density	12/km^2
Number of transmitters	1
IL2: Non-specific SRDs	
Frequency	870-876 MHz, 0.6 MHz steps
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 70 m)
ILT density, Options I/II	1000/500 1/km^2
Number of transmitters, Options I/II	14/7
IL3.A: Smart Metering – low DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
ILT probability of transmission	0.1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 155 m)
ILT density	1900/km^2
Number of transmitters	144
IL3.B: Smart Metering – high DC terminal nodes	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 155 m)
ILT density	100/km^2
Number of transmitters	7
IL1.C: Smart Metering – NAPs	
Frequency	870-876 MHz, 0.2 MHz steps
ILT power e.i.r.p.	27 dBm/200 kHz
APC threshold and range/step	-86 dBm/200 kHz; range 20 dB, step 2 dB
ILT probability of transmission	10%
ILT → VLR interfering path	Hata-SRD, urban, Outdoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 155 m)
ILT density	10/km^2
Number of transmitters	1
IL4: HA	
Frequency	870-876 MHz, 0.2 MHz steps

Simulation input/output parameters	Settings/Results
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 70 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters, Options I/II	682/341
Simulation results	
dRSS, dBm/500 kHz (Std.dev., dB)	-61 (19)
Probability of interference (unwanted and blocking modes) , Density Option **I**, C/I, %	**3.0**
Probability of interference (unwanted and blocking modes) , Density Option **II**, C/I, %	**2.1**

Note 1: note that in this case victim's normal operational (simulation) radius is extended from 40 m to 200 m in order to justify requested increased power of 27 dBm.

Based on the above reported simulations, it may be concluded that the overall probability of interference in intra-SRD scenarios in the band 870-876 MHz is at reasonably low levels of between 1-4%.

5.3 INTRA-SRD/RFID SHARING IN 915-921 MHZ

In this section the subject of study is the interference potential amongst the different SRD families proposed for the band 915-921 MHz. This case is analysed similarly to the case of intra-SRD co-existence in 870-876 MHz with the only difference that in this band the mix of considered SRD families will be different, as discussed in previous sections.

The mutual placement of SRD vs RFID channels is important and it is assumed that:

- ALDs are operating in the same channels as RFID interrogators;
- Non-specific SRDs Type B are operating in the same channels as RFID interrogators;
- Other types of SRDs may operate in sub-bands interleaved amongst the "high-power" RFID channels. However, in order to model least restrictive regulatory scenario, other SRDs were assumed to be operating randomly across channels evenly spread throughout the entire band 915-921 MHz.

This interleaved frequency arrangement would correspond to the vision originally outlined in ETSI TR 102 649-2 [1].

Note that in all following simulations no activity-periods/DC impact was considered on the victim, i.e. it was "receptive to interference" constantly, without any sleep time or similar inactivity periods.

Further particular details of the various parameter settings are reported in the simulation tables below.

The first case considers the RFID as a victim against the mix of proposed SRDs as interferers. First the calculation of number of interferers is provided, followed by the results of SEAMCAT simulations.

Table 45: Example of calculating number of interferers for Intra-SRD-RFID case in 915-921 MHz

	Non-specific B	HA	ALD	Non-specific A
Input fields				
f/GHz	0.916	0.916	0.916	0.916
SRD interferer				
Tx power mW	100	25	10	25
Tx power dBm/Bwi	20.00	13.98	10.00	13.98
Receiver Bandwith BWi kHz	400	200	200	600
Uniform density / km^2	500	50000	40	500
Duty Cycle	1.00%	0.0025%	25.00%	1.00%
Victim definition: RFID				
Sensitivity dBm/BWv	-75	-75	-75	-75
BWv kHz	400	400	400	400
Signal level above Sens dB	3	3	3	3
SIR dB	8	8	8	8
Feeder loss dB	0	0	0	0
Splitter loss dB	0	0	0	0
Max permissible interf dBm/BWv	-80	-80	-80	-80
Reception antenna gain dBi	0	0	0	0
Interference assessment				
Propagation exponent n (Note 1)	3.5	3.5	3.5	3.5
Additional wall loss aw dB (Note 1)	0	0	0	0
Protection distance rp, m (Note 1)	89.20	60.02	46.20	60.02
Interference area Ai, km^2	0.02	0.01	0.01	0.01
Transmitters in interference area	12.50	565.95	0.27	5.66

Note 1: Propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+aw

Table 46: Intra-SRD vs RFID co-existence in 915-921 MHz: *RFID* as a victim

Simulation input/output parameters	Settings/Results
VL: RFID Interrogator's receiver	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
VLR sensitivity	-75 dBm/400 kHz
VLR selectivity	35 dB
VLR C/I threshold	12 dB
VLR antenna	0 dBi, Directional
VLR antenna height	1.5 m
VL dRSS user defined (from tags)	-72 dBm/400 kHz
IL1: Non-specific SRD Type A	

Simulation input/output parameters	Settings/Results
Frequency	915-921 MHz, 0.6 MHz channels
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 60 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	6/3
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 90 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	13/7
IL3: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 50 m)
ILT density	40/km^2
Number of transmitters	1
IL4: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, Indoor-Outdoor/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 60 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters, Options I/II	566/283
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-72 (0)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**3.9**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**3.2**

These results show that the probability of interference from SRDs to RFID would be marginal.

The following tables show the results of simulations for urban Mixed SRD scenario, including RFID, by considering different representative non-specific and specific SRD families as victims.

Table 47: Intra-SRD co-existence in 915-921 MHz: *Non-specific SRD (Type A)* as a victim

Simulation input/output parameters	Settings/Results
VL: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz channels
VLR sensitivity	-91 dBm/600 kHz
VLR selectivity	42 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	14 dBm/600 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 90 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	13/7
IL2: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 50 m)
ILT density	40/km^2
Number of transmitters	1
IL3: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 60 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of active transmitters, Options I/II	566/283
IL4: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m

Simulation input/output parameters	Settings/Results
ILT → VLR positioning mode	None (simulation radius 90 m)
ILT density	480/km^2
Number of transmitters	12
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-72 (18)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**4.4**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**3.9**

Table 48: Intra-SRD co-existence in 915-921 MHz: *Non-specific SRD (Type B)* as a victim

Simulation input/output parameters	Settings/Results
VL: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
VLR sensitivity	-93 dBm/400 kHz
VLR selectivity	43 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	20 dBm/400 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz , two 0.6 MHz channels
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 70 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	7/4
IL2: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 50 m)
ILT density	40/km^2
Number of transmitters	1
IL3: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%

Simulation input/output parameters	Settings/Results
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 70 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters, Options I/II	736/368
IL4: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 100 m)
ILT density	480/km^2
Number of transmitters	16
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-67 (18)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**3.9**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**3.9**

Table 49: Intra-SRD co-existence in 915-921 MHz: *Assistive Listening Device* as a victim

Simulation input/output parameters	Settings/Results
VL: ALD	
Frequency	917.5 MHz
VLR sensitivity	-96 dBm/200 kHz
VLR selectivity	47 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	10 dBm/200 kHz
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz channels
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	11/6
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels

Simulation input/output parameters	Settings/Results
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 125 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	24/12
IL3: HA	
Frequency	915-921 MHz, 0.2 MHz steps
ILT power e.i.r.p.	14 dBm/200 kHz
ILT probability of transmission	0.0025%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	50000/25000 1/km^2
Number of transmitters	1090/545
IL4: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, outd-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 125 m)
ILT density	480/km^2
Number of transmitters	23
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-76 (18)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**5.8**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**3.8**

Table 50: Intra-SRD co-existence in 915-921 MHz: *HA* as a victim

Simulation input/output parameters	Settings/Results
VL: HA	
Frequency	915-921 MHz, 0.2 MHz steps
VLR sensitivity	-96 dBm/200 kHz
VLR selectivity	47 dB
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, Non-directional
VLR/Tx antenna height	1.5 m
VL Tx power e.i.r.p.	14 dBm/200 kHz

Simulation input/output parameters	Settings/Results
VL Tx → Rx path	Hata-SRD, urban, ind-ind/below roof, R=0.04 km
IL1: Non-specific SRD Type A	
Frequency	915-921 MHz, 0.6 MHz channels
ILT power e.i.r.p.	14 dBm/600 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 85 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	11/6
IL2: Non-specific SRD Type B	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	1%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 125 m)
ILT density, Options I/II	500/250 1/km^2
Number of transmitters, Options I/II	24/12
IL3: ALD	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 200 kHz channels
ILT power e.i.r.p.	10 dBm/200 kHz
ILT probability of transmission	25%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 65 m)
ILT density	40/km^2
Number of transmitters	1
IL4: RFID	
Frequency	916.3; 917.5; 918.7; 919.9 MHz; 400 kHz channels
ILT power e.i.r.p.	20 dBm/400 kHz
ILT probability of transmission	2.5%
ILT → VLR interfering path	Hata-SRD, urban, ind-ind/below roof
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 125 m)
ILT density	480/km^2
Number of transmitters	23
Simulation results	
dRSS, dBm/600 kHz (Std.dev., dB)	-73 (18)
Probability of interference (unwanted and blocking modes), Density Option I, C/I, %	**4.0**
Probability of interference (unwanted and blocking modes), Density Option II, C/I, %	**2.9**

The results of intra-SRD sharing analysis in the band 915-921 MHz demonstrate low probability of interference around 3-6%.

5.4 CONCLUSION OF THE COMPATIBILITY STUDIES ON INTRA-SRD AND RFID SHARING

It may be concluded from the above reported simulation results of several representative intra-SRD interference case studies that, in general, the prospects of intra-SRD co-existence appear to be very good.

For intra-SRD sharing in both 870-876 MHz and 915-921 MHz the interference probabilities are between 1% and 6%, even for very dense urban deployment scenarios and without assuming band segmentation or any special co-existence requirements except the intrinsic operational DC limits. However, the implementation of additional mitigation mechanisms and transmission timing considerations might be nevertheless helpful in order to maintain the probability of intra-SRD interference around zero levels, as well as alleviating some remaining co-existence concerns with other systems (TRR, ER-GSM).

For SRD and RFID sharing at 915-921 MHz, it has been demonstrated that the effective power output from RFID is lower (20dBm rather than 36dBm) in relation to its interference with services. To a great extent this also applies with Intra SRD and RFID sharing however due to the portable nature of many SRDs, the worst case situation also has to be considered. This sharing was extensively covered in ECC Report 37 [2] which concluded that co-channel sharing was not simple for SRDs and RFID within the same building.

The proposed channelized sharing of the 915-921 MHz band between RFID and non-specific/specific SRDs could also provide additional spectrum for SRD applications and will be of particular benefit in situations where higher powers or higher DC are required for SRDs (e.g. some kinds of automotive or smart metering SRDs that may require higher output powers), where proximity use was not an issue.

6 CONCLUSIONS

All conclusions in this report are based on SRD/RFID parameters (e.g. channel bandwidths, DC and transmit power ranges) as derived from respective ETSI SRDocs (see chapter 3 and Annex 2) except for the explicit provisions mentioned below.

A. Countries where bands 870-876 / 915-921 MHz are used for TRR and/or UAS:

Countries where bands 870-876 / 915-921 MHz or parts of the band are used for TRR and/or UAS may consider introduction of SRD/RFIDs only with certain additional considerations, such as:

- For countries that in the time of peace restrict the use of TRR to designated military exercise areas, adequate physical separation between SRD/RFID and TRR must be ensured. Under these conditions sharing with SRD/RFIDs may be feasible and further aided by requiring SRDs to use APC;
- For countries that in time of peace allow the use of TRR anywhere across their territory, especially in urban areas,
  - sharing between SRD (band 870-876 MHz) and TRR may be feasible subject to specific conditions. In particular, these conditions must impose limitations on SRDs covering emitted power, DC and the density of SRDs per square km, as indicated in the studies. Irrespective, there will be some residual level of interference and the overall noise level to TRR will be increased;
  - sharing between RFID (band 915-921 MHz) and TRR will not be feasible
- For countries that allow use of UAS anywhere across their territory, especially in urban areas,
  - co-frequency sharing between SRD (870-876 MHz) and UAS may be feasible subject to specific conditions. In particular, these conditions impose limitations on the emitted power of SRDs, their DC and the density of SRDs per square km, as indicated in the studies. Irrespective, there will be some residual level of interference and the overall noise level to UAS will be increased;
  - co-frequency sharing between RFID (915-921 MHz) and UAS will not be feasible in general;
- The countries that use the subject bands for TRR and/or UAS systems in the band 870-876 MHz may allow SRDs as Class 2 devices provided they comply with limits on power and duty cycle. Furthermore there must be certainty that the estimate for the density of devices is not exceeded;
- Sharing conditions may be improved if SRD/RFID could employ additional, more sophisticated mitigation mechanisms, such as DAA[4].

B. Countries where the bands 873-876 / 918-921 MHz may be used for ER-GSM:

- The subject bands include sub-bands 873-876 / 918-921 MHz that are allocated as an extension for pan-European GSM-R systems (referred to as the ER-GSM bands). They may be used by countries that have a heavy railways infrastructure requiring additional network capacity in addition to that provided by the main GSM-R bands 876-880 / 921-925 MHz.
- Co-frequency sharing with ER-GSM is not generally possible without addition mitigation. It is therefore proposed that countries with plans for using 873-876 / 918-921 MHz for ER-GSM, may consider the following regulatory arrangements for introducing SRD/RFIDs:
  - Within the bands 870-873 / 915-918 MHz the considered SRDs/RFIDs may be allowed with the parameters assumed in this report (see Table 52);
  - Within the bands 873-876 / 918-921 MHz, administrations wishing to avoid harmful interference in both typical and worst case scenarios should introduce the option 1 and/or option 2 timing restrictions for SRDs in Table 1 below. Administrations willing to disregard the high risk of interference for worst case scenarios, and accepting interference probabilities in the average case simulations in the order of 5%, do not require these restrictions.
  - A further option to use ER-GSM bands for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the ER-GSM bands (see Option 3 in Table 1).

[4] The analysis presented in ANNEX 4: proves that, with simple power sensing on the candidate operational frequency, DAA may only work with very low detection threshold values (in some cases below the noise floor) or for high SNR margins at the victim link receiver. The situation would be improved if the SRD could monitor the emission at the same position where the victim receiver is located. However this would require knowledge about the TRR/UAS duplexing and channel arrangement which cannot be generally assumed. Therefore DAA as a method of operation is not very promising for the protection of TRR and UAS links. Note that due to very low threshold levels DAA may only be possible in cases with prior knowledge of the TRR frequency plan (TDD or FDD with dual band sensing).

Table 51: Options for sharing with ER-GSM

	Option 1: For devices with high deployment figures	Option 2: For devices where low deployment is ensured by regulatory means (e.g. access points) (Note 2)	Option 3: Cognitive approach (Note 1 and Note 3)
DC limit in a bandwidth of 200 kHz	▪ Short term DC limit Max Ton 5ms, Min Toff 995ms, and ▪ Long term DC of around 0.01% per 1 hour	Short term DC limit Max Ton 5ms, Min Toff 995ms	NA
Max Tx power	25 mW	500mW	For RFID at 36 dBm (4W) and SRD at 27 dBm (500 mW). A frequency offset of 100kHz from GSM-R channels is applicable

Option 1 and Option 2 should be considered as lower and upper regulatory boundaries.

Note 1: The requirements for this cognitive approach with ER-GSM are analysed for the band 918-921 MHz in Annex 6 and are provided in TS 102 902 V1.2.2 and ETSI TS 102 903 V1.1.1 (2011-08). The latter document also describes the various compliance tests necessary to verify proper operation of the proposed mitigation technique for inclusion in an ETSI standard. The effectiveness of this approach was not tested against non-GSM systems (e.g. 4G, 5G).

Note 2: Low deployment means about 1 device per km^2

Note 3: The DAA mechanism considered and tested for coexistence between ER-GSM and RFID devices in the 918-921 MHz band (see Annex6) could be also adapted to identify channels not being used by ER-GSM in the vicinity of SRDs in the 873-876 MHz band

C. Countries that deploy Wind Profiler Radars and other than above mentioned services in 870-876 / 915-921 MHz:

It was noted that UK and Isle of Man each have one remote site with a Wind Profiler Radar that are in constant use. However these administrations considered that the Wind Profiler Radars would be adequately protected from the assumed SRD applications (see Table 2). They also considered that any interference events could be managed due to the very low number of WPR in operation, their remote situation and if necessary, the size of any exclusion zone that would be required to provide protection to their WPRs.

D. Countries that do not use the bands 870-876 / 915-921 MHz:

The adjacent band co-existence between candidate SRD/RFIDs and GSM/GSM-R may be feasible with the SRD/RFID applications and parameter settings assumed in this report.

Other than consideration of coexistence with other services in the subject bands, this study also addressed the feasibility of intra sharing for the envisaged broad variety of SRD and RFID uses as requested by ETSI. This is of primary importance to countries that do not use the bands. Some consideration has been given to this exercise.

As a general conclusion, this study found that intra-SRD sharing of the investigated uses in the bands 870-876 MHz is feasible, assuming the SRD parameters set out in the relevant SRDocs (see Table 52). Even Network Access Points (NAPs) with up to 10% DC may be easily accommodated in most typical co-existence situations, 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.

A similar conclusion on the feasibility of general intra-SRD/RFID sharing of the investigated uses may be drawn also for the band 915-921 MHz assuming the following frequency arrangements:

- Higher-power SRDs and RFIDs are placed in four “high power” channels;
- Lower-power SRDs are interleaved between the “high power” channels;
- Assistive Listening Devices (ALD) with DC up to 25% is also placed in the four RFID channels, assuming co-location is unlikely.

However, manufacturers of devices using the band 915-921 MHz should be aware that the channels 916.3, 917.5, 918.7 and 919.9 MHz may be used by high power SRDs/RFIDs with channel bandwidths of up to 400 kHz.

For countries that do not use the bands 870-876 / 915-921 MHz, the summary of assessed technical assumptions and parameters for SRDs and RFIDs being deployed in 870-876 MHz and 915-921 MHz bands is provided in the following table.

Table 52: Summary of assessed technical parameters for SRDs and RFIDs for countries that do not use the bands 870-876/915-921 MHz

Frequency Band	SRD Category	Equivalent ETSI SRDoc	Max Power	Max DC	Channel arrangement	Bandwidthwidth
870-876 MHz	Non-specific (low power)	TR 102 649-2	25 mW	1%	870-876 MHz	Up to 600 kHz
	Personal wearable devices (e.g. alarms)	TR 103 056	25 mW	0.1%	870-876 MHz	25 kHz
	Indoor stationary devices (e.g. low duty cycle Home Automation and Sub-Metering)	TR 102 649-2 TR 102 886	25 mW	0.1%	870-876 MHz	Up to 200 kHz
	Automotive	TR 102 649-2	500 mW (2) (3)	0.1%	870-876 MHz	Up to 500 kHz
	Infrastructure network nodes(4)	TR 102 886 TR 103 055	500 mW (3)	2.5%	870-876 MHz	200 kHz
	Infrastructure network access points (4)	TR 102 886 TR 103 055	500 mW (3)	10%	870-876 MHz	200 kHz
915-921 MHz	Non-specific (low power)	TR 102 649-2	25 mW	1%	915-921 MHz	Up to 600 kHz
	Non-specific (medium power)	TR 102 649-2	100 mW	1%	4 channels in 915-921 MHz (1)	Up to 400 kHz
	Indoor stationary devices (e.g. low duty cycle Home Automation and Sub-Metering)	TR 102 649-2 TR 102 886	25 mW	0.1%	915-921 MHz	Up to 200 kHz
	Indoor stationary devices (e.g. high duty cycle Assistive Listening Devices)	TR 102 791	10 mW	25%	4 channels in 915-921 MHz (1)	Up to 400 kHz (6)
	RFID (interrogators)	TR 102 649-2	4 W	2.5% (5)	4 channels in 915-921 MHz (1)	Up to 400 kHz

Note 1: four channels: 916.3, 917.5, 918.7 and 919.9 MHz.
Note 2: for Vehicle-to-Vehicle applications only; <100 mW for in-vehicle applications.
Note 3: APC always required for applications to reduce unnecessary emission levels.
Note 4: Installation only by professionals – e.g. operator of Smart Metering/M3N network
Note 5: For RFID, a DC of 2.5% is assumed for the hot-spot scenario. In less dense scenarios higher DCs are possible.
Note 6: All ALD simulations were carried out with 200 kHz. If ALD share the channel plan with RFID, the bandwidth permitted may be 400 kHz.

Table 2 provides an example of a possible solution for SRD sharing in countries that do not use the bands 870-876 / 915-921 MHz and may not necessarily represent the final solution. Not considered were for example broadband SRDs using direct sequence or other spread spectrum techniques and sophisticated channel access techniques such as LBT and AFA.

Where the interrelationship between power, DC and deployment density has been used further consideration may be necessary in developing regulations.

ANNEX 1: CHARACTERISTICS OF EXISTING SYSTEMS IN STUDIED BANDS

A1.1 GSM-R SYSTEM

The frequency bands 876-880 MHz (uplink) and 921-925 MHz (downlink) are harmonised within CEPT for the operational communication of railway companies using so called GSM for Railways (GSM-R) technology in accordance with ECC/DEC(02)05 [38]. As the name suggests, this communications system in essence uses the well-known GSM technology.

In addition to the above mentioned R-GSM frequency band, the ER-GSM frequency bands 873-876 MHz (uplink) and 918-921 MHz (downlink) may also be used as extension bands for GSM-R on a national basis as primary user, in accordance with ECC/DEC(04)06 [35]. These frequencies are known as Extended R-GSM (ER-GSM) bands . Seen from the results of the recent CEPT questionnaire on the subject (May-June 2012), 8 of 39 responding European administrations indicated their interest in using this extension band. Further details collected through the questionnaire show that the ER-GSM frequencies are planned to be used at local hotspots such as some metropolitan stations or big shunting sites only in the vast majority of cases. At the present time, it should also be noted that 3GPP has not yet assigned the Mobile Class Mark (identity for ER-GSM capability in the GSM protocol for GSM equipment), i.e. ER-GSM is still in the planning stage with the first tests expected in 2013.

Apart from the frequency, the other technical parameters of systems deployed in ER-GSM band are generally identical to those of R-GSM (except that different sharing situation in the shifted band may have an impact on RF filtering inside the GSM-R terminals). Therefore when further in this report references are made to R-GSM, this should be understood to cover both R-GSM and ER-GSM frequency bands, unless a specific distinction is made, such as in cases of in-band (ER-GSM vs. SRD/RFID) and adjacent-band (R-GSM vs. SRD/RFID) interference mechanisms.

To conclude, the official terminology for railways radio system based on GSM standards is:

R-GSM: Frequency band from 876-880/921-925 MHz
ER-GSM: Frequency band from 873-876/918-921 MHz
GSM-R: GSM system for Railways

GSM-R provides the operational communication used exclusively by the European Railways. GSM-R supports services for train-network management such as speech communications and command and control (data) for trains travelling at speeds of up to 500 km/h. GSM-R frequencies may generally not be used for public and commercial services. For more details refer online to the European Frequency Information System (EFIS) or document UIC O-8700

GSM-R networks offer a linear coverage of railway lines with dedicated radio sites installed along the track, as shown in the following Figure 13:. Two different cell site configurations are commonly used (composite cells and cells with two or more sectors).

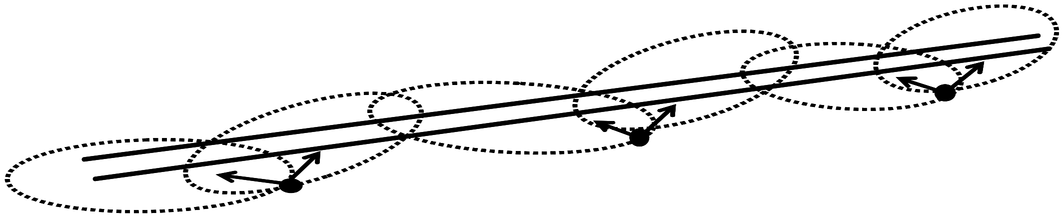


Figure 13: GSM-R typical deployment along railway tracks [22]

In Europe, most of the GSM-R networks are designed with a BTS antenna height of about 30 m and a cell range of around 5-6 km. The assumption used in this study of BTS antenna height of 45 m and cell range of

8 km in rural areas and antenna height of 20 m and cell range of 2 km in urban areas, which would represent the Case A – Typical scenario – for the sharing study in this report.

This is done with a recognition that the primary purpose of ER-GSM extension is to provide extra capacity, thus assuming that ER-GSM cells would be capacity-limited, not distance/noise limited. This may be illustrated by the data received from UIC and derived from questionnaire of railway operators in various European countries (for full study refer to CEPT Doc. SRDMG(12)075rev2. This data, shown in the following table, illustrates that when considering the utilisation of ER-GSM band, majority of railways plan to use it high traffic deployment use cases such as shunting yards.

Table 53: Planned use of ER-GSM frequencies (source: UIC)

Railways (country)	Use Case	Assigned	Usage planned	Not planned
DB (DE)	shunting, Train Radio	x		
Network Rail (UK)	shunting, GPRS Monitoring		x	
Adif (Spain)	shunting, hot spot coverage etc.		x	
SBB (SUI)	Hot spot coverage		x	
ProRail (NL)	shunting, PMR/short range radio, local capacity enhancements for telemetry applications, migration to next generation radio services		x	
ÖBB (A)	shunting (yards), coverage of hot spots or disposed application areas		x	
Trafikverket (SE)	Possibly to use during and after migration to other technology for the railway		x	
FTA (FIN)	shunting, switch-man and train brake testing communications and during the migration period from GSM technology to the next generation radio technology			x
RFF (FR)	plans to use the ER-band in congested or subject to congestion areas, like Paris large railway stations or shunting areas, some important railway nodes etc.		X	

However, also Case B – Critical scenario – may be considered in some administrations, to correspond to situations of very low operating margin on wanted link, such as when requiring high availability coverage in the hand-over areas on the fringe of noise-limited cells. The maximum speed of the trains influences the cell overlap and the nominal radio network design of the various GSM-R networks in Europe.

There are two types of GSM-R Mobile Stations (MS): handheld MS and train-mounted MS. The train-mounted MS is mounted permanently inside the driver's cabin. It is able to take advantage of the train's electricity mains supply to transmit at greater power levels. Also the external antenna mounted on the roof of the train improves the link conditions with the BTS. Handheld MS may be used by railway personnel for such tasks as servicing tracks, marshalling trains in shunting yards, by station attendants, etc. Examples of different types of users are illustrated in Figure 14:.

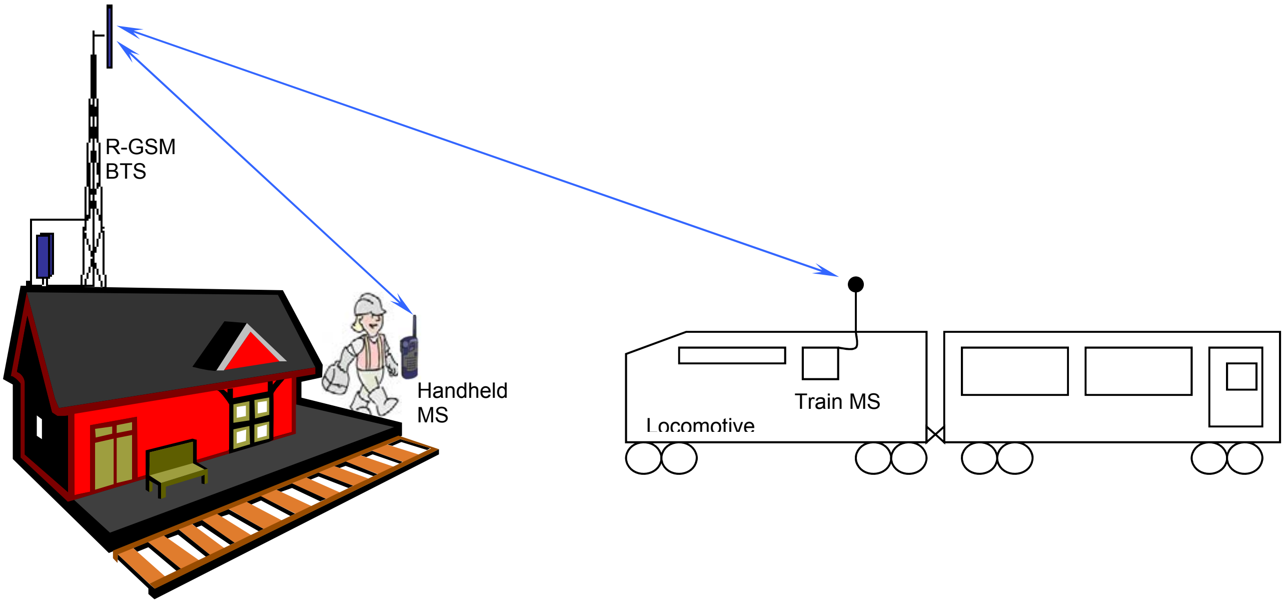


Figure 14: Different types of stations/users in GSM-R

Below Figure 15: shows an example of train-mounted MS antenna with its radiation pattern in vertical plain. It demonstrates that the effective antenna gain in horizontal plane may be even negative due to the fact that the antenna pattern is tilted upwards to provide better reception towards mast-mounted BTS antennas. In the horizontal plane the omni-directional radiation pattern shall be assumed.

The antennas used at GSM-R BTS are assumed not to be identical to those used in conventional GSM BTS. The antennas used at GSM-R have main beam of around 30 degrees and gain of up to 21 dBi. The signal is typically split between two antennas with a splitting loss of 3 dB and a cable loss of additional 3 dB, therefore an efficient antenna gain reduction of 6 dB may be assumed in order to calculate e.i.r.p. With reference to a typical GSM-R systems in Germany as an example, this study shall use for SEAMCAT simulations the BTS antenna pattern based on the example of Kathrein Type 80010642 antenna (32^O half-power beam width in horizontal plane, 14^O in vertical plane, gain 17.6 dBi), shown in Figure 16: below.

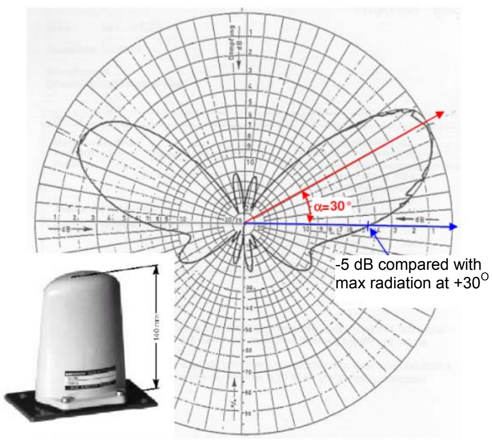


Figure 15: Example of train-mounted GSM-R MS antenna and its vertical radiation pattern [23]

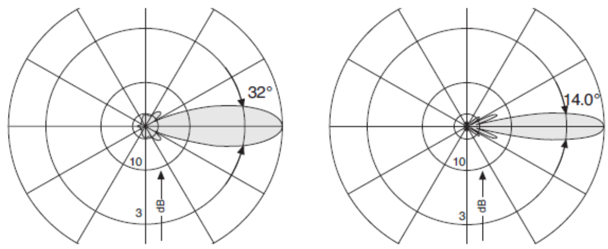


Figure 16: Radiation pattern of directional GSM-R BTS antenna (ref. Kathrein Type 80010642)

It may be thus concluded that, from a deployment point of view, GSM-R networks have almost a linear structure along the railway tracks. However, the locally higher traffic demand close to railway traffic nodes requires a higher network density which also implies a reuse of radio frequencies in such traffic hot spots. Considering the limited number of radio channels available in the R/ER-GSM frequency bands, this leads to difficulty in radio network planning.

Details of the GSM-R RF performance and system parameters can be found in 3GPP technical specification TS45.005 [24]. The specific ETSI standard for GSM-R that incorporates GSM specifications by reference is EN 301 515 [25] and additionally the EIRENE requirements (SRS 15.1 and FRS 7.1) applies.

The main GSM-R system characteristics are summarized in Table below, as used in previous CEPT studies, such as ECC Report 96 [22] in combination with newest inputs from GSM-R community.

Table 54: Main GSM-R system parameters

Parameter	Values		
Channel bandwidth, kHz	200		
Modulation	GMSK		
BTS-MS Minimum Coupling Loss, dB	60 (urban) / 70 (rural)		
Considered transceiver types	**BTS**	**Handheld MS**	**Train MS**
Maximum Tx power, dBm	Up to 46	33	39
Thermal noise, dBm	-121		
Rx noise figure, dB	5	9	7
Noise floor, dBm	-116	-112	-114
Rx sensitivity, dBm	-104	-102	-104
Derived protection ratio C/(N+I), dB	9 (1)	10	10
Antenna height above ground, m	20 (urban) 20/45 (rural)	1.5	4.5
Antenna gain, dBi	18	0	0
Antenna down tilt, deg	3	NA	NA
Feeder loss, dB	3	0	0
Splitter loss, dB	3	0	0
Spurious emissions (2), dBm	-36	-36	-36

1. At the hand-over area a C/(N+I) of 12 dB is applied.
2. Based on 100 kHz. Measurement band depends on the carrier separation, which is defined in TS45.005 [24]

The unwanted emissions mask of GSM-R MS is assumed identical to that of regular GSM MS, and is depicted below.

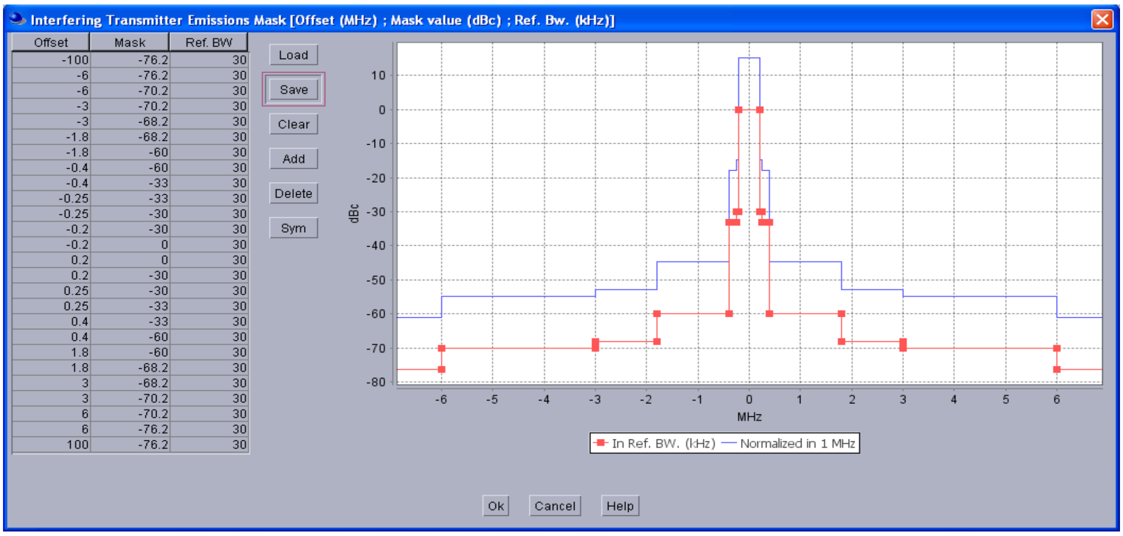


Figure 17: Unwanted emissions mask of GSM-R MS (based on GSM MS specs)

Similarly, the unwanted emissions mask for GSM-R BTS is depicted below.

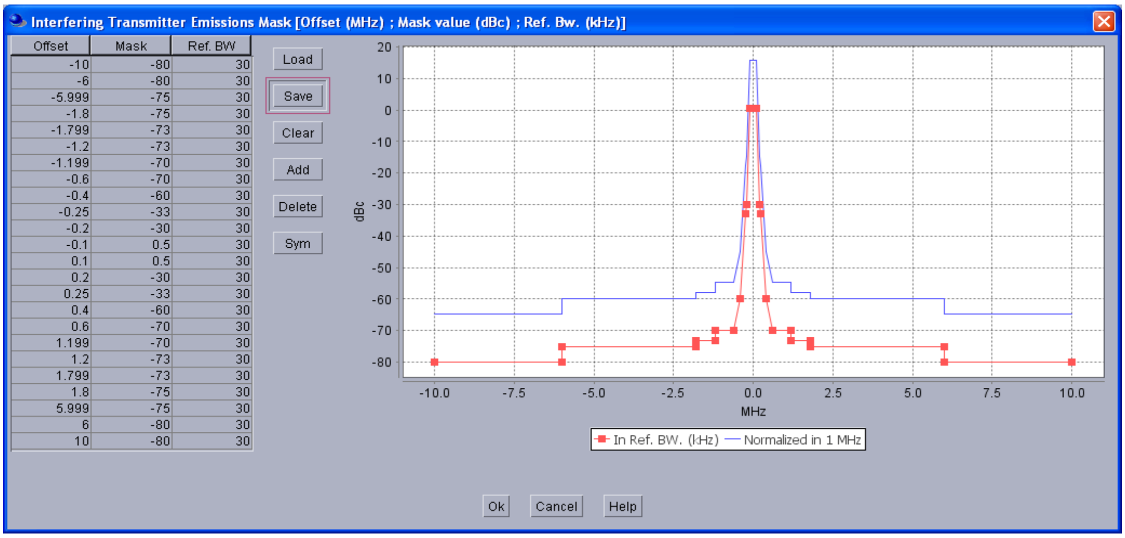


Figure 18: Unwanted emissions mask of GSM-R BTS [22]

Blocking levels of GSM-R receivers are provided in tabular form in the below Table, showing the differences between the parameters of different GSM-R receiver types.

Table 55: Blocking levels (maximum tolerable interfering signal level) of GSM-R receivers, dBm/200kHz [22]

Frequency range	Handheld MS [(1)]	Train MS [(2)]	BTS
$\|f-f_o\| \leq$ 100 kHz	-116	-116	-116
100 kHz < $\|f-f_o\|$ < 300 kHz	-98	-98	-98
300 kHz ≤ $\|f-f_o\|$ < 600 kHz	-66	-66	-66
600 kHz ≤ $\|f-f_o\|$ < 800 kHz	-43	-38	-26
800 kHz ≤ $\|f-f_o\|$ < 1.6 MHz	-43	-33	-16
1.6 MHz ≤ $\|f-f_o\|$ < 3 MHz	-33	-23	-16
3 MHz ≤ $\|f-f_o\|$	-23	-23	-13
For OOB signals	0	0	8

1. Understood to correspond to category "Small MS"
2. Understood to correspond to category "Other MS"

It is thus obvious, that co-existence studies involving GSM-R have to take into account the distinction between various types of transceivers, especially between two types of MS. The latter would have not only different RF parameters, but would also exhibit different deployment patterns.

A1.2 GSM/LTE CELLULAR SYSTEMS

The 900 MHz band has been widely used by GSM networks in Europe. This spectrum will be gradually introduced for use by UMTS (W-CDMA) or broadband LTE technology, reference to Commission Decision 2011/251/EU. It is believed that GSM900 will continue to exist and will co-exist with UMTS and LTE systems in this band. In order to have a good understanding of co-existence situation, the compatibility studies between SRDs and each of these three cellular networks should be considered.

Emphasizing that UMTS/LTE will be deployed by operators for offering coverage in rural area or for indoor coverage in urban areas and the fact that the main usage of SRDs are indoors; in this study we consider the compatibility study for Macro/Pico UMTS and Macro LTE deployments.

Table 53, summarizes characteristics of base station receivers of cellular systems, namely Macro/Pico UMTS, LTE Macro BS and GSM BTS. The UMTS characteristics are derived from the 3GPP technical specifications, TS25.104 and TS25.101 and ECC Report 82, the LTE characteristics from TS36.104 and GSM specifications from TS45.005 and ECC Report 82.

Table 56: BTS victim parameters and values used in simulations (see section 4.5)

Parameters	UMTS BS Macro / Pico (Urban)/(indoor)	LTE BS Macro (Urban)	GSM BTS (Urban)
Channel bandwidth, MHz	5 / 5	10	0.2
Antenna gain (dBi)	18 / 6	18	15
Feeder loss (dB)	3 / 0	3	3
Antenna height (m)	30 / 3	30	30
Antenna down-tilt (°)	6 / 0	6	2
BS-UE MCL (dB)	70 / 45	70	70
Receiver noise figure (dB)	5 / 19	4	5
UE maximum Tx power (dBm)	23 / 23	23	23

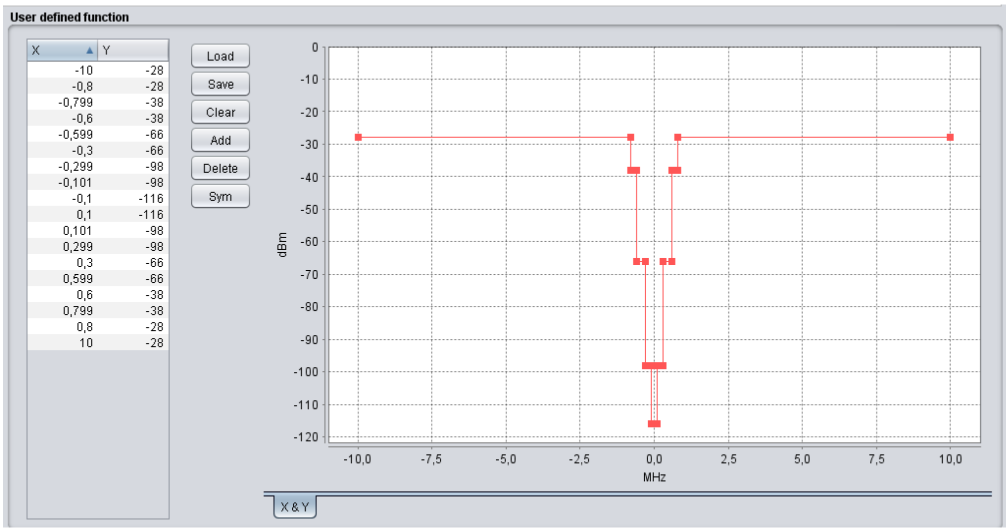


Figure 19: Receiver blocking mask GSM BS

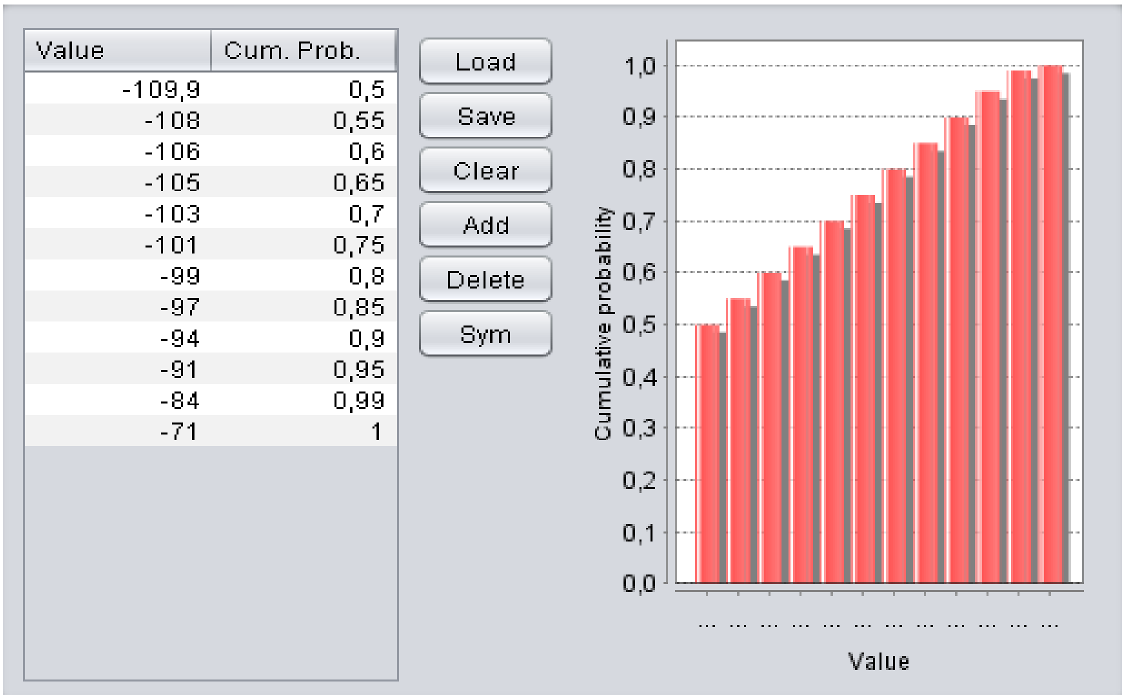


Figure 20: User defined dRSS at the GSM BS for a full loaded system

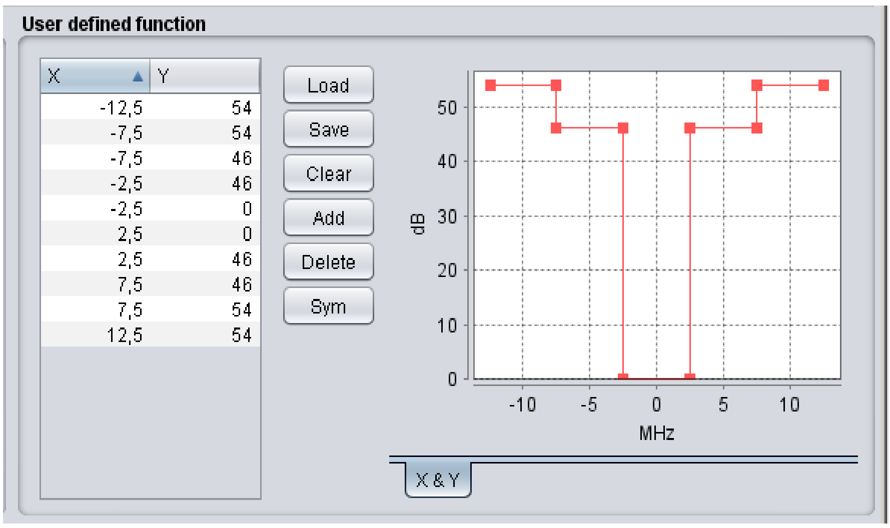


Figure 21: ACS UMTS pico

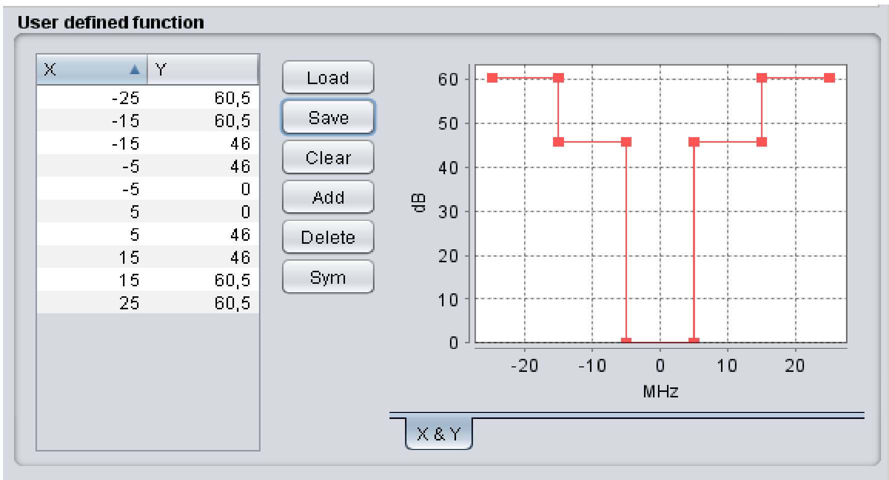


Figure 22: ACS LTE BS

A1.3 TACTICAL RADIO RELAY SYSTEMS

Tactical Radio Relay (TRR) systems are transportable fixed links used by military forces in some European countries in the frequency bands 870-876 / 915-921 MHz and in some cases within 870-880 / 915-925 MHz. Due to the tactical nature of their operation, their operational sites cannot be coordinated in advance and therefore frequency coordination and sharing considerations for TRR systems are akin to mobile systems.

As shown by the results of the recent CEPT questionnaire on the subject (May-June 2012), 10 out of 39 responding European administrations indicated that they designate the subject bands for military systems. Of those countries using these bands for military services, at least 5 intend to maintain military use in the near future, while 4 considered reducing the military use of the bands.

Typical RF parameters of TRR systems are presented in the Table below as taken from the previous CEPT studies presented in ECC Report 146 [18].

Table 57: Parameters of TRR systems [18]

Parameter	Values
Channel spacing	750 kHz
Link distance	30-70 km
Tx power	37 dBm
Rx bandwidth	1500 kHz
Rx sensitivity	-93 dBm
Required protection ratio (C/I)	15 dB
Allowed static interference level (P_{sens}-PR)	-108 dBm
Antenna height above ground	25 m
Antenna gain (bore sight)	16 dBi

Note that TRR user community proposed to also consider other protection criteria in this study, such as I/N (-6 dB, -10 dB, -20 dB).

An example of TRR antenna pattern is depicted below.

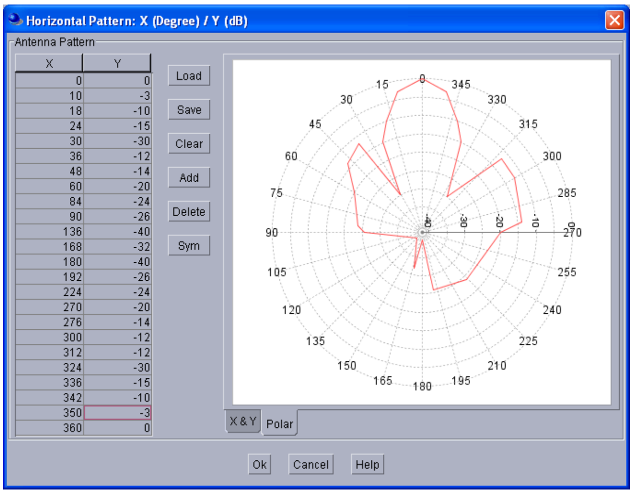


Figure 23: Radiation pattern of TRR antenna [18]

For the considered example of TRR reference type based on STANAG 4212 agreement, the transmitter unwanted emissions mask is shown below. The receiver blocking function is shown in Figure 21.

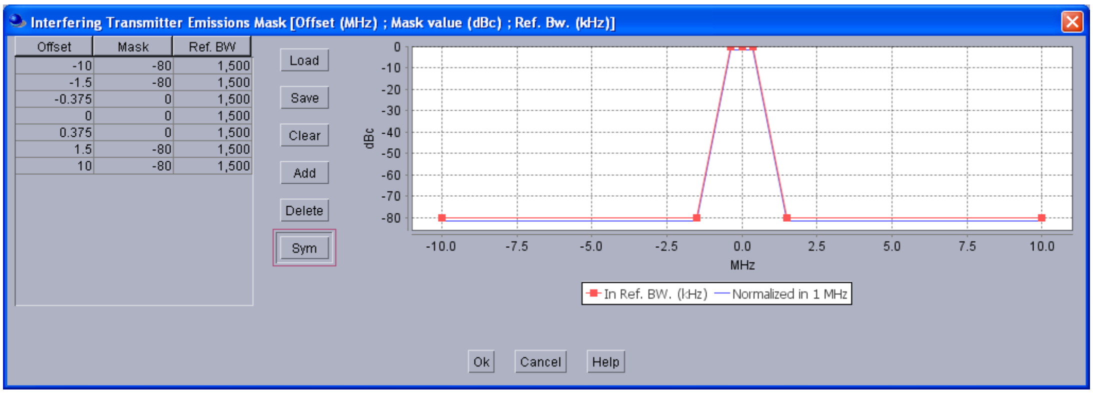


Figure 24: Unwanted emissions mask of TRR (ref. STANAG-4212 [18])

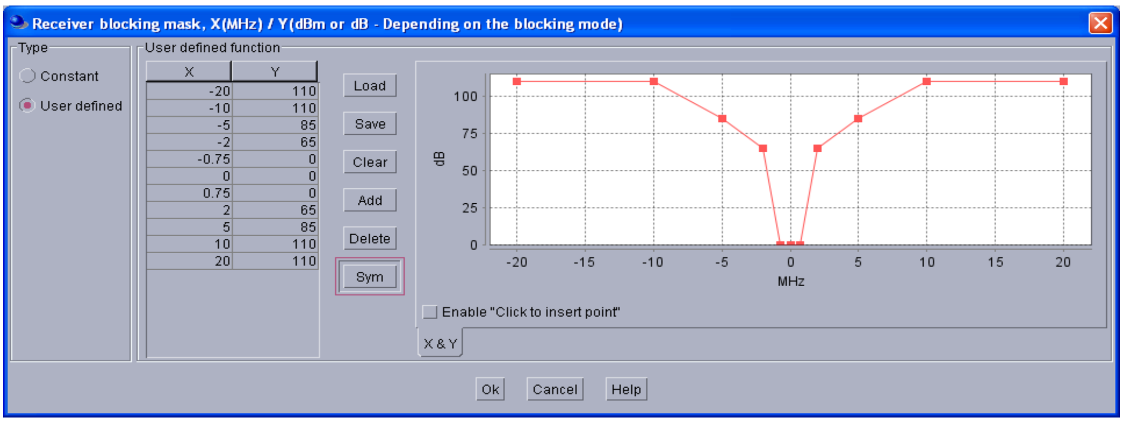


Figure 25: Receiver blocking function of TRR (ref. STANAG-4212 [18])

During the simulations in this study, the TRR was modelled as a PMR-like system, i.e. with one fixed central station and one transportable terminal.

A1.4 TELECOMMAND TO UNMANNED AIRCRAFT SYSTEMS

According to the findings of the CEPT questionnaire (May-June 2012), some European countries used the European designation of the frequency band 870-880 / 915-921 MHz for Defence applications to deploy the wireless systems for remote controlling of Unmanned Aircraft Systems (UAS), i.e. pilot-less aircraft. see e.g. ITU-R Reports M.2171[5] and M.2233[6]

The reported parameters of UAS systems as to be used in this study are presented in the Table below.

Table 58: Parameters of UAS transceivers

Parameter	Value
e.i.r.p.	43 dBm (30-52 dBm)
Frequency range	870-878 MHz (1)
Width of the tuning range	8 MHz
Tx/Rx channel bandwidth	200 kHz (2)
Rx noise figure	5-6 dB
Rx sensitivity	-90 dBm
Required protection ratio (I/N)	- 6 dB
Antenna height agl (terrestrial/airborne)	3/100…300 m
Antenna gain (terrestrial/airborne)	3/0 dBi

1. Additional frequency to be considered in the 915-921 MHz band to suit possible requirements of some countries
2. ITU-R Report M.2171 [16] estimates bit-rate of approx. 30 kbps for command-and-control communications with low flying UAS

Only miniature UAS (also called micro Air Vehicles (MAVs) are considered by the study in this report, that is, UAS flying at an altitude of up to 300 m.

Note that according ITU-R Report M.2171 [16] also other frequency bands are envisaged for operation of UAS, such as (960-1164 MHz and 5000-5150 MHz frequency bands for line-of-sight (LoS), 1545-1555 MHz, 1610-1626.5 MHz, 1646.5-1656.5 MHz, 5030-5091 MHz, 12/14 GHz and 20/30 GHz frequency bands for Beyond LoS). This broad range of frequencies may allow for certain redundancy of primary and back-up operational bands.

It is remarked that in some cases when an UAS up-link is operated in the bands considered in this study, 870-876 MHz and 915-921 MHz, at the same time a downlink is operated in the same bands; however this is not the case for all types of UAS.

A1.5 GOVERNMENTAL TELEMETRY SYSTEMS

According to the information received by this study, at least one European country plans to move wireless telemetry systems currently operated in the band 862-863 MHz and used by governmental agencies that provide emergency and rescue services, to the band 870-872 MHz. This move was conceived in order to avoid the anticipated danger of adjacent band interference from the newly deployed mobile services below 862 MHz.

[5] Report ITU-R M.2171 (12/2009). Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace.
[6] Report ITU-R M.2233 (11/2011). Examples of technical characteristics for unmanned aircraft control and non-payload communications links.

Such governmental telemetry systems feature a number of fixed base stations and mobile units with omni-directional antennas and transmitting at a low duty cycle. The emissions from both fixed and mobile transmitters are FM-modulated bursty signals of 5 seconds to 1 minute duration. Each has a duty cycle[7] of 0.1% to 3%, biased towards daytime and highest in the large cities.

Another special case of the same European country's governmental telemetry operations is a breathing apparatus equipment (BA Telemetry) used by Fire Rescue services. Telemetry collects real-time data during incidents, allowing the continued monitoring of the air supply of each individual fire-fighter's breathing apparatus and other data to assist the operational response to incidents. These systems also currently use the 862-863 MHz band and plan to be relocated to other bands in order to avoid interference from anticipated deployment of mobile services below 862 MHz's. In the short term they are planned to be re-located to the frequency of 869.5 MHz and in the longer term further on to a new dedicated frequency within the 870-876 MHz band.

However, it was noted by the above mentioned European country's administration that these nationally deployed systems would comply with general SRD requirements and therefore do not need a separate co-existence study.

A1.6 WIND PROFILER RADARS

According to the information provided to this study, two Wind Profiler Radars are being operated at remote sites in the UK by the meteorological services using the frequency of 915 MHz. UK Administration considers it unlikely that any additional sites will be deployed in the UK at this frequency.

The technical parameters of Wind Profiler Radars operated at 915 MHz are provided in the Table 59 below.

Table 59: Parameters of Wind Profiler Radars at 915 MHz

Parameter	Values
Transmit power (average/peak)	100/600 W
Pulse width	0.4-2.8 μs
Pulse repetition frequency	1-50 kHz
Tx/Rx channel bandwidth	2500 kHz
Rx noise figure	0.6 dB
kTBF	-146.2 dBW/MHz
Required protection ratio (I/N)	- 6 dB
Maximum interference level at receiver input	-152.2 dBW/MHz
Antenna height agl	0 m
Antenna gain in the main beam	26.3 dBi
Number of beams (see Fig. 23(a))	5
Antenna elevation angle	74.5° - 90°
Antenna radiation pattern (see Fig. 22)	$26.3 - 0.044\,(1.1 + \varphi)^{2.83}$ $\varphi < 6.66°$ $35 - 28.2\log(\varphi)$ $6.66° \leq \varphi < 80°$ -18.7 $80° \leq \varphi$

[7] Duty Cycle is not specified in the same terms as EN 300 220.

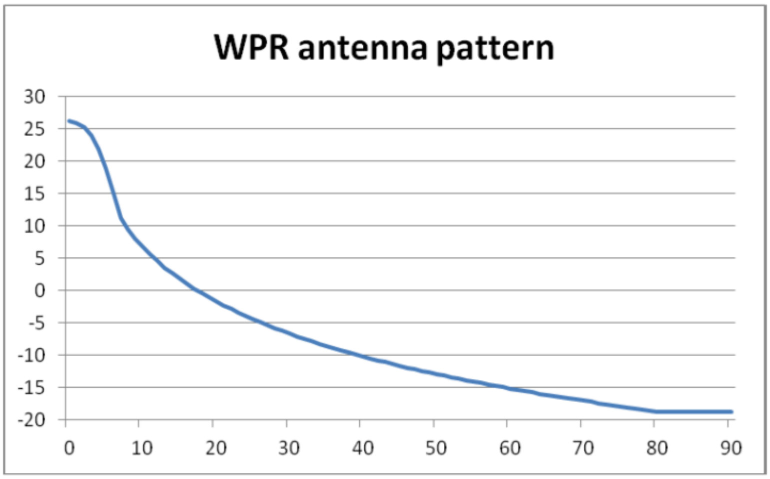
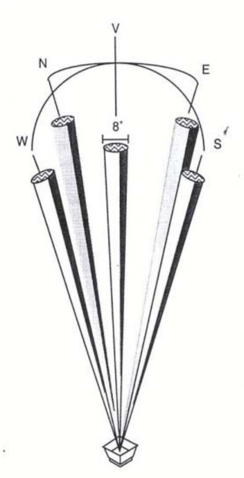


Figure 26: Antenna pattern of Wind Profiler Radar at 915 MHz



(a) (b)

Figure 27: Wind Profiler Radar antenna beams (a) and installation within screened enclosure (b)

Since SRDs are assumed to be ground based or near ground based, it is expected that compatibility with Wind Profiler Radars is controlled by the Wind Profiler Radar's relative antenna gain at horizon. Taking into account Wind Profiler Radars antenna beam elevation ranging 74.5-90°, as illustrated by Figure 27:(a), and the antenna pattern shown in Figure 26:, the Wind Profiler Radar's relative gain at horizon will roughly range -17.7 to -18.7 dBi. It was agreed to consider an approximate figure of -18 dBi in the compatibility analysis.

The power levels measured at a number of points at a distance of 10 m outside a distribution centre equipped with RFID never exceeded a power level of – 36 dBm e.r.p. For an interrogator transmitting at current regulatory levels in free space the power level at 10 m would be equal to a power of - 19 dBm. The additional attenuation attributable to the portal installed within the distribution centre is 17 dB. Thus the equivalent power from an interrogator transmitting at 36 dBm under the same partially shielded conditions would be 19 dBm.

In addition, as seen on Figure 27:(b) above, the protection of Wind Profiler Radar operations is improved by consideration of the fact that the installed Wind Profiler Radars are fitted within a screened enclosure intended to provide a high level of off-axis attenuation in order to limit at maximum the ground clutter to the radar. It is expected that this screened enclosure will also give an additional attenuation to the potential SRD interference on the horizontal plane. Based on results of ad hoc measurements on real Wind Profiler Radar installations in the UK, this additional attenuation was estimated at 10 dB.

ANNEX 2: CHARACTERISTICS OF SRD AND RFID

A2.1 NON-SPECIFIC SRD

This family of SRD was proposed for deployment in the lower sub-band of 870-876 MHz, as illustrated in Figure 2:. Their primary co-existence mechanisms might be Duty Cycle (DC) or Listen Before Talk (LBT) and Adaptive Frequency Agility (AFA), in different possible combinations, or equivalent techniques.

A non-exhaustive list of applications for SRDs using either: duty cycle or LBT + AFA (or equivalent techniques) is provided below, based on information in A.2 of [1]:

- Home and Building automation (some examples):
  - Lighting control;
  - Shutter, awnings and blinds control;
  - Windows, doors and gates openers control, garage doors, electrical door lock systems;
  - Heating, ventilation regulation and air condition control;
  - Swimming pool surveillance and control;
  - Combined scenarios;
  - Sensors (temperature, wind, light, rain);
  - Presence monitoring;
- Telemetry and telecommand (some examples):
  - Pumping station monitoring;
  - Electricity network monitoring;
  - Crane and machinery control;
- Mixed speech and data (some examples):
  - Wireless door entry;
  - Alarm ambiance background scanning;
  - Baby and elderly monitoring;
- Access control (some examples):
  - Disabled persons access;
  - Security applications;
- Machine to Machine (some examples):
  - Remote data collection (state of machines);
  - Remote control (management);
  - Remote payment;
  - Remote restaurant/bar customer orders data collection;
  - Portable Bar Code Scanner;
- Aviation and Maritime applications (some examples):
  - Remote data maintenance collection (service information of aircraft downloaded while taxiing).

Given the very wide variety of such non-specific SRDs already in existence and that may be developed by innovative wireless industry in the future, it appears futile to try predicting specific deployment densities for various concerned applications. Therefore, it was considered that the density of generic non-specific SRDs may be within the range of 10-1000/km^2, the latter limit representing urban scenarios. The densities of some prominent derivative specific SRD applications are further discussed in annex A2.3.

In accordance with the request in [1], ETSI envisaged the following regulatory parameters for this family of SRDs, as given in Table 60 and Table 61.

Table 60: ETSI proposal for parameters of non-specific SRDs in lower part of 870-876 MHz [1]

Sub-band	Max Power	Max DC/ Mitigation technique	Channel BW
870-873 MHz (1)	25 mW	1% or LBT/AFA (2)	No spacing

1. Upper limit may change depending on the outcome of these studies
2. The specifics of DC and/or LBT/AFA use require additional study, such as whether they are substitute or complement for each other, and whether it would be useful for intra-SRD sharing or for protection of primary services in the band, or both. Clarifying this issue is one of objectives for studies presented in this report.

In accordance with ETSI TR 102 649-2 [1], the characteristics of transmitters and receivers for this family of SRDs are defined in EN 300 220 [27], most notably:

- maximum occupied bandwidth of 600 kHz (cf. Table 7 in Clause 7.4.2.2 of [27]);
- unwanted emission mask derived from Figure 7/Table 10 in Clause 7.7 of [27].

A2.2 SPECIFIC SRDS

This family of specific SRDs was proposed by ETSI for deployment in the upper sub-band of 870-876 MHz, as illustrated in Figure 2:. The ETSI envisaged [1] that the distinctive feature of this family of devices would be their reliance on DC as the sole co-existence mechanism, inter-linked with transmitted power. The regulatory parameters are summarised in Table 61.

Table 61: ETSI proposal for parameters of DC-limited SRDs in upper part of 870-876 MHz [1]

Sub-band	Max Power	Max DC	Channel BW
873-876 MHz (1)	1 mW	5%	No spacing
	25 mW	1%	
	100 mW	0.1%	

1. Upper and lower limits may change depending on the outcome of these studies. It should be noted that specific SRDs have a minimum requirement for 2 MHz of usable spectrum

Examples of practical SRD applications proposed for this sub-band are listed in the TR 102 649-2 [1] and include the following:

- Metering: 25 mW, channel BW of 200 kHz, DC up to 1%;
- Alarms: 25 mW, channel BW of 200 kHz, DC up to 1%;
- Portable Alarms (for personal security): 100 mW, channel BW of 25 kHz, DC up to 0.1%;
- Automotive Devices[8]: 100 mW up to 500 mW, channel BW up to 500 kHz, DC up to 0.1% (transmit power and DC were considered within the ETSI SRdoc as possibly inter-linked as shown in Table 2).

Some other ETSI SRDocs offer description of various functionally focused derivatives from the generic families described in TR 102 649-2 [1]. For example, , the focused analysis of various Alarm & Social Alarm SRD applications is offered in TR 103 056 [6], arguing for necessity of spectrum access arrangements characterised by low latency and high reliability for these socially important applications, with powers of up to 25-100 mW and flexible channel bandwidth.

Another emerging specific application proposed for this band is Smart Metering (SM), see TR 102 886 [3]. This application is intended to support the smart utility networks e.g. electricity grid installation, and requires

[8] The requirements for Automotive family of SRDs may need revision, noting the currently discussed draft revision of TR 102 649, where Automotive applications, such as Vehicle-to-Vehicle communications may require up to 500 mW transmit power and up to 1 MHz channel bandwidth, with APC mitigation technique

greater operating ranges in order provide acceptable indoor-to-outdoor communication. To achieve this, they have requested the following parameters for SM applications:

- transmit power: 100 - 500 mW;
- channel BW of 200 kHz;
- DC up to 2.5% (as suggested by results of compatibility study, see [13].

Another family of emerging SRD applications is Metropolitan Mesh Machine Networking (M3N), see TR 103 055 [4], which requires similar parameters to SM except that DC might be smaller: up to 1-1.25%.

When comparing the emerging Automotive, SM and M3N requirements against the original TR 102 649-2 proposal outlined in Table 2, it becomes clear that this study needs to determine acceptable DC limits at different power levels up to 500 mW.

It is also important to take into account the draft[9] ETSI ES 202 630 [28],which provides the European profile for SRDs in the frequency band 870 to 876 MHz and, in particular, the proposed 200 kHz channelling for SRDs operated in the upper sub-band as well as certain transmitter timing options. This study has taken into account these tentative requirements.

It is also important to take into account SRD receiver parameters to be used for consideration of interference impact to SRDs. The table below lists some of the essential parameters for this kind of analysis. These were derived from formulas in clauses 8.1.4 (sensitivity) and 8.3.3 (selectivity) of EN 300 220-1 [27].

Table 62: Assumed parameters of specific SRDs as victims ([1] ,[27])

SRD receiver bandwidth	Sensitivity, dBm	Min C/I, dB	Selectivity, dB
25	-105	8	50
200	-96	8	47
500	-92	8	43
600	-91	8	42

Another example of Specific SRD is the family of Assistive Listening Devices (ALD), as described in TR 102 791 [5]. It is envisaged that the modern *digital* versions of these devices may be operated in the frequency band 915-921 MHz with DC of 25% when in use. They would be deployed as groups of 10 dBm “base stations”, installed indoors in public buildings only (stations, museums, etc.) and employing up to 400 kHz per channel. It is also possible that ALD terminal devices carried by people may be provided with return channel, with emission power of -3 dBm. It is proposed to use EN 300 422 [29] as the basis for defining the radio emission parameters of ALD, such as spectrum mask.

Measurements at the BNetzA test laboratory in Kolberg [13] investigated the use of duty cycle techniques to mitigate the impact of SRD devices on E-GSM-R. This measurement suggests the following criteria in order to improve the situation:

- Maximum Tx_{ON} for a single burst = 25 ms;
- Minimum Tx_{OFF} period = 500 ms;
- Maximum DC within 1 s interval = 2.5%.

Additional sets of measurements were later carried out in November 2012 at Siemens’ Berlin laboratories to investigate the impact of interference from SRD to GSM-R in real life settings [19]. These measurements addressed two distinct cases of interference to “transparent data bearers” and “voice bearers” of GSM-R. They also looked at the interference impact during setting up of calls as well as during on-going calls.

These latest measurements suggested that as regards temporal effect of duration of individual SRD transmissions, the victim GSM-R link might withstand disturbances from SRD transmissions of up to 20 to 40 ms for GSM-R link transparent data and voice bearer modes respectively.

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[9] The document is expected to be finalised and published prior to completion of this report.

A2.3 SRD DENSITIES, PLACEMENT AND ACTIVITY FACTORS

A2.3.1 SRD densities

An important issue to consider is the anticipated deployment densities of the various types of SRD. The following table provides the data gathered from the relevant ETSI System Reference Documents and consultations with various SRD industry groups. In cases where specific deployment densities for various scenarios were provided in the referenced document, these were taken directly into the table. When only the total estimates of the European market size were provided, the average density was derived by dividing the number of anticipated devices used in Europe by the combined area of five European countries: France (550 000 km^2), Germany (350 000 km^2), Italy (300 000 km^2), Poland (300 000 km^2) and Spain (500 000 km^2), i.e. 2 million km^2. By choosing only these five larger countries in the core of Europe, with a reasonably uniformly spread population, we tried to balance out the uneven spread of population across the entire European continent (total area 10.2 million km^2). Although this is not precise, the method could be used to derive some reference numbers, in the absence of any better predictions. However these figures are no more than a European average and therefore may not be fully representative of specific deployment scenarios.

Table 63: Representative average deployment densities for various SRD families

Family of SRDs	Deployment density (1/sq.km)		
	Pan-Europan Average	Suburban	Urban
Generic Alarms	12 (1)	-	-
Assistive Listening Devices	5 (2)	-	40 (3)
Non-specific SRDs	10 (rural)	-	1000
ITS/Automotive high power (100+ mW)	80 (4)	-	-
Home Automation, incl. sub-metering, specialised home alarms, etc.	100 (5)	1500	50000 (7)
Automotive low power (up to 25 mW)	400 (6)	-	-
Metropolitan utilities, such as Smart Metering/M3N	-	1000	2000 (8)

1. Based on European market size of 24 million devices divided by area of five reference countries (ref. TR 102 649-2)
2. New digital systems deployed in the subject range would be used indoor public buildings (stations, museums, cinemas)
3. Based on updated industry predictions for indoor public use
4. Based on UNECE data on number of passenger vehicles in five reference countries (ca. 160 mio), divided by total area of those countries and the assumption of one active high power automotive SRD per vehicle. Note that this “active device” might be different automotive device at different times, e.g. some security enabling device during car movement, or functional comfort control system in parking position, etc.
5. Based on extrapolated from TR 102 649-2 figure of 200 million devices, divided by area of five reference countries
6. Based on UNECE data on number of passenger vehicles in the same five reference countries (ca. 160 mio), divided by total area of those countries and the assumption of five active low power automotive SRD per vehicle (such as TPM, etc.)
7. Based on Home Automation SRD industry’s long-term (10 years) forecasts, assuming up to 20 devices per household.
8. Worst case estimate for major cities like London, note that this number excludes the “sub-metering” category that is considered part of Home Automation.

Inspection of this table shows that the average deployment densities of the various SRD applications may vary between 10-3000 devices/km^2. This will depend on the particular nature of each device family. For instance, the types of SRDs used for machine-to-machine automated operations are likely to see ever increasing penetration, especially in densely populated urban areas, leading to deployment densities in the range of several to several tens of thousands devices per square kilometre. Conversely person -linked applications are likely to remain at relatively “low” densities in the range of up to 100 devices per square kilometre.

The automotive represents an interesting example of increasingly proliferating application; the average number of such devices shown in the above table is derived from the recent standardisation activities, and is effectively the sum of two broadly different types of device: on average one active at a given time “high-power” SRD for what could be described as environmental sensing/communication (inter-vehicle communication while driving, remotely controlled functional comfort systems, etc), and on average 5 (active) low power/low duty cycle devices for various functionalities inside the vehicle and for vehicle-driver communication, such as wireless keys, tire pressure monitoring (TPM) devices and the likes. In such manner the automotive devices may be seen as a mid-way between the person-linked and machine-to-machine application scenarios.

It should be noted that some low power SRD device families may be allowed to be operated across the both considered bands 870-876 MHz and 915-921 MHz, namely the “non-specific SRD” category and Home Automation/Sub-metering applications. In that case it is proposed to half the predicted density of these devices in both the upper band (915-921 MHz) and lower band (870-876 MHz) due to assumption that the devices may spread equally between the two available bands. Accordingly, two options are considered as regards simulation of non-specific SRDs and Home Automation/Sub-metering applications:

- Option I: when subject SRD device families may be allowed to be deployed in only one of the considered bands: either 870-876 MHz or 915-921 MHz, and therefore their density in that band being as described above;
- Option II: when those SRD device families may be allowed to be deployed across *both* 870-876 MHz *and* 915-921 MHz band, and therefore their respective densities in each of those bands being reduced by a factor of two.

Other important and interlinked issues are the placement mode and activity factor of the SRDs that need to be taken into account in statistical simulations of interference scenarios.

A2.3.2 SRD placement modes in SEAMCAT simulations

As regards the placement mode, the issue is for modelling Interferer-Victim interaction in SEAMCAT, and the main question is whether it may be assumed that the nearest interferer (i.e. one per IL of given type) is likely to pose the largest danger due to most direct power coupling (in which case the “Closest interferer” mode should be used in SEAMCAT), or whether the preference would be to consider the aggregated interference from multiple interferers (modelled in SEAMCAT through the “Uniform density” mode). The former choice would provide for a reasonable estimation of “average” probability of interference. The latter choice would provide estimation of probability of interference on the more conservative side, i.e. the worst case maximum envelope of the interference. This study has chosen to use as a reasonable compromise the combination of simulations with both placement modes and judge that the “real” interference potential should be somewhere between the estimates derived by using the two different modes. Note however, that when both the victim and the interferer may be closely located, especially assuming scenarios with some kind of low-placed low-antenna-gain devices, such as would be the case with handheld mobile terminal vis-à-vis an SRD device, then the “Closest interferer” mode may be the most logical option to use.

A2.3.3 SRD activity considerations

When using the “Uniform” placement mode, one critical parameter is the "number of active devices” which effectively means the number of devices that are transmitting *simultaneously at any given time*. Note that when considering SRDs as interferer, this number may be different for different SRD systems and scenarios. This study has chosen to use the assumption that this number could be up to 10 and could be derived using the following formula to evaluate a number of instantaneously active SRDs within the impact range of victim receiver:

$$N_{active}=Density\ x\ Impact\ Area\ x\ DC$$

The following represents an example of applying this method to a specific case:

assume the impact area of 50 km^2 and the density of considered SRDs being 3000 devices/km^2, this results in a pool of 50 x 3000 = 150 000 potentially interfering devices;
assuming 0.1% DC, uniformly distributed in time, then it follows that 150 000 x 0.001= 150 devices may be active at any given time instance;
the impact area should be chosen carefully; the radius of the impact area should be at least the protection distance, which is dependent on a number of parameters..

Accordingly, calculations of applicable impact areas and numbers of active devices shall be considered for each specific scenario as reported in respective sections of this report.

A2.3.4 The case of FHSS

The case of SRDs using FHSS deserves separate notice due to the specifics of defining their activity on a given channel. Following consultations with FHSS device manufacturers, this study assumes the following principles for modelling FHSS SRDs:

- the DC and power limits are expressed for a single channel, i.e. the static channel used by a victim;
- the per-device and per-channel DC are interlinked by a factor which is the number of channels used by FHSS system. For example, if the per-device DC is 1% then system employing 100 hopping channels will produce a per-channel DC of 0.01%;
- specific channel dwell time and Tx ON-OFF limits (such as outlined by Kolberg tests [13]) should be specified within this report. However they need to take into account the system-level specifics of the considered FHSS systems, such that the system-centric FHSS will cause "wave" effects whereas all population of devices jointly moves from one channel to another and the total Tx_{ON} time affecting the victim may be composed of multiple transmissions from individual devices. The periodicity of "wave" may be calculated as $T_{wave} = T_{dwell} \cdot N_{channels}$, i.e. for system with dwell time of 20 ms and utilising 30 channels, the periodicity of all devices "flooding" any given channel will be 20 ms x 30 = 600 ms. This value could be used as averaging window over which the interference is spread.

A2.4 MODELLING OF UTILITIES NETWORKS (SM, M3N)

As was mentioned in section 3.1.2 some of the SRDs may be used as means of building professional wide area networks, such as SM or M3N application. Such networks would first of all need devices to act as facilitators for aggregating information from (user) terminal nodes into utility infrastructure, thus acting as Network Access Points (NAPs).

Additionally, it may be also considered that in network deployment the SM terminal nodes may have a wider spread of operational DCs, as their respective TR 102 886 [3] requests that some (transit) terminal nodes may benefit of having DC up to 2.5% in mesh networking configuration. Therefore it may be suggested also to model that the overall density of SM terminal nodes (2000/sq.km) is split between the nodes with various DC as follows:

- 1900 nodes/sq.km (i.e. 90% of total nodes) with DC=0.1%;
- 90 nodes/sq.km (i.e. 10% of total nodes) with DC=2.5%;
- 10 nodes/sq.km (0.5%) of NAP.

The examples of NAPs include various types of infrastructure devices that may be referred in various SRDocs and standards as gateway devices, Coordination Group devices, eBridges, relays, etc.

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

- Low density of around 10 dev/sq.km ensured by regulatory means;
- High 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.

Given that the DC of NAPs may fluctuate beyond the general limits indicated in ETSI SRDocs for respective SRD applications, their introduction requires additional check against the backdrop of general co-existence scenarios. Taking note of the various studies scenarios of co-existence between SRDs and existing services, the following representative in-band sharing scenarios were tested to verify possible impact of introducing NAPs:

- TRR Case A (Population pockets) with APC on SRD side;
- ER-GSM Urban cell Case A, with SRDs operating across entire band 870-876 MHz.

In general it may be noted that the devices used as part of professional network would need to have at least APC required as the means for reducing noise levels from wide area deployment.

The other scenarios (UAS, TRR Case B, ER-GSM Case B) were not tested as even the initial complement of SRD deployment creates challenging co-existence requirements. Although, in some of those challenging cases, most notably for ER-GSM Case B, the use of NAPs may have additional benefit of managed network deployment whereas the utilities installing the networks may create certain protection zones == corridors along the railway tracks. However such scenario falls into the domain of impact analysis and therefore was not further considered in this technical report.

A2.5 RFID IN 915-921 MHz BAND

It is proposed that SRD & RFID should operate in the band 915-921 MHz in accordance with TR 102 649-2 [1]. The parameters of SRDs for this band would generally conform to those described in previous sub-sections, and any band-specific deviations are addressed during simulations. This section therefore focuses on the RFID applications.

To enable multiple RFID interrogators to transmit simultaneously in the same geographic space and to minimise possible interference with other users of the same spectrum, it is proposed in [1] to use a 4 channel plan. To obtain maximum benefit from this arrangement, it is proposed that RFID systems operate in the dense interrogator mode. The principle of the dense interrogator mode is shown in the diagram below for illustration of the concept.

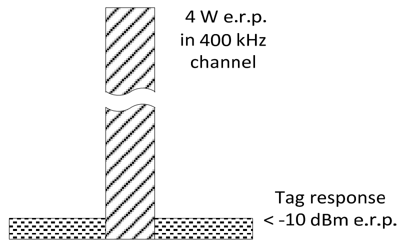


Figure 28: The RFID transmissions arrangement in dense interrogator mode

As seen from the figure, the transmit signal from an RFID interrogator may be at a power level of up to 4 W e.r.p. and occupies the centre channel of 400 kHz. The two channels on each side of the transmit channel are reserved for the backscatter response from the tag. Typically tags will respond at offset frequencies of approximately 600 kHz or 300 kHz, which is set by the configuration of the interrogator. The power level of the response from a tag will be –10 dBm e.r.p. or less depending on its distance from the interrogator and the nature of the material to which it is attached. The dense interrogator mode separates the high power transmission of the interrogator from the low power signals of the tags, which improves system performance. It also permits transmissions from multiple interrogators on the same channel. In fact provided that an adequate minimum working distance is maintained between adjacent interrogators, there is no upper limit to the number of interrogators that may simultaneously operate at the same frequency. In all high density applications alternate interrogators will operate on different channels. Typically no more than two channels will be in use at a given time/place.

Using the principle of the dense interrogator mode illustrated above, TR 102 649-2 [1] has proposed four channels for high power SRD/RFID use, as previously shown in the diagram in Figure 2:. This diagram proposes that both high power SRDs & RFID Interrogators may operate on any of the four specified high power channels within the band 915-921 MHz at power levels up to 4 W e.r.p. The centre frequencies of the four high power channels as in the SRDoc TR 102 649-2 [1] are 916.3 MHz, 917.5 MHz, 918.7 MHz and 919.9 MHz. This will ensure that an interrogator transmitting at 917.5 MHz will not interfere with an ER-GSM device operating *at* its lowest channel frequency. The bandwidth of each high power channel is 400 kHz. Tags respond in the dense interrogator mode within the adjacent low power channels. Such scheme also ensures that the 3 upper ER-GSM channels in the band 918-921 MHz will always remain free from interference from RFID.

The SRDoc specifies the maximum transmitted power from a tag as -18 dBm/100 kHz. For an ER-GSM device with a channel bandwidth of 200 kHz this would be subject to a maximum interfering signal from a tag of -15 dBm. Assuming a value for σ of 3.5, the maximum power level experienced by an ER-GSM device from a tag, which is outdoors at 20 m would be given by {-15 – 32 – 35*log (20)}. This equates to a figure of -92.5 dBm.

Measurements at the BNetzA test laboratory in Kolberg [11] demonstrated that the introduction of an offset of 700 kHz between the centre frequencies of ER-GSM and RFID gave an improvement in mitigation of 9 dB. Full details of these measurements are available in annex A6.1.1.

TS 102 902 [7] showed that the worst case scenario for interference from RFID is produced in the portal scenario. Therefore, the report uses this scenario as the basis for simulations, and omits any analysis of handheld readers and checkout tables.

The simulations were performed on the assumption that RFID interrogators transmitted only in the four specified channels with the mandatory requirement for DAA in the upper two high power channels. Tags responded in the adjacent low power channels. Five different scenarios were considered representative of the way in which RFID might be used. These included:

- “Hotspot”: multiple RFID interrogators in a hotspot such as a large warehouse/distribution centre (dense interrogator scenario);
- “Airport”: RFID readers on conveyors at airport terminals for baggage handling (e.g. a baggage handling hall in an airport terminal building. Such systems would be carefully designed and have to satisfy the requirements of the airport frequency management department);
- “Store”: a line of interrogators at the check-outs of a store (a row of check-out counters at a supermarket; due to shorter distances only 500 mW e.r.p. is assumed);
- “Other”: a typical concentration of RFID interrogators in an outdoor environment (any other usage not specially defined);
- “Item tagging”: RFID in a store, i.e. an additional variation of the store scenario, in which individual items are tagged so that they may be identified.

The table below lists the RFID parameters suitable for simulations of respective usage scenarios.

Table 64: Parameters used for RFID as interferer

Parameter	RFID use scenarios				
	Hotspot	Airport	Store/Item tagging	Industrial	Other
E.r.p. (dBm)	36 (7)	36(7)	27	24	36
Antenna gain (dBi)	8 (2)	8 (3)	8 (3 and 4)	8 (3)	8 (3)
Density (per hotspot or per sq.km, see text below the table)	480	480	20	400	12
Duty Cycle (%)(1)	5.0	4	25	50	2
Duty Cycle per active channel (6)	2.5	2	12.5	50	1
Environment	Indoor	Indoor	Indoor	Indoor	Outdoor
Protection zone (m)	20	1000	20	20	20

1. Ratio of Tx_on to (Tx_off+Tx_on) time
2. RFID antenna Type 1, as defined further below
3. RFID antenna Type 2, as defined further below
4. RFID antenna Type 3, as defined further below

5. As a worst case 4 interrogators have been simulated on a single floor (radius of 150 m), i.e. one per channel
6. Assuming that only half the population of interrogators will ever transmit simultaneously on the same channel
7. Due to the semi-shielded environment an average Tx power of 20 dBm is suggested for interrogators in hot-spots for all compatibility simulations

A number of factors affect the values assumed for interferers in the different scenarios. The densities used for the “Hotspot” and “Airport” scenarios were derived from [1]. A large distribution centre may have up to 120 dock doors, each equipped with an interrogator. It is possible in an industrial park for up to 4 distribution centres to be located within a square kilometre, which equates to a density of 480 interrogators per sq. km. It was considered reasonable to assume this same unit density for interrogators in airport terminals.

In the “Hotspot” scenario it is probable that less than a quarter of the portals would ever be in operation at any time. Each portal requires the use of one interrogator, which typically is connected to four antennas that transmit in accordance with a pre-arranged sequence. Also based on observations at a distribution centre the typical total time taken to load a pallet onto a truck is 10 s. During the loading operation an interrogator would be active for less than 2 s. The combination of the maximum number of portals in use and the transmission time for each loading cycle leads to an overall duty cycle of 5%. At a distribution centre it is normal for portals to be arranged close to each other in a line. To avoid co-channel interference, adjacent interrogators are configured to operate on alternate channels. This means that the duty cycle per channel is effectively halved to 2.5%.

At each dock-door it is normal to install RFID in a portal to minimise unwanted emissions outside the interrogation zone. Measurements taken at a distance of 10 m from the outside of a distribution centre, where RFID was in operation, showed that the field strength never exceeded -36 dBm e.r.p. (see Annex C of ETSI TR 103 151 [21]). For an interrogator transmitting at current regulatory levels in free space the power level at 10 m would be equal to a power of - 19 dBm. The additional attenuation attributable to the portal installed within the distribution centre is 17 dB. Thus the equivalent power from an interrogator transmitting at 36 dBm under the same partially shielded conditions would be 19 dBm. In addition it should be noted that this high level of activity typically is restricted to periods between 03:00 hrs and 06:00 hrs when trucks are being loaded before leaving for the retail outlets. Taking the above into account, it would be appropriate to use the value of 20 dBm for interrogators in hot-spots for all compatibility simulations.

All transmitting devices at an airport come under the jurisdiction of the airport frequency management department. This department will consider the proposed location of each interrogator and satisfy themselves that there are no incompatibilities. Therefore for airport applications only those victims situated outside the airport perimeter are of interest to this study. For this reason a minimum (protection) distance of 1000 m was used for the airport application case.

For the checkout terminals in a “Store” scenario, a power level of 500 mW is assumed. This is because the application must be tightly controlled and powers kept to a minimum, otherwise there is a risk of incorrectly charging customers in adjacent lanes. The reading of tagged items for stock inventories is carried out manually and is usually undertaken at close range using low powers

The densities of interrogators assumed for both the “Store” and the “Other” scenario were derived from data contained in the industry report on European Passive RFID Market Sizing 2007 – 2022.

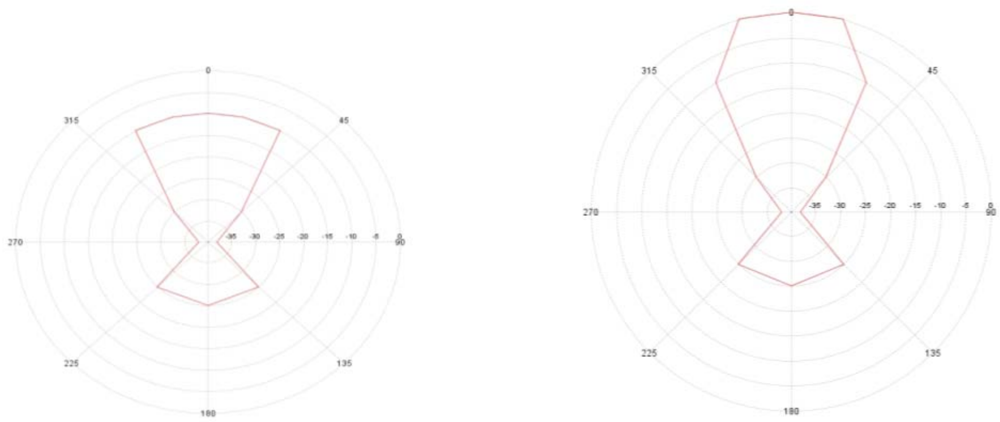
The mitigation technique described in TS 102 902 [7] Clause 6.4.2.2 to protect ER-GSM shall be initiated if an interrogator detects a signal from a base station in excess of -38.5 dBµV/m (equivalent to -98 dBm). Following discussions with an ER-GSM operating company, it is proposed to implement downlink detection using the information transmitted by the BCCH to identify both BCCH and TCH channels.

The parameters of RFID as a victim are presented below. Note that only the RFID interrogator is considered since the RFID tags are some 60 dB less sensitive than the receivers of interrogators.

Table 65: Parameters used for RFID as victim

RFID device	BW (kHz)	Sensitivity (dBm)	C/I (dB)	Selectivity (dBm)
Interrogator receiver	400	-75	12	≤ -35

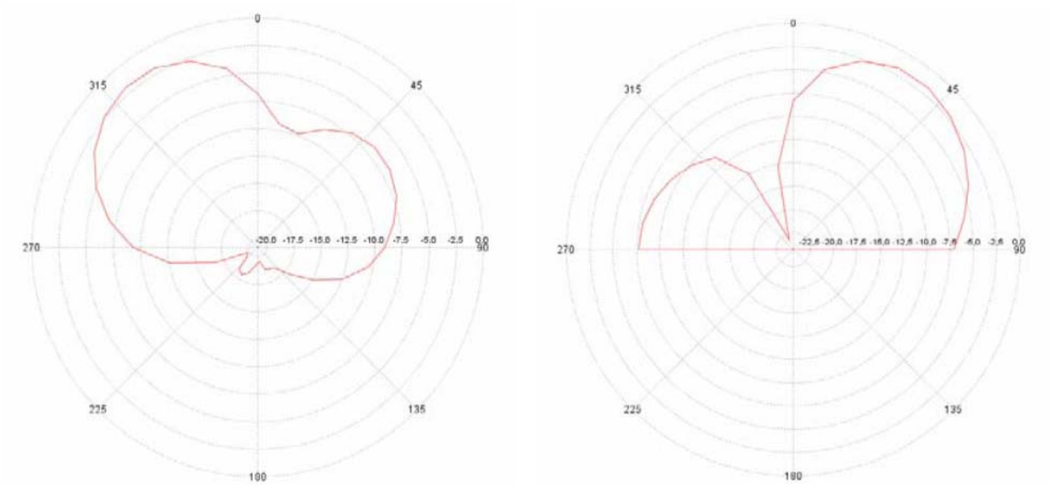
The antenna patterns for the different types of RFID antennas are shown in the following figure. Note that the radiation pattern of the “Type 1” antenna, used in the “Hotspot” scenario, takes into account the loss of 10 dB caused by the portal, which is positioned in front of the main beam.



(a) (b)

Figure 29: Radiation pattern of RFID interrogator antenna Type 1 (a) and Type 2 (b)

The following Figure shows horizontal and vertical patterns of antenna “Type 3” used in handheld RFID interrogators.



(a) (b)

Figure 30: Radiation patterns of RFID antenna Type 3: horizontal (a) and vertical (b) planes

The transmit spectrum mask of the RFID interrogator is taken from ETSI TR 102 649-2 [1] and was used in the SEAMCAT simulations. A diagram of the spectrum mask is provided below

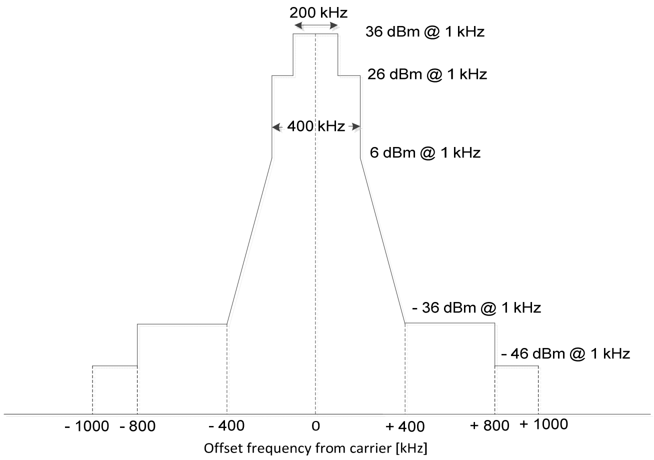


Figure 31: Spectrum emissions mask of RFID interrogator's transmitter

It should be noted that the values for unwanted emissions within the necessary band are measured in a 1 kHz resolution bandwidth. In addition, outside of 250 % of the necessary bandwidth, the values specified for the resolution bandwidth shall be in accordance with CEPT/ERC/Rec 74-01 [30].

A2.6 SRD AND RFID TRANSMITTER MASKS

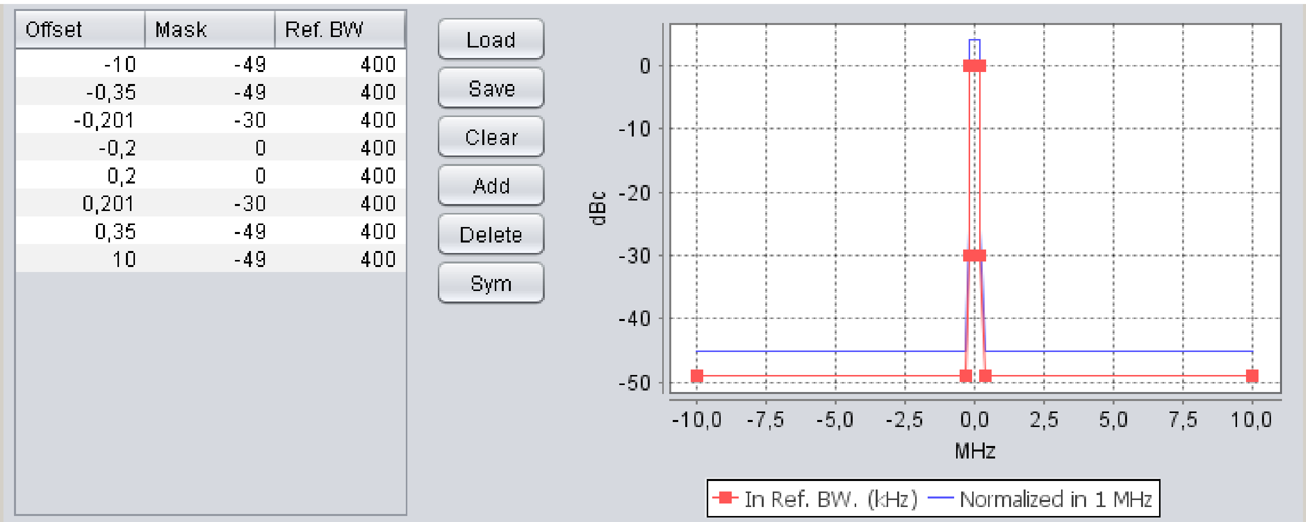
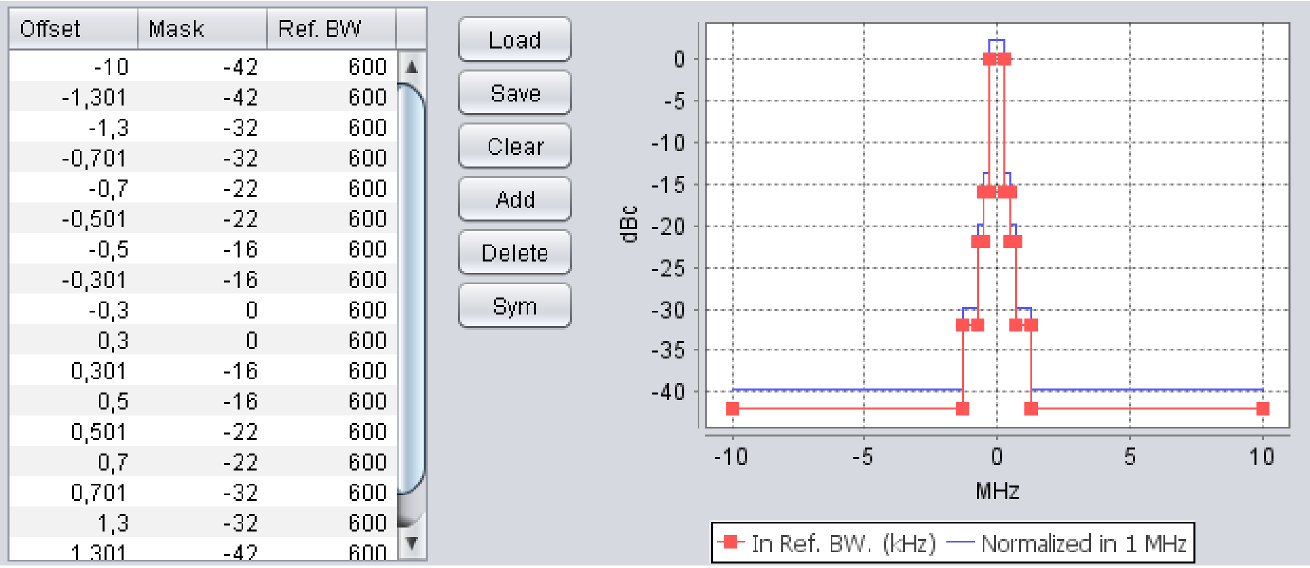
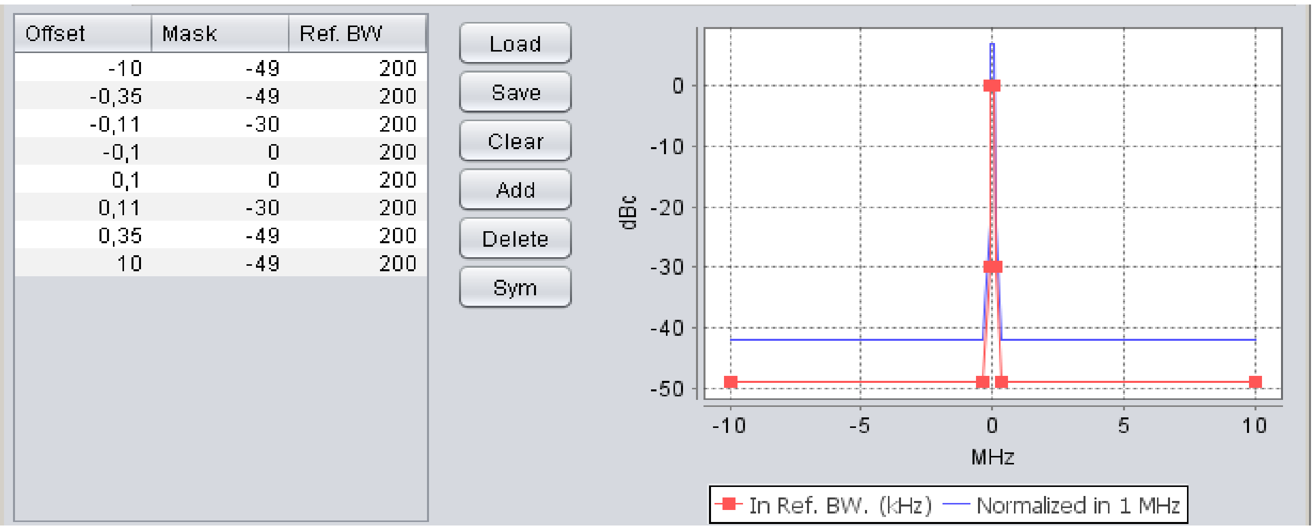


Figure 32: Non-specific Type B



Offset	Mask	Ref. BW
-10	-42	600
-1,301	-42	600
-1,3	-32	600
-0,701	-32	600
-0,7	-22	600
-0,501	-22	600
-0,5	-16	600
-0,301	-16	600
-0,3	0	600
0,3	0	600
0,301	-16	600
0,5	-16	600
0,501	-22	600
0,7	-22	600
0,701	-32	600
1,3	-32	600
1,301	-42	600

Figure 33: Non-specific Type A



Offset	Mask	Ref. BW
-10	-49	200
-0,35	-49	200
-0,11	-30	200
-0,1	0	200
0,1	0	200
0,11	-30	200
0,35	-49	200
10	-49	200

Figure 34: ALDs

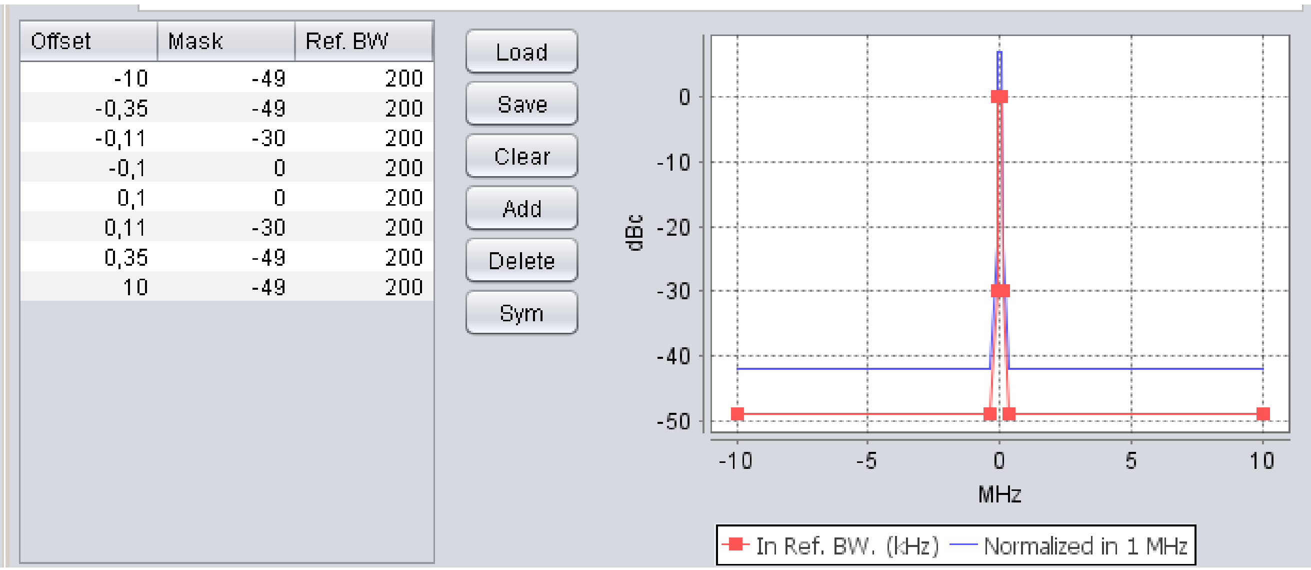


Figure 35: Home automation

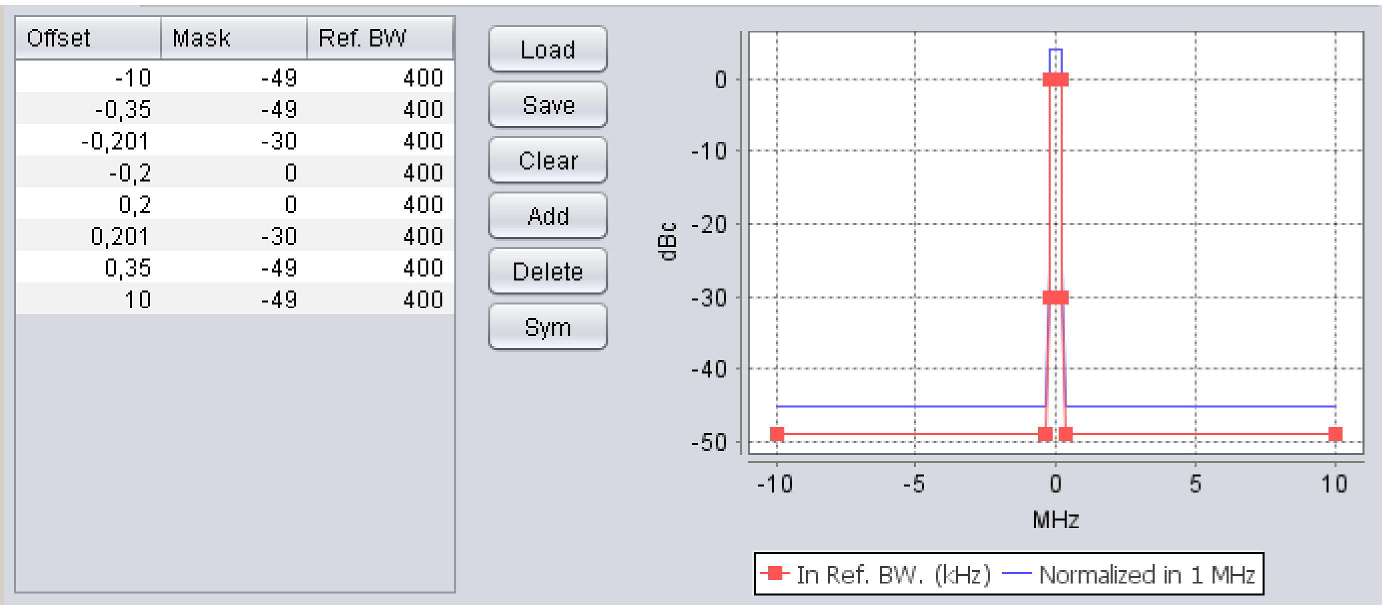


Figure 36: RFID

Note: The simulations for RFID were performed using a simplified spectrum mask, which deviates slightly from the mask provided in ETSI TR 102 649-2. However, the simplified mask has slightly higher OOB emissions than the mask from the SRDoc. Thus the results with the simplified mask represent a conservative assumption.

A2.7 SUMMARY OF REQUIREMENTS

The original vision for the frequency bands 870-976 / 915-921 MHz as defined in TR 102 649-2 [1] is given in Figure 2: and Figure 3:. From the latest SRD/RFID requirements as described above, it is possible to re-draw the proposed bands 870-876 MHz and 915-921 MHz as shown in Figure 37: and Figure 38:

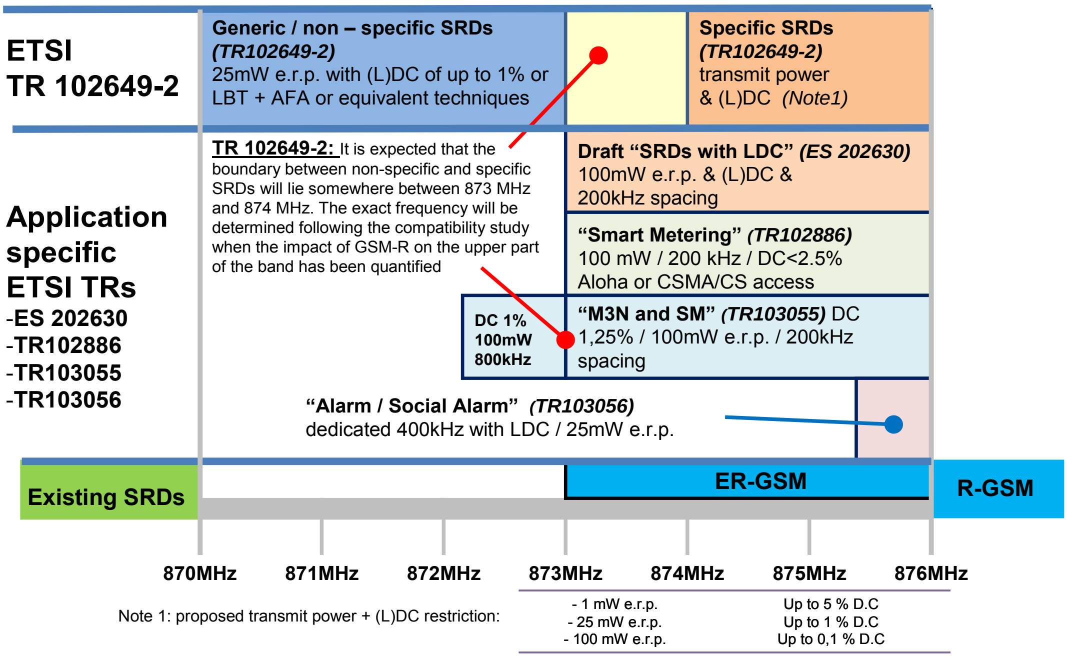


Figure 37: The summary of the updated SRdocs outlining SRD requirements in the band 870-876 MHz

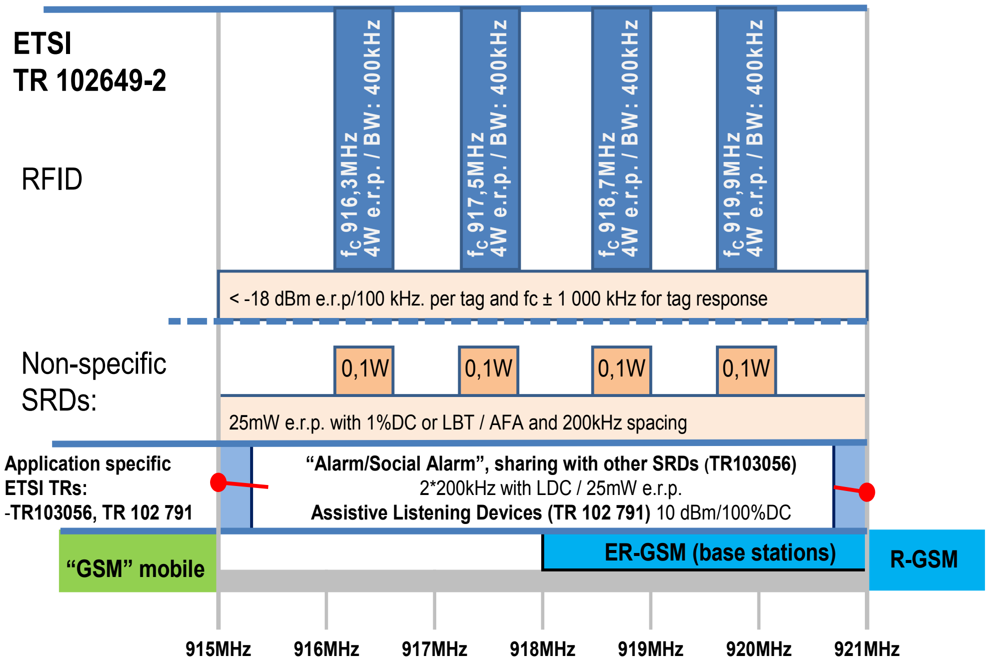


Figure 38: The summary of the updated SRdocs outlining SRD/RFID requirements in the band 915-921 MHz

These requirements are therefore considered in the studies reported further in this document. In some limited applications SRDs may use up to 500 mW.

ANNEX 3: SIMULATION METHODS AND TOOLS

A3.1 USE OF SEAMCAT

Taking note of discussion of general approach in the previous sub-section and in accordance with general practice of sharing studies, the official CEPT simulation tool SEAMCAT was the prime instrument for carrying out most of the basic co-existence simulations.

The simulations were carried out using SEAMCAT Version 4.0.0. It may be useful at this point to reminisce on the basic constituent elements of any SEAMCAT simulation, as shown in the following figure.

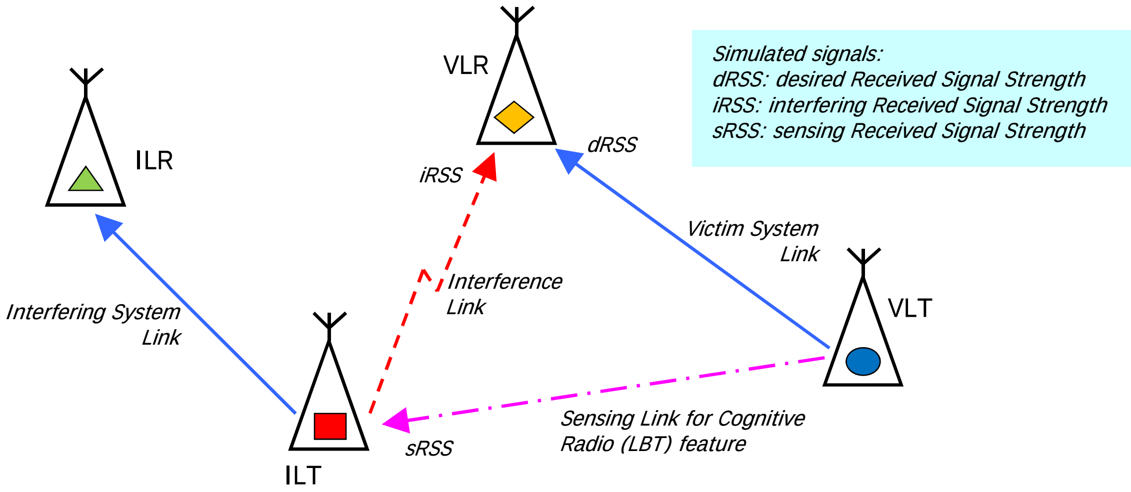


Figure 39: Modernised representation of SEAMCAT scenario elements

Note that although the traditional configuration for a SEAMCAT scenario has not changed and remains based on two pairs of interacting peer transmitters and receivers, it was recently decided to abandon the previous naming convention (Wanted Transmitter → Victim Receiver pair and Interfering Transmitter → Wanted Receiver pair), and now refer to them as: Victim Link's Transmitter (VLT) and Receiver (VLR) and correspondingly the Interfering Link's Transmitter (ILT) and Receiver (ILR). This was to make the naming more intuitively clear for the casual user/reader. Therefore this report adopts this new naming nomenclature and the above mentioned references to transceivers.

A3.2 MODELLING OF DC AND AF IN SEAMCAT

Modelling of Duty Cycle (DC) and Activity Factor (AF) is a very critical element in simulating co-existence of SRDs since the DC/AF is the natural primary mitigation factor for these ubiquitous power savvy devices characterised by transmission patterns, which occur in sparse bursts.

The SEAMCAT allows modelling DC/AF in two major ways, both of which would be considered and used in simulations of this report as required.

The first and most typical method would be to reflect the **AF value** in settings of ILT-VLR placement modes. When using "Uniform density" or "Closest interferer" placement modes, the SEAMCAT allows the description of the density and activity of interferers. Then during simulations, the SEAMCAT assumes that all generated interferers are active (i.e. transmitting the signal burst at the time instance of the snapshot). However their placement is statistically spread throughout the area, based on density and activity (i.e. AF) parameters, using the following formula:

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi \times dens_{it}^{active}}}$$

where:

- n^{active}: number of active interferers in the simulation;
- $dens_{it}^{active}$: density of active transmitters, calculated as follows:

$$dens_{it}^{active} = dens_{it} \times p_{it}^{tx} \times activity_{it}(time)$$

where:

- $dens_{it}$: nominal density of interferers;
- p_{it}^{tx}: probability of transmission of interferer, i.e. *it's AF equivalent*;
- $activity_{it}(time)$: temporal activity function, i.e. accounting for different activity periods as a function of time of the day (rush hour effect vs. night time). Note: this function is set in SEAMCAT by first creating a reference look-up table and then separately defining the time determinant. In most scenarios users opt to set this function to 1 and instead directly modify in one go the probability of transmission, to scale it as required by changing the AF;

So by looking at these formulas, it could be concluded that in this manner SEAMCAT derives the simulation radius as a straightforward geometric function of probability of encountering the desired number of "simultaneously active" interferers based on their density and activity. Given that the two latter parameters are usually easily available as part of the scenario definition, this method is the obvious preferred choice to incorporate the respective input data.

Another different option is to model the DC by direct toggling (ON/OFF) of the ILT power between the snapshots. This could be easily done by the users through respectively adjusting ILT's transmit power distribution function, where any desired pattern of interferer's activity could be implemented. In this manner the probability of collisions in the time domain could be analysed directly for the desired number of modelled interferers.

The above described methods allow modelling the statistical impact of DC and AF over long time periods of real-life scenarios. However, since the succession of SEAMCAT snapshots is not linked to any specific time reference, these methods do not completely address the "time dynamics" of possible interaction between bursty digital signals in the specific systems.

Modelling the DC of an interferer by using the probability of transmitting in SEAMCAT is currently under review.

ANNEX 4: FEASIBILITY OF DAA FOR SRD SHARING WITH TRR AND UAS

This annex is dedicated to reviewing the feasibility and efficiency of implementing Detect-And-Avoid (DAA) mitigation technique to improve co-existence between SRD and other services and applications envisaged in the bands 870-876 / 915-921 MHz. The essence of this consideration is to evaluate the extent to which the phenomenon of Hidden Nodes might be manifest in subject SRD co-existence scenarios; as such occurrences would render inefficient operation of DAA.

A4.1 APPLYING ANALYTICAL ANALYSIS OF HIDDEN NODES

All mitigation methods that rely on sensing of the radio environment in order to establish occupied channels, such as LBT and DAA, have one inherent problem called Hidden Nodes. It manifests itself due to the fact that the LBT or DAA sensing mechanism of interfering transmitter needs to detect the transmitter of the victim link, which may be below the detection threshold. Under these conditions the interfering transmitter may deem that the channel is available, begin transmitting over it, and thus create interference to a victim receiver that might be positioned nearby..

The concept of Hidden Nodes is analysed here briefly, based on more elaborate analysis presented in ECC Report 181 [31]. It should be noted that this analysis does not consider a corollary effect of “exposed nodes” as this is of no concern to co-existence scenarios addressed in this report.

The following figure represents a graphical illustration of Hidden Node scenario. In it a Victim Link Receiver VLR is receiving messages from the wanted Victim Link Transmitter VLT over area defined by maximum link distance R_{sig}. A potential interferer, Interfering Link Transmitter ILT is randomly placed anywhere in the area, and, simply viewed, the combination of its sensitivity and VLT power result in certain detection distance R_{det}, over which the ILT could instantaneously detect the VLT. Thus, in Figure 40:, the blue region depicts the area where ILT is able detect VLT reliably, whereas red-coloured region depicts the area where ILT’s sensing mechanism is not able to detect the VLT and will create Hidden Node situation.

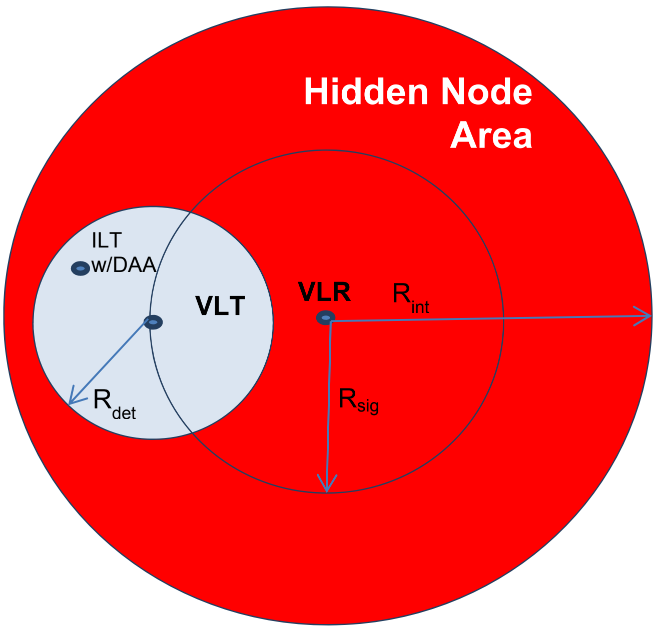


Figure 40: Illustration of DAA sensing deficiency zone (Hidden Node), adapted from ECC Report 181 [31]

Note that the scales of the circles in the above figure are arbitrary.

In order to evaluate the real extent and ratios of the identified areas, it is possible to use the methodology described in Annex 1 of ECC Report 181 [31]. However the analysis performed in ECC Report 181 [31] for the case of intra-SRD co-existence did not make provisions for antenna gains, which might be relevant in this study. Some non-SRD systems may have significant antenna gains. The above depicted situation would in reality look different, as illustrated in the following figure.

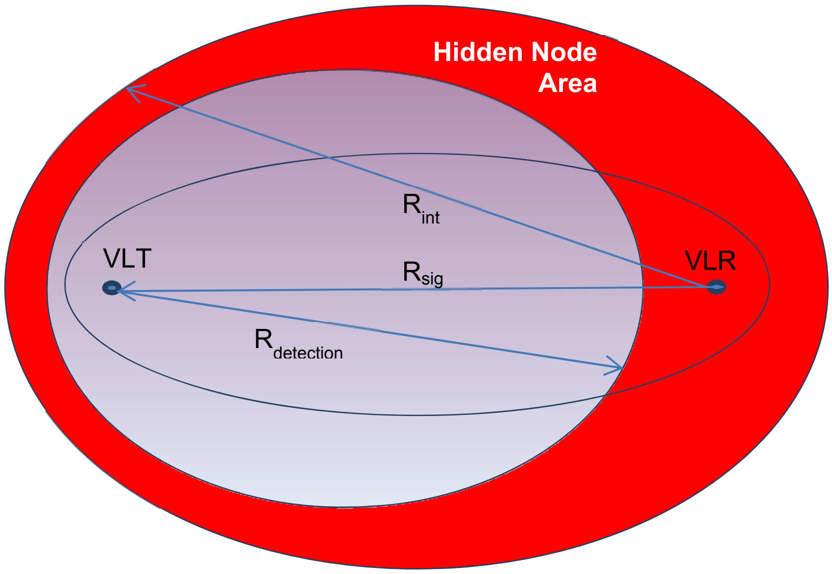


Figure 41: Illustration of DAA sensing deficiency (Hidden Node)

This Figure 41: illustrates that the impact of high gain antennas on the victim link and would mean that the circular areas in Figure 40: would become non-circular. However, it also illustrates that the principal impact on distances such as R_{int}, R_{sig} and R_{det} would be determined by the high antenna gain sectors. Therefore by retaining the simplification of circular areas in Figure 40:, but with radiuses as defined by antennas with high gain, the methodology of ECC Report 181 [31] would be still valid, but applied to the scenarios in Figure 41: would give a conservative result.

Hence, with the assumption of antenna gains on victim link (SRDs assumed with 0 dBi antenna gains), the original formulas in ECC Report 181 Annex 1, used to express the balance of link budgets at interference threshold and the resulting Hidden Node areas may be written as follows:

$$S = N + SNR = P_{VLT} + G_{VLT} + G_{VLR} - PL(R_{sig}) \quad (A4.1)$$
$$I = S - SIR_{min} = (N + SNR) - SIR_{min} = P_{ILT} + G_{VLR} - PL(R_{int}) \quad (A4.2)$$
$$P_{thr} = P_{VLT} + G_{VLT} - PL(R_{det}) \quad (A4.3)$$
$$PL = 32.5+10*n*\log(R/m)+20*\log(0.87GHz) = 31.3 + 10*n*\log(R) \quad (A4.4)$$

where:

P_{VLT} – transmit power of VLT;
P_{ILT} – transmit power of ILT SRD (e.i.r.p. due to assumed zero antenna gain);
G_{VLT} and G_{VLR} – antenna gain of VLT and VLR respectively;
P_{thr} – DAA sensing threshold;
N – noise floor (kTBF) of VLR;
SNR – Signal to Noise Ratio for operational level of wanted signal at VLR;
SIR_{min} - minimum Signal to Interference Ratio (C/I objective);
n - path loss exponent, n=2.5 rural area, n=3.5 urban area with walls, see section 4.4.1.2 Table 17 and Figure 10.

With those essential formulas established, it becomes possible to derive the (maximum) areas of circular zones according (here at 0.87 GHz) to the principal relationships as described in Figure 41::

(A4.1) & (A4.4) → $10n*\log(R_{sig}) = P_{VLT} + G_{VLT} + G_{VLR} – N – SNR – 31.3$ (A4.5)

(A4.2) & (A4.4) → $10n*\log(R_{int}) = P_{ILT} + G_{VLR} – N – SNR + SIR_{min} – 31.3$ (A4.6)

(A4.3) & (A4.4) → $10n*\log(R_{det}) = P_{VLT} + G_{VLT} – P_{thr} – 31.3$ (A4.7)

This assumes the following: all devices are using the same frequency that means the VLR is only receiving and the VLT is only transmitting, and VLR and VLT are at different locations.

The requirement to avoid the hidden node is given by Rdet>=Rsig+Rint.

The next table shows the distances Rsig, Rint and Rdet for the example of TRR (37dBm 1.5 MHz bandwidth) and SRDs (20dBm, 200 kHz bandwidth) for different SNRs at the victim link receiver and for different antenna gain values seen from the SRD device. The assumed propagation exponent is 2.5, and the assumed DAA threshold value is -90 dBm.

Table 66: Calculating DAA efficiency in addressing Hidden Node problem in TRR scenarios

f/GHz	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
BW 1/MHz	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
BW 2/MHz	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pit dBm/BW 1 e.i.r.p.	14	14	14	14	14	14	14	14	14	14
Pwt dBm/BW 2	37	37	37	37	37	37	37	37	37	37
Pwt dBm/BW 1	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
Gsmax dBi	16	16	16	16	16	16	16	16	16	16
NF dB	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
N dBm/BW 2	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24
Pthr dBm/BW 1	-90	-90	-90	-90	-90	-90	-90	-90	-90	-90
Wall dB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNR dB	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00
Smin dBm/BW 2	-87.24	-82.24	-77.24	-72.24	-67.24	-62.24	-57.24	-52.24	-47.24	-42.24
SIRmin dB	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Imax dBm/BW 2	-102.24	-97.24	-92.24	-87.24	-82.24	-77.24	--72.24	-67.24	-62.24	-57.24
Propagation exp n	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Rsig m	30000.0	30000.0	30000.0	25000.5	15774.2	9952.9	6279.8	3962.3	2500.0	1577.4
Rint/m										
Gs dBi seen from SRD										
16	10913.1	6885.7	4344.6	2741.2	1729.6	1091.3	688.6	434.5	274.1	173.0
14	9077.1	5727.3	3613.7	2280.1	1438.6	907.7	572.7	361.4	228.0	143.9
12	7550.0	4763.7	3005.7	1896.5	1196.6	755.0	476.4	300.6	189.6	119.7
10	6279.8	3962.3	2500.0	1577.4	995.3	628.0	396.2	250.0	157.7	99.5
8	5223.3	3295.7	2079.4	1312.0	827.8	522.3	329.6	207.9	131.2	82.8
6	4344.6	2741.2	1729.6	1091.3	688.6	434.5	274.1	173.0	109.1	68.9
4	3613.7	2280.1	1438.6	907.7	572.7	361.4	228.0	143.0	90.8	57.3
2	3005.7	1896.5	1196.6	755.0	476.4	300.6	189.6	119.7	75.5	47.6
0	2500.0	1577.4	995.3	628.0	396.2	250.0	157.7	99.5	62.8	39.6

Rsig+Rint/m										
Gs dBi seen from SRD										
16	40913.1	36885.7	34344.6	27741.7	17503.8	11044.2	6968.4	4396.8	2774.2	1750.4
14	39077.1	35727.3	33613.7	27280.5	17212.9	10860.6	6852.6	4323.7	2728.1	1721.3
12	37550.0	34763.7	33005.7	26896.9	16970.8	10707.9	6756.2	4662.9	2689.7	1697.1
10	36279.8	33962.3	32500.0	26577.9	16769.5	10580.8	6676.1	4212.3	2657.8	1677.0
8	35223.3	33295.7	32079.4	26312.5	16602.1	10475.2	6609.4	4170.3	2631.3	1660.2
6	34344.6	32741.2	31729.6	26091.8	16462.8	10387.3	6554.0	4135.3	2609.2	1646.3
4	33613.7	32280.1	31438.6	25908.2	16347.0	10314.2	6507.8	4106.2	2590.8	1634.7
2	33005.7	31896.5	31196.6	25755.5	16250.6	10253.4	6469.5	4082.0	2575.5	1625.1
0	32500.0	31577.4	30995.3	25628.4	16170.5	10202.9	6437.6	4061.8	2562.8	1617.0
Rdet/m										
Gs dBi seen from SRD										
16	13132.9	13132.9	13132.9	13132.9	13132.9	13132.9	13132.9	13132.9	13132.9	13132.9
14	10923.5	10923.5	10923.5	10923.5	10923.5	10923.5	10923.5	10923.5	10923.5	10923.5
12	9085.7	9085.7	9085.7	9085.7	9085.7	9085.7	9085.7	9085.7	9085.7	9085.7
10	7557.2	7557.2	7557.2	7557.2	7557.2	7557.2	7557.2	7557.2	7557.2	7557.2
8	6285.8	6285.8	6285.8	6285.8	6285.8	6285.8	6285.8	6285.8	6285.8	6285.8
6	5228.3	5228.3	5228.3	5228.3	5228.3	5228.3	5228.3	5228.3	5228.3	5228.3
4	4348.7	4348.7	4348.7	4348.7	4348.7	4348.7	4348.7	4348.7	4348.7	4348.7
2	3617.1	3617.1	3617.1	3617.1	3617.1	3617.1	3617.1	3617.1	3617.1	3617.1
0	3008.6	3008.6	3008.6	3008.6	3008.6	3008.6	3008.6	3008.6	3008.6	3008.6
Hidden node disappears for Rdet>=Rsig+Rint										
Gs dBi seen from SRD										
16	No	No	No	No	No	YES	YES	YES	YES	YES
14	No	No	No	No	No	YES	YES	YES	YES	YES
12	No	No	No	No	No	No	YES	YES	YES	YES
10	No	No	No	No	No	No	YES	YES	YES	YES
8	No	No	No	No	No	No	No	YES	YES	YES
6	No	No	No	No	No	No	No	YES	YES	YES
4	No	No	No	No	No	No	No	YES	YES	YES
2	No	No	No	No	No	No	No	No	YES	YES
0	No	No	No	No	No	No	No	No	YES	YES

The main result is that as long as the interfering transmitter is only sensing the frequency band where it is wishing to transmit, only for very high margins above sensitivity at the victim link, or with very low threshold values (in the order of -115 dBm/200kHz), DAA may work efficiently.

The above method and Table 66 with results of calculations may be used to establish analytically the feasibility of DAA depending on assumed DAA sensing threshold as well as TRR operational margin:

$$P_{thr} = P_{VLT} + G_{VLT} - P_{ILT} - G_{VLR} + N + SNR - SIR_{min}.$$

A4.2 PRACTICAL CASE STUDY ANALYSIS FOR THE PROTECTION OF TRR

The feasibility of DAA depends heavily on the reliability of the spectrum sensing mechanism. This section analyses a practical example of what this could mean in practical terms, by making a quick assessment of the order of magnitude of the sensing threshold that would be required to be implemented by SRDs in the band, if one considers no separation distance between SRDs and TRRs.

Figure 42: below depicts a typical deployment situation for TRR: the vehicles are masked by positioning among the local clutter, whereas reliable operation of TRR is ensured by raising their antennas on telescopic masts, in order to be above the surrounding clutter.

Figure 42: Practical example of TRR antennas mounted above clutter

Thus let's assume a TRR RX antenna located at 10 above ground level, and mean received wanted power level of -X dBm, e.g. at a certain fading margin over sensitivity threshold. Assuming TRR antenna gain of 16 dBi and a cable loss of 3 dB, this would mean that the received mean wanted signal level on the air at 10 m above ground is around X-16+3=X-13 dBm.

Now let's assume that the SRD is at the ground level (1.5 m), in a range of 50 m from the TRR receiving antenna. The question is: what level of TRR received wanted signal SRD DAA sensor needs to detect in order to identify that a given channel is being in use by other system?

In order to estimate this signal detection level, we proceed as follows:

- We need to take into account receive antenna height loss, from a 10 m height above the clutter (where the TRR antenna is located) to a position at the ground level, where the SRD is located. This height loss, at 900 MHz, can be estimated, for instance, by referring to the Okumura-Hata model and evaluating the variation of its parameter called "receive antenna height gain" when the height varies from 10 m to 1.6. The value of the loss when decreasing receiver antenna height from 10 m to 1.5 m, for a suburban environment, is around 20 dB. This gives an average level of TRR wanted signal at the ground level of X-13-20= X-33 dBm;

- We also need to consider fading conditions of wanted TRR signal. At 900 MHz, we can assume a standard deviation of slow fading of 6 dB. That is, the TRR's wanted signal level as seen at the ground level in the neighborhood of victim TRR receiver will have a mean value of -X-33 dBm, with Gaussian distribution of variations and standard deviation of 6 dB;
- Then if assuming the need of detection with probability of, say, 98%, the DAA sensor must be able to detect signal level of X-33 dBm – 2.05*6 = X – 45.3 dBm, measured over 1500 kHz, or equivalent of X – 45.3 – 9 = X – 54.3 dBm in a typical SRD receiver bandwidth of 200 kHz.

Based on this method, the following Figure 34 depicts the dependence of required DAA sensing threshold as a function of assumed operational mean level of TRR wanted signal.

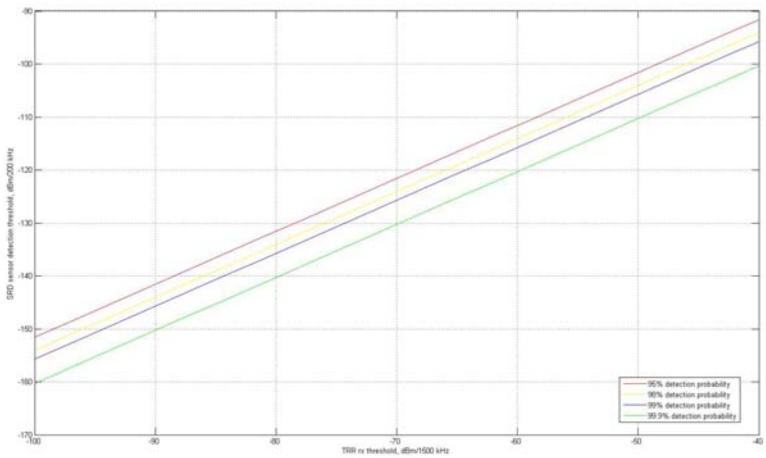


Figure 43: Required DAA sensing threshold as a function of mean level of TRR wanted signal

As shown by this analysis, in order to detect TRR signal with a good degree of reliability, the SRD DAA sensors would be required to detect very low signal levels that are comparable with the thermal noise levels.

A4.3 PRACTICAL CASE STUDY ANALYSIS FOR THE PROTECTION OF UAS

Figure 44: shows the geometry that has been considered for assessing the reliability of spectrum sensing/DAA as a mechanism for the protection of UAS.

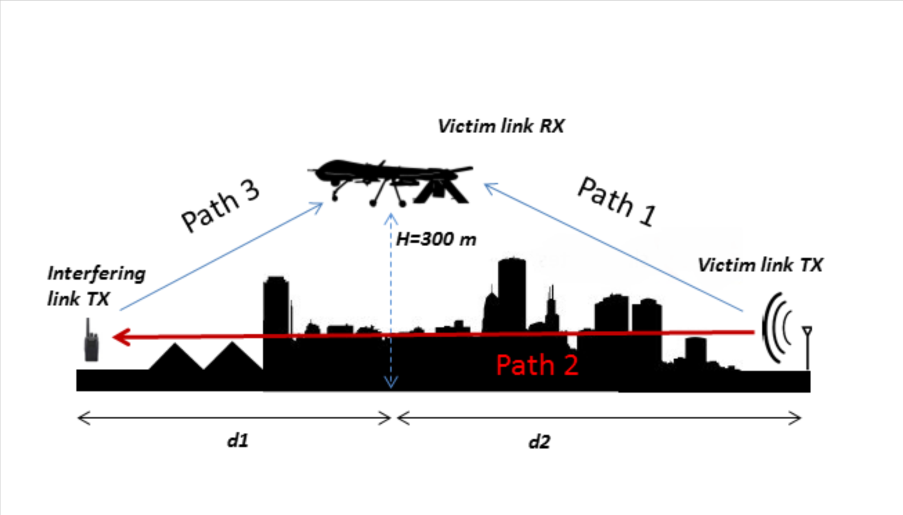


Figure 44: Considered DAA sensing configuration for UAS scenarios

As it can be seen, three different propagation paths are identified:

- Path 1: from the victim link TX (the ground station of the UAS link) to the victim receiver (the UAS receiver, flying at a height up to 300 m). The length of this path is dictated both by link budget limitations and operational conditions of the UAS. Its projection on the horizontal plane is d_2. This path not necessarily will be in line of sight. For sake of simplicity we take d_2=2 km , noting that is can be higher.
- Path 2: from wanted TX to the SRD. The signal that the SRD must be able to detect propagates along this path. Its length is d_1+d_2
- Path 3: from the interfering SRD to the SRD. Its length is dictated by the maximum interfering distance of the SRD. MCL calculations, as reported in Table 3, indicate a distance ranging from 24 km to 133 km, depending on the type of SRD. In our case, considering the effect of the earth curvature, we limit d_1 to the horizon distance, neglecting refraction. For an SRD at 1.5 m and an UAS at 150 m, d_1= 48 km.

Assuming the following parameters:

- Victim TX e.i.r.p. : 43 dBm
- Victim TX height a.g.l. : 5 m
- SRD height 1.5 a.g.l. (outdoor): 1.5 m
- Length of path 3: d_2+d_1=50 km

And using Okumura-Hata in a sub-urban environment, at 900 MHz, we get that the propagation loss distribution over Path 2 is the one shown in Figure 45:.

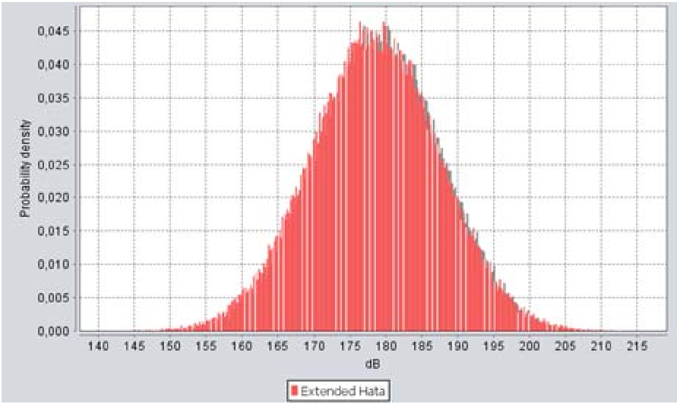


Figure 45: Simulated path loss on DAA sensing path in UAS scenarios

Its average value is roughly 177 dB.
Now we consider a margin in order to obtain a 98% detection probability, and the reception with an SRD with an omni, lossless antenna (0 dBi). Under these assumptions, the power that the sensor should be able to detect is – 155 dBm, considerably below the noise level of the receiver.

The conclusion is that spectrum sensing is not applicable for the protection of UAS (up)links.

A4.4 POSSIBILITY OF IMPROVING DAA BY DUPLEX BAND SENSING

It may be observed that possibility of DAA detection might be improved if the SRD could be sensing not the low levels of useful signal around the victim receiver site, but much stronger signal emitted by duplex transmitter operating at the same site. This situation may be depicted as shown in the following figures.

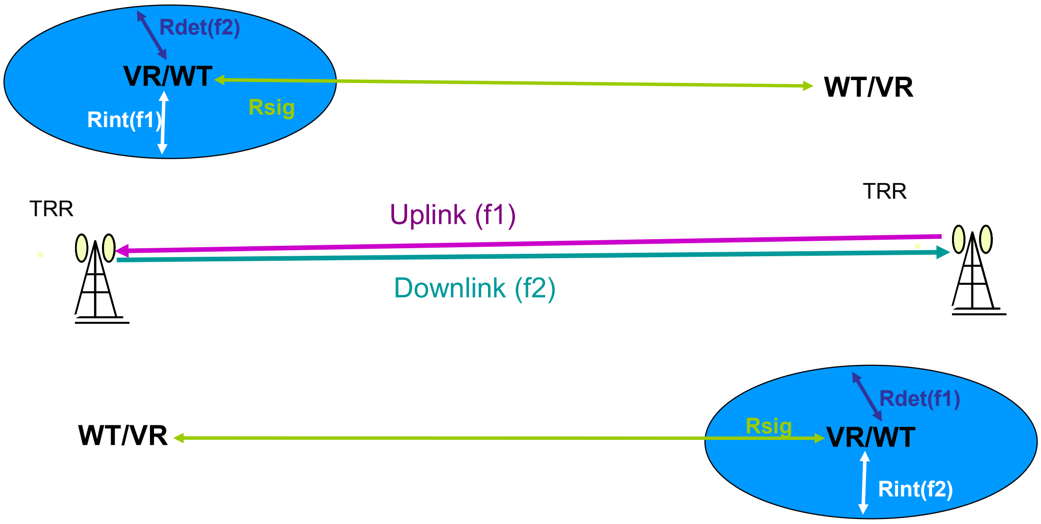


Figure 46: Illustration of scenario that assumes TRR with FDD

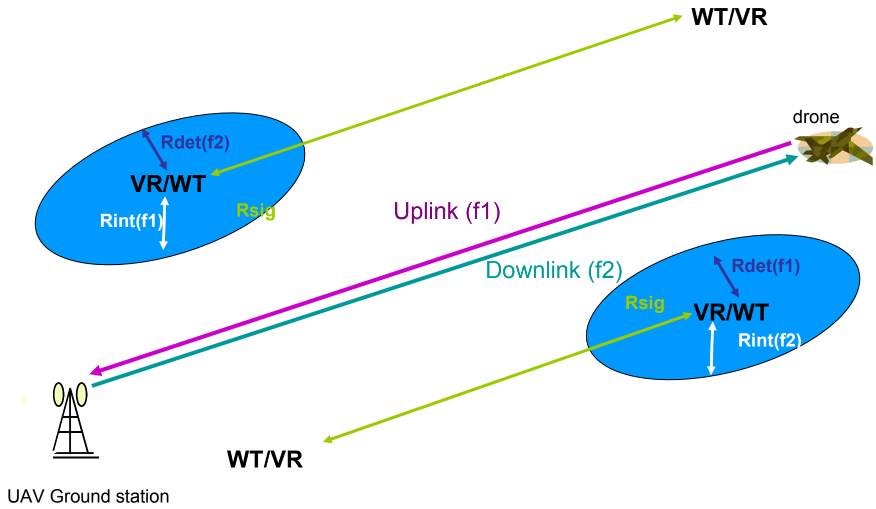


Figure 47: Illustration of scenario that assumes UAS with FDD

In such scenario the SRD is sensing the emission from the same location where the victim receiver is located (e.g. sensing on the left side on frequency f_2, but avoiding interference at f_1). Here under the assumption R_{det}=R_{int} the SRD system should be perfectly able to detect the victim system and thus from earlier analytical analysis it may be derived:

$$. P_{thr}(f_2)=P_{VLT}(f_2)-P_{ILT}(f_1)+N+SNR-SIR_{min}$$

The following table shows some examples of required threshold values for different types of SRDs.

Table 67: Threshold values for DAA detection if knowing the frequency channel arrangement

SRD Type:	Non-spec		Home Automation		Smart Metering		Automotive	
BW 1/MHz SRD	0.6	0.6	0.2	0.2	0.2	0.2	0.5	0.5
BW 2/MHz TRR	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pit dBm/BW 1 e.i.r.p.	14	14	14	14	27	27	27	27
Pit dBm/BW 2 e.i.r.p.	14	14	14	14	27	27	27	27
Pwt dBm/BW 2	37	37	37	37	37	37	37	37
NF dB	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
N dBm/BW 2	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24	-102.24
Wall dB	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
SNR dB	15.00	30.00	15.00	30.00	15.00	30.00	15.00	30.00
Smin dBm/BW	-87.24	-72.24	-87.24	-72.24	-87.24	-72.24	-87.24	-72.24
SIRmin dB	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Pthr dBm/BW 2	-79.24	-64.24	-79.24	-64.24	92.24	-77.24	-92.24	-77.24
Pthr dBm/BW 1	-83.2184875	-68.2184875	-87.9897	-72.9897	-100.9897	-85.9897	-97.01003	-82.0103

But how to transfer this case study analysis to the different use cases of TRR and UAS? The following table is summarising the different modes and the related requirements for the DAA mechanism.

Table 68: DAA requirements for different TRR and UAS frequency arrangements

TRR/UAS channel arrangement	SRDs 870-873 MHz	SRDs 915-918 MHz
TDD 870-873 MHz	A4.3 scenario applicable: Monitoring 870-873 MHz & avoiding 870-873 MHz	No DAA required
TDD 915-918 MHz	No DAA required	A4.3 scenario applicable: Monitoring 915-918 MHz & avoiding 915-918 MHz
FDD Uplink 870-873 or 915-918 MHz, Downlink 915-918 MHz or 870-873 MHz	A4.3 scenario applicable: Monitoring 915-918 MHz but avoiding the 870-873 MHz, if threshold exceeded in 915-918 MHz	A4.3 scenario applicable: Monitoring 870-873 MHz but avoiding the 915-918 MHz if threshold exceeded in 870-873 MHz
FDD Only Up or Downlink (other direction at a unknown frequency)	Hidden Node analysis (A4.1/A4.2) applicable: high risk for hidden node	Hidden Node analysis (A4.1/A4.2) applicable: high risk for hidden node

In conclusion, it may be observed that hidden node scenarios of victim TRR and UAS services may be avoided if SRDs could know the victim channel arrangement and monitor the emission from the same location where the victim receiver is located. As shown in this section A4.3, if it may be assumed that both duplex bands are known by the SRD, then DAA mechanism may work with relatively high sensing thresholds.

A4.5 SUMMARY

The analysis presented in this Annex (see Table 66) proves that with simple power sensing on the candidate operational frequency, the DAA may only work with very low detection threshold values (in some cases below the noise floor) or for high SNR margins at the victim link receiver.

The situation would be improved if the SRD might monitor the emission from the same location where the victim receiver is located, but then the knowledge about the TRR/UAS duplexing and channel arrangement would be required (see Table 68). But this cannot be generally assumed and therefore this DAA method of operation is not very promising method to protect operation of TRR and UAS links.

ANNEX 5: RESULTS OF BERLIN TESTS OF SRD VS GSM-R

A set of tests (aka ‘Kolberg 1’) were carried out at BNetzA’s Kolberg test facility in 2009 to investigate the feasibility of coexistence between SRDs and GSM-R radios. The results of these tests confirmed that, for voice and protected data bearers, sharing were feasible as long as the transmissions were restricted to a maximum Ton time and DC (Duty Cycle). The impact of transmitter power appeared to be insignificant.

Analysis and discussion of these results has led the study team to conclude that further investigations should be carried out to test some theories concerning the behaviour of the coexistence mechanism, and characterize the properties of some aspects of the interference scenario that were not investigated earlier, in particular transparent data mode, the impact on GSM-R signalling and call establishment.

A5.1 EXPERIMENTAL RESULTS

A5.1.1 Experimental set up

The testing campaign focused on call set up and data integrity measurements in Siemens’ laboratories. Experiments with voice bearers involved the data modems with voice radios. It has to be noted that all the tests were carried out in an GSM-R network in operation but under static propagations conditions. Bearing in mind this perquisite it is clear that these tests can give no answer on the impact to GSM-R radios under moving conditions (fading, hand over, shadowing etc.) All tests were carried out mobile-to-mobile, but in doing so, it was not possible to investigate the impact of interference on the signaler-train required call setup time, but the relative impact was able to be demonstrated.

A5.1.2 Investigations

All communications were conducted between two mobile devices connected via a nearby (1.5km distant) base station (operating on the carrier 883.6 / 924.6 MHz) via antennas mounted on the roof of the Siemens building.

For each experiment, a quick initial set of measurements was used to determine the parameters that define the edge of the achievable operational envelope ie what level of interference causes services to just be interrupted, before a more detailed set of measurements determined the exact quality of the remaining services.

For data bearers, telegrams were conveyed for two minutes (allowing approximately 160 telegrams to pass) and the overall failure rate measured.

For voice bearers, TrioTrace software was used to measure the RxQual parameter.

An interfering signal similar to a SRD signal was set up modulated as FSK with deviation of 60 kHz, which gave a Tx envelope 3dB width of approximately 200kHz. The strength of the bearer was set to -70dBm to ensure that a sufficiently strong interferer could not be confused with potential fading effects which were causing the results to be inconsistent.

The interfering signal was ‘time-controlled/switched’ – ie time-domain constraints imposed - by allowing WINIQ software on a controlling laptop to set the Tx on and Tx off. For technical reasons, the interfering waveform modulation needed to change to an equivalent FM modulation whenever this software was used.

A set of measurements were carried out investigating the impact of interference on transparent mode bearers (those used to convey ETCS data).

Initially, interference from simulated single interferers was investigated. An initial set of for a variety of Tx on and duty cycle parameters are summarized below. This illustrates the envelope within which ongoing calls can coexist with a single interferer.

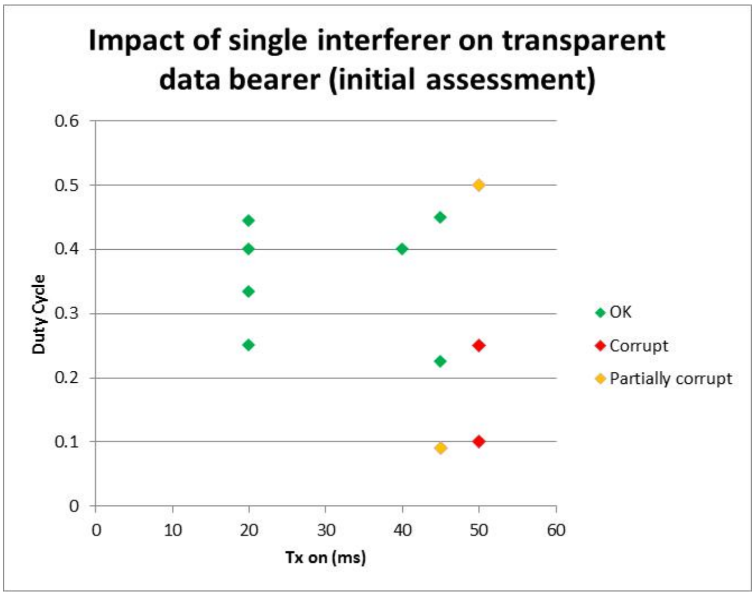


Figure 48: Impact of a single interferer on a transparent data bearer (initial assessment)

A second, more precise set of measurements was taken to examine the exact conditions under which the already established data bearer services are disrupted and the results are shown below.

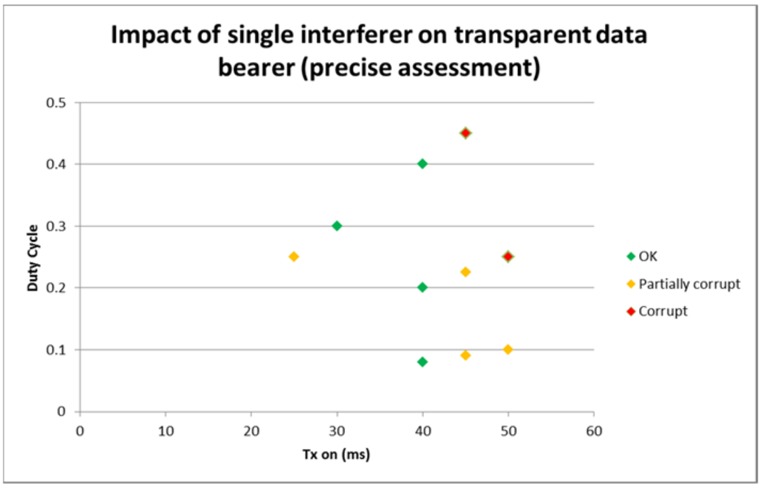


Figure 49: Impact of a single interferer on a transparent data bearer (precise assessment)

The same experiment as above was carried out, but this time the impact of interference conditions on ***call set up time*** investigated. Two sets of results were taken: a first rough set of measurements to investigate call set up success rates; and then four precise sets attempting to set up around 100 calls under each set of interference conditions.

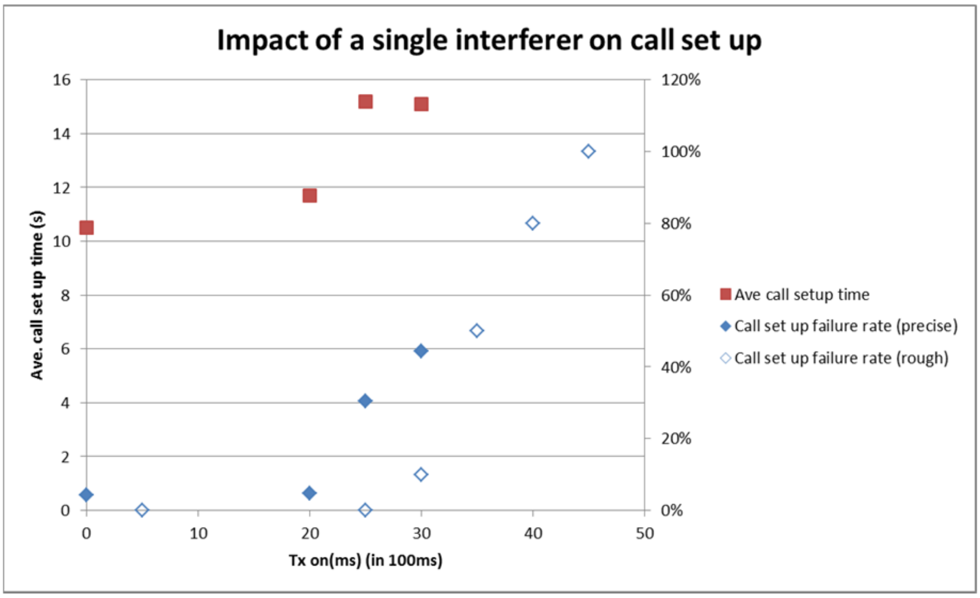


Figure 50: Impact of a single interferer on call set up

A set of further measurements were carried out investigating the impact of interference from a ***group*** of interferers to a data modem's operation. This was simulated by making the time-domain switching controller generate (pre-programmed) 5ms transmissions with a Poissonian distribution. The statistics associated with this population is summarized in the table below.

Table 69: Statistics associated with a group of interferers leading to an equivalent aggregate DC

Number of interferers	Interference Tx length (ms)	Individual device repeat time (ms)	Equivalent device DC (%)	Equivalent aggregate DC (%)
10	5	1000	0.5	≤5*
30	5	1000	0.5	≤15*
50	5	1000	0.5	≤25*

* due to a possible time overlap of uncoordinated SRD transmissions

The results of the measurements are summarized in the graph below.

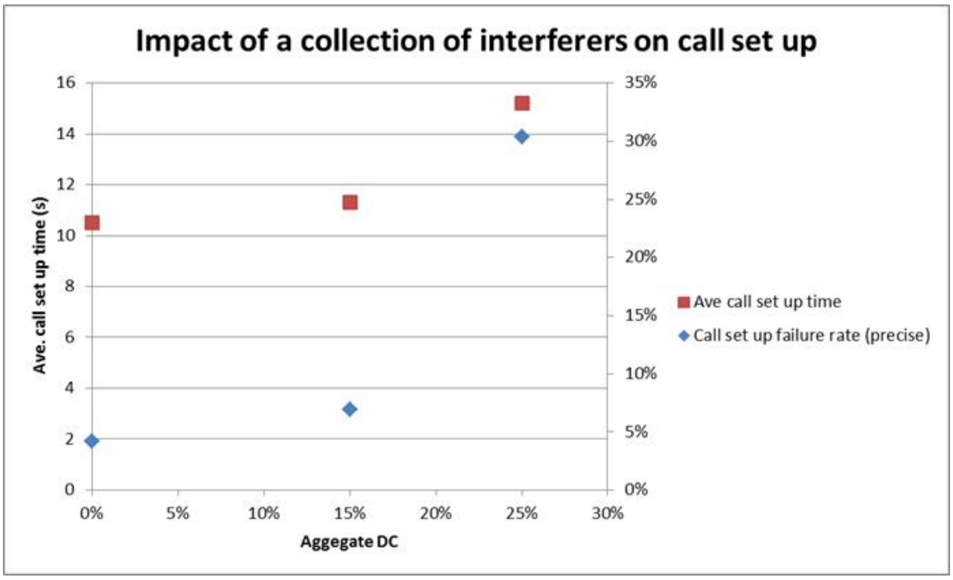


Figure 51: Impact of a collection of interferers on call set up

A set of data bearer measurements was carried out to investigate the impact of interferers in adjacent (and next adjacent) GSM channels. This was achieved by switching off the time-domain modulation (which allowed the more realistic FSK bearer to be established).

The Tx frequency of the interferer was shifted to the adjacent channel and next adjacent channel and their impact investigated on both established call data bearers and call set up times.

Detailed measurements show that the protection ratio necessary (C/I) is as shown below.

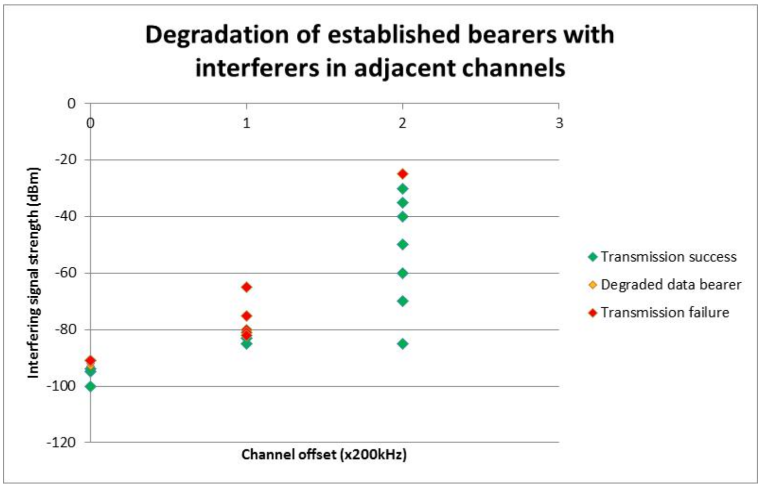


Figure 52: Detailed measurements of the impact of a 100% DC interferer in adjacent channels on bearer transmission reliability (wanted signal -91dBm)

Ten attempts were made to set up calls in the presence of an interferer of differing power in the adjacent and next adjacent channels. The results are summarized in the graph below.

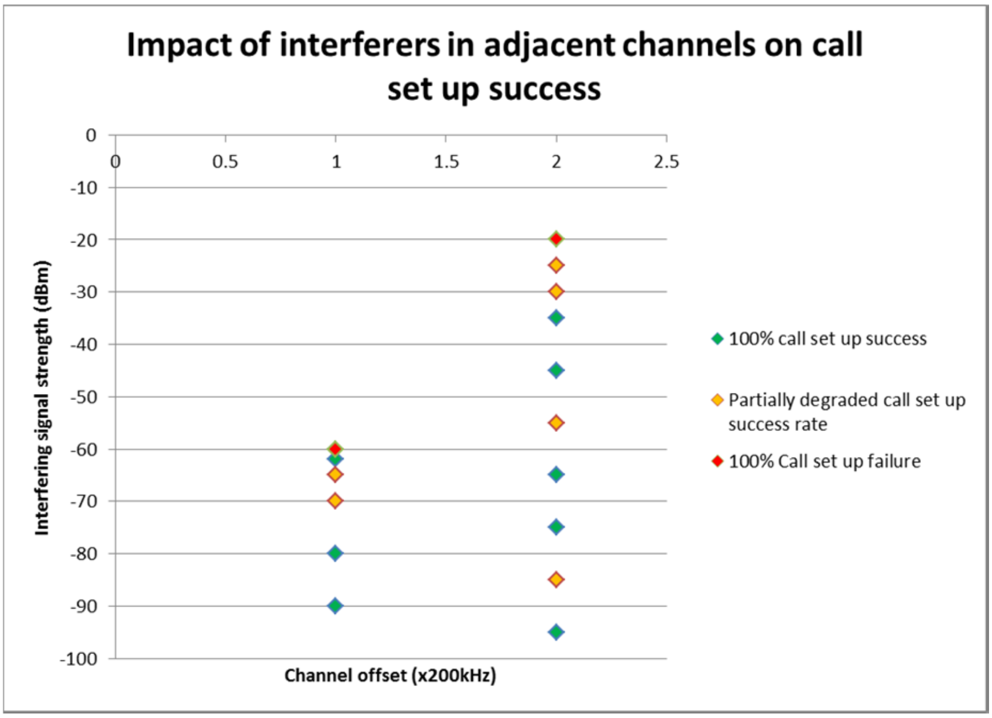


Figure 53: Detailed measurements of the impact of a 100% DC interferer in adjacent channels on call set up success (wanted signal -91dBm)

A5.1.3 Discussion

Investigations into the impact of single interferers on a GSM-R bearer victim are instructive to understand the nature of degradation caused.

Transparent bearers, protected only by interleaving and FEC (which minimises latency) can (once a call is set up) lose up to 50% of the underlying data, and withstand a maximum interferer's Tx on time of up to 45ms, indicating the excellent performance of the underlying FEC mechanism. For this particular case the resources of the GSM-R system for error recovery are to 100 % exhausted.

Simulations of aggregate interference from a population of interferers (transmitting shorter 5ms bursts), however, has allowed us to establish that aggregate duty cycle disruption of up to a value of between 15 and 25% can be withstood.

Call set up, however, is more sensitive to interference, with degradation – call set up failures - occurring for individual transmissions beyond 20ms (equivalent to 20% duty cycle) with a corresponding lengthening of successful call set ups of up to 50%. This suggests that the signalling channels used to set up calls are more vulnerable than the data channels.

Adjacent channel operation of interferers allows even 100% duty cycle so long as the strength of the interfering signal is kept to below -65dBm in order for calls to be set up, probably due to the blocking performance/dynamic range of the front end of the receiver. Next adjacent operation is possible (both call set up and data transmission) for signals as high as -25dBm, which, in effect, would allow unfettered operation of SRDs in that channel.

In summary, adjacent channel interferers (up to a duty cycle of 100%), require a protection ratio of -25dB C/I for established data calls and call set up. Interferers in ***next*** adjacent channels allow aggregate interference up to -60dB C/I for both established data calls and for call set up.

Equivalent voice measurements show that bearers can only withstand disturbances from a single interferer of up to a DC of around 10% (with single bursts up to 40ms) before the audio quality becomes operationally unacceptable. Aggregate interference measurements show that a similar total interfering DC of between 5% and 15% is tolerable when comprised of shorter bursts.

Interferers operating at 100% DC in both adjacent channel and next adjacent channels appear to have little impact on voice quality and call set up mechanisms.

These results were carried out under 'reasonable' conditions (-90dBm) lying between the extremes that would be expected at cell edges (-95 to -98dBm) and typical average (12dB less). Under more demanding conditions, the 'capacity' of the interleave/FEC mechanisms will, to a certain extent, be required to maintain the signal.

The interferences of SRD have an influence of the QoS behavior. In the case of call establishment the number of failures to establish a call grows (error rate) and also the mean-time-to-establish-a-call grows.

It should be noted that interference into mobile receivers was investigated, for technical reasons, whereas the band 873-876 MHz is anticipated to be used as the uplink (ie the factual victim shall be a base station receiver). The performed measurements, therefore, are likely to be pessimistic, because base station front ends are likely to be manufactured to a higher standard than mass market radios.

The measurements carried out as part of this campaign are, in one sense, more realistic than those carried out in Kolberg in 2009, because they involved wanted signals that have been transmitted through a realistic channel.

A5.1.4 Conclusions

Investigations into the feasibility of sharing between SRDs and GSM-R bearers have shown that generally, signaling channels seem to be more sensitive to interference in GSM-R systems than traffic channels. The impact of interference on signaling channels is to extend call set up times, which is an important requirement for railway operations.

For transparent data Bearer service 25 (TCH full-rate with 4.8 kbps), aggregate interference activity that can be withstood (both setting up calls and established bearers) into a victim operating towards the limit of its performance envelope lies between 15% and 25% (leading to extended call set times from 10s without interference to 11 seconds with 15% and 15s with 25 %,, and corresponding to 30 and 50 interferers each transmitting at 5ms every 1 second). Thus an aggregated DC limit of 15 % will be used later on to derive a long term DC limit for the protection of GSM-R (see Annex 5.2). This appears to be true irrespective of the interfering power. The impact of the duration of *individual* transmissions is inconclusive, but keeping transmissions below 20ms would appear to be sensible (leading to an extended call set time of around 1 second).

Operation (up to 100% duty cycle) in adjacent and next adjacent channels is feasible, but the protection ratio (C/I) for the former should be at most -25dB (eg -65dBm adjacent channel interferer into a victim receiving -90dBm) in order for calls to be able to be set up reliably. The protection ratio for next adjacent channel is -65dB.

For voice bearers, aggregate interference activity that can be withstood (both setting up calls and established bearers) into a victim operating towards the limit of its performance envelope lies around 10%. This appears to be true irrespective of the interfering power. Again, the impact of the duration of individual transmissions is inconclusive, but transmissions of up to 40ms appear feasible depending on the required RXQual-value and with the TXoff time set to 500 ms.

Operation (up to 100% duty cycle) in adjacent and next adjacent channels is feasible with a protection ratio of at least -65dB.

A5.2 COMPLEMENTARY MODELLING B ASED ON MEASUREMENT RESULTS

To complement the practical measurements, this section uses their data to analyse in more detail the possibilities for SRDs to operate in co-channel sharing scenarios without producing harmful interference to ER-GSM.

Based on measurements an interfering scenario of about 30 uncoordinated SRD with Ton ≤ 5 ms, Toff ≥ 995 ms, DC 0.5%/s have a QoS influence to ER-GSM with rarely call drops and can be tolerated. As an example 25mW non-specific SRD devices with deployment figures of up to 1000/km2 may coexist with E-GSM-R if a specific short term DC limit could be fulfilled (Ton ≤ 5 ms, Toff ≥ 995 ms, DC 0.5%/s). The question is how to enforce and fulfil the deployment figure.

It is expected that applications like home automation and smart metering are able to increase this deployment figures. A long term DC limit (e.g. 0.03%) on top of the short term DC limit could solve that problem. It could be imaginable to claim this long term limit only for applications where we expect high deployment figures (> 1 per household?), but it needs to be discussed if this would be enforceable.

A possibility for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the E-GSM-R bands similar like the RF-ID approach. This seems to be feasible as those devices are assumed to be installed by a service provider (e.g. for energy suppliers/smart grid) and not by the consumer.

A5.2.1 Evaluation of possibilities for SRDs in E-GSM-R bands

The results of available measurements on the required DC limitation for SRDs to protect GSM-R are summarised in the following table.

Table 70: Summary of Berlin test results

Tests	Mode	Scenario	SRD device parameters		
			Max TX on ms	DC per second	Minimum TX off ms
Berlin 2012	Transparent mode	Single SRD	25.0	15%	141.7
Berlin 2012	Transparent mode	Single SRD	25.0	25%	75.0
Berlin 2012	Voice	Single SRD	40.0	10%	360
Kolberg 2009	Voice	Single SRD	25.0	20%	100.0
Kolberg 2009	Data	Single SRD	25.0	5%	500.0
	Average	Single SRD	28.0	0.15	235.3
Berlin 2012		Multiple SRDs (30-50)	5.0	0.5%	995.0

From the single SRD measurements based on an established call, an average limit of Ton ≤ 25 ms, Toff ≥ 225 ms and DC 15% could be derived. The aggregated measurement results in 30 to 50 randomized interferers each transmitting at 5ms every 1 second shows an influence of QoS, mainly as an extension of the call establishment time. This could be seen as consistent with the single results, where 5 devices each transmitting 5ms packets every 250ms would lead to 20 devices per second.

From the view of ER-GSM a coherent Txon time >20 ms composed of all relevant SRD leads to unacceptable interferences.

In the following calculations it is assumed that:

- All SRD devices having a bandwidth of 200kHz;
- All SRD devices are choosing there channel randomly;
- All devices are transmitting with a max Ton of 5ms and a max DC of 0.5% per second per device;
- 5ms is assumed to be the lowest useable packet length for SRDs.

Based on this we derived the required DC per hour in order to get an average No of 30 devices with 5ms packets in every second within the GSM-R channel (Table 71 for non-specific SRD, Table 72 and Table 73 for specific SRDs).

A5.2.2 Non-specific SRDs

Table 71: DC limits for Non-specific SRDs

Input fields				
f/GHz	0.873	0.873	0.873	0.873
LDC definition	Rural case A	Rural case B	Urban case A	Urban case B
Tx power mW	25	25	25	25
Tx power dBm/Bwi	13.98	13.98	13.98	13.98
Receiver Bandwith BWi kHz	200	200	200	200
Available band kHz	3000	3000	3000	3000
Device density / km^2	10	10	1000	1000
No channels (Note 2)	15	15	15	15
Victim definition: GSM-R BS				
Sensitivity dBm/BWv	-104	-104	-104	-104
BWv kHz	200	200	200	200
Signal level above Sens dB	25	9	25	9
S/(I+N), dB	9	9	9	9
Feeder loss dB	3	3	3	3
Splitter loss dB	3	3	3	3
Max permissible interf dBm/BWv	-82	-98	-82	-98
Reception antenna gain dBi	18	18	18	18
Interference assessment				
Propagation exponent n (Note 1)	2.5	2.5	2.5	2.5
Additional wall loss aw dB (Note 1)	0	0	0	0
Protection distance rp, m (Note 1)	2024.72	8838.22	229.98	658.92
Impact area Ai, km^2	12.88	245.40	0.17	1.36
No of devices within Ai	129	2454	166	1364
Average no of devices per channel	9	164	11	91
Max no of devices with Ton<=5ms Dc<=0.5% per s	30	30	30	30
Average no/max no	0.29	5.45	0.37	3.03
On top of Note 2 limitation the following addition DC per h limit is required	not required	0.0917%	not required	0.1650%
For comparison: DC limit from the SRDoc	1%	1%	1%	1%

Note 1: Propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+aw

Note 2: Basic limit of Ton<=5ms and Dc<=0.5% per s

From Table 71 it can be seen that for non-specific SRDs for case A (average GSM-R signal level) only the short term limitation is required. But for case B (worst case situation, hand-over) a long term DC of 0.1% would be needed on top of the short term DC limitation (Ton ≤ 5 ms, DC 0.5%/s) to protect GSM-R.

A5.2.3 Specific SRDs

Table 72: DC limits for specific SRDs, propagation exponent 3.5

SRD (Case A average case, case B worst case)	Alarms Case A	Alarms Case B	Home automation Case A	Home automation Case B	Smart Metering Case A	Smart Metering Case B	Automotive Case A	Automotive Case B		
Input fields										
f/GHz	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87		
TX power mW	100.00	100.00	25.00	25.00	500.00	500.00	500.00	500.00		
Tx power dBm/BWi	20.00	20.00	13.98	13.98	26.99	26.99	26.99	26.99		
Receiver Bandwith BWi kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Available band kHz	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00		
Device density/km^2	12.00	12.00	50000.00	50000.00	2000.00	2000.00	80.00	80.00		
No channels (Note 2)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00		
Victim definition: GSM-R BS										
Sensitivity dBm/BWv	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00		
BWv kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Signal level above Sens dB	25.00	9.00	25.00	9.00	25.00	9.00	25.00	9.00		
S/(I+N), dB	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00		
Feeder loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Splitter loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Max permissible interf dBm/BWv	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00		
Reception antenna gain dBi	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00		
Interference assessment										
Propagation exponent n (Note 1)	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50		
Additional wall loss aw dB (Note 1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Protection distance rp, m (Note 1)	341.75	979.15	229.98	658.92	541.27	1550.80	541.27	1550.80		
Impact area Ai, km^2	0.37	3.01	0.17	1.36	0.92	7.56	0.92	7.56		
No of devices within Ai	4.40	36.14	8308.03.	68199.88	1840.79	15110.86	73.63	604.43	**Sum Case A**	**Sum Case B**
Average no of devices per channel	0.29	2.41	553.87	4546.66	122.72	1007.39	4.91	40.30	681.79	5596.75
Max no devices with Ton<=5ms and Dc<=0.5% per s	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	31.00
Average no/max no	0.01	0.08	18.46	151.56	4.09	33.58	0.16	1.34	22.73	180.54
On top of Note 2 limitation on the following addition DC per h limit is required	**Not required**	**Not required**	**0.0271%**	**0.0033%**	**0.1222%**	**0.0149%**	**Not required**	**0.3722%**	**0.0220%**	**0.0028%**

Note 1: Propagation model PL= 32.5DB+20log(f/GHz)+n*10*log(r/m)+aw
Note 2: Basic limit of Ton<=5ms and Dc<=0.5% per s

Table 73: DC limits for specific SRDs, propagation exponent 2.5 plus 10dB wall loss

SRD (Case A average case, case B worst case)	Alarms Case A	Alarms Case B	Home automation Case A	Home automation Case B	Smart Metering Case A	Smart Metering Case B	Automotive Case A	Automotive Case B		
Input fields										
f/GHz	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87		
TX power mW	100.00	100.00	25.00	25.00	500.00	500.00	500.00	500.00		
Tx power dBm/BWi	20.00	20.00	13.98	13.98	26.99	26.99	26.99	26.99		
Receiver Bandwith BWi kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Available band kHz	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00		
Device density/km^2	12.00	12.00	50000.00	50000.00	2000.00	2000.00	80.00	80.00		
No channels (Note 2)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00		
Victim definition: GSM-R BS										
Sensitivity dBm/BWv	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00		
BWv kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Signal level above Sens dB	25.00	9.00	25.00	9.00	25.00	9.00	25.00	9.00		
S/(I+N), dB	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00		
Feeder loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Splitter loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Max permissible interf dBm/BWv	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00		
Reception antenna gain dBi	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00		
Interference assessment										
Propagation exponent n (Note 1)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50		
Additional wall loss aw dB (Note 1)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00		
Protection distance rp, m (Note 1)	1403.42	6126.16	806.05	3518.56	2671.63	11662.10	2671.63	11662.10		
Impact area Ai, km^2	6.19	117.90	2.04	38.89	22.42	427.27	22.42	427.27		
No of devices within Ai	74.25	1414.84	102058.48	1944684.24	44846.97	854541.35	1793.88	34181.65	**Sum Case A**	**Sum Case B**
Average no of devices per channel	4.95	94.32	6803.90	129645.62	2989.80	56969.42	119.59	2278.78	9918.24	188988.14
Max no devices with Ton<=5ms and Dc<=0.5% per s	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	31.00
Average no/max no	0.17	3.14	226.80	4321.52	99.66	1898.98	3.99	75.96	330.61	6096.39
On top of Note 2 limitation on the following addition DC per h limit is required	**Not required**	**0.15903%**	**0.00220%**	**0.00012%**	**0.00502%**	**0.00026%**	**0.12543%**	**0.00658%**	**0.00151%**	**0.00008**

Note 1: Propagation model PL= 32.5DB+20log(f/GHz)+n*10*log(r/m)+aw
Note 2: Basic limit of Ton<=5ms and Dc<=0.5% per s

For specific SRDs as in Table 72 and Table 73 the situation is more critical as for non-specific SRDs, as much higher deployment figures and higher power levels are assumed for some applications. This mix of applications would require a very low long term DC limit for most applications on top of the short term limit (e.g. for case A below 0.03% for home automation and below 0.1% for smart metering).

For some specific applications there are possibilities with the short term limit and without any additional long term DC restrictions (e.g. alarms, automotive). In the following we are trying to select different combinations of applications with different assumptions.

A5.2.4 Alarms and automotive

Table 74: DC limits for specific SRDs with changed parameters, propagation exponent 3.5

SRD (Case A average case, case B worst case)	Alarms Case A	Alarms Case B	Home automation Case A	Home automation Case B	Smart Metering Case A	Smart Metering Case B	Automotive Case A	Automotive Case B		
Input fields										
f/GHz	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87		
TX power mW	100.00	100.00	25.00	25.00	500.00	500.00	500.00	500.00		
Tx power dBm/BWi	20.00	20.00	13.98	13.98	26.99	26.99	26.99	26.99		
Receiver Bandwith BWi kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Available band kHz	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00		
Device density/km^2	12.00	12.00	0.00	0.00	0.00	0.00	80.00	80.00		
No channels (Note 2)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00		
Victim definition: GSM-R BS										
Sensitivity dBm/BWv	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00		
BWv kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Signal level above Sens dB	25.00	9.00	25.00	9.00	25.00	9.00	25.00	9.00		
S/(I+N), dB	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00		
Feeder loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Splitter loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Max permissible interf dBm/BWv	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00		
Reception antenna gain dBi	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00		
Interference assessment										
Propagation exponent n (Note 1)	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50		
Additional wall loss aw dB (Note 1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Protection distance rp, m (Note 1)	341.75	979.15	229.98	658.92	541.27	1550.80	541.27	1550.80		
Impact area Ai, km^2	0.37	3.01	0.17	1.36	0.92	7.56	0.92	7.56		
No of devices within Ai	4.40	36.14	0.00	0.00	0.00	0.00	73.63	604.43	**Sum Case A**	**Sum Case B**
Average no of devices per channel	0.29	2.41	0.00	0.00	0.00	0.00	4.91	4030	5.20	42.71
Max no devices with Ton<=5ms and Dc<=0.5% per s	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	31.00
Average no/max no	0.01	0.08	0.00	0.00	0.00	0.00	0.16	1.34	0.17	1.38
On top of Note 2 limitation on the following addition DC per h limit is required	**Not required**	**Not required**	**Not required**	**Not required**	**Not required**	**Not required**	**Not required**	**0.3722%**	**Not required**	**0.3630%**

Note 1: Propagation model PL= 32.5DB+20log(f/GHz)+n*10*log(r/m)+aw
Note 2: Basic limit of Ton<=5ms and Dc<=0.5% per s

In this case only the short term DC would be required.

A5.2.5 Reduced power for alarms, smart metering and automotive

Table 75: DC limits for specific SRDs with changed parameters, propagation exponent 3.5

SRD (Case A average case, case B worst case)	Alarms Case A	Alarms Case B	Home automation Case A	Home automation Case B	Smart Metering Case A	Smart Metering Case B	Automotive Case A	Automotive Case B		
Input fields										
f/GHz	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87		
TX power mW	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00		
Tx power dBm/BWi	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98		
Receiver Bandwith BWi kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Available band kHz	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00		
Device density/km^2	12.00	12.00	50000.00	50000.00	2000.00	2000.00	80.00	80.00		
No channels (Note 2)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00		
Victim definition: GSM-R BS										
Sensitivity dBm/BWv	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00	-104.00		
BWv kHz	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00		
Signal level above Sens dB	25.00	9.00	25.00	9.00	25.00	9.00	25.00	9.00		
S/(I+N), dB	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00		
Feeder loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Splitter loss dB	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Max permissible interf dBm/BWv	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00	-82.00	-98.00		
Reception antenna gain dBi	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00		
Interference assessment										
Propagation exponent n (Note 1)	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50		
Additional wall loss aw dB (Note 1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Protection distance rp. m (Note 1)	229.98	658.92	229.98	658.92	229.98	658.92	229.98	658.92		
Impact area Ai, km^2	0.17	1.36	0.17	1.36	0.17	1.36	0.17	1.36		
No of devices within Ai	1.99	16.37	8308.03	68199.88	332.32	2728.00	13.29	109.12	**Sum Case A**	**Sum Case B**
Average no of devices per channel	0.13	1.09	553.87	4546.66	22.15	181.87	0.89	7.27	577.04	4736.89
Max no devices with Ton<=5ms and Dc<=0.5% per s	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	31.00
Average no/max no	0.00	0.04	18.46	151.56	0.74	6.06	0.03	0.24	19.23	152.80
On top of Note 2 limitation on the following addition DC per h limit is required	**Not required**	**Not required**	**0.0271%**	**0.0033%**	**Not required**	**0.0825%**	**Not required**	**Not required**	**0.0250%**	**0.0033%**

Note 1: Propagation model PL= 32.5DB+20log(f/GHz)+n*10*log(r/m)+aw
Note 2: Basic limit of Ton<=5ms and Dc<=0.5% per s

Here the Tx power of all applications was reduced to 25mW in order to show a mix of non-specific regulated SRD devices. Here only for home automation and smart metering (only for case B) a long term limit would be needed; it could be imaginable to restrict only for applications where we expect high deployment figures the long term DC to say 0.03% (on top of the short term DC limit). It needs to be discussed if this could be claimed in the regulation.

A possibility for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the E-GSM-R bands. This seems to be feasible as those devices are assumed to be installed by a service provider (e.g. for energy suppliers/smart grid) and not by the consumer.

A5.2.6 Deployment figures and the environmental context

The analysis for non-specific SRDs is provided with a range of deployment figures (low values in rural areas, and high values in urban areas). For the specific SRDs only one deployment assumption is taken in the current report. But especially the assumptions for home automation and smart metering are only valid in urban areas. The following table taken from SE24 document M69_15R1 shows the correlation between density and environment.

Table 76: SRD densities and corresponding area

Scenario	Maximum meter density (/km^2)	Percentage of land area*
Dense urban	2.000	6%
Urban average (including dense urban)	600	20.9%
Rural	92	79.1%

* based on UK figures

The probability of having the dense urban SRDs at the same location where GSM-R is deployed depends also on the percentage of railway deployment over the land area. The next tables show the probability of occurrence for different assumptions.

Table 77: Probability of occurrence for railway in general

Scenario	Maximum meter density (/km^2)	Percentage of land area*	Percentage of railway area	Composite probability of encountering railways
Dense urban	2,000	6%	5%	0.3%
Urban average (including dense urban)	600	20.9%	5%	1%
Rural	92	79.1%	5%	3.9%

Table 78: Probability of occurrence for E-GSM-R

Scenario	Maximum meter density (/km^2)	Percentage of land area*	Percentage of railway area	Composite probability of encountering railways
Dense urban	2,000	6%	1%	0.06%
Urban average (including dense urban)	600	20.9%	1%	0.2%
Rural	92	79.1%	1%	0.78%

This information would be important to consider when evaluating the potential impact of interference to ER-GSM.

A5.2.7 Summary for co-channel sharing between SRD and ER-GSM

There may be some possibilities for 25mW non-specific SRD devices with deployment figures of up to 1000/km^2 to coexist with ER-GSM if a specific short term DC limit could be fulfilled (Ton≤ 5 ms, Toff ≥ 995 ms, DC 0.5%/s). A small risk of interference remains at the hand-over region of ER-GSM, for the case that these 1000 devices per km^2 are deployed around the ER-GSM base station. An additional long term DC limit of 0.1% could solve that problem.

The assumed mix of specific SRD applications is more critical, as much higher deployment figures and higher power levels are assumed for some applications. This mix of applications would require a very low long term DC limit for most applications on top of the short term limit (e.g. below 0.03%). For some specific applications there are possibilities with the short term limit and without any additional long term DC restrictions (e.g. alarms, automotive) due to the expected low deployment figures. If the uniform density and other parameters could be changed for the mix of specific applications (especially home automation and smart metering applications), then there may be a possibility for all applications.

If the Tx power for all SRD applications would be reduced to 25mW, then only for home automation and smart metering a long term limit would be needed. This scenario reflects a mix of non-specific SRDs and is consistent with the non-specific scenario above, as both shows a possibility up to certain deployment figures.

For devices with high deployment figures it could be imaginable to restrict only for applications where we expect high deployment figures (í.e. more than 1 per household) the long term DC of around 0.03% (on top of the short term DC limit). It needs to be discussed if this could be claimed in the regulation.

It should be noted that all simulations heavily rely on the SRD device density assumptions. Since administrations would have no opportunity to control the practical deployment densities of SRDs in the real life, this means that the above conclusion are conditional on the understanding that the ETSI and industry predicted long term SRD deployment densities are well justified.

A possibility for higher power applications could be a coordination procedure with the railway operator or a cognitive procedure in order to avoid the E-GSM-R bands. This seems to be feasible as those devices are assumed to be installed by a service provider (e.g. for energy suppliers/smart grid) and not by the consumer. Additional cognitive approach, like solution by the RFID could allow higher device densities in areas with ER-GSM deployment.

ANNEX 6: DETAILS OF STUDY ER-GSM AND RFID COMPATIBILITY.

A6.1 DESCRIPTION OF CO-EXISTENCE SCENARIO 915-921 MHz

In this case the proposed SRD & RFID applications would have to co-exist with ER-GSM deployment in the frequency band 918-921 MHz (downlink). The co-existence scenario would be somewhat similar to the case of SRD vs. ER-GSM in the 870-876 MHz band, except that in this case the direction of interference paths would be different (directed towards ER-GSM mobile station receivers). Also the different types of SRD/RFID devices and their applications might lead to significant differences in their deployment. This situation is illustrated in the figure below (Note that for simplicity only two units and two types of SRD/RFID devices are shown).

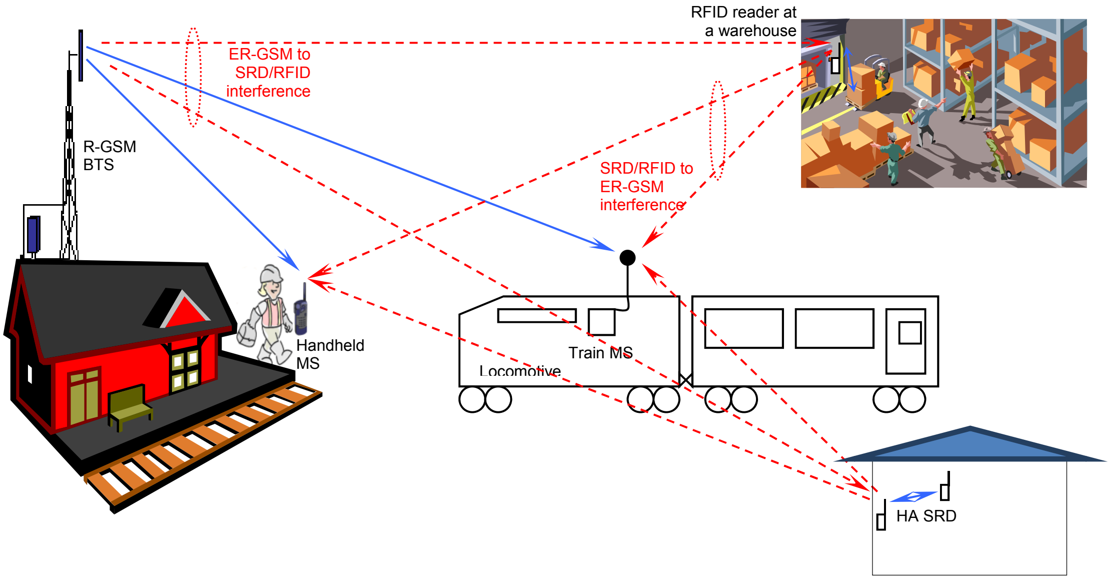


Figure 54: In-band SRD/RFID vs. ER-GSM co-existence: wanted and interfering paths in 918-921 MHz

This means that the following two interference directions and cases should be studied:

Multiple SRD/RFIDs to ER-GSM MS Rx
ER-GSM BTS Tx to SRD/RFID Rx in ER-GSM cell

The geographic representation of the co-existence scenario will be identical to the one described for SRD vs. ER-GSM in the 870-876 MHz band, see Figure 8.

A6.1.1 The impact of RFID on ER-GSM without mitigation techniques 915-921 MHz

A6.1.1.1 Lessons from ETSI TR 101 537

The results of a co-existence test between ER-GSM and RFID are described in ETSI TR 101 537 V1.1.1 (2011-02) [11]. These tests were undertaken at the BNetzA Test Laboratory at Kolberg to determine the parameters necessary to permit RFID to share the band 918 MHz to 921 MHz with ER-GSM.

During the tests it was possible to monitor the interference threshold of the ER-GSM receiver using the RxQual level. An RxQual level of 0 indicated a perfect connection while a level of 7 showed that the connection was broken. The tests showed that there was a sharp knee of only a 1 dB change between a good connection and one which failed. For the tests the interference threshold was determined by increasing the interference power until the level at the ER-GSM device dropped to a value of 2.

Three wanted power levels were used for the measurements:

Cab low power -96 dBm.
Cell edge -86 dBm
Good link -76 dBm.

Figure 55: below shows the max acceptable interference power vs frequency offset at the ER-GSM mobile, which was the main purpose of the campaign.

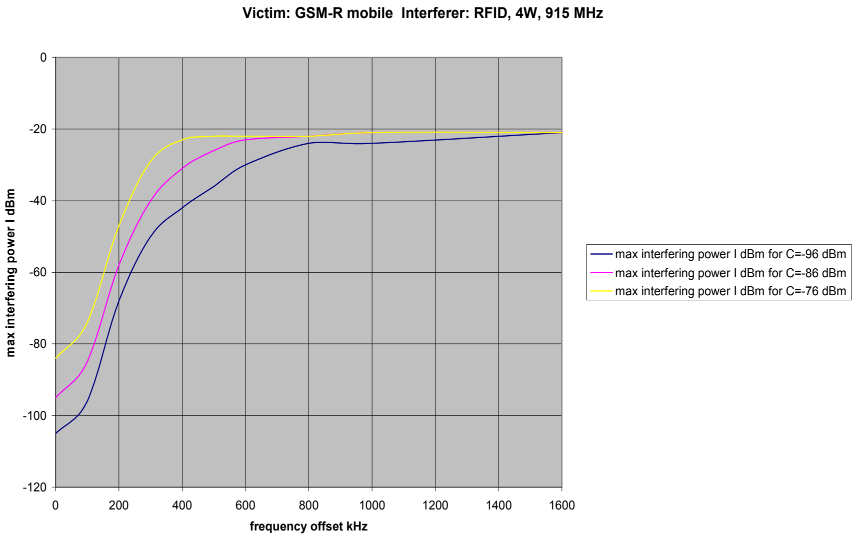


Figure 55: Main results of ETSI TR 101 537: max acceptable interference power at ER-GSM receiver

These tests showed that a minimum frequency offset of 700 kHz between the centre of the R-GSM channel and the centre of the RFID channel would be necessary, and confirmed the results of measurements taken previously in June 2009. This means that if an interrogator detects an ER-GSM channel with a power above a certain limit, the interrogator should use a channel with a centre frequency which is at least 700 kHz away from the centre frequency of the detected ER-GSM channel. For RFID channel planning this means that the highest RFID channel should be at least 700 kHz below the centre frequency of the lowest existing R-GSM channel of 921.2 MHz. This equates to a centre frequency for the RFID system of 920.5 MHz.

The 700 kHz frequency offset was not affected by variations in the channel width or depth of modulation of the RFID interrogator. This means that an RFID Interrogator cannot influence the required offset frequency of 700 kHz. A more stringent RFID spectrum mask will not improve the 700 kHz spacing of the channels, because the 700 kHz spacing is dependent on the filter width and filter steepness of the R-GSM receivers.

The test confirmed that RFID interrogators, which maintain a 700 kHz frequency offset from an operational R-GSM, cannot cause interference to it provided the RFID interrogator is more than 20 m away from the R-GSM terminal. The test *also* showed that it is useful to implement a 100 kHz offset between the ER-GSM channels and the RFID channels because this adds an additional mitigation factor of around 9 dB independent of the deployed RFID channel bandwidth (200 kHz and 400 kHz). This result is important for the further discussion related to the channelization.

The measured protection levels in the tests in which R-GSM was the victim represent worst-case scenarios (voice mode). R-GSM terminals in idle mode require between 5 and 10 dB lower protection levels. This should be considered in further discussion of the protection level for the different ER-GSM protection models.

As in the tests in June 2009, it was again possible to generate IM3 products. One test showed that the interrogator did not generate the IM3 products, which interfered with the R-GSM system. This means that a stringent IM3 test in the relevant RFID standards will not improve the level of mitigation for the co-existence of R-GSM and RFID.

Assuming that the current GSM band below 915 MHz uses 200 kHz channels (centre frequency at 914.8 MHz) and based on the presented measurement results, RFID transmit channels can be placed at a minimum frequency separation between the GSM centre frequency and the RFID systems centre frequency of 800 kHz. This means that the first RFID channel could be placed above 915.6 MHz.

A6.1.1.2 Consequences of the Kolberg measurements

Based on the protection criteria derived as a result of *the* Kolberg measurements (see Figure 55:), the next two figures show respectively the corresponding protection distances for 4 W RFID interrogators under line of sight condition (LOS), and under NLOS condition (propagation exponent 3).

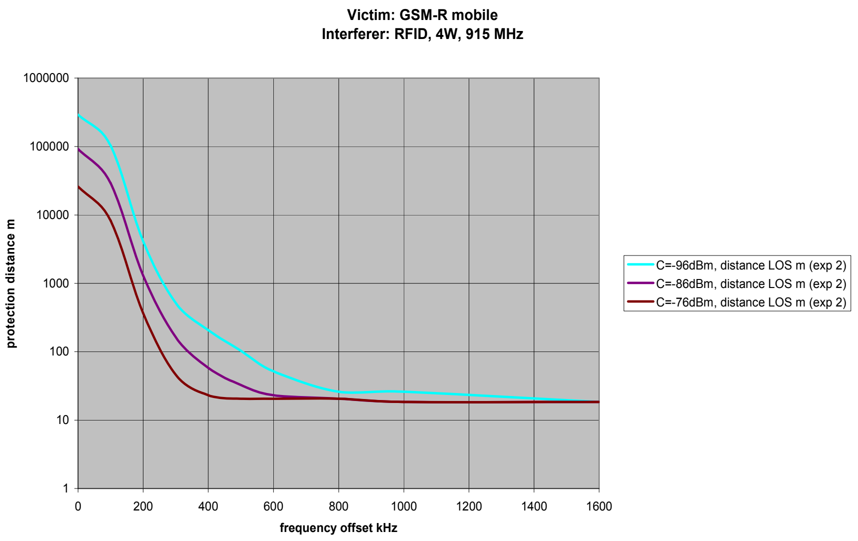


Figure 56: Protection distance between RFID interrogator and ER-GSM mobile under LOS conditions

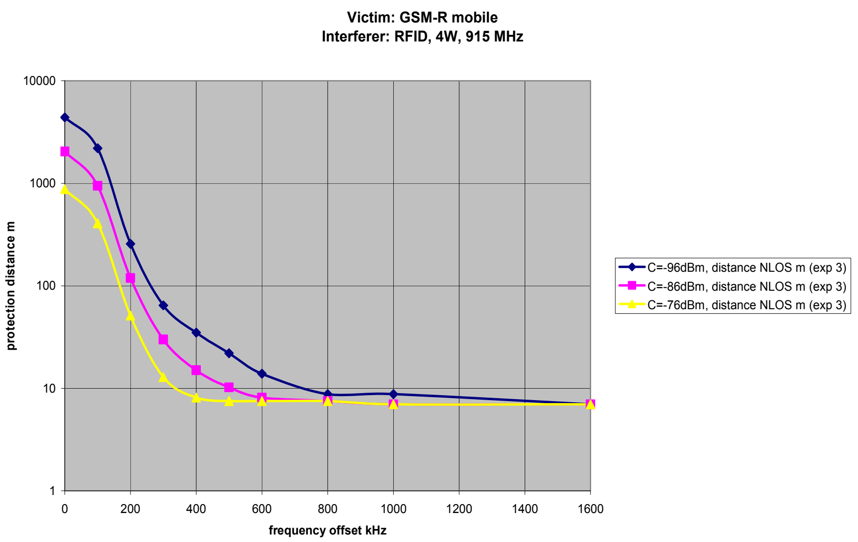


Figure 57: Protection distance between RFID interrogator and ER-GSM mobile under NLOS conditions

Figure 58: shows the protection distances for RFID tags with a Tx power of -15/200 kHz dBm (-18 dBm/100 kHz) under line of sight condition (LOS), and Figure 50 under NLOS conditions (propagation exponent 3). Due to the wider Tx mask of the RFID tags and the fact that the tag responds passively to the request from the interrogator (that means around the same frequency as the interrogator) only the co-channel results are applicable (frequency offset = 0).

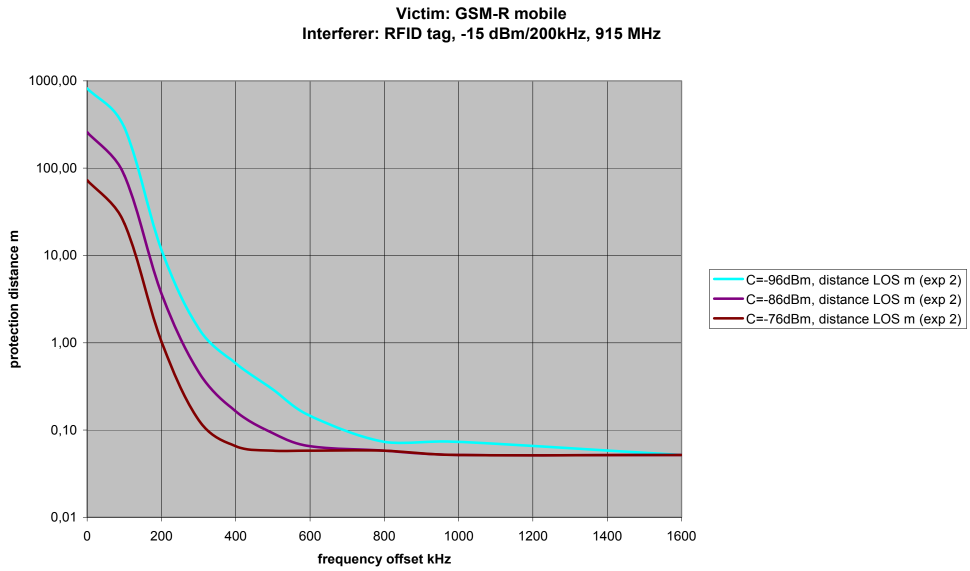


Figure 58: Protection distance between RFID tags and ER-GSM mobile under LOS conditions

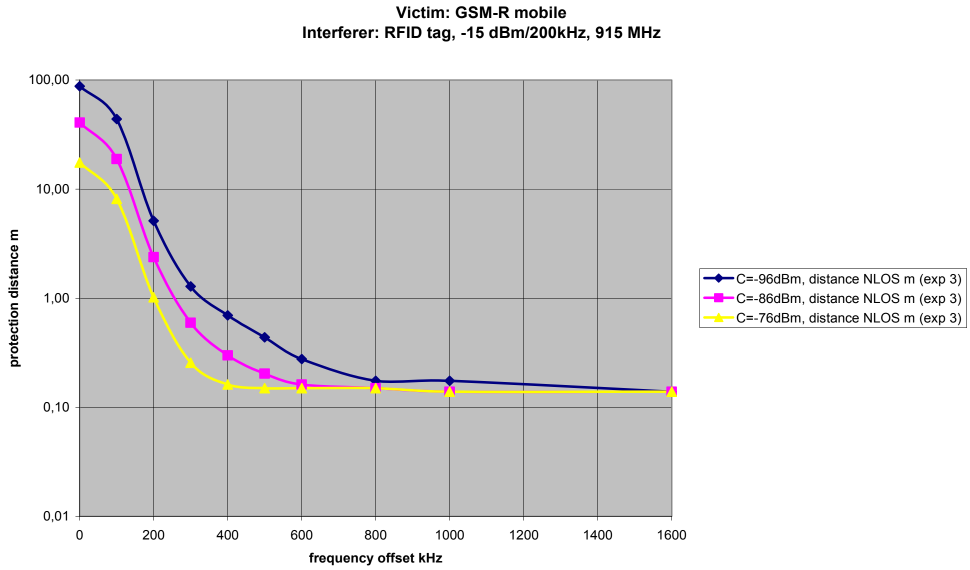


Figure 59: Protection distance between RFID tags and ER-GSM mobile under NLOS conditions

The response of –15 dBm/200 kHz from the tag represents the very maximum that is achievable when it is mounted in free space at close proximity to and in optimum orientation with respect to the interrogator. Where a tag is in a non-preferred orientation or operating at a greater range, the strength of its response will be less. Furthermore in normal use tags are attached to the items that are to be identified. Depending on the nature of the particular item, the response from the tag may be reduced either due to mistuning or absorption. Also in practice the majority of RFID applications take place indoors. In typical operation therefore only a very small number of tags will ever transmit outdoors at the maximum permitted value.

Furthermore for a normal read operation of a single tag in the band 915-921 MHz the whole cycle is completed within approximately 2 ms with the tag reply taking approximately 0.5 ms. In a situation where multiple tags are read the time taken to read the first tag is 2 ms and the time to read all subsequent tags is 1 ms. In this latter scenario the transmit time of each tag is 0.3 ms or less, depending on the encoding format.

A6.1.1.3 Conclusions on RFID vs. ER-GSM co-existence without mitigation techniques

Summarising the material presented in this section, for a protection criterion SIR of 0 dB, 100 kHz offset between RFID and the ER-GSM channels and a minimum signal level of -86 dBm at the ER-GSM mobile, the following conclusions may be reached

Co-channel operation of the ***RFID interrogators*** and the ER-GSM downlink in the band ***918-921 MHz*** should be avoided due to the large protection distances required:

- for non-specific outdoor 4 W RFIDs between 400m (NLOS conditions, propagation exponent 3.5) and up to 30 km (LOS conditions);
- for handheld indoor 1W RFIDs between 150m (NLOS conditions, propagation exponent 3.5) and up to 5 km (LOS conditions);
- for low power indoor 500 mW RFIDs between 80m (NLOS conditions, propagation exponent 3.5) and up to 2.5 km (LOS conditions);

For the protection of ER-GSM mobiles from ***RFID interrogators*** a frequency offset of ≥ 700kHz is required assuming a separation distance of more than 20m;

The avoidance procedure for ***RFID interrogators*** should be specified:

- Manually (e.g. just the bands below 918 MHz to be used);
- Or a dynamic DAA where the threshold levels and the timing should be specified;
- This is further studied in the next section;

For the protection of ER-GSM mobiles from ***RFID tags*** the following protection distances are necessary:

- for outdoor Tags between 40 m (NLOS conditions, propagation exponent 3.5) and 260 m (LOS conditions);
- for indoor Tags between 20 m (NLOS conditions, propagation exponent 3.5) and 80 m (LOS conditions);
- In a multiple tag scenario, the average power transmitted by an RFID tag over its interrogation cycle is one third of its maximum value, which corresponds to a reduction of 4.8 dB. Since the maximum possible power from a tag while transmitting is -15 dBm/200 kHz, its average power over an interrogation cycle will be -19.8 dBm/200 kHz. This equates to a reduction in the worst case protection distances of approximately 60% of the values shown above.
- This may be seen as acceptable as the use of this application is predominantly indoor;

There is no impact from the proposed two RFID channels in the band 915-918 MHz (916.*3* and 917.*5* MHz) on ER-GSM mobiles. Furthermore the 3 upper ER-GSM channels in the 918 – 921 MHz band are also free from interference from RFID. However, the impact on other services in this band should be analysed (e.g. tactical radio relay, UAS) before this band can be seen as “interference free”;

No harmful interference is expected to the GSM band below 915 MHz due to the frequency separation;

In the following both an analysis of the effectiveness of the DL detection and a SEAMCAT simulation are provided.

A6.1.2 The impact of RFID on ER-GSM with mitigation techniques

From the previous section it follows that RFID needs to avoid any co-channel interference in the ER-GSM band 918-921 MHz. Proposals for the avoidance procedure are provided in an updated version of ETSI TS 102 902 V1.2.2, which was adopted by ETSI TC ERM for publication in November 2012. Additionally the results of a demonstration of principal of the mitigation technique are described in ETSI TS 102 903 V1.1.1 (2011-08) [12]. The latter document also describes the various compliance tests necessary to verify proper operation of the proposed mitigation technique for inclusion in an ETSI standard.

Subsequently the effectiveness of the avoidance procedure was investigated in a series of tests using modified interrogators (demonstrators) that incorporated the proposed mitigation technique. Preliminary tests were performed at a test house in Kolleda that was equipped with GSM-R mobile radios and base stations. The demonstrators were subjected to a series of scenarios as defined in a test plan that were designed to show whether the mitigation technique performed as intended. The results from the tests verified that the technique behaved correctly.

The preliminary tests were followed by a trial at Wiesbaden Hauptbahnhof where GSM-R is in continuous use. Two demonstrators were set up close to platforms where there was frequent movement of trains. The demonstrators were again subjected to a set of scenarios similar to those at Kolleda. The outcome of the tests was satisfactory and demonstrated that the mitigation technique would allow RFID to share the spectrum with ER-GSM without causing unacceptable levels of interference. Full details of the preliminary tests and the trail are available in TR 101 602 [20].

The ideas from ETSI TS 102 902 [12]. In the short term regulatory methods may be used in order to allow operators of RFID systems a simple way to occupy the new band (915-921 MHz). In particular the band 915-918 MHz will be of special interest since *use of the two RFID high power channels* may give interference free operation with ER-GSM. In the medium term active mitigation techniques should be implemented in RFID systems. This will permit more flexible deployment across *the entire* new band without adding interference risks to potential victim systems sharing the band.

An illustration of the coexistence strategy presented in TS 102 902 is given in the following Figure.

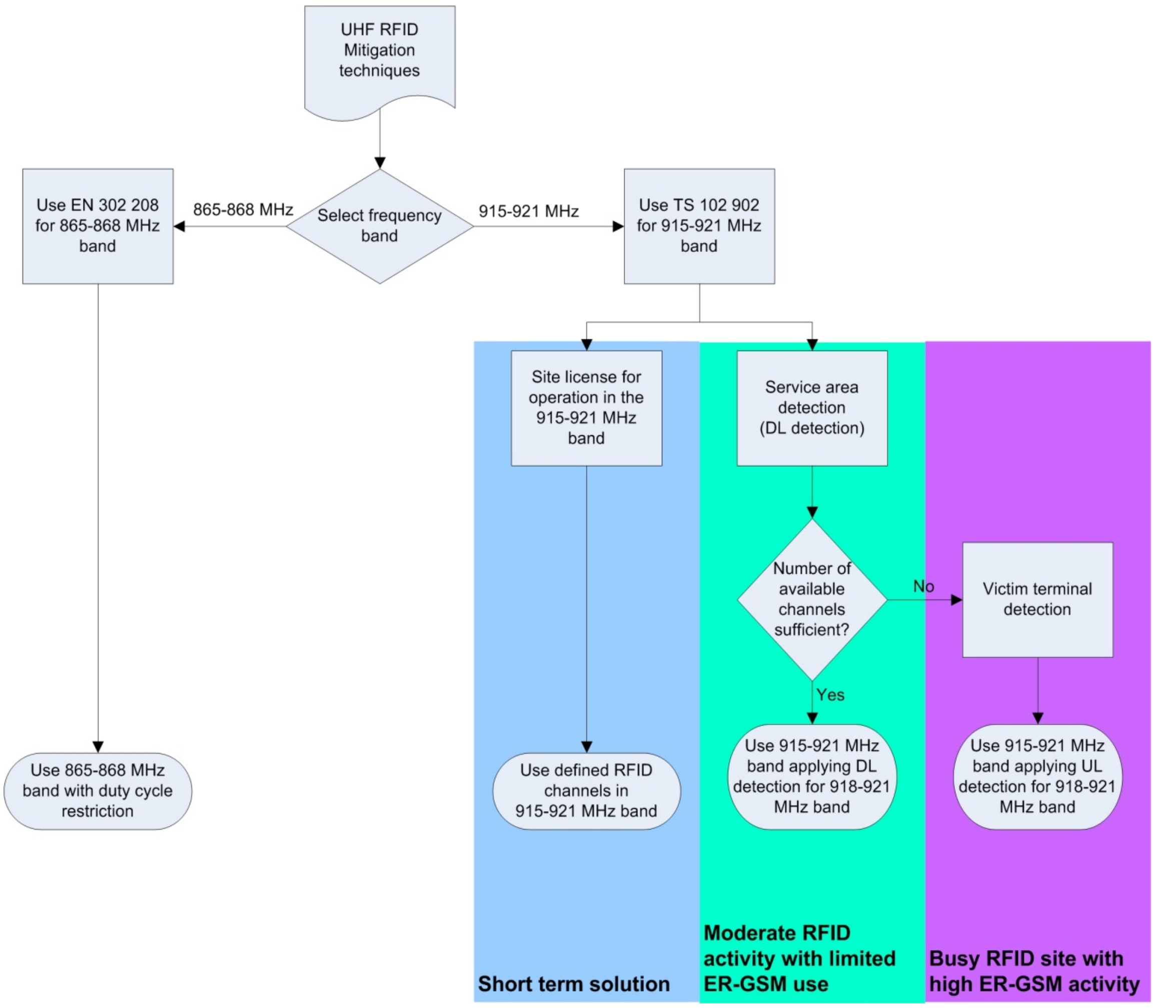


Figure 60: Overall coexistence strategy between ER-GSM and RFID

For the foreseeable future it is anticipated that the deployment of ER-GSM will be restricted to a few very busy sites. Under these circumstances it is expected the users of RFID will achieve acceptable performance by implementation of the mid-term solution described in Figure 60:. It will only be necessary to implement the "long term solution" if ER-GSM is deployed across most railway tracks.

A6.1.2.1 Site licensing and coordination with ER-GSM operators 915-921 MHz

The so called "site licensing" proposal is presented in TS 102 902 [7] and TS 102 903 [12] for operation in the short term. Here the avoidance of the ER-GSM downlink channels will be enforced by a practical coordination procedure between the Administration and the ER-GSM and RFID operators. This is seen as a feasible solution.

A kind of "light licensing" is proposed in the mid-term. Here access by RFID interrogators to the channel allocations transmitted regularly by the BCCH will make it possible to avoid any interference to ER-GSM. Responsibility for avoidance of interference with ER-GSM will therefore rest with the RFID operators. A similar proposal is documented in ECC Report 167 [37] ("Practical implementation of registration/coordination mechanism for UWB LT2 systems") and a regulatory proposal is given in ECC/REC/(11)09 [36].

This procedure is imaginable and is definitely an option in the future as it is similar to cognitive radio. However it is not expected to be commercially available in less than two years.

A6.1.2.2 ER-GSM Downlink detection 915-921 MHz

The idea of downlink and uplink detection is illustrated in the following Figure.

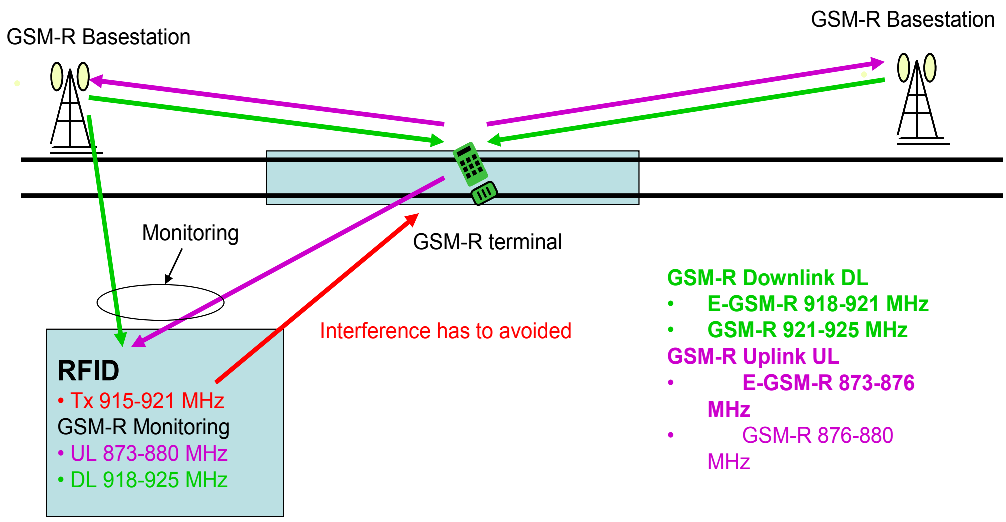


Figure 61: Illustration of concept of spectrum sensing by RFID

As illustrated in the flow diagram below, interrogators will monitor the BCCH messages transmitted by the BTS. By decoding the content of the BCCH messages it will be possible, in almost all situations, for interrogators to assign channels that will avoid interference to ER-GSM.

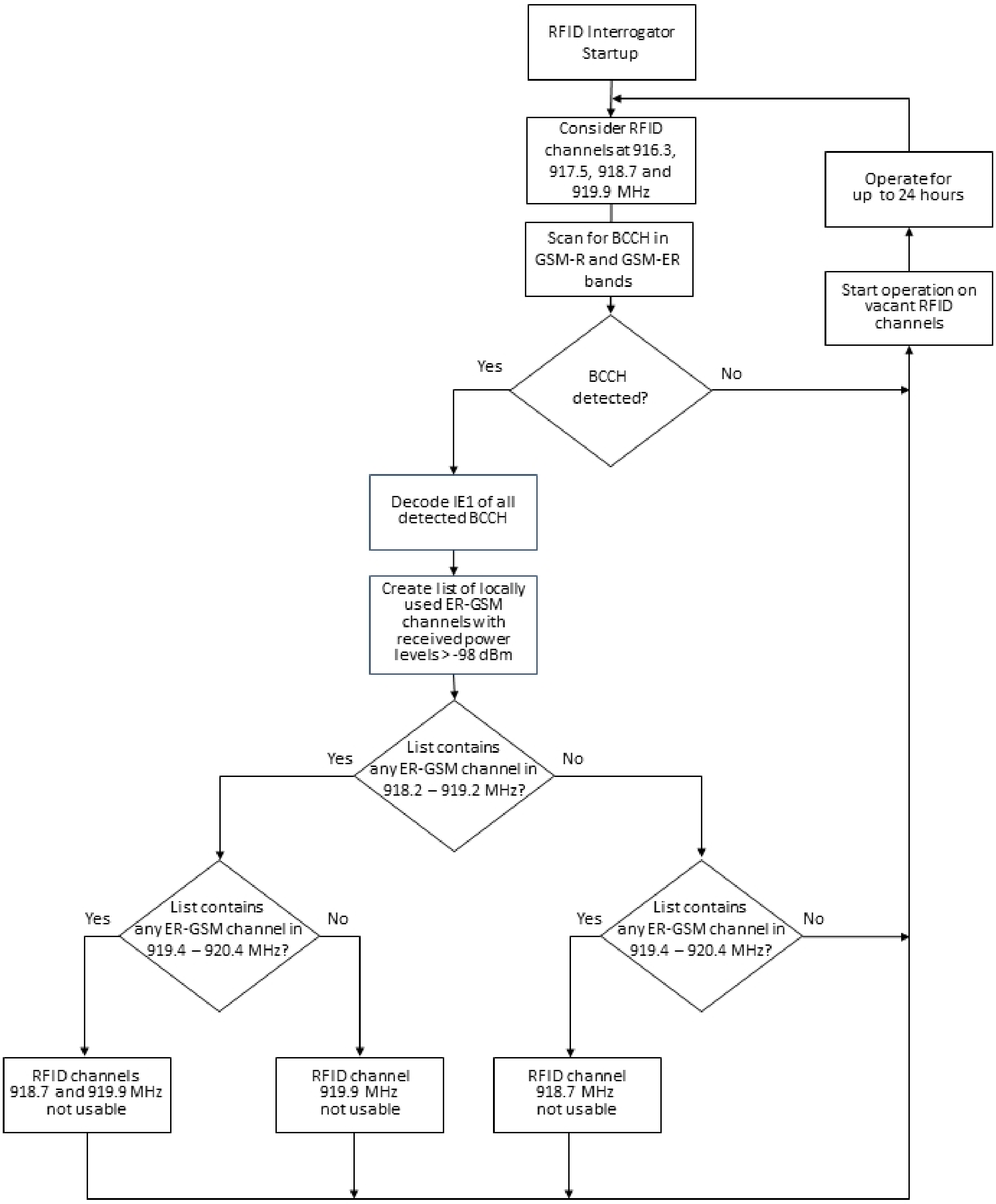


Figure 62: GSM-R Downlink detection for ER-GSM band and RFID DAA process

To permit sharing of the band 918-921 MHz, interrogators will scan all downlink channels used by ER-GSM and R-GSM for BCCH and TCH transmissions. BCCH and TCH channels require the same protection although TCH channels are only temporarily allocated while, once configured, BCCH channels are assigned permanently.

Scanning for BCCH or TCH channels will take place immediately an interrogator is initialised and before it starts to transmit. Thereafter, assuming the interrogator is permanently switched on, scanning for a BCCH channel will be repeated at least once every 24 hours. The detection threshold at the antenna of the interrogator shall be 38.5 dBµV/m (equivalent to -98 dBm at the antenna port) at the centre frequency of the ER-GSM or R-GSM channel. This is the minimum signal level specified for coverage of non-high-speed railway tracks (see [i.15]).

The RFID interrogator shall scan the entire (E)R-GSM downlink band (918-924 MHz) for BCCH transmissions. The RFID interrogator shall successfully receive and decode every BCCH transmission above the threshold level. The message of relevance within the Broadcast Channel is the SYSTEM INFORMATION TYPE 1 (See Section 9.1.31 of 3GPP TS 44.018 [i.13]) message containing the Cell Channel Description IE.

From the received information corresponding to the BCCH Cell Channel Description IE, the RFID interrogator shall create a list of all ARFCN used by (E)R-GSM in the local area of operation.

An interrogator shall not use any RFID TX channel with a centre frequency of less than 700 kHz from any channel stored in the ARFCN list, if the received BCCH signal level at the antenna of the interrogator is greater than 38.5 dBμV/m (equivalent to -98 dBm).

The following figure shows those ER-GSM channels that prevent the use of either the 918.7 MHz or the 919.9 MHz RFID TX channel.

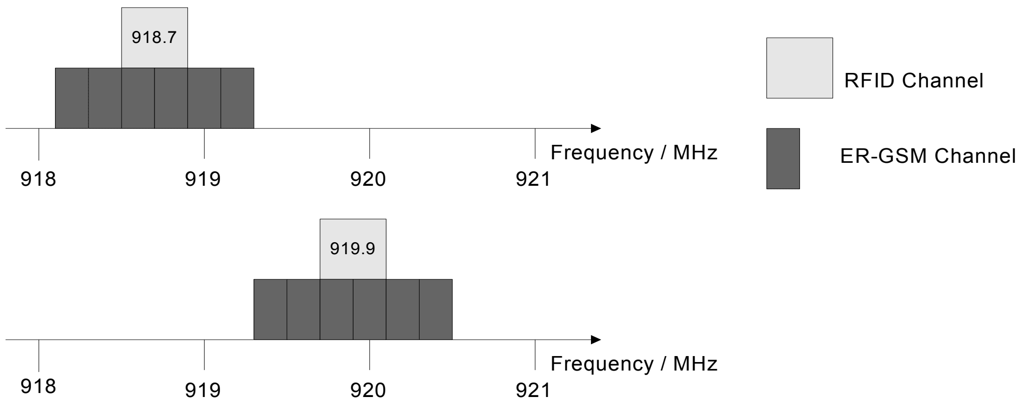


Figure 63: Illustration of interference between ER-GSM and RFID channels

A6.1.3 Analytical analysis and SEAMCAT simulations of efficiency of detecting ER-GSM downlink 915-921 MHz

This section provides an analysis of the effectiveness of the DL detection with threshold of 38.5 dBμV/m (equivalent to -98 dBm) using both the MCL approach and a SEAMCAT simulation.

A6.1.3.1 Analytical analysis of downlink detection

In this sub-section the compatibility of *the* RFID (Interfering transmitter IT, transmitting to its wanted receiver WR) with ER-GSM (Wanted transmitter WT transmitting to the victim receiver VR) is analysed. IT is able to monitor the WT, which is the basis for the sensing mechanism, which is called LBT in this section.

The following abbreviations and definitions are valid in this sub-section:

- Dimensions: r/m, P/dBm, S/dBm, SIR/dB, f/GHz, All antennas 0dBi
- VR Victim receiver (GSM-R MS)
- N_{th}: Thermal noise floor kTB of VR (-120 dBm/200kHz)
- F: Noise figure of VR, (GSM-R mobile 7 dB)
- N: Receiver noise floor kTBF (-111 dBm/200kHz, including 2dB cable loss)
- S: Signal strength received at the VR from WT (Pwt)
- SNR: signal to noise ratio, or C/N at VR
- SIRmin: Signal to interference ratio, or C/I at VR (9 dB, with 100kHz offset 0 dB)
- WT Wanted transmitter (victim link, GSM-R BS)
- Pwt Transmit power of WT (GSM-R BS 38 dBm =43 dBm-2dB attenuation – 3 dB splitter)

- Gs Antenna gain WT (18…21 dBi, see section 3.2)
- IT Interfering Transmitter (RFID)
- Pit Transmit power e.i.r.p. of IT (RFID 36 dBm)
- WR Wanted receiver (Interfering Link, RFID) :
- I: Interfering power at VR,
- Plbt: LBT power received at WR from WT (Pwt)
- Pthr: power threshold for the LBT mechanism at IT
- n: Path loss exponent n (n=2 free space loss)
- Rint: radius around VR; inside interference can occur (S-I<SIRmin)
- Rsig: radius around VR; inside the victim link works wit*h* S-N<SNRmin
- Rdet: radius around WT; inside the IT can detect the WT
- Wall: wall attenuation dB (RFID indoor 10dB).

The following figure explains the investigated scenario. Within a radius of Rint around the VR the IT can exceed the protection objective of the VR (e.g. C/I). Within a radius of Rdet around the WT the IT can detect the WT (Threshold is exceeded).

In the light blue area in the following figure LBT is working effectively. The red area is the so called "hidden node", where the IT is not able to detect the WT.

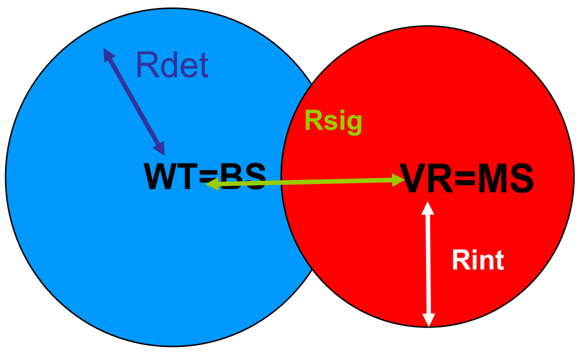


Figure 64: Illustration of the analysed hidden node scenario

The formulas given hereafter are the basis for the analysis.

Minimum usable Signal strength at the GSM-R receiver:

S (at MS) = N + SNR = Pwt (BS)+Gsmax - PL(Rsig) (A6-1)

The interference power at the GSM-R receiver:

I (at MS) = S - SIRmin = Pit (RFID)-Wall - PL(Rint) (A6-2)

The threshold power at the interrogator:

Pthr (at RFID) = Pwt (BS)+Gs-Wall - PL(Rdet) (A6-3)

Path loss model:

PL = 32.5+10*n*log(R/m)+20*log(f/GHz) (A6-4)

The size of the circles in the previous figure can be calculated as follows (the detection zone is for directional antennas not a circle and depends on the antenna diagram of the WT, the GSM-R base station; thus Gs is meant as a function of the angle between *the* mainbeam direction of the BS antenna and the RFID location):

(A6-1)+(A6-4) -> 10n*log(Rsig) = Pwt+Gsmax-N-SNR-32.5-20logf (A6-5)

(A6-2)+(A6-4) -> 10n*log(Rint) = Pit-Wall-N-SNR+SIRmin-32.5-20logf (A6-6)

(A6-3)+(A6-4) -> 10n*log(Rdet) = Pwt+Gs-Wall-Pthr-32.5-20logf (A6-7)

Relation Rint/Rsig: (A6-6)-(A6-5) -> 10n*log(Rint/Rsig)=Pit-Pwt-Gsmax-Wall+SIRmin (A6-8)

Relation Rdet/Rint: (A6-7)-(A6-6) -> 10n*log(Rdet/Rint)=Pwt-Pit-Pthr+Gs+N+SNR-SIRmin (A6-9)

Under the assumption Rsig+Rdet≤Rint the hidden node portion could be easily calculated as 1-(Rdet/Rint)^2, but this is not realistic in this case.

The following two figures show the distances for R_{sig}, R_{int} and R_{det} as a function of the signal strength at the GSM-R mobile for indoor RFID applications; and for outdoor RFID applications respectively. A propagation exponent of 3.5 was assumed in the calculations.

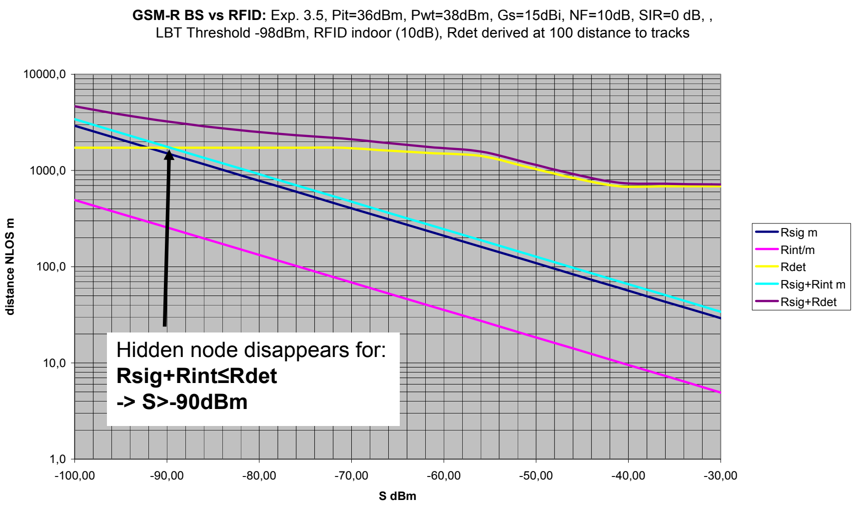


Figure 65: Calculated area sizes for indoor RFID case

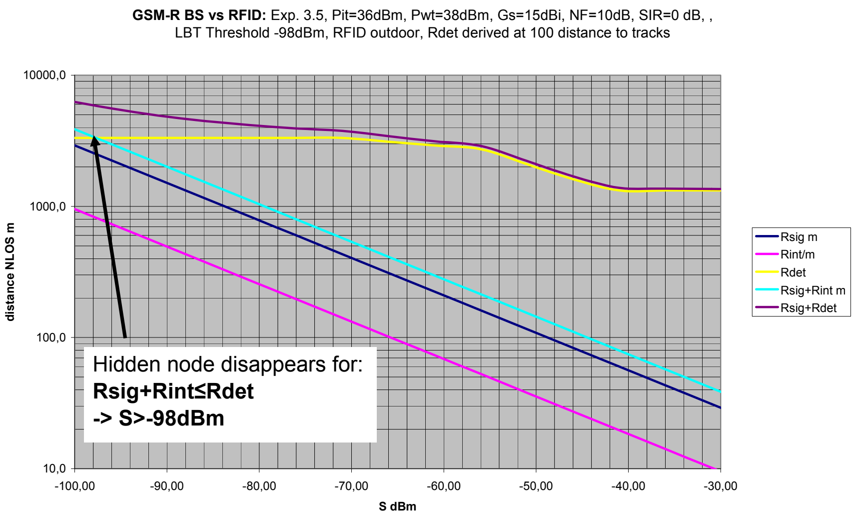


Figure 66: Calculated area sizes for outdoor RFID case

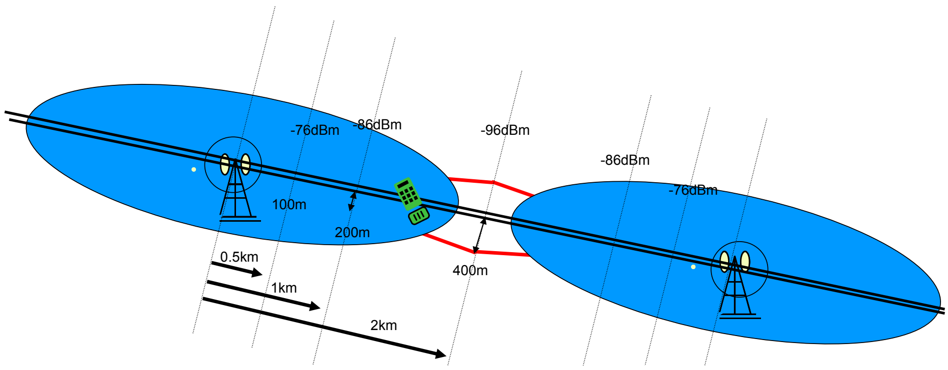
The following observations can be made:

R_{sig} is the distance between WT (GSM-R BS) and VR (GSM-R MS) to achieve the corresponding signal strength S at the GSM-R mobile, e.g. for S of -96dBm is reached at about 2km with a propagation exponent of 3.5;

R_{int} is the protection distance around the VR required to achieve a SIR of 0dB (under the assumption that with 100kHz frequency offset between RFID and GSM-R channels this is sufficient), e.g. with S=-86 dBm the protection zone is 400m for RFID outdoor and 200m for RFID indoor;

R_{det} is the radius around the GSM-R base station, where the RFIDs can detect WT. Outside this radius the detection is not working. What can be seen is that the detection range is changing according to the distance of the RFIDs to the railway tracks, which is a consequence of the antenna gain the RFID sees from the GSM-R base station. R_{det} is a function of the distance of the RFID to the tracks. The above figures show the results for R_{det} for 100 m distance to the tracks.

The two following figures illustrate the main results of this analysis. The first figure shows the detection areas and hidden nodes for indoor RFIDs, and the second one for outdoor RFIDs.



GSM-R vs RFID: blue zone= detection possible, red zone= hidden node
Exp. 3.5, Pit=36dBm, Pwt=38dBm, NF=10dB, SIR=0 dB, Gs=20dBi/30°,
LBT Threshold -98dBm, RFID indoor (10dB)

Figure 67: Hidden nodes (red areas) and detection areas (blue), RFID indoor

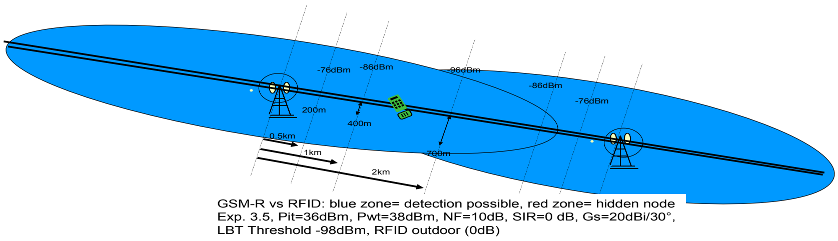


Figure 68: Figure 59: Hidden nodes (red areas) and detection areas (blue), RFID outdoor

The hidden node disappears for the RFID outdoor case and only a small section remains for indoor RFID.

It has to be noted that this analysis is limited to equal propagation conditions in all links (exponent 3.5). For unbalanced conditions the situation can be less critical (e.g. sensing link with better propagation conditions as the wanted and interfering link) and more critical (e.g. e.g. sensing link with worse propagation conditions as the wanted and interfering link)

A6.1.3.2 SEAMCAT analysis of downlink detection 915-921 MHz

The following simplifications were made when programming this scenario in SEAMCAT:

- Victim is the ER-GSM downlink at fixed frequency of 918 MHz
- Interferer is an RFID with LBT, modelled using SEAMCAT's "Cognitive Radio" feature, tuned at the same frequency as ER-GSM (worst case);

Limitation by SEAMCAT:

- When using the option "Cognitive Radio", the receive frequency range of *the* Victim Link should be equal to that of the Interfering Link.

Victim Link

The victim link is the downlink between an ER-GSM base station and an ER-GSM terminal with a normal distance of up to about 6 km. Within the simulation the distance was set between 3 and 12 km. The transmit power of the base station is assumed to be 38dBm (43 dBm minus 2 dB cable attenuation minus 3dB splitter) with a 20 dBi antenna.

Interfering Link

The interfering link is the link between the RFID interrogator and the ER-GSM mobile. The interrogator transmits with 36 dBm with the antenna of RFID Type 2 (see A2.5), with the horizontal pattern reproduced below.

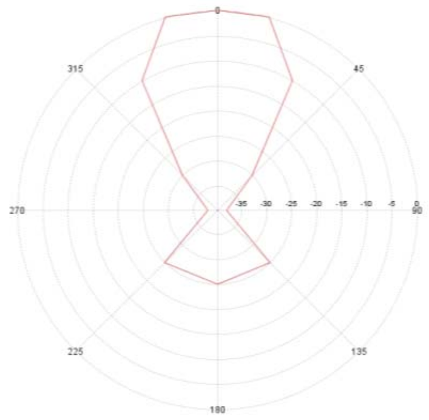


Figure 69: Horizontal antenna pattern of RFID Type 2 antenna

The interferer has a listen receiver with 200 kHz bandwidth.

Sensing Link

The detection threshold was set to -98 dBm/200kHz.

Scenario

A single interferer is located arbitrarily in a circle around the ER-GSM terminal. The protection criterion for ER-GSM is assumed with a C/I=SIR value of 9 dB and alternatively 0 dB. The used propagation model is Extended Hata with following parameter: Suburban, Outdoor Outdoor. Above roof. To simulate worse propagation conditions in sensing path as in the wanted and interfering path, the propagation model in the sensing link was set to Extended Hata (urban mode).

Simulation

Dependent on the value of the detection threshold and the propagation path, the RFID interrogator will detect the base station up to a certain distance. If the distance is lower the RFID interrogator will never transmit and if the distance is higher it will always transmit.

Figure 61 below illustrates the simulation scenario for a 3 km wanted link length.

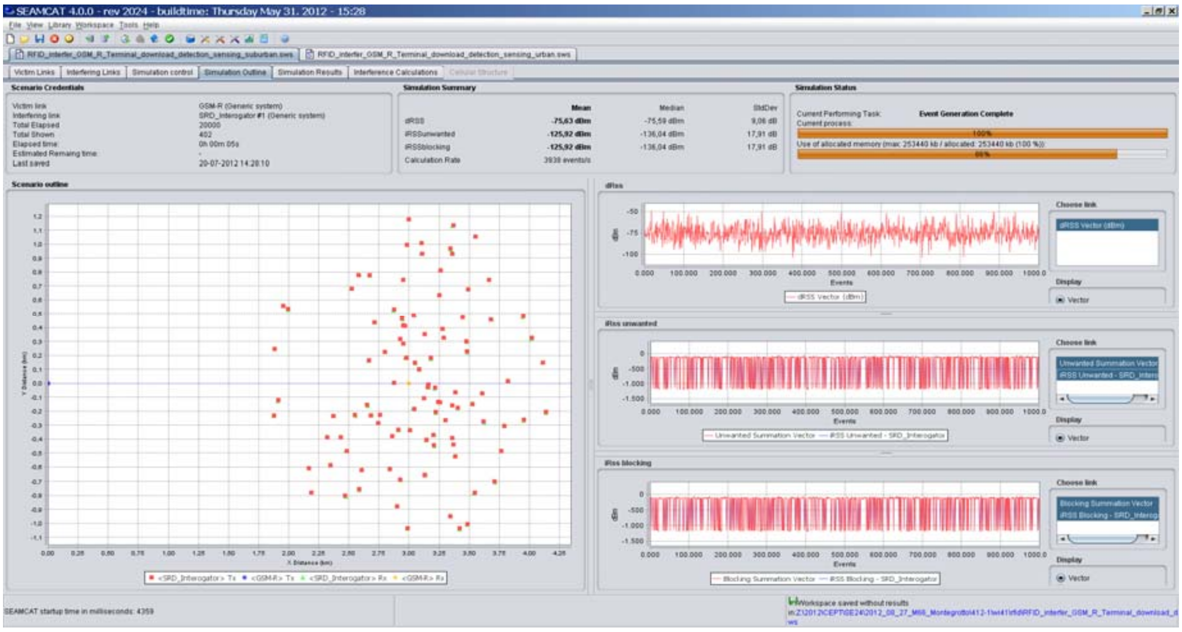


Figure 70: SEAMCAT simulation of RFID downlink sensing scenario

The following tables contain the results of SEAMCAT simulations under the assumptions that: (1) all links have the same propagation model (Extended Hata, suburban, outdoor), and (2) the propagation model was set to Extended Hata, urban only for the sensing link, in order to assess the impact of different propagation conditions.

Table 79: SEAMCAT simulation results of ER-GSM downlink sensing by RFID (RFID outdoor, antenna Type 2)

d_{victim} , km	dRSS Mean, dBm (Std. Dev, dB)	Probability of interference, %	
		With SIR=9 dB	With SIR=0 dB
Case I: all links with the same propagation model: Extended Hata, suburban, outdoor-outdoor			
3	-76 (9)	2.1	0.8
6	- 86 (9)	5.9	2.7
12	-96 (9)	11.3	5.4
Case II: sensing link propagation model set to Extended Hata, urban, outdoor-outdoor			
3	-76 (9)	2.7	1
6	-86 (9)	6.7	2.8
12	-96 (9)	12	5.9

Table 80: SEAMCAT simulation results of ER-GSM downlink sensing by RFID (RFID indoor, antenna Type 2)

d_{victim} , km	dRSS Mean, dBm (Std. Dev, dB)	Probability of interference, %	
		With SIR=9 dB	With SIR=0 dB
Case I: all links with the same propagation model: Extended Hata, suburban, outdoor-outdoor			
3	-76 (9)	-	0.3
6	- 86 (9)	-	1.1
12	-96 (9)	-	2.3

A6.1.3.3 Conclusions from analytical and SEAMCAT analysis of ER-GSM downlink detection 915-921 MHz

The results presented in the two previous sub-sections show that with a threshold value of -98 dBm the GSM-R is protected in most of the cases.

A6.1.4 Summary and conclusions on RFID vs. ER-GSM coexistence 915-921 MHz

A6.1.4.1 Coexistence without mitigation techniques 915-921 MHz

Assuming a protection criterion SIR of 0 dB and 100 kHz offset between RFID and the ER-GSM channels, the following can be summarised:

Co-channel operation of the ***RFID interrogators*** and the ER-GSM downlink in the band ***918-921*** MHz needs to be avoided due to the large protection distances required;

For the protection of ER-GSM mobiles from ***RFID interrogators*** a frequency offset of ≥ 700kHz is required assuming a separation distance of more than 20m;

For the protection of ER-GSM mobiles from ***RFID tags*** protection distances of up to some 60 m are necessary (see annex A6.1.1). This may be seen as acceptable as the use of RFID applications is predominantly indoors;

No impact is expected from the two proposed high power RFID channels in the band 915-918 MHz (916.3 and 917.5 MHz) on ER-GSM mobiles (NB: the centre frequency of the lowest ER-GSM channel is 918.2 MHz);

Also no harmful interference is expected to the GSM band below 915 MHz due to the frequency separation;

The results of some practical tests at an operational site between ER-GSM and RFID are reported in TS 101 602. These tests were carried out with modified interrogators that were fitted with DAA operating in accordance with the proposed mitigation technique. The results showed that RFID can share the band with ER-GSM without causing unacceptable interference.

A6.1.4.2 Downlink detection

The results show that, with a threshold value of -98 dBm, the ER-GSM mobile is protected in most cases.

A6.1.4.3 Uplink detection

It was possible to validate the threshold values proposed in ETSI TS 102 902 [12] under the assumption that the max acceptable interference power received by the ER-GSM mobile is -86dBm. This means that a SIR of 0dB (which comes from the proposed channel offset of 100 kHz)) and minimum signal strength of -86 dBm might be acceptable. For the usual minimum signal strength of -96 dBm the threshold values should be 10 dB more stringent.

ANNEX 7: LIST OF REFERENCE

[1] ETSI TR 102 649-2 V1.2.1 (2010-06). 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
[2] ECC Report 37. Compatibility of planned SRD applications with currently existing radiocommunications applications in the frequency band 863 – 870 MHz.
[3] ETSI TR 102 886 V1.1.1 (2011-07). Technical characteristics of Smart Metering SRD in the UHF Band; Spectrum Requirements for Smart Metering European access profile Protocol (PR-SMEP)
[4] ETSI TR 103 055 V1.1.1 (2011-09). Spectrum Requirements for Short Range Device, Metropolitan Mesh Machine Networks (M3N) and Smart Metering (SM) applications
[5] ETSI TR 102 791 V1.2.1 (2012-02). Technical characteristics of wireless aids for hearing impaired people operating in the VHF and UHF frequency range
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[7] ETSI TS 102 902 V1.1.1 (2011-02). Methods, parameters and test procedures for cognitive interference mitigation towards ER-GSM for use by UHF RFID using Detect-And-Avoid (DAA) or other similar techniques
[8] CEPT Report 14. Report from CEPT to the European Commission in response to the Mandate to: Develop a strategy to improve the effectiveness and flexibility of spectrum availability for Short Range Devices (SRDs)
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[17] ECC Report 34. Compatibility between Narrowband digital PMR/PAMR and tactical radio relay in the 900 MHz band. Cavtat, May 2003
[18] ECC Report 146. Compatibility between GSM MCBTS and other services (TRR, RSBN/PRMG, HC-SDMA, GSM-R, DME, MIDS, DECT) operating in the 900 and 1800 MHz frequency bands
[19] SE24 Doc. M68_06. Measurements on the impact of SRDs on GSM-R (15.12.2012)
[20] ETSI TS 101 602: Technical Specification on Preliminary Tests and Trial to verify mitigation techniques for sharing spectrum between RFID and ER_GSM
[21] ETSI TR 103 151: Tests on the immunity of Wind Profiler Radar to transmissions from RFID, ALDs and GSM
[22] ECC Report 96. Compatibility between UMTS 900/1800 and Systems Operating in Adjacent Bands
[23] ECC Report 162. Practical mechanism to improve the compatibility between GSM-R and public mobile networks and guidance on practical coordination
[24] 3GPP TS45.005: GSM/EDGE Radio Access Network, Radio Transmission and Reception
[25] ETSI EN 301 515 V2.3.0 (2005-02): Global System for Mobile communication (GSM). Requirements for GSM operation on railways
[26] ETSI TS 136 101: Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 11.4.0 Release 11)
[27] ETSI EN 300 220 (all parts) (V2.1.2). Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW
[28] Draft ETSI ES 202 630 : Short Range Devices (SRD); Radio equipment to be used in parts of the frequency range 870-876 MHz and 915-921 MHz, with Transmitter Duty Cycle (TDC) restriction and power levels up to 25 mW; Technical characteristics and test methods
[29] ETSI EN 300 422: Wireless microphones in the 25 MHz to 3 GHz frequency range
[30] ERC Recommendation 74-01: Wireless microphones in the 25 MHz to 3 GHz frequency range
[31] ECC Report 181. Improving spectrum efficiency in the SRD bands (September 2012).

[32] ETSI EN 302 208-1 V1.4.1 (2011-07). Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W; Part 1: Technical requirements and methods of measurement
[33] ECC Report 131. Derivation of a block edge mask (BEM) for terminal stations in the 2.6 GHz frequency band (2500-2690 MHz). Dublin, January 2009.
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[37] ECC Report 167. Practical implementation of registration/coordination mechanism for UWB LT2 systems
[38] ECC Decision (02)05 on the designation and availability of frequency bands for railway purposes in the 876-880 MHz and 921-925 MHz bands